Equitable Responsibility for Transformative Design:

A systems-based approach to stormwater management

Lake Simcoe Region conservation authority

Summary Document

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Table of Contents

List of Figures

List of Tables

Acronyms & Abbreviations

SCM	Best Management Practice
CAO	Chief Administrative Officer
CBP3	Community-Based Public-Private Partnerships
CVC	Credit Valley Conservation
DAR	Drainage Area Ratio
DEP	Department of Environmental Protection
EPA	Environmental Protection Agency
FAR	Floor Area Ratio
GI	Green Infrastructure
GIS	Geographic Information Systems
GDP	Gross Domestic Product
GSFLOW	Ground and Surface Flow (model)
GSI	Green Stormwater Infrastructure
GW	Ground Water
HEC-RAS	Hydrologic Engineering Center River Analysis System
HRU	Hydrologic Response Unit
HSPF	Hydrological Simulation Program-Fortran (model)
ICI	Industrial, Commercial and Institutional
IMC	Inter-municipal Collaboration
IWMP	Integrated Watershed Management Plan
LCCT	Life Cycle Costing Tool
LID	Low Impact Development
LSPC	Loading Simulation Program in C++ (model)
LSRCA	Lake Simcoe Region Conservation Authority
MECP	Ministry of Environment, Conservation and Parks (Ontario)
MF	Multi-Family
MODFLOW	Modular Three-Dimensional Finite-Difference Groundwater Flow Model (groundwater modelling systems)
O&M	Operations and Maintenance
OBWB	Okanagan Basin Water Board
OCP	Official Community Plan

OP	Official Plan
PES	Payment for Ecological Services
P3s	Public-Private Partnerships
PRMS	Precipitation Runoff Modelling System
QAPP	Quality Assurance Project Plans
RCP	Representative Concentration Pathway
ROW	Right-of-Way
SCM	Stormwater Control Measure
SF	Single-Family
SRC	Stormwater Retention Credit
STEP	Sustainable Technologies Evaluation Program
SUDS	Sustainable Drainage Systems
SUSTAIN	System for Urban Stormwater Treatment and Analysis Integration
SWM	Stormwater Management
TAC	Technical Advisory Committee
TP	Total Phosphorus
TRCA	Toronto Region Conservation Authority
US	United States
USGS	United States Geological Survey
WoE	Weight of Evidence

1. Executive Summary

The Lake Simcoe Region Conservation Authority (LSRCA), in collaboration with area municipalities and conservation authorities, completed a study evaluating alternative stormwater management strategies.

The study, entitled "Equitable Responsibility for Transformative Design: A systems-based approach to stormwater management", was formulated to determine the best approach to meet the growing challenge of managing stormwater in the face of development and a changing climate. Flooding and resulting property and environmental damage, declining water quality, erosion, impact to aquatic and riparian habitats, loss of biodiversity, depletion of groundwater and impairment of sources of fresh drinking water are recognized potential consequences of insufficient Stormwater Management (SWM).

The study, referred to in this report as the *System-wide SWM* study, tested the hypothesis that stormwater runoff can be more effectively managed via a watershed-wide approach that includes locating Stormwater Control Measures (SCMs) on both publicly owned and privately-owned properties.

2. Introduction

Stormwater runoff is rainfall or snowmelt that flows over the surface of the ground. In natural areas such as forests and fields, there is very little runoff as most of the precipitation that falls slowly filters into the ground. In urban areas, impervious surfaces, such as roads, roofs, driveways, and parking lots prevent rainfall from infiltrating the ground (Figure 2-1).

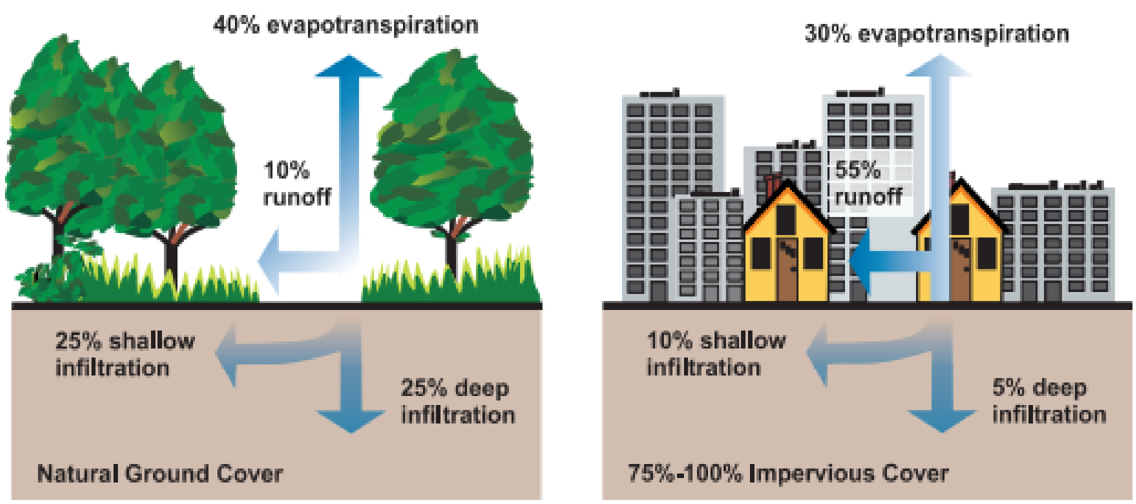


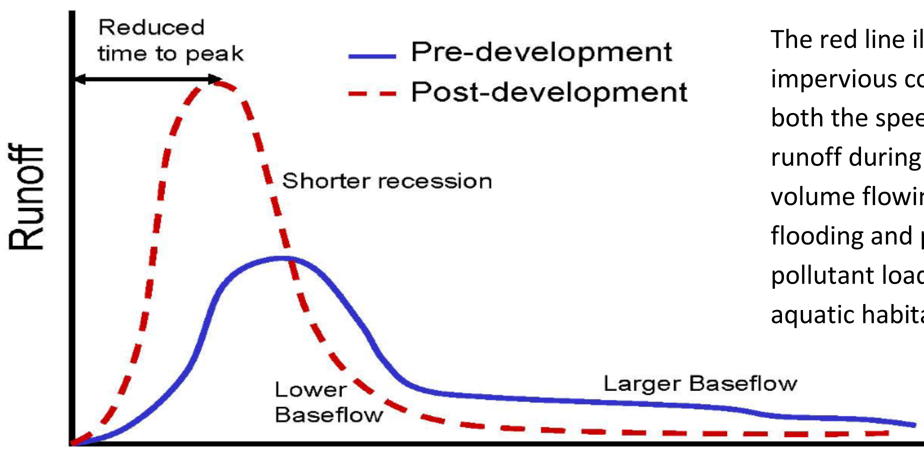
Figure 2-1: Impact of urbanization on stormwater runoff (Source: US EPA)

2.1. Historical context

Stormwater infrastructure in place in Canadian municipalities reflects a legacy of investments dating back decades and, in most municipalities, to the mid-20th Century or earlier. Stormwater infrastructure was planned at a time when there was limited understanding of urban stormwater runoff and efforts focused on conveyance of runoff, wholly untreated, to a receiving water body or alternatively, combining wastewater and stormwater into one sewer to transport flows to a municipal treatment plant. Both of these approaches cause excessive flooding and erosion, compromise natural hydrology leading to large fluctuations of flows in surface waters and recharge of groundwater, and increase pollutant loadings to lakes and rivers resulting in declining water quality, damage to aquatic habitats, and contamination of sources of drinking water.

2.2. Urbanizing landscapes

Older stormwater infrastructure cannot cope with increased runoff due to urbanization. Figure 2-2[1] illustrates the impact of urbanization and expanding impervious cover on stormwater runoff and the resulting increase in overland flows. Increased stormwater runoff can lead to flooding and erosion and impair water quality. As runoff flows over hard surfaces, it picks up debris and pollutants such as motor oil and fertilizers along the way. In older urban and suburban areas across Canada, much of this contaminated runoff is channeled via underground pipes and deposited directly into lakes, streams and rivers degrading water quality, increasing erosion, and damaging aquatic habitats.



The red line illustrates how an increase in impervious cover results in a large increase in both the speed and volume of stormwater runoff during a rain event. More runoff volume flowing at a higher speed increases flooding and property damage, erosion, and pollutant loadings to waterways, and harms aquatic habitats.

Figure 2-2: Impact of impervious surfaces on stormwater runoff and base flow. (Source: *Water*)

Urbanization changes the natural hydrology as expanding impervious cover means less precipitation and snow melt infiltrates the ground to recharge groundwater sources that slowly feed streams, maintaining base flows. Climate change will exacerbate SWM deficiencies due to more frequent extreme weather events resulting in higher flow volumes and velocities. Increased flooding and erosion, protracted drought, lower base flows in streams, declining water quality, and the attendant impacts represent a growing risk for communities and the natural environment.

2.3. Stormwater Management

Municipalities in Canada have primary frontline responsibility for managing stormwater within their boundaries. Conventional stormwater infrastructure has been the dominant form of municipal SWM for decades. Conventional stormwater infrastructure emphasizes channeling of runoff away from developed areas to an end-point such as a lake, river, sewage treatment plant or stormwater pond. This end-of-pipe approach to managing stormwater combined with an historic legacy of poor planning and inadequate SWM infrastructure has created a significant challenge for municipalities. Many municipalities across Canada and around the world are struggling to address areas with insufficient stormwater infrastructure while confronting the added SWM demands associated with expanding urbanization and the increasing frequency and severity of weather events due to climate change. Hence, despite increasing investments and new financing mechanisms, the overall municipal stormwater and wastewater deficit in Canada is increasing (Figure 2-3). Taken collectively, the limitations of existing SWM infrastructure combined with rapidly changing land use and climate variability are leading to increasing runoff and erosion, deteriorating water quality, flooding, habitat loss and ever-accumulating downstream impacts.

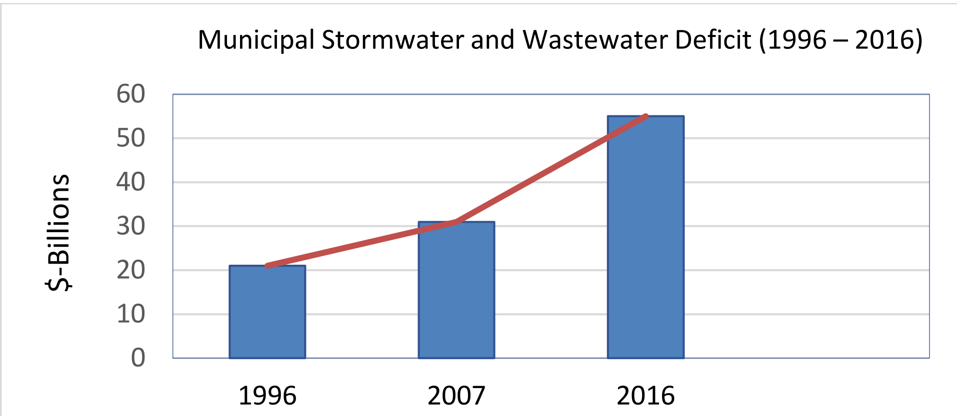


Figure 2-3: Municipal stormwater and wastewater deficit (1996-2016) (Adapted from the Federation of Canadian Municipalities infrastructure report cards)[2]

2.3.1. Watersheds

A watershed is the natural area of land that channels precipitation and snowmelt to creeks, streams, and rivers where it is carried to an outflow point such as a lake, bay or ocean (Figure 2-4).

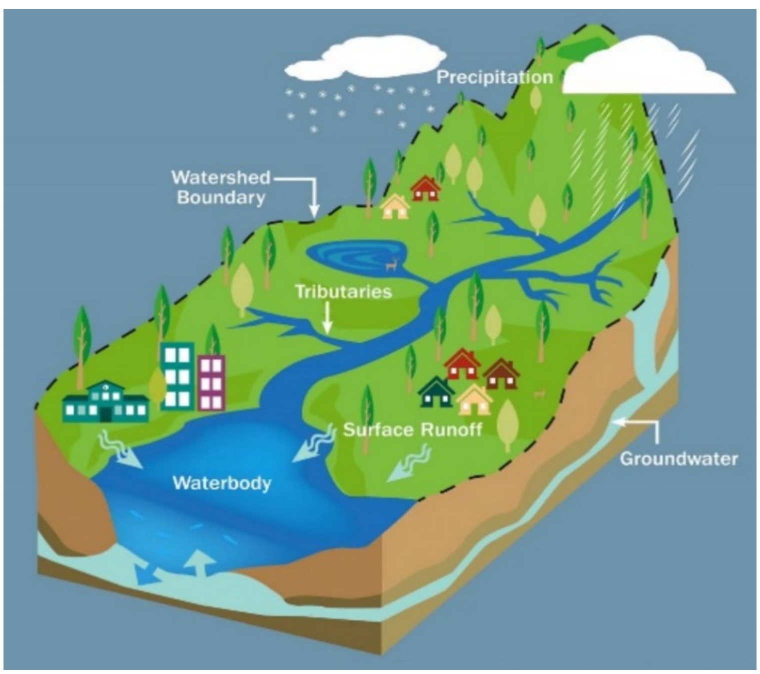


Figure 2-4: Illustration of a watershed. (Source: Greenscapes North Shore Coalition)

Equitable Responsibility for Transformative Design

Everyone on the planet lives in a watershed. Watersheds are integrated systems, with actions in one part of a watershed impacting other parts of the watershed. The natural boundaries of a watershed are determined by topography, because water flows from high ground to low, and rarely correspond with the political boundaries of a municipality (Figure 2-5). Because municipalities plan development and SWM infrastructure within their boundaries and those boundaries do not align with watershed boundaries, potential downstream or watershed-wide impacts are often not considered. In other words, development decisions by municipality in the upper portions of a watershed may result in water quality or flooding issues in downstream municipalities.

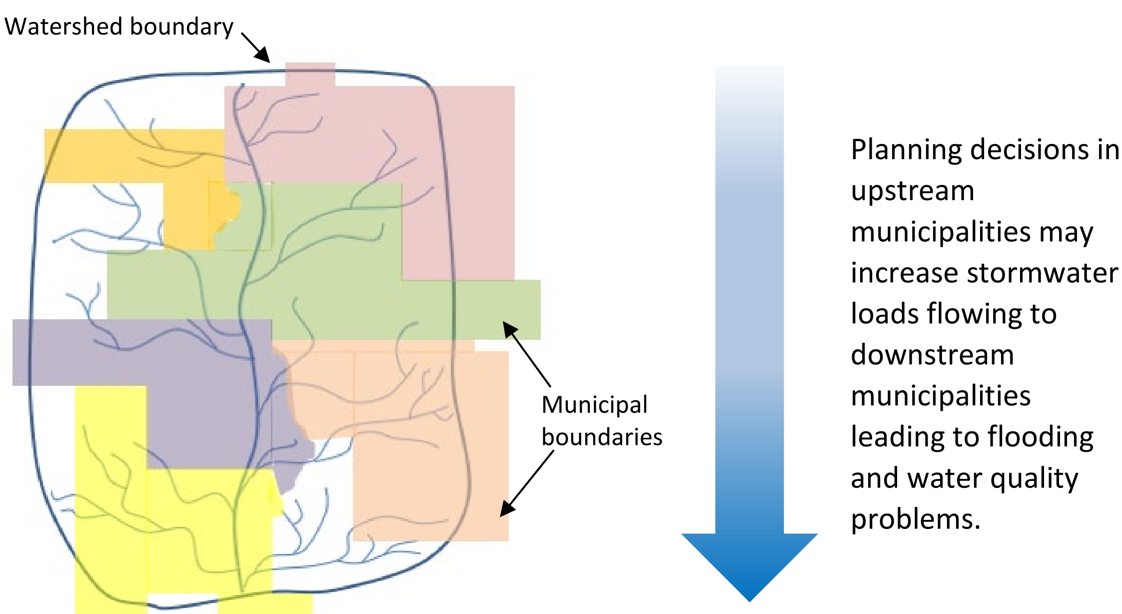


Figure 2-5: Watershed boundary do not align with municipal boundaries; downstream impacts may result from planning and SWM infrastructure decisions made by upstream municipalities.

As watersheds become more developed, the volume and rate of stormwater runoff increase considerably, leading to flooding, erosion, and degraded water quality. (Figure 2-6)

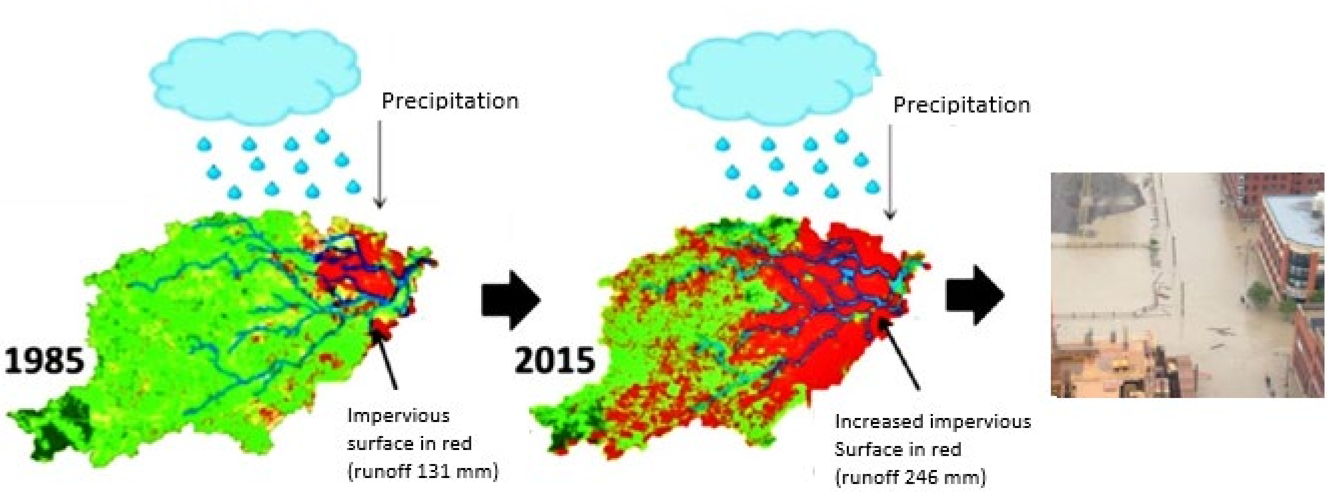


Figure 2-6: Impact of development in a watershed. (Source: Igulu, B.S.; Mshiu, E.E.; The Impact of an Urbanizing Watershed to Surface Runoff)

In Canada, over 80% of the population lives in urban and peri-urban watersheds. With expanding impervious cover and the concurrent loss of natural areas such as forests and wetlands that slow runoff, increase its absorption into the ground and filter out pollutants, these watersheds are experiencing declining water quality and increasing flooding, erosion and habitat loss (Figure 2-7).

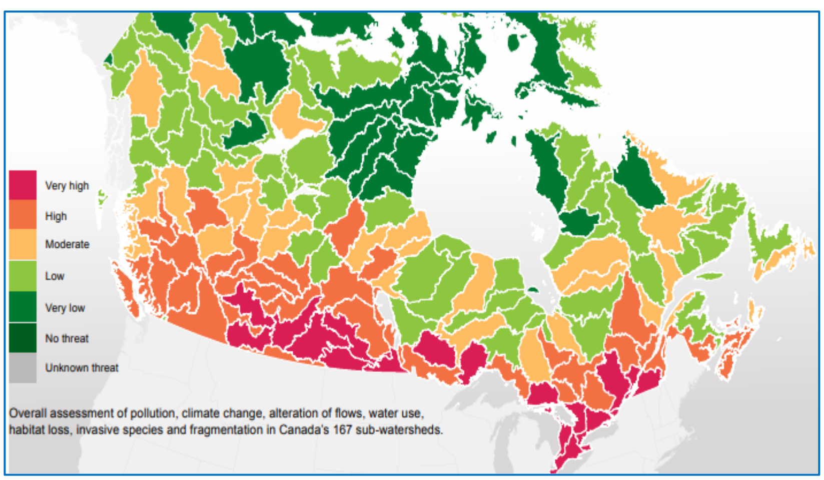


Figure 2-7: Level of stress of watersheds in Canada. (Source: WWF Canada)[3]

Many of the highly stressed watersheds in Canada are host to the urban, suburban, and rural areas that were planned and developed with little consideration of SWM or for the impacts of future growth and development. Expanding impervious landscapes in these watersheds with the attendant loss of natural areas, farmland, and open green space; older built-up areas lacking adequate stormwater control and climate change related increase in extreme weather, has resulted in significant damages and costs nation-wide (Figure 2-8). Flooding is now responsible for the vast majority of disaster-associated costs, accounting for about 75% of all weather-related damages.[4]

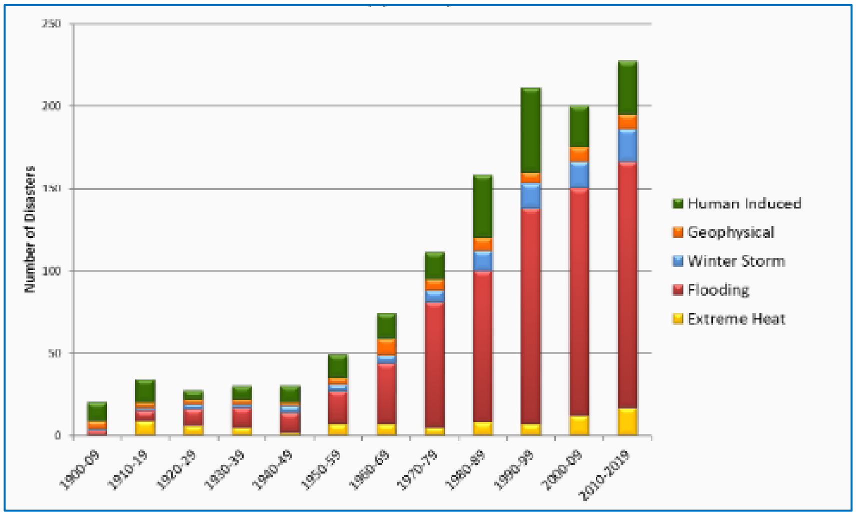


Figure 2-8: Disaster trend in Canada by decade (Source: Public Safety Canada)

Improved understanding of hydrology and the complex interaction between meteorology and land surfaces, has led more municipalities to implement integrated SWM planning, use new nature-based technologies to manage stormwater where it lands, and reconsider the role and value of natural assets such as forests and wetlands in managing stormwater. Green Infrastructure (GI) and Low Impact Development (LID) practices, such as rain gardens, green roofs and rainwater harvesting are more frequently used in combination with conventional SWM. Still, the focus remains on municipal boundary-based stormwater planning and management and the use of conventional, end-of-pipe infrastructure, although within Lake Simcoe we are witnessing a more rapid uptake in LID driven by LSRCA stormwater guidelines and offsetting polices.

2.3.2. Public and private property

In urban municipalities about 70% to 90% of the land is privately owned leaving limited parcels of available public land for siting stormwater infrastructure (Figure 2-9). With rapid urbanization and increasing climate variability there is insufficient public land to cost-effectively manage stormwater. Implementing centralized (e.g., constructed wetlands) and distributed (e.g., rain gardens or cisterns) SCMs on private property as well as available municipal property will provide needed additional stormwater management capacity.[5]

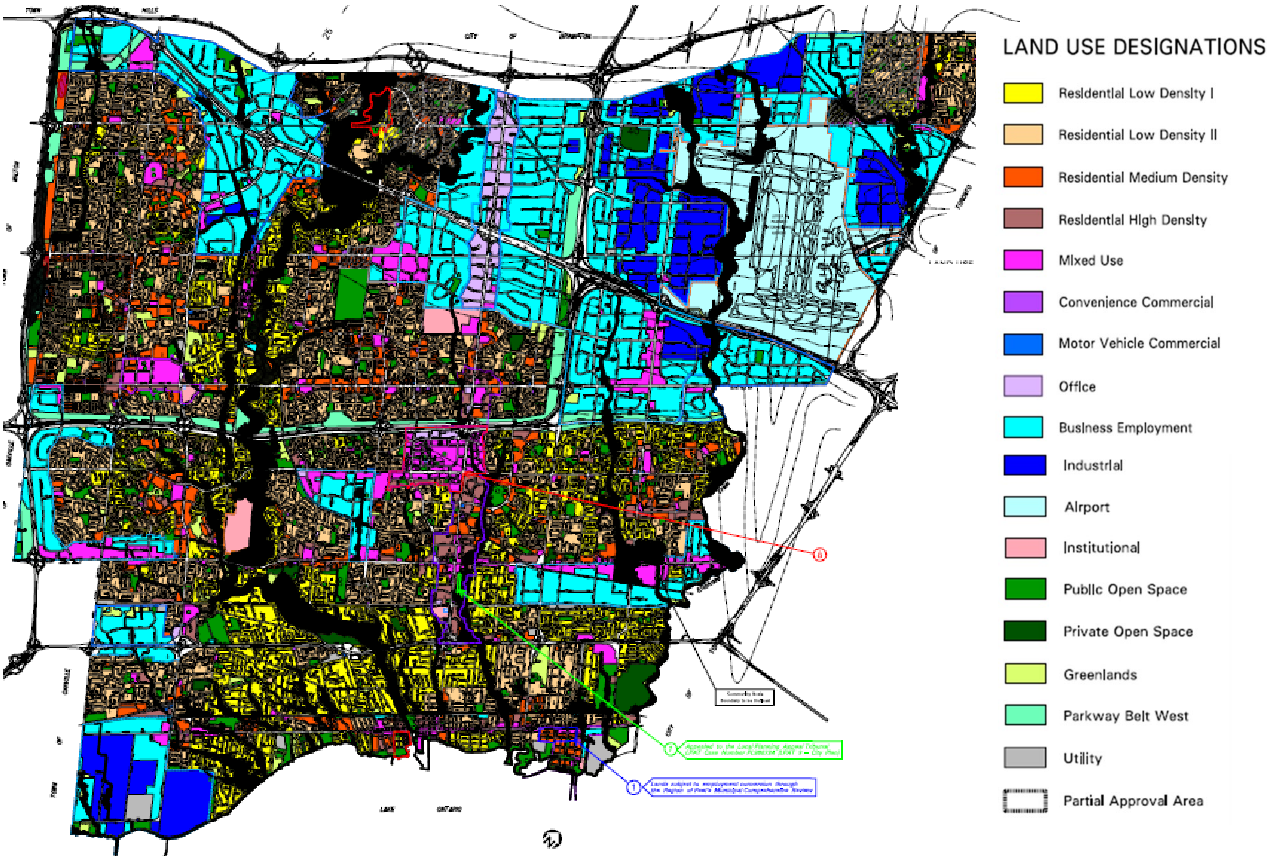


Figure 2-9: Example showing vast majority of land is privately-owned in urban municipalities (Source: City of Mississauga)

2.3.3. A new stormwater management framework

Transitioning to a new SWM framework, one based on an integrated system of centralized and distributed stormwater control measures (SCMs) implemented watershed-wide, unencumbered by political boundaries and utilizing public and private lands to host stormwater infrastructure is critical to achieving sustainable SWM and the basis for the study.

3. System-wide SWM Study

In this section, the purpose and context of the System-wide SWM study, and the methodology used to carry out the analyses are discussed.

3.1. Study purpose

The System-wide SWM study examined the use of scale (municipal vs watershed-wide), and integration and aggregation (municipal public property only vs public and private property) to achieve optimal SWM performance at the greatest cost-efficiency under multiple scenarios, such as climate change and future growth and development.

3.2. Study context

The study was informed by research undertaken by partner organizations and other municipal stakeholders into barriers to integrated, watershed wide SWM. Findings of several important water quality and hydrology monitoring and modelling efforts undertaken by the LSRCA, and pointing to the limits of the current approach to SWM in the Lake Simcoe basin, further informed the study design.

3.2.1. Study area

The study was undertaken in the East Holland River watershed located in the Lake Simcoe basin in Ontario, Canada (Figure 3-1). The East Holland is one of the fastest developing watersheds in the country and has experienced declining water quality and impaired hydrology.

Figure 3-1: The East Holland watershed is located in the Lake Simcoe basin, Ontario, Canada. Source: Natural Resources Canada NRCan (2000)

The East Holland River watershed is located in the southern portion of the Lake Simcoe basin (Figure 3-2) and is about 238.7 km^2 in size. The East Holland was selected for the study as conditions in the watershed reflect those typically found in urban and peri-urban (i.e., mixture of urban and rural land uses) watersheds across Canada and globally. Local watershed municipalities – the towns of Aurora, East Gwillimbury, Georgina, Newmarket, and Whitchurch-Stouffville – face the same challenges of constrained budgets, areas with inadequate SWM, rapid urbanization, and increasing climate variability as other municipalities across Canada.

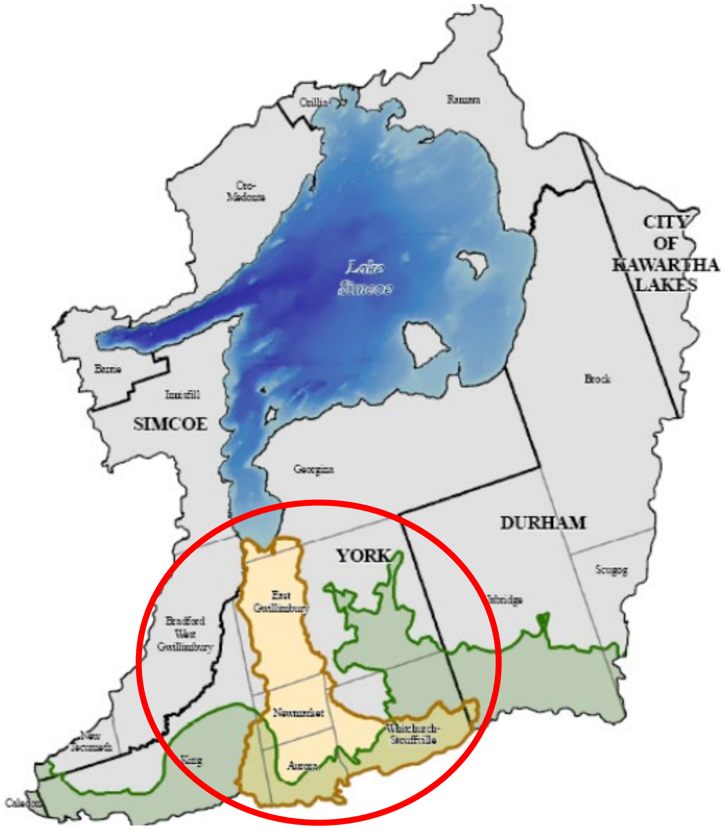


Figure 3-2: The East Holland River watershed located in the southern portion of the Lake Simcoe basin. (Source: LSRCA)

The East Holland River watershed provided the necessary conditions to, 1) assess municipal versus watershed wide SWM and, 2) the use of public property only versus both public and private property to host SCMs. These conditions include:

- six local municipalities having responsibility for SWM (Table 3-1);
- a regional upper tier municipality;
- a large portion of privately held property of different land use types;
- a mix of urban and rural development; and,
- rapid urbanization.

Table 3-1: Resident East Holland municipalities analyzed in the study.

Municipality	Total area (ha)	Impervious area (ha)
Georgina	433	8
East Gwillimbury	7,555	129
King	1,480	17
Newmarket	3,171	364
Aurora	4,572	225
Whitchurch-Stouffville	5,985	79

3.2.2. Lake Simcoe Protection Plan

Management of the Lake Simcoe basin is governed by the Lake Simcoe Protection Plan (LSPP), established under the Province of Ontario's Lake Simcoe Protection Act (2008). The LSPP sets out policies and water quality targets for the lake and its tributaries. A key target in the LSPP is 7mg/L dissolved oxygen in Lake Simcoe. Dissolved Oxygen (DO) is a measure of how much oxygen is dissolved in the water and available to aquatic organisms like fish. DO is one of the most important indicators of water quality. The DO target of 7mg/L in the LSPP represents a 40% phosphorus reduction target for the lake. This phosphorus reduction target was used for the System-wide SWM study.

3.2.3. Study principles

Three study principles were formulated based on the conviction that an alternative, system-based approach to stormwater planning and management is necessary to achieve sustainable, cost-efficient and future-ready SWM. Testing of the following principles informed the study design and methodology:

1) Using an optimization methodology will significantly enhance understanding of the characteristics and processes influencing watershed hydrology and expand the scope and depth of the evaluation of management options providing a cost-efficient strategy to achieve SWM targets under current and future state scenarios.
2) In addition to municipal-owned properties, including privately-owned property as potential sites for implementation of SCMs will improve SWM at greater cost-efficiency than the current approach restricting siting of management measures exclusively to public land.
3) Municipal collaboration on integrated, watershed-wide SWM will provide improved performance at greater cost-efficiency than the current, municipal-boundary based approach to SWM, and also provides a more equitable approach for all watershed resident municipalities and constituents.

3.3. Study Methodology

A watershed model and decision support system were developed to evaluate strategies to manage stormwater based on their impact on watershed processes and their cost-effectiveness. The study methodology involved the calibration of a 'Current State' model to generate a 'boundary' or base case condition. This current state model was linked to a 'Future State' model that simulates hundreds of thousands of future SWM scenarios to generate cost optimization curves. Figure 3-3 schematically represents the study methodology.

3.3.1. Current State Model

Development of a 'Current State' hydrologic profile of the East Holland watershed from which potential management strategies, including centralized and distributed SCMs to effectively manage stormwater. The current state continuous simulation model, referred to as *Loading Simulation Program in C++* (LSPC), produced outputs that identified the following:

- Stormwater and watershed drainage boundaries.
- Municipal areas where stormwater is currently controlled by pond infrastructure.
- Sources of imperviousness and runoff.
- Current state of hydrology in the local waterbodies/creeks.

The current state outputs as indicated above, provide the necessary understanding of the watershed and sources of runoff to determine potential management strategies.

The LSPC model generates a time series (i.e., a series of data points in time order) to represent hydrology at the landscape level. Figure 3-4 provides a schematic of the land simulation processes captured by LSPC that produce runoff from land, including time varying rain or snow accumulation and melting, evaporation from ponded surfaces, infiltration of rain or snowmelt into impervious and unsaturated soil, percolation of infiltrated water into groundwater, and non-linear reservoir routing of overland flow.[6]

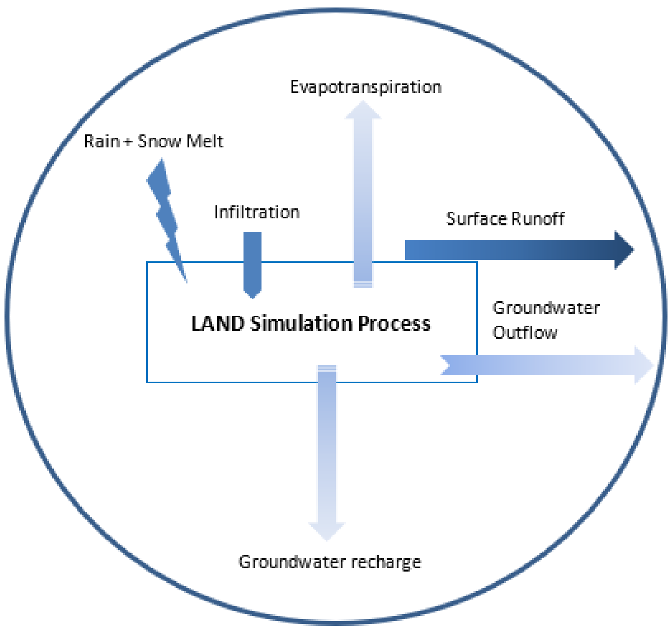


Figure 3-3: Land simulation processes captured by the LSPC model (Source: US EPA)

For the LSPC modelling exercise, a top-down Weight of Evidence (WoE) methodology was applied and is illustrated in Figure 3-5. A WoE approach is a decision-making process that considers multiple sources of data and lines of evidence providing a higher level of accuracy in the analysis. Data for the model build was compiled based on project objectives and desired outputs and prepared for configuration of the model. Once configured, the model was calibrated to represent processes. Feedback loops between configuration and calibration functions enabled both adaptation (e.g., needs for additional data) and validation (i.e., quantifying performance and ensuring the predictions are robust in correlation with the model segmentation).

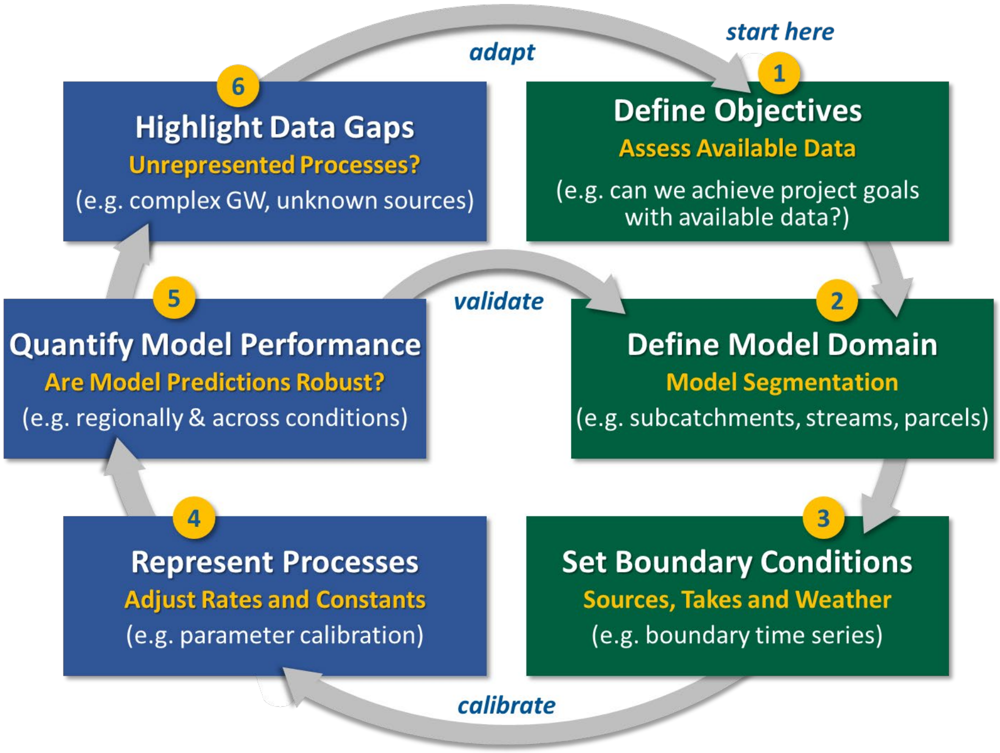


Figure 3-4: Current State LSPC model – a top-down Weight of Evidence approach

Understanding these processes and their interrelationship is critical to determining current state hydrology and in turn, identifying areas vulnerable to flooding, controlled vs uncontrolled areas, and potentially viable management strategies and priority locations for them. Figure 3-6 illustrates model inputs and outputs for a current state land use and hydrologic profile of the East Holland sub-watershed study area.

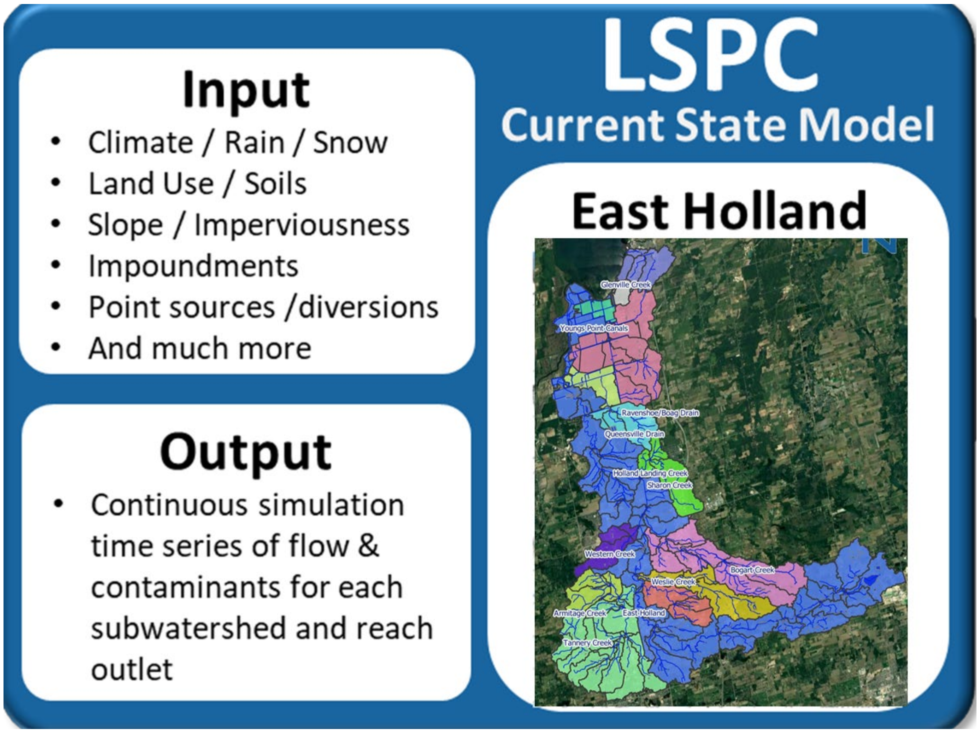


Figure 3-5: LSPC modelling system for the East Holland watershed study area

After weather data and meteorological boundary conditions are well established, a top-down Weight of Evidence (WoE) approach progresses as follows: (1) calibrate background conditions that are typically upstream and relatively homogeneous, (2) add intermediate mixed land use areas with more varied hydrological characteristics, and (3) aggregate all sources via routing to a downstream location for comparison with actual flow data.

LSPC was used to simulate baseline hydrologic and water quality conditions for the East Holland River watershed. Additional information configuration of LSPC can be found in the Current State Modelling Report (refer to Appendix 1 in full study technical report (LSRCA, 2021). The baseline LSPC simulation served as the 'boundary', or base case, condition for the 'Future State' model.

3.3.2. Future State – SUSTAIN Model

A decision support tool, System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) was selected for the Future State model based on its ability to analyze scenarios and options for managing stormwater at both jurisdictional and watershed-based, cross-jurisdictional scales. SUSTAIN is open-source and includes a process-based watershed model that simulates watershed hydrology and hydraulics, water quality, and SCM processes at multiple scales (US EPA 2009).

SUSTAIN uses optimization algorithms to identify cost-effective management strategies. These strategies are optimal combinations of SCM types and sizes at strategic locations on the landscape, identified through thousands of computer iterations to generate cost-effectiveness optimization curves (an example of a cost-effectiveness optimization curve generated by SUSTAIN is shown in Figure 3-7). The combinations of SCMs at strategic locations throughout the watershed are optimal because they achieve desired water quality and runoff mitigation objectives at the lowest financial cost. 'Future State' model that simulates hundreds of thousands of future SWM scenarios to generate cost optimization curves.

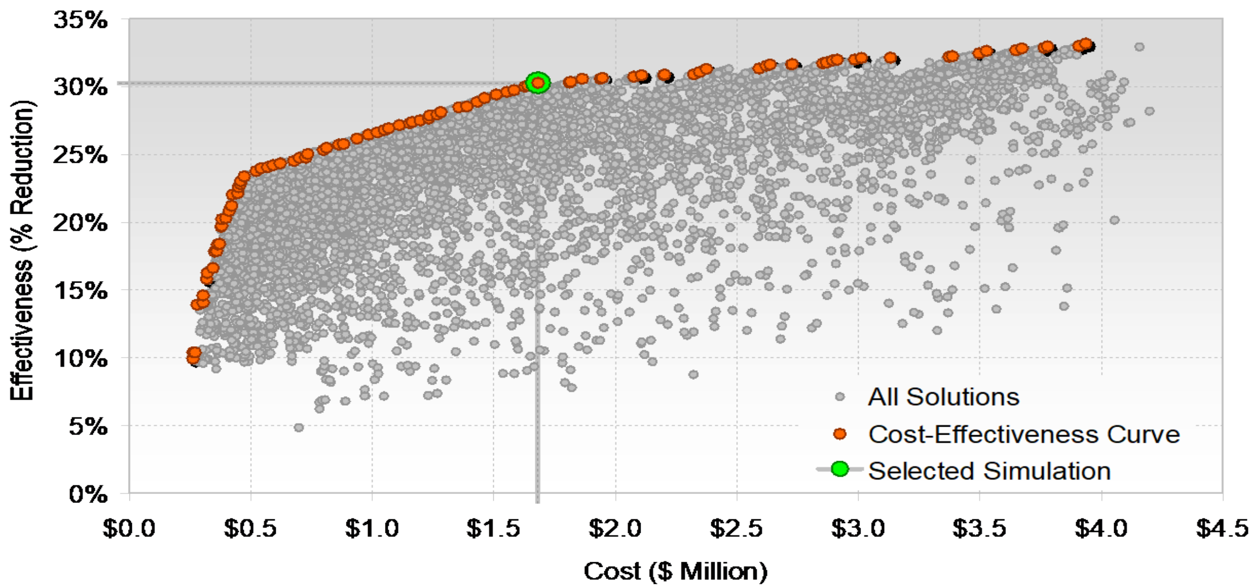


Figure 3-6: Cost-effectiveness Optimization – hundreds of thousands of possible solutions analyzed (Source: Paradigm Environmental)

3.3.3. Economic analysis

Cost-effectiveness of SCMs is used by SUSTAIN as its criteria for identifying management strategies (combinations of SCMs that meet watershed quality and runoff mitigation targets, at least cost). Cost curves, essentially cost data in graph form, are used by the optimization algorithms in SUSTAIN to identify management strategies. A life-cycle analysis, based on total capital, Operating and Maintenance (O&M) and replacement costs for each SCM over a 30-year time period was used to develop the cost curves. The total costs were expressed in present value terms assuming a discount rate[1] of 5% and annual inflation of 3%. The cost relationships are documented in the Cost Function Report (Refer to Appendix 2 in the full study technical report).

3.3.4. Flood damages

Flood damages were evaluated to enable comparison of savings from reductions in flood damages to the cost of implementing SCMs that give rise to those savings. Flood damages were evaluated over a 30-year period and expressed as net present values calculated using the same inflation and discount rate assumptions applied to estimation of costs.[2]

[1] This is the nominal discount rate and it includes an allowance for inflation. With annual inflation of 3%, the 'real' or inflation free discount rate is 1.9%

[2] 5% nominal discount rate, 3% inflation and 1.9% real discount rate

3.3.5. Co-benefits

Co-benefits of SCMs, such as reduced air pollution with the addition of street trees, were identified and qualitatively evaluated for the study. Co-benefits were assessed for both the representative SCMs used for the study and those SCMs to be targeted for future implementation. Based on leading jurisdictions research and an extensive literature review (Refer to Appendix 3 in the full study technical report), the potential or capacity of an individual SCM to produce a given co-benefit was qualitatively rated on a scale of 1 to 5 and results tabulated.

3.3.6. Climate change

Climate change will lead to more frequent and severe precipitation events, rapid snow melt, extreme heat waves, and expanded drought. Depending on the where one lives in Canada, the potential consequences of increasing climate variability include property and infrastructure damage; continued impairment of ground and surface water quality; increased erosion and loss of soil fertility; depletion of groundwater reserves; an expanded forest fire season and increased frequency, intensity and size of forest fires; continued loss of natural habitats and biodiversity; rising agricultural losses (crop and livestock); and amplifying risk to human health and safety.

In the East Holland River watershed, the primary climate change-driven weather impacts will be increased precipitation intensity and rapid snow melt, hence the mitigation of peak flows under climate change scenarios were the focus of the analysis via SUSTAIN.

3.3.7. Representative SCMs

Representative SCMs are structural measures that statistically represent management options by type (e.g., green roof or permeable paving), site location or parcel (e.g., road right-of-way), source (e.g., runoff from parking lots) and footprint size (e.g., up to a maximum of 20% of available area within the location or parcel). There are two categories of SCMs; centralized and distributed. Centralized measures are moderate to large in size and manage stormwater from mixed land use drainage areas. Distributed measures are smaller in size and manage stormwater from a specific land use parcel or parcels, such as one or more parking lots in a commercial business park. A description of the representative centralized and distributed SCMs used in the study is provided Table 3-2.

Table 3-2: Representative Stormwater Control Measures

Centralized SCMs

Hybrid ponds / wetlands

In this study, hybrid ponds/wetlands were applied to manage stormwater for larger upstream areas.

Hybrid ponds/wetlands reduce the volume of stormwater runoff entering storm drains and surface waters and provide water quality improvement through detention, infiltration, filtration, and/or reuse (e.g., on-site irrigation). Two types represented in the study:

Inline facilities are adjacent to streams and rivers and treat streamflow.

Offline facilities are located adjacent to storm drains and capture and treat stormwater runoff impervious surfaces that would otherwise enter the storm drains.

Distributed SCMs

Infiltration Chambers

In this study, infiltration chambers were applied to manage stormwater runoff from parking lots.

Infiltration chambers contain modular structures installed underground that create large void spaces for temporary storage of stormwater runoff and allow it to infiltrate into the underlying native soil. They typically have open bottoms, perforated side walls and optional underlying granular stone reservoirs.

Source: Nilex - https://nilex.com

Infiltration trenches

In this study, infiltration trenches were applied to manage stormwater runoff rooftops.

Infiltration trenches are narrow ditches lined with geotextile fabric and filled with clean granular stone that intercept runoff from impervious areas such as rooftops and driveways.

Source: North Dakota State University

Table 3-2: Representative Stormwater Control Measures

Distributed SCMs

Bioretention facilities

In this study, bioretention facilities were applied to manage stormwater runoff in new developments (i.e., future growth scenario).

Bioretention practices are designed to mimic the natural hydrologic processes of pre-development land use. Broadly, a bioretention facility is a vegetated shallow depressed area supported by soil media and treat stormwater runoff through detention, evapotranspiration, pollutant uptake, filtration through soil media, and/or percolation into native soils when infiltration rates are sufficient.

Source: City of Vancouver

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Enhanced boulevard tree cell

In this study, stormwater runoff from regionally owned roads were treated with an enhanced tree cell design.

The enhanced tree cell incorporates infiltration trench. These installations are used to capture and treat runoff from roads and parking lots. The tree cell itself is a modified bioretention unit, in both design and function but used in combination with an infiltration trench.

3.3.8. Future State Model Configuration

The future state modelled was configured to forecast the effectiveness of SCMs for reducing flooding and improving water quality under future state scenarios and to compare a 'business as usual' approach to a transformational watershed-scale approach. The key elements of the SUSTAIN model configuration were; 1) the menu of representative SCMs; 2) opportunities to site and the footprint of the representative SCMs; 3) areas managed by the representative SCMs; and, 4) the cost of the representative SCMs.

The menu of representative SCMs is illustrated in Figure 3-8 and indicates the representative SCM by parcel type under public plus private lands and public lands exclusively scenarios.

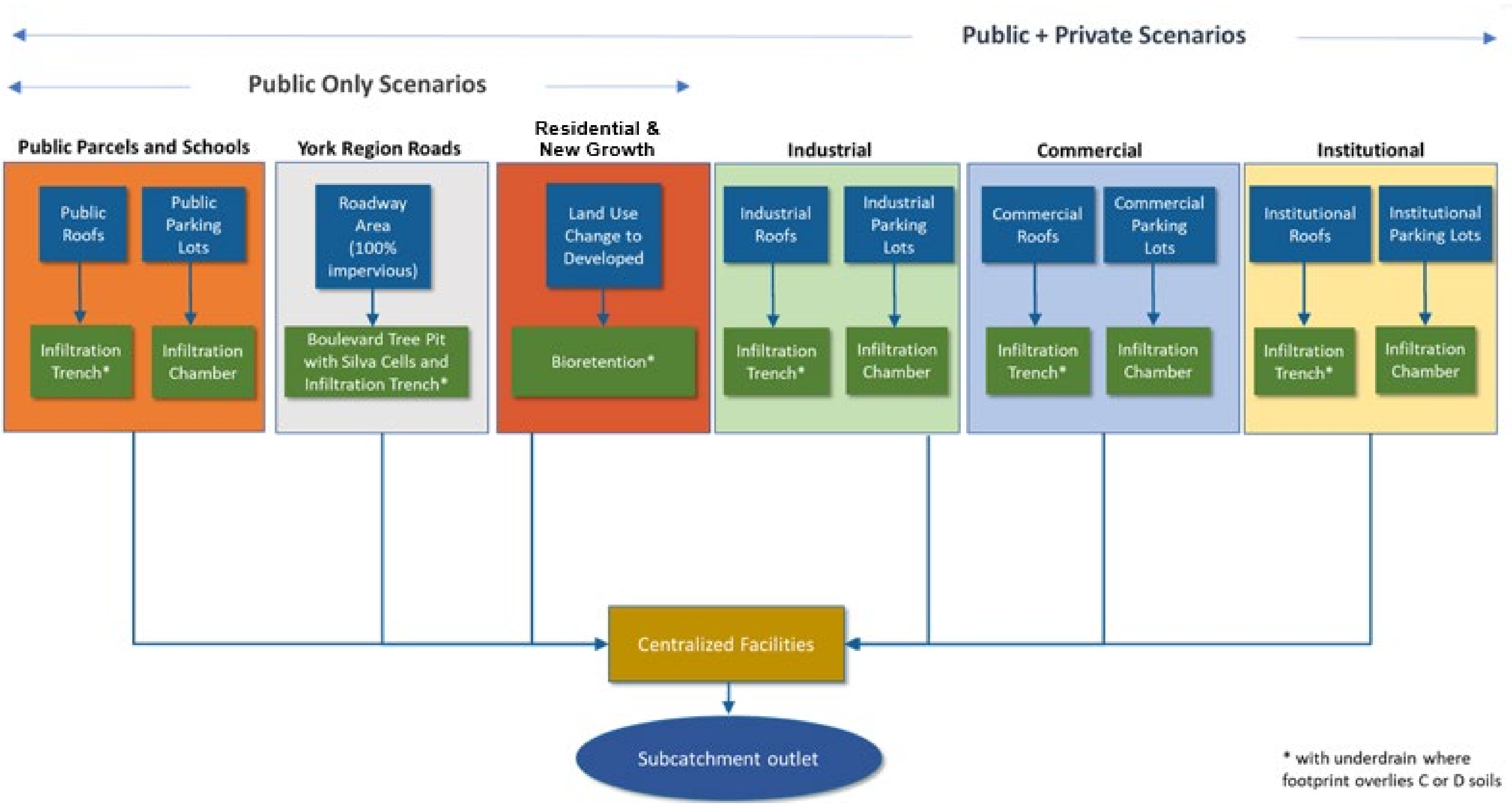

Figure 3-7: Representative SCM menu

(Note: depending on identified opportunities the distributed systems may or not be routed through a centralized facility as depicted.)

3.3.9. SCM opportunity screening

With SUSTAIN optimization, most SCMs are optimized based on ‘opportunities’, and optimization selects which SCMs are included in each solution. The opportunity screening defines for SUSTAIN which footprint areas in each municipality, referred to here as ‘jurisheds’, are available for siting SCMs, and optimization may use all or none of that footprint. Jurisheds, as indicated in Figure 3-9, is a term used to describe the portion of a sub-catchment that is within a specific jurisdiction or municipality. Sometimes a sub-catchment is entirely within a jurisdiction, often a sub-catchment crosses several jurisdictions, resulting in several jurisheds. Jurisheds allow for restricting the assessment of SCM implementation to individual jurisdictions or municipalities.

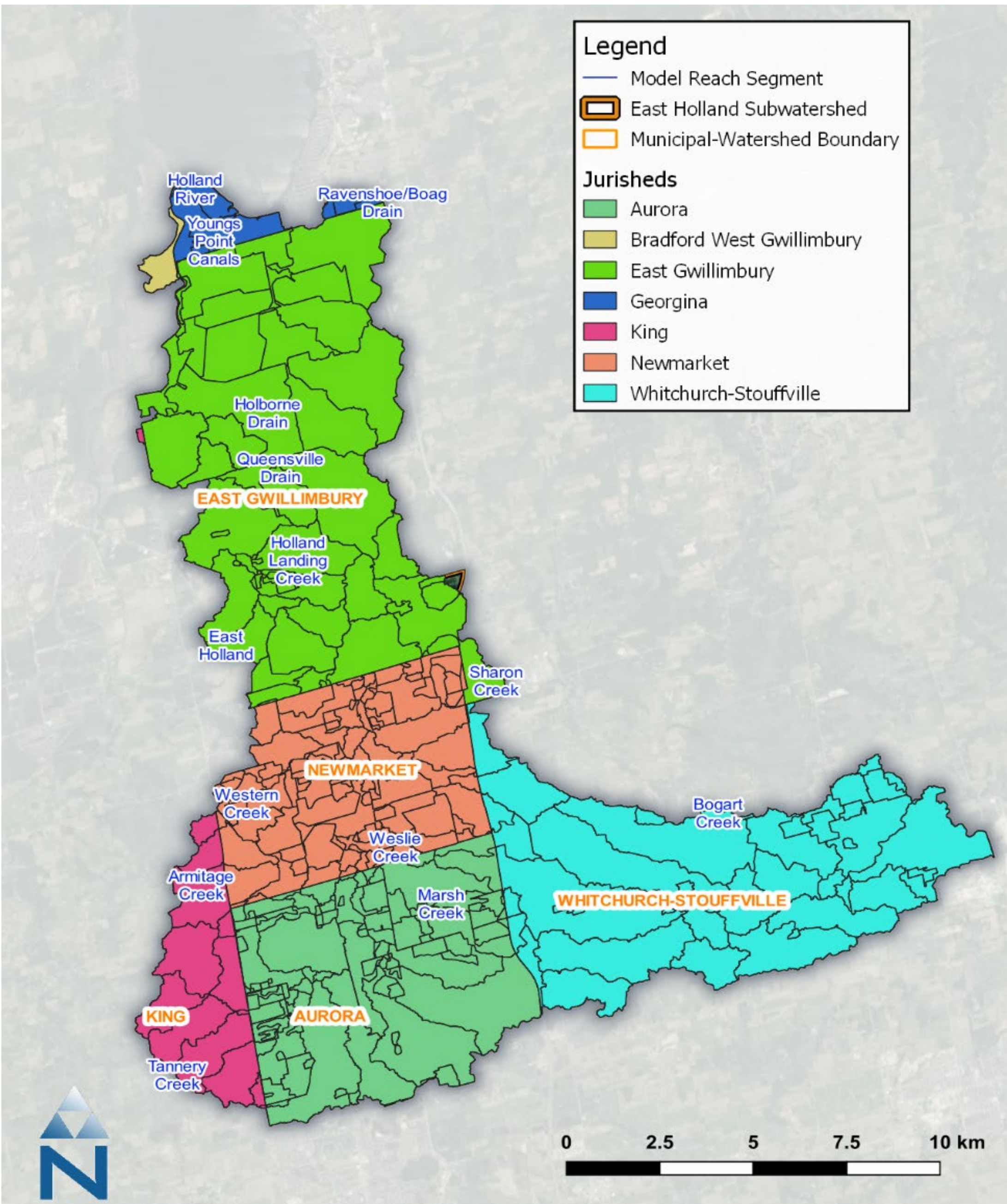

Figure 3-8: Sub-catchments and municipalities in East Holland River watershed

GIS analyses were conducted to identify potential siting opportunities for distributed and centralized SCM implementation. Identified opportunities included public land parcels, large private pervious areas such as golf courses, private and public schools, and industrial, commercial and institutional impervious areas such as roofs and parking lots.

For distributed SCMs, 80% of the parking lot, roof, and regional road area within each jurished was configured as an uptake opportunity for optimization. The 80% was set as a maximum uptake area to avoid completely infeasible outcomes where every single roof or parking lot is managed (Table 3-3).

Table 3-3: Impervious surface by land use and type for distributed SCMs

Land Use	Impervious Surface Type	Area (ha)	% of total area
Public (municipal and regional properties)	Roof	18.2	6.10%
	Parking Lot	20.5	12.90%
	Regional Roads	201.2	100.00%
	Total	239.9	36.45%
Schools	Roof	25.1	8.40%
	Parking Lot	17.7	11.10%
	Total	42.8	9.40%
Industrial	Roof	123.1	41.40%
	Parking Lot	36.2	22.70%
	Total	159.4	24.22%
Commercial	Roof	109.7	36.90%
	Parking Lot	56.7	35.50%
	Total	166.3	25.27%
Institutional	Roof	21.3	7.20%
	Parking Lot	28.3	17.80%
	Total	49.6	7.54%
Totals	**Total Roof Area**	**297.4**	**45%**
	Total Parking Lot Area	**159.5**	**24%**
	Total Regional Road Area	**201.2**	**31%**
	Total LID Opportunity Area	**658.1**	**100%**

Note: % of total area based on the total values at bottom of table. For example, 8.4% (25.1 ha) of the total roof area (297.4 ha) available for SCM treatment was associated with schools. Additionally, the total roof area is 45% of all LID opportunity. 100% (201.2 ha) of the roads were regional public roads and regional roads make up 31% of LID opportunity.

For centralized SCMs, Quality Assurance (QA) and cost-effectiveness screening criteria were used to evaluate and screen for suitable parcels by SCM type, while performance criteria was applied to screen for suitable centralized SCM by land use. Water quality, specifically, Total Phosphorus (TP)reduction, and water quantity, specifically, peak flow reduction were the criteria used to screen for suitable centralized opportunities. Two-hundred and eighty centralized opportunities were evaluated and screened resulting in the identification of sixty-eight centralized SCM opportunities for optimization analysis via SUSTAIN as shown in Figure 3-7.

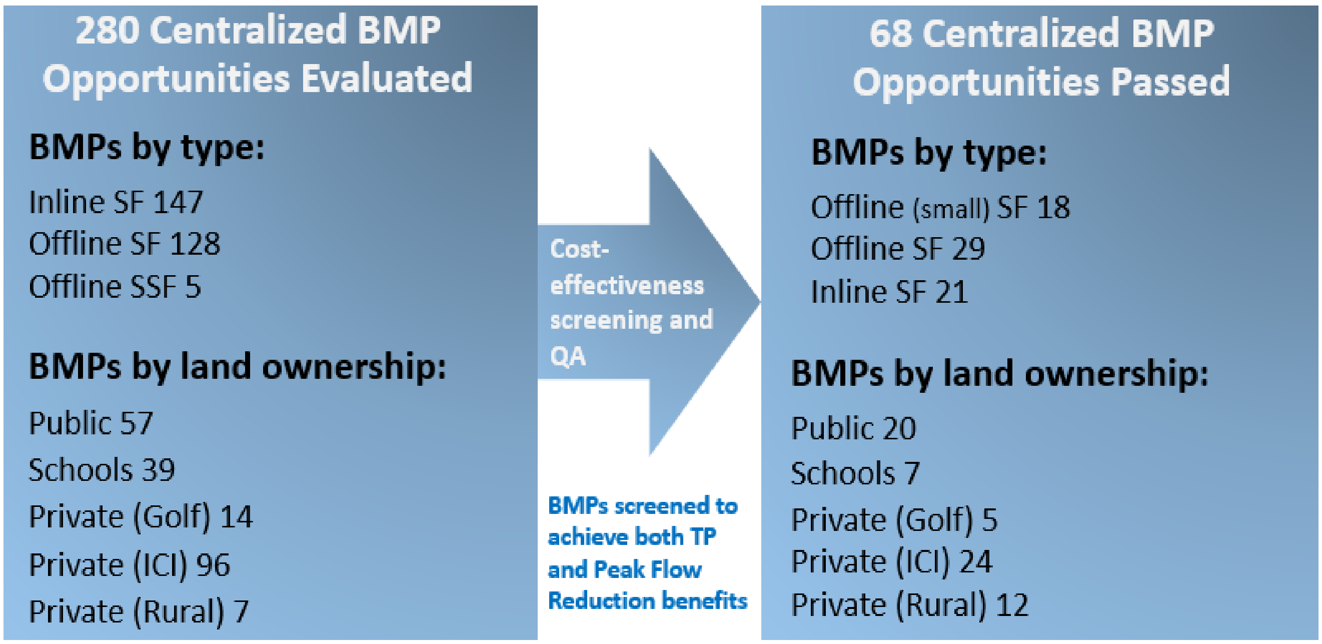

Figure 3-9: Opportunities screening of centralized SCMs (SF=surface feature / SSF=sub-surface feature)

4. Study Findings

The discussion of the System-wide SWM study findings has been organized around the three study principles.

4.1. Principle #1:

Using an optimization methodology for stormwater planning will significantly expand the scope and depth of SCM evaluation, enabling the development more efficient SWM strategies.

A watershed-scale decision support framework based on cost optimization enables targeting of watershed-scale investments to manage stormwater and achieve water quality goals. The innovative, tiered optimization approach utilized by SUSTAIN enabled the evaluation of the SCM cost-effectiveness in the East Holland watershed. The outputs from the Future State model provide the first detailed economic feasibility assessment of achieving phosphorus reduction targets in the East Holland watershed.

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The Future State optimization methodology was used to create a watershed-wide strategy to reduce phosphorus loading from East Holland River into Lake Simcoe (Figure 4-1). Strategy development began with the TP objective and flood analysis was integrated during the opportunity screening and by evaluating the flood reduction co-benefits that would be achieved by the SCMs selected for phosphorus reduction. Opportunities on public and private property are included in Figure 4-1. Inline centralized SMCs, which are adjacent to streams and rivers and treat streamflow, are the most cost effective, with parking lots and green streets providing substantial opportunities for phosphorus reduction. To achieve phosphorus reduction above 45% is significantly more costly. All of the reduction is achieved by managing runoff (inline facilities do not treat baseflow).

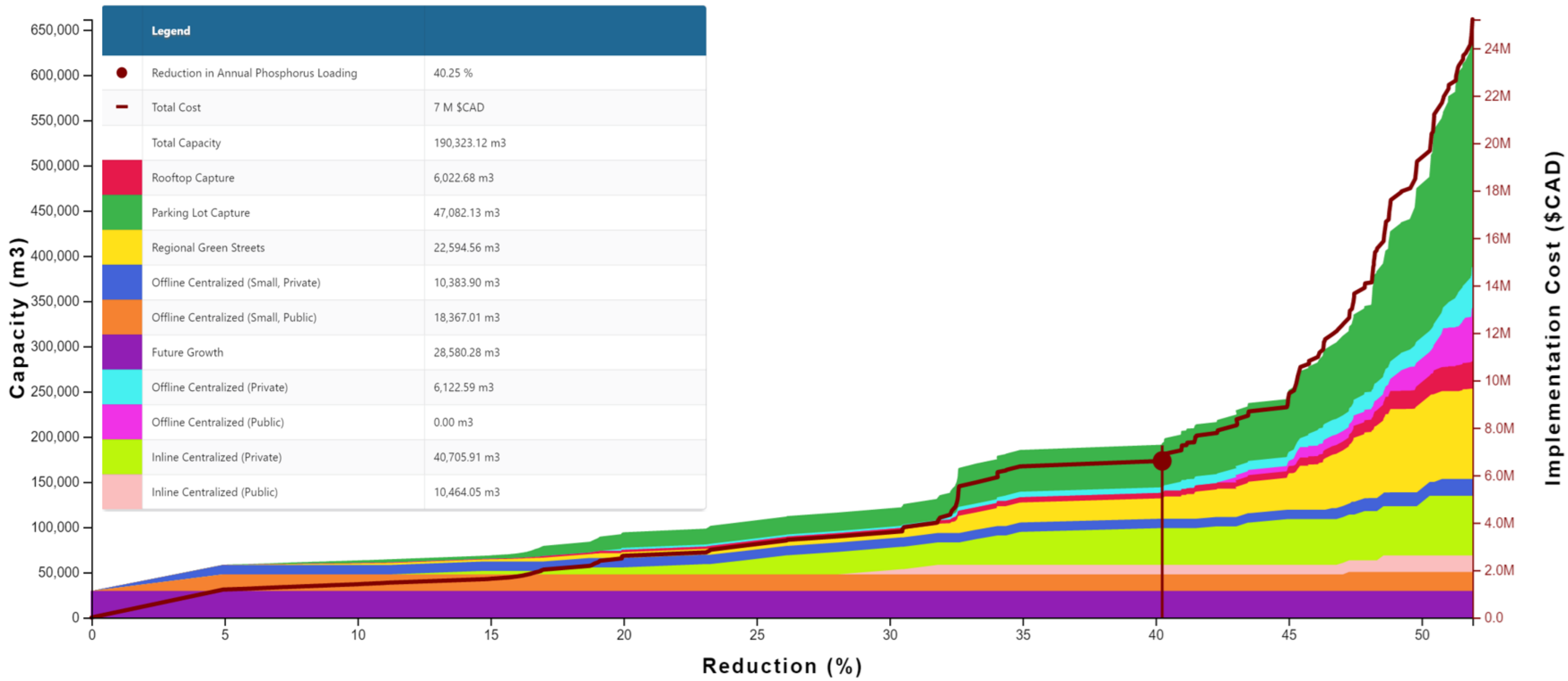

Figure 4-1: Phosphorus reduction strategy at the East Holland Landing (Costs annualized over 30-years)

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The jurisdiction-by-jurisdiction implementation strategy for attaining 40% reduction at East Holland Landing is shown in Figure 4-2, organized by SCM type. The output in Figure 4-2 assumes basin-wide coordination, and no constraints to force individual jurisdictions to achieve individualized reduction targets, instead the optimization was allowed to site SCMs based on cost-effectiveness and without jurisdictional or public land siting constraints. In addition, this output includes cost and capacity 'sharing' for jurisdictions that drain into centralized SCMs – for example, much of the centralized SCM capacity shown for Whitchurch-Stouffville, which is in the upstream portion of the watershed, is actually located downstream but a portion of the cost and capacity of the downstream SCMs is still allocated to Whitchurch-Stouffville.

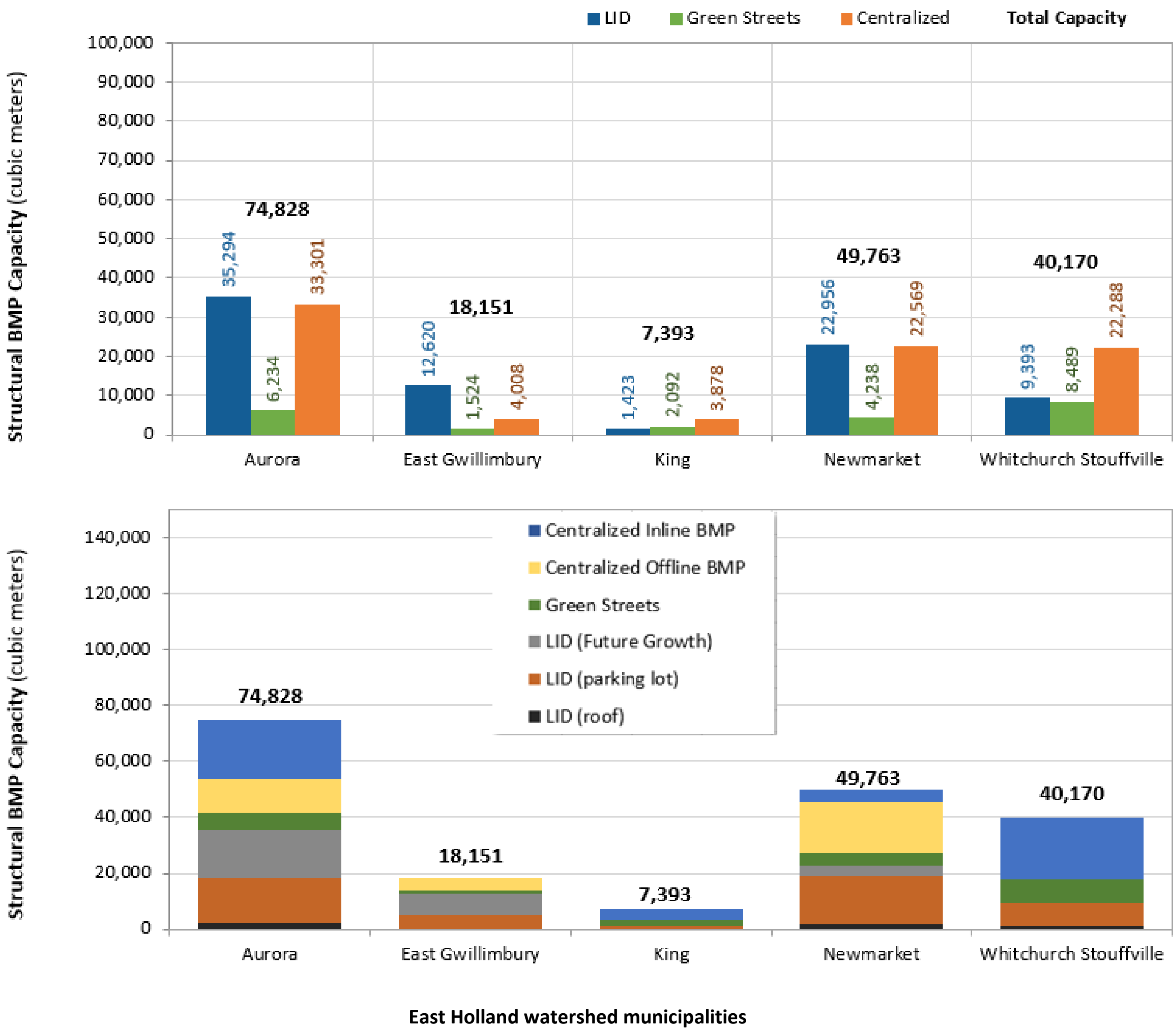

Figure 4-2: Cost Optimization Strategy - Summary of type and size of SCMs implemented on a watershed-wide basis and considering both public and private site opportunities to achieve a 40% phosphorus load reduction at Holland Landing

4.2. Principle #2

Siting SWM SCMs on private properties (vs municipal-owned properties only) will provide improved performance at greater cost-efficiency.

The implementation strategy presented for East Holland landing includes distributed and centralized SCMs that are sited on private land. The findings show that if, in addition to evaluating municipal public parcels for siting SWM infrastructure, suitable privately-owned parcels were also considered, then implementation targets could be achieved at greater cost-efficiency than by the current system of exclusively considering only municipal public parcels. And more importantly, it is unclear that reduction targets could be achieved with SCMs on public land only, which provide opportunities on parcels owned by municipalities and schoolboards.[3]

There are insufficient opportunities for SCMs on public land in the East Holland watershed to meet the 40% phosphorus reduction target (Figure 1-11). The maximum achievable phosphorus reduction using only public lands to site SCMs is 14.8% at an annual cost of $13-million. Including private property for the same 20.5% reduction, would cost $2-million, a savings of $11-million annually.

[3] The inclusion of schools for East Holland represents a strategy beyond 'business as usual' as schools are not normally evaluated as a straight-forward option for siting SCMs.

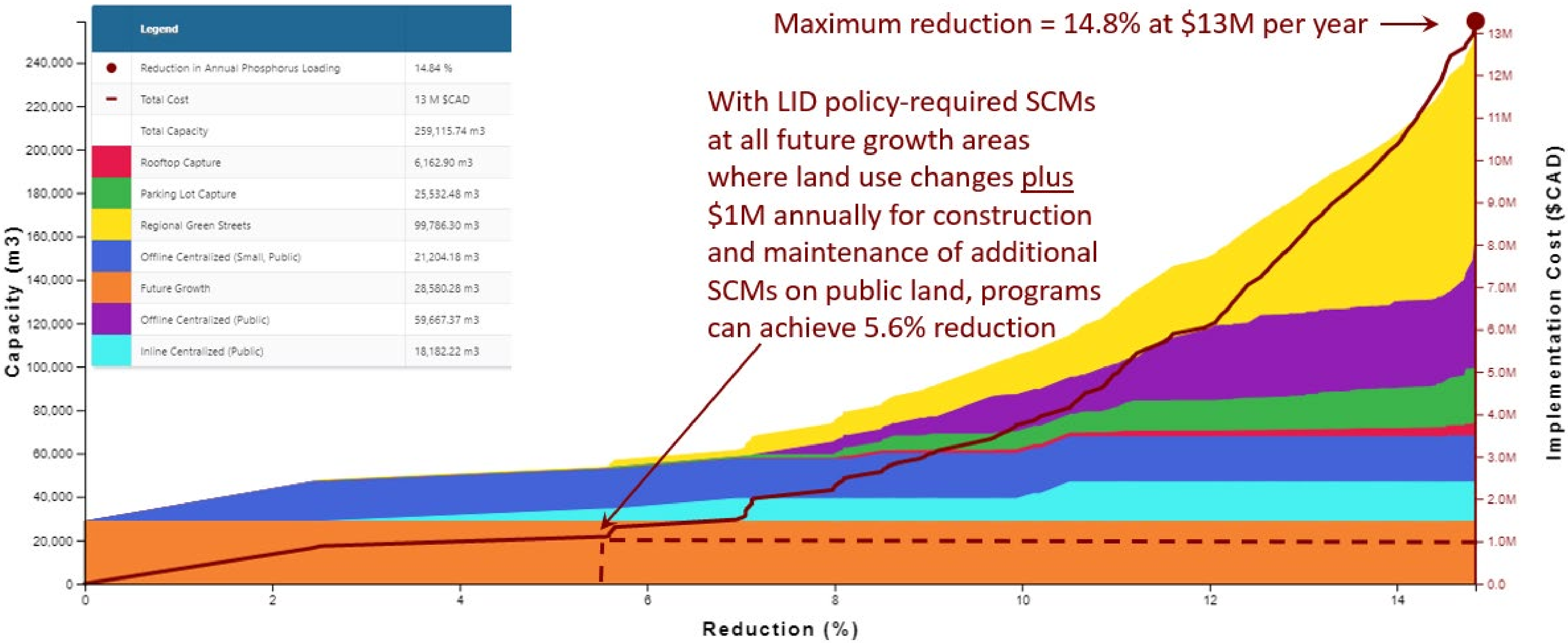

Figure 4-3: Phosphorus Reduction Strategy at the East Holland Landing - opportunities to site SCMs on publicly-owned land only (costs annualized over 30 years)

4.3. Principle #3

Planning and managing stormwater using a watershed-wide framework will provide improved performance at greater cost-efficiency as compared with municipal-scale planning.

Municipal collaboration for watershed-wide implementation of a SWM strategy would result in a 28% cost savings and 30% reduction in SCM capacity requirements (Figure 4-4). Conversely, implementation of a SWM strategy on an individual municipal-basis may be significantly more costly for the following reasons:

Municipalities are unable to leverage cross-boundary opportunities and must use less cost-effective, local opportunities in order to achieve phosphorus reductions.

Costs for centralized SCMs are allocated to the jurisdiction where the SCM footprint is located, even if those SCMs are reducing pollutants that originated in other jurisdictions.

Simulated approach is 'best case scenario' for jurisdictional-based approach, because the centralized SCMs are based on the optimal watershed-wide 40% solution.

If municipalities did not collaborate on centralized SCMs, the % difference cost would be much larger.

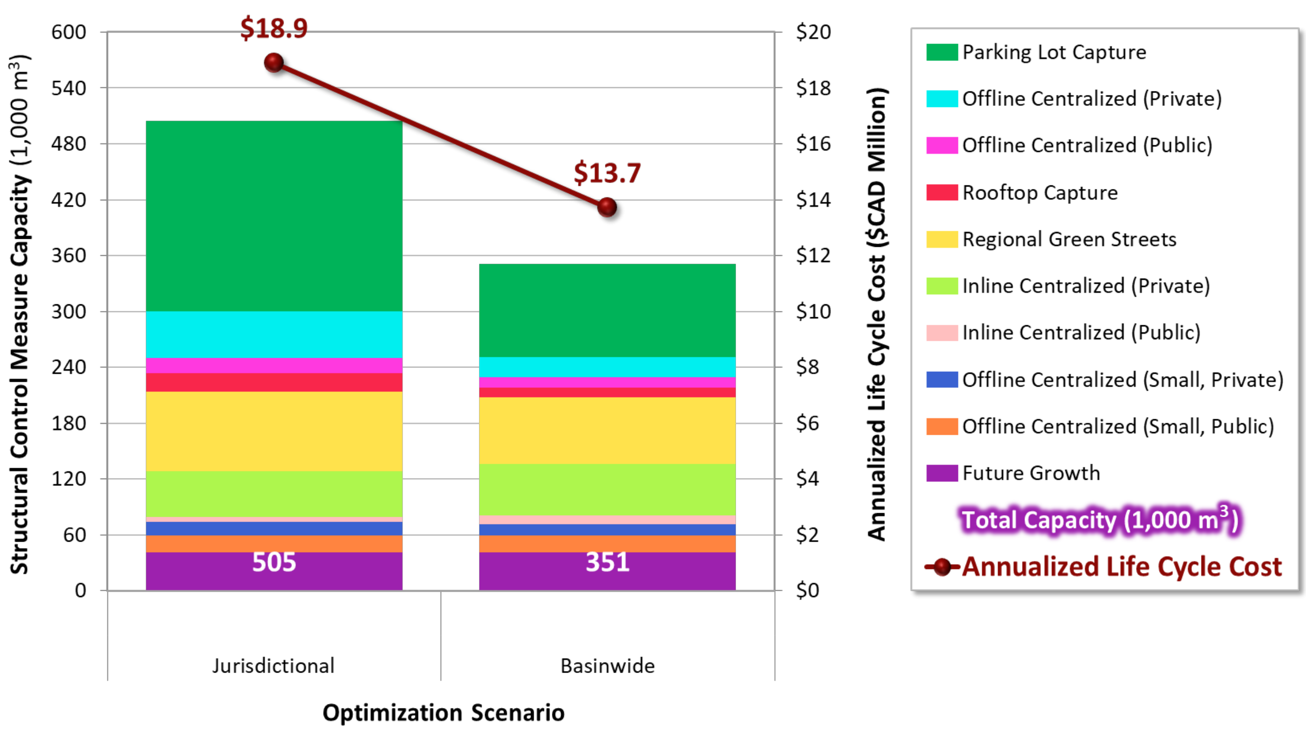

Figure 4-4: Optimized jurisdictional versus watershed-wide strategy for 40% phosphorus reduction

4.4. Climate change

The benefits of employing system based SWM and associated SCMs under future climate scenarios were simulated via SUSTAIN. Rainfall Intensity Duration Frequency (IDF) curves under climate change scenarios were used to simulate future "design storms". An IDF curve is a mathematical function that relates the rainfall intensity with its duration and frequency of occurrence and are developed using local historical rainfall time series data.

Two climate future pathways – RCP 8.5 and RCP 4.5 – were used for the simulations. RCPs (Representation concentration Pathways) are scenarios that describe different trajectories of Carbon Dioxide (CO_2) gas concentration in the atmosphere from the years 2000 to 2100. The RCP 8.5 pathway is the worst-case scenario wherein CO_2 emissions are not mitigated and would result in a global temperature increase of 2.6°C to 4.8°C by 2100 (relative to pre-industrial temperatures). The RCP 4.5 pathway is a moderate scenario wherein Green House Gas (GHG) emissions peak at 2040 and then decline translating to a projected global temperature increase of 1.1°C to 2.6°C by 2100.[7,8]

Climate change increased peak flows for a 10-year storm event under both RCP 4.5 and 8.5 scenario were mitigated 100% by the SCMs in all but two areas of the watershed. For the 100-year design storm, SCMs reduced peak flows by 23% and 31% under RCP 4.5 and 8.5 scenarios, respectively.

4.5. Flood reduction

A total of six flood-prone areas were identified in the East Holland watershed with potential for flood damage to structures located in the floodplain (see Figure 4-5).[4] Flooding strategies were integrated with water quality strategies during both the opportunity screening (by emphasizing centralized project opportunities that provide both flood reduction and water quality benefits[5]) and by evaluating the flood reduction co-benefits that would be achieved by the SCMs selected to achieve phosphorus reduction targets.

As expected, the benefits of SCMs for flood mitigation are reduced as the design storms become larger. The maximum peak flow reduction achieved for the 10-year storm was 23.09% compared to 14.85% for the 100-year storm. These peak flow reductions are considered relatively large for such large storms – many flood control engineers are generally under the impression that water quality SCMs are unable to significantly mitigate flood storms, even at the 10-year level (20mm of rainfall in 12-hours).

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[4] Other flood-prone areas (not analyzed further) were either nuisance flooding away from waterways or there were no structures identified near the floodplain would be damaged during 100-year events.

[5] When centralized SCM opportunities were screened, centralized SCMs that would achieve both water quality and flood reduction targets were carried forward. With this approach, the flooding and water quality outcomes were integrated during model configuration and optimization.

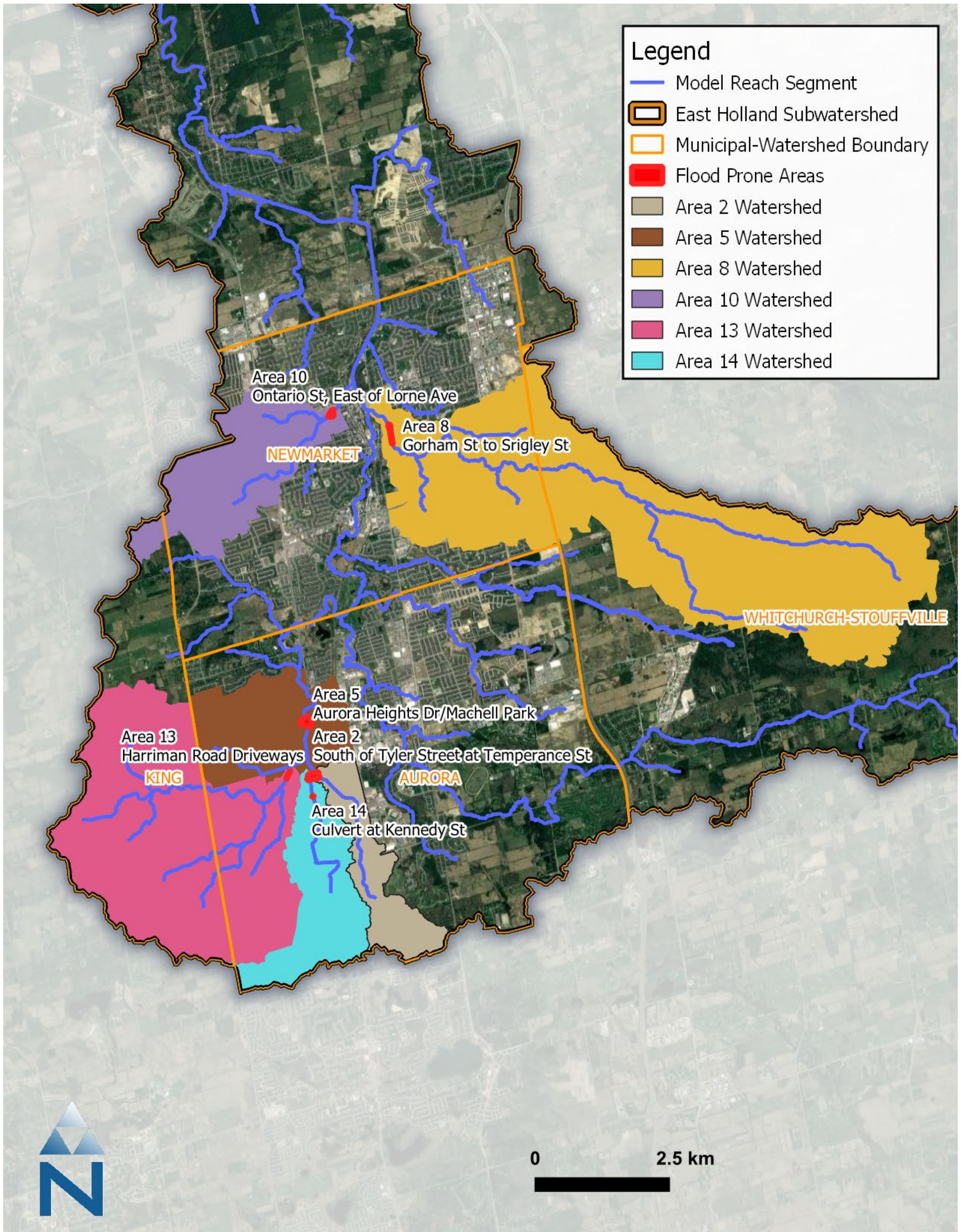

Figure 4-5: Assessed flood-prone areas of the East Holland watershed.

4.6. Co-benefits

A qualitative evaluation co-benefits produced by selected SCMs was undertaken to understand the potential value (environmental, social and economic) of individual management actions. There is no accepted standard for assessing the value of co-benefits. The qualitative analysis relied on leading jurisdictions research, an extensive literature review, including peer-refereed journals and reports from recognized government agencies, research and academic organizations and subject experts from project partner organizations and consultants. A rating scale (Table 4-1) of 0.0 to 1.0 – where '0.0' is very low and '1.0' is very high – is used to reflect the level of potential or capacity of a SCM to provide a specified benefit, such as improved air quality, increased biodiversity or enhanced property values.

The ratings developed in this exercise were used to qualitatively evaluate the co-benefits realized under the Principle 2 base case (i.e., current practice of using only available public lands with a municipality to host, primarily centralized SCMs and limited distributed SCMs), as compared with the Principle 2 optimal case (i.e., proposed practice of evaluating both publicly-owned and privately-owned lands to select optimal sites to host a combination of distributed and centralized SCMs. The average co-benefit ratings are interpreted as weights applied to each scenario to measure relative overall performance with respect to co-benefits (Table 4-2). Assuming that co-benefits generated by an SCM are proportional to its size, capacities of each type of SCM are used as a proxy measures of co-benefit performance. Cost and P-reduction are both assumed to have a weight of 1.0. A summary description of the co-benefits for the representative SCMs and for those targeted for future scenario analysis are provided in Appendix 4 of the full study technical report.

Table 4-1: Qualitative rating of co-benefits for representative SMC

Rating*	Co-benefit Capacity or Potential
0	**Very low potential or capacity to provide the co-benefit**
¼	**Limited or mediocre potential or capacity to provide the co-benefit**
½	**Medium or reasonable potential or capacity to provide the co-benefit**
¾	**High potential or capacity to provide the co-benefit**
1	**Very high potential to provide the co-benefit**

* Qualitative rating based on the capacity of a SCM to provide co-benefits

Table 4-2: Qualitative rating of co-benefits for representative SCMs

Stormwater Control Measure		Co-Benefits														
		Bio-diversity	Habitat for species	Supports pollinators	Groundwater recharge & base flow	Erosion control	CO_2 sequestration & storage	Air quality Improve-ment	Drinking source water quality	Reduced Heat Stress	Energy savings	Improved aesthetics	Increased recreational opportunities	Increased Property Value	Reduced demand on infrastructure	Average rating
Decentralized	Bioretention	½	½	½	¾	¾	¾	½	¾	½	½	¾	½	½	½	**0.59**
	Infiltration trench / chamber	**0**	**0**	**0**	**1**	½	¼	¼	½	¼	¼	¼	**0**	**0**	¼	**0.25**
	Enhanced boulevard tree cell	½	½	½	¾	½	¾	¾	½	¾	½	¾	¼	½	½	**0.57**
Centralized	Hybrid wetland /pond	¾	¾	¾	**1**	**1**	¾	½	**1**	¾	½	**1**	¾	¾	**1**	**0.80**

5. Considerations and Implications

The optimization and economic analyses generated results with implications for multiple facets of SWM at both a local- and a macro-scale. Taken collectively, the stormwater planning and management practices set out in the study principles represents a new SWM framework – one that facilitates whole-system, basin-wide SWM integrating existing stormwater infrastructure with new centralized and distributed SCMs on public and private lands. The implications of System-wide SWM present both challenges and opportunities at local, provincial and federal levels.

5.1. Local context – East Holland Watershed

In terms of the East Holland watershed, the most cost-effective strategy to meet water quality targets and mitigate the future combined impacts of expanding urbanization and increasing climate variability entails implementing distributed and centralized SCMs on both public and private land at a watershed-wide scale vs the current individual municipal approach.

Given the extent and scope of factors influencing stormwater runoff throughout the watershed, an unequal distribution (on a jurisdictional basis) of preferred sites for representative SCMs was an anticipated outcome of the watershed-wide optimization analysis. The concept of equitable responsibility is based on an understanding of this expected outcome and a recognition that watershed resident municipalities benefit equally from cost-effective whole-system SWM. There are implications in taking such an approach in the East Holland but, the opportunities for innovation; alternative financing; market and economic development; substantial cost-savings; improved water and air quality; reduced erosion and flooding; higher property values with a corresponding increase in tax revenue; greater biodiversity and habitats for native flora and fauna, including pollinator species, enhanced carbon sequestration; reduced Urban Heat Island effect; and more livable and enticing communities are truly game-changing for municipalities in the East Holland watershed and throughout the remainder of the Lake Simcoe basin. Equitable cost sharing is an ultimate strategy for collective efficiency, but for the purposes of clarity and relevance, costs generated by SUSTAIN are presented with a municipal budgeting perspective.

The underlying calculation of the SCM costs allows their breakdown into capital costs and Operation and Maintenance (O&M), relevant to different municipal departments. These costs are provided by municipality in Table 4-2. The costs presented in Table 4-2 are based on watershed-wide implementation approach assessed East Holland Landing. This is in contrast to Figure 4-4 which used the mouth of East Holland River in order to capture all municipalities within the East Holland River watershed to properly compare jurisdictional vs watershed-wide approaches.

Table 5-1: Breakdown of project costs by jurisdiction (total annualized costs $1,000s)

Community	Annualized Capital Cost	Annual OM Cost	Total Annual Life Cycle Cost
King	$261	$99	$360
East Gwillimbury	$426	$229	$655
Whitchurch–Stouffville	$1,152	$447	$1,600
Newmarket	$1,178	$546	$1,725
Aurora	$1,465	$683	$2,149
TOTAL	**$4,482**	**$2,005**	**$6,489**

5.2. Overall context

In Canada, the principal frontline responsibility for SWM resides with municipalities, but watershed authorities/agencies also have local-level responsibilities for stormwater planning and management. Provinces and territories are the level of government with primary oversight of water resources and review and approval of municipal SWM plans and capital projects resides with the province. The federal government's role in water resource management is limited to fisheries and international boundary waters (e.g., The Great Lakes), however, federal funding initiatives provide critical support for planning and capital projects for SWM.

Transitioning to System-wide SWM has implications for Governance and Policy, Finance and Administration and Operations at the local, provincial and federal levels. A detailed discussion of the implications by study principle is provided in the full technical report.

5.2.1. Intermunicipal Collaboration

Inter-municipal collaboration (IMC) frameworks and supporting policies exist at both the municipal and provincial level. Municipalities have collaboration agreements in place for emergency and public health services, water supply and wastewater treatment, transit and other areas where cooperation is advantageous. At the provincial level in Canada, there are no impediments to inter-municipal collaboration and, in the case of Alberta, intermunicipal collaboration frameworks are specified in legislation (Municipal Government Act – part 17.2) to provide for integrated and strategy planning delivery and funding of intermunicipal services. IMCs are more commonly used by local jurisdictions in the United States and Europe with the rationale that they provide a logical approach to the planning, construction and management of shared infrastructure, reduce unit costs and enable economy of scale, strengthen resource capacity and attract to external investments/funding by improving cost-benefit ratios of projects. [9,10]

5.2.2. SCMs on Private Property

Securing private property hosting of centralized and distributed SCMs on private property will require the progressive use of market-based financial instruments. Payment for Ecological Services, leasing arrangements, local Public-Private Partnerships (P3s), financial and non-financial incentives, fee credits or rebates, property tax reductions, district financing, grants, low or no interest financing, reverse auctions and other mechanisms to drive uptake of SCMs on private commercial, industrial and residential properties. The use of market-based instruments by Canadian municipalities is limited. One-time payments for disconnecting downspouts in older areas with combined stormwater and wastewater sewers and rebates on stormwater fees for landowners who implement SCMs on their properties are the two most common incentive mechanisms used by municipalities in Canada. The uptake rates for such incentives are low, typically below 6%.

Other jurisdictions, particularly in the US, have implemented more progressive incentive programs to motivate private property uptake of SCMs with good success. Philadelphia, PA; New York City, NY; Seattle, WA; Portland, OR; Grand Rapid, MI; and Montgomery County, ME. Common elements of all these programs are, clearly defined goals based on watershed needs; strategic targeting of incentives, strategy development based on robust cost-benefit analysis; strong political support; defined goals tailored to incentives, adequate incentives to secure cost-effective uptake; and programs tailored to property type (e.g., residential, commercial, industrial, etc.). Public energy utilities in Canada have been equally progressive in utilizing market based financial instruments to target private property owner uptake of energy conservation and alternative energy technologies. The leading jurisdictions' and energy sector incentive programs provide a basis for municipalities to formulate tailored strategies.

Developing and implementing SWM strategies targeting private property uptake of SCMs through the use of market based financial instruments has significant implications for municipalities in the East Holland watershed and across Canada but there are a significant Return of Investment (ROI) and multiple benefits to be realized.

5.3. Summary

A watershed model and decision support system were developed for the East Holland River watershed to evaluate strategies to manage stormwater based on their impact on watershed processes and their cost-effectiveness. The identified strategies represent a shift away from the business-as-usual approach of municipalities building mostly large, centralized SCMs on public property. A combination of distributed LID and centralized SCMs (green and grey infrastructure), implemented on a watershed-wide basis on both public and private property provides the most cost-effective approach. A summary of the key findings is provided in Table 5-1. The strategy provides several other co-benefits including local economic stimulus, flood mitigation, climate change resiliency, increased property values, and support for biodiversity.

Table 5-2: Key study findings comparing the current SWM practice with System-wide SWM

Current SWM Practice	System-wide SWM
Primarily centralized SCMs located on available publicly owned lands (excludes private property) with limited use of distributed SCMs.	**Watershed-wide, integration of centralized and distributed SCMs located on viable publicly owned and privately-owned lands**
• Cannot meet, at any cost, the water quality target (40% P-load reduction). • 15% maximum achievable P-load reduction. • \$13-million annual cost to achieve 15% P-load reduction.	• Meets the water quality target (40% P-load reduction). • 40% P-load reduction achieved. • \$2.6-million annual cost to achieve the same 15% P-load reduction (an annual savings of \$10.4million).
Jurisdictional based (planning and management of stormwater based on the political boundaries of individual municipalities)	**Integrated, watershed-wide (collaborative approach to stormwater planning and management unrestrained by political boundaries)**
• \$18.9-million annualized life-cycle cost to achieve 40% P-load target.	• \$13.7-million annualized life-cycle cost to achieve 40% P-load reduction target. • 28% cost savings and 30% lower SCM capacity requirement

The study examined three principles that are the basis for integrated, system-based planning and management of stormwater, that collectively provide future-ready SWM capacity. Applying the three principles of System-wide SWM will enable municipalities to collectively build sustainable and resilient communities:

Optimization modelling provides a more detailed understanding of watershed processes and expands the scope and depth of evaluation of SCMs to determine a cost-efficient SWM management strategy.

In addition to public property, including viable private property as potential sites for hosting SCMs enabled target phosphorus reductions to be achieved at a significantly lower cost. The current and typical practice of restricting siting of SCMs on public property came at a higher cost and failed to meet water quality targets.

Implementing integrated stormwater planning and management on a watershed-scale, not restricted by political boundaries provides optimal SWM at the greatest cost-efficiency, a more equitable and viable system and ensures more robust SWM capacity providing greater resiliency in the face of rapid urbanization and increasing climate variability.

5.4. Recommendations

The results of the study provide the business case - economic, environmental and social/community-well being – for municipalities and local watershed authorities to collaborate on the development and implementation of the next generation in stormwater management and planning, System-wide SWM. Achieving this new, watershed-scale SWM paradigm will involve a re-tooling of current practices within municipalities and watershed authorities/agencies. As with any re-invention, there will be challenges, but the potential benefits far outweigh the costs of following the current SWM trajectory. The recommendations discussed below are informed by the study findings including the economic analyses, market and leading jurisdictions research, and extensive literature review that accompanies the optimization analysis.

5.4.1. Recommendations – Lake Simcoe Region

To follow are the primary recommendations for establishing System-wide SWM in Lake Simcoe region:

Establish a senior-level working group, possibly an extension of the existing study Technical Advisory Committee (TAC), to develop a work plan and strategy for the implementation of System-wide SWM. The working group will direct research and evaluation into constraints and opportunities, options, mechanisms, tools and approaches for the efficient transition to System-wide SWM, including but not limited to *governance and policy*, *finance and administration*, and *operations* associated with:

- harmonization of methodologies and data for optimization and integration of SWM plans and practices;
- inter-municipal/inter-agency collaboration;

- private property hosting of SCMs and uptake of non-structural SCM practices (e.g., no-till farming and cover crops in agriculture);
- targeted pilot / living laboratory studies; and,
- outreach and engagement.

1) Meet with municipal councils and senior municipal staff to discuss and explore opportunities intra-departmental and/or inter-municipal coordination for SWM (e.g., parks departments implementing sustainable landscaping practices; finance departments establishing TBL analysis requirements and templates for infrastructure projects; transportation departments identifying ROW opportunities, etc.)
2) Meet with senior representatives of the Chippewa of Georgina Island First Nation to discuss the study findings and explore opportunities for collaboration.
3) Meet with area agricultural organizations and other key agricultural stakeholders to discuss the study findings and explore opportunities for collaboration, specifically, the opportunity to test a PES process to secure uptake of structural and non-structural SCMs by farm-owners.
4) Identify strategic partnership opportunities for targeted pilot / living laboratory studies to evaluate and adapt processes and practices.
5) Develop guidance and training materials and tools to support area municipalities in the use of optimization analysis for SWM planning.
6) Develop a mechanism for identifying opportunities throughout the watershed to twin planned public and private sector projects for greater cost-efficiency (e.g., planned golf course with engineered wetland, new/major renovation of a public building with a green roof, etc.).

5.4.2. Recommendations for additional analysis

Given the potential and implications of a new municipal SWM framework for the East Holland, the Lake Simcoe-basin and nationally, additional analyses (optimization and economic) are recommended as follows:

1) Evaluate the application of System-wide SWM principles, Lake Simcoe-wide to determine the impact of scale and expanded distribution and enhanced integration of SCMs on performance and costs.
2) Evaluate integrating the use of non-structural SCMs and natural assets as integral parts of the SWM system. Based on the significance of the study findings, specifically improved SWM capacity at greater cost-efficiency, integrating structural practices with non-structural measures (e.g., planting cover crops and no-till farming, integrated pest management on agricultural lands and xeriscaping on public lands) and natural assets could further increase cost-efficiency and SWM system performance.
3) Evaluate remaining SCMs identified in the menu of management measures (see full study report - Appendix 3).

4) Expand evaluation of climate change scenarios and flood mitigation considerations.
5) Evaluate the impact of incorporating of other source control strategies and programs, such as enhanced street sweeping, residential tree planting programs, etc.
6) The strategy at the outlet to Lake Simcoe essentially 'overbuilds' urban SCMs to make up for the untreated loading from the agricultural areas in the lower part of the watershed. To reflect a more feasible and integrated strategy for the agricultural areas, a more detailed analysis of SCM opportunities for managing phosphorus loading from the lower, agricultural area of the watershed is needed, which would likely also entail source control strategies to reduce phosphorus yields rather than solely relying on SCMs. This analysis should incorporate an assessment of non-structural measures on agricultural lands (recommendation #2).
7) A detailed assessment of co-benefits associated with a selected SWM strategy, including a quantitative analysis where established economic values and valuation methodologies exist, will provide a more complete understanding of the added environmental, social and economic value of System-SWM.
8) An assessment of all or some of the components of System-wide SWM, as defined by the study principles, to help achieve climate change adaption objectives. Municipalities in the East Holland watershed and across Canada are developing climate change adaptation plans, assessing where there are risks and vulnerabilities and determining ways and means of adapting and increasing resiliency of the built environment.

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[1] Lui, J; Sample, D.J.; Bell, C; and Guan, Y; *Review and Research Needs of Bioretention Used for the Treatment of Urban Stormwater*; Water (Special edition entitled "Sustainable Drainage Systems"); July 2014. https://www.mdpi.com/2073-4441/6/4/1069

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