ASSESSING METABOLIC PERFORMANCE OF HYBRID WATER SYSTEMS WITH INTEGRATED WATER RESOURCES EVALUATION TOOL

PROJECT REPORT

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Disclaimer

1 SETTING THE CONTEXT

Over the last decades, a rapidly growing number of cities around the world have become challenged by a diverse set of problems associated with planning and management of municipal water resources and infrastructure. In addition to abundant social, economic and environmental pressures, one trend can be particularly detrimental to municipal water infrastructure if not addressed appropriately. Due to the intensive urbanization on one side, and a lack of developable land on the other, cities like Toronto, Canada, are forced to increase the rates of population density in their urban cores. While environmentally justified, such intensification efforts raise numerous concerns as the scale of new developments and a range of different socio-economic activities within the existing systems challenge their ability to sustain and improve the quality of life for local residents. This leaves urban planners seeking for criteria and tools that facilitate assessment of alternative solutions in an effort to plan and manage sustainable communities under constraining environmental conditions. This is especially important with the development of dynamic long-term master plans that include conceptual layouts of infrastructural systems that should be able to guide and support future growth.

This problem requires an active collaboration of multiple decision makers, including environment specialists, urban designers, engineers, economists, government officials, and the local community. It also needs a clear sustainability framework for analyzing the potential solutions and identifying the most preferred option considering both quantitative and qualitative criteria.

This document provides details on the development process for Integrated Water Resources Evaluation Tool (IWRET). IWRET is a result of a collaboration between academia (Ryerson University, Toronto, Canada) and governmental institutions (Waterfront Toronto, Canada), in an endeavor of a participatory modelling and application of bottom-up modelling approach to address local water management issues. The main motivation for this collaboration and IWRET development lies in potential water management issues at Toronto's waterfront. The revitalization of Toronto's waterfront presents the largest urban redevelopment project currently underway in North America. A reclaimed, once industrial, land will bring thousands of new residents and jobs to Toronto's city core, further expanding the pressure on existing infrastructure. To steer the sustainable redevelopment of the waterfront, a comprehensive sustainability framework ensures that consistent principles are implemented into every aspect of decision-making. Nevertheless, while the proposed servicing options consider a range of criteria in determining preferred alternatives of a sustainable urban water system (UWS), the sustainability framework lacks a comprehensive assessment of the integrated source-drinking-wastewater-stormwater systems over their life-cycles [1]. Moreover, the sustainability framework, through the existing master plans, considers only traditional, centralized solutions, and does not take into consideration the potential benefits of alternative, decentralized water technologies.

Having that in mind, the key objective of IWRET is to expand the scope of existing framework and support decision-makers in analysis and comparison of the sustainability performance of alternative, decentralized approaches against a baseline conventional approach.

2 TOWARDS SUSTAINABLE URBAN WATER SYSTEMS

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. Based on similar conclusions, in 1965, a scientist and sanitary engineer, Abel Wolman, envisioned the concept of urban metabolism as a holistic sustainability paradigm that takes into account all these aspects simultaneously, [2]. After years of dormancy, the urban metabolism concept has been reintroduced 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, deals with the quantification of the overall flows and fluxes of energy, water, materials, nutrients and wastes into and out of an urban region, Figure 1.

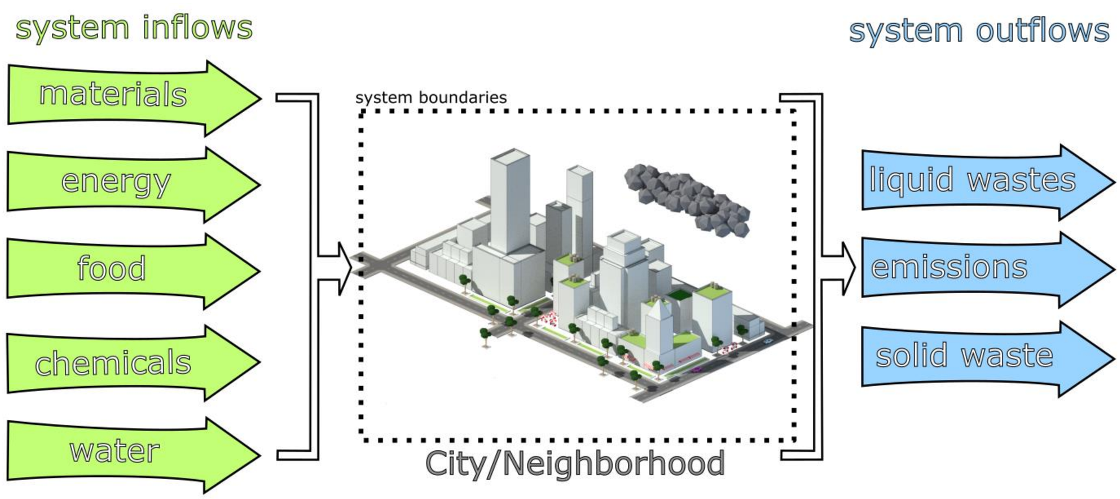

Figure 1 Flows and fluxes of urban metabolism

However, numerous studies completed for different urban regions, including the City of Toronto, demonstrate an increasing per-capita metabolism with respect to all fluxes, which is recognized as an issue threatening sustainable urban development [3]. With the growing environmental concerns, the pursuit for balanced urban metabolism has become a key element in determining levels of sustainability in cities around the world.

From the perspective of urban water resources and infrastructure, according to [4], the importance of water-related fluxes in urban metabolism model is particularly emphasised since the urban water cycle has a rather substantial impact on flows of materials, energy, wastes and nutrients. Traditional urban water metabolism approach has largely focused solely on centralized drinking, stormwater and wastewater systems, with the main intent of matching supply to demand, Figure 2.

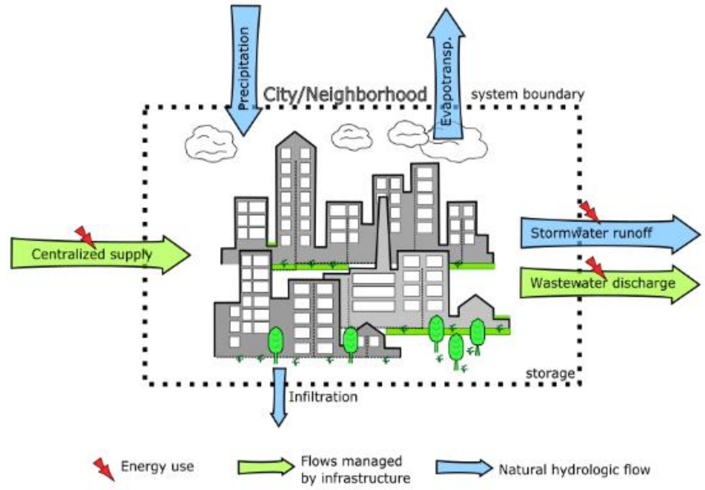

Figure 2 Traditional (centralized) urban water metabolism model

However, this centralized approach has become characterized by an increasing discrepancy between system entries and outflows, causing considerable social, economic, and environmental impacts. In progressively resource limited cities, adopting new technologies and recreating urban morphology has become a paramount in achieving a sustainable water metabolism, Figure 3.

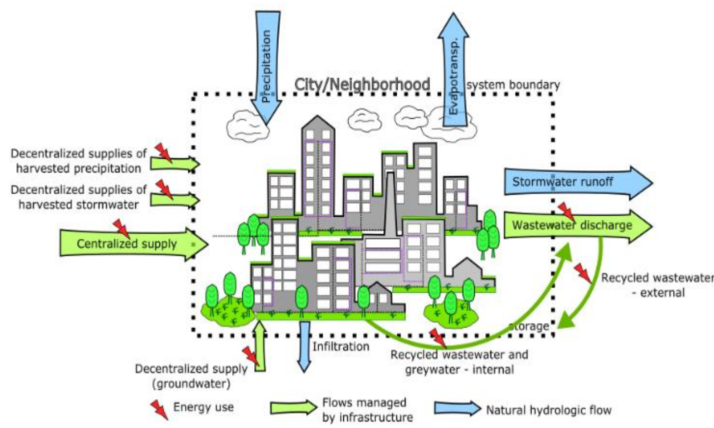

Figure 3 Alternative (decentralized) urban water metabolism model

The question remains what are the technologies that can be offered to improve and balance the urban water metabolic process. Also, it is important to recognize what would be their benefits, limitations and weaknesses. A basket of potential solutions to a long-term sustainability of urban water metabolic process can be offered by a holistic approach named Integrated Urban Water Management (IUWM). This approach has been introduced international water community in order to deal with the mounting pressures over the valuable resource and complex systems of municipal water infrastructure [5]. Regarding planning and management of urban water infrastructure, IUWM approach encompasses supervision of all urban water cycle components, such as drinking water treatment, distribution, sewerage and storm drainage, and wastewater treatment. However, the reality for many cities around the world, including Toronto, is significantly different. One of the main legacies of the conventional approach is that urban areas rely predominantly on centralized water systems that typically consist of separate drinking water, stormwater and wastewater sub-systems. This fact embodies an enormous social and engineering issue for many urban developments, as further expansion of existing systems is neither economically nor environmentally viable. In view of that, IUWM suggests development of water systems that utilize alternative water sources, previously treated as nuisance, including rainwater, stormwater, greywater, or wastewater [6]. Within a built environment, there are four groups of decentralized solutions available to water utilities to achieve this:

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

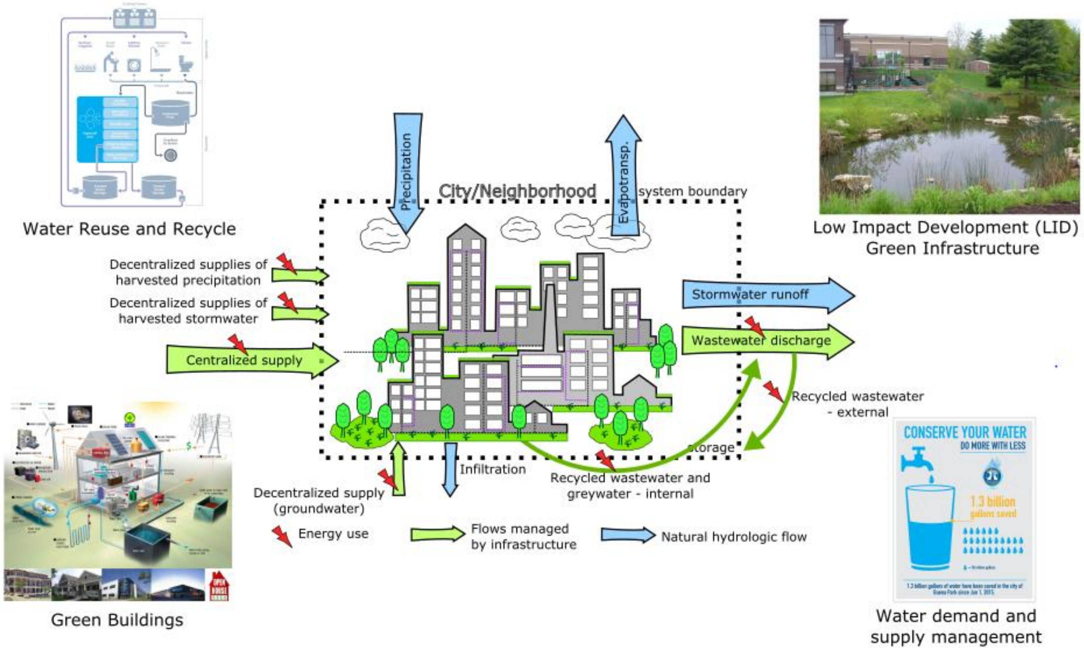

Figure 4 Four major groups of decentralized water technologies

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 in constructing building and neighbourhood-scale decentralized systems, where the wastewater generated within a residential and commercial building is treated and reused to satisfy the non-potable needs.

While utilization of decentralized technologies can potentially provide a number of benefits (such as cost reduction, resource efficiency, service security, system failure reduction, local economic strength, community wellbeing, and environmental protection), it also involves the trade-offs between water use, energy use , land use and public concerns that must be taken into consideration. Perhaps the biggest challenge facing the implementation of hybrid systems is the lack of empirical information depicting the system architecture, and quantifying the system success or failure.

Having that in mind, the key IWRET requirement is that it represents a tool that can assist planners, utility managers, engineers, and other decision-makers determine the optimal trade-offs of hybrid water systems in order to support sustainability at the community level. IWRET, therefore, analyses and compares the sustainability performance of alternative approaches to integrated urban water management strategies and technologies against a baseline conventional approach. From an operational perspective, a comprehensive representation of complex, interconnected water resources systems in IWRET is achieved by:

- Integrating all elements of the urban water cycle (drinking water, stormwater, wastewater, and recycle/reuse);
- Including all four groups of decentralized (distributed) solutions to allow flexible representation of hybrid water systems;
- Building the model on the open-source technology, publicly available for use, modification and distribution;
- Incorporating low data requirements typically used for master planning process; and,
- Integrating of sustainability performance indicators recognized by the potential users.

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, such as financial costs, energy savings, greenhouse gas (GHG) emissions, climate change resiliency, chemical use, and nutrient recovery.

3 COMMUNITY INVOLVEMENT

In an effort to achieve the structural accuracy and validity of the tool, promote shared vision and assist consensus building regarding hybrid water systems, more than 50 stakeholders (area experts from governmental institutions, technology developers, providers and distributors, developers and builders, consultants, and non-governmental organizations) were actively engaged in an IWRET development workshop. The main objective of this workshop was to address the challenge of adequate representation of decentralized water management practices in hybrid water systems. Workshop participants were presented with an opportunity to provide a direct input on the tool development by providing the direct feedback on:

- Anticipated decentralized technologies to be supported by IWRET;
- Harmonization of quantitative and qualitative sustainability indicators for the evaluation of alternative solutions; and, finally,
- Preference on the features of tool's graphical user interface (GUI).

Firstly, workshop participants were introduced to a set of decentralized urban water technologies divided into three groups (water supply, wastewater, and stormwater), including their integration through recycling/reuse. Participants then prioritized distributed technologies on a scale 1 – not important, to 5 – very important. The group of stakeholders recognized water saving devices as the most important technology to be included in IWRET, followed by smart water meters and integration of smart water and energy metering, Figure 5. On the other side, downspout disconnections and stormwater reuse systems were considered the most important distributed stormwater technologies, Figure 6. Regarding wastewater distributed systems, packaged wastewater treatment plants and constructed wetlands were valued as the most significant technologies, Figure 7. 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 8.

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 an ambiguous process. While numerous categories of sustainability criteria have been suggested to evaluate alternative solutions, literature suggests that they can be categorized into a four primary groups including economic, environmental, engineering and socio-cultural. Since they are strongly context driven, workshop participants were presented with a preliminary list of sustainability indicators based on similar tools developed around the world.

Participants of the workshop identified life-cycle costs as the most dominant factor to sustainable water infrastructure planning. This result suggests that IWRET must take into consideration the financial aspects of construction, operation and maintenance. Participants further identified the performance and reliability of assets amongst the most important indicators. The participants pointed out that IWRET should include dynamic analysis of device performances (e.g. operations of pumps). Amongst the most important environmental indicators were rainwater runoff, both quality and quantity, in addition to savings in wastewater generation and indicators related to energy use and energy reductions. Finally, among social indicators the potential risk to human health is the indicator of highest importance.

The final objective of the workshop was to receive input from the stakeholders to inform the development of IWRET graphical user interface (GUI). Based on a poll taken during the workshop, 55% of participants preferred a user-friendly interface built within a familiar platform that would incorporate user feedback and it should include not more than limited representation of spatial variability of urban water systems.

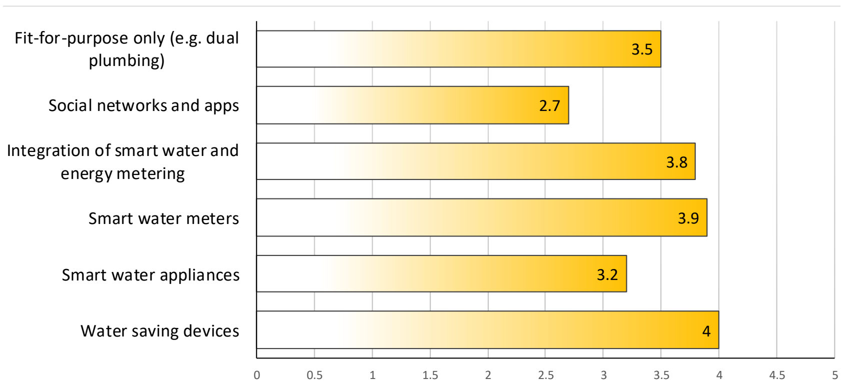

Figure 5 Distributed water supply technologies

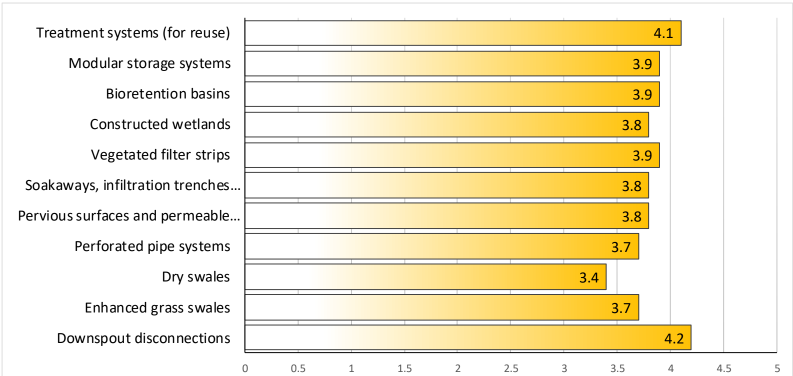

Figure 6 Distributed stormwater technologies

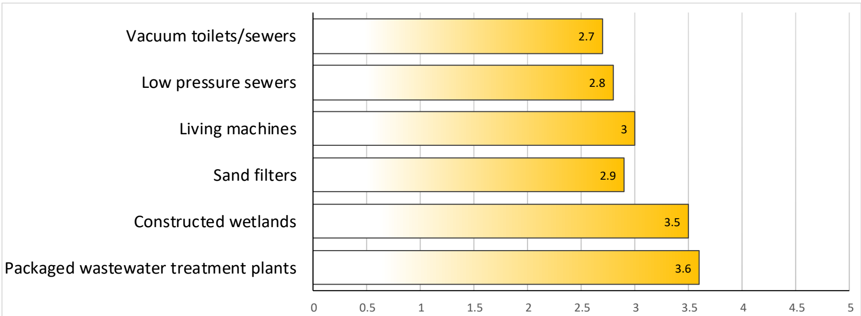

Figure 7 Distributed wastewater technologies

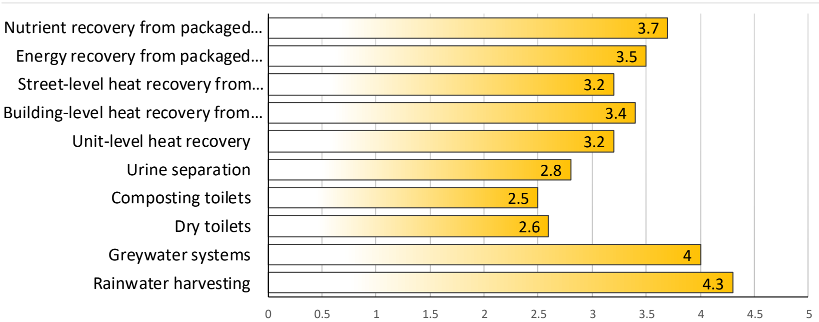

Figure 8 Reuse/recycle technologies

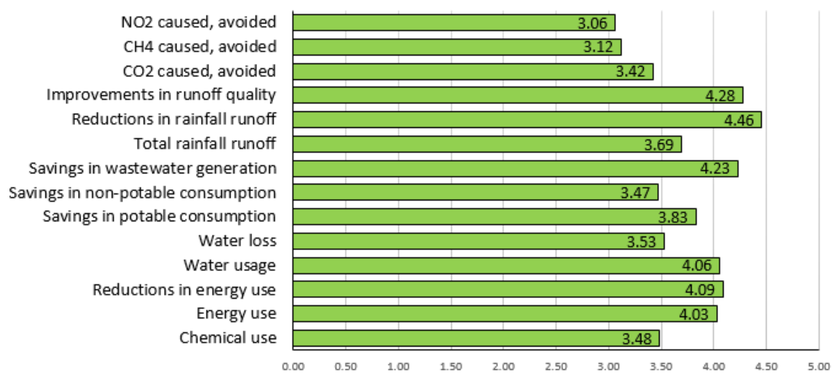

Figure 9 Environmental sustainability indicators

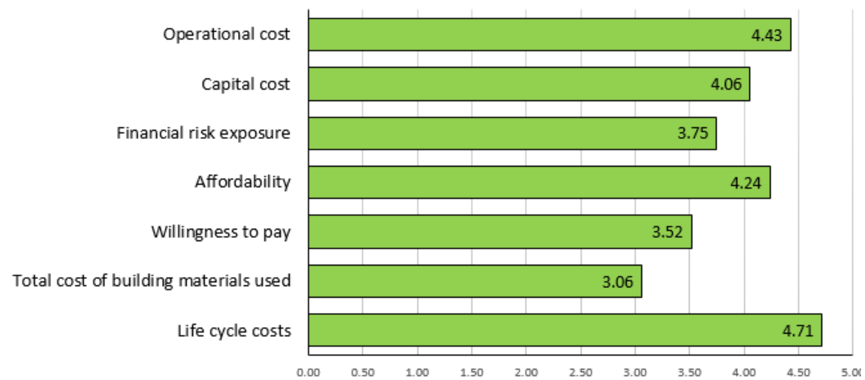

Figure 10 Economic sustainability indicators

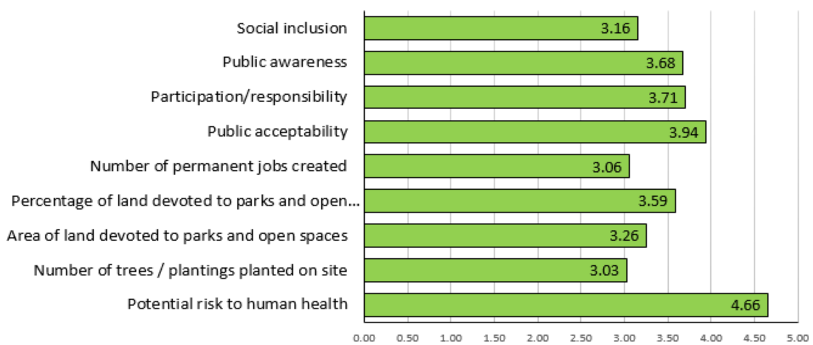

Figure 11 Socio-cultural sustainability indicators

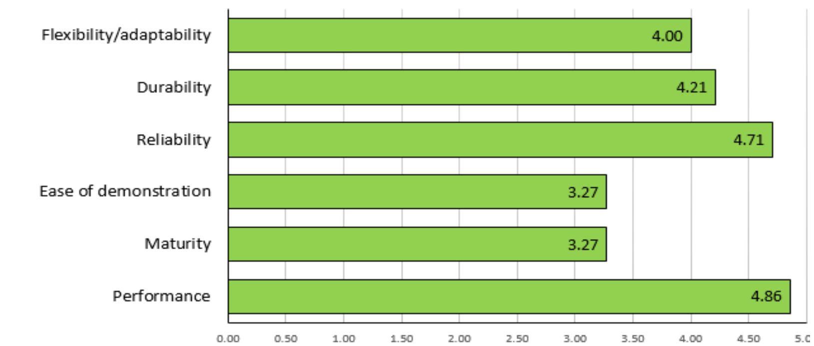

Figure 12 Engineering sustainability indicators

4 METHODOLOGY BEHIND IWRET

Dictated by the limited representation of spatial variation of urban water systems, system dynamics (SD) is considered the most suitable modelling method for creating the numerical core of the model. SD simulation is a modelling method commonly used in water resources management for its capacity to describe complex relations between different components of water systems [7]. It utilizes the principles of the feedback control theory to form simulation models in which a feedback loop presents the core building block.

Stocks and flows represent the central elements of all SD models, Figure 13. While flows represent the rates of change in time (such as m^3/day), the stocks can be described as accumulations or quantities (i.e. m^3, kg, etc.). In a mathematical sense, stocks are simply integral equations [8].

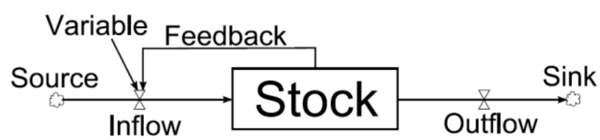

Figure 13 Main elements of System Dynamics (SD) simulation model

Obtained simulation results require post-processing for analysis, communication and clear comparison of alternatives. In order to provide a user-friendly GUI, IWRET is being developed as a web-based platform, running a SD model in the background. The platform uses Python programming language and PySD package to simulate SD models [9]. PySD translates SD model files into Python modules, and provides methods to simulate and analyze converted models.

4.1 REPRESENTING COMPONENTS OF HYBRID WATER SYSTEMS

In order to conduct a comparative analysis of metabolic performance, the user describes detailed properties of hybrid water system. Each hybrid system in IWRET comprises of integrated four main system components:

- Water supply;
- Separate stormwater and wastewater;
- Hydrology;
- Water recovery systems;

More specifically, IWRET divides all four system components into the following elements of a hybrid urban water system:

- Water demand(WD);
- Water treatment works (WTW);
- Water supply conduits (WSC), water trunk mains (WTM) and water distribution mains (WDM);
- Wastewater collection system (WWCS) and stormwater collection systems (SWCS);
- Wastewater treatment works (WWTW);
- Stormwater treatment works (SWTW);

- Pumping stations for drinking water (WP), wastewater (WWP) and stormwater (SWP);
- Rainwater harvesting system (RHS);
- Greywater system (GWS);
- Blackwater reuse system (Living Machines or Membrane Bioreactors);
- Neighborhood hydrology (H) with Low Impact Development (LID) techniques (bioswales, rain barrels and cisterns, green roofs, bioretention and raingarden, porous pavement and permeable patio, and stormwater management ponds).

4.2 ACCOUNTING METABOLIC FLOWS AND FLUXES OF HYBRID WATER SYSTEMS

Since it represents a mass-balance-based model that quantifies and assesses the sustainability of the metabolic performance for the hybrid urban water systems, IWRET computes primary water-related flows. In addition, IWRET also supports accounting of the following flows and fluxes that are typically required for system operation and maintenance:

- Energy fluxes through embodied and operational energy consumption;
- Greenhouse gas (GHG) flows through embodied and operational emissions;
- Chemical fluxes required for urban water system operation;, and,
- Financial fluxes through Life Cycle Costs (LCC).

All these flows and fluxes are calculated in each time step based on the amount of the water conveyed or treated and the amount of that flux consumed per unit volume of water.

4.2.1 Water flows

IWRET simulates the main water flows including potable water, storm water, and wastewater. Hybrid system also include optional grey water, green water, and recycling/reuse schemes. Potable water accounts the treated water in water treatment plants, originally supplied from water resources. Storm water accounts the rainfall on both impervious and pervious areas. Green water represents the treated rainwater. Grey water is the dilute wastewater originating from clean water consumption. More precisely, shower, hand basin, dishwasher and washing machine are appliances that produce grey water. Black water is the used wastewater obtained from toilet and polluted water consumed by industrial/commercial users. Recycling water is water treated by either decentralized treatment options.

4.2.2 Energy fluxes

Urban water systems include processes of collecting, conveying, treating, and delivering water to end users, consuming the water, and, finally, collecting, treating, and disposing of wastewater. All these processes require significant amounts of energy and release significant amounts greenhouse gases into the atmosphere, contributing to the overall environmental footprint. Therefore, IWRET accounts energy intensity of a typical urban water system. In this case, energy intensity is defined as the amount of energy consumed per unit of water to perform water management-related actions (such as water, wastewater and stormwater pumping) in the number of kilowatt-hours consumed per cube meter (kWh/m^3) of water. This energy consumption IWRET also applies to infrastructure construction and operation stages. The embodied energy calculates the total energy consumed and related emissions in the construction stage, corresponding to the sum of energy and emissions associated to each constructive activity. Energy consumption and CO_2 emissions related to the construction of a water supply, wastewater and stormwater collection systems are expressed in kWh and $kgCO_2eq$ per size unit, respectively. Size units are m, m^2, m^3 or kg. In addition, IWRET also interprets energy intensity of periodic and annual maintenance. IWRET accounts embodied and energy consumption for following system elements:

- Water treatment works(WTW);
- Wastewater treatment works (WWTW);
- Stormwater treatment works (SWTW);
- Pumping stations for drinking water (WP), wastewater (WWP) and stormwater (SWP);
- Rainwater harvesting system (RHS);
- Greywater system (GWS);
- Blackwater reuse system (Living Machines or Membrane Bioreactors);
- Decentralized Low Impact Development (LID) options (bioswales, green roofs, bioretention and raingardens, rain barrels and cisterns, porous pavement and permeable patio, and stormwater management ponds).

4.2.3 Greenhouse gas emissions

IWRET accounts two different sources of greenhouse gas (GHG) emissions. Firstly, GHG emitted indirectly from electricity consumption in the components such as water pumping, water and wastewater treatment facilities to the atmosphere. Secondly, the model accounts GHG emitted indirectly from material flux (resulted from embodied energy of materials) such as chemicals used for treatment processes. Contribution of GHG emission is reported in kilograms of CO_2 emissions equivalent ($kgC0_2eq$). IWRET contains a default information regarding GHG emissions, but also a user is able to modify or assign new values. IWRET accounts embodied and operational greenhouse gas emissions for following system elements:

- Water treatment works (WTW);
- Wastewater treatment works (WWTW),
- Stormwater treatment works (SWTW);
- Pumping stations for drinking water (WP), wastewater (WWP) and stormwater (SWP);
- Rainwater harvesting system (RHS);
- Greywater system (GWS);
- Blackwater reuse system (Living Machines or Membrane Bioreactors);
- Decentralized Low Impact Development (LID) options (bioswales, green roofs, bioretention and raingardens, rain barrels and cisterns, porous pavement and permeable patio, and stormwater management ponds).

4.2.4 Chemical fluxes

The fluxes of chemicals used in the urban water systems over the planning horizon are also analyzed by IWRET. These chemical fluxes are linked to urban water system assets and their characteristics with focus on the water, wastewater and stormwater treatment. Also, material fluxes are used to calculate the embodied energy and related GHG emissions associated with the life cycle of the water, wastewater and stormwater pipelines, including asset manufacturing, installation, operation/maintenance, rehabilitation and retirement. IWRET accounts chemical fluxes for following system elements:

- Water treatment works (WTW);
- Wastewater treatment works (WWTW);
- Stormwater treatment works (SWTW).

4.2.5 Financial fluxes through analysis of Life Cycle Costs (LCC)

In order to provide the analysis of financial aspects of urban water systems, IWRET allows life cost analysis of all system elements. Life Cycle Costs (LCC) refer to a process of assessment of overall economic values, achieved by analyzing an initial cost and discounted future costs for tasks such as maintenance, reconstruction, reinforcement, repair and replacement. LCC calculates all costs generated during the entire process from planning to disposal of a component.

The Life Cycle Cost (LCC) of a system element is estimated based on installation cost, maintenance cost, disposal and replacement cost. The initial installation cost include planning and design cost, supervision cost and construction cost. The maintenance cost is constituted of direct and indirect management cost, inspection and diagnosis cost, repair and reinforcement cost and emergency recovery cost. The disposal and replacement cost is consisted of disposal cost and replacement cost.

$$LCC_{TOTAL} = C_{CAP} + C_{INT} + C_{MAN} + C_{OPT} + C_{DRE}$$

Where,

LCC_{Total}: Total Life Cycle Cost;
C_{cap}: Capital Investments required for potential extension and expansion of existing assets;
C_{INT}: Initial Installation/Construction Costs for new assets;
C_{MAN}: Maintenance Costs;
C_{OPT}: Operational Costs;
C_{DRE}: Disposal and Replacement Costs

IWRET accounts Life Cycle Costs (LCC) for the following system elements:

- Water treatment works(WTW);
- Water supply conduits (WSC), water trunk mains (WTM) and water distribution mains (WDM);
- Wastewater collection system(WWCS) and stormwater collection systems (SWCS);
- Wastewater treatment works (WWTW),
- Stormwater treatment works (SWTW) and
- Pumping stations (PS) (Drinking water, wastewater and stormwater);

- Rainwater harvesting system(RHS);
- Greywater system (GWS);
- Blackwater reuse system (Living Machines or Membrane Bioreactors);
- Decentralized Low Impact Development (LID) options (bioswales, green roofs, bioretention and raingardens, rain barrels and cisterns, porous pavement and permeable patio, and stormwater ponds).

4.3 SPATIAL AND TEMPORAL DISCRETIZATION

In many aspects, the unsustainable nature of modern cities stems as a consequence of poor planning at the neighborhood level. Therefore, the development of sustainable neighborhoods is seen as a viable option that can gradually help achieving a sustainable urban form at the city level. This is the main motivation for IWRET to assess and support strategic planning of hybrid water systems on the neighborhood level. However, IWRET takes the administrative limits of an urban water utility as the spatial boundary of the hybrid urban water system in order to represent certain centralized options, such as water and wastewater treatment works. Figure 14 shows the three spatial levels used to represent the complexity of urban water system in IWRET.

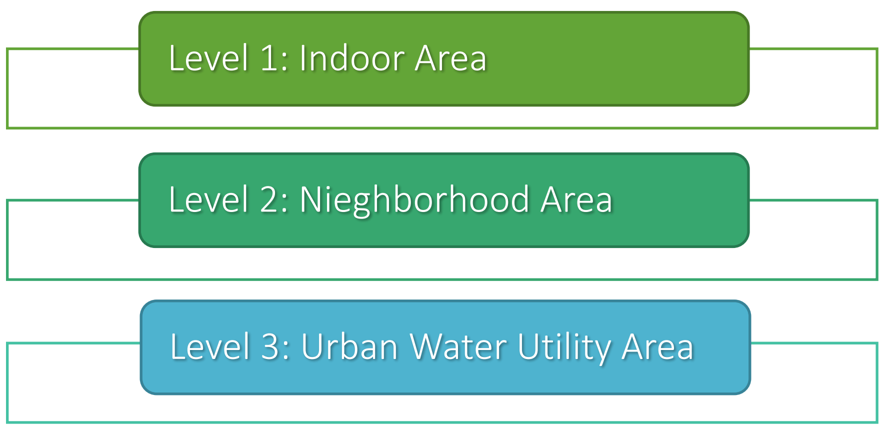

Figure 14 Representation of three spatial levels in IWRET

Level 1: Indoor

The smallest spatial scale is an indoor area where residential water demand is generated through different appliances and fixtures (faucet, shower, dishwasher, bathtub, clothes washer, toilet, leaks and other). This level is used to represent a single household, differentiating between residential single-family and multi-family units, with surroundings (e.g. garden or open space representing any outdoor area).

Level 2: Neighborhood Area

A group of indoor, commercial, institutional and industrial properties with a surrounding area is represented as a neighborhood. It can contain any number of indoor areas. The surrounding area is divided into pervious surfaces and impervious surfaces. The main task of neighborhood area is to handle outdoor water demands, rainfall-runoff modelling and on-site water treatment options which are discussed in following sections. The main elements of hybrid water systems modelled only on this level are on-site water treatment options (i.e. rainwater harvesting, grey and black water recycling schemes). Moreover, components of hybrid water system modeled in IWRET on neighborhood level include:

- Water demand (domestic/residential, commercial/institutional, industrial, and irrigation of public spaces);
- Wastewater collection system (WCS) and stormwater collection system (SWCS);
- Neighborhood hydrology and LID options (porous pavement and permeable patios, green roofs, bioretenition and rain gardens, rain barrels and cisterns; bioswales and stormwater ponds);
- Rainwater harvesting (RH);
- Greywater reuse (GW);
- Living machines (LM) and Membrane bioreactors (MBR).

Level 3: Urban Water Utility

The main components of an urban water utility are represented on the urban water utility scale as the top level of the IWRET modelling resolution. The following main components are defined and modelled only at this level, which will be described in more details in following sections:

- Water Pumping Station (WPS);
- Wastewater Pumping Station (WWPS);
- Stormwater Pumping Station (SWPS);
- Water Treatment Works (WTW);
- Wastewater Treatment Works (WWTW);
- Stormwater Treatment Works (SWTW);
- Water Supply Conduits (WSC);
- Water Trunk Mains (WTM);
- Water Distribution Mains (WDM).

A list of all the flows, fluxes for different system components modelled at different spatial levels are summarized in Table 1.

In terms of temporal resolution, IWRET uses a daily time step to simulate the performance of urban water systems for the period of N years, where number of years is specified by the user. As a result, all the time series required, such as climate data, need to be provided on a daily basis for the entire time-period being analyzed. A minimum of one year is required to take into account any seasonal variations of water demands, while longer simulation durations are more rational.

System Element	Scale			Metabolic Flows and Fluxes				
	Indoor	Neighborhood	UWS	Water	Life Cycle Costs	GHG (Embodied and Operational)	Energy (Embodied and Operational)	Chemical
Water Demand (WD) and Conservation Measures	x	x		x				
Water Pumping Station (WPS)			x	x	x	x	x	x
Wastewater Pumping Station (WWPS)			x	x	x	x	x	x
Stormwater Pumping Station (SWPS)			x	x	x	x	x	x
Water Treatment Works (WTW)			x		x	x	x	x
Wastewater Treatment Works (WWTW)			x		x	x	x	x
Stormwater Treatment Works (SWTW)			x		x	x	x	x
Water Supply Conduits (WSC)			x		x	x	x	
Water Trunk Mains (WTM)			x		x	x	x	
Water Distribution Mains (WDM)			x		x	x	x	
Wastewater Collection System (WCS)		x			x	x	x	
Stormwater Collection System (SWCS)		x			x	x	x	
Permeable Pavement (PP)		x		x	x	x	x	
Green Roof (GR)		x		x	x	x	x	
Bioretention and Rain Gardens		x		x	x	x	x	
Bioswales		x		x	x	x	x	
Stormwater Management Ponds (SMP)		x		x	x	x	x	
Rainwater Harvesting (RWH)		x		x	x	x	x	
Greywater Reuse (GWR)		x		x	x	x	x	
Living Machines (LM) and Membrane Bioreactors (MBR)		x		x	x	x	x	

Table 1 Spatial scales, and flows and fluxes of metabolic performance represented IWRET

5 MODELING COMPONENTS OF HYBRID WATER SYSTEMS

As described previously, a typical hybrid system in IWRET comprises of four major components:

- Water supply;
- Separate stormwater and wastewater;
- Hydrology;
- Water reuse and recovery systems;

The following section discusses in details representation of each component in IWRET.

5.1 WATER SUPPLY COMPONENT

IWRET adopts a simplified approach to represent the water supply subsystem in which 'source to tap' modelling is performed. The elements modelled in the water supply component are, Figure 15:

- A raw water source (WS) and a water treatment works (WTW). Service reservoirs (SR) are not included in this version;
- Three principal flow courses including water supply conduits (WSC), trunk mains (WTM) and distribution mains (WDM);
- Water pumping stations (PS);
- The neighborhood as a water consumption point (WD).

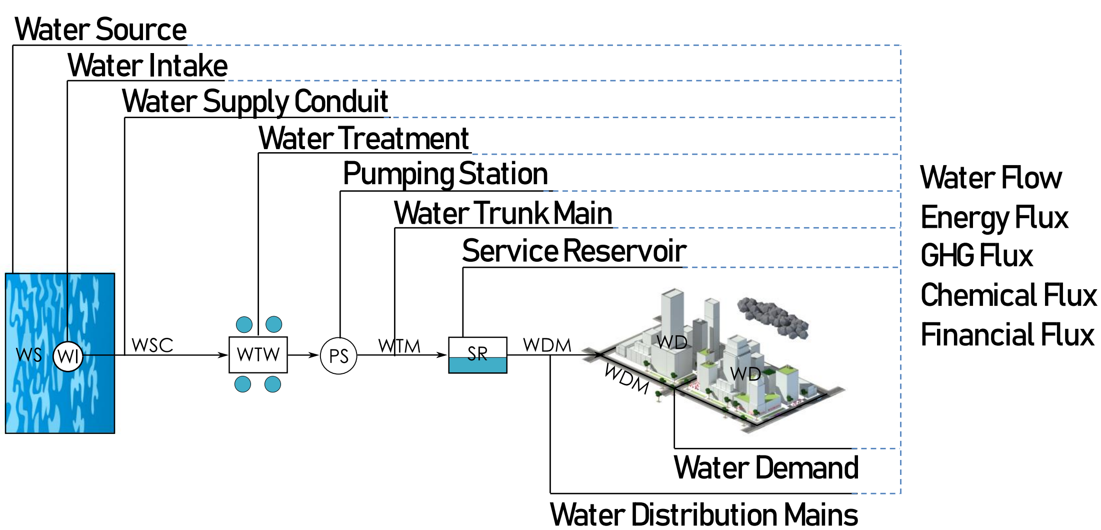

Figure 15 Elements of water supply component

Simulation of the water supply component is carried out in two steps. The first step deals with the calculation of daily water demand in the neighborhood and aggregating in the upstream direction until it reaches the water resource. Through this procedure, the calculated water demand in the neighborhood may be limited by the capacity of the relevant elements. Having determined water demand, the second step starts with distributing water flow in the downstream direction. At the most upstream point, the water abstraction is first supplied from a water source providing there is enough source capacity. The released/abstracted water is transferred to the downstream elements until it reaches the neighborhood. This procedure is initiated by transferring raw water to water treatment works by water supply conduits. Then, treated water is transferred through trunk mains and distribution mains to the neighborhood, where neighborhood is assumed to receive its share of potable water from the water treatment works.

5.1.1 Calculating water demand in the neighbourhood

Water demand evaluates the water consumption in the neighborhood, including both drinking and non-drinking water. Drinking water demand is supplied through water distribution network, while non-drinking water demand (i.e. irrigation and landscaping) can be supplied by potable water sources through water distribution network or non-potable water sources (e.g. rainwater harvesting scheme, greywater or blackwater recycling systems). Water demand accounts two levels of demand: indoor demand based on available appliances for a typical single and multifamily residential unit and neighborhood demand. User can define the rates of change in a volume of single-family and multi-family residential units on an annual basis. All types of water demand defined in a neighborhood are:

- Indoor (Single-Family Residential and Multi-Family Residential Households);
- Irrigation and landscaping (individual lot level and neighborhood level);
- Commercial and Institutional, and;
- Industrial.

Indoor water demand includes requirements of single-family and multi-family household units in the neighborhood. Single-family residential demand includes single-detached, semi-detached, row housing (3-6 units), and plexes (2-6 units). Alternatively, multi-unit households include high-rise or low-rise apartment buildings, condominiums, co-operatives, each with more than six units. Each unit includes a number of appliances and fittings and provides an indoor per capita per day water demand. To estimate the total domestic water demand on the neighborhood level, this number is multiplied by the total number of single and multifamily household units in the neighborhood and an average occupancy rate distinctive for that neighborhood. If water efficient appliances are used, water saving coefficient are applied. The appliances and fittings represented in IWRET are faucet, shower, dishwasher, bathtub, clothes washer, toilet and leaks. The unit of all water demand types are m^3 per day except indoor water demand, which is m^3 per day per capita.

Commercial and institutional water demand accounts all water required for planned social and economic activities in the neighborhood, Table 2. The unit of all water demand types are m^3 per day.

	Commercial/Institutional Demand	User Input	User Input
1	Restaurants	Number of Seats	Liters per Seat
2	Hotels/Motels	Total Area	Liters per m^2
3	Office Buildings	Area of Office Building	Liters per m^2
4	Schools	Number of Students	Liters per Student
5	Hospitals	Number of Beds	Liters per Bed
6	Daycares	Number of Children	Liters per Child
7	Retail	Retail Space	Liters per m^2
8	Community Centers	Community Center Area	Liters per m^2
9	Evaporative Cooling Systems	System Requirements	Liters/day

Table 2 Commercial/Institutional water demand on the neighborhood level

Water demand for landscaping and irrigation takes into account water required for all green spaces and public areas in the neighborhood. It also accounts water required for watering a typical lawn developed around a single-family household unit. Finally, industrial water demand is expressed in terms of water requirements per gross hectare of industrial development. Such demand are dependent upon the type of industry in the area being considered.

Variability of demand on three temporal scales

IWRET contains coefficients that are used to describe the variability in demand on three temporal scales - annual, seasonal and daily. Firstly, on the annual level, variations over the planning horizon are defined through variation of stocks of single-family and multi-family units and the overall annual population growth in the neighborhood. This can be used for defining different scenarios of water demand growth. The second temporal scale is a seasonal variation of water demand in which monthly pattern coefficients are specified (i.e. irrigation and landscaping). Finally, the third temporal level deals with daily variations, and coefficients are used to describe unpredictability and stochasticity in daily demand patterns. All three levels of temporal variability typically can be used for model calibration purposes. For instance, residential water demand varies throughout a day, month and year. Therefore, seasonal variations of daily water demand rates are represented using pattern coefficients and are specified for all five types of water demand.

Water demand in the neighborhood can be satisfied by different types of water resources. Potable water from distribution mains is the default water supply but the user can allocate other water sources (i.e. rainwater harvesting, greywater and blackwater recycling).

5.1.2 Water supply conduits, trunk mains and distribution mains

Water supply conduits transmit raw water from water resources to water treatment works (WTWs) on a daily basis. Two main characteristics for each conduit are daily capacity and leakage percentage. Both values are defined by the user. The daily capacity controls the maximum water flow transferred by the conduits. The leakage is based on a percentage of transferring water defined by the user. In addition, embodied energy (kWh), embodied greenhouse gas emissions (kgCO_2eq), and life-cycle costs ($) are calculated based on the material type used for construction and daily total volume of water transferred by each conduit, including leakage. IWRET assumes the total leakage can be expressed as a percentage of water demand. Furthermore, the flow of materials is also tracked down in distribution mains based on pipeline materials.

On the other hand, water trunk mains and distribution mains convey potable water from water treatment works to the point of consumption. They are characterized by a number of parameters over the planning horizon. These parameters are daily water transmission capacity and leakage percentage. The leakage is defined by the user as a percentage of transferred water in water mains.

Furthermore, the flow of materials is also tracked down in distribution mains based on pipeline materials. The pipeline is characterized by material type, length, and diameter. The consequence of material flow (i.e. pipeline replacement) is reflected in flows of cost, energy (i.e. fossil fuel and embodied energy) and GHG emissions and general system performance (i.e. leakage).

5.1.3 Water treatment works

After transmitting raw water from a water resource, the treatment process is carried out in a water treatment plant. The main physical characteristics of water treatment works, defined by the user, are daily treatment capacity and water loss. The daily treatment capacity sets the maximum daily treatment in m^3/day, while water loss takes into account the percentage of treated water which is removed from the water flow (e.g. evaporation or infiltration). However, a share of maximum daily treatment capacity is generally already utilized, while only a user defined portion of the capacity can be typically dedicated to the new neighborhood. The user can, therefore, define the percentage of total daily water treatment capacity available for the new development. Water treatment works are analyzed with five metabolic processes including water flows, chemical fluxes, energy fluxes, greenhouse gas emissions, and financial fluxes.

The chemical flux is calculated by multiplying the volume of treated water by the amount of required chemicals per unit volume of water. Learning from the experience of similar models, such as WaterMET[2] [10], a predefined list of chemicals typically used in water treatment process is included in IWRET:

- Alum [Aluminium sulphate];
- Calcium Hydroxide [$Ca(OH)_2$];

- Carbon dioxide [CO_2];
- Microsand;
- Polyaluminium chloride (PAX) and
- Sodium Hypochlorite [NaOCl].

Once the total amount of chemicals for water treatment is calculated, the embodied energy and associated greenhouse gas emissions are estimated. On the other hand, the Life Cycle Cost (LCC) of a water treatment works include capital investments, initial installation/construction costs, maintenance costs and operational costs. Initial/construction costs refer to the costs that are required for the construction of a completely new water treatment plant. In contrast, capital investments include initial costs in case the extension of existing treatment capacity is required. Annual operational costs for water treatment works include water resource fee, electricity fee, staff cost, administration, maintenance and potential replacement cost.

5.2 PUMPING STATIONS

A typical water system contains pumps that are used to increase water pressure and push the water (drinking, waste and storm water) from the source level to the higher elevated areas. For each pumping station in the system, energy requirements, greenhouse gas emissions, and financial costs of operation are calculated based on user inputs. The cost of pumping depends on the flow, pump head, efficiency, price of energy, and the duration of time that the pump is running. The cost for pumping energy over a given time period is determined using the following equation:

$$C = \frac{C_f h_p Q p t}{(e_p e_m e_d)}$$

Where, in Table 3:

Table 3 Parameters for calculating required energy for pumping and costs

	Pump properties	Unit
$\boldsymbol{C}$	Daily operation costs	$/day
$\boldsymbol{C_f}$	Unit Conversion factor	101.9 for SI
$\boldsymbol{Q}$	Flow rate	l/s
$\boldsymbol{h_p}$	Total dynamic head of pump	meters
$\boldsymbol{p}$	Price of energy	$/kWh
$\boldsymbol{t}$	Duration that pump is operating	Hours
$\boldsymbol{e_p}$	Pump efficiency	%
$\boldsymbol{e_m}$	Motor efficiency	%
$\boldsymbol{e_d}$	Variable speed drive efficiency	%

5.3 SEPARATE SANITARY SEWER COMPONENT

In addition to the drinking water supply and distribution, IWRET takes a simplified approach to represent a wastewater component, Figure 16. The key elements modelled in this subsystem are:

- Principal wastewater (WWCS) and stormwater collection systems (SWCS), denoting mainly separate draining routes at the neighborhood level;
- Wastewater treatment works(WWTW) and stormwater treatment works (SWTW) on the urban water utility level;
- Wastewater Pumping Station (WWPS) and Stormwater Pumping Station (SWPS);
- Discharge Point (D) and Receiving water body (E).

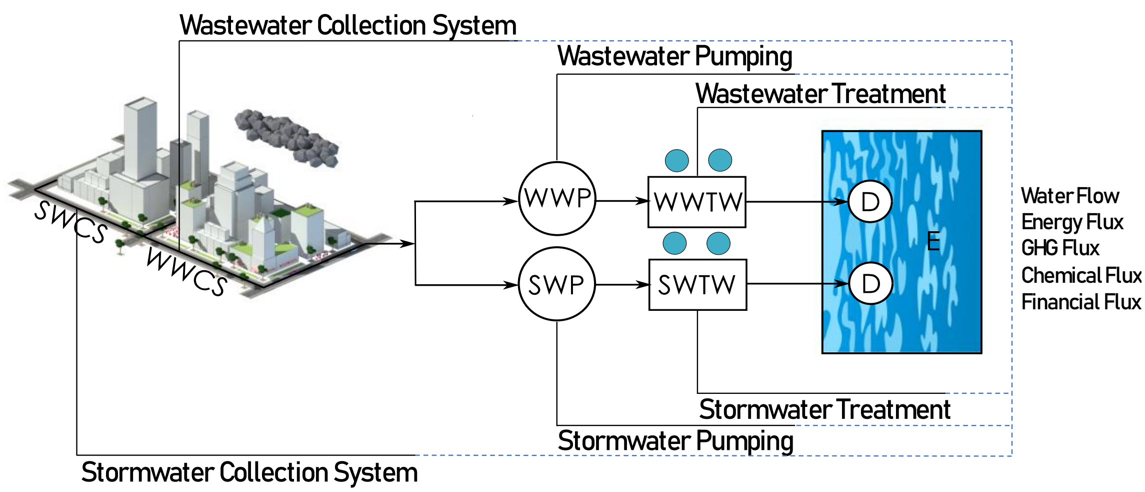

Figure 16 Separate stormwater and wastewater component

5.3.1 Wastewater collection system

The inflows to the wastewater and stormwater collection systems in the neighborhood are sanitary sewage and storm water runoff calculated by the hydrology (rainfall-runoff) component. A user-defined percentage of consumed water is converted to sanitary sewage and the rest is assumed to be lost. The sewer systems transport sanitary sewage and storm water runoff to waste and stormwater treatment works. Embodied energy (kWh), embodied greenhouse gas emissions (kgCO_2eq), and life-cycle costs ($) are calculated based on the material type used for construction. IWRET assumes the total leakage can be expressed as a percentage of water demand. Furthermore, the flow of materials is also tracked down in distribution mains based on pipeline materials.

5.3.2 Wastewater treatment works

IWRET allows modelling of wastewater treatment works on the urban water utility level as the final destination of sanitary sewer systems. In wastewater treatment works, sanitary wastewater is treated, producing treated effluent and resource recovery. Total daily inflow to a WWTW is limited to the daily treatment capacity [m^3/day] of the wastewater treatment works. Surplus inflow exceeding the sum of the storage and daily treatment capacity is diverted into receiving water bodies as untreated wastewater. However, a share of maximum daily treatment capacity is generally already utilized, while only a user defined portion of the capacity can be dedicated to the new neighborhood. The user can define the percentage of total daily wastewater treatment capacity available for the new development.

In addition to water flows, wastewater treatment works are analyzed with other metabolic processes, such as chemical fluxes, energy fluxes, greenhouse gas (GHG) emissions, and financial fluxes. Similarly to WaterMET^2 model[10], chemical flux is calculated in a similar manner like for water treatment works. The chemicals modelled in IWRET are:

- Ferric Chloride [$FeCl_3$],
- Ferric Sulphate [$Fe_2(SO_4)_3$],
- Polyaluminium chloride (PAX),
- Calcium Hydroxide [$Ca(OH)_2$],
- Ethanol,
- Methanol, and
- Nitric acid.

The model user can specify the unit demand required for treatment of 1m^3 of potable water and wastewater. The embodied energy and associated greenhouse gas emissions are estimated based on the total amount of chemicals for water treatment.

The Life Cycle Cost (LCC) of a water treatment works include Capital Investments, Initial Installation/Construction Costs, Maintenance Costs and Operational Costs. Initial/Construction cost refer to the costs that are required for the construction of a completely new water treatment plant. On the other hand, Capital Investments include initial capital costs in case the extension of existing treatment capacity is required. Annual operational costs for water treatment works include water resource fee, electricity fee, staff cost, administration, maintenance and potential replacement cost.

5.4 HYDROLOGY OF THE NEIGHBORHOOD

IWRET contains a model to describe the rainfall–runoff relations at the neighborhood level. More precisely, the model produces a surface runoff hydrograph in response to a daily rainfall event. Enhanced The Long-Term

Hydrologic Impact Assessment (L-THIA) mathematical model is used to analyze the hydrologic component of the urban water system [11]. Fundamental L-THIA model estimates the average runoff for different land use configurations based on daily precipitation data, combined with soils and land use data for an area. By using multiple years of climate information, L-THIA focuses on the average impact, rather than extreme events.

In contrast, L-THIA-LID represents an enhanced version of L-THIA. L-THIA-LID evaluates the hydrologic benefits of low impact development (LID) practices. IWRET, through LTHIA-LID model, represents seven LID practices including porous pavement and permeable patio, rain barrel and cistern, grass swale, bioretention system, green roof, and stormwater management pond.

Evaluating the effectiveness of LID practices involves use of SCS-CN values to estimate runoff. The Curve Number (CN) method is used to estimate runoff based on the relationship between rainfall, land uses, and hydrologic soil group (HSG). The relationship between rainfall, runoff and CN value is non-linear, meaning that small changes in land use or rainfall can produce large changes in runoff. Although used in simple everyday stormwater management methods, the CN method is also often used in complex models for more sophisticated analyses. The use of the CN equation in L-THIA-LID is a simple alternative to complex hydrological models that require extensive data inputs which are often not readily available for most areas.

The CN method contains one parameter (Curve Number), and represents an empirically based procedure to determine how much of a rainfall event translates to runoff. The initial abstraction, which describes all losses of precipitation before runoff begins (interception, infiltration, surface storage and evaporation), is a function of the CN and is calculated as:

$$S = \frac{25400}{CN} - 254$$

Under the condition that precipitation P_h*(mm) > 0.2S,* direct runoff depth Q_h *(mm)* is estimated as:

$$Q_h = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

$$Q_h = 0 \text{ if } P_h <= 0.2S$$

The volume of runoff from an area is determined as:

$$Q_v = Q_h A$$

Where Q_v is the volume of water, and A is the area of interest.

The soil component involves the use of four types of soil. This system used the classification of hydrologic soil groups (HSG) which indicate the status of infiltration in the soil. The minimum rate of infiltration obtained for bare soil after a minimum amount of wetting determines the classification. The four groups are denominated as A, B, C, and D. The specific characteristics of the groups are displayed in Table 4.

Table 4 Properties of different hydrologic soil groups (HSGs)

Hydrologic Soil Group	Hydrologic Soil Group Characteristics
Group A	These soils display low runoff potential and high infiltration rates even when thoroughly wetted. Consisting chiefly of *deep*, *well drained* to *excessively drained* sand or gravel. These soils have a high rate of water transmission (greater than 0.30 in/hr).
Group B	These soils display moderate infiltration rates when thoroughly wetted. They consist chiefly of moderately deep to deep, moderately well drained to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15- 0.30 in/hr).
Group C	These soils display low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water, and are soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05-0.15 in/hr).
Group D	These soils have high runoff potential. They display very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr).

In the absence of a soil survey, or in the presence of disturbed soil profiles (e.g. native soil profile is mixed, or removed and replaced), there is a method for the modeler to estimate the hydrologic soil group from the texture of the surface soil in the area of interest, provided that significant compaction has not occurred. This relationship for determining the HSG classification for disturbed soils is reported below in Table 5.

Table 5 Simplified hydrologic soil groups (HSG)

Estimates HSG	Surface soil texture
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

Most urban areas are only partially covered by impervious surfaces and the soil remains an important factor in runoff estimates. Urbanization has a greater effect on runoff in watersheds with soils having high infiltration rates (sands and gravels) than in watersheds predominantly of silts and clays, which generally have low infiltration rates. Since IWRET focuses on urban environments, Table 6 presents the runoff curve numbers (CN) for different land cover types and hydrologic soil groups in urban areas.

Table 6 Typical CN values for different cover type categories

Cover description	APA	Curve number for hydrologic soil group			
Cover type and hydrologic condition		A	B	C	D
Fully developed urban areas					
Open space:					
Poor condition (grass cover <50%)		68	79	86	89
Fair condition (grass cover 50 to 75%)		49	69	79	84
Good condition (grass cover >75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (including right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel(including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses) (~500m^2)	65	77	85	90	92
1/4 acre (~1000m^2)	38	61	75	83	87
1/3 acre (~1400m^2)	30	57	72	81	86
1/2 acre (~2000m^2)	25	54	70	80	85
1 acre (~4000m^2)	12	51	68	79	84
2 acres (~8000m^2)		46	65	77	82

APA = Average percent impervious area

Recommended CN values are used to adjust default values in the model characterize the effect of LID practices on runoff, allowing comparison between hydrologic and water quality conditions before and after implementation of the practices.

6 ALTERING MORPHOLOGY OF URBAN WATER SYSTEMS

In increasingly resource limited cities, a search for more efficient and sustainable water urban metabolism implies reconstructing the urban morphology through implementation of alternative, decentralized technologies. Based on the direct input of the group of stakeholders, the following section provides detailed description of decentralized technologies available to the user in IWRET. They are divided in three groups: drinking water technologies, storm water technologies, and water recovery systems (greywater and blackwater).

6.1 DRINKING WATER TECHNOLOGIES AND SUPPLY MANAGEMENT

Residential conservation efforts can make a positive contribution to reducing pressure on water resources. Reducing water use in urban water systems also contributes to climate change mitigation by decreasing energy consumption and greenhouse gas emissions. Water conservation can lead to large savings in the energy used to transport, treat and distribute water. The most common water conservation appliances include dishwashers and clothes washing machines, while popular fixtures include toilets, showerheads and faucets. These appliances simply use less water while yielding comparable performance (e.g. low-flow showerheads). Alternatively, these appliances can be more complex, as devices that use gray water from the sink for toilet flushing. Other products give visual or audible feedback to the user about resource consumption and rely on behavior change. The costs for individual households are generally small and may be fully recovered by water savings over the lifetime of the product.

Therefore, IWRET analyzes the potential effects of water conservation appliances on water balance, and then on cascading energy and greenhouse gas emissions. The user can define the rate of adoption in the neighborhood and the efficacy rates for specific features (faucet, shower, bathtub, clothes washer, dishwasher, and toilet.

6.2 STORMWATER TECHNOLOGIES

Decentralized storm water technologies in IWRET include Low-impact development (LID) and Green Infrastructure (GI) techniques. This term describes a land planning and engineering design to manage stormwater runoff as part of green infrastructure. LID and GI underline conservation and use of on-site natural features to protect water quality. This approach uses small-scale hydrologic controls to replicate the pre-development hydrologic regime through infiltrating, filtering, storing, evaporating, and detaining runoff close to its source. The following section provides details on LID and GI techniques represented in IWRET.

6.2.1 Green roofs

Green roofs consist of a thin layer of vegetation and growing medium installed on top of a conventional roof. In addition to their water quality, water balance, and peak-flow control features, green roofs provide benefits to urban environments as they improve energy efficiency, reduce urban heat island effects, and create greenspace for passive recreation or aesthetic enjoyment. The green roof acts like a lawn by storing rainwater in the growing medium and ponding areas [12]. Excess rainfall enters underdrains and overflow points and is conveyed in the building drainage system. After the storm, a large portion of the stored water is evapotranspired by the plants, evaporates or slowly drains away. There are two types of green roofs: intensive and extensive. Intensive green roofs contain greater than 15 cm depth of growing medium, can be planted with deeply rooted plants and are designed to handle pedestrian traffic. Extensive green roofs consist of a thinner growing medium layer (15 cm depth or less) with herbaceous vegetative cover.

Therefore, IWRET allows assessment of potential effects of green roofs on sustainability by accounting following metabolic processes:

- Water flows;
- Embodied greenhouse gas(GHG) emissions and embodied energy fluxes for construction and maintenance;
- Financial fluxes through Life Cycle Costs (LCC).

To estimate the effects on urban stormwater runoff, IWRET hydrologic component uses the CN value of 85 for all four hydrologic soil groups. However, this value can be changed by the user. To determine the direct runoff from green roofs, following equation is used:

$$V = ChA_{roofarea}$$

Where C is runoff coefficient, h is the height of daily rainfall [mm], and $A_{roofarea}$ is total area of green roofs [m^2]. Depending on the type of the green roof, runoff coefficient is provided in Table 7.

Table 7 Runoff coefficients for different types of green roofs

Type of Green Roof	Depth [mm]	Vegetation	Water Retention Annual Average [%]	C Coefficient
Extensive	20-40	Moss/Sedum	40	0.6
	40 - 60	Sedum/Moss	45	0.55
	60 -100	Sedum/Moss/Herbs	50	0.5
	100 – 150	Sedum/Moss/Grass	55	0.45
	150 – 200	Grass/Herbs	60	0.4
Intensive	150 – 250	Lawns/Shrubs	60	0.4
	250 – 500	Lawns/Shrubs	70	0.3
	500+	Lawns/Shrubs/Trees	90+	0.1

Since construction of urban water infrastructure systems involves a large consumption of different resources (water, energy, etc.), energy demand for conventional and sustainable urban drainage systems requires energy mainly in the form of electricity and fuel. Some examples include - energy to modify the topography, energy for the production of building materials, etc. Energy demand in drainage systems construction is calculated taking into consideration the energy consumed (electricity and fuel) and the materials used per m, m_2 or m^3, which is also associated to an energy used and CO_2 emission factor per material manufacturing. Table 8 shows energy requirements and CO_2 emissions for green roofs during the construction phase [13]. This document also includes energy requirements and CO_2 emissions for various different stormwater management techniques.

Table 8 Embodied energy and grenhouse gass emissions for green roof production

Type	Size Considered	Unit	Construction Energy [kWh/Unit]	Construction Emissions [kgCO2eq/Unit]
Green Roof	1	m^2	93.3	28.1

IWRET requires the estimates of design and capital costs and annual maintenance costs for m^2 of green roof area. For detailed estimates, the user is advised to consult Low Impact Development Practice Costing Tool [14], published by Toronto and Region Conservation Authority(TRCA), that allows estimate of the overall construction and maintenance costs for different system designs.

6.2.2 Bioretention and Rain Gardens

As stormwater filter and infiltration practices, bioretention and rain gardens temporarily store, treat and infiltrate runoff. Bioretention and rain garden systems consist of shallow depressions designed for holding stormwater runoff from impervious surfaces such as parking lots, rooftops, sidewalks, and drive ways. They stimulate infiltration by allowing rain water to soak into the ground, thus reducing runoff that can potentially enter stormwater systems. Bioretention and rain garden systems also support runoff filtration for water quality improvement with planted non-invasive vegetation. In urban communities using combined sewer systems, they reduce the overflow frequency of these combined sewer systems. During winter, both systems may capture the majority of runoff produced by melting snow from impervious surfaces. Typical contributing drainage areas for bioretention system ranges between 100 m^2 and 0.5 hectares, while the maximum recommended contributing drainage area is 0.8 hectares. IWRET allows assessment of potential effects of bioretention and rain gardens on sustainability by accounting following metabolic processes:

- Water flows;
- Embodied greenhouse gas(GHG) emissions and embodied energy fluxes for construction and maintenance;
- Financial fluxes through Life Cycle Costs (LCC).

In order to estimate the hydrologic benefits, the values of runoff Curve Number (CN) used to represent bioretention and rain garden systems are 15, 20, 35, and 40 for Hydrologic Soil Group (HSG) A, B, C, and D, respectively. Table 9 shows energy requirements and CO_2 emissions for bioretention and rain gardens during the construction phase [13].

Table 9 Energy Consumption and CO_2 Emissions Indicators for Bioretention and Rain Garden Construction

Type	Size Considered	Unit	Construction Energy [kWh/Unit]	Construction Emissions [kgCO_2eq/Unit]
Rain Garden	32	m^2	118	36
Bioretention	200	m^2	137.1	42.1

Bioretention and rain gardens require routine inspection and maintenance of the landscaping as well as periodic inspection for less frequent maintenance needs or remedial maintenance. Moreover, regular watering may be required during the first two years. Table 10 shows life-cycle costs calculated based on three different discount rates [14]. Net present values based on a discount rate of 5% are shown. There are few data on the operation and maintenance because only recently have they started to become more widely implemented. However, it was assumed that if the bioretention and rain garden area was routinely maintained, it would need major rehabilitation only once in 25 years, at a cost of roughly $6345. This rehabilitation cost includes replacement of the filter media, re-mulching and replanting. Average costs of regular maintenance and landscaping are similar over the entire 50 year time period ($945 to $952). The exceptions are higher costs for watering and inspection in the early phases of plant establishment initially and after rehabilitation, and cleaning of underdrain pipes once every 10 years. Variation in present values is largely explained by differences in capital costs, as the maintenance and rehabilitation of the different scenarios was similar.

Table 10 Estimated life cycle costs for bioretention and rain garden system in 2014 US$ (130 m^2).

	Full Infiltration	Partial Infiltration	No Infiltration
Life span	25 Years	25 Years	25 Years
Capital Cost	$31,973	$41,476	$39,028
Rehabilitation Cost at 25 years	$7,504	$7,504	$7,504
Annual Maintenance	$945	$952	$952
Present value including capita, maintenance and rehabilitation costs			
at 50 Years			
if i = 0 %	$86,716	$96,604	$94,156
if i = 3 %	$60,471	$70,146	$67,698
if i = 5 %	$52,183	$61,798	$59,350
NPV at 25 years			
if i = 0 %	$56,266	$65,923	$63,475
if i = 3 %	$49,228	$58,831	$56,383
if i = 5 %	$46,129	$55,709	$53,261

However, for more detailed estimates, the user is advised to consult the Low Impact Development Practice Costing Tool [14] that allows estimates of the overall costs of different system designs.

6.2.3 Bioswales

Bioswales are vegetated open channels constructed to convey, treat and attenuate stormwater runoff. Check dams and vegetation in the swale slows the water to allow sedimentation, filtration through the root zone and soil matrix, evapotranspiration, and infiltration into the underlying native soil. Simple grass channels or ditches have long been used for stormwater conveyance, particularly for roadway drainage. Enhanced grass swales incorporate design features such as modified geometry and check dams that improve the contaminant removal and runoff reduction functions of simple grass channel and roadside ditch designs. When incorporated into a site design, they can reduce impervious cover, accent the natural landscape, and provide aesthetic benefits. Therefore, IWRET allows assessment of potential effects of bioswales on sustainability by accounting following metabolic processes:

- Water flows;
- Embodied greenhouse gas(GHG) emissions and embodied energy fluxes for construction and maintenance;
- Financial fluxes through Life Cycle Costs (LCC).

In order to estimate the hydrologic benefits, the values of runoff Curve Number (CN) used to represent bioswales are 15, 20, 35, and 40 for HSG A, B, C, and D, respectively. Table 11 shows energy requirements and CO_2 emissions bioswales during the construction phase [13].

Table 11 Energy Consumption and CO_2 Emissions Indicators for Bioswales Construction

Type	Size Considered	Unit	Construction Energy [kWh/Unit]	Construction Emissions [$kgCO_2eq$/Unit]
Bioswales	32	m^2	118	36

Maintenance of bioswales consists of regular inspections, watering, litter and sediment removal, and mowing. Grass may also need to be restored periodically. These routine costs add significantly to the overall long term costs, but the practice remains one of the least expensive LID practices. Table 12 presents the estimated life cycle costs by EPA [15].

Table 12 Estimated Life-Cycle Costs of Bioswales

Input Parameters	Curb Check Dam	Filter Sock Check Dam	Rock Check Dam
Life Span	50+ years	50+ years	50+ years
Capital Cost	$18,582	$18,233	$18,347
Replacement Cost	n/a	n/a	n/a
Annual Maintenance	$500	$500	$500

However, for more detailed estimates, the user should consult Low Impact Development Practice Costing Tool [12] that allows estimates of the overall costs of different system designs.

6.2.4 Porous Pavement and Permeable Patio

Permeable pavements or asphalts are used to capture and filter runoff from impervious parking lots, driveways, streets, roads and patios. This technique also helps regulating non-point sources of pollution. Therefore, IWRET allows assessment of potential effects of porous pavement and permeable patios on sustainability by accounting following metabolic processes:

- Water flows;
- Embodied greenhouse gas(GHG) emissions and embodied energy fluxes for construction and maintenance;
- Financial fluxes through Life Cycle Costs (LCC).

The original CN value of 98 for conventional asphalt is changed to 70, 80, 85 and 87 for driveways and sidewalks with porous materials for HSG A, B, C, and D. Table 13 presents the estimated life cycle costs for conventional and permeable pavement (1000m^2) [15].

Table 13 Estimated life cycle costs for conventional and permeable pavement

	Full Infiltration	Partial Infiltration	No Infiltration
Life Span	30 Years	30 Years	30 Years
Capital Cost	US$98,313	US$99,652	US$110,153
Replacement Cost at 30 years	US$72,990	US$72,990	US$72,990
Annual Maintenance	US$443	US$436	US$436

However, for more detailed estimates, the user should consult Low Impact Development Practice Costing Tool [12] that allows estimates of the overall costs of different system designs.

6.2.5 Rainwater Harvesting using Rain Barrels and Cisterns

Rainwater harvesting system intercepts, conveys and stores runoff in rain barrels and cisterns for future use from impervious surfaces and green roofs. Collected runoff can be used for non-potable water demands. Typically, standard and green roofs represent the catchment area, although rainwater from low traffic parking lots and walkways can also be used for some non-potable uses (e.g., outdoor washing). The quality of the water varies according to the type of catchment area and material from which it is constructed.

In IWRET, two inflows, from impervious areas (standard roof, road and parking pavement) and green roof runoff are considered. The collected water is used for any of the water demand profiles (i.e. toilet flushing, dish washer, hand basin, kitchen sink, shower, washing machine, industry and landscape irrigation). The water volume exceeding the capacity of the tank is discharged into the sewer system.

IWRET allows assessment of potential effects of rainwater harvesting systems by accounting:

- Water flows;
- Embodied greenhouse gas(GHG) emissions and embodied energy fluxes for construction and maintenance;
- Financial fluxes through Life Cycle Costs (LCC).

The storage tank is the most significant component of a rainwater harvesting system. The required size of storage tank depends on several parameters: rainfall and snowfall frequencies and totals, the intended use of the harvested water, the catchment surface area, aesthetics, and budget. In the Greater Toronto Area, an initial target for sizing the storage tank could be the predicted rainwater usage over a 10 to 12 day period. Storage tanks and rain barrels range in size from rain barrels for residential land uses (typically 190 to 400 liters in size), to large cisterns for industrial, commercial and institutional land uses. A typical pre-fabricated cistern can range from 750 to 40,000 liters in size [16].

With minimal pretreatment, the captured rainwater can be used for outdoor non-potable water uses such as irrigation and landscaping, or in the building to flush toilets or urinals. It is estimated that these applications alone can reduce household municipal water consumption by up to 55%. By providing a reliable and renewable source of water to end users, rainwater harvesting systems can also help reduce demand on municipal treated water supplies. This helps to delay expansion of treatment and distribution systems, conserve energy used for pumping and treating water and lower consumer water bills.

Most distribution systems are gravity fed or operated using pumps to convey harvested rainwater from the storage tank to its final destination. Typical outdoor systems use gravity to feed hoses via a tap and spigot. For underground cisterns, a water pump is needed. Indoor systems usually require a pump, pressure tank, back-up water supply line and backflow preventer. The typical pump and pressure tank arrangement consists of a pump, which draws water out of the storage tank into the pressure tank, where it is stored for distribution.

The value of CN used to represent rain barrels and cisterns 85 for driveways and sidewalks with porous materials for HSG A, B, C, and D. Table 14 shows energy requirements and CO_2 emissions for green roofs during the construction phase [13].

Table 14 Embodied energy and GHG emissions for rainwater harvesting system

Type	Size Considered	Unit	Construction Energy [kWh/Unit]	Construction Emissions [$kgCO_2eq$/Unit]
Rainwater Harvesting Systems	4	m^3	245.4	80.6

The cost of rainwater harvesting systems includes the cost of the storage tanks, as well as any necessary pumps, wiring and distribution system piping. Storage tanks often make up the majority of system costs. Their cost varies depending on the size, construction material and whether they are located above or below ground.

The capital cost to homeowners of an individual rainwater harvesting system can range between $6,000 and $14,000 (in 2006 Canadian dollars), depending on its size and configuration. Based on analysis by the Center for Watershed Protection, base construction costs per cubic meter of runoff stored (in 2006 US dollars) range from $212 to $777, with a median of $530. However, for more detailed estimates, the user should consult Low Impact Development Practice Costing Tool [12] that allows estimate of the overall cost of different system designs.

6.2.6 Stormwater Management Ponds

There are two types of ponds. A dry pond is a detention basin that temporarily stores collected stormwater runoff and releases it at a controlled rate through an outlet. Dry ponds do not have a permanent pool of water.

This implies that there is no opportunity for settling of contaminants between storm events and dilution of stormwater contaminants during storms. Therefore, although dry ponds can be effective for erosion and flood control, they do not perform as well as wet ponds for water quality control. In contrast, a wet pond is different from a dry pond in that it maintains a permanent pool of water between storm events. Wet ponds are the most common end-of-pipe stormwater facility used in Ontario [18]. A single wet pond can provide water quality, erosion, and flooding control.

Conventional stormwater ponds have little to no vegetation underwater and are surrounded by standard grass, which creates an unbalanced ecosystem. The lack of submerged plants allows for uncontrolled algae growth in the pond and large geese populations can develop as the grass offers no camouflage for predators. Routine maintenance costs on standard stormwater ponds are high, with regular grass mowing and control/removal of unwanted aquatic weeds. On other hand, naturalized stormwater ponds include natural plantings both on the banks and below the surface of the pond, creating a fully balanced ecosystem where weeds cannot compete while also providing superior water treatment.

6.3 WATER REUSE AND RECOVERY SYSTEMS

Cyclic water recovery can be performed in both centralized and decentralized facilities. While centralized water recovery at the water system utility level is performed in water treatment plants, decentralized water treatment facilities include grey water recycling (GWR) and black water recycling schemes (using constructed wetlands and membrane bioreactors). All schemes employ a tank for which a storage capacity is specified by the user. It is assumed that the storage volume is first controlled by daily inflow and thus the tank overflow is only affected by inflow and the tank volume left from the previous day.

6.3.1 GREY WATER RECYCLING (GWR) SYSTEM

Grey water recycling (GWR) system collects grey water and provides recycled water for reuse in a household or a neighborhood. In households with conventional flush toilets, greywater can make up to 65% of the total wastewater produced by that household. The GWR system receives inflow of grey water used in local area including dishwasher, hand basin, shower, washing machine, and industry. The outflow at both levels is used for satisfy the water demand profile.

Greywater usually contains some traces of pathogens. The quality of greywater can deteriorate rapidly during storage. The treatment processes that can be used are in principle the same as those used for sewage treatment, but built on much smaller scale, often at household or building level:

- Biological systems such as constructed wetlands or living walls and bioreactors or more compact systems such as membrane bioreactors.
- Mechanical systems (sand filtration, lava filter systems and systems based on UV radiation)

Graywater system costs at the household scale vary widely depending on the size and complexity of the system. San Francisco Public Utilities Commission [19] reports that systems cost a few hundred dollars for a self-installed system and $1,000-$2,000 for a professionally installed system. Costs increase if a pump or filtration system is needed and with professional installation. This document also reports that a simple graywater system with a tank and pump, but no filtration costs between $500 and several thousand dollars, depending on the extent of plumbing work and whether the system is professionally installed. Adding a sand filter system increases per household costs into the range of $5,000 to $15,000.

Although cost data are limited, one graywater collection system for irrigation with professionally installed dual plumbing and homeowner-installed tank and pump costs $2,300 for a five-bedroom house, with the bulk of that cost ($1,700) being associated with the dual plumbing system. A smaller home would have lower plumbing installation costs. The costs of retrofitting dual plumbing in an existing home would be substantially higher.

The costs associated with graywater systems naturally increase as they are scaled up to neighborhoods and regions. Table 15 breaks down capital and operation and maintenance costs for 14 different graywater system sizes (50-5,000 gpd; 190-190,000 1pd). For example, for a 1,000 gpd (3,800 lpd) system (capable of treating enough graywater to provide toilet flushing for about 150 to 160 people in a dormitory-type setting), total storage and treatment costs (plumbing not included) amount to $4.39 per 1,000 gallons (Kgal). As shown in the table, initial and annual operating costs increase with capacity, but units over 100 to 300 gpd (380 to 1,100 1pd) achieve economies of scale that significantly reduce the cost per unit of water. These costs are comparable to or lower than potable water rates in many cities, and they are significantly lower if combined wastewater charges are considered. However, the plumbing cost, which is omitted but may be the most expensive component, especially for a retrofit application, would also need to be taken into account. An analysis of costs of graywater use in a mixed-use development ranging from 40,000 to 500,000 ft2 (3,700 to 46,000 m^2) revealed that installation of dual collection and distribution plumbing during building construction represented 77 to 93 percent of the capital costs for the project.

Table 12 Costs of greywater treatment and storage systems of varying scales, including a coarse filter and chlorine disinfection (plumbing excluded), in 2014 US$.

System Size (gpd)	Capital	Annual Maintenance	$/Kgal
50	$2,136	$253	$24.33
75	$2,136	$253	$16.50
85	$2,294	$253	$15.17
100	$2,294	$505	$18.91
150	$2,376	$505	$13.08
300	$2,369	$505	$6.97
500	$3,168	$758	$6.16
750	$3767	$758	4.61
1000	$4218	$1010	$4.39
2000	$5270	$2021	$3.96
3000	$6.906	$3031	$3.86
4000	$8773	$4041	$3.83
5000	$12435	$5052	$3.92

6.3.2 BLACKWATER REUSE USING LIVING MACHINES (LMs) AND MEMBRANE BIOREACTORS (MBRs)

IWRET represents two types of decentralized blackwater reuse systems: Living Machine (LM) and Membrane Bioreactors (MBR). The Living Machine represents a proprietary system of wastewater treatment technology designed to replicate the functions of natural wetlands. While treating the wastewater, the living machine can also produce beneficial byproducts, such as reuse-quality water, ornamental plants and plant products—for building material, energy biomass, and animal feed. This form of constructed wetland uses aquatic and wetland plants, bacteria, algae, protozoa, plankton, snails and other organisms to provide specific cleansing or trophic functions. In tropical and temperate climates, living machine systems can be outdoors, as the temperature will sustain sufficient biological activity throughout the winter. In cold climates, a greenhouse is used to keep water temperatures warm so that plants do not freeze. The living machine includes a system of tanks, pipes and filters that can be housed in a greenhouse to prevent freezing and raise the rate of biological activity.

Compared to conventional wastewater treatment, living machine systems offers a number of advantages. First, conventional treatment focuses narrowly on treating water and produces an often toxic sludge as a by-product of this cleaning process. Living machine systems can greatly reduce this sludge by conversion into biomass. Secondly, Conventional treatment uses environmentally harmful chemicals, such as chlorine, to disinfect effluent following precipitation of solids (sludge) from the wastewater stream. Ecological treatment uses biological processes instead of chemical inputs. Finally, conventional treatment is capital and energy intensive, whereas natural treatment is design intensive. The embodied fossil fuel energy in the heavy industrial infrastructure used in traditional activated sludge treatment is much greater than in the construction of a living machine system with a large greenhouse, manufacture of plastic tanks, mechanical aerators, pumps and valves among other equipment.

The scale of living machine systems ranges from the individual building to community-scale public works. Each system is designed to handle a certain volume of wastewater per day, but the system is also tailored for the qualities of the specific influent.

According to EPA [20], Table 16 shows the comparison between conventional systems and living machines in terms in US$.

Table 13 Estimated costs of living machines in US$, 2018

Price	151 m^3/day	302 m^3/day	3785 m^3/day
Living Machine with Greenhouse	US$1,487,332.00	US$1,359,840	US$14,431,408
Living Machine without Greenhouse	US$2,360,186	US$2,166,939	US$12,740,515

In addition, Table 17 shows energy requirements and CO_2 emissions for living machines during the construction phase.

Table 17 Embodied energy and GHG emissions for living machines

Type	Size Considered	Unit	Construction Energy [kWh/Unit]	Construction Emissions [$kgCO_2eq$/Unit]
Living Machine	143	m^2	71.9	10.8

6.3.3 MEMBRANE BIOREACTORS (MBR)

Membrane bioreactors (MBRs) are used for domestic and industrial wastewater treatment. This technology represents a combination of a membrane process (microfiltration or ultrafiltration) and a biological wastewater treatment process (the activated sludge process) [21]. MBRs can produce effluent of high quality to be released to coastal, surface or brackish waterways or to be reclaimed for urban irrigation. Other advantages of MBRs over conventional processes include small footprint, easy retrofit and upgrade of old wastewater treatment plants. Two MBR configurations exist:

- Internal (submerged), where the membranes are immersed in and integral to the biological reactor;
- External (sidestream), where membranes are a separate unit process requiring an intermediate pumping step.

Recent technical innovation and significant membrane cost reduction have enabled MBRs to become an established process option to treat wastewaters. As a result, the MBR process has now become an attractive option for the treatment and reuse of industrial and municipal wastewaters, as evidenced by their constantly rising numbers and capacity.

Capital costs for MBR systems have tended to be higher than those for conventional systems because of the initial costs of the membranes. In certain situations, however, including retrofits, MBR systems can have competitive capital costs because MBRs have lower land requirements and use smaller tanks, which can reduce the costs for concrete.

[21] also reported on a cost comparison of technologies for a 12-MGD design in Loudoun County, Virginia. Because of a chemical oxygen demand limit, activated carbon adsorption was included with the MBR system. It was found that the capital cost for MBR plus granular activated carbon at $12/gallon treated was on the same order of magnitude as alternative processes, including multiple-point alum addition, high lime treatment, and post-secondary membrane filtration.

On the other hand, operating costs for MBR systems are typically higher than those for comparable conventional systems. The amount of air needed for the scouring has been reported to be twice that needed to maintain aeration in a conventional activated sludge system. These higher operating costs are often partially offset by the lower costs for sludge disposal associated with running at longer sludge residence times and with membrane thickening/dewatering of wasted sludge.

7 DESCRIBING THE IWRET USER INTERFACE

This chapter presents the graphic user interface and data requirements for model development in Integrated Water Resources Evaluation Tool (IWRET). When working with IWRET to model a neighborhood and a hybrid urban water system, the user should take the following steps:

- Define all components in the hybrid water system and specify the relevant features;
- Specify the components' characteristics;
- Specify the constant values;
- Run a simulation;
- View and extract simulation results.

In order to complete these tasks, IWRET guides a user through a set of forms representing different components of the urban water system. In the main menu, all forms are grouped into different categories according to the described methodology, Figure 16.

Figure 17 Defining system components in IWRET

PROPERTIES OF THE NEIGHBORHOOD

- GLOBAL VARIABLES;
- HOUSING OPTIONS;
- DOMESTIC DEMAND;
- COMMERCIAL, INSTITUTIONAL AND INDUSTRIAL DEMAND;
- WATER EFFICIENCY REDUCTION COEFFICIENTS;

SYSTEM NETWORKS

- WATER DISTRIBUTION NETWORK (WATER SUPPLY CONDUITS, WATER TRUNK MAINS, AND WATER DISTRIBUTION MAINS);
- SEWERAGE COLLECTION SYSTEM (STORMWATER COLLECTION SYSTEM AND WASTEWATER COLLECTION SYSTEM);

TREATMENT OF RESOURCES

- WATER TREATMENT WORKS
- WASTEWATER TREATMENT WORKS
- STORMWATER TREATMENT WORKS

PUMPING STATIONS

- WATER PUMPING
- WASTEWATER PUMPING
- STORMWATER PUMPING

HYDROLOGY OF THE NEIGHBORHOOD

- RAINFALL – RUNOFF MODEL
- LOW IMPACT DEVELOPMENT TECHNIQUES AND GREEN INFRASTRUCTURE

RECYCLE AND REUSE SYSTEMS

- RAINWATER HARVESTING
- GREYWATER REUSE
- BLACKWATER REUSE USING LIVING MACHINES OR MEMBRANE BIOREACTORS

All these forms represent basic input data forms which are described in the following sections. Following sections provide detailed information about used labels, describe units and present description on the required model inputs. After completing the forms, the user activates the Compute button to receive the results of simulation presented in the Report Menu.

7.1 PROPERTIES OF THE NEIGHBORHOOD

Table 18. Global Variables Form in Properties of the Neighborhood Group

GLOBAL VARIABLES			
Label	Units	Form	Description
Simulation Time Period	Years	Global Variables	Desired simulation time
Price of electrical energy	$(Dollars)/KWh		Local price of electrical energy
Electricity generation emission factor	kgCO2eq/kWh		Local CO_2 electricity generation factor
Construction and installation costs for $1m^2$ of asphalt	$/m2		Property of convention asphalt
Construction and installation GHG emissions for $1m^2$ of asphalt	kgCO2eq/m^2		Property of convention asphalt
Construction and installation embodied energy for $1m^2$ of asphalt	kWh/m^2		Property of convention asphalt

Table 19. Housing Options Form in Properties of the Neighborhood Group

HOUSING OPTIONS			
Label	Units	Form	Description
Initial number of units in the neighborhood	Number	Single Family Units	Stock of single family (SF) units at start of simulation
Initial number of units in the neighborhood	Number	Multi-Family Units	Stock of multi-family (MF) units at start of simulation
Number of units built every year	Number	Single Family Units	Stock of SF units built every year
Number of units built every year	Number	Multi-Family Units	Stock of MF units built every year
Number of units decommissioned every year	Number	Single Family Units	Stock of SF units removed every year
Number of units decommissioned every year	Number	Multi-Family Units	Stock of MF units removed every year
Average size of a single family lot	m^2	Single Family Units	Size of typical SF lot in neighborhood
Lawn area as percentage of a lot	%	Single Family Units	Portion of SF lot covered with grass
Average occupancy of a single family unit	Number	Single Family Units	Number of persons living in a typical SF household
Average occupancy of a multi-family unit	Number	Multi-Family Units	Number of persons living in a typical MF household

Table 20. Water Demand Form in Properties of the Neighborhood Group

DOMESTIC DEMAND			
Label	Units	Form	Description
Daily Faucet Demand Per Capita	l/day/capita	Domestic Single Family	Daily water demand per capita for different water appliances in a single family household
Daily Shower Demand Per Capita	l/day/capita		
Daily Bathtub Demand Per Capita	l/day/capita		
Daily Dishwasher Demand Per Capita	l/day/capita		
Daily Toilet Demand Per Capita	l/day/capita		
Daily Clothes Washer Demand Per Capita	l/day/capita		
Daily Leaks Per Capita	l/day/capita		
Other Daily Demand Per Capita	l/day/capita		
Daily Faucet Demand Per Capita	l/day/capita	Domestic Multi-family	Daily water demand per capita for different water appliances in a multi-family household
Daily Shower Demand Per Capita	l/day/capita		
Daily Bathtub Demand Per Capita	l/day/capita		
Daily Dishwasher Demand Per Capita	l/day/capita		
Daily Toilet Demand Per Capita	l/day/capita		
Daily Clothes Washer Demand Per Capita	l/day/capita		
Daily Leaks Per Capita	l/day/capita		

Table 21. Commercial, Institutional and Industrial Water Demand Form in Properties of the Neighborhood Group

COMMERCIAL, INSTITUTIONAL AND INDUSTRIAL DEMAND			
Label	Unit	Form	Description
Floor area	m^2	Community Centers	Estimates of Daily water demand in Community Centers
Unit demand per m^2	l/day/m^2		
Variation Coefficient Upper	Dmnls		
Variation Coefficient Lower	Dmnls		
Number of children	Number	Daycares	Estimates of Daily water demand in daycares
Unit demand per Child	l/day/child		
Variation Coefficient Upper	Dmnls		
Variation Coefficient Lower	Dmnls		
Number of seats	Number	Restaurants	Estimates of Daily water demand in restaurants
Unit demand per seat	l/day/seat		
Coefficient Upper	Dmnls		
Coefficient Lower	Dmnls		
Floor area	m^2	Hotels	Estimates of Daily water demand in hotels
Unit demand per m^2	l/day/ m^2		
Floor area	m^2	Office buildings	Estimates of Daily water demand in office buildings
Unit demand per m^2	l/day/ m^2		
Variation Coefficient Upper	Dmnls		
Variation Coefficient Lower	Dmnls		
Number of students	Number	Schools	Estimates of Daily water demand in schools
Unit demand per student	l/day/student		
Number of beds in hospitals	Number	Hospitals	Estimates of Daily water demand in hospitals
Unit demand per bed	l/day/bed		
Floor area	m^2	Retail	Estimates of Daily water demand in retail
Unit demand per m2	l/day/ m^2		
Variation Coefficient Upper	Dmnls		
Variation Coefficient Lower	Dmnls		
Floor area	m^2	Industrial	Estimates of daily water demand for industry
Unit demand per m2	l/day/ m^2		
Public spaces for irrigation in neighborhood	m^2	Irrigation	Estimates of Daily water demand for irrigation
Unit water demand for irrigation	l/day/ m^2		
Demand in liters per hour	Liters/Hour	HVAC	Estimates of Daily water demand for evaporative cooling
Hours of operation per day	Hours		

Table 22. Water Efficiency Form in Properties of the Neighborhood Group

WATER EFFICIENCY MEASURES			
Label	Units	Form	Description
Water Sensitive Faucet Efficiency Coefficient	Percentage	Single Family Households	Efficiency performance of water sensitive compared to conventional appliances
Water Sensitive Shower Efficiency Coefficient	Percentage		
Water Sensitive Dishwasher Efficiency Coefficient	Percentage		
Water Sensitive Bathtub Efficiency Coefficient	Percentage		
Water Sensitive Clothes Washer Efficiency Coefficient	Percentage		
Water Sensitive Toilet Efficiency Coefficient	Percentage		
Water Sensitive Leaks Reduction Coefficient	Percentage		
Water Sensitive Faucet Efficiency Coefficient	Percentage	Multi-family Households	
Water Sensitive Shower Efficiency Coefficient	Percentage		
Water Sensitive Dishwasher Efficiency Coefficient	Percentage		
Water Sensitive Bathtub Efficiency Coefficient	Percentage		
Water Sensitive Clothes Washer Efficiency Coefficient	Percentage		
Water Sensitive Toilet Efficiency Coefficient	Percentage		
Water Sensitive Leaks Reduction Coefficient	Percentage		
Single family households	Percentage	Water Conservation adoption rates	Portion of single family homes adopting new technology
Multi-family households	Percentage		Portion of multi-family homes adopting new technology

7.2 TREATMENT OF RESOURCES

Table 23. Water Treatment Works Form in Treatment of Resources Group

WATER TREATMENT WORKS			
Label	Units	Form	Description
Rated Capacity of Water Treatment Works	m^3/day	Physical Properties	Rated capacity of treatment work
Capacity Available for New Neighborhood	Percentage		Percentage of total capacity available for new neighborhood
Capital investments required for capacity extension	Millions $	Life-cycle Costs	Investments required for potential capacity extension of existing facility
Construction and installation costs for new water treatment plant	Millions $		Investments required for construction and installation of new facility
Estimated annual maintenance costs	Millions $		Overall maintenance costs for equipment
Energy required for treatment of $1m^3$ raw water	kWh/m^3		Estimate of energy required for treatment process
Number of persons required for daily service	Persons		Number of staff servicing facility
Average salary of personnel	$		Average salary
Administration costs as percentage of total staff costs	Percentage		Share of administration costs
Water resource intake fee	$/$m^3$		Fee payed for water intake
Required for treatment of $1m^3$ water	kg/m^3	Alum	Quantity of chemicals required for water treatment, embodied energy, and embodied GHG emissions
Embodied energy for 1kg	KWh/kg		
Greenhouse house emissions for 1kg	$kgCO_2eq/kg$		
Required for treatment of $1m^3$ water	kg/m^3	Calcium Hydroxide	
Embodied energy for 1kg	KWh/kg		
Greenhouse house emissions for 1kg	$kgCO_2eq/kg$		
Required for treatment of $1m^3$ water	kg/m^3	Carbon Dioxide	
Embodied energy for 1kg	KWh/kg		
Greenhouse house emissions for 1kg	$kgCO_2eq/kg$		
Required for treatment of $1m^3$ water	kg/m^3	Microsand	
Embodied energy for 1kg	KWh/kg		
Greenhouse house emissions for 1kg	$kgCO_2eq/kg$		
Required for treatment of $1m^3$ water	kg/m^3	Polyaluimium Chloride	
Embodied energy for 1kg	KWh/kg		
Greenhouse house emissions for 1kg	$kgCO_2eq/kg$		
Required for treatment of $1m^3$ water	kg/m^3	Sodium Hypochlorite	
Embodied energy for 1kg	KWh/kg		
Greenhouse house emissions for 1kg	$kgCO_2eq/kg$		
Affordability of Technology	Dmnls	Qualitative Indicators	Subjective assessment of technology affordability
Reliability of Technology	Dmnls		Subjective assessment of Reliability
Social Acceptability	Dmnls		Subjective assessment of technology Social Acceptability
Perception of Risk to Human Health	Dmnls		Subjective assessment of Perception of Risk to Human Health
Flexibility and Adaptability to Changing Conditions	Dmnls		Subjective assessment of technology Flexibility and Adaptability
Spatial Requirements	Dmnls		Subjective assessment of technology Spatial Requirements

Table 24. Wastewater Treatment Works Form in Treatment of Resources Group

WATER TREATMENT WORKS			
Label	Units	Form	Description
Wastewater Generation Factor	Percentage	Physical Properties	Wastewater generated as percentage of total water delivered
Rated Capacity of Wastewater Treatment Works	m^3/day		Rated capacity of wastewater treatment works
Capacity Available for New Neighborhood	Percentage		Percentage of total capacity available for new neighborhood
Capital investments required to extend capacity of existing WWTW	Millions $	Life Cycle Costs	Investments required for potential capacity extension of existing facility
Construction and installation costs for new wastewater treatment works facility	Millions $		Investments required for construction and installation of new facility
Annual maintenance costs	Millions $		Overall maintenance costs for equipment
Energy required for treatment of 1m^3 of wastewater	kWh/m^3		Estimate of energy required for treatment process
Number of persons required for daily service	Persons		Number of staff servicing facility
Average salary of personnel	$		Average salary
Administration costs as percentage of total staff costs	Percentage		Share of administration costs
Sludge generated for treatment of 1m^3 of wastewater	kg/m^3		Quantity of sludge generated in wastewater treatment process
Cost of sludge transport and disposal	$/kg		Estimated costs for transportation and disposal of sludge
Required for treatment of 1m^3 wastewater	kg/m^3	Ferric Chloride	Quantity of chemicals required for wastewater treatment, embodied energy, and embodied GHG emissions
Embodied energy for 1kg	KWh/kg		
Greenhouse house gas emissions for 1kg	kgCO2eq/kg		
Required for treatment of 1m^3 wastewater	kg/m3	Ferric Sulphate	
Embodied energy for 1kg	KWh/kg		
Greenhouse house gas emissions for 1kg	kgCO2eq/kg		
Required for treatment of 1m^3 wastewater	kg/m^3	Calcium Hydroxide	
Embodied energy for 1kg	KWh/kg		
Greenhouse house emissions for 1kg	kgCO2eq/kg		
Required for treatment of 1m^3 wastewater	kg/m^3	Ethanol	
Embodied energy for 1kg	KWh/kg		
Greenhouse house gas emissions for 1kg	kgCO2eq/kg		
Required for treatment of 1m^3 wastewater	kg/m^3	Methanol	
Embodied energy for 1kg	KWh/kg		
Greenhouse house gas emissions for 1kg	kgCO2eq/kg		
Required for treatment of 1m^3 wastewater	kg/m^3	Nitric Acid	
Embodied energy for 1kg	KWh/kg		
Greenhouse house gas emissions for 1kg	kgCO2eq/kg		
Affordability of Technology	Dmnls	Qualitative Indicators	Subjective assessment of technology affordability
Reliability of Technology	Dmnls		Subjective assessment of Reliability
Social Acceptability	Dmnls		Subjective assessment of technology Social Acceptability
Perception of Risk to Human Health	Dmnls		Subjective assessment of Perception of Risk to Human Health
Flexibility and Adaptability to Changing Conditions	Dmnls		Subjective assessment of technology Flexibility and Adaptability
Spatial Requirements	Dmnls		Subjective assessment of technology Spatial Requirements

Table 25. Stormwater Treatment Works Form in Treatment of Resources Group

STORMWATER TREATMENT WORKS			
Label	Unit	Form	Description
Construction and installation costs for new water treatment works facility	$ (Millions)	Life Cycle Costs	Investments required for construction and installation of new facility
Capital investments required for capacity extension of existing SWTW	$ (Millions)		Investments required for potential capacity extension of existing facility
Annual maintenance costs	$		Estimated annual maintenance
Energy required for treatment of 1m^3 of stormwater	KWh/m3		Estimate of energy required for treatment process
Number of persons required for daily service	Persons		Number of staff servicing facility
Average salary of personnel	$		Average salary of staff servicing the treatment works
Chemicals required for treatment of 1m^3 stormwater	kg/m^3	Metabolic Processes	Quantity of chemical required for water treatment
Embodied energy for 1kg chemical used for treatment	kWh/kg		Embodied energy for specific chemical
Greenhouse house emissions for 1kg of chemical used for treatment	kgCO_2eq/kg		Embodied GHG emissions for specific chemical

7.3 SYSTEM NETWORKS

Table 26. Water Distribution Network Form in System Networks Group

Label	Units	Form	Description
WATER DISTRIBUTION MAINS			
Unit Weight of 1m' of material	kg/m	Material 1	Properties of water distribution network and materials
Total length of WDM network in the neighborhood	m		
Embodied energy required for 1kg of material	kWh/kg		
GHG emissions for 1 kg of material	kgCO2eq/kg		
Energy required for 1m maintenance	kWh/m		
GHG emissions for 1m maintenance	kgCO2eq/m		
Unit Weight of 1m' of Material	kg/m	Material 2	Properties of water distribution network and materials
Total length of WDM network in the neighborhood	m		
Embodied energy required for 1kg of material	kWh/kg		
GHG emissions for 1 kg of material	kgCO2eq/kg		
Energy required for 1m maintenance	kWh/m		
GHG emissions for 1m maintenance	kgCO2eq/m		
Number of trips required for annual maintenance	Number of Trips Per Year	Life Cycle Costs	Number of trips required for annual maintenance
Replacement costs	$		Estimate of replacement costs for existing network
Disposal costs	$		Estimate of disposal costs for existing network
Construction costs	$		Estimate of construction costs for new network
Annual maintenance costs	$/Year		Annual maintenance costs
WATER SUPPLY CONDUITS			
Replacement costs	$	Water Supply Conduits	Estimate of replacement costs for existing network
Disposal costs	$		Estimate of disposal costs for existing network
Construction costs	$		Estimate of construction costs for new network
Annual maintenance costs	$/Year		Annual maintenance costs
Total carrying capacity of water conduit	m^3/day		Carrying capacity of water supply conduits
Available carrying capacity for new neighborhood	%		Share of total capacity available for new development
WATER TRUNK MAINS			
Replacement costs	$	Water Trunk Mains	Estimate of replacement costs for existing network
Disposal costs	$		Estimate of disposal costs for existing network
Construction costs	$		Estimate of construction costs for new network
Annual maintenance costs	$/Year		Annual maintenance costs

Table 27. Stormwater Collection System Form in System Networks Group

STORMWATER COLLECTION SYSTEM			
Label	Units	Group within Form	Description
Embodied energy required for 1kg of material	kWh/kg	Embodied Energy and GHG Emissions: Material 1	Properties of water distribution network and materials
GHG emissions for 1 kg of material	kgCO2eq/kg		
Unit Weight of 1m' of Material	kg/m		
Total length of SWCS network in the neighborhood	m		
Energy required for 1m maintenance	kWh/m		
GHG emissions for 1 kg of material	kgCO2eq/m		
Embodied energy required for 1kg of material	kWh/kg	Embodied Energy and GHG Emissions: Material 2	Properties of water distribution network and materials
GHG emissions for 1m maintenance	kgCO2eq/kg		
Unit Weight of 1m' of Material	kg/m		
Total length of SWCS network in the neighborhood	m		
Energy required for 1m maintenance	kWh/m		
GHG emissions for 1 kg of material	kgCO2eq/m		
Network replacement costs	$	Life Cycle Costs	Estimate of replacement costs for existing network
Disposal costs	$		Estimate of disposal costs for existing network
Construction costs	$		Estimate of construction costs for new network
Annual maintenance costs	$/Year		Annual maintenance costs
Number of trips required for annual maintenance	Number		Number of trips

Table 28. Wastewater Collection System Form in System Networks Group

WASTEWATER COLLECTION SYSTEM			
Label	Units	Form	Description
Embodied energy required for 1kg of material	kWh/kg	Embodied Energy and GHG Emissions: Material 1	Properties of water distribution network and materials
GHG emissions for 1 kg of material	kgCO2eq/kg		
Total length of WDM network in the neighborhood	m		
Unit Weight of 1m' of Material	kg/m		
Energy required for 1m maintenance	kWh/m		
GHG emissions for 1m maintenance	kgCO2eq/m		
Embodied energy required for 1kg of material	kWh/kg	Embodied Energy and GHG Emissions: Material 2	Properties of water distribution network and materials
GHG emissions for 1 kg of material	kgCO2eq/kg		
Total length of WDM network in the neighborhood	m		
Unit Weight of 1m' of Material	kg/m		
Energy required for 1m maintenance	kWh/m		
GHG emissions for 1m maintenance	kgCO2eq/m		
Replacement costs	$	Life Cycle Costs	Estimate of replacement costs for existing network
Disposal costs	$		Estimate of disposal costs for existing network
Construction costs	$		Estimate of construction costs for new network
Annual maintenance costs	$/Year		Annual maintenance costs
Number of trips required for regular maintenance	Number		

7.4 PUMPING STATIONS

Table 29. Water Pumping Form in Pumping Stations Group

WATER PUMPING			
Label	Units	Group within Form	Description
Construction and installation costs	$	Water Pumping	Estimate of replacement and installation costs for existing network
Annual maintenance fees	$/Year		Annual maintenance costs
Pump efficiency coefficient	Percentage		Pump properties
Variable speed drive efficiency	Percentage		
Motor efficiency	Percentage		
Total dynamic head of water pump	Meters		Dynamic head
Hours of pump operation per day	Hours		Hours of operation
Affordability of technology	Dmnls	Qualitative Indicators	Subjective assessment of technology affordability
Reliability of technology	Dmnls		Subjective assessment of Reliability
Social acceptability	Dmnls		Subjective assessment of technology Social Acceptability
Perception of risk to human health	Dmnls		Subjective assessment of Perception of Risk to Human Health
Flexibility and adaptability	Dmnls		Subjective assessment of technology Flexibility and Adaptability
Spatial requirements	Dmnls		Subjective assessment of technology Spatial Requirements

Table 30. Wastewater Pumping Form in Pumping Stations Group

WASTEWATER PUMPING			
Label	Units	Form	Description
Construction and installation costs	$	Wastewater	Estimate of construction costs for new network
Projected annual maintenance fees	$/Year		Annual maintenance costs
Pump efficiency coefficient	Percentage		Pump properties
Variable speed drive efficiency	Percentage		
Motor efficiency	Percentage		
Total dynamic head of wastewater pump	Meters		Dynamic head
Hours of pump operation per day	Hours		Pump operating hours per day
Affordability of technology	Dmnls	Qualitative Indicators	Subjective assessment of technology affordability
Reliability of technology	Dmnls		Subjective assessment of Reliability
Social acceptability	Dmnls		Subjective assessment of technology Social Acceptability
Perception of risk to human health	Dmnls		Subjective assessment of Perception of Risk to Human Health
Flexibility and adaptability	Dmnls		Subjective assessment of technology Flexibility and Adaptability
Spatial requirements	Dmnls		Subjective assessment of technology Spatial Requirements

Table 31. Stormwater Pumping Form in Pumping Stations Group

STORMWATER PUMPING			
Label	Units	Form	Description
Projected annual maintenance fees	$/Year	Stormwater	Annual maintenance costs
Construction and installation costs	$		Estimate of construction costs for new network
Hours of pump operation per day	Hours		Pump operating hours per day
Total dynamic head of pump	Meters		Dynamic head
Motor efficiency	Percentage		Pump properties
Variable speed drive efficiency	Percentage		
Pump efficiency coefficient	Percentage		
Affordability of technology	Qualitative	Qualitative Indicators	Subjective assessment of technology affordability
Reliability of technology	Qualitative		Subjective assessment of Reliability
Social acceptability	Qualitative		Subjective assessment of technology Social Acceptability
Perception of risk to human health	Qualitative		Subjective assessment of Perception of Risk to Human Health
Flexibility and adaptability	Qualitative		Subjective assessment of technology Flexibility and Adaptability
Spatial requirements	Qualitative		Subjective assessment of technology Spatial Requirements

7.5 HYDROLOGY OF THE NEIGHBORHOOD

Table 32. Rainfall-Runoff Model Form in Hydrology of the Neighborhood Group

HYDROLOGY OF THE NEIGHBORHOOD			
Label	Units	Rainfall – Runoff Model	Description
Curve Number (CN)	Dmnls	Type 1	Estimated CN for land use Type 1
Total area	m^2		Total surface covered with Type 1 land use
Curve Number (CN)	Dmnls	Type 2	Estimated CN for land use Type 2
Total area	m^2		Total surface covered with Type 2 land use
Curve Number (CN)	Dmnls	Type 3	Estimated CN for land use Type 3
Total area	m^2		Total surface covered with Type 3 land use
Curve Number (CN)	Dmnls	Type 4	Estimated CN for land use Type 4
Total area	m^2		Total surface covered with Type 4 land use

Table 33. Low Impact Development Techniques Form in Hydrology of the Neighborhood Group

LOW IMPACT DEVELOPMENT TECHNIQUES			
Label	Unit	Group	Description
Curve Number (CN) for permeable pavement	Dmnls	Permeable Pavement	Curve Number
Total area covered with permeable pavement	m^2		Surface covered
Embodied GHG emissions per m^2	$kgCO2eq/m^2$		Embodied GHG for production and installation
Unit costs of permeable pavement	$/m^2$		Costs of production and installation
Annual costs required for maintenance per m^2	$/m^2$		Estimated annual costs
Curve Number (CN) for green roofs	Dmnls	Green Roof	Curve Number
Total area covered with green roofs	m^2		Surface covered
Runoff coefficient for green roofs	Dmnls		Runoff coefficient C
Embodied GHG emissions per m^2	$kgCO2eq/m^2$		Embodied GHG for production and installation
Unit costs of green roof	$/m^2$		Costs of production and installation
Annual costs required for maintenance	$/m^2$		Estimated annual costs for maintenance
Curve Number (CN) for bioretention and rain gardens	Dmnls	Bioretention and Rain Gardens	Curve Number
Total area of bioretention and rain gardens	m^2		Surface covered
Annual costs required for maintenance	$/m^2$		Estimated annual costs for maintenance
Embodied GHG emissions per m^2	$kgCO2eq/m^2$		Embodied GHG for production and installation
Unit costs of bioretention and rain gardens	$/m^2$		Costs of production and installation
Curve Number (CN) for bioswales	Dmnl	Bioswale	Curve Number
Total area of bioswales	m^2		Surface covered
Annual costs required for maintenance	$/m^2$		Estimated annual costs for maintenance
Unit costs of bioswales	$/m^2$		Costs of production and installation
Embodied GHG emissions per m^2	$kgCO2eq/m^2$		Embodied GHG for production and installation
Curve Number (CN) for Rain Barrels and Cisterns	Dmnl	Rain Barrels and Cisterns	Curve Number
Total area occupied by Rain Barrels and Cisterns	m^2		Surface covered
Annual maintenance costs for $1m^3$	$/m^3$		Estimated annual costs for maintenance
Design and Capital Costs for $1m^3$	$/m^3$		Costs of production and installation
Embodied GHG Emissions for $1m^3$	$kgCO2eq/m^3$		Embodied GHG for production and installation
Total volume of Rain Barrels and Cisterns in the neighborhood	m^3		Total volume
Curve Number (CN) for Stormwater Ponds	Dmnl	Stormwater Ponds	Curve Number
Total area occupied by stormwater ponds	m^2		Surface covered
Volume of storage	m^3		Total volume
Embodied GHG Emissions for construction of $1m^3$	$kgCO2eq/m^3$		Embodied GHG for production and installation
Design and Capital Costs for $1m^3$	$/m^3$		Costs of production and installation
Annual maintenance costs for $1m^3$	$/m^3$		Estimated annual costs for maintenance

7.6 RECYCLE AND REUSE SYSTEMS

Table 34. Rainwater Harvesting Form in Recycle and Reuse Systems Group

RAINWATER HARVESTING WITH RAIN BARRELS AND CISTERNS			
Label	Unit	Group	Description
Footprint of standard roofs in the neighborhood	m^2	Rainwater Harvesting Scheme	Surface covered with conventional roofs
Footprint of car parking lots in the neighborhood	m^2		Parking lots
Footprint of roads and sidewalks in the neighborhood	m^2		Roads and sidewalks
Runoff coefficient (C) for impervious areas	Dmnls		Runoff coefficient for roofs, parking lots, roads and sidewalks
Percentage of total impervious areas harvested	Percentage		Percentage of impervious areas used for rainwater collection
Estimated annual maintenance costs	$/Year	Rainwater Harvesting Pumps	Annual maintenance costs
Construction and installation costs	$		Costs for construction and installation
Rainwater harvesting pump efficiency	Percentage		Properties of rainwater harvesting pumps
Rainwater harvesting pump variable speed drive efficiency	Percentage		
Rainwater harvesting pump motor efficiency	Percentage		
Average pumping head in the neighborhood	m		Average total dynamic head
Hours of pump operation per day	Hours		Number of hours per day
Number of pumps in the neighborhood	Number		Number of pumps in the system
Affordability of technology	Dmnls	Qualitative Indicators	Subjective assessment of technology affordability
Reliability of technology	Dmnls		Subjective assessment of Reliability
Social acceptability	Dmnls		Subjective assessment of technology Social Acceptability
Perception of risk to human health	Dmnls		Subjective assessment of Perception of Risk to Human Health
Flexibility and adaptability	Dmnls		Subjective assessment of technology Flexibility and Adaptability
Spatial requirements	Dmnls		Subjective assessment of technology Spatial Requirements

Table 35. Greywater Reuse Form in Recycle and Reuse Systems Group

GREYWATER REUSE			
Label	Units	Form	Description
Volume of an average tank	m^3	Greywater Reuse System	Size of a typical tank in the system
Number of Tanks in the system	Number		Number of tanks in the system
Estimated system maintenance costs per year	$/Year		Estimated annual maintenance costs for the system
Estimated installation and construction costs for 1m³	$/m³		Installation and construction costs for the system
Dual plumbing costs per m²	$/m²		Costs of dual plumbing
Total area covered in the neighborhood with dual plumbing	m^2		Total surface covered with dual plumbing installations
Percentage of the neighborhood serviced by the system	Percentage	Greywater Reuse System	Portion of neighborhood serviced by the system
Number of pumps in greywater system	Number		Number of pumps in
Construction and installation costs for one pump	$		Construction and installation costs for a typical pump
Annual maintenance fees for the pumping system	$/Year		Annual maintenance costs
Pump efficiency coefficient	Percentage		Pump properties
Variable speed drive efficiency	Percentage		
Motor efficiency	Percentage		
Average dynamic head of pump	Meters		Average dynamic head
Daily duration of pump operation	Hours		Number of hours per day for pump operation
Affordability of technology	Dmnls	Qualitative Indicators	Subjective assessment of technology affordability
Reliability of technology	Dmnls		Subjective assessment of Reliability
Social acceptability	Dmnls		Subjective assessment of technology Social Acceptability
Perception of risk to human health	Dmnls		Subjective assessment of Perception of Risk to Human Health
Flexibility and adaptability	Dmnls		Subjective assessment of technology Flexibility and Adaptability
Spatial requirements	Dmnls		Subjective assessment of technology Spatial Requirements

Table 36. Blackwater Reuse Form in Recycle and Reuse Systems Group

BLACKWATER REUSE USING LIVING MACHINES OR MBRS			
Label	Units	Form	Description
Percentage of total water consumption in office buildings converted to blackwater	Percentage	Quantity of Blackwater	Portion of collected blackwater
Percentage of office buildings used to collect black water	Percentage		Portion of office building area covered with blackwater reuse system
Percentage of total water consumption in hospitals converted to blackwater	Percentage		Portion of collected blackwater
Percentage of hospitals used to collect black water	Percentage		Portion of office building area covered with blackwater reuse system
Percentage of total water consumption in schools converted to blackwater	Percentage		Portion of collected blackwater
Percentage of schools used to collect black water	Percentage		Portion of office building area covered with blackwater reuse system
Installation and construction costs for one LM or MBR	$	Blackwater Reuse	Installation and construction costs
Number of LMs and MBRs installed in the neighborhood	Number		Number of individual blackwater reuse systems
Annual maintenance fees for one LM or MBR	$		Annual costs of maintenance for individual system
GHG emissions per m^3 of influent that is treated and recycled	$kgCO2eq/m^3$		GHG emissions for treated water
Electricity required for settling, pumping, and treatment of $1m^3$	kWh/m^3		Energy requirements for system operation
Maximum treatment capacity of LMs or MBRs in the neighborhood	m^3/day		Capacity of the system
Affordability of technology	Dmnls	Qualitative Indicators	Subjective assessment of technology affordability
Reliability of technology	Dmnls		Subjective assessment of Reliability
Social acceptability	Dmnls		Subjective assessment of technology Social Acceptability
Perception of risk to human health	Dmnls		Subjective assessment of Perception of Risk to Human Health
Flexibility and adaptability	Dmnls		Subjective assessment of technology Flexibility and Adaptability
Spatial requirements	Dmnls		Subjective assessment of technology Spatial Requirements

7.7 RESULTS FORM

After providing required information, the user runs the simulation through Compute Button and selects the Report Menu tab that summarizes the simulation results in numerical and graph forms. Table 37 presents performance indicators for the urban water system as a whole, and indicators for particular urban water system components.

Table 37. Blackwater Reuse Form in Recycle and Reuse Systems Group

Label	Graphical Representation	Units	Description
Water Demand			
Number of Years in Simulation	Number	Years	Number of Years
Single Family Households	Graph	Number of Units	Stock variation of single family homes
Multi-family Households	Graph	Number of Units	Stock variation of multi-family homes
Total Area Occupied by Single Family Households	Graph	m^2	Area
Irrigation Area in Single Family Households	Graph	m^2	Irrigation area for single family homes
Adoption Rate of Water Conservation Appliances in Single Family Households	Number	%	Rate of adoption for water sensitive appliances
Adoption Rate of Water Conservation Appliances in Single Family Households	Number	%	Rate of adoption for water sensitive appliances
Average Occupancy in Single Family Households	Number	Persons/Household	Persons per single family household
Average Occupancy in Multi-Family Households	Number	Persons/Household	Persons per multi-family household
Daily Rates of Domestic Demand	Graph	m^3/Day	Change in daily domestic water demand
Daily Rates of Irrigation Demand	Graph	m^3/Day	Change in daily irrigation water demand
Daily Rates of Commercial and Institutional Demand	Graph	m^3/Day	Change in daily commercial and institutional water demand
Daily Rater of Cumulative Demand in Neighborhood	Graph	m^3/Day	Change in daily cumulative water demand
Number of Days with Reached Water System Capacity	Number	Days	Change in daily domestic water demand
Pumping Stations			
Life Cycle Costs for System Pumping	Number	$	Total costs of pumping stations
Greenhouse Gas Emissions for System Pumping	Number	$kgCO_2eq$	Greenhouse gas emissions
Energy Required for System Pumping Operations	Number	kWh	Energy used for pumping
System water, wastewater, and stormwater treatment			
Greenhouse Gas Emissions During Treatment Process	Number	$kgCO_2eq$	Greenhouse gas emissions

Energy Required for Treatment and Embodied Energy of Used Chemicals	Number	kWh	Energy used
Life Cycle Costs of Treatment	Number	$	Total costs
Water, Wastewater and Stormwater Networks			
Embodied Energy for Network Construction and Maintenance	Number	kWh	Embodied energy
Embodied Greenhouse Gas Emissions for Network Construction and Maintenance	Number	$kgCO_2eq$	Embodied GHG emissions
Life Cycle Costs for Water, Wastewater and Stormwater Network	Number	$	Total costs
Neighborhood Hydrology			
Total Neighborhood Area	Number	m^2	Neighborhood area
Composite Curve Number (CN)	Number	Dimensionless	Composite curve number
Daily Rainfall Events	Bars	mm	Precipitation
Stormwater Runoff at Catchment Outlet	Graph	m^3/day	Surface stormwater runoff
Volume of Stormwater Runoff	Number	m^3	Total volume
Low impact Development			
Life Cycle Costs for Implemented LID options	Number	$	Total costs
Greenhouse Gas Emissions for LID construction and maintenance	Number	$kgCO_2eq$	Embodied GHG emissions
Water Recycle and Reuse System			
Volume of Rainwater Harvested	Number	m^3	Rainwater harvested
Rates of Daily Stormwater Runoff from Impervious Areas	Graph	m^3 / day	Rainwater from impervious areas
Total Volume of Stormwater Runoff from Impervious Areas	Number	m^3	Total volume
Volume of Greywater Treated	Number	m^3	Total volume of treated greywater
Volume of Greywater Untreated Due to System Capacity Constraints	Number	m^3	Untreated greywater
Volume of Wastewater Treated by Blackwater Reuse System	Number	m^3	Blackwater treated
Volume of Wastewater Untreated Due to Blackwater System Capacity Constraints	Number	m^3	Blackwater untreated
Daily Rates of Water Reused and Recycled	Graph	m^3 / day	Daily volume of water reused and recycled
Life Cycle Costs of Reuse and Recycle System	Number	$	Total costs
Greenhouse Gas Emissions for Construction, Maintenance and Operation of Reuse and Recycle System	Number	$kgCO_2eq$	GHG emissions of reuse and recycle systems
Energy Required for Construction, Maintenance and Operation of Reuse and Recycle System	Number	kWh	Energy consumed for water reuse and recycle systems

Overall Hybrid Urban Water System Performance			
Energy required for urban water system construction, maintenance and operation	Number	kWh	Overall system performance
Greenhouse Gas Emissions for system construction, maintenance and operation	Number	$kgCO_2eq$	
Life cycle costs of urban water system	Number	$	
Qualitative Assessment of the System			
Assessment of system affordability	Number	Mark	Qualitative assessment of the hybrid system
Assessment of system acceptability	Number	Mark	
Assessment of system reliability	Number	Mark	
Assessment of system's risk to human health	Number	Mark	
Assessment of system flexibility and adaptability	Number	Mark	
Assessment of spatial requirements	Number	Mark	

8 PRACTICAL IMPLEMENTATION OF IWRET MODEL

This chapter presents the practical implementation of Integrated Water Resources Evaluation Tool (IWRET) based on the real world data. The development process describes how to construct a new IWRET model, and demonstrates how to run a simulation model, retrieve and analyze the resulting values. At the end, several scenarios are provided to represent how the tool can be used to model different configurations of hybrid water systems. The application of the IWRET software tool is demonstrated using the reference neighborhood on newly built Villiers Island in Toronto, Ontario, and the local water system. The model is evaluated for a period of 30 years with a daily time step. The preparation of input data is described in a step-by-step process within which it is demonstrated how they are collected and arranged for modelling in IWRET. Furthermore, the case study explains how the result of the simulation can be shown and analyzed in different ways.

8.1 DESCRIPTION OF THE NEIGHBORHOOD AND URBAN WATER SYSTEM

By using the Villiers Island Precinct, Toronto, here as a reference neighborhood combined with assumptions, when required, this section aims to explain how the metabolism methodology can be applied using IWRET. The data used in this chapter have been adjusted for Toronto and Ontario. However, the model can be applied to represent any other urban water system and neighborhood.

The Villiers Island Precinct holds a substantial place in the transformation of Toronto's waterfront. The area is located in Toronto's Port Lands, to the east of the downtown core. It is currently a 33.5 hectare area, bounded by the Inner Harbour to the west, the Keating Channel to the north, the Don Roadway and future Don Greenway to the east, and Commissioners Street and the future Don Valley lands to the south.

In the decades to come, Villiers Island will develop from an industrial port, Figure 17, to a complete island community with parks and open spaces on more than three kilometers of water edges, Figure 18. As a gateway to the Port Lands, Villiers Island will offer exciting new waterfront experiences for residents and visitors, providing places for people to live, work, shop, explore, relax and connect with nature.

Figure 187 Current state of Lower Don Lands, Toronto's waterfront

Sustainability is, naturally, an essential component of the revitalization of Toronto's waterfront. New neighborhood on Villiers Island will serve as a blueprint of practical solutions that can help mitigate climate change that exceed the Port Lands wide ambitions for a net-zero energy district. The City of Toronto and Waterfront Toronto aim to show leadership on sustainable development at Villiers Island, by creating and communicating real-world solutions that help mitigate climate change. These actions to support carbon reductions will create environmental, social and economic co-benefits for the city such as improved air quality, increased green space, improved energy and food security and economic development.

Figure 18 New communities planned at Toronto's waterfront

One of the major tasks of Waterfront Toronto is to advance an environmental agenda for Villiers Island, by striving to reduce greenhouse gas emissions, in accordance with the C40 Cities' Climate Positive Development Program. Climate Positive developments aim to reduce significantly overall emissions in the communities in which they are built, by addressing energy use in buildings, transportation fuels, and emissions from waste. By reducing local emissions as much as possible and creating new green spaces that will act as carbon sinks, Villiers Island will play a role in ensuring Toronto can achieve its GHG emissions reduction targets.

According to the local precinct plan, the island consists of a fine-grain street and block structure, made up of ten development blocks. The development blocks will accommodate a variety of building types, sizes and styles. The Port Lands Planning Framework identifies the majority of Villiers Island as a mixed-use residential district, with a broad range of uses such as residential, office, retail and services, institutional, recreational and cultural activities. A minimum of 20 percent of the Island's total gross floor area will be non-residential uses, which include employment/commercial uses, destination/catalytic uses, community facilities and retail uses. Villiers Island will include a range of community services and facilities to meet the needs of the local community and wider area, including an elementary school community center and pool, childcare services, and emergency services fire station. It is projected that the neighborhood will include 4985 household units providing home for 8000 to 10000 people. Villiers Island precinct will also create around 2900 new jobs, and will provide more than 11 ha of public parks.

According to The Built Form Framework, the island will contain low-rise buildings (buildings up to five storeys), base-buildings (buildings from 1 to 10 storeys), and mid - base and mid-rise buildings ranging from 6 to 10 storeys (19 - 32 metres). This form will be the predominant building type of the Island. On the other hand, tall buildings in Villiers Island will only be permitted in strategic locations, and contribute to a varied and interesting skyline and a mix of building types on the Island. The majority of tall buildings will be in the low to mid-twenties, ranging from 16 to 29.

8.2 WATER INFRASTRUCTURE ON THE ISLAND

The redevelopment of Villiers Island will replace the existing infrastructure systems, including water, stormwater management and wastewater systems. According to the master plan, the neighborhood on Villiers Island will employ techniques of low-impact development, water conservation and reuse measures.

The development of Villiers Island will put additional pressure on existing municipal water infrastructure by significantly increasing water demands. This will require the removal of much of the existing water supply network. The existing water supply system will be replaced with a modern system, which requires significant financial investment. The water infrastructure master plan consists of a network of new watermains that maintain connectivity with the City's existing distribution system and provide a looped configuration of watermains. New water infrastructure will be built wherever possible beneath the travel lanes of roadways. All water is supplied via the centralized system, which supplies treated water from RC Harris water treatment plant, outside the neighborhood boundary.

In terms of wastewater infrastructure, the development of Villiers Island requires the removal of the existing wastewater collection system and development of a higher capacity system. According to the master plan, the preferred wastewater design alternative suggests that the existing sanitary and servicing infrastructure will be replaced and upgraded with a new gravity sanitary sewer main. The new sanitary sewers will be concrete encased. Also, the existing receiving sewer is currently undersized, built with negative slope, and has a hydraulic grade line near the existing road surface elevation. Storage tanks at the temporary pump station may need to be sized to minimize sewage peak flows leaving the site to mitigate risks of increasing combined sewer overflows. As development progresses, a new gravity trunk sewer will be constructed to Ashbridges Bay Sewage Treatment Plant. This a local wastewater treatment plant conforming the wastewater to surface water discharge standards and discharging to the nearby Lake of Ontario.

Finally, the redevelopment of Villiers Island will also require the removal of existing storm drainage infrastructure as the area is re-graded to elevate the existing grades for flood protection, create the new river channel and the flood protection spillway. The stormwater management approach includes of the following controls:

- Source controls integrated throughout the precinct area to reduce stormwater runoff from key sources. Source controls include green infrastructure water retention and detention systems including green roofs, rainwater storage systems for reuse of rain water, and water gardens;
- Conveyance controls at locations where stormwater runoff is conveyed from a source to a receiving water to reduce the amount of stormwater runoff and to reduce sediment and pollutants in the runoff. The proposed conveyance systems and associated controls include green infrastructure systems (tree box filters, sand filters, etc.) and oil/grit separators; and,
- End-of-Pipe Controls to clean the runoff to the required water quality levels. Proposed End-of-Pipe Controls include new wetlands and a new storage tank and pump system to control stormwater flows to a new ballasted flocculation and ultraviolet (BF/UV) disinfection facility.

8.3 RECOMMENDATIONS FOR CONSIDERATION OF ALTERNATIVE SOLUTIONS

The current precinct plan does not incorporate additional supply of rainwater and stormwater or recycling of wastewater and greywater. However, water conservation and reuse measures will also be promoted, and facilitated, including:

- Water efficiency measures;
- Grey and/or black water reuse for non-potable water systems, such as irrigation and toilets; and
- Privately owned non-potable water distribution systems.

To test the framework, water metabolism indicators are generated for a Villiers Island development, Toronto waterfront. A set of scenarios include a range of strategies, ranging from the development of base line strategy with a traditional, centralized urban water system, to alternative water servicing strategy, incorporating internal supplies of rainwater, stormwater, and recycled wastewater. Table 38 gives description of six scenarios developed to test different configurations of a local hybrid water system.

Table 38. List of six scenarios developed to assess urban water metabolism at Villiers Island

Number	Scenario Name	Description of Scenario
1	Baseline	Describes conventional, centralized urban water system
2	Baseline and Green Infrastructure	Adds implementation of green infrastructure and low impact development techniques to the baseline scenario
3	Baseline, Green Infrastructure and Rainwater Harvesting	Incorporates rainwater harvesting scheme
4	Baseline, Green Infrastructure and Greywater Reuse	Combines baseline scenario with greywater reuse system
5	Baseline, Green Infrastructure and Blackwater Recycle	Integrates baseline scenario and reuse of blackwater
6	Ultimate	Incorporates all decentralized water techniques

In alternative configurations of hybrid systems, stormwater runoff is harvested from hard surfaces (parking, roads, and roofs) and green roofs within the neighborhood. Volume harvested is calculated in every time step based on climate information. Stormwater is treated, and then supplied for different water demand profiles, such as to irrigate open spaces plus natural areas to enhance vegetation, plus all legal sub-potable demand in residential and commercial (irrigation, toilet flushing, clothes washing) by third pipe supply. Moreover, rainwater harvested from the roofs (rain barrels and cisterns) of residential and commercial buildings. Water supplied untreated is used for sub-potable demand – garden irrigation and toilet flushing. Next, a user defined portion of wastewater from all residential, commercial, institutional facilities is treated at local MBR or living machines, and then used for irrigation. Finally, greywater from residential dwellings collected at individual tanks, and supplied back (lawn irrigation, toilet flushing and clothes washing). Derived indicators are compared to explore the changes could be discerned, and what new insights the information provided.

8.4 SETTING UP THE DATA

This section provides an overview of specific information used to create a metabolic model for urban water system on Villiers Island. Table 39 specifies information related to the new neighborhood and Toronto's urban water system.

Table 39. Properties of the neighborhood and urban water system

Properties of neighborhood and local urban water system	Unit	Value
Initial Number of Single-Family(SF) units	Number	3000
Initial Number of Multi-Family(MF) units	Number	0
New SF units added annually	Number	150
New MF units added annually	Number	0
Decommissioned SF units annually	Number	5
Decommissioned MF units annually	Number	0
Average SF lot size	m^2	0
Lawn area as percentage of a SF lot	%	0
Average occupancy of SF unit	Number	1.9
Average occupancy of MF unit	Number	0
SF, MF Water efficient appliances adoption rate	%	70
Industrial floor area	m^2	0
Community center floor area	m^2	3250
Number of children in daycares	Number	120
Number of seats in restaurants	Number	250
Hotels - floor area	m^2	3000
Office buildings floor area	m^2	10000
Number of students in schools	Number	850
Number of beds in hospitals	Number	100
Retail floor area	m^2	10000
Evaporative cooling	m^3/day	10
Total area of the neighborhood	m^2	300.000
Footprint of all buildings	m^2	120.000
Land Use and Hydrologic Soil Group (HSG)		A
Total green roof area	m^2	20.000
SWCS Pipe length (Concrete)	m	4000
Capital costs for stormwater pumping stations	$	1.000.000
Annual Maintenance costs for stormwater pumping stations	$	100.000
SWTW Capital costs	$	1.000.000
SWTW Added annual maintenance costs	$	300.000
SWTW Daily treatment capacity	m^3/day	200
WWCS Pipe length (Concrete)	m	4000
Capital costs for wastewater pumping stations	$	1.000.000
Annual Maintenance costs for wastewater pumping stations	$	100.000
Capital costs (Ashbridges Bay WWTW)	$	0
Added annual maintenance costs (Ashbridges Bay WWTW)	$	1.000.000
Daily treatment capacity (Ashbridges Bay WWTW)	m^3/day	818.000
Capacity available for new development (Ashbridges Bay WWTW)	%	15
Pipe length (made of concrete)	m	4000
Daily capacity of water distribution mains	m^3/day	100.000
Capital costs for water pumping stations	$	0

Annual Maintenance costs for water pumping stations	$	0
Capital costs (RC Harris WTW)	$	0
Added annual maintenance costs (RC Harris WTW)	$	1.000.000
Daily treatment capacity (RC Harris WTW)	m^3/day	950.000
Capacity available for new development (RC Harris WTW)	%	15
WTW/WWTW Added number of staff (RC Harris, Ashbridges Bay)	Number of People	15/10

Where:

- **SF** Single-family units;
- **MF** Multi-family units;
- **WTW** Water Treatment Works;
- **WWTW** Wastewater Treatment Works;
- **SWTW** Stormwater Treatment Works;
- **WDM** Water Distribution Mains;
- **SWS** Stormwater Collection System
- **WWCS** Wastewater Collection System

Table 40 describes global variables, related to energy costs and requirements.

Table 40. Environmental variables

Variable	Unit	Value
Energy required for water treatment	kWh/m^3	2.8
Energy required for wastewater treatment	kWh/m^3	4.5
Energy required for stormwater treatment	kWh/m^3	0.10
Electricity generation emission factor	kgCO_2eq/kWh	0.348
Sludge generated in wastewater treatment	kg/m^3	0.091

Table 41 provides information how water domestic water demand is generated in the neighborhood, lowest indoor level – fixtures and appliances, according to the Toronto's Design Criteria for Sewers and Watermains.

Table 41. Single-family and Multi-family household water demand

	Appliance	Units	Quantity
1	Faucet	Liters/Capita/Day	29
2	Shower	Liters/Capita/Day	36
3	Dishwasher	Liters/Capita/Day	4
4	Bathtub	Liters/Capita/Day	6
5	Clothes Washer	Liters/Capita/Day	22
6	Toilet	Liters/Capita/Day	53
7	Leaks	Liters/Capita/Day	10
8	Other	Liters/Capita/Day	3

Table 42 indicates the coefficients applied to characterize to seasonal variability of domestic water demand.

Table 42. Coefficients of monthly residential water demand variation

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Coeff.	1.16	1.02	1	1	1	1.13	1.18	1.16	1	1	1.1	1.12

Table 43 details on the commercial and institutional water demand in the neighborhood.

Table 43. Commercial and Institutional water demand in the neighborhood

	Commercial and Institutional Demand	Units	Unit Demand	
1	Restaurants	Number of Seats	Liters per Seat	91.6
2	Hotels/Motels	Total Area	Liters per m^2	10.5
3	Office Buildings	Area of Office Building	Liters per m^2	4.2
4	Schools	Number of Students	Liters per Student	25.1
5	Hospitals	Number of Beds	Liters per Bed	1310
6	Daycares	Number of Children	Liters per Child	25
7	Retail	Retail Space	Liters per m^2	4.3
8	Community Centers	Community Center Area	Liters per m^2	30

Table 44 indicates the coefficients applied to characterize to seasonal variability of commercial and Institutional water demand.

Table 44. Commercial and Institutional water demand in the neighborhood

Daily Variation Coefficient	Community Centers	Daycares	Restaurants	Office Buildings	Retail
Upper Value	0.8	0.85	1.21	1.17	1.33
Lower Value	1.22	1.14	0.78	0.81	0.91

Table 45 provides assumed industrial demand and irrigation demand in the region.

Table 45. Industrial and irrigation water demand in the neighborhood

	Other	Units	Unit Demand	
1	Industry	Total Industrial Area in m^2	Liters per m^2	91.6
2	Irrigation	Public spaces for irrigation in m^2	Liters per m^2	10.5

Table 46 provides assumed industrial demand and irrigation demand in the region.

Table 46. Variation of Irrigation water demand in the neighborhood

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Coeff.	0	0	0	0.5	1	1.1	1.25	1.3	1	0	0	0

According to the recommendations of the master plan, local water distribution network will be built using concrete. Table 47 provides required information about concrete as a material.

Table 47. Unit weight of concrete pipes (drinking water, wastewater and stormwater)

Nominal Diameter	Wall thickness	Usable Length	Weight Per meter Length	Weight of entire pipe
cm	cm	meter	kg	kg
40	7.5	2.5	312	780
50	8.5	2.5	408	1020
60	10	2.5	570	1425
80	12.4	2.5	890	2225
100	14.8	2.5	1300	3250
125	17.5	2.5	2010	5025
150	18	2.5	2360	5900
180	20	2.5	3180	7950
200	20	2.5	3530	8825
240	24	2.5	4770	11925
320	30	2.5	7900	19750

Table 48 shows embodied energy and GHG emissions required for production of 1 kg of different materials.

Table 48. Embodied energy and GHG emissions for different categories of pipe materials

Name of Material	Embodied Energy	GHG Emissions
	kWh/kg	$kgCO_2eq/kg$
Concrete	0.1	0.125
PVC	0.9	2.36
Mild steel	26.67	6.5
Ductile iron	10.56	3.4
Copper	0.73	1.16

Table 49 provides Curve Number (CN) values for different types of land cover. This information is required for rainfall-runoff calculation.

Table 49. CN values for different types of land cover

Cover description	APA	Curve number for hydrologic soil group			
Cover type and hydrologic condition		A	B	C	D
Fully developed urban areas					
Open space:					
Poor condition (grass cover <50%)		68	79	86	89
Fair condition (grass cover 50 to 75%)		49	69	79	84
Good condition (grass cover >75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (including right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel(including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:	65				
1/8 acre or less (town houses) (~500m^2)	38	77	85	90	92
1/4 acre (~1000m^2)	30	61	75	83	87
1/3 acre (~1400m^2)	25	57	72	81	86
1/2 acre (~2020m^2)	20	54	70	80	85
1 acre (~4000m^2)	12	51	68	79	84
2 acres (~8000m^2)		46	65	77	82

Table 50 presents different CN values for a range of low impact development and green infrastructure techniques.

Table 50. Curve Number (CN) for different LID techniques

Cover Description	Curve Number (CN)			
Cover Type	A	B	C	D
Parking with porous pavement – good	61	75	83	87
Parking with porous pavement – fair	46	65	77	82
Parking with porous pavement – poor	46	65	67	72
Street curbs with porous pavement	70	80	85	87
Bioswales	76	85	89	97
Bioswales with porous pavement	61	75	83	87
Driveway with porous pavement	70	80	85	87
Sidewalks with porous pavement	70	80	85	87
Rain Barrels	94	94	94	94
Cistern	85	85	85	85
Green Roof	86	86	86	86
Bioretention	35	51	63	70
Agricultural land	64	75	82	85
Open space – good	30	55	70	77
Open space – fair	49	69	79	84
Open space – poor	68	79	86	89
Woods space – good	30	55	70	77
Woods space – fair	36	60	73	79
Woods space – poor	45	66	77	83
Open Water Bodies (Lakes, Wetlands, Ponds)	0	0	0	0

Following tables provide estimated amounts of chemical required for water treatment, Table 51, wastewater treatment, Table 53, while Table 52 and 54 illustrate the embodied energy and greenhouse gas emissions for used chemicals. IWRET also allows users to assume and calculate the effects of any other chemicals.

Table 51. Amount of chemicals required for water treatment

Water Treatment Chemicals	Unit	Quantity
Alum – Aluminium Sulphate ($Al_2(SO_4)_3$)	kg/m^3	0.00166
Calcium hydroxide $Ca(OH)_2$	kg/m^3	0.03341
Carbon Dioxide (CO_2)	kg/m^3	0.03393
Silica sand/Microsand	kg/m^3	0.00308
Polyaluminium Chloride (PAX)	kg/m^3	0.02886
Sodium Hypochlorite NaOCl	kg/m^3	0.00293
Chlorine	kg/m^3	0.0001

Table 52. Embodied energy and GHG emissions for chemicals used for water treatment.

Water Treatment Chemicals	Embodied Energy	GHG Emissions
	kWh/kg	$kgCO^2eq/kg$
Alum – Aluminium Sulphate ($Al_2(SO_4)_3$)	0.89	0.49
Carbon Dioxide (CO_2)	1.4	0.794
Calcium hydroxide $Ca(OH)_2$	1.0	0.763
Polyaluminium Chloride (PAX)	2.79	1.14
Sodium Hypochlorite NaOCl	6.0	5.63
Chlorine	1.0	1.05
Silica sand/Microsand	0.06	0.021

Table 53. Chemicals used in wastewater treatment

Wastewater Treatment Chemicals	Units	Quantity
Ferric Chloride $FeCl_3$	kg/m^3	0.0299
Ferric Sulphate $Fe_2(SO_4)_3$	kg/m^3	0.0215
Calcium Hydroxide $Ca(OH)_2$	kg/m^3	0.03
Ethanol	kg/m^3	0.0003
Methanol	kg/m^3	0.0329
Nitric Acid	kg/m^3	0.0245

Table 54. Embodied energy and GHG emissions for chemicals used for water treatment.

Wastewater Treatment Chemicals	Embodied Energy	GHG Emissions
	kWh/kg	$kgCO^2Eq/kg$
Ferric Chloride $FeCl_3$	1.39	0.26
Ferric Sulphate $Fe_2(SO_4)_3$	2.0	0.39
Calcium hydroxide $Ca(OH)_2$	1.0	0.763
Polyaluminium Chloride (PAX)	2.79	1.14
Ethanol	0.83	1.23
Methanol	4.56	0.736
Nitric Acid	3.31	6.3

Table 55 exemplifies the efficiency properties of pumps in the system.

Table 55. Assumed pump efficiency rates

Pump efficiency coefficients	Value
Pump efficiency	93
Variable Speed Drive Efficiency	88
Motor Efficiency	80

9 SIMULATION RESULTS

After providing required information, the user runs the simulation and selects the Model Output tab that summarizes the simulation results in numerical and graph forms. Table 56 presents performance indicators for the urban water system as a whole, and indicators for particular urban water system components.

Table 56. An overview of IWRET outputs

Label	Representation	Units
Water Demand		
Number of Years in Simulation	Number	Years
Single Family Households	Graph	Number of Units
Multi-family Households	Graph	Number of Units
Total Area Occupied by Single Family Households	Graph	m^2
Irrigation Area in Single Family Households	Graph	m^2
Adoption Rate of Water Conservation Appliances in Single Family Households	Number	%
Adoption Rate of Water Conservation Appliances in Single Family Households	Number	%
Average Occupancy in Single Family Households	Number	Persons/Household
Average Occupancy in Multi-Family Households	Number	Persons/Household
Daily Rates of Domestic Demand	Graph	m^3/Day
Daily Rates of Irrigation Demand	Graph	m^3/Day
Daily Rates of Commercial and Institutional Demand	Graph	m^3/Day
Daily Rater of Cumulative Demand in Neighborhood	Graph	m^3/Day
Number of Days with Reached Water System Capacity	Number	Days
Pumping Stations		
Life Cycle Costs for System Pumping	Number	$
Green House Gas Emissions for System Pumping	Number	$kgCO_2eq$
Energy Required for System Pumping Operations	Number	kWh
System water, wastewater, and stormwater treatment		
Green House Gas Emissions During Treatment Process	Number	$kgCO_2eq$
Energy Required for Treatment and Embodied Energy of Used Chemicals	Number	kWh
Life Cycle Costs of Treatment	Number	$
Water, Wastewater and Stormwater Networks		
Embodied Energy for Network Construction and Maintenance	Number	kWh
Embodied Green House Gas Emissions for Network Construction and Maintenance	Number	$kgCO_2eq$
Life Cycle Costs for Water, Wastewater and Stormwater Network	Number	$
Neighborhood Hydrology		
Total Neighborhood Area	Number	m^2
Composite Curve Number (CN)	Number	Dimensionless
Daily Rainfall Events	Bars	mm
Stormwater Runoff at Catchment Outlet	Graph	m^3/day
Volume of Stormwater Runoff	Number	m^3
Low impact Development		
Life Cycle Costs for Implemented LID options	Number	$
Green House Gas Emissions for LID construction and maintenance	Number	$kgCO_2eq$

Water Recycle and Reuse System		
Volume of Rainwater Harvested	Number	m^3
Rates of Daily Stormwater Runoff from Impervious Areas	Graph	m^3 / day
Total Volume of Stormwater Runoff from Impervious Areas	Number	m^3
Volume of Greywater Treated	Number	m^3
Volume of Greywater Untreated Due to System Capacity Constraints	Number	m^3
Volume of Wastewater Treated by Blackwater Reuse System	Number	m^3
Volume of Wastewater Untreated Due to Blackwater System Capacity Constraints	Number	m^3
Daily Rates of Water Reused and Recycled	Graph	m^3 / day
Life Cycle Costs of Reuse and Recycle System	Number	$
Green House Gas Emissions for Construction, Maintenance and Operation of Reuse and Recycle System	Number	$kgCO_2eq$
Energy Required for Construction, Maintenance and Operation of Reuse and Recycle System	Number	kWh
Overall Hybrid Urban Water System Performance		
Energy required for urban water system construction, maintenance and operation	Number	kWh
Greenhouse Gas Emissions for system construction, maintenance and operation	Number	$kgCO_2eq$
Life Cycle Costs of urban water system	Number	$
Qualitative Assessment of the System		
Assessment of system affordability	Number	Mark
Assessment of system acceptability	Number	Mark
Assessment of system reliability	Number	Mark
Assessment of system's risk to human health	Number	Mark
Assessment of system flexibility and adaptability	Number	Mark
Assessment of spatial requirements	Number	Mark

Once the model is simulated, the result can be viewed in terms of different quantitative indicators. These quantitative indicators can be used as metrics for some specific criteria especially when comparing different scenarios or introducing different intervention options in the model. When running the model, the quantitative indicators can be obtained in two ways:

- those which are directly supported by the IWRET model and are available in list of indicators of the tool;
- those which are not available in that list but their calculation is supported by the indicators in the list.

In this section, some instance of the indicators for each component as well as the entire urban water system are presented and analyzed for the entire planning horizon with daily time step. Table 57 provides results of selected indicators for six different scenarios.

Table 57. Results of IWRET simulation for six different scenarios developed for Villiers Island, part 1

Label	Units	Scenario					
Water Demand		1	2	3	4	5	6
Number of Years in Simulation	Years	30	30	30	30	30	30
Adoption Rate of Water Conservation Appliances in Single Family Households	%	0	75	75	75	75	75
Adoption Rate of Water Conservation Appliances in Multi-Family Households	%	0	75	75	75	75	75
Average Occupancy in Single Family Households	Persons/Household	2.8	2.8	2.8	2.8	2.8	2.8
Average Occupancy in Multi-Family Households	Persons/Household	1.9	1.9	1.9	1.9	1.9	1.9
Number of Days with Reached Water System Capacity	Days	0	0	0	0	0	0
Pumping Stations							
Life Cycle Costs for System Pumping	million $	33.5	28.99	31.25	35.66	39.52	40.52
Greenhouse Gas Emissions for System Pumping	$kgCO_2eq$	3335	2889	3233	3899	4544	5122
Energy Required for System Pumping Operations	kWh	99854	85254	100123	105144	111478	113252
System water, wastewater and stormwater treatment							
Greenhouse Gas Emissions During Treatment Process	million $kgCO_2eq$	62.43	57.33	56.20	51.04	48.52	52.35
Energy Required for Treatment and Embodied Energy of Used Chemicals	million kWh	31.65	26.65	24.35	21.22	19.25	21.22
Life Cycle Costs of Treatment	million $	124.36	111.72	108.25	99.87	94.55	96.55
Water, wastewater and stormwater networks							
Embodied Energy for Network Construction and Maintenance	million kWh	19.78	19.78	19.78	19.78	19.78	19.78
Embodied Greenhouse Gas Emissions for Network Construction and Maintenance	million $kgCO_2eq$	42.33	42.33	42.33	42.33	42.33	42.33
Life Cycle Costs for Water, Wastewater and Stormwater Network	million $	11.69	11.69	11.69	11.69	11.69	11.69
Neighborhood Hydrology							
Total Neighborhood Area	m^2	385000	385000	385000	385000	385000	385000
Composite Curve Number (CN)	Dimensionless	78	72	72	72	72	72
Volume of Stormwater Runoff	million m^3	15.66	13.42	11.25	11.25	11.25	11.25
Low impact Development							
Life Cycle Costs for Implemented LID options	million $	0	7.21	7.21	7.21	7.21	7.21
Greenhouse Gas Emissions for LID construction and maintenance	million $kgCO_2eq$	0	0.99	0.99	0.99	0.99	0.99

Table 58. Results of IWRET simulation for six different scenarios developed for Villiers Island, part 2

Label		SCENARIO					
Water Recycle and Reuse System		1	2	3	4	5	6
Volume of Rainwater Harvested	million m^3	0	0	3.10	3.10	3.10	3.10
Total Volume of Stormwater Runoff from Impervious Areas	m^3	0	0	2.56	2.56	2.56	2.56
Volume of Greywater Treated	million m^3	0	0	0	1.92	1.92	1.92
Volume of Greywater Untreated Due to System Capacity Constraints	million m^3	0	0	0	0	0	0
Volume of Wastewater Treated by Blackwater Reuse System	m^3	0	0	0	0	0.78	0.85
Volume of Wastewater Untreated Due to Blackwater System Capacity Constraints	m^3	0	0	0	0	0	
Life Cycle Costs of Reuse and Recycle System	million $	0	0	0	2.2	3.25	3.35
Greenhouse Gas Emissions for Construction, Maintenance and Operation of Reuse and Recycle System	$kgCO_2eq$	0	0	0	3.6	3.95	4.1
Energy Required for Construction, Maintenance and Operation of Reuse and Recycle System	kWh	0	0	0	9.55	10.55	11.25
Overall Hybrid Urban Water System Performance							
Energy required for urban water system construction, maintenance and operation	million kWh	39.88	41.22	46.58	47.66	49.22	52.33
Greenhouse Gas Emissions for system construction, maintenance and operation	million $kgCO_2eq$	56.77	59.36	73.53	71.56	70.23	71.25
Life Cycle Costs of urban water system	million $	154.44	159.33	161.25	164.78	168.87	170.25
Qualitative Assessment of the System							
Assessment of system affordability	Mark	4.23	4.1	4.23	4.10	4.05	4.10
Assessment of system acceptability	Mark	5	5	4.69	4.32	4.12	4.23
Assessment of system reliability	Mark	5	4.87	4.77	4.55	4.22	4.12
Assessment of system's risk to human health	Mark	5	4.9	4.78	4.4	4.15	4.05
Assessment of system flexibility and adaptability	Mark	3.25	3.98	3.9	4.12	4.5	4.12
Assessment of spatial requirements	Mark	3.1	2.87	2.83	2.78	2.65	2.71

All scenarios are compared in terms of the improvement they can potentially provide with respect to the baseline. In terms of water balance, all system configurations have the potential to significantly improve the situation. Even scenario 2 provides an overall improvement of across many of indicators. It also generates more substantial improvements in reducing the use of potable water and stormwater. Scenarios 3, 4, and 5 achieve potable water savings, but also improve further by reducing wastewater through the use of treated greywater for non-potable uses. The increased use of stormwater management ponds and on-site storage also provides a further reduction in runoff volume. Scenario 6 has the potential to produce a very significant decrease in external water supply. Due to the extensive use of rainwater, greywater and blackwater as both a potable and a non-potable source, this strategy also demonstrates the greatest potential for runoff reduction. In all other respects, the strategy performs at least as well as the best prior strategy. However, all scenarios are able to improve on the potential concerns about wastewater treatment capacity becoming the limiting factor for new developments.

In terms of energy, all system configurations demonstrate variations compared to the benchmark, due to the reduced requirements for water and wastewater treatment and the energy requirements for rainwater harvesting, greywater reuse and blackwater recycling. These energy requirements are mainly associated with pumping costs in water reuse and recycle systems. However, scenarios 4, 5 and 6 indicate a substantial increase in energy consumption due to the significant energy costs associated with point-of-use water treatment. Similar conclusions are emerging in terms of greenhouse gas emissions required for system construction and operation.

In terms of qualitative indicators, although land availability is important in strategy 4, it does not necessarily result in a reduction in the land available for development, since energy plants could potentially be cultivated in land set aside for other (non-urban development) uses (for example, sacrificial land set aside as part of a flood management strategy).

A general conclusion that emerges from comparing the strategy is that there are trade-offs between water use, energy use, greenhouse gas emissions and other qualitative indicators, and these have an equilibrium point that is associated with the technological state-of-art. At a given technological state-of-art, further reductions in water savings signify increases in either energy consumption and greenhouse gas emissions or land use and risk to human health. The strategies indicate that until this equilibrium point is reached there can be significant gains in all three aspects. The choice of desired trade-off then depends on the specific constraints of the problem at hand. If the wastewater system is close to capacity, then greywater recycling can alleviate the problem substantially. If additional water resources are unavailable or the development is a significant distance from existing infrastructure, more autonomous solutions can be investigated, at the expense of costs, energy or system land use requirements.

10 SUMMARY AND CONCLUSION

This report presents the IWRET methodology, describes modelling concepts including, principal flows, fluxes and the relevant mass balance equations, and, finally, shows the application of IWRET on a real world case study. Moreover, different input forms of the tool are described in more details. The IWRET case study illustrated the modelling process for the urban water system of the Villiers Island community, as a reference neighborhood, in which input data preparation, forms' population and samples of the results are described. The case study is analyzed for two different scenarios including the conventional approach and modelling of some decentralized interventions.

Based on the report and the analyses in the case study, the following conclusions are emerging. Firstly, IWRET methodology and the corresponding tool can be used for the strategic-level planning of the future hybrid water systems. Despite the fact that the level of detail modelled may not be able to provide the comprehensive list of interventions but it can definitely assist identify the most promising ones. This type information can be further used as an input to the next level of planning. Moreover, it is important to assess the long-term urban water systems performance by using a range of different evaluation criteria, both quantitative and qualitative. The IWRET model enables the calculation of most quantitative performance criteria values based on the metabolism approach. Finally, IWRET as an integrated modelling tool enables the planners to assess the long-term impact of intervention options on both water supply, wastewater and stormwater systems simultaneously. This can result in recognizing which intervention options can improve the overall performance of the whole urban water system.

Modelling of the conventional conditions and some interventions for the hybrid water system is for illustrative purposes only, with the aim of demonstrating some resulting indicators. Further testing and verification on other real-life urban water system is strongly compulsory. The reference neighborhood modelled here is not fully representative for the City of Toronto. It is used for the purpose of understanding the most significant interactions among the different assets of hybrid water systems and to recognize the main drivers potentially impacting on urban water systems. Therefore, the analysis conducted and the corresponding results have been used only to demonstrate possible application and functionality of the IWRET simulation model and software tool.

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