Equitable Responsibility for Transformative Design:

A systems-based approach to stormwater management

Lake Simcoe Region conservation authority

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This report was prepared by the Lake Simcoe Region Conservation Authority (LSRCA) in collaboration with all project team members. LSRCA is member of the Sustainable Technologies Evaluation Program (STEP). Documents prepared in collaboration with STEP are available at www.sustainabletechnologies.ca.

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The Sustainable Technologies Evaluation Program
The water component of the Sustainable Technologies Evaluation Program (STEP) is a partnership between Toronto and Region Conservation Authority (TRCA), Credit Valley Conservation and Lake Simcoe Region Conservation Authority. STEP supports broader implementation of sustainable technologies and practices within a Canadian context by:

- Carrying out research, monitoring and evaluation of clean water and low carbon technologies;
- Assessing technology implementation barriers and opportunities;
- Developing supporting tools, guidelines and policies;
- Delivering education and training programs;
- Advocating for effective sustainable technologies; and
- Collaborating with academic and industry partners through our Living Labs and other initiatives.

Technologies evaluated under STEP are not limited to physical devices or products; they may also include preventative measures, implementation protocols, alternative urban site designs, and other innovative practices that help create more sustainable and liveable communities.

We forget that the water cycle and the life cycle are one.

Jaques Yves Cousteau

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1.0 Executive Summary

The study, *Equitable Responsibility for Transformative Design: A systems-based approach to stormwater management (SWM)*, was formulated to evaluate alternative strategies for cost-effective SWM.

The study, heretofore referred to as the *System-wide SWM study*, was motivated by a recognition that an alternative SWM paradigm is needed to meet the growing challenges posed by inadequate stormwater infrastructure capacity, budgetary constraints, rapid development and a changing climate.

The study tested the hypothesis that improved environmental outcomes can be realized at lower capital and operating costs via a watershed-scale approach that includes siting centralized and distributed infrastructure on both publicly-owned and privately-owned properties.

1.1. Introduction

A historic legacy of poor planning and stormwater management (SWM) combined with rapidly changing land use and aging stormwater infrastructure has led to impaired water quality, flooding and erosion and compromised hydrology in urban and peri-urban watersheds throughout Canada.

Municipalities own most of the stormwater infrastructure in this country and have primary frontline responsibility for SWM within their boundaries. Although municipalities are evolving the way they plan and manage stormwater within their municipal-boundaries, conventional, end-of-pipe SWM infrastructure remains the dominant form of stormwater control. Conventional stormwater infrastructure, which emphasizes channeling of runoff away from developed areas, is typically employed on a 'one-off' basis (e.g., a SWM pond to capture runoff from a new development or to manage intermittent riverine flooding along a stream segment). Given rapidly changing land use and increasing climate variability, a holistic and integrated approach to planning and managing stormwater is now understood to provide enhanced SWM capacity. No longer, is conventional SWM alone sufficient to address expanding urbanization and the increasing frequency and severity of climate change driven storm events.

Improved understanding of hydrology and the complex interaction between meteorology and land surfaces, has led more municipalities to implement integrated SWM planning, employing a treatment train approach which emphasizes, in order of priority, managing stormwater where it lands (i.e., at the lot-level,), via conveyance (e.g., exfiltration pipe or sequenced SWM facilities) and end-of-pipe (i.e., centralized facilities). At its best, integrated SWM planning employs;

1) distributed nature-based technologies or Low Impact Development (LID);
2) natural assets (i.e., consideration and evaluation of existing natural areas such as forests and wetlands as functional infrastructure within the SWM system);
3) non-structural measures (e.g., no-till farming and cover crops in agriculture, integrated pest management at public facilities, etc.);
4) conveyance measures (infiltration/detainment and transport to end-of-pipe); and,
5) centralized green and grey infrastructure (e.g., constructed wetlands, dry ponds, etc.) as a holistically functioning system. Still, the focus remains on municipal boundary-based stormwater planning and management and the use of conventional, end-of-pipe infrastructure.

The current management framework is insufficient to address the costly and complex challenges of inadequate SWM capacity, aging assets, expanding urbanization and increasing climate variability. Transitioning to a new stormwater paradigm, 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.

1.2. Study purpose

The System-wide SWM study examines the use of scale (municipal vs watershed), and integration and aggregation (municipal public property only vs public and private property) to achieve optimal system performance at the greatest cost-efficiency.

1.3. Study context and description

The study evolved from research by key partner organizations and other municipal stakeholders into barriers to integrated, watershed-scale stormwater planning and management in Canada and leading jurisdiction best SWM practices. The study design was further informed by findings of several important water quality and hydrology monitoring and modelling efforts undertaken by the Lake Simcoe Region Conservation Authority (LSRCA) for the East Holland watershed pointing to the limits of the current approach to SWM.

The study was undertaken in the East Holland River watershed, located in the Lake Simcoe Basin in Ontario, Canada (Figure 1-1). The East Holland is one of the fastest developing watersheds in the country and is experiencing declining water quality and impaired hydrology. Conditions in the East Holland reflect those typically found in urban and peri-urban watersheds across Canada and globally. Watershed resident municipalities – the towns of Aurora, East Gwillimbury, Newmarket, and Whitchurch-Stouffville – face the same challenges of constrained budgets, insufficient SWM capacity, rapid urbanization, and increasing climate variability as other municipalities in developed and developing watersheds.

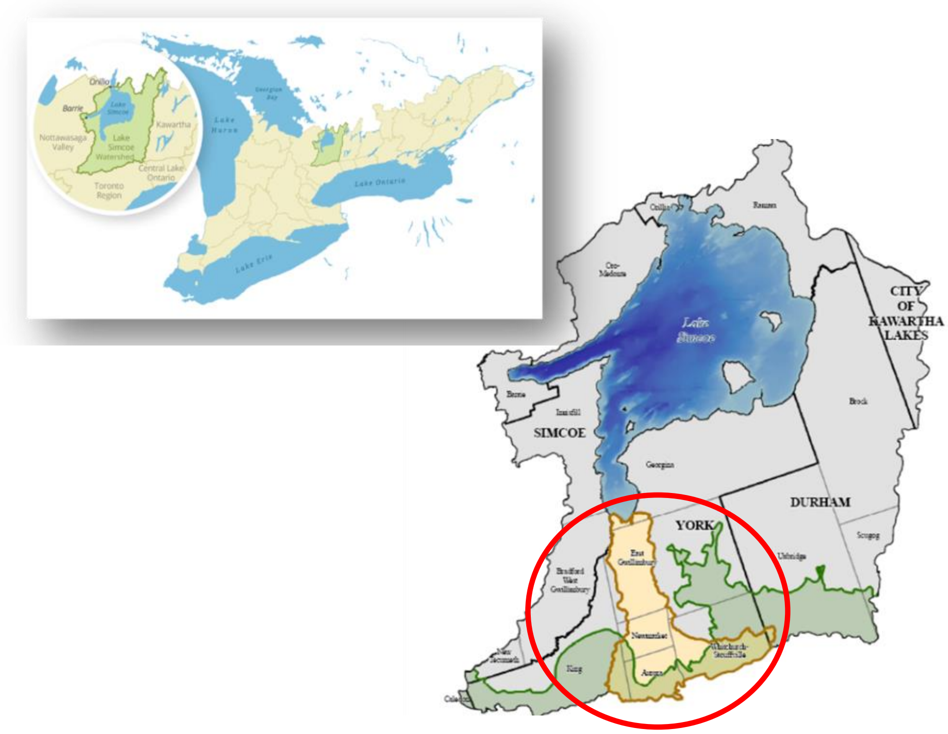

Figure 1-1: Location of the Study Area - East Holland River watershed, Ontario Canada

1.3.1. Municipal context

The conventional approach to stormwater planning in Canadian municipalities involves the development of SWM plans or master plans within the context of provincial and local policies. SWM plans are restricted in geographic scope to the municipal jurisdiction. In some older municipalities in Canada, where combined sewers are still in use, the master plan may address issues that cross over to wastewater management, but this is the extent of integration across the closely related sectors of water supply, and management of wastewater, stormwater and source waters.

There is growing recognition in the municipal sector, that a siloed approach to water management has significant limitations and places a substantial and growing burden on municipal resources. An integrated approach considers SWM from a watershed perspective where water quality impairment and flooding are recognized as related problems having potentially more effective and less costly shared solutions. Remedial measures are defined at a watershed-scale, crossing municipal boundaries where necessary. They are evaluated based on an accounting of all costs, public and private, and these costs are measured over the lifetime of each measure using a life cycle cost-efficiency analysis.

Using a system-wide based approach and integrated planning at the watershed-scale accounts for the entire water cycle—seasonal patterns, upstream vs. downstream contributions, rural and urban catchments, connections between overland flows, stream flows and ground water, and so on. This approach also considers longer-term changes in land use and climate and evaluates how these will impact water quality and quantities (run off and flooding) and evaluates potential management strategies to mitigate impacts.

1.3.2. Study area

The East Holland River watershed is located in the southern portion of the Lake Simcoe basin. The watershed is about 238.7 km^2 in size and encompasses seven local municipalities (See Table 1-1). The East Holland watershed was selected for the study as it is reflective of the conditions found in urbanizing watersheds across Canada, specifically:

- rapid growth and development with increasing density of urban cores;
- a mix of urban, suburban and rural agricultural lands;
- significant older urban areas built prior to SWM control that are subject to both riverine and sewer overflows during large precipitation events;
- impaired water quality in tributaries and Lake Simcoe due to non-point source pollution in runoff;
- significant portion of land throughout the watershed privately-owned and representing a mix of commercial, industrial, residential and agricultural land use types.
- municipalities facing significant demand on resources for upgrading, repairing and replacing aging SWM infrastructure and responding to increasing climate variability.

With seven resident municipalities and a large portion of privately-held property of different land use types, the East Holland provides the necessary elements to assess municipal versus watershed-wide approaches to SWM and evaluate viable privately-owned parcels in combination with public lands to host SCMs versus siting SCMs exclusively on public property.

1.3.3. 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 (DO) in Lake Simcoe (which equates to a phosphorus load to the lake from all sources of approximately 44 tonnes/year). This DO target represents a 40% phosphorus reduction, which was used for the System-wide SWM study.

1.3.4. 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 provides a more equitable approach for all watershed resident municipalities and constituents.

1.4. Study Methodology

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. A current state continuous simulation model (Loading Simulation Program in C++ or LSPC) was calibrated for the study watershed and linked to "SUSTAIN" (System for Urban Stormwater Treatment and Analysis), a process-based decision model developed by the US EPA that continuously simulates hundreds of thousands of future state SWM scenarios to generate cost-benefit curves. Figure 1-2 schematically represents the study methodology.

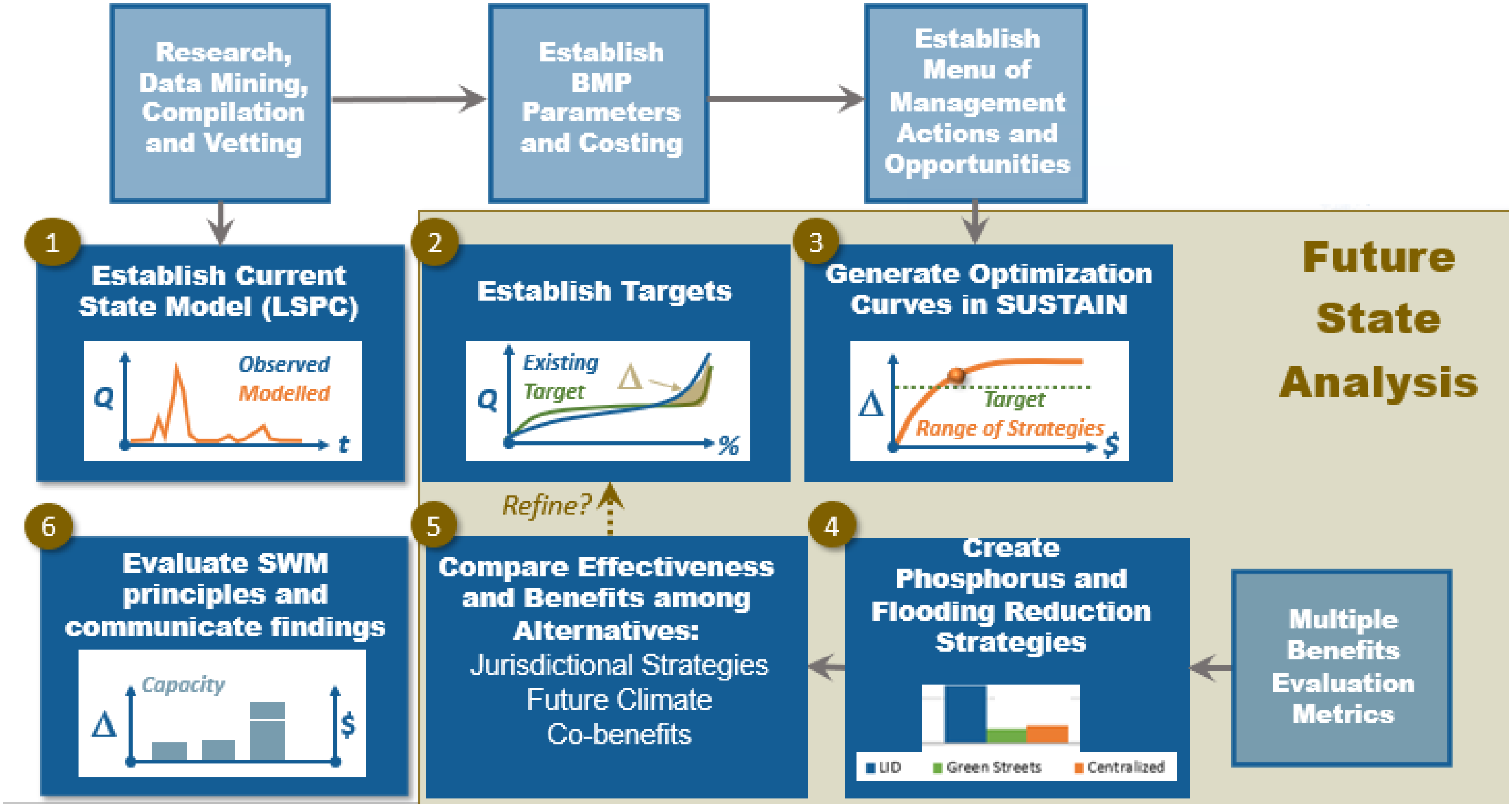

Figure 1-2: Overview methodology for the System-wide SWM study

1.4.1. Current State – LSPC model

For the LSPC modelling exercise, a top-down Weight of Evidence (WoE) methodology was applied and is illustrated in Figure 1.2 below. 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).

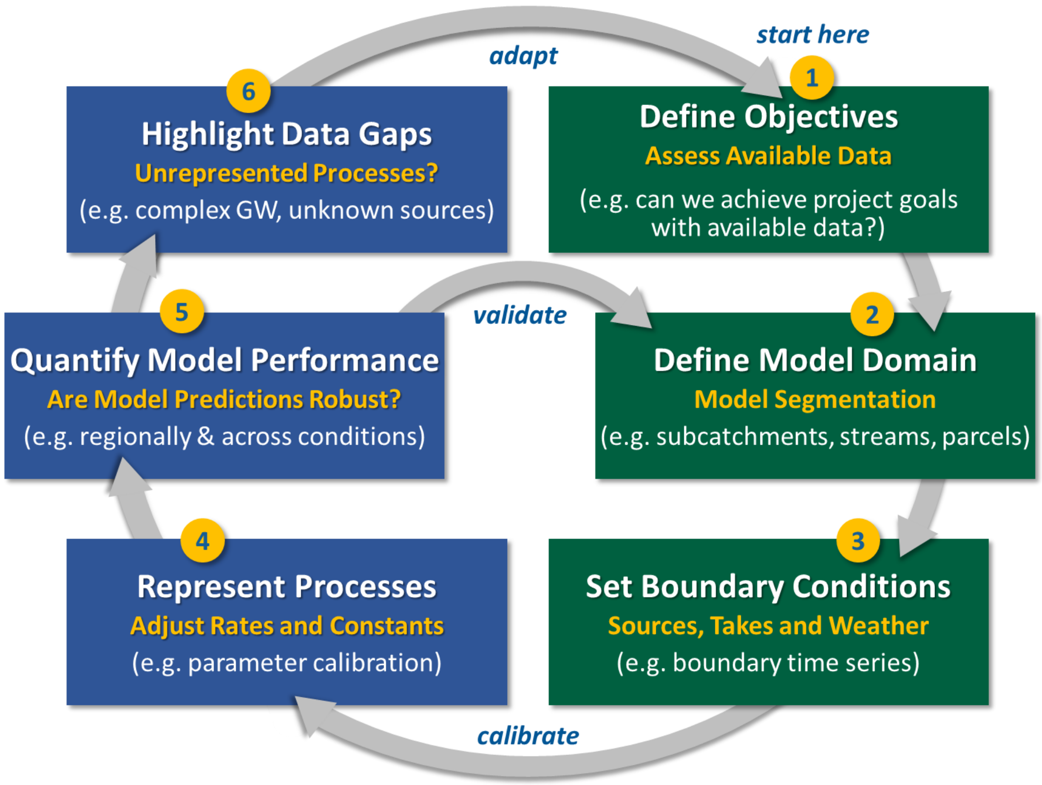

Figure 1-3: Current State LSPC model - A top-down Weight of Evidence approach

LSPC was used to simulate baseline hydrologic and water quality conditions for the East Holland River watershed. The baseline LSPC simulation served as the 'boundary', or base case, condition for the 'Future State' model, described in this report. The LSPC generates a time series to represent hydrology at the landscape level, capturing the land simulation processes 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.[1]

1.4.2. Future State – SUSTAIN model

SUSTAIN, a decision support tool, 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 stormwater management solutions. These solutions are optimal combinations of SCM types and sizes at strategic locations on the landscape, identified through thousands of computer iterations. They are optimal because they achieve desired water quality and flow objectives at least cost.

1.4.3. 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 (OM) 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 (Appendix 5).

1.4.3.1. 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 are 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]

The total damage caused by flooding includes direct damage to buildings and their contents and to municipal infrastructure like roads, bridges, parks and storm sewers as well as indirect damages associated with business closures, missed employment and other types of disruption caused by flooding. The calculation is repeated for each of the flood-prone areas in the watershed.

1.4.3.2. Co-benefits

The co-benefits of SCMs, modelled (representative) and those to be targeted for future implementation, were identified and qualitatively evaluated. Based on leading jurisdictions research (Appendix 2) and an extensive literature review, the potential or capacity of a SCM to produce a given co-benefit was qualitatively rated on a scale of 1 to 5 and results tabulated.

1.4.4. Climate change scenarios

Climate change will lead to more frequent and severe precipitation events, rapid snow melt, extreme heat waves, and expanded drought. The 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.

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[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

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.

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 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.[2,3]

1.4.5. Current State Model Configuration

A Current State model was configured and calibrated to provide the ‘baseline’ for establishing existing hydrology and water quality conditions in the East Holland River watershed (Appendix 1 – Current State Modelling Report, Paradigm Environmental, 2020)[4].

A primary element of hydrologic model development is watershed delineation which enabled the portrayal of specific characteristics of the East Holland River watershed such as slope, land use, impervious cover, climatic variations, etc. to simulate the hydrology. A fine resolution sub-catchment delineation provides increased spatial resolution and model accuracy for predicting hydrologic characteristics within a watershed. Figure 1-4 presents the 273 LSPC sub-catchments in the East Holland River watershed utilized for this report, organized by municipality.

Jurisheds, as indicated in Figure 1-4 is a term used to describe the portion of a sub-catchment that is within a specific jurisdiction or municipality. While the LSPC sub-catchment delineation purposely did not account for municipal boundaries, the resulting polygons were intersected with jurisdictional boundaries to produce ‘jurisheds’ presented in Figure 1-4. A jurished is 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.

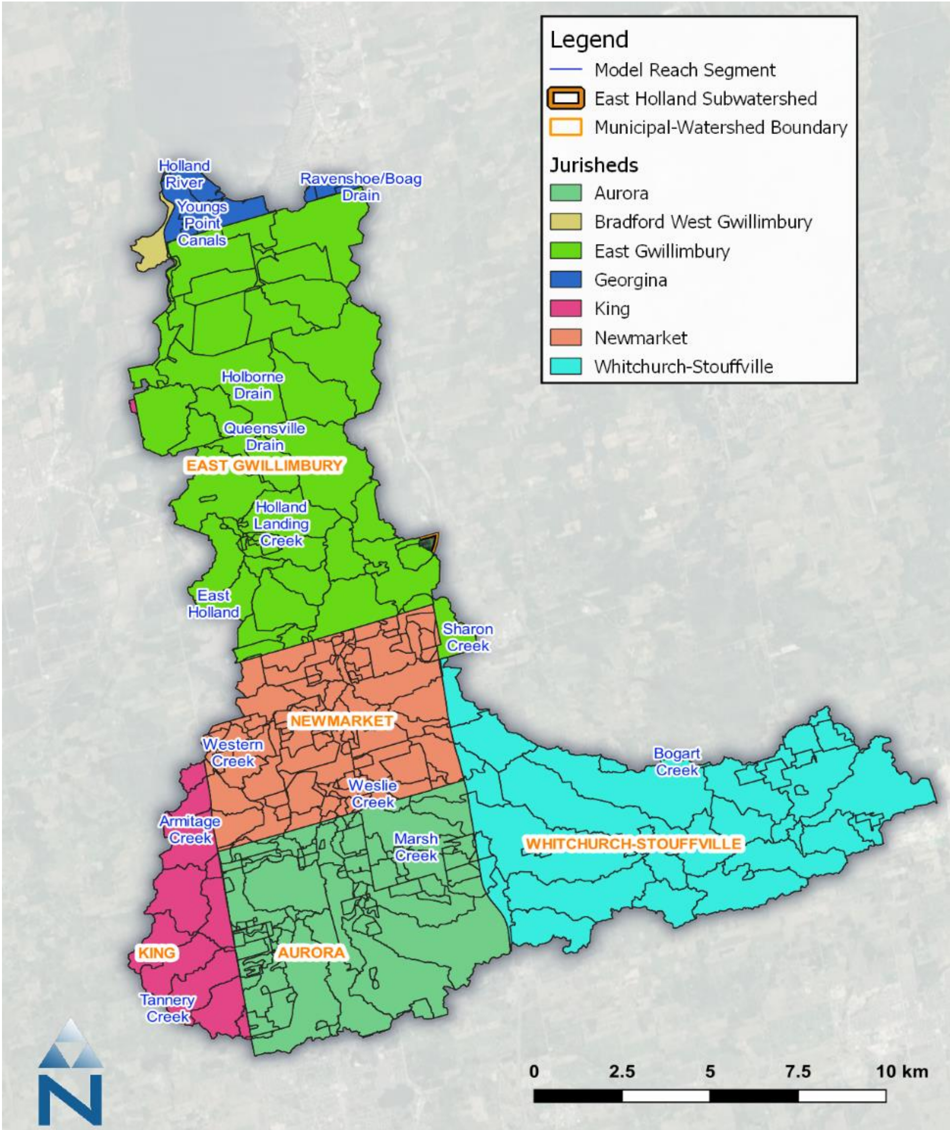

Figure 1-4: Sub-catchments and municipalities in the East Holland watershed

1.4.5.1. Hydrologic Response Units

Hydrologic Response Units (HRUs) are the land building blocks of the LSPC model. These HRUs are the core hydrologic modelling land units in the watershed model. Each HRU represents areas of similar physical characteristics attributable to certain processes. Each sub-catchment in the East Holland study area is comprised of HRUs that were created by combining land use, soil, slope and surficial geology. Essentially, HRUs represent overlays that influence the hydrologic response to the climate and other scenarios providing a land modelled response as illustrated in Figure 1-5 below.

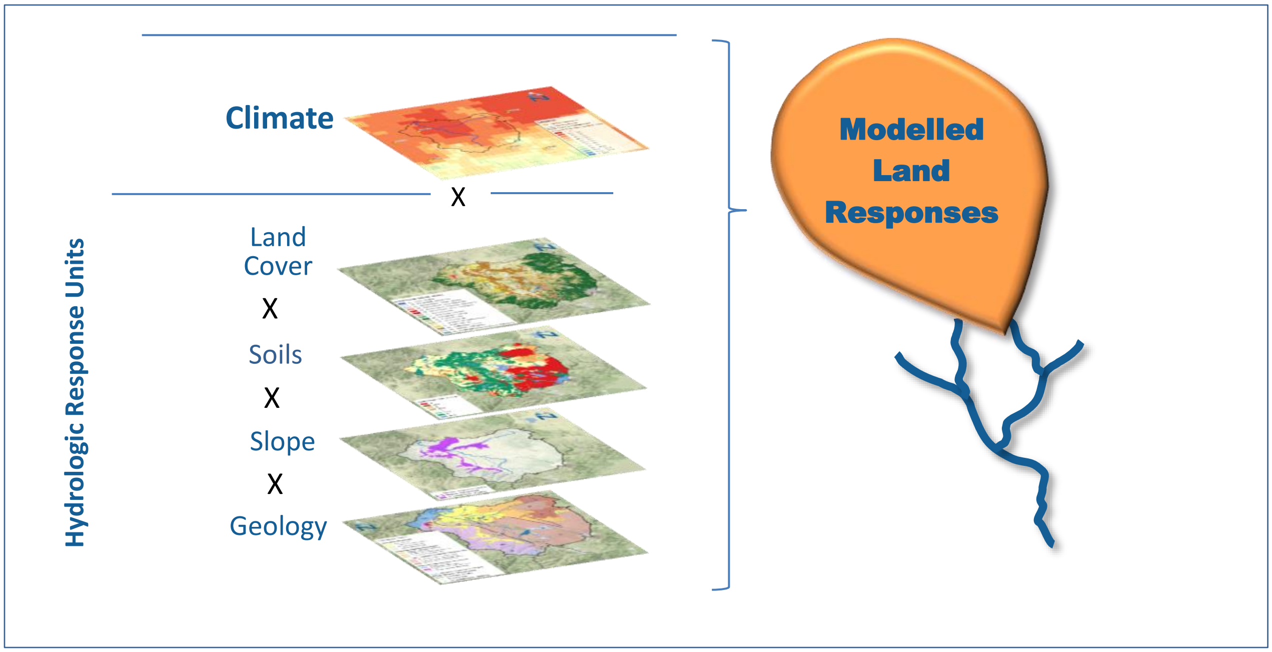

Figure 1-5: Generation of HRUs by sub-catchment to model land response

1.4.5.2. Groundwater representation

Processes impacting baseflow, interflow, and groundwater recharge were represented both on the land and within stream channels. On the land surface, geologic information was incorporated into the HRUs using data from the E-Flows study developed in 2018.[5] Within the stream channel, in-stream losses were simulated based on groundwater flux information provided by the Oak Ridges Moraine Groundwater Program (Figure 3-12). The data was extracted from a coupled groundwater/surface water model built using GSFLOW, the integration of PRMS and MODFLOW maintained by the USGS. Additional information on groundwater representation can be found in the Current State Modelling Report (Appendix 1).

1.4.6. Calibration

1.4.6.1. Approach

The East Holland River watershed modelling approach leveraged local data sources, research efforts, and followed internationally recognized modelling protocols and conventions.

Demonstrating reasonable model calibration is key to the model development process, as it forms the basis for establishing the degree of confidence and uncertainty in model predictions and the reliability of the model for making management decisions. Models are deemed acceptable when they can simulate field data within a reasonable range of statistical accuracy, as described in the Current State Modelling Report (Appendix 1).

After weather data and meteorological boundary conditions are well established, a top-down 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.

1.4.6.2. Model performance

Calibration was assessed using a combination of visual assessments and computed statistical evaluation metrics. Visual assessment involved reviewing plots of simulated vs observed outputs, which are presented in the following sections, and review of the simulated conditions during the sampling period for pollutant loadings (2011-2012) at Holland Landing. For statistical assessment of model performance, agreement between LPSC outputs and observed data was assessed using performance metrics based on those recommended by Moriasi et al.[6]

1.4.6.3. Simulation of design storms

Soil Conservation Service (SCS) Type II design storms were identified as suitable for estimating flood peak flows within the East Holland River watershed[7]. For the study, the 10, 25, 50, and 100-year, 12-hour SCS Type II design storms were used to assess the effect of SCM implementation on flood mitigation.

1.4.6.4. Peak flows

LSPC output was formatted for input into the Hydrologic Engineering Center River Analysis System (HEC-RAS) model to simulate the mitigation of elevated water levels for optimized management actions. SUSTAIN results were used to calculate the percent reduction in LSPC peak flow rates and HEC-RAS was used to estimate the corresponding water levels pre- and post-SCM implementation.

1.4.7. 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 may be summarized as follow:

- Menu of representative SCMs
- Opportunities to site/footprint those SCMs
- Areas managed by those SCMs
- Costs of those SCMs

The menu of representative SCMs is illustrated in Figure 1-6 below and indicates the representative SCM by parcel type under *public plus private lands* and *public lands exclusively* scenarios.

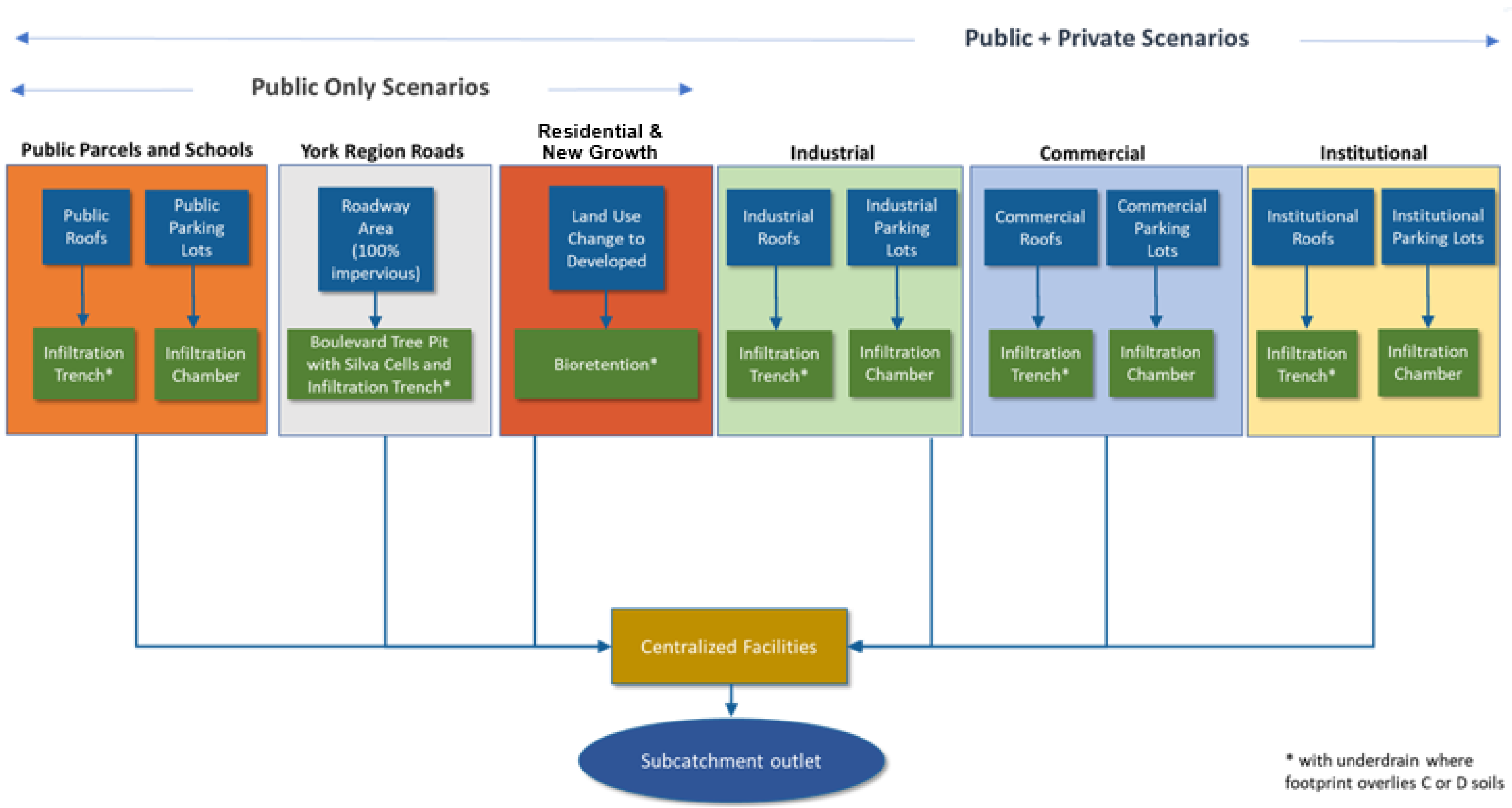

Figure 1-6: Representative SCM Menu

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

1.4.7.1. *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). Representative SCMs fall into two categories: One, centralized measures – facilities that are moderate to large in size and manage stormwater from mixed land use drainage areas – such as detention ponds or constructed wetlands and; two, distributed measures or LID installations, such as green roofs, rain gardens, and vegetative buffers distributed across land uses (e.g., commercial parking lots, single-family homes, industrial developments, etc.) that are smaller in size and manage stormwater from specific land use parcel or parcels such as one or more parking lots in a commercial business park. Table 1-1 illustrates the menu of representative SCMs used for Future State modelling

Table 1-1: Representative SCMs

SCM Type	Subtype	Manages	Footprint locations	Rules on footprint size	Notes
Centralized	Offline - Hybrid ponds	Large upstream areas	Open/ pervious areas	Capped at 20% of available area in parcel/ opportunity	Intercepts storm drains, pumping required if depth to GW <1m below footprint
	Inline – Hybrid ponds				Intercepts creeks
Distributed	Infiltration chambers	Parking lots	Parking lots	Capped at 20% total area	
	Infiltration trenches	Rooftops	Adjacent to buildings	Capped at 20% total area	
	Bioretention	Future growth	In future growth areas	Locked at 25mm sizing	No cost.
	Green streets with tree pits	Regional roads	Regional roads	Capped at 20% total area	

1.4.7.2. *Opportunity screening for SCMs*

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 jurished are available for siting SCMs, and optimization may use all or none of that footprint.

Geographic Information System (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. Eighty-percent was set as a maximum uptake area to avoid completely infeasible outcomes where every single roof or parking lot is managed (Table 1-2).

Table 1-2: 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 1-7.

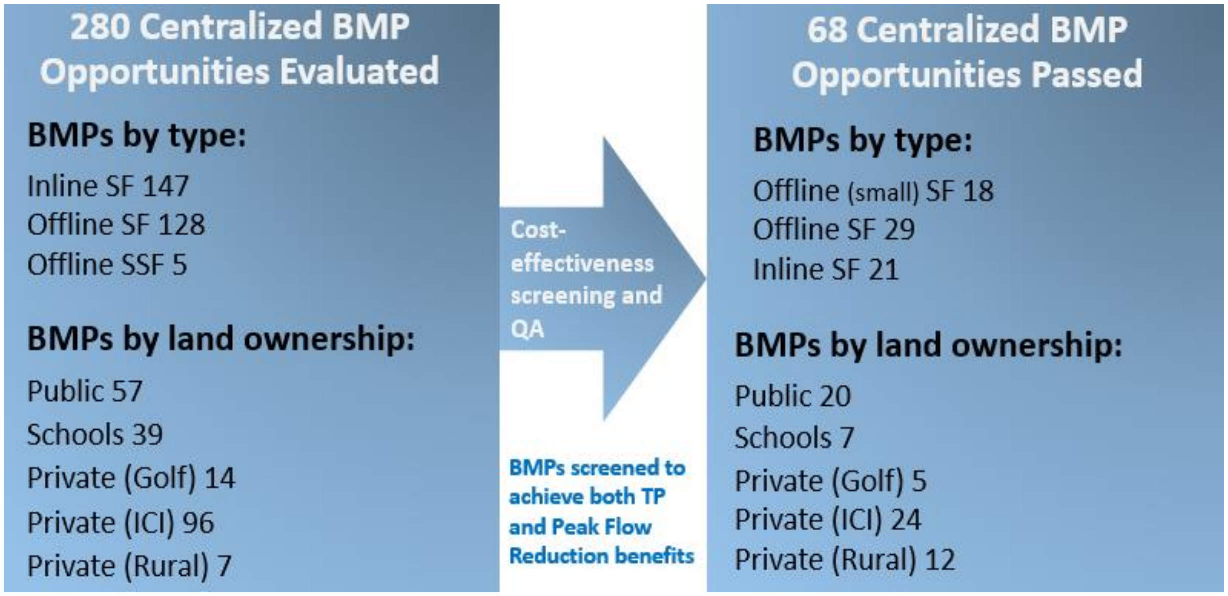

Figure 1-7: Screening for centralized SCM opportunities. (SF=surface feature, SSF=sub-surface feature)

1.4.7.3. Cost functions

Life cycle costs were developed for 17 selected SCMs and used to generate cost functions for application in SUSTAIN. Cost functions were developed using the Sustainable Technologies Evaluation Program (STEP) Life Cycle Costing Tool (LCCT), conceptual designs and costing, previously published cost curves or actual cost data provided by area municipalities. A summary of costs for representative SCMs is provided in Figure 1-8. Cost functions for all 17 SCMs are presented in the report.

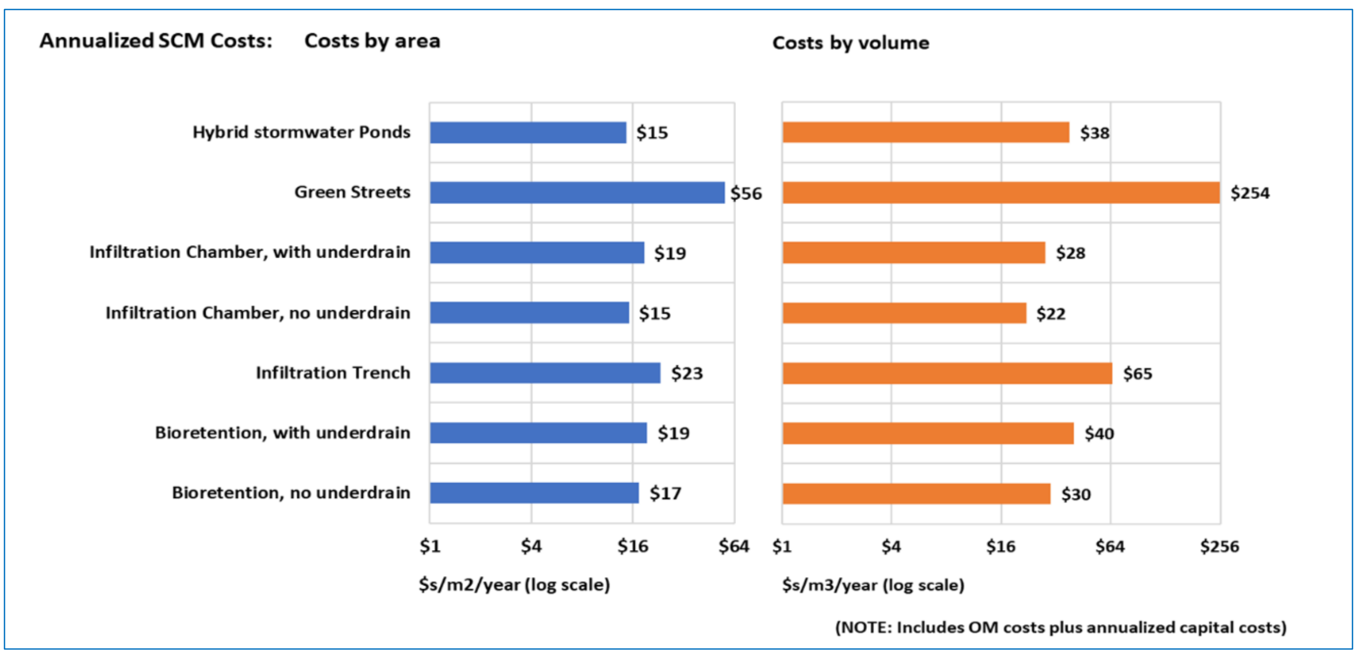

Figure 1-8: Summary of costs for SWM measures

1.5. Study Findings

The discussion of study findings has been organized around the three study principles and includes the results of the analysis of future climate change and planned growth and development scenarios, avoided flood costs and co-benefits of representative SCMs used in the study.

1.5.1. 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 River watershed.

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 1-9). Strategy development began with the Total Phosphorus (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 1-9. Inline centralized SCMs 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).

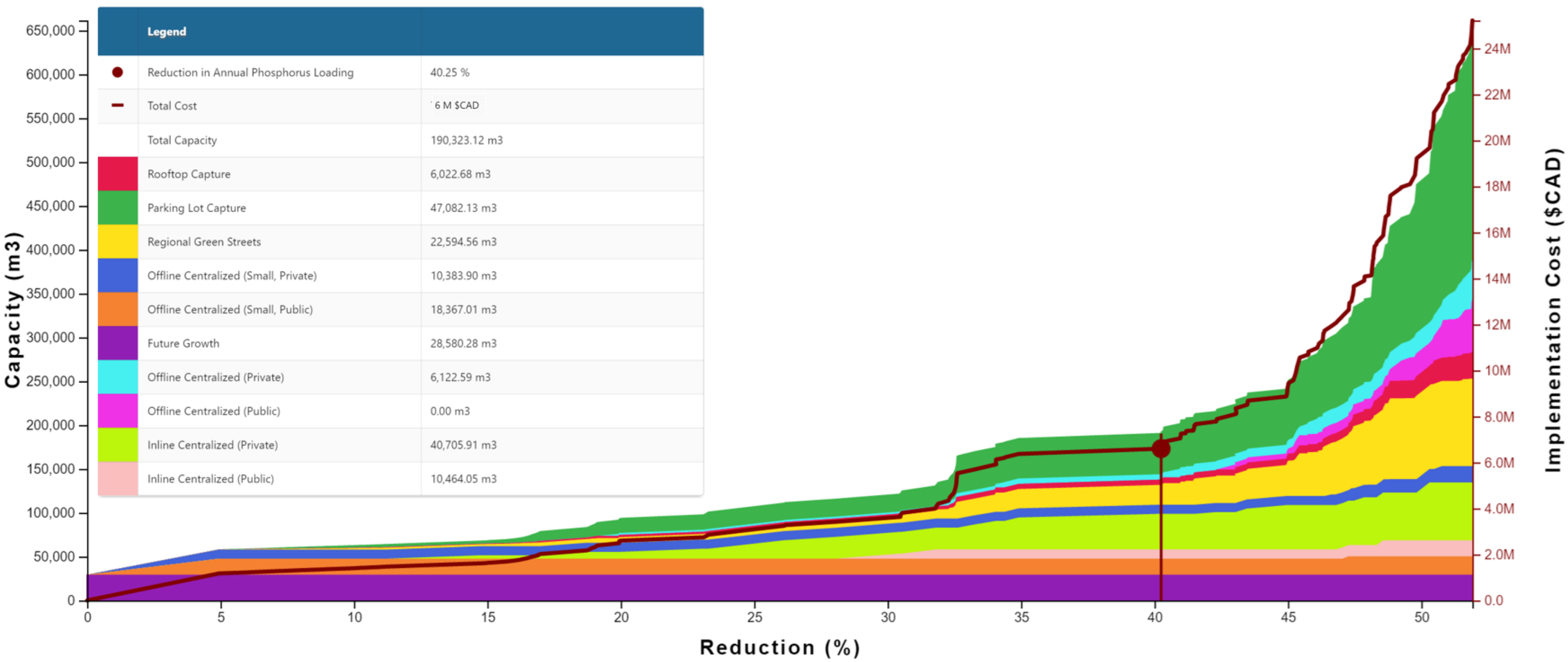

Figure 1-9: Phosphorus reduction strategy at the East Holland Landing (Costs annualized over 30-year)

The jurisdiction-by-jurisdiction implementation strategy for attaining 40% reduction at East Holland Landing is shown in Figure 1-10, organized by SCM type. The output in Figure 1-10 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 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.

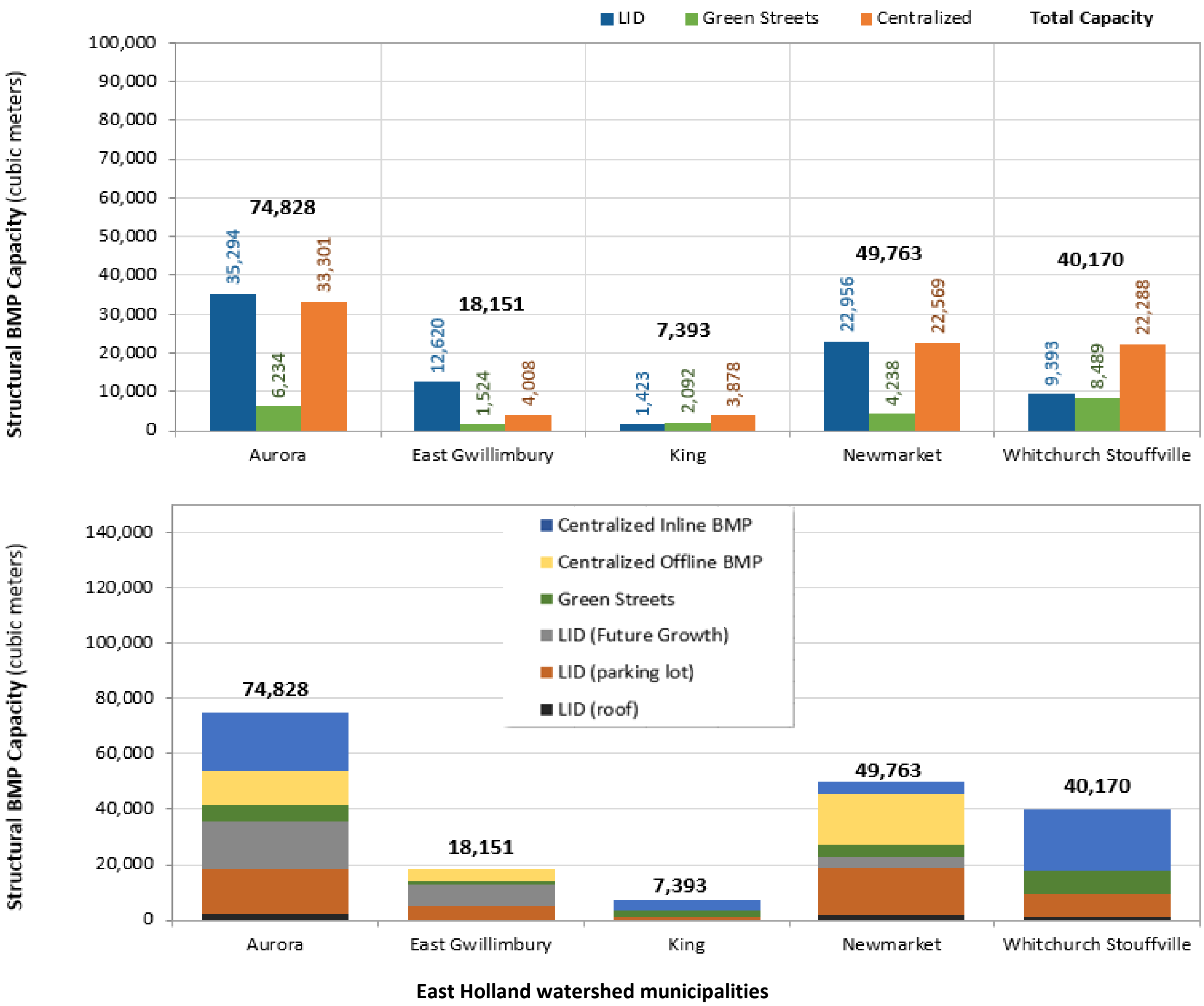

Figure 1-10: Cost Optimization Strategy - Summary of type and size of SCMs implemented on a watershed-wide basis, considering both public and private site opportunities to achieve a 40% phosphorus load reduction at Holland Landing

1.5.2. 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.

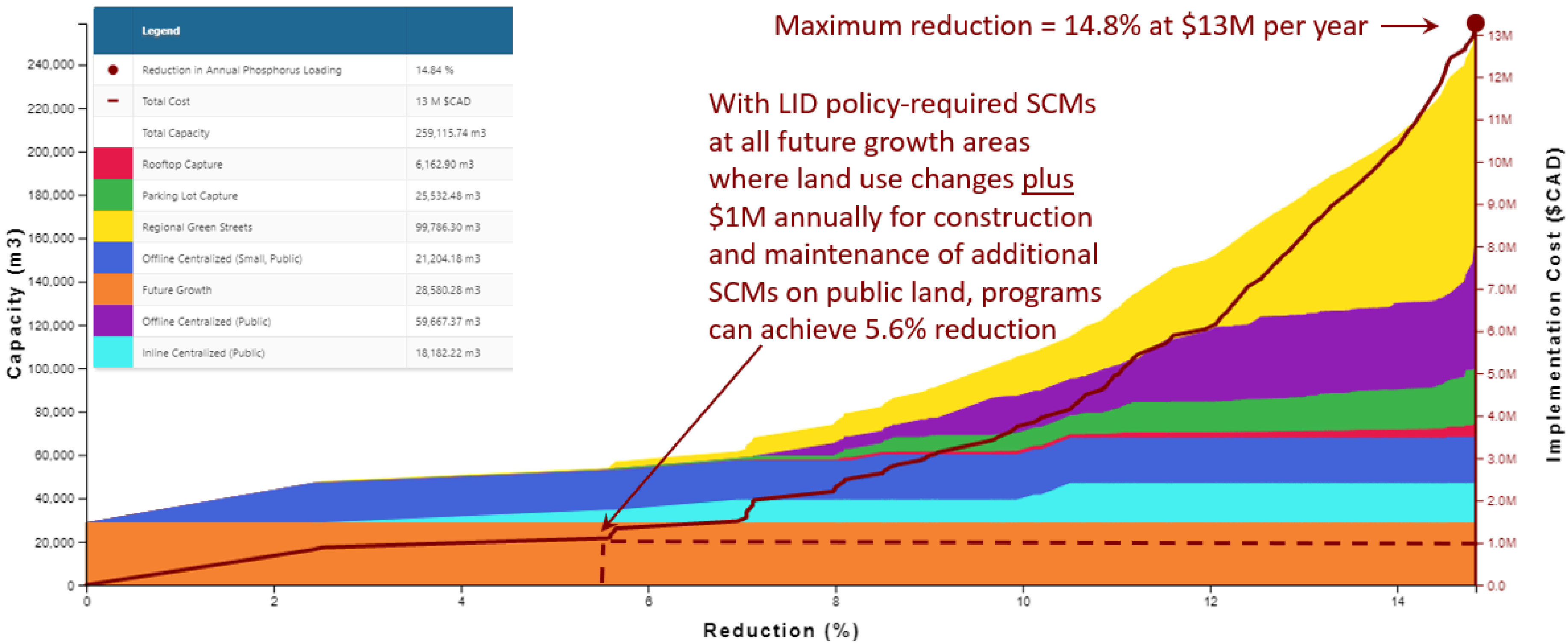

Figure 1-11: Phosphorus Reduction Strategy at the East Holland Landing - Public land opportunities only (costs annualized over 30 years)

1.5.3. 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 1-12). 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.

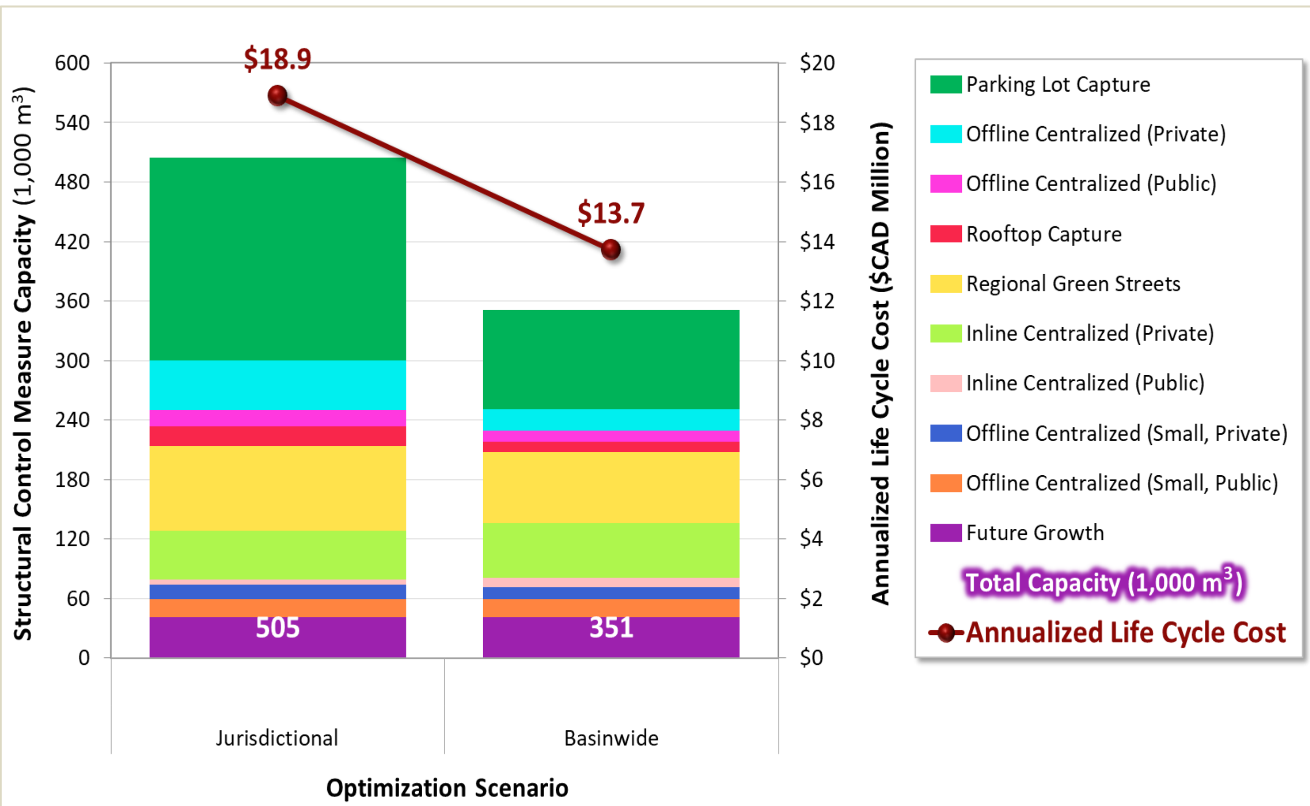

Figure 1-12: Optimized jurisdictional vs. watershed-wide solution for 40% phosphorus reduction.

1.5.4. 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.

As previously discussed (section 1.4.4), two climate future pathways – RCP 8.5 and RCP 4.5 – were used for the climate change simulations.

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 the increase in peak flows expected from climate change by 23% and 31% under RCP 4.5 and 8.5 scenarios, respectively. Therefore, peak flows for the 100-year design storm still increased under climate change, but SCMs had a mitigating effect on their magnitude.

1.5.5. 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 1-13).[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).

Comparisons between peak flow reductions discussed above and those described under climate change should be limited. The climate change reductions are focused on mitigating the expected increase to peak flows while the flood reduction percentages are an overall reduction. Under climate change scenarios, peak flows still increase from their baseline for the 100-year storm with SCM implementation, but the SCMs do have a mitigating effect on their magnitude.

[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.

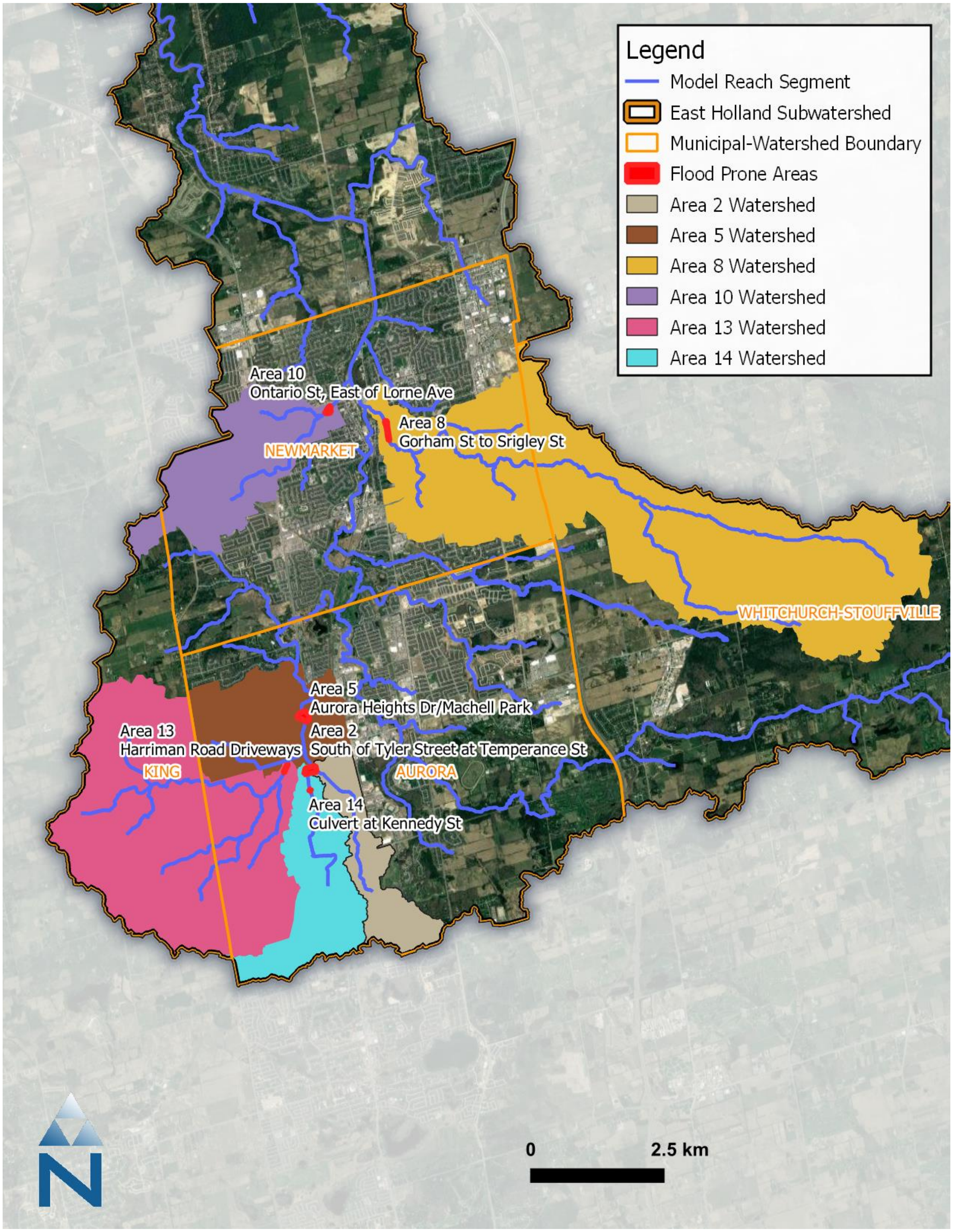

Figure 1-13: Assessed flood-prone areas in the East Holland watershed

1.5.6. 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 1-3) 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 1-4). 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.

Table 1-3: Qualitative rating based on the capacity of a SCM to provide co-benefits

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 1-4: Qualitative rating of co-benefits for representative SCMs

STORMWATER CONTROL MEASURE	CO-BENEFITS														
	Biodiversity	Habitat for species	Supports pollinators	Groundwater recharge & base flow	Erosion control	CO_2 sequestration & storage	Air quality Improvement	Drinking source water quality	Reduced Heat Stress	Energy savings	Improved aesthetics	Increased recreational opportunities	Increased Property Value	Reduced demand on infrastructure	AVERAGE RATING
Decentralized SCMs															
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 SCMs															
Hybrid wetland/pond	¾	¾	¾	1	1	¾	½	1	¾	½	1	¾	¾	1	0.80

1.6. Considerations and Implications

The results of the optimization and economic analyses have implications for multiple facets of SWM at 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.

1.6.1. Local context – East Holland River Watershed

In terms of the East Holland River 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 system-wide SWM. There are implications in taking such an approach in the East Holland but, the opportunities for substantial cost-savings; innovation; alternative financing; market and economic development; improved water and air quality; reduced erosion and flooding; higher property values; 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 1-5. The costs presented in Table 1-5 are based on watershed-wide implementation approach assessed East Holland Landing. This is in contrast to **Error! Reference source not found.** which used the mouth of East H olland River in order to capture all municipalities within the East Holland River watershed to properly compare jurisdictional vs watershed-wide approaches.

Table 1-5: Breakdown of project cost 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**

1.6.2. 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, as well, review and approval of municipal SWM plans and capital projects resides with them. 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 section 4.6.2.

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.[8,9]

Securing private property hosting of centralized and distributed SCMs will require the progressive use of market-based financial instruments. These progressive uses would include Payment for Ecological Services (PES), 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 areas with CSOs 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 quite low, typically below 6%, and therefore, have a very poor Return on Investment (ROI) value in terms of SWM.

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 (See Appendix 2 for more details on individual leading jurisdictions' SWM incentive programs). 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.

Designing and effectively using financial- and market-based instruments to target private property uptake of SCMs will require municipalities in the in the East Holland River watershed and across the country to adopt innovative market-based strategies that work in a Canadian context. There are numerous examples – from leading SWM jurisdictions with proven financial and market incentive programs to the energy sector (public and private utilities), which has significant success using financial and market instruments to secure private property-owner hosting of renewable energy installations for back-up micro-grids and up-take of energy conservation measures. Not only have these undertakings generated notable returns on dollars invested, these returns are compounded and reflected in economic development at the local level.

1.7. 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 current, jurisdictional boundary-based approach to SWM, whereby, primarily centralized SCMs and limited distributed SCMs are located exclusively on available public lands, was comparatively evaluated against a collaborative, watershed-wide (unrestricted by municipal boundaries) approach that, in addition to available public lands, considers viable private properties to site a combination of centralized and distributed SCMs. A summary of the key findings is provided in Table 1-6 below.

Table 1-6: 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. • 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 20.5% P-load reduction.	**Watershed-wide, integration of centralized and distributed SCMs located on viable publicly-owned and privately-owned lands** • 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 $10.4-million).
Jurisdictional-based (planning and management of stormwater based on the political boundaries of individual municipalities) • $18.9-million annualized life-cycle cost to achieve 40% P-load target.	**Integrated, watershed-wide (collaborative approach to stormwater planning and management unrestrained by political boundaries)** • $13.7-million annualized life-cycle cost to achieve 40% P-load reduction target. • 28% cost savings and 30% lower SCM capacity requirements.

The System-wide SWM 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:

1. **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.
2. 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.

3. 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.

1.7.1. Recommendations for implementation – Lake Simcoe region

1) 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.
2) 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.)
3) Meet with senior representatives of the Chippewa of Georgina Island First Nation to discuss the study findings and explore opportunities for collaboration.
4) 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.
5) Identify strategic partnership opportunities for targeted pilot / living laboratory studies to evaluate and adapt processes and practices.
6) Develop guidance and training materials and tools to support area municipalities in the use of optimization analysis for SWM planning.
7) Develop a mechanism for identifying opportunities throughout the watershed to twin planned public and private sector projects for greater cost-efficiency (e.g., gas line install with ROW infiltration trench, planned golf course with engineered wetland, new/major renovation of a public building with a green roof, etc.

1.7.2. Recommendations for further study

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 (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-wide 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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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
GDP	Gross Domestic Product
GHG	Green House Gas
GI	Green Infrastructure
GIS	Geographic Information Systems
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	Surface Feature

ACRONYMS & ABBREVIATIONS

SRC	Stormwater Retention Credit
SSF	Sub-surface Feature
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

2.0 Introduction

Stormwater runoff is a primary stressor on surface waters in urban and peri-urban watersheds. The East Holland watershed – the selected area for this study – is a rapidly urbanizing and increasingly stressed watershed located in the Lake Simcoe Basin (Figure 2-1). Conditions in the East Holland watershed mirror those found in many urban and peri-urban watersheds across the country, and area municipalities are contending with the same SWM challenges as municipalities across Canada and globally.

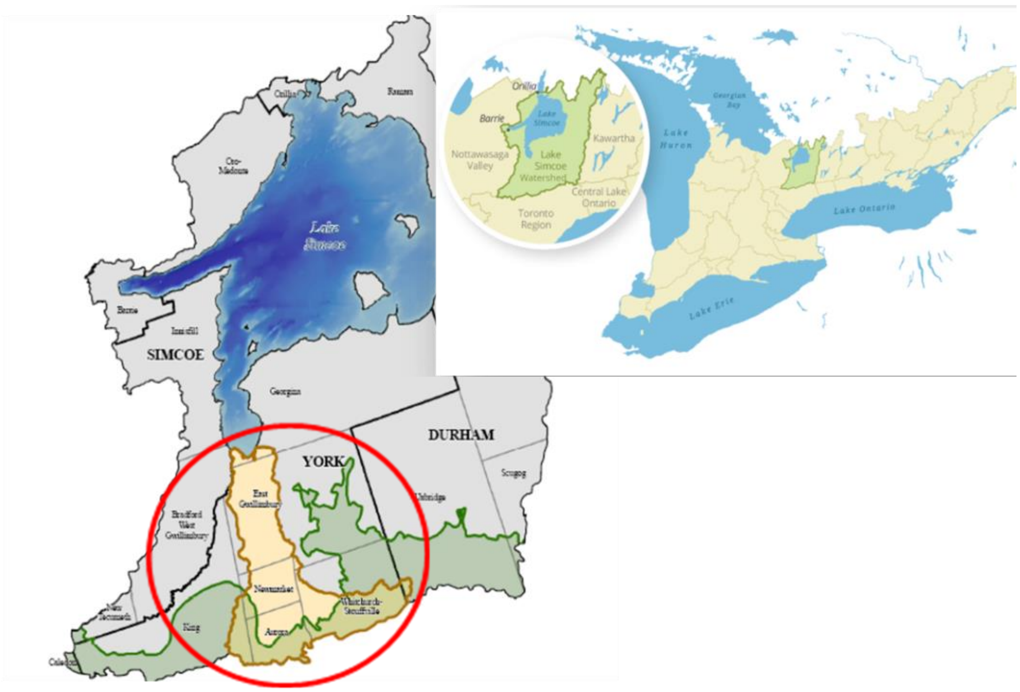


Figure 2-1: Location of the Study Area - East Holland River watershed, Ontario Canada

2.1. State of Affairs

Managing stormwater is an increasingly complex, costly and demanding challenge exacerbated by expanding urbanization and more intense storms and droughts due to climate change. Municipalities are grappling with historic stormwater infrastructure deficiencies, costly upgrades of aging assets, and building additional SWM capacity to accommodate new growth and development. Providing for adaptation of stormwater infrastructure to mitigate the effects of rapid urbanization and increasing climate-change variability is compounding an already challenging situation for municipalities.

Conventional stormwater infrastructure remains the dominant form of municipal SWM. Conventional 'grey' infrastructure generally treats stormwater as a "simple waste product"[10] and was designed to quickly channel runoff away from developed areas. This conventional approach wherein stormwater is collected and piped via conveyance systems to treatment facilities or directly to receiving bodies of water, is insufficient to manage the combined effect of rapidly changing land use and increasingly intense and recurrent precipitation events.[11]

2.1.1. Governance Framework

The evolution of SWM policies and practices in Canada has placed municipalities on the frontline of planning and management of stormwater infrastructure with provincial governments having primary oversight excluding those areas where SWM activities impact federal areas of responsibility, such as fisheries. Figure 2-2 provides an overview of the governance framework for managing stormwater.

Under the current governance framework, provinces in Canada are responsible for over-arching policies, legislation and regulations, and guidance for SWM planning, construction, operation, financing and asset management. In general, provincial government ministries review and approve municipal SWM plans and projects and, via transfer payments to municipalities, provide financial support for SWM planning and capital works. Most major uses of water in Canada are permitted or licensed under the authority of provincial governments.[12]

Federal jurisdiction applies to oceans and boundary waters shared with the US and fisheries. The federal government provides financial support for SWM via direct and in-direct funding for municipally-led plans, studies, and capital projects. The federal government also provides indirect funding for municipal SWM planning, infrastructure and asset management via transfer payments to the provinces and territories.

Municipalities own and manage in excess of 90% of all non-linear and linear stormwater assets[13] and are responsible for financing SWM planning and construction, Operation and Maintenance (O&M), and replacement of stormwater infrastructure via property tax or stormwater fees.

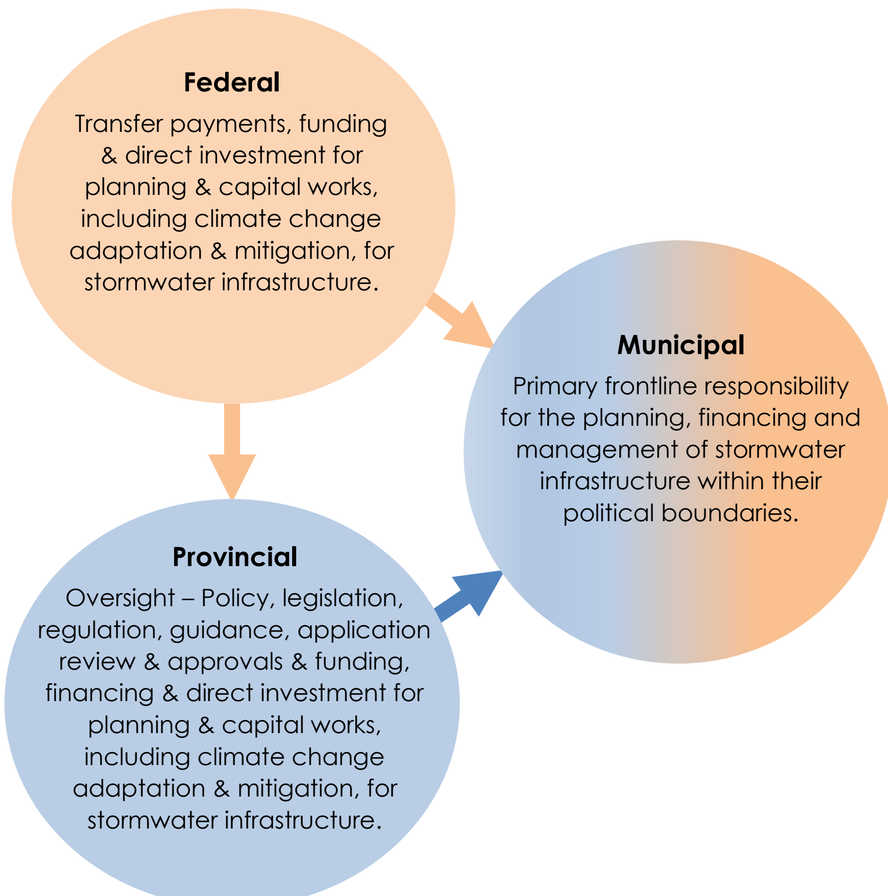


Figure 2-2: Governance Framework for SWM in Canada

In some provinces, public watershed authorities/agencies have a role ensuring protection of water resources and flood mitigation and management. These are the only public entities in Canada whose mandate is watershed-wide and represent a viable model for realizing holistic and integrated watershed-scale stormwater planning and management. In the Lake Simcoe basin, which includes the study area, the Ontario Ministry of Environment, Conservation and Parks transferred responsibility for preliminary review of municipal SWM Master Plans to the Lake Simcoe Region Conservation Authority (LSRCA). This arrangement is an important shift toward integrated, watershed-scale approach to SWM planning and source water protection.

2.1.2. Urbanizing watersheds

The continuing trend of urbanization – currently, over eighty percent of Canada's population live in built-up areas[14] – and the associated expansion of impervious surfaces, has significantly altered the natural hydrology in urban[15] and peri-urban watersheds across the country. In fact, there is a direct correlation between imperviousness and the volume and rate of stormwater runoff. A 2006 study determined that "a typical city block generates greater than 5 times more runoff than a woodland area of the same size"[16]. This increased runoff can cause flooding and related damage to property and infrastructure; pollutes ground and surface waters; harms riparian and aquatic habitats; and increases erosion. A recent study into the causal effects of impervious cover on annual flood magnitude found that *a one percentage point increase in impervious basin cover causes a 3.3% increase in annual flood magnitude*.[17]

2.1.3. Accumulating impacts and climate change

Inadequate SWM capacity and the limitations of conventional stormwater infrastructure have adverse economic, social and environmental impacts. Since 1970, about half of all natural disasters in Canada have been caused by floods[18] accounting for $673 million or 75 per cent of federal disaster assistance costs[19]. Mitigating the growing risks of flooding associated with climate change represents the highest cost of adaptation as a percentage of Gross Domestic Product (GDP) than the costs of mitigating <u>all</u> other risks combined[20] as illustrated in Figure 2-3 below. This fact is highly concerning given that about 60 percent of property exposure in Canada is not insured against flood risk[21] and that precipitation events are expected to occur with greater frequency and intensity in the future.[22]

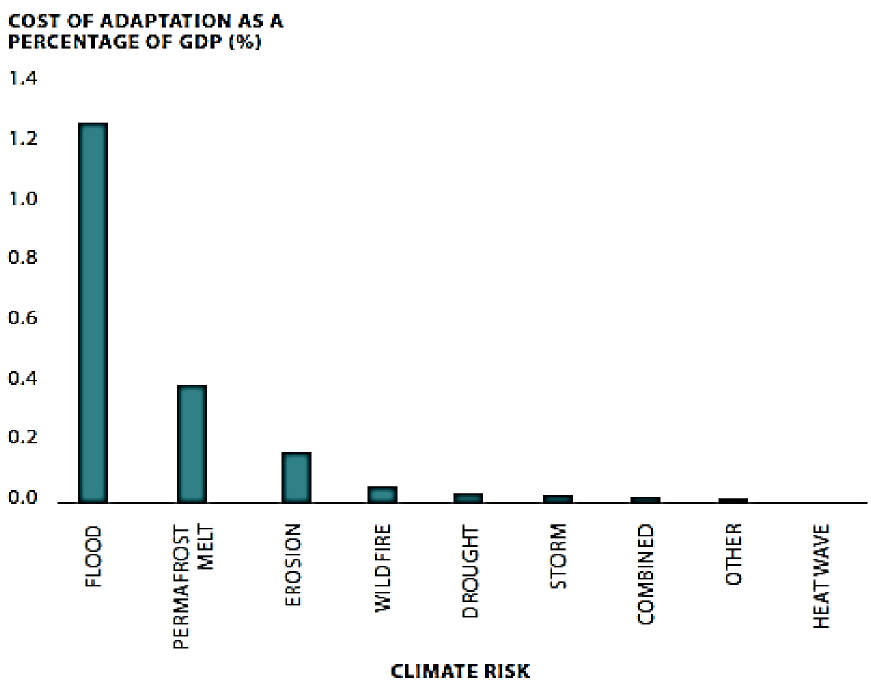


Figure 2-3: Adaptation cost as a percentage of GDP by climate change risk
(Source: Environment and Climate Change Canada)[23]

2.2. Study Context: Defining the problem

The efficacy of a treatment train approach to SWM that considers opportunities to detain or retain stormwater at source, followed by infiltration via conveyance infrastructure and lastly, end-of-pipe capture is well established. Integrating centralized and distributed green and grey infrastructure to manage stormwater is now accepted as a more sustainable practice by most jurisdictions.[24] Green Infrastructure (GI) and LID are being used in combination with conventional SWM infrastructure by many municipalities yet, for the most part, it is used on an ad hoc or demonstration basis.

Municipal-centric responsibility for managing stormwater has led to a boundary-based approach to SWM planning and design that ignores impacts to downstream communities.

SWM planning focuses at a jurisdictional-level (versus a watershed-wide scale) and limits siting of infrastructure to available municipal property (versus both publicly-held and privately-held property). Not only does this approach place a huge burden on municipal resources and capacity, it fails to consider watershed hydrologic function holistically and, by excluding privately-owned property in site selection, it fails to consider potentially ideal or optimal locations for hosting SWM infrastructure.

2.3. Formulating the study

The genesis of the *System-wide SWM* study, was the culmination of research by key partner organizations and other municipal stakeholders. Primary and secondary research[25] exploring the impediments to the use of GI and integrated SWM system design by Canadian municipalities, and best practices by leading jurisdictions in GI strategies and programing[26] identified major constraints to integrated SWM in urban and peri-urban watersheds. In addition to this research, the formulation of the study drew on several important water quality and hydrology monitoring and modelling efforts undertaken by the LSRCA for the East Holland watershed pointing to the limits of current SWM practices.

Answers to three critical questions, as summarized below, provided insight into the barriers to a holistic, watershed-scale approach to SWM:

1) Why, despite significant advancements in municipal stormwater planning and management, are communities across Canada experiencing increased flooding? (Figure 2-4)

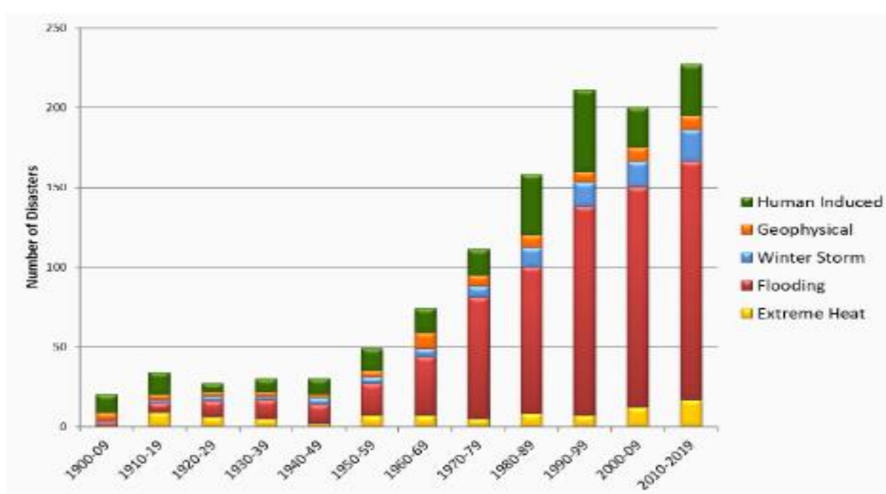
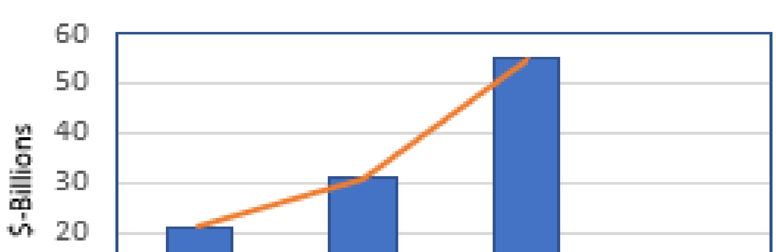


Figure 2-4: Disasters trend in Canada (by decade)
(Source: Public Safety Canada)[27]



2) Why, despite increasing investments in SWM infrastructure and new financing mechanisms, such as stormwater utility fees, is the overall municipal stormwater and wastewater deficit increasing?

Figure 2-5: Municipal stormwater and wastewater deficit (1996 - 2016)
(Source: FCM)[28]

3) Why, despite expanded and improved watershed-level planning and management are most urban and peri-urban watersheds in Canada experiencing high levels of stress associated with declining water quality and hydrologic impairment? (Figure 2-6)

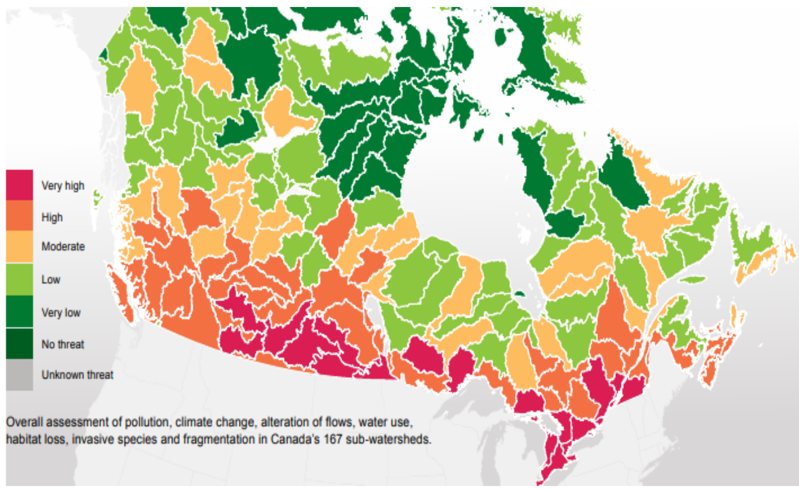


Figure 2-6: Level of watershed stress in Canada
(Source: WWF Canada)[29]

2.3.1. Finding answers

Distillation of the research findings identified multiple constraints to the sustainable and efficient management of stormwater study as summarized below:

- Federal and provincial government fiscal policies and associated SWM infrastructure funding emphasizing "shovel-ready" capital projects by individual municipalities.
- Policies at all levels of government that support or require municipal boundary-based SWM planning and thereby discourage a co-operative approach to SWM amongst municipalities in shared watersheds and by extension, discourage integrative water management and scalable, systems-based infrastructure planning and design.
- Limited public policies, particularly fiscal, supporting holistic integration of GI, natural assets, conventional SWM infrastructure and non-structural SCMs into comprehensive plan.
- Policies and practices at all levels of government that support or require planning for, and siting of, municipal SWM infrastructure on public lands.

- The majority of land in municipalities is privately owned; in fact, in urban cores as much as ninety percent or more of land is privately held. Yet, with the exception of new greenfield development, municipal SWM planning focuses on the use of public lands for siting stormwater infrastructure.
- Many municipalities take an issue-based approach to SWM with the result that capital funds are directed to centralized end-of-pipe infrastructure.
- Integrated planning of GI, natural assets and non-structural practices for SWM is still evolving and hence is widely considered an 'add-on' to conventional stormwater infrastructure within many municipal stormwater divisions.
- Municipal efforts to secure uptake of GI on private property primarily involve direct adoption or modification of market-based economic instruments used in other jurisdictions (in particular, the USA) or sectors (e.g., energy, GHG emissions, etc.), that are often inapplicable or insufficient in a Canadian context and/or for motivating uptake of GI by private property owners.

Findings from this research explained the limitations of the current SWM framework. Given the consequences of these limitations – contamination of water sources, flooding and impaired hydrologic functions, and their attendant social, economic and ecological consequences – a new SWM paradigm is proposed. This new paradigm is centered on the premise that a watershed-scale, system-based approach to managing stormwater will provide more effective, resilient and adaptable SWM. This new SWM paradigm represents the Next Generation in stormwater management.

2.4. Next Generation SWM: Building an Integrated System

A primary motivation for this study is a conviction that SWM must evolve to meet the future challenges posed by on-going urbanization, climate change, and public sector budgetary constraints. Like other urban and peri-urban watersheds throughout Canada and across the globe, hydrology and water quality in the Lake Simcoe basin have been adversely impacted by rapid development and climate change.

2.4.1. Study Principles

The System-wide SWM study proposes a fundamental re-tooling of stormwater planning and management based on the following three principles:

Principle #1 – Using an optimization methodology for stormwater planning will significantly expand the scope and depth of Best Management Practice (SCM) evaluation, enabling the development of integrated strategies and plans for more efficient and effective SWM.

Principle #2 – In addition to municipal-owned properties, evaluating and utilizing private properties for structural SCMs will provide improved performance at greater cost-efficiency vs restricting consideration and siting of municipal SWM infrastructure exclusively to public land.

Principle #3 – Municipalities in a shared watershed have an equal responsibility for protecting the watershed in its entirety and collaborative SWM planning by municipalities in a shared watershed will provide improved performance at greater cost-efficiency as compared with individual municipal-scale planning and SWM.

2.4.1.1. Principal #1 – Optimization analysis

Optimization analysis was used to determine the most cost-effective strategy to achieve stormwater and watershed management objectives. The optimization model, **S**ystem for **U**rban **S**tormwater **T**reatment and **A**nalysis **I**ntegratio**N** (SUSTAIN), identified the most cost-effective combination of Stormwater Control

Measures (SCMs) to meet target water quality and hydrology objectives. Detailed economic analysis generated life-cycle cost functions for each of the SCMs used within SUSTAIN.

SUSTAIN employs two search algorithms, *scatter search* and *non-dominated sorting genetic algorithm-II* (NSGA-II), for the optimization analysis. The optimization module of SUSTAIN uses a tiered approach to evaluate the cost-effectiveness of strategies in individual and/or multiple nested watersheds. Importantly, this approach has both regional- and municipal-scale applications. Shoemaker at el[30], present a detailed discussion of the optimization processes in SUSTAIN.

The optimization algorithms in SUSTAIN, combined with high-resolution geospatial data, evaluate literally hundreds of thousands to millions of combinations of SCMs enabling the development of long term, cost-effective and integrated SWM strategies at local, regional and watershed scales as illustrated in Figure 2-7.

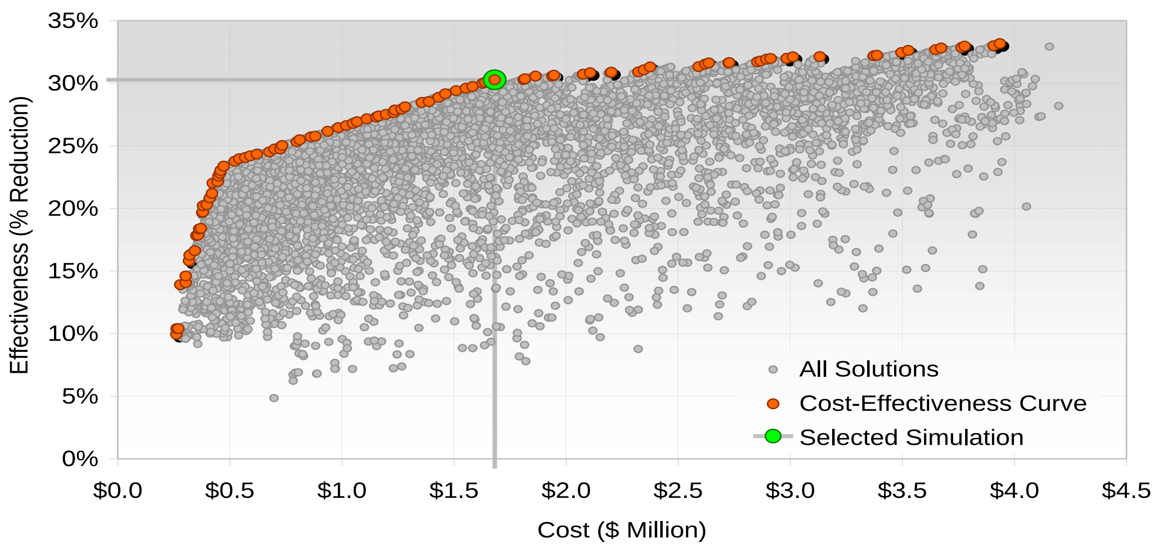


Figure 2-7: Cost-effectiveness Optimization - Millions of possible solutions analysed
(Source: Paradigm Environmental)

2.4.1.2. *Principle #2 – Private Property*

The conventional view holds that SWM infrastructure should be located on publicly-owned property, such as a municipal park or road right-of-way.[31] Privately-owned land typically comprises 70% or more of land in urban and peri-urban municipalities and in densely developed city centres, more than 90% of property may be privately-owned. With expanding urbanization, available municipal lands for hosting SCMs are insufficient for effective management of stormwater.[32]

Current municipal SWM planning does not consider privately-owned properties when assessing viable land parcels on which to site centralized or distributed stormwater infrastructure. Constraints and opportunities to siting of public SWM assets on private property, along with potential strategies to secure SCM opportunities on private property are discussed in Section 4.6.2.

The System-wide SWM study used SUSTAIN to evaluate pre-screened, privately-owned parcels for hosting centralized and decentralized SCMs. Optimization analysis of viable private and public properties determined the most cost-effective combination of host locations by SCM type. As discussed in detail in Section 4.2, not only were numerous privately-owned parcels selected by SUSTAIN as preferred sites, an optimization run considering only publicly-owned parcels resulted in substantially higher costs and, more significantly, a failure to meet required water quality objectives. Siting of SCMs on viable privately-owned properties is not only more cost effective, it is critical to meeting LSPP mandated water quality objectives.

2.4.1.3. Principle #3 – Equitable Responsibility: Watershed-scale SWM model

Planning SWM on an individual municipal basis prevents a fulsome analysis of potentially more cost-effective options upstream in the watershed. Furthermore, municipal boundary-based planning ignores watershed-scale hydrology, cumulative downstream impacts and prevents coordination and harmonization of individual SWM plans and projects. In fact, a study of stormwater detention facilities in Valley Creek watershed in Chester Pennsylvania found that a lack of coordination in SWM planning and siting of infrastructure can actually increase downstream flooding due to the cumulative impact of multiple facilities discharging into a receiving water course (Emerson, et. al.; 2005).[33]

Although more municipalities are developing comprehensive SWM plans, prioritizing problem areas to target for SCMs continues to be the standard planning practice. As well, the conventional municipal planning and design of stormwater infrastructure on a subdivision-basis remains commonplace. The result of these two planning practices in combination with municipal boundary-based SWM, is no integration of SCMs as a holistic system across the watershed.[34] (National Research Council; 2008)

The principle of 'equitable responsibility' recognizes that all municipalities in a common watershed or nested watersheds have a shared interest in working together to cost-effectively manage stormwater catchment-wide. Water does not follow municipal boundaries, the sources of stormwater and the best opportunities to capture it are not evenly distributed across all municipalities, and downstream communities must contend with the consequences of inadequate upstream controls. A new SWM paradigm that considers hydrologic function throughout a watershed and employs an integrated network of distributed and centralized stormwater infrastructure, natural assets and non-structural stormwater mitigation practices is critical to realizing sustainable and future-ready SWM.

2.4.2. Future Urbanization and Climate Change

The combination of the three principles represents System-wide SWM. This new paradigm for managing stormwater applies scale, placement, aggregation and integration of stormwater infrastructure, natural assets and non-structural SCMs. Unlike built SCMs, natural assets (e.g., wetlands and forests) and alternative land management practices (e.g., no-till and cover-crop farming), do not degrade over time nor pose a risk of catastrophic failure during an extreme event, and for these reasons, are an integral part a responsive and adaptable SWM system. The functions of many GI measures, such as boulevard trees, afforestation and constructed wetlands improve as they develop, providing enhanced system capacity over time. A network of structural and non-structural SWM practices and natural assets functionally interconnected across a watershed will create a hydrologically responsive system more closely mimicking undeveloped watersheds. Realizing intrinsic resilience to balance future adverse impacts of increasing urbanization and climate variability will require a complex of SWM strategies working in tandem at a watershed scale.

3.0 Study Design and Methodology

This section describes the design of the study and the methodology for the modelling and inputs to the models (including SCM designs, SCM economic analysis and climate change projections). Findings from the engineering and economic analyses of the study principles and the results for water quality, hydrology and flood reduction are discussed in Section 4.0

3.1. Study Design

The study was designed to address key principles described in Section 2.0 with findings organized around the principles discussed in Section 4.0. The analysis was organized into two components – Current State and Future State. The Current State analysis was designed to characterize the watershed hydrology and water quality processes, in order to develop a strong 'baseline' for modelling scenarios for SWM strategies in the watershed. The Current State outputs provide the 'boundary condition' for the Future State component, which evaluates the cost and effectiveness of potential SWM strategies in the watershed. Figure 3-1 provides an overview of the Current and Future State components, which integrates an array of engineering and economic analyses, including development of SCM life-cycle costs, detailed assessment of opportunities for siting SCMs on public and private land in the watershed, optimization modelling to evaluate millions of potential scenarios, and outlining flood and phosphorus reduction strategies. The co-benefits of those strategies, as well as evaluation of limitations that are imposed in the absence of coordination between municipalities, are also assessed (quantitatively for flood damages and jurisdictional-based strategies and qualitatively for other co-benefits).

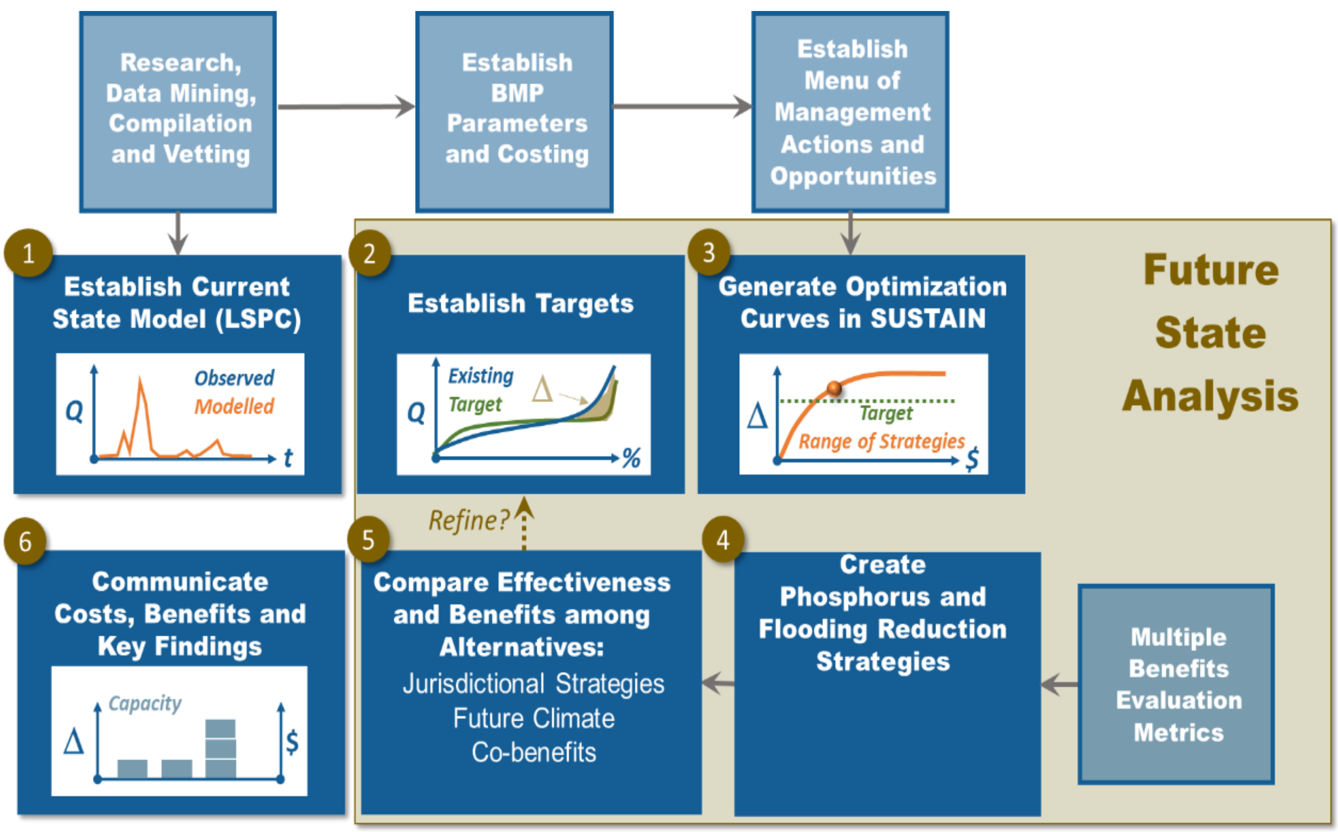


Figure 3-1 : Overview of Current State and Future State components or study design

3.1.1. Study Area

Lake Simcoe is the largest lake in southern Ontario, Canada aside from the Great Lakes (Ontario MECP, 2019). The entire Lake Simcoe basin is approximately 3,611 km^2 in size, inclusive of lake surface area. Management of the basin is governed by the Lake Simcoe Protection Plan (LSPP), established under the Province of Ontario's Lake Simcoe Protection Act (2008). The Lake Simcoe Conservation Authority (LSRCA), in conjunction with basin municipalities, Provincial Ministries, First Nations and stakeholders work together to support the LSPP. Established water quality targets and goals for protecting the lake and mitigating the impacts of pollution loadings to the lake are set out in the LSPP and discussed in Section 3.2.2.

The East Holland River watershed is located to the south of Lake Simcoe (Figure 3-2) and is 238.7 km^2 in size. The LSRCA *State of the Watershed* report describes the water quality and flooding challenges in the watershed due to rapid changes in land use and increasing climate variability[35]. A detailed discussion of the physical characteristics of the watershed, including land cover and use, elevation and slope, soils and seepage/groundwater recharge areas, can be found in the Current State Modelling Report (Appendix 1). Land use in the watershed is generally mixed with agricultural areas (generally in the northern, most downstream portion of the watershed), urban areas (generally in the middle portion of the watershed) and upland rural and open space areas (southeast portion of watershed).

The watershed contains seven municipalities – the majority of watershed area is within the jurisdictions of East Gwillimbury and Whitchurch-Stouffville, however, Newmarket and Aurora contain the most impervious surfaces (Table 3-1). Bradford East Gwillimbury only accounts for a relatively small, undeveloped portion of the north western part of the watershed and was not assessed in this study.

Table 3-1: Municipalities analysed in the East Holland watershed

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

For phosphorus loading, land use and groundwater impacts are in important consideration – lowland agriculture in the northern portion of the watershed approximating Lake Simcoe generates relatively high phosphorus loadings from overland flow as well as having high phosphorus concentrations in groundwater (Figure 3-3).

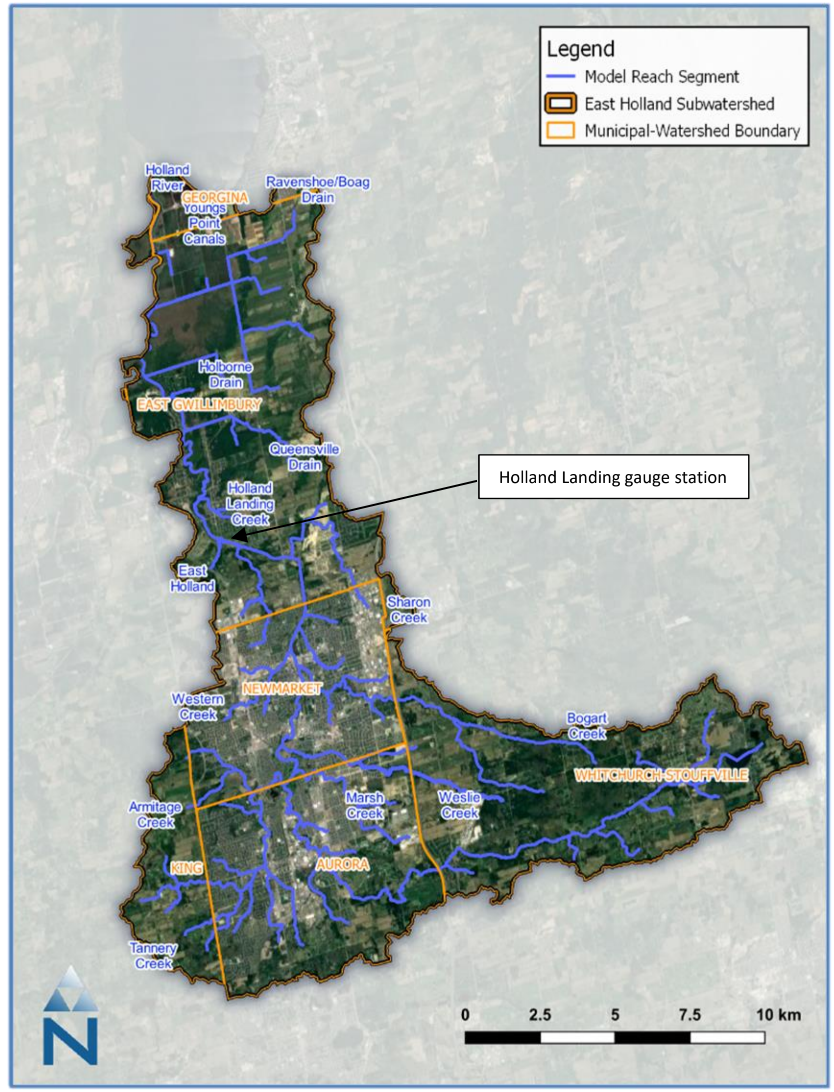


Figure 3-2: Lake Simcoe basin and East Holland River watershed

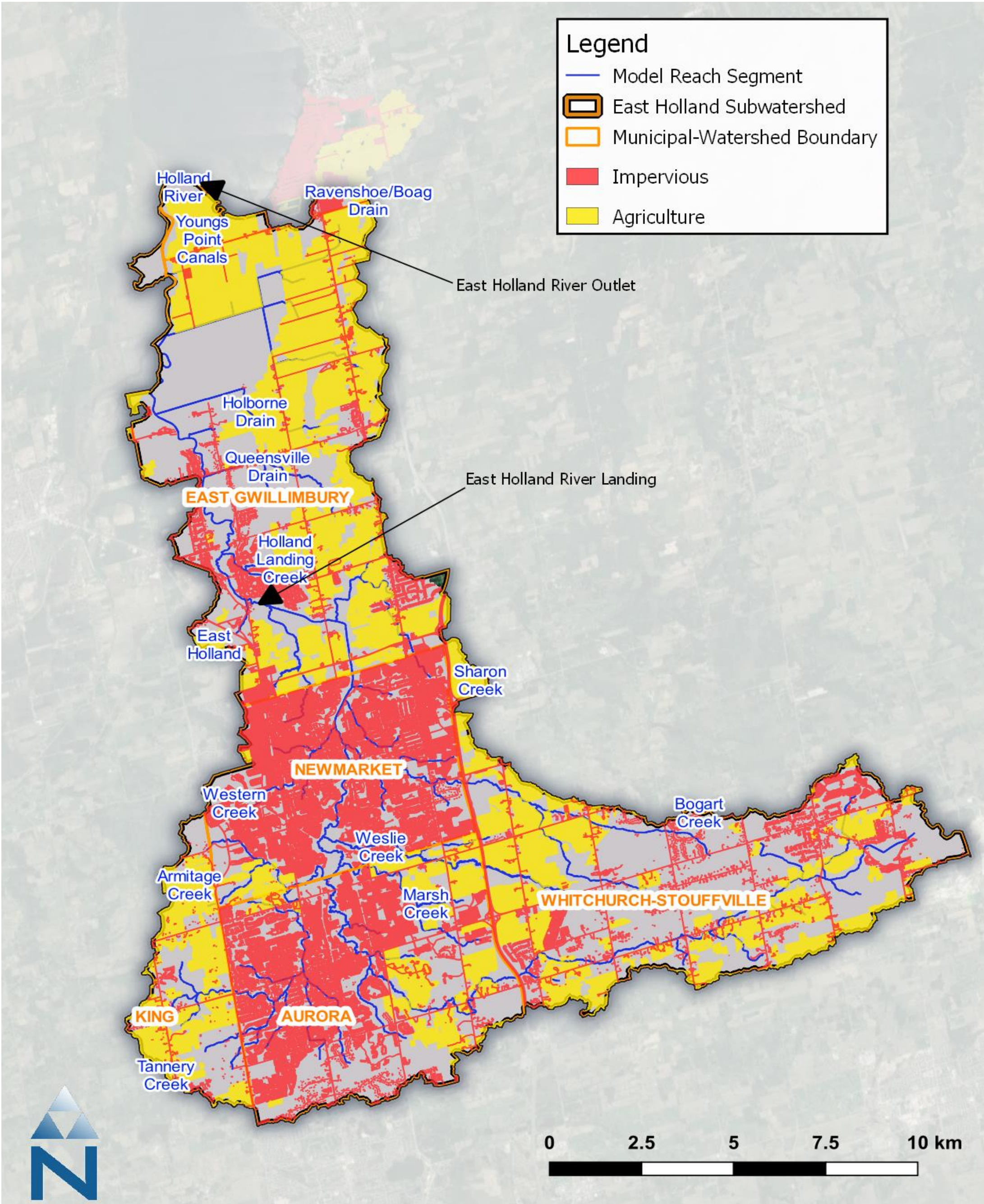


Figure 3-3: Agricultural and impervious surfaces in the East Holland river watershed with the East Holland river landing and outlet to Lake Simcoe identified

3.1.1.1. Rationale for Study Area Selection

The East Holland River watershed is a peri-urban area undergoing rabid urbanization (LSRCA 2000). As of 2018, the York region had the fastest population growth rate of any large municipal jurisdiction in Ontario, with an expected increase of 1.8 million people within the next 25 years[36]. Having a significant portion of land throughout the sub-watershed privately-owned and representing a mix of commercial, industrial, residential and agricultural land use types, enables inclusion in the evaluation viable privately-owned parcels in combination with public lands to host SCMs versus siting SCMs exclusively on public property. As well, the East Holland River watershed includes seven municipal boundaries, providing an excellent opportunity to assess municipal versus watershed-wide approaches to SWM.

The East Holland River watershed was selected for the System-wide SWM study as it is reflective of the conditions found in most urban and peri-urban watersheds across Canada, specifically:

- Significant older urban areas built prior to stormwater control that experiences riverine overflows during large precipitation events.
- A mix of urban, suburban and rural agricultural lands.
- Growing population and associated requirements for greenfield development, brown field re-development and new SWM infrastructure.
- Municipalities facing growing demands on SWM infrastructure, need for upgrading, repair and replacement of existing infrastructure and to address SWM deficits in older, underserviced areas.
- Degraded water quality in freshwater tributaries and Lake Simcoe (source of drinking water and cold-water fisheries) due to increased loadings of nonpoint source pollution from stormwater runoff.
- Increasing density of downtown corridors and associated increases in non-pervious surfaces.
- More intense precipitation events due to climate change and limited municipal resources and capacity to plan and design adaptive stormwater infrastructure.

3.1.2. Lake Simcoe Protection Plan

The LSPP sets out ambitious targets for improving water quality in the lake and its tributary rivers and streams, and a number of policies for achieving these targets. The water quality targets are as follows:

- 7 mg/L dissolved oxygen in Lake Simcoe (which equates to a phosphorus load to the lake from all sources of approximately 44 tonnes/year).
- Reduce pathogen loading to eliminate beach closures.
- Reduce total phosphorus levels that achieve Provincial Water Quality Objectives or better, being 20 µg/L for lakes and 30 µg/L in rivers and streams.

The policies to achieve these targets include the following requirements for managing stormwater:

- Preparation and implement comprehensive SWM master plans for each settlement area in the Lake Simcoe basin.
- Municipalities are to incorporate policies related to reducing stormwater runoff volume and pollutant loadings from major development and existing settlement areas into their official plans.
- Applications for major development must be accompanied by a SWM plan that demonstrates, among other requirements:
    - an integrated treatment train approach to SWM;
    - how changes between the pre- and post-development water balance will be minimized; and,
    - how phosphorus loadings will be minimized.
- Every owner and operator of a new SWM works to inspect and maintain the works on a periodic basis.

3.1.3. Flood-prone Areas

Flooding is the most significant natural hazard that exists in the East Holland River watershed[37]. Flooding concerns in the East Holland River include inundation of backyards, groundwater intrusion into basements, streambank erosion, and local drainage problems not associated with streams. Generally, flood hazards include both inundation and fluvial erosion risks. Inundation is the rise of water levels that result in flooding of structures and infrastructure while fluvial erosion is the erosion of riverbed and bank material causing undermining of structures and infrastructure. Flooding and erosion are natural occurrences that become hazards when they threaten human lives and built assets. These hazards are exacerbated by human development and channel modification.

The ability of SCMs to mitigate floods was assessed for six flood-prone areas (Figure 3-4). These sites were a subset of 22 sites identified through discussions with local officials and review of existing stormwater master planning documents[38,39,40,41]. However, 16 of these sites were removed from further analysis because of a lack of adjacent structures below the 100-year storm elevation or because the sites were not represented in the hydrologic model used for flood flow analysis.[6] The analysis focused on inundation risks associated with rising stream levels for the six analyzed sites.

While SCMs may help mitigate flooding by capturing overland flow from impervious surfaces, other factors can drive the flood risks at a specific site. For example, one flood-prone area on Harriman Road in the Town of Aurora experiences erosion and flood risks due to a series of undersized culverts, which exacerbate the impact of flood events[42]. Under-sized culverts and bridges appear to be a common occurrence in the watershed[43,44]. The design storms and modelling used to assess flooding are described further in Section 3.4.4.

[6] This is a HEC-RAS model set up to complement LSPC by generating estimates of flood water elevations based on predicted peak flow rates during flood flows.

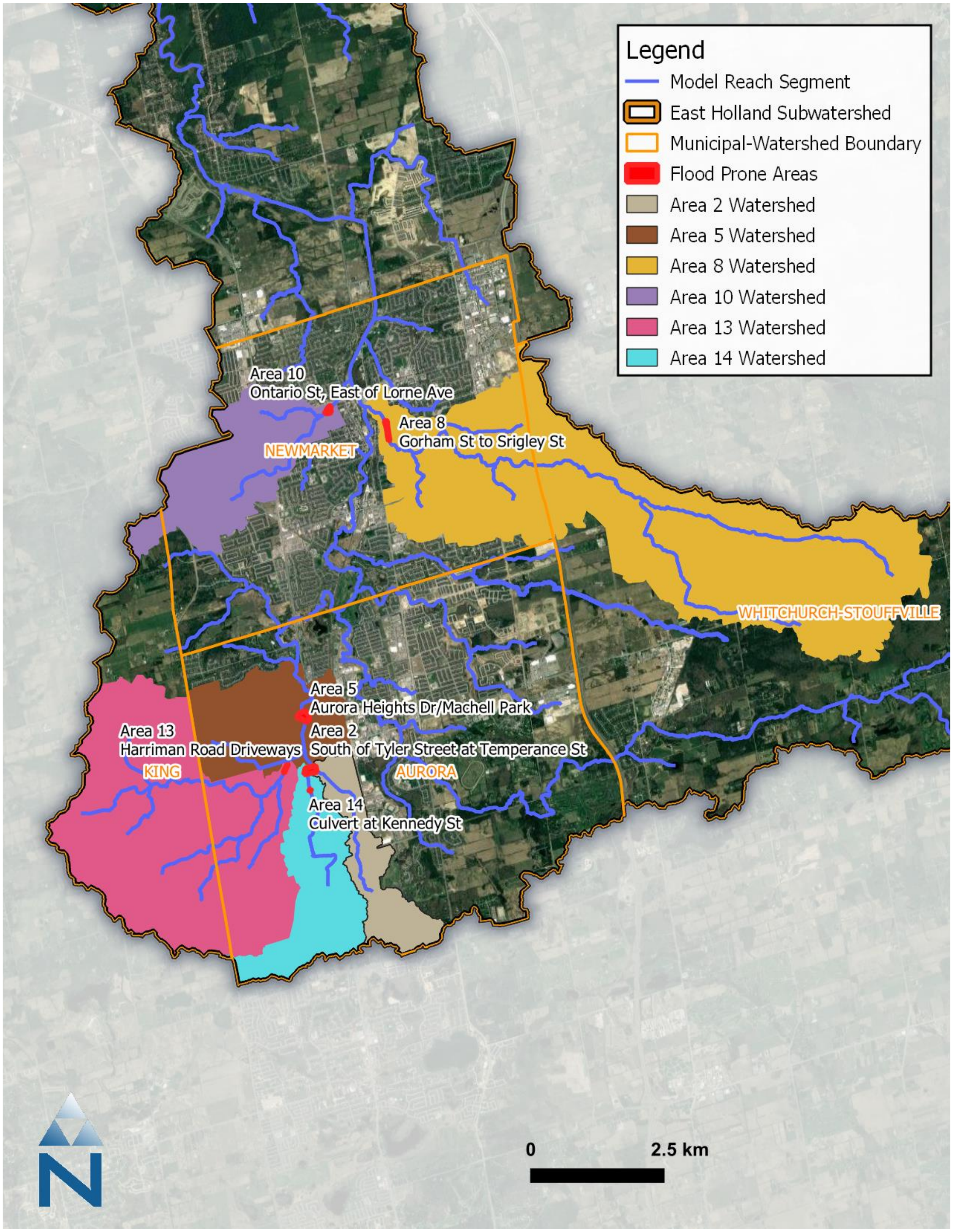


Figure 3-4: Assessed flood-prone areas

3.2. Model Selection and Methodology

As shown in Figure 3-5, the modelling system used to address the study design is composed of a Current State model built with LSPC and a Future State model built with the SUSTAIN. The selection of these models was based on the determination of the following required characteristics:

- Open source: allows for modelling files to be readily transferred without hindrance by licensing fees or intellectual property restrictions
- Continuous simulation: supports analysis of an array of critical conditions, ranging from 12-hour flood storms to average years and decades
- Process-based: allows for simulation of key routines that drive pollutant transport (e.g., build-up, wash off) and are key for mitigation of hydrology and water quality with SCMs (fill-up, draw-down and bypass of SCMs during small and large storms)
- Peer-reviewed and applied in numerous watersheds: increases reliability and confidence in model outputs

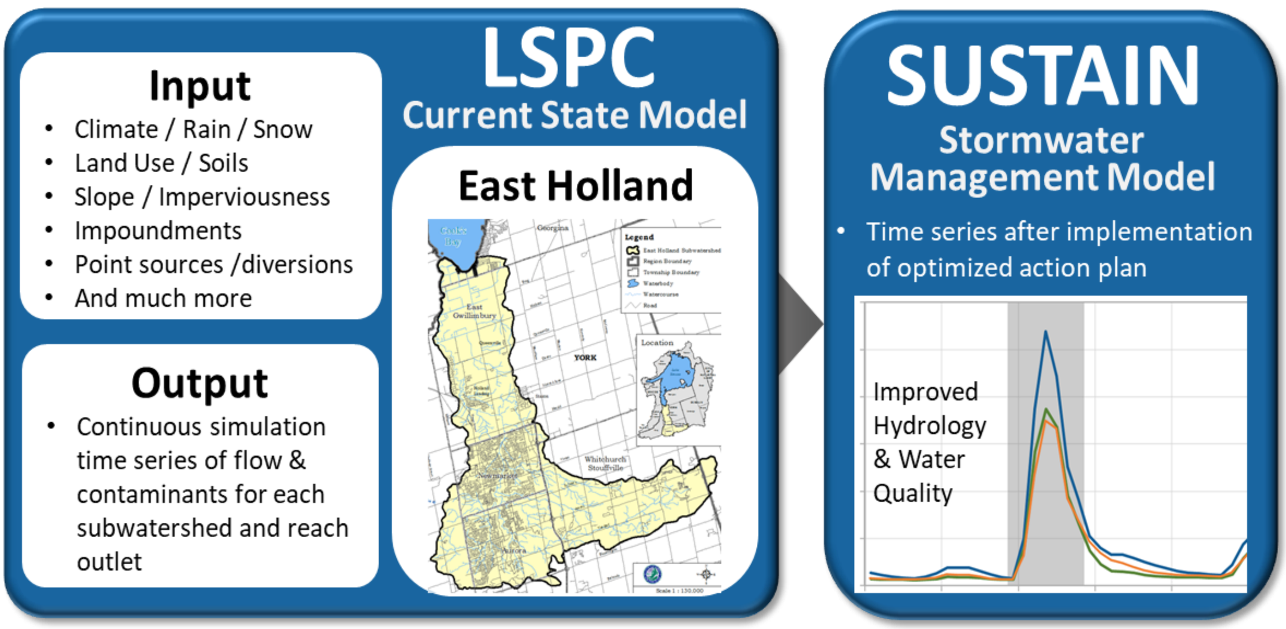


Figure 3-5: Overview of open-source, process-based modelling system developed for the System-wide SWM study

The two selected models based on these requirements, LSPC and SUSTAIN, are described below.

3.2.1. Current State Model: LSPC

The first component of this study, the Current State model utilized a hydrologic model, LSPC[45], to simulate baseline hydrologic and water quality conditions for the East Holland River watershed. The baseline LSPC simulation served as the 'boundary', or base case, condition for the 'Future State' model, described in this report. The LSPC generates a time series to represent hydrology at the landscape level. Figure 3-6 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.[46]

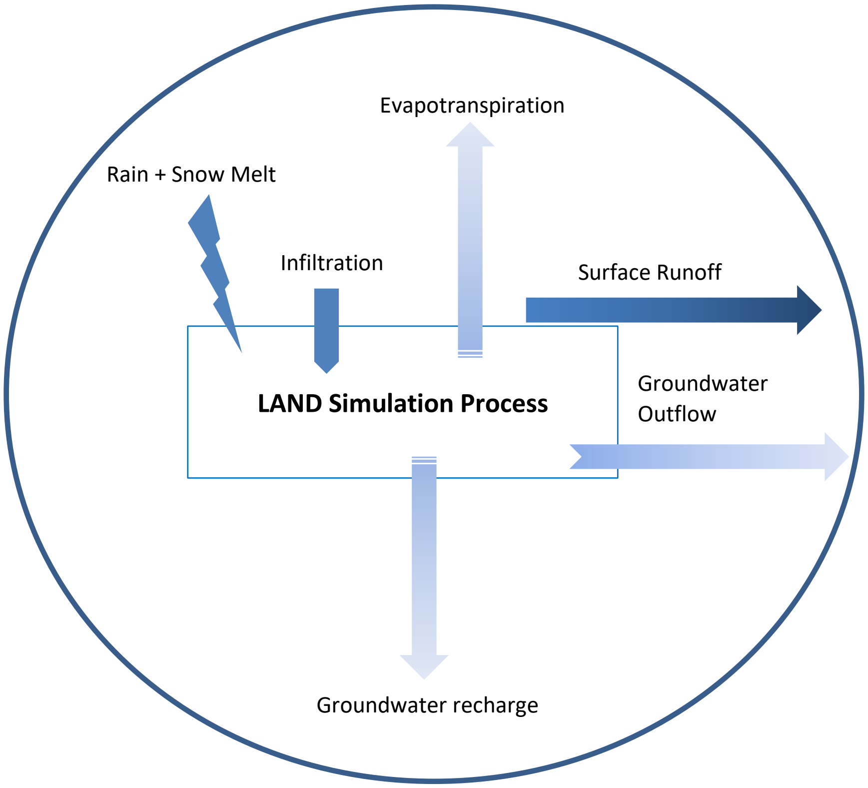


Figure 3-6: LSPC modelling system for the East Holland watershed study area

A watershed model like LSPC is essentially a series of algorithms for representing the interaction between meteorology and land surfaces, resulting in surface and subsurface flows that generate and distribute contaminants to streams, lakes or coastal waters. The LSPC model simulates flow accumulation and transport of contaminants instream, subject to a range of transformational processes (e.g., deposition, resuspension, scour, desorption, nitrification, denitrification). Through the combination of erosion, build-up, wash-off, and transformational processes, LSPC is capable of dynamically simulating flow, sediments, nutrients, metals, dissolved oxygen, temperature, and other contaminants for pervious and impervious lands and waterbodies of varying stream order. LSPC has been used by the United States Environmental Protection Agency (USEPA) in thousands of watersheds across the U.S. to develop water quality improvement plans for bacteria, nutrients, metals, toxics and more.

The algorithms of LSPC were developed from a subset of those in the Hydrological Simulation Program – FORTRAN (HSPF)[47]. The hydrologic portion of HSPF/LSPC is based on the Stanford Watershed Model[48], which was one of the pioneering watershed models. Over time, there have been several upgrades to LSPC with the latest version being 6.0, which is the 64-bit version created in 2019. The most recent version of the LSPC user manual can be downloaded from the open-source repository: LSPC User Manual).

LSPC is built upon a relational database platform, meaning that process-based parameters are organised or associated with physical characteristics of the model at various layers (i.e., sub-watershed, land type, stream type)[49]. LSPC integrates GIS outputs, comprehensive data storage and management capabilities, the original HSPF algorithms, and a data analysis/post-processing system into a convenient PC-based Windows environment.

3.2.2. Future State Model: SUSTAIN

SUSTAIN is a decision support tool developed by the USEPA to assist SWM professionals develop strategies to protect source waters and meet water quality goals. 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[50]. Released in 2003, SUSTAIN allows practitioners to evaluate the cumulative impacts of SCM implementation on urban hydrology and water quality across a watershed[51]. SUSTAIN is a composite of a number of other models and simulation modules integrated into a cohesive, powerful framework [52,53,54,55,56]. SUSTAIN's key components include a watershed module, an SCM module, and an optimization module:

- The watershed module simulates watershed hydrology, transport, and water quality processes through a network of model nodes linked by conveyances such as stream channels and overland flow routes (e.g., SCMs).
- The SCM module allows a process-based simulation of SCMs based on physically represented features such as ponding sites, soils, infiltration and percolation of stormwater to underlying native soils. SCMs can be individually configured by their type (e.g., dry pond, bioretention), dimension, flow routing, performance, and cost.
- Lastly, the optimization module searches for optimal SCM implementation strategies by iterating through various combinations of type, size, location and configuration of SCMs. This search uses a mathematical routine known as a Non-dominated Sorting Genetic Algorithm II (NSGA-II) that sorts through millions of potential SCM strategies to identify optimal configurations based on multiple interacting and competing scales and factors (e.g., cost, configuration, and effectiveness)[57].

SUSTAIN uses optimization algorithms to identify cost-effective SWM solutions. These solutions are optimal combinations of SCM types and sizes at strategic locations on the landscape, identified through thousands of computer iterations. They are optimal because they achieve desired water quality and flow objectives at least cost. Of the overall modelling process illustrated previously in Figure 3-1, this report represents Steps 2 through 6, and describes the establishment of targets, the generation of optimization curves, the quantification of the effectiveness of SCM implementation at achieving targets, the comparison of costs and benefits among alternatives, and the selection of a strategy to achieve water quality and flood mitigation goals.

SUSTAIN has been used to assess urban runoff and the capability of SCMs to improve water quality in a number of research efforts[58,59,60,61,62,63] and watershed-scale implementation efforts[64,65,66,67].

3.3. Economic Framework & Benefits Analysis Methodology

By economic framework, it is meant the specific cost and benefit criteria used in this study to evaluate alternative SWM strategies. As already discussed, SUSTAIN uses cost-effectiveness as its criteria for identifying optimal strategies. Using these criteria SUSTAIN searches the combination of SCM options that achieve stipulated watershed goals at least cost.

The least cost criteria goes beyond the conventional and singular focus on capital costs that often characterized earlier infrastructure planning studies. The analysis is based on life-cycle costs, meaning, capital, O&M and replacement costs over the expected life span of the various SCMs are taken into account. These costs are captured in a summary measure of the annual cost for each type of SCM based on initial capital costs plus operating, maintenance and replacement costs incurred over a 30-year period. This summary annual cost includes the on-going annual O&M costs plus an annualized measure of costs for the initial investment and subsequent major replacements calculated as the amortized value of these costs. This amortized cost is equivalent to the mortgage payment you might make every month for your home and is estimated assuming a 30-year time period, 3% annual inflation and 5% cost of capital.

3.3.1. Determining Avoided Flood Damage Costs

Flood damages are 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 are 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.[7] The calculation accounts for uncertainty by considering a wide range of floods from the smaller floods that are expected, say, every 2 to 5 years to the very large floods that are expected once every 100 years or more. Damages from these events are averaged taking into account their probability of occurrence to estimate average annual flood damage.

The total damage caused by flooding includes direct damage to buildings and their contents and to municipal infrastructure like roads, bridges, parks and storm sewers as well as indirect damages associated with business closures, missed employment and other types of disruption caused by flooding. The calculation is repeated for each of flood-prone areas in the watershed, all located in Aurora and Newmarket.

The calculation of flood damages begins with a detailed inventory of structures in the flood plain that classifies buildings using descriptors such as type of use, quality, size and elevation. The classification by type of use includes 9 residential categories and 20 industrial, commercial and institutional (ICI) categories. For each of these categories, the direct flood damage was estimated using damage curves for structures that estimate damage incurred by a structure at successively higher levels of inundation.[8]

Other damages caused by flooding are direct damages to public infrastructure (roads and other linear infrastructure, bridges, parklands, streambanks) and indirect damages, which include emergency response costs (e.g., evacuation, temporary flood proofing), lost income and employment, time and expense of post flood responses, general inconvenience, etc. Based on a review of flood damage research, we assume that direct public damages are 15% of direct residential and non-residential damages; and that indirect damages are 12.5% of direct residential damages and 30% of direct ICI damages.

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[7] 5% nominal discount rate, 3% inflation, 1.9% real discount rate

[8] Developed in 2015 for the Government of Alberta IBI Group and Golder Associates Ltd., 2015, op. cit. These were adjusted to account for cost inflation and Alberta-Ontario construction cost differentials.

The damage curve for an individual structure shows the amount of damage expected to occur at successive levels of flooding relative to the first floor. Damages are assumed to commence once the flood level reaches the level of the first opening into a building which may be the first-floor entryway, or in the case of buildings with basements, a basement window or entryway. Damages at each flood elevation for each building are then added together to determine total damages for the flood prone area. The resulting curve, called a flood stage damage curve, shows all direct plus indirect flood damage costs at each level of flooding as illustrated in Figure 3-7 below showing aggregated damages for flood-prone areas in Aurora and Newmarket. Stage damage curves aggregated by municipality are provided in section 4.4. Measured at the level of the 100-year flood, residential and ICI damages account, respectively, for 43% and 57% of total damages, while direct and indirect damages account respectively for 71% and 29% of total damages.[9]

Damages at each flood elevation for each building are then added together to determine total damages for the flood prone area. The resulting curve, called a flood stage damage curve, shows all direct plus indirect flood damage costs at each level of flooding as illustrated in Figure 3-7 below showing total damages for a flood-prone area in Newmarket. Stage damage curves aggregated by municipality are provided in section 4.4. Measured at the level of the 100-year flood, residential and ICI damages account, respectively, for 43% and 57% of total damages, while direct residential and ICI damages account for 71% of total damages.

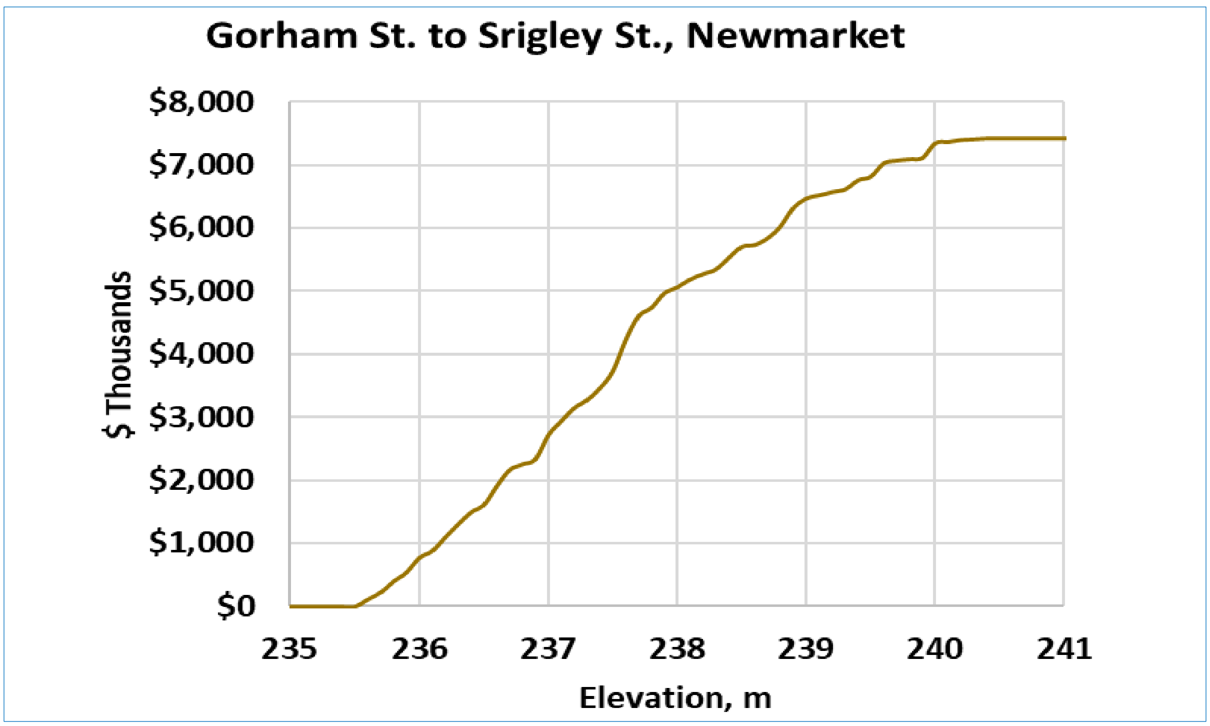


Figure 3-7: Example flood damage curve

Another way of depicting flood damages, shown in Figure 3-8, plots damages against the return frequency of the flood flow rather than the level of the flood. The 100, 50, 25, 10, and 5-year floods, have a 1%, 2%,4%, 10%, and 20% chance of occurring in any given year, respectively. As the return frequency goes lower, the storm becomes larger and less frequent. The blue line represents existing conditions and the orange line, flood

[9] Water's Edge Environmental Solutions Team Ltd, W.F. Baird & Associates Coastal Engineers Ltd., Planning Solutions Inc., 2007. Flood Damage Estimation Guide 2007 Update and Software Guide. Prepared For: Ontario Ministry of Natural Resources. IBI Group, Golder Associates Ltd., 2015, Provincial Flood Damage Assessment Study. Prepared for Government of Alberta

damages after SWM measures are implemented. In the case depicted, flood damages up to the 20-year flood are eliminated, and damages for larger floods up to the 100-year flood are marginally reduced.

This reduction in damages, expressed in terms of average annual damages, is the value to consider when comparing the costs of conventional and green SWM measures to the benefits.

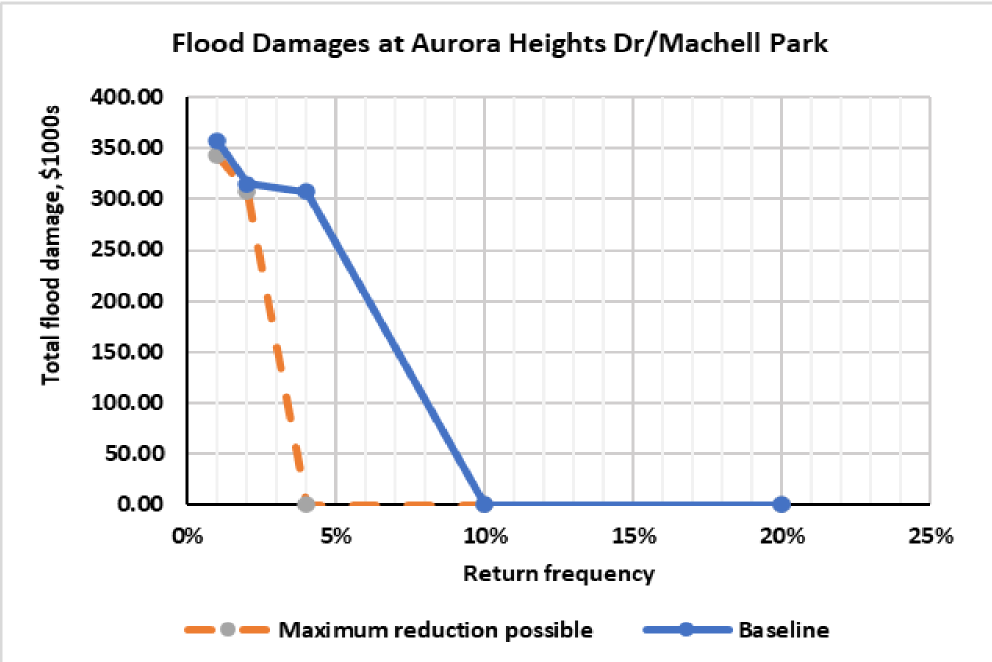


Figure 3-8: Flood damages by return frequency

Objectives imposed as targets in SUSTAIN can be either water quality or flood flow goals. The water quality objective of a 40% reduction in loading of phosphorus to Lake Simcoe are derived from the Lake Simcoe Protection Plan and associated Phosphorus Reduction Strategy. Flood control has been evaluated primarily by considering the impact of SCMs on peak flows and the resulting flood damages expected to occur at flood prone areas. The estimate of flood damage reductions for this study involved a detailed inventory of flood plain buildings and estimation of the damages to their structure and contents that these buildings would incur at levels of inundation ranging from the 10-year to the 100-year flood, i.e. during floods that are expected on average once every 10 to 100 years.

The flood damage calculation takes into account the type of structure based on 33 categories of residential, industrial, commercial or institutional buildings. It also accounts for the presence of features such as basements, a split-level design and garages, which all affect the severity of damage. A final adjustment is made to estimated direct damages to structures, to account for indirect damages associated with such things as the disruption of business and loss of employment income and to account for damages to public infrastructure such as roads.

3.3.2. Co-benefits – A Qualitative Analysis

In addition to improved water quality and reduced risk of flooding, SCMs, non-structural practices (e.g., no till agriculture) and natural assets provide other multiple benefits. There are well established methodologies for determining flood damage reductions, but other 'co-benefits' of SCMs, both individual and those used in combination as an integrated system, are not so easily quantified using a dollar yard-stick. Co-benefits such as an aesthetic enhancement, improved groundwater recharge or increased biodiversity have been well documented for various SCMs, but the monetization of such co-benefits is highly complex and an evolving discipline with no recognized standard for monetary valuation.

For two principal reasons, this study did not attempt to quantify, in monetary units, a value for the multiple co-benefits of selected SCMs or System-wide SWM for two principal reasons:

1) To date, there is no universally accepted standard or methodology[68] for ascertaining the monetary value of multifunctional benefits or co-benefits.

   Increasing recognition of the multiple benefits of natural assets and GI, both individually and collectively as an integrated 'eco-system', has led to efforts to quantify the value of the benefits in monetary terms. Determining a dollar value for co-benefits presents several challenges. Firstly, a given feature, such as a bioretention facility or an existing wetland, provides multiple benefits simultaneously. Secondly, due to the scope and high degree of complexity of co-benefits generated by a SWM practice or feature, it is extremely difficult to determine a dollar value equivalent for all but a limited few. Lastly, methods, tools and units of measurement apply to different types of co-benefits and, both determining the benefits themselves and quantifying those benefits involves a degree of subjectivity.

2) The goals of the study were to analyse and compare the life-cycle cost-effectiveness of System-wide SWM – as defined by the study principles – with the typical municipal approach to SWM. A direct, monetized comparison of co-benefits of each SCM, given different SCMs provide different co-benefits with each co-benefit requiring a different form of measurement[69], would not produce reliable monetary values for an accurate comparison and was beyond the scope of the project.

For the study, co-benefits were identified and evaluated using a qualitative scale rating scale (Table 3-2) 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. Findings from a comprehensive leading jurisdictions research (Appendix 2) and an extensive literature review, including peer-refereed journals and reports from recognized government agencies and subject expert organizations, informed the development of criteria by which the potential or capacity of a SCM to produce a given co-benefit was qualitatively evaluated.

Table 3-2: Rating assignment based on the capacity or potential of the SCM to realize the co-benefit

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

Management strategies, both modelled (representative) and those to be targeted for future implementation, were qualitatively evaluated. The co-benefits determined via an extensive literature review for individual SCMs were identified, verified (to the degree possible) and tabulated. The results of this qualitative analysis are presented in Section 4.5.

3.4. Establishing the Current State for Hydrology and Water Quality

The Current State modelling report, attached as Appendix 1, provides comprehensive details of the LSPC configuration, calibration and simulation of flood design storms. This section provides a higher-level overview of Current State model development.

3.4.1. Modelling Overview

A Current State model was configured and calibrated to provide the 'baseline' for establishing existing hydrology and water quality conditions in the East Holland River watershed[70].

The process to develop the Current State model was iterative and adaptive – model application included incrementally increasing the resolution of the model by incorporating smaller sub-catchment areas and additional land use types, incrementally incorporating data and findings from previous studies, and adjusting parameters to better match observed data. In the long-term, the vision for the Current State model is a 'living' platform that evolves as additional data are collected and lessons are learned from other efforts in the watershed. This long-term vision also foresees a Current State model that can inform future data acquisition efforts by highlighting gaps in the predictive capability of the model and corresponding factors that have the most impact on conditions in the East Holland River.

3.4.2. Configuration

3.4.2.1. Sub-catchments and jurisheds

A primary element of hydrologic model development is watershed delineation. Identifying watershed boundaries enables modellers to portray specific characteristics of the region's watersheds such as slope, land use, impervious cover, climatic variations, elevation, etc. to simulate the hydrology of the region. A fine resolution sub-catchment delineation provides increased spatial resolution and model accuracy for predicting hydrologic characteristics within a watershed. Figure 3-9 presents the 273 LSPC sub-catchments in the East Holland River watershed utilized for this report, organized by municipality. While the LSPC sub-catchment delineation purposely did not account for municipal boundaries, the resulting polygons were intersected with jurisdictional boundaries to produce 'jurisheds' presented in Figure 3-9. A jurished is 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. The East Holland River Watershed was modeled with 273 sub-catchments, these sub-catchments were further divided into 314 jurisheds based on municipal boundaries.

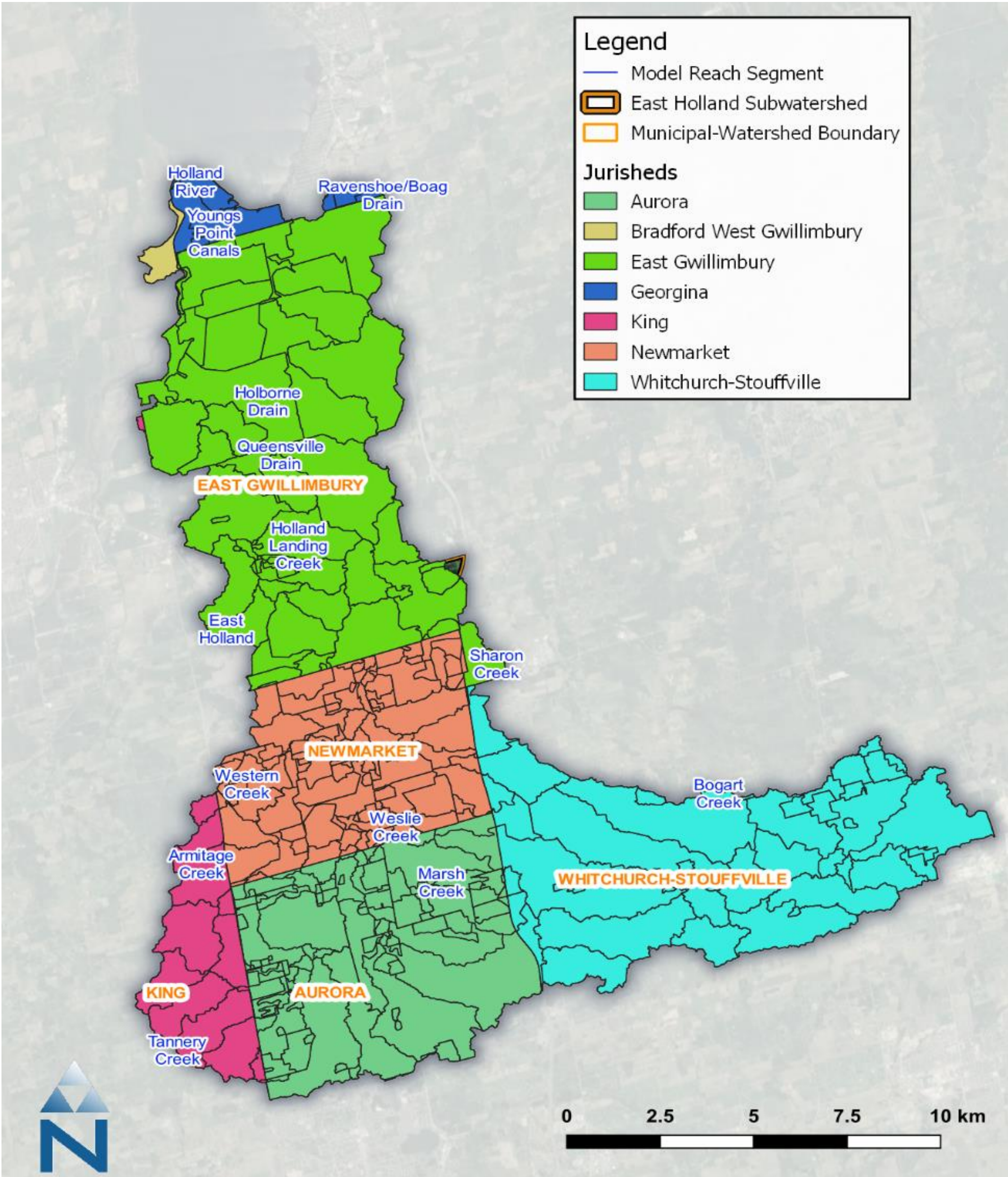
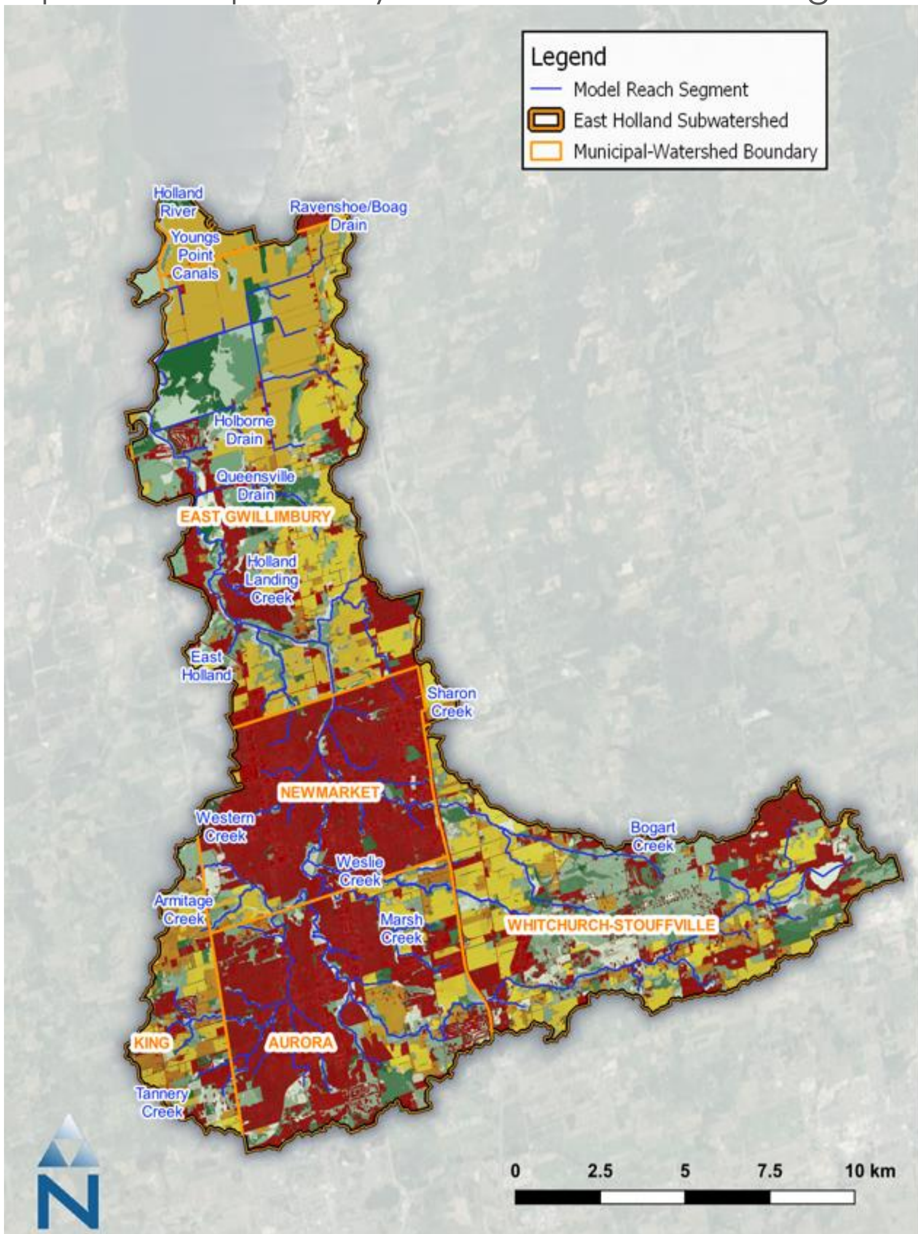


Figure 3-9: Sub-catchments and municipalities in East Holland River watershed

3.4.2.1.1. Hydrologic Response Units

For purposes of the simulation modelling with LSPC, the land area of the watershed is divided into land units called Hydrologic Response Units (HRUs). For each HRU, process-based parameters reflecting differences in geology, soils, vegetation, and land cover govern the rates and volumes of water at each stage throughout a simulated period. These HRUs are the core hydrologic modelling land units in the watershed model. Each HRU represents areas of similar physical characteristics attributable to certain processes. The HRUs are delineated by reference to the major data types that are available and local knowledge of the major drivers of hydrology in the watershed. For the East Holland River, four categories of land characteristic were used to create the HRUs: slope, soils, land cover, and geology. The areal combination of these primary landscape characteristics ultimately determined the number of meaningful HRU categories considered for the model. Some consolidation of HRUs was implemented to balance the need for spatial resolution with model simulation efficiency. Figure 3-10 presents the HRUs for the East Holland River watershed.



Hydrologic Response Groups

1111	Agriculture_High-A-Low-1
1112	Agriculture_High-A-Low-2
1121	Agriculture_High-A-Med-High-1
1122	Agriculture_High-A-Med-High-2
1211	Agriculture_High-B-Low-1
1212	Agriculture_High-B-Low-2
1221	Agriculture_High-B-Med-High-1
1222	Agriculture_High-B-Med-High-2
1311	Agriculture_High-C-Low-1
1312	Agriculture_High-C-Low-2
1321	Agriculture_High-C-Med-High-1
1322	Agriculture_High-C-Med-High-2
1411	Agriculture_High-D-Low-1
1412	Agriculture_High-D-Low-2
1421	Agriculture_High-D-Med-High-1
1422	Agriculture_High-D-Med-High-2
2111	Agriculture_Low-A-Low-1
2112	Agriculture_Low-A-Low-2
2121	Agriculture_Low-A-Med-High-1
2122	Agriculture_Low-A-Med-High-2
2211	Agriculture_Low-B-Low-1
2212	Agriculture_Low-B-Low-2
2221	Agriculture_Low-B-Med-High-1
2222	Agriculture_Low-B-Med-High-2
2311	Agriculture_Low-C-Low-1
2312	Agriculture_Low-C-Low-2
2321	Agriculture_Low-C-Med-High-1
2322	Agriculture_Low-C-Med-High-2
3111	Natural_Heritage_Open-A-Low-1
3112	Natural_Heritage_Open-A-Low-2
3121	Natural_Heritage_Open-A-Med-High-1
3122	Natural_Heritage_Open-A-Med-High-2
3211	Natural_Heritage_Open-B-Low-1
3212	Natural_Heritage_Open-B-Low-2
3221	Natural_Heritage_Open-B-Med-High-1
3222	Natural_Heritage_Open-B-Med-High-2
3311	Natural_Heritage_Open-C-Low-1
3312	Natural_Heritage_Open-C-Low-2
3321	Natural_Heritage_Open-C-Med-High-1
3322	Natural_Heritage_Open-C-Med-High-2
3411	Natural_Heritage_Open-D-Low-1
3412	Natural_Heritage_Open-D-Low-2
3421	Natural_Heritage_Open-D-Med-High-1
3422	Natural_Heritage_Open-D-Med-High-2
4111	Natural_Heritage_Treed-A-Low-1
4112	Natural_Heritage_Treed-A-Low-2
4121	Natural_Heritage_Treed-A-Med-High-1
4122	Natural_Heritage_Treed-A-Med-High-2
4211	Natural_Heritage_Treed-B-Low-1
4212	Natural_Heritage_Treed-B-Low-2
4221	Natural_Heritage_Treed-B-Med-High-1
4222	Natural_Heritage_Treed-B-Med-High-2
4311	Natural_Heritage_Treed-C-Low-1
4312	Natural_Heritage_Treed-C-Low-2
4321	Natural_Heritage_Treed-C-Med-High-1
4322	Natural_Heritage_Treed-C-Med-High-2
4411	Natural_Heritage_Treed-D-Low-1
4412	Natural_Heritage_Treed-D-Low-2
4421	Natural_Heritage_Treed-D-Med-High-1
4422	Natural_Heritage_Treed-D-Med-High-2
5111	Natural_Heritage_Shrub-A-Low-1
5112	Natural_Heritage_Shrub-A-Low-2
5121	Natural_Heritage_Shrub-A-Med-High-1
5122	Natural_Heritage_Shrub-A-Med-High-2
5211	Natural_Heritage_Shrub-B-Low-1
5212	Natural_Heritage_Shrub-B-Low-2
5221	Natural_Heritage_Shrub-B-Med-High-1
5222	Natural_Heritage_Shrub-B-Med-High-2
5311	Natural_Heritage_Shrub-C-Low-1
5312	Natural_Heritage_Shrub-C-Low-2
5321	Natural_Heritage_Shrub-C-Med-High-1
5322	Natural_Heritage_Shrub-C-Med-High-2
5411	Natural_Heritage_Shrub-D-Low-1
5412	Natural_Heritage_Shrub-D-Low-2
5421	Natural_Heritage_Shrub-D-Med-High-1
5422	Natural_Heritage_Shrub-D-Med-High-2
6111	Dev_Pervious-A-Low-1
6121	Dev_Pervious-A-Med-High-1
6211	Dev_Pervious-B-Low-1
6221	Dev_Pervious-B-Med-High-1
6311	Dev_Pervious-C-Low-1
6321	Dev_Pervious-C-Med-High-1
7000	Dev_Roof-IMP-IMP-IMP
8000	Dev_Residential_Low-Medium-IMP-IMP-
9000	Dev_Residential_Medium-High-IMP-IMP-
10000	Dev_Commercial-IMP-IMP-IMP
11000	Dev_Industrial-IMP-IMP-IMP
12000	Dev_Transportation-IMP-IMP-IMP
13000	Water-IMP-IMP-IMP

Figure 3-10: East Holland river HRUs

3.4.2.1.2. Groundwater representation

Processes impacting baseflow, interflow, and groundwater recharge were represented both on the land and within stream channels. On the land surface, geologic information was incorporated into the HRUs using data from the E-Flows study developed in 2018. Within the stream channel, in-stream losses were simulated based on groundwater flux information provided by the Oak Ridges Moraine Groundwater Program (Figure 3-11). The data was extracted from a coupled groundwater/surface water model built using GSFLOW, the integration of PRMS and MODFLOW maintained by the USGS.

Streamflow losses to groundwater (mm/hr) were used as a calibration parameter to improve agreement between observed and predicted flows in the watershed upstream of the Vandorf gauge. An initial value, based on analysis of the groundwater data, of 0.005 mm/hr was applied to the model reaches. During calibration this value was increased to 1.72 mm/hr to achieve improved results. The incorporation of groundwater losses to the Vandorf gauge watershed resulted in improved representation of processes known to occur in the region. Further refinement of groundwater dynamics is possible in LSPC, including varying the loss rate seasonally. However, while such changes would result in increasing the complexity of the model, they are not expected to meaningfully improve the agreement between existing and predicted flows in the area. The relatively high rate of 1.72 mm/hr that was required to improve results suggests that the model was not very sensitive to the loss parameter. Additionally, observed discharge at the Vandorf gauge were limited to approximately two years of data; a longer dataset could help to justify any seasonally-based adjustments to stream flow losses to groundwater. Additional information on groundwater representation can be found in the Current State Modelling Report (Appendix 1).

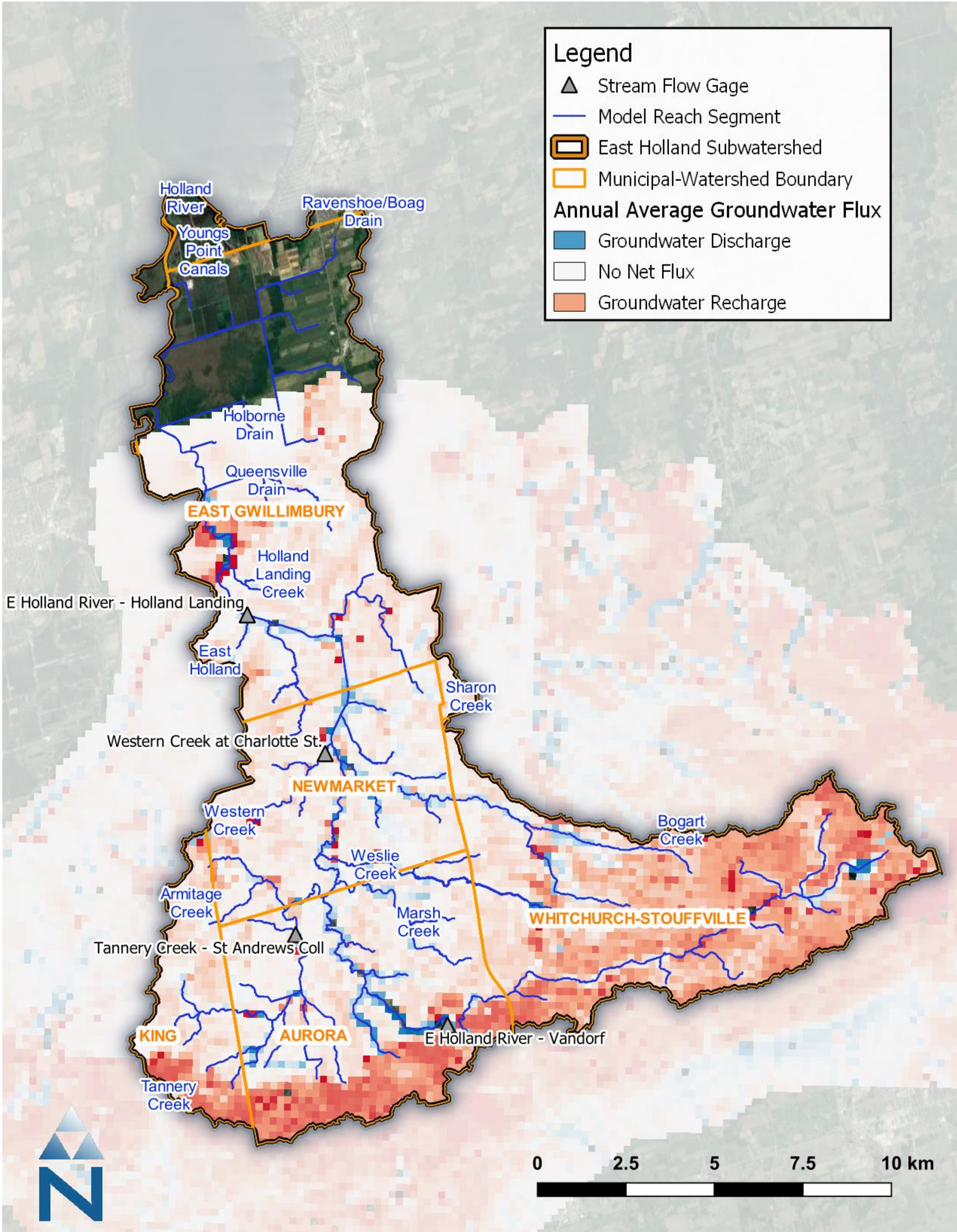


Figure 3-11: Average annual groundwater flux from GSFLOW data (Source: Oak Ridges Moraine Groundwater Program)

3.4.3. Calibration

3.4.3.1. Approach

The East Holland River watershed modelling approach leveraged local data sources, research efforts, and followed internationally recognized modelling protocols and conventions. For example, the 2002 EPA guidance document on developing Quality Assurance Project Plans (QAPP)[71] for modelling refers to calibration as the configuration and refinement of the analytical instruments that will be used to generate analytical data to support the decision-making process. The "instrument" is the predictive tool (i.e., the model) that is to be developed and/or applied.

Demonstrating reasonable model calibration is key to the model development process, as it forms the basis for establishing the degree of confidence and uncertainty in model predictions and the reliability of the model for making management decisions. Models are deemed acceptable when they can simulate field data within a reasonable range of statistical accuracy, as described in the baseline modelling report.

After weather data and meteorological boundary conditions are well established, a top-down weight of evidence 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.

Figure 3-12 presents a schematic showing the parameterization and calibration sequence for land hydrology and stream transport. Unit-area results from this step were summarized and compared relative to each other and against representative published literature values. This step provides an early opportunity to identify possible errors, anomalies, or other unrepresentative behavior prior to aggregation, instream routing, and transport. Next, outputs from land hydrology are aggregated and routed to the stream transport model. In some cases, other features such as SWM ponds, diversions, withdrawals, and point sources influence the water balance.

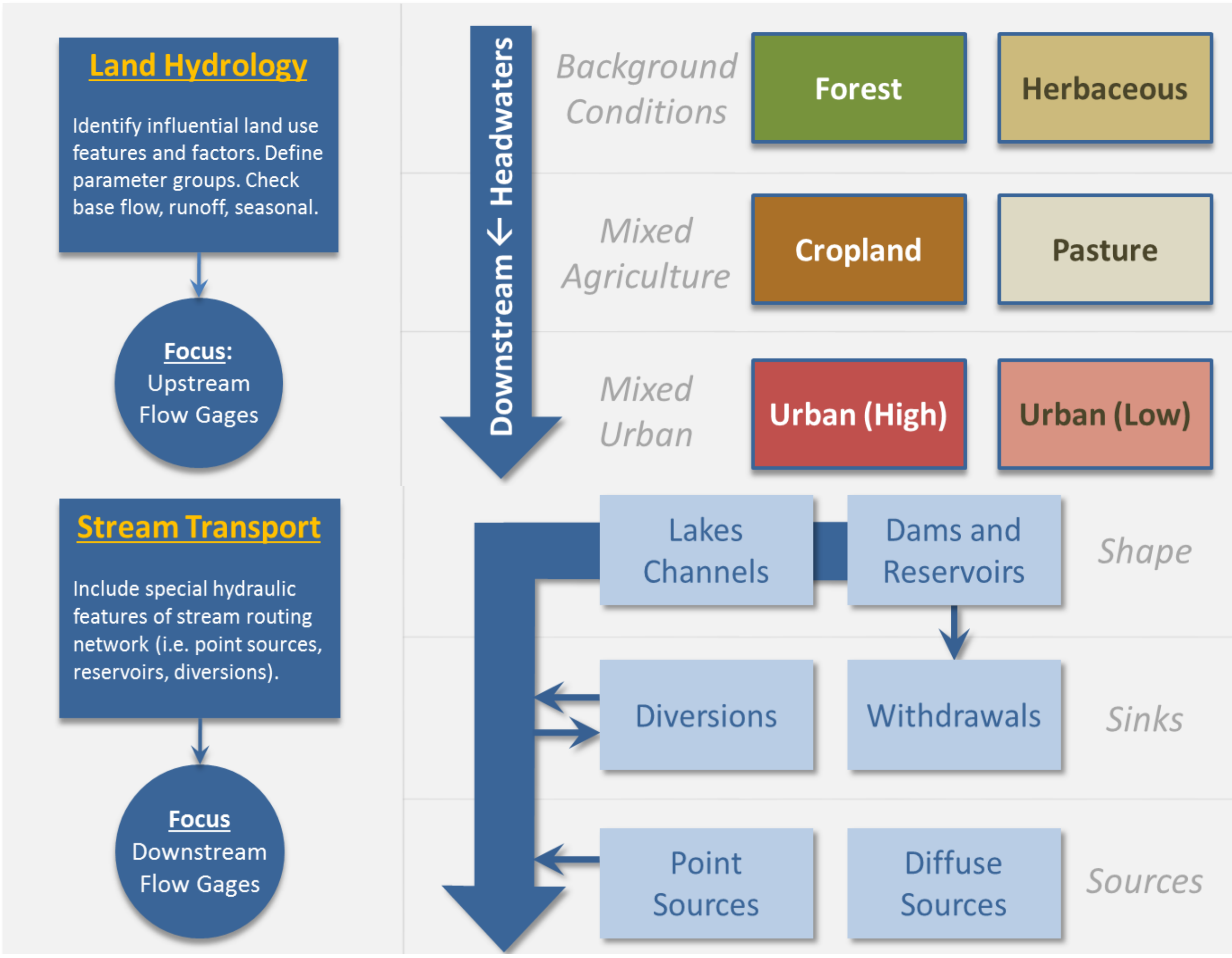


Figure 3-12: Model parameterization and calibration sequence for land hydrology and stream transport

3.4.3.1. *Model Performance*

Calibration was assessed using a combination of visual assessments and computed statistical evaluation metrics. Visual assessment involved reviewing plots of simulated vs observed outputs, which are presented in the following sections, and review of the simulated conditions during the sampling period for pollutant loadings (2011-2012) at Holland Landing. For statistical assessment of model performance, agreement between LPSC outputs and observed data was assessed using performance metrics based on those recommended by Moriasi et al[72]. These performance metrics are considered highly conservative, and it is very rare to receive "Very Good" evaluations across all metrics – "Satisfactory" is a significant outcome. The metrics are used as a weight of evidence approach to evaluate whether model performance is reasonable.

The hydrology calibration was assessed using a series of graphical outputs called 'calibration panels' and statistical metrics as described the baseline modelling report[73]. The calibration outputs are a result of a series of iterative parameter adjustments based on investigation into model performance compared to observations. The statistical assessment of seasonal hydrological performance for the stream gauges assessed in the baseline report is presented in Table 3-3.

Table 3-3: Hydrologic performance evaluation across all stations by season

Hydrology Monitoring Locations	Performance Metrics (Seasonal)														
	PBIAS					R-squared					Nash-Sutcliffe E				
	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall
Tannery Creek - St Andrews Coll	- (Good)	- (Very Good)	- (Very Good)	+ (Very Good)	- (Good)	(Satisfactory)	(Good)	(Good)	(Very Good)	(Satisfactory)	(Satisfactory)	(Good)	(Good)	(Very Good)	(Good)
Western Creek at Charlotte St.	- (Good)	+ (Very Good)	- (Very Good)	- (Good)	- (Satisfactory)	(Very Good)	(Good)	(Very Good)	(Satisfactory)	(Very Good)	(Very Good)	(Good)	(Very Good)	(Good)	(Good)
East Holland River - Vandorf	+ (Good)	- (Unsatisfactory)	+ (Good)	+ (Unsatisfactory)	+ (Good)	(Unsatisfactory)	(Good)	(Unsatisfactory)	(Satisfactory)	(Satisfactory)	(Satisfactory)	(Good)	(Unsatisfactory)	(Unsatisfactory)	(Satisfactory)
East Holland River - Holland Landing	+ (Very Good)	+ (Very Good)	- (Very Good)	+ (Satisfactory)	+ (Very Good)	(Satisfactory)	(Satisfactory)	(Good)	(Good)	(Very Good)	(Satisfactory)	(Good)	(Very Good)	(Good)	(Very Good)

Very Good | Good | Satisfactory | Unsatisfactory

\+ Positive | - Negative

NOTE: 'PBIAS', 'R-squared' and 'Nash-Sutcliffe E' are the 3 statistical metrics used to assess calibration.

A phased weight-of-evidence approach was used for water quality calibration. An initial set of HRU model parameters were derived based on Paradigm's previous nutrient modelling projects, which incorporate a variety of literature values and the results of model calibration in other watersheds. The water quality calibration effort including two major components: (1) evaluation of resulting pollutant yields and event mean concentrations (EMCs) when compared to literature values and observations studies and (2) comparison to instream concentrations using graphical panels and statistical performance metrics. A graphical panel for total phosphorus is presented in Table 3-4. A review of LSPC calibrated parameters and evaluation metrics as well as a complete set of calibration panels is presented in the baseline modelling report (Appendix 1).

Two important objectives of the 'Current State' modelling effort were to provide representative runoff timeseries at the HRU level to be used as boundary conditions for Future State modelling including: (1) simulation of the benefit of distributed and regional SWM practices modelled in SUSTAIN and (2) peak flow estimates for flood modelling and linkage to HEC-RAS. In addition, outside of the System-wide SWM study, the Current State model generated for East Holland could potentially provide a starting point for a modelling framework that could support Lake Simcoe-wide assessment and tracking of offset programs to mitigate phosphorus. For all of the above application, robust simulation of *storm runoff conditions* and mitigation by SWM practices is a top priority.

The calibrated LSPC model is reasonably calibrated or well-calibrated for storm conditions. The calibrated LSPC current state model provided a satisfactory prediction of hydrology and water quality within the East Holland River watershed. The Current State model achieved 'Very Good' metrics for both the 'Highest 10% of Flows' and seasonal storm volume predictions achieved 'Very Good' across all seasons, suggesting that model simulation of rainfall runoff is representative of measured conditions for an urban/peri-urban watershed. Compared to the hydrology calibration, which compared continuously simulated data to continuously monitored data, water quality comparisons between observed and predicted data is inherently more challenging. This is because a daily average fully mixed model output is being compared to a grab sample result which represents an instantaneous concentration from a single point in the cross section. The NSE metric shows the poorest performance grading. During periods of unsatisfactory NSE results, the residual variance (the variance in the differences between observations and predictions) is larger than the variance of the observed data. NSE is very sensitive to extreme values and also reflects the timing of simulated versus observed values. There is potential that using a single rain gauge for the entire watershed affected the predicted timing of pollutant concentrations and loads. Overall, because a suite of metrics was used to assess performance, calibration to achieve improvements in one metric can result in poorer performance in another metric. Furthermore, for the calibration assessments, the LSPC model performance at Western Creek is excellent. Western Creek is the most representative station for developed/impervious areas within East Holland watershed, which emphasises overland flow, the key driver of SCM performance. The model performance at Western Creek is best of all stations which provides confidence for using the LSPC model as a boundary condition to SUSTAIN. The LSPC model provides a useful and powerful tool for informing stormwater policy and decisions through the EqR4TD project. Additionally, coupling LSPC and HEC-RAS provides an opportunity to assess the flood mitigation benefits of watershed-wide SCM implementation, as described in the following subsections.

Table 3-4: Water Quality Calibration - Performance metrics for total phosphorus load by season and flow regime

Water Quality Monitoring Locations	Performance Metrics (Seasonal)														
	PBIAS					R-squared					Nash-Sutcliffe E				
	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall
East Holland River - Holland Landing	Unsatisfactory -	Unsatisfactory -	Satisfactory -	Very Good -	Very Good -	Satisfactory	Good	Very Good	Good	Good	Unsatisfactory	Satisfactory	Good	Satisfactory	Unsatisfactory
Tannery Creek - Yonge St	Satisfactory -	Unsatisfactory -	Unsatisfactory -	Unsatisfactory +	Very Good -	Satisfactory	Good	Good	Good	Good	Unsatisfactory	Unsatisfactory	Satisfactory	Unsatisfactory	Unsatisfactory
Western Creek	Very Good -	Good +	Very Good -	Good +	Good +	Very Good	Good	Very Good	Very Good	Very Good	Good	Unsatisfactory	Very Good	Very Good	Satisfactory

Water Quality Monitoring Locations	Performance Metrics (Flow Regime)														
	PBIAS					R-squared					Nash-Sutcliffe E				
	All	Top 25%	Storms	Low 50%	Baseflow	All	Top 25%	Storms	Low 50%	Baseflow	All	Top 25%	Storms	Low 50%	Baseflow
East Holland River - Holland Landing	Unsatisfactory -	Satisfactory -	Satisfactory -	Satisfactory +	Very Good -	Satisfactory	Satisfactory	Good	Unsatisfactory	Good	Unsatisfactory	Unsatisfactory	Satisfactory	Unsatisfactory	Unsatisfactory
Tannery Creek - Yonge St	Satisfactory -	Good -	Good -	Unsatisfactory -	Unsatisfactory +	Satisfactory	Satisfactory	Good	Unsatisfactory	Good	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory
Western Creek	Very Good -	Very Good +	Very Good +	Unsatisfactory -	Unsatisfactory -	Very Good	Good	Very Good	Unsatisfactory	Very Good	Good	Good	Very Good	Unsatisfactory	Very Good

Very Good | Good | Satisfactory | Unsatisfactory
+ Positive | - Negative

3.4.4. Simulation of Design Storms

Soil Conservation Service (SCS) Type II design storms have been previously identified as suitable for estimating flood peak flows within the East Holland River watershed[74]. The 12-hour SCS design storm is sufficiently long in duration that the majority of the East Holland River Watershed can contribute to peak flows at the lower reaches and is considered the most appropriate distribution and duration for floodplain mapping in the watershed[75]. For this study, the 10, 25, 50, and 100-year, 12-hour SCS Type II design storms were used to assess the effect of SCM implementation on flood mitigation. Total and peak storm depths for each storm are the same as used in LSRCA[76] and are presented in Table 3-5.

Table 3-5: Summary of the 12-hour, SCS Type-II return period design storms evaluated

Design Storm	Total Depth (mm)	Peak 15-minute Depth (mm)
10-year, 12-hour	62.70	20.69
25-year, 12-hour	73.10	24.12
50-year, 12-hour	80.80	26.66
100-year, 12-hour	88.50	29.20

3.4.4.1. *Peak Flows*

Although LSPC can predict water levels, it is primarily a hydrologic model and does not account for backwater effects and in-channel structures that impact water levels. As such, LSPC output was formatted for input into the Hydrologic Engineering Center River Analysis System (HEC-RAS) model to simulate the mitigation of elevated water levels for optimized management actions. SUSTAIN results were used to calculate the percent reduction in LSPC peak flow rates and HEC-RAS was used to estimate the corresponding water levels pre- and post-SCM implementation. The HEC-RAS model was previously configured as part of a hydrologic and hydraulic modelling study for the West/East Holland rivers and the Maskinonge River watersheds[77]. Goals of the 2005 study included evaluating flood peak flows at key locations and evaluating the impact of future land use changes on peak flow rates.

3.4.4.2. *Hydraulics (HEC-RAS)*

The U.S. Army Corps of Engineers HEC-RAS model allows for one-dimensional steady flow and one and two-dimensional unsteady flow river hydraulics calculations[78]. Figure 3-13 shows features of a stream cross section incorporated into HEC-RAS, including channel profile and adjacent structures, as well as an aerial view showing the same area, structures, and flood inundation boundary.

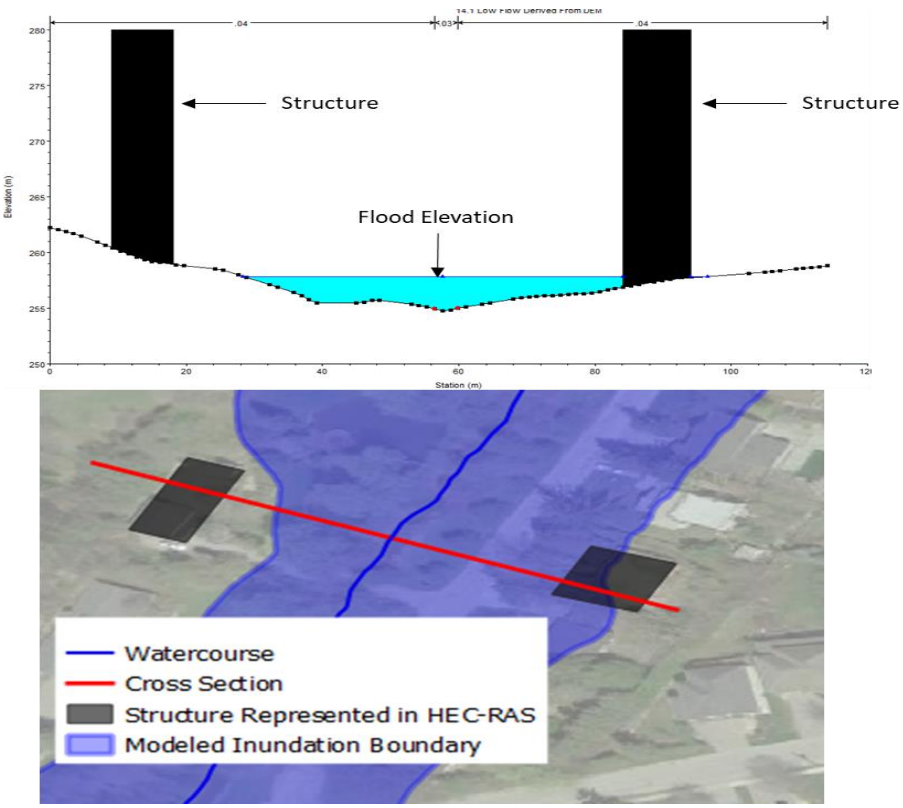


Figure 3-13: HEC-RAS (top) and Aerial (bottom) views of a cross-section

3.5. Projecting Future State Strategies, Outcomes and Cost-benefit

The SUSTAIN decision support system was used to investigate the impact of SCM selection and placement on achieving a given objective. As SCM sizes and locations change in SUSTAIN, so do cost and performance. SUSTAIN runs iteratively to generate a cost-effectiveness curve comprised of millions of SCM scenarios. These scenarios are constrained by the assumptions and decisions discussed below.

3.5.1. Major Decisions Analysed by Scenario

The major focus of analysis using SUSTAIN addressed the costs and benefits of a 'business as usual' approach compared to a transformational watershed-scale, SCM implementation program to improve water quality and reduce flooding. Business as usual generally involves municipalities paying for and constructing SCMs on public lands within their own boundaries without major consideration of watershed-scale opportunities or constraints outside their boundaries. Alternatively, a transformational SCM implementation program would ensure equitable responsibility for managing stormwater, consider SCM implementation on both public and private land, and would not be constrained by jurisdictional boundaries.

3.5.2. Configuration Overview

SUSTAIN configuration requires defining four key components:

- The **Management Objectives** are the drivers for SCM optimization. For the System-wide SWM study the management objectives were:
    - Maximize phosphorus load reduction
    - Maximize peak flow rate reduction

  The primary management objectives for this study were to minimized peak flows at the six flood prone areas and to reduce phosphorus loading by 40%. For the peak flow objective, a three-day period, which included the 6-hr design storm occurring on the first day was simulated. For the phosphorus reduction goal, the simulation period was a year long, representing water year 2011 which was a year with an average amount of precipitation.

- An **Assessment Point** is a location where a management objective is evaluated during optimization. For the System-wide SWM study, the assessment points were:
    - Outlet of East Holland River to Lake Simcoe;
    - East Holland Landing; or,
    - just upstream of a flood-prone area.

  For assessment of urban SCM implementation strategies, the East Holland Landing assessment point was emphasized because it is upstream of a majority of the agricultural areas.

- A **Decision Variable** is a dimension that changes during optimization (e.g., SCM footprint, volume, number of SCMs). The full range of decision variables represents the search domain for optimization.

- A **Management Scenario** is the combination of management objectives, assessment points, and/or decision variables to be evaluated.

3.5.3. Management Action Menu

As discussed in Section 3.2.1, the Current State LSPC analysis was designed to characterize the East Holland River watershed hydrology and water quality processes. The detailed understanding of the watershed dynamics generated by LSPC provided the basis for identifying and screening potential management measures or SCMs. Potential structural and non-structural SCMs were evaluated by the Project Team, Technical Advisory Committee and municipal and stakeholder experts. Structural SCMs included GI (e.g., hybrid ponds/wetlands), LID measures (e.g., bioswales, hybrid ponds/wetlands, infiltration trenches, etc.), and conventional infrastructure (e.g., wet and dry stormwater ponds, oil-grit separators, etc.), and natural assets (e.g., wetlands, forests, etc.). Non-structural measures include practices such as the use of cover crops, no-till planting, and land cycling on agricultural lands.

Selection and ranking of preferred SCMs was based on their functional application to a land use type or category of HRU (e.g., commercial property parking lot or municipal Right-of-Way).

Out of the initial assessment and screening of all possible SCMs, viable management measures by HRU category were generated. The initial screening selected for viable, meaning industry recognized, structural and non-structural measures. A more detailed evaluation and screening of viable SCMs by subject experts and based on the established performance (tested and proven in-situ) of a given measure to provide targeted hydrologic and water quality control for the particular HRU category was completed. The Menu of Management Measures covering the Current State (existing development) and Future State (planned development), is included in Appendix 3. Definitions of each management strategy are provided in Appendix 4.

3.5.4. Representative Stormwater Control Measures

To represent the various applications and an initial strategy for SCM planning and design in the watershed, a variety of 'representative' SCM configurations were used (Table 3-6). Figure 3-14 is a schematic representing SUSTAIN SCM routing. Distributed SCMs are generally implemented at the street or parcel scale, have small footprints (e.g., street right of way, parking lot, or roof), and capture and treat runoff from correspondingly small drainage areas (e.g., parcel or street). Centralized SCMs are large-scale projects that can treat runoff from 100's or 1000's of hectares of upstream drainage.

This menu provides the building blocks for managing parking lots and roofs with distributed SCMs and large areas with centralized SCMs. This menu does not cover all possible alternatives for watershed-scale implementation but provides the basis for an initial assessment of cost and feasibility for meeting water quality and flood reduction goals in the watershed. Future applications could further compare alternatives for managing different types of land (e.g., compare rooftop SCM alternatives [cistern vs infiltration trench] and parking lot SCM alternatives [infiltration chamber vs bioretention]). Bioretention to treat future growth had no associated costs for this study. While there are certainly O&M and lifecycle costs for these SCMs, these costs are associated with current stormwater management strategies in the watershed. This study assumed the costs for bioretention to treat future growth would be bore by the developers under the status quo. The costs presented in this analysis represent investments beyond the status quo.

Table 3-6: Menu of SCMs listed by design type, typical treatment area and program

SCM Type	Sub-type	Manages	Footprint locations	Rules on footprint size	Notes
Centralized	Offline - Hybrid ponds	Large upstream areas	Open/ pervious areas	Capped at 20% of available area in parcel/ opportunity	Intercepts storm drains, pumping required if depth to GW <1m below footprint
	Inline – Hybrid ponds				Intercepts creeks
Distributed	Infiltration chambers	Parking lots	Parking lots	Capped at 20% total area	
	Infiltration trenches	Rooftops	Adjacent to buildings	Capped at 20% total area	
	Bioretention	Future growth	In future growth areas	Locked at 25mm sizing	No cost.
	Enhanced boulevard tree cell	Regional roads	Right-of-way on Regional roads	Capped at 20% total area	

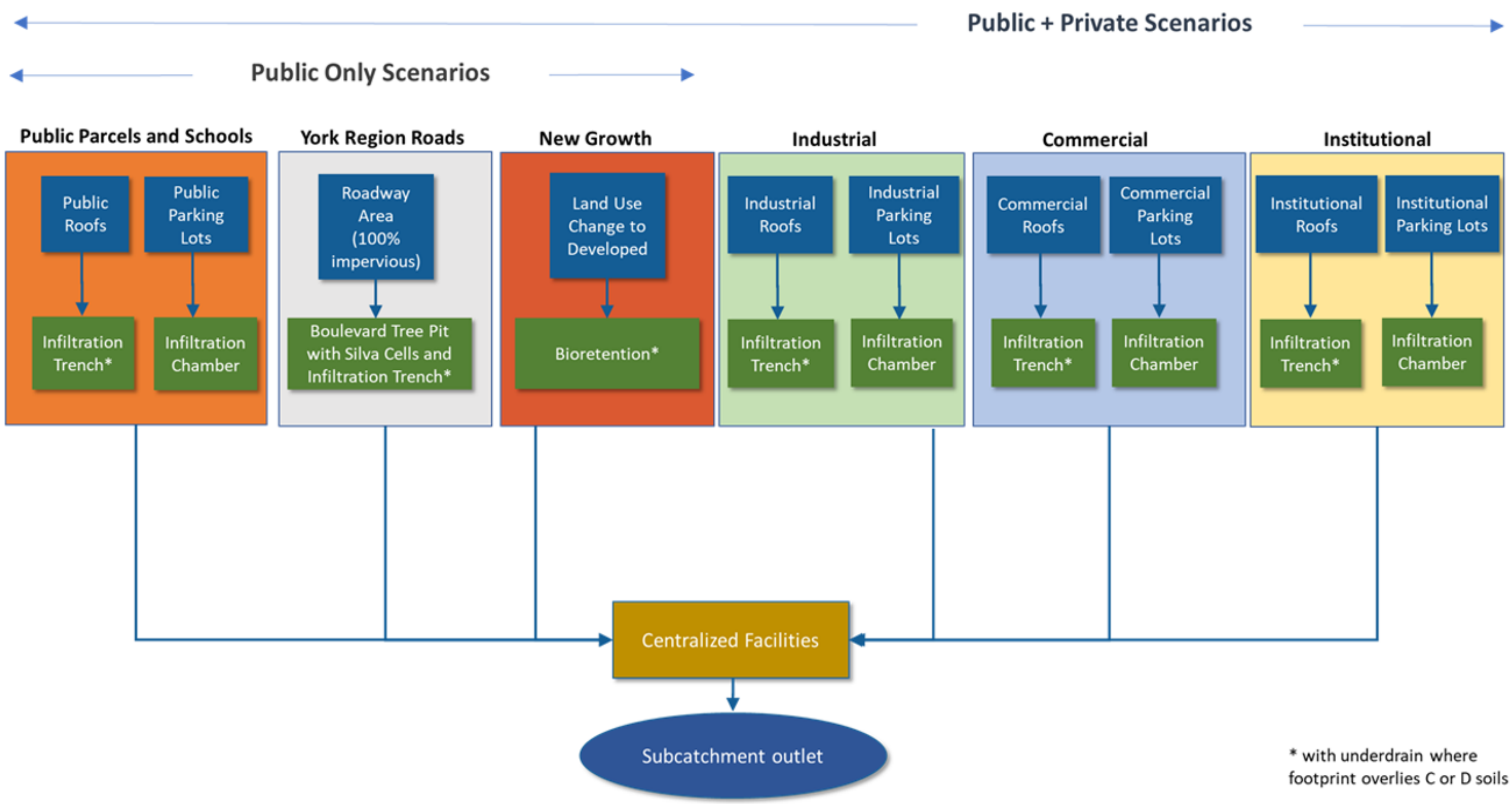


Figure 3-14: Schematic representation of parking lot and roof SCM routing in SUSTAIN

3.5.4.1. Typical designs for representative SCMs

The following subsections describe the model details of each distributed SCM from the menu and their design variations (e.g., with and without an underdrain). These SCM designs are based on output of the Low Impact Development Life Cycle Costing Tool developed under the conservation authority-led Sustainable Technologies Evaluation Program (STEP). This costing tool allows the user to estimate life cycle costs for SCMs based on model parameters and design dimensions specified by the user.

3.5.4.2. Distributed SCMs

Distributed SCMs or LID provide water quality improvement through several mechanisms, including runoff volume reduction, sedimentation, settling, filtration, and other treatment processes (WERF 2016, CASQA 2003). In addition, these SCMs often provide other important benefits, including but not limited to flood management, traffic calming, neighborhood greening, and reduced heat island effect[79]. These types of SCMs generally treat stormwater from small-scale localized areas, but when distributed throughout a watershed, they can have substantial cumulative benefits.

3.5.4.2.1. Infiltration Trench

Infiltration trenches (Figure 3-15) are narrow ditches filled with gravel that intercept runoff from impervious areas. Infiltration trenches were used in SUSTAIN to treat runoff from rooftops, as illustrated previously in the representative SCMs; section 3.5.4.

Figure 3-15: Example Infiltration Trench (source: North Dakota State University)

Table 3-7: SUSTAIN Infiltration Trench design parameter

Design Parameters	Values	Units
Weir Height	0.4	M
Orifice Diameter	1.55	Cm
Drainage media porosity	0.4	No unit
Underdrain?	Y	NA
Underdrain soil media depth	0.03	Mm
Underdrain media infiltration rate	1,524	mm/hr
Native soil infiltration	0.89 – 7.11	mm/hr
Underdrain Depth	50.3	Mm

3.5.4.2.2. Infiltration Chamber

Infiltration chambers are open-bottomed systems that infiltrate into native soils (Figure 3-16). Infiltration chambers were used in the optimization analysis to treat runoff from parking lots.

Figure 3-16: Example infiltration chamber design. (source: Nilex - https://nilex.com)

Table 3-8: SUSTAIN Infiltration Chamber design parameters

Design Parameters	Values	Units
Weir Height	0.74	M
Orifice Diameter	1.55	Cm
Drainage media porosity	0.4	No unit
Underdrain?	Yes/No	NA
Underdrain soil media depth	0.03	Mm
Underdrain media infiltration rate	1.78 – 1,524	mm/hr
Native soil infiltration rate when underdrain present	0.89	mm/hr
Native soil infiltration rate when no underdrain present	1.78 – 1,524	mm/hr
Underdrain Depth	50.3	Mm

3.5.4.2.3. *Enhanced Boulevard Tree Cell*

Stormwater runoff from regionally owned roads were treated with an enhanced tree cell design incorporating an infiltration trench (Figure 3-17). The tree cell is a modified bioretention unit, in both design and function but used in combination with an infiltration trench as previously described (section 3.5.4.2.1). The enhanced boulevard tree cell has the same parameters (Table 3-9) as the infiltration trench (Table 3-7) with the additional cost of a tree cell included in the total unit cost.

Figure 3-17: Surface visual of a Boulevard Tree Cell installation (source: City of Portland)

Table 3-9: SUSTAIN Enhanced Boulevard Tree Cell with Infiltration Trench design parameters

Design Parameters	Values	Units
Weir Height	0.4	M
Orifice Diameter	1.55	Cm
Drainage media porosity	0.4	No unit
Underdrain?	Yes	NA
Underdrain soil media depth	0.03	Mm
Underdrain media infiltration rate	1,524	mm/hr
Native soil infiltration	0.89 – 7.11	mm/hr
Underdrain Depth	50.3	Mm

3.5.4.2.4. Bioretention

Bioretention practices are designed to mimic the natural hydrologic processes of pre-development land use. Broadly, a bioretention unit 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. In areas where infiltration to native soils is not feasible, an underdrain layer can be implemented to direct treated stormwater back to the storm drain network. When implemented with an underdrain layer this configuration is a regarded as a biofiltration unit. Bioretention/biofiltration was used to capture the runoff from areas of future growth. (Figure 3-18) shows a bioretention installation and Table 3-10 presents SUSTAIN parameters for bioretention.

Figure 3-18: Example Bioretention Unit (Source: City of Vancouver)

Table 3-10: SUSTAIN Bioretention design parameters

Design Parameters	Values	Units
Weir Height	0.2	m
Orifice Diameter	1.55	cm
Soil Depth	0.82	m
Infiltration Method	Holtan	NA
Vegetation Parameter	1	Dense/mature
Growth Index	1	Maximum maturity
Drainage media porosity	0.4	unitless
Has underdrain?	Y/N	NA
Underdrain depth	0 - 0.22	m
Underdrain soil media infiltration rate	127.0	mm/hr
Native soil infiltration rate when no underdrain present	1.8 - 7.1	mm/hr
Native soil infiltration rate when underdrain present	0.89	mm/hr

Primary components of bioretention/biofiltration design often include:

- The depressed nature of bioretention units creates a ponding area for stormwater to accumulate and ultimately percolate through the soil media layer.
- Native vegetation provides uptake of stormwater, reduced heat island, micro-scale urban habitat, and neighborhood greening. Uptake of stormwater is particularly important aspect of performance as it replenishes the unit's capacity to absorb future rain events.
- A soil media layer that supports vegetation, provides filtration, and storage of stormwater.

In cases where native soils are not conducive to infiltration an underdrain layer is implemented below the media layer to convey treated stormwater. The underdrain layer is gravel filled and collects and conveys stormwater to the SCM outlet.

3.5.4.3. Drainage Area to Footprint Ratios for Distributed SCMs

An important element of the design assumptions for SUSTAIN is the drainage area to footprint ratio for the distributed SCMs. Several of the STEP designs called for a maximum of 15:1 ratio. For optimization, however, the ratio was not locked – larger ratios up to 60:1 to allowed during optimization. Upon review of simulation outputs, it is clear that optimization emphasized SCMs with greater than 15:1 ratios. In LSPC, phosphorus is represented as sediment-associated, and sediment washes off from parking lots and roads relatively quickly. Furthermore, the configuration in SUSTAIN includes an underdrain with high-passthrough media (127 mm/hr) that prevents distributed SCMs from bypassing except for the most extreme events.

Figure 3-19 shows example simulation outputs that chart phosphorus reduction versus drainage area to footprint ratio, and points to examples where cost-effectiveness greatly decreases at ratios beyond 30:1 to 60:1. If the ratio had been locked at 15:1 for optimization simulations, the costs would be greatly increased because SUSTAIN optimization suggests the extra capacity beyond 15:1 is not cost-effective for phosphorus reduction from parking lots and roads. However, it is acknowledged that it may be appropriate in future analyses to further investigate ratio assumptions, and also perhaps increase O&M costs to account for larger drainage areas.

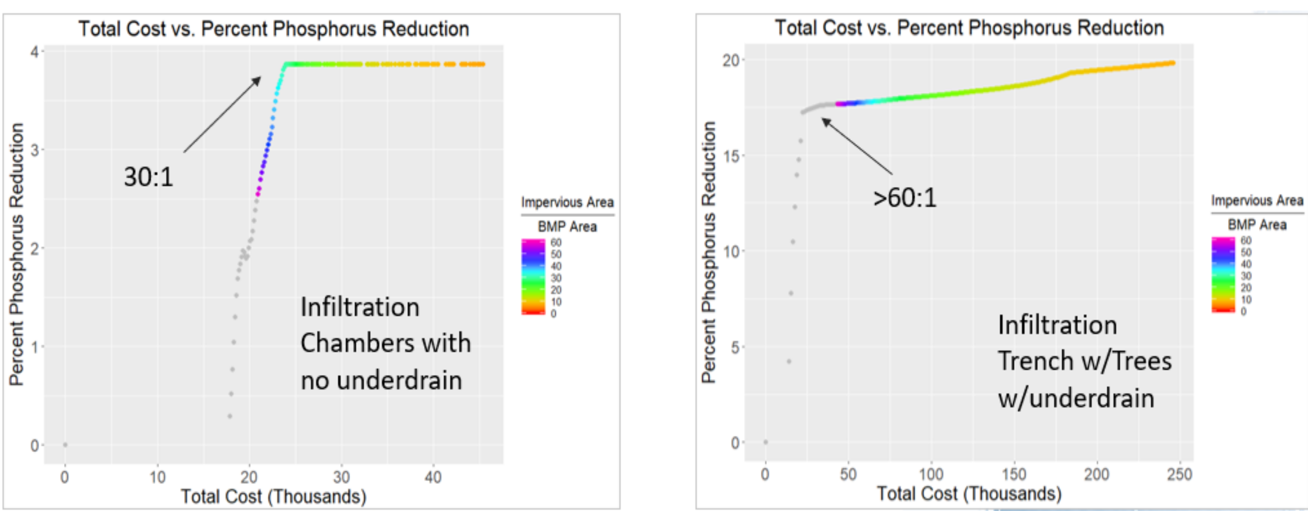


Figure 3-19: Example evaluation of cost-effectiveness versus SCM Footprint to Drainage Area Ratios for distributed SCMs

3.5.4.4. Centralized SCMs – Hybrid Stormwater Management Pond

Centralized stormwater capture projects provide water quality improvement, in addition to other potential benefits including flood mitigation. Both surface and subsurface (e.g., infiltration facilities below parking lots, parks, or other recreational facilities) were initially considered for the System-wide SWM study. However, surface facilities were found to be most cost effective, therefore subsurface facilities were not considered during optimization.

Centralized SCMs can provide water quality improvement of stormwater runoff through detention, infiltration, filtration, and/or beneficial use (e.g., on-site irrigation). Generally, these facilities capture stormwater from adjacent channels or storm drains, therefore requiring a diversion structure to divert stormwater to the SCM. The result is much larger capture areas and volumes as compared to distributed SCMs. Two types of centralized SCMs were configured (Table 3-20):

1) **Inline facilities** were adjacent to streams and rivers and treated streamflow while offline facilities treated overland flow from impervious surfaces. Inline wet detention ponds did not have a diversion rate, they treated stream water until they reached their capacity, at which point water bypassed the SCM. It is important to note the SUSTAIN configuration does not route baseflow thru inline facilities, only storm flows. This approach avoids representing facilities as devices directly treat the stream, and instead they treat surface runoff/elevated flows only.
2) **Offline facilities** divert runoff from adjacent storm drains with a maximum possible diversion rate of 10.8 m^3/s. In practice, a diversion structure would be installed at nearby stormwater infrastructure and stormwater would be diverted to the SCM.

Both inline and offline centralized SCMs were configured in SUSTAIN as hybrid ponds (Figure 3-20: Example Hybrid SWM Pond) based on STEP design parameters, which could represent practices such as constructed wetlands and restored floodplains that aim to improve water quality and mitigate flooding. Table 3-11 presents SUSTAIN parameters for hybrid SWM ponds. It is important to note the configuration using a pond design does not suggest a vision for the watershed with a network of new ponds being built. In contrast, the configuration is envisioned as most sustainable practices such as wetland restoration and other SCMs that provide multiple benefits and integrate sustainably with the environment.

The STEP design for a dry pond was modified to ensure a 63% reduction for total phosphorus (TP), based on published data on the effectiveness of wet detention ponds[80]. Phosphorus reduction for ponds was configured in SUSTAIN using a combination of an orifice for outflow control and a pollutant decay rate. The orifice diameter was sized for an average pond size (1,650 m^3) to produce an 18-hour retention time. The first-order decay rate constant was calculated to achieve 63% phosphorus reduction for an 18-hour retention time. Larger-than-average ponds have a longer retention time and achieve greater than 63% reduction. Smaller-than-average ponds have a shorter retention time and achieve less than 63% reduction.

Figure 3-20: Example Hybrid Stormwater Pond (Photo Source USEPA 2016[81])

Table 3-11: Hybrid Stormwater Pond rules for Inline versus Offline

Centralized SCMs	In-line	Off-line
Locations based on screening	Within 100m of stream	Within 100m of storm drain
Upstream drainage area assumptions	Based on nearby nodes. Check stream nodes within 25m and use node that has largest upstream area to estimate drainage area.	Based on nearby nodes. Check storm drain nodes within 100m and use node that has largest upstream area to estimate drainage area.
Cap on SCM footprint size	Max per site = 1 hectare or 20% of opportunity pervious area (whichever is smallest)	Max per site = 1 hectare or 20% of opportunity pervious area (whichever is smallest)
Pumping requirements	None	Assess pumping need based on average elevation of site compared to ultimate outlet elevation

Table 3-12: SUSTAIN Hybrid Stormwater Pond parameters

Centralized SCMs	Inline	Offline
Weir Height	1.92	m
Orifice Height	0.86	m
Orifice Diameter	10.4	cm
Soil Depth	.03	mm
Infiltration Method	Holtan	NA
Vegetation Parameter	1	Dense/mature
Growth Index	1	Maximum maturity
Porosity	0.4	unitless
Has underdrain?	No	NA
Native soil infiltration rate	1.18– 7.11	mm/hr
Diversion Rate	0 – 10.8	m^3/s

3.5.4.5. Opportunity Screening for SCM

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 jurished are available to siting SCMs, and optimization may use all or none of that footprint.

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. An example screenshot of the GIS opportunity screening for distributed and centralized SCMs is shown in Figure 3-21: Example distributed and centralized SCM Opportunity Screening to identify Footprint sites. Rules for available area assessed for screening are previously listed in Table 3-6. Aggregated parcels were screened to assess available footprint to site SCMs. Aggregation was used to combine adjacent parcels into a single opportunity and avoid splitting contiguous areas that could provide an SCM siting opportunity (pervious areas for centralized SCM footprints, and roofs and parking lots for distributed SCMs).

For distributed SCMs, 80% of the parking lot, roof and regional road area within each jurished was configured as an uptake opportunity for optimization. 80% was set as a maximum uptake area to avoid completely infeasible outcomes where every single roof or parking lot is managed. Industrial and commercial areas had the most opportunity for distributed SCM implementation to treat impervious roofs and parking lots and regional roads (Table 3-13). Note that roofs are a larger opportunity area, but have a low yield of phosphorus which would limit their uptake during optimization for phosphorus reduction.

Table 3-13: Impervious surfaces 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.

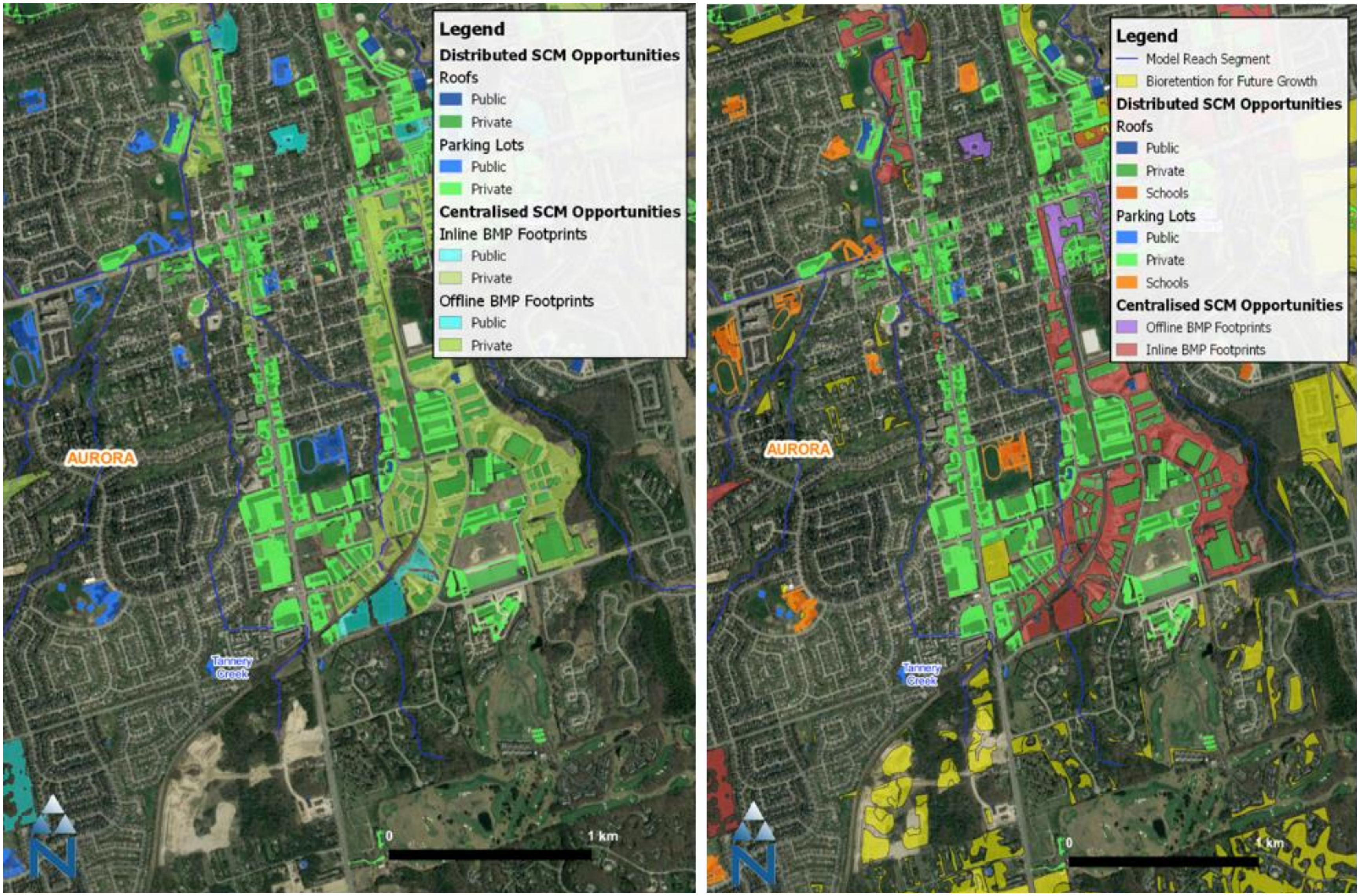


Figure 3-21: Example distributed and centralized SCM Opportunity Screening to identify Footprint sites

For centralized SCMs, a series of screening efforts were used to pare down the number of opportunities into a manageable number for optimization modelling. The initial screening used a tiered approach to differentiate between adequate (screening tier 1) and preferred (screening tier 2) site conditions. Table 3-14 presents rules used to initially screen opportunities. For centralized SCMs, a total of 499 sites were assessed. Screening identified 280 suitable locations for centralized SCMs (Figure 3-22). The remaining opportunities were further screened to include only sites within the group accounting for 90% cumulative TP reduction or 30% cumulative costs, which resulted in 68 centralized SCMs being considering during optimization. A majority of centralized SCM opportunities considered during optimization were on private land. Roofs and parking lots that were not suitable for centralized SCMs were still considered as opportunities for distributed SCMs.

Table 3-14: Centralized SCM screening criteria

Project Type	Screening Tier	Distance to Watercourse[1]	Distance to Storm Drain	Within Floodplain	Unpaved Area	Groundwater Separation[2]
Inline Surface Feature	1	≤ 100 m	N/A	N/A	≥0.5 ha	≥2.0 m
	2	≤25 m	N/A	N/A	≥1.0 ha	≥2.0 m
Offline Surface feature	1	N/A	≤ 100 m	No	≥0.25 ha	≥2.0 m
	2	N/A	≤25m	No	≥0.5 ha	≥2.0 m

[1] Distance to watercourse measured from edge of public parcel or ICI footprint
[2] Depth to groundwater averaged across public parcel or ICI footprint

For the centralized SCM opportunity screening, because they treat large upstream areas, an important component was delineation of upstream drainage areas for each opportunity. The screening analysis required intensive geoprocessing to estimate drainage areas for all 499 sites to allow for the processes that screened them down to 280 potential opportunities for more in-depth evaluation to, ultimately the 68 viable opportunities as illustrated in Figure 3-22. A node network was created for both the storm drain and watercourse networks to allow for estimation of upstream drainage area at any node. An example screenshot for the node-drainage area GIS analysis is shown in Figure 3-23. The geoprocessing effort was a breakthrough in opportunity screening for SUSTAIN; the ability to analyze hundreds of drainage areas without manual delineation allowed the SCM optimization to incorporate many more opportunities than typically possible.

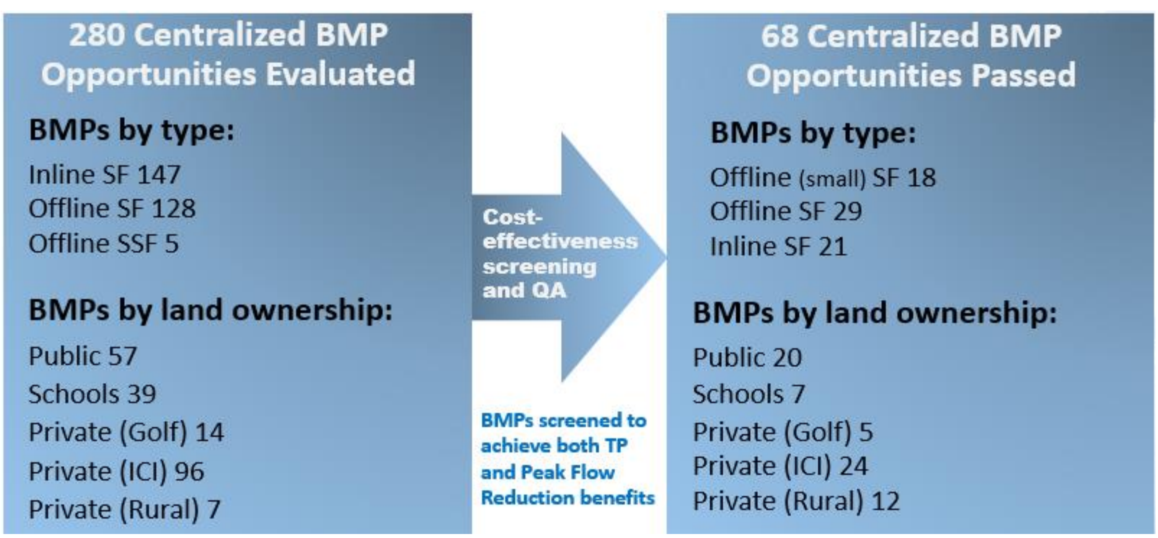


Figure 3-22: Opportunity Screening of centralized SCMs (SF = surface feature, SSF – Subsurface features)

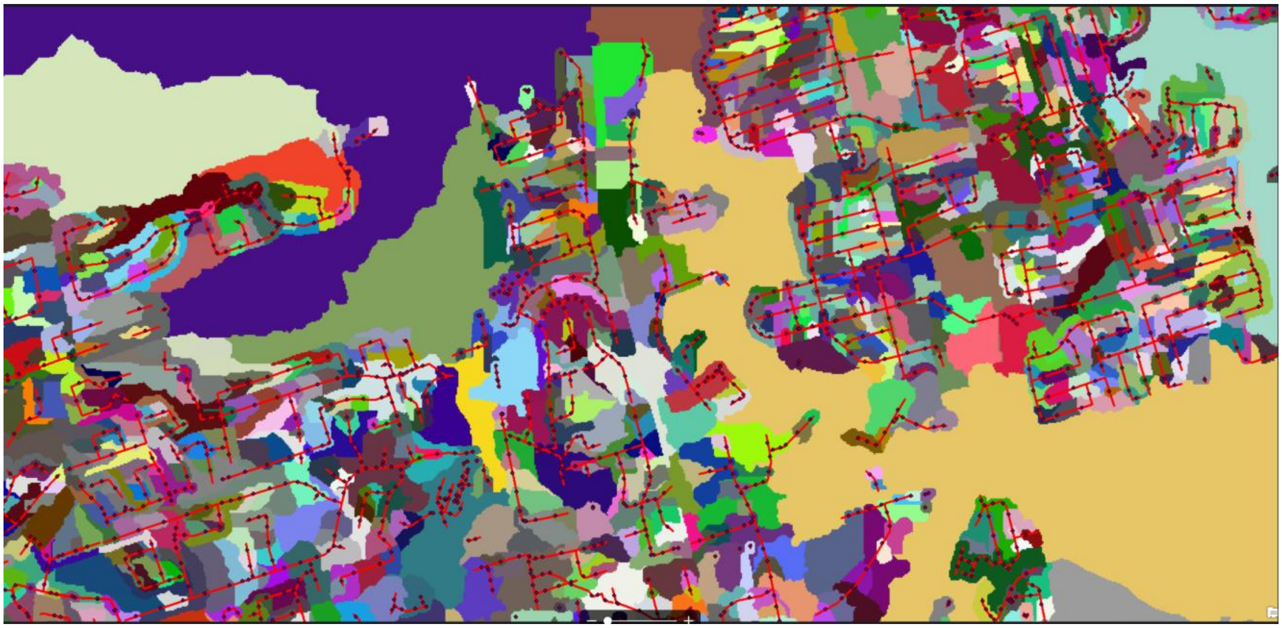


Figure 3-23: Example screenshot of Node-drainage Area Network used to assess upstream capture areas for hundreds of centralized SCM opportunities

3.5.4.6. Cost functions

Costs of SWM measures were estimated to support the optimization analysis completed using SUSTAIN. The analysis uses a life cycle approach based on total capital, O&M costs over the life of each measure. Individual cost relationships were developed for capital, operating and maintenance costs and total costs were then estimated over a 30-year time horizon. The total costs were expressed in present value terms assuming a discount rate[10] of 5% and annual inflation of 3%.

The cost relationships are documented in the Cost Function Report (Appendix 5) and show how costs increase with project scale. Cost functions are presented for 17 SCMs in the report. For nine of the measures, cost functions are based on conceptual design and costing using the STEP life cycle costing tool (LCCT). Costs for SCMs and related cost functions in the STEP tool were updated for this study. The tool enables pre-feasibility level costing of SWM measures based on basic information on cost-drivers such as drainage area, soil type and water quality performance targets. Costing for the remaining measures is based on conceptual designs and costing, previously published cost curves or actual cost data provided by area municipalities. While more detailed, site-specific assessment is needed to understand the true costs pertaining to the implementation of specific SCM projects, the relative costs between project types are well represented for the optimization of project types and planning-level assessment provided in this report and are sufficient for optimization and comparison of alternative implementation scenarios to select the most cost-effective strategy and combination of SCMs to meet SWM goals. Cost functions used for the SUSTAIN optimization analysis are listed in Table 3-15 and a summary of costs for SCMs is provided in Figure 3-24.

Property value differentials across watershed municipalities are not considered in the cost functions in order to focus on the cost-effectiveness of alternative SWM measures based on their capital and O&M costs. The annualized unit costs for measures considered in the analysis are depicted in Figure 3-24.

[10] 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%

Table 3-15: SCM project cost functions for SUSTAIN cost-optimization

Project Type	Project Sub-type	Cost Estimate Formula ($)	User Inputs
Centralized Project	Hybrid Pond	830.12 * capacity	capacity (m^3)
Retrofit LID	Infiltration Trench	528.93 * area	area (m^2)
	Infiltration chamber with underdrain	422.74 * area	
	Infiltration chamber without underdrain	342.43 * area	
	Green street	899.47 * area	
Future Growth LID	Bioretention with underdrain	440.43 * area	
	Bioretention without underdrain	395.0 Area	

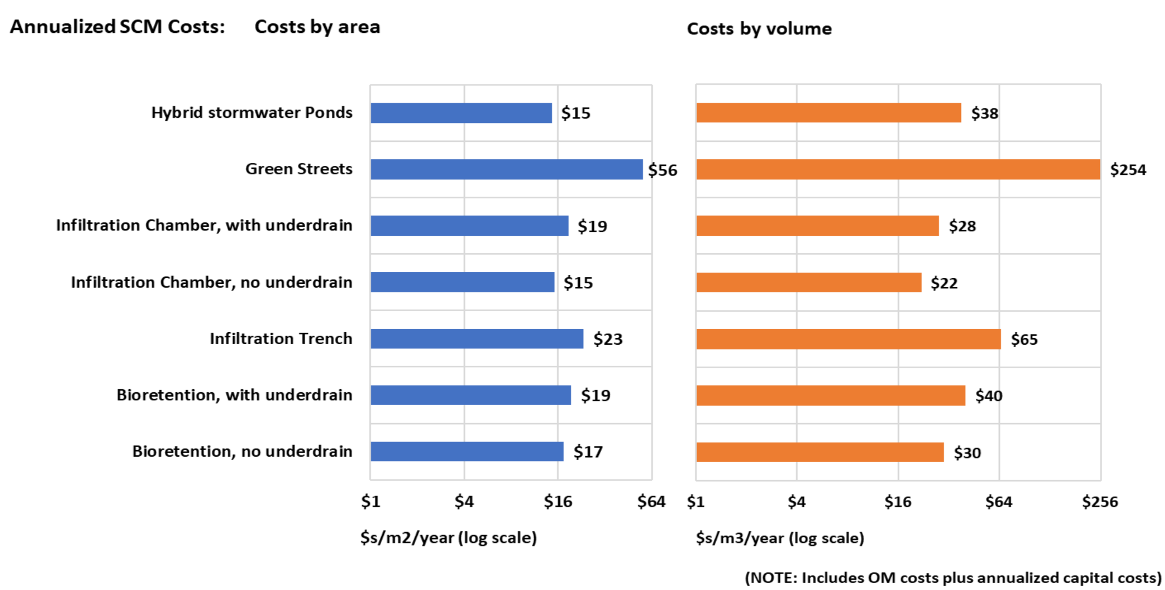


Figure 3-24: Summary of costs for SWM measures

3.5.4.7. Growth and development

In addition to optimization of future SCM retrofits (roofs, parking lots and roads), the SUSTAIN modelling analysis accounted for future growth and associated impervious surfaces within the watershed. Future growth and development areas were assumed to have SCM treatment installed as part of their construction, not as a retrofit. Areas of potential future growth were identified based on York Region and municipal Official Plan data and were included in all scenarios. Available data identifying areas of future growth were classified into two categories: residential and ICI (Figure 3-25). This data was combined with the land use data used in HRU development (Section 3.5.2). All areas identified as future growth that were already developed based on the land use data were excluded from this analysis (i.e., areas where the land use changed was assumed to have SCMs included with development, others were not). The remaining areas (Figure 3-26) were identified as undeveloped land designated for future growth that would have SCM treatment to capture 25 mm of runoff, according with LSRCA SWM guidelines.

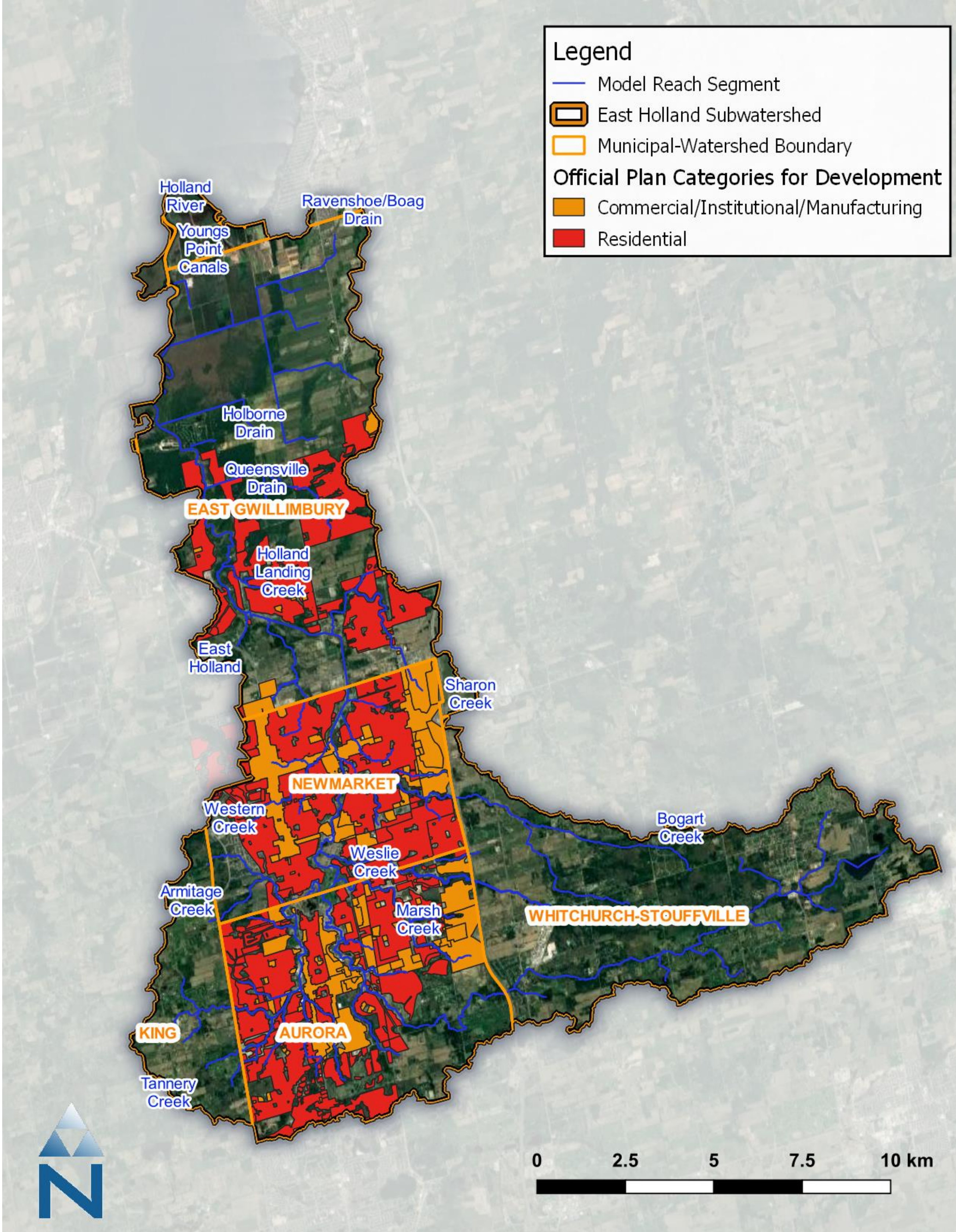


Figure 3-25: Areas of future growth and redevelopment identified in Official Plan data

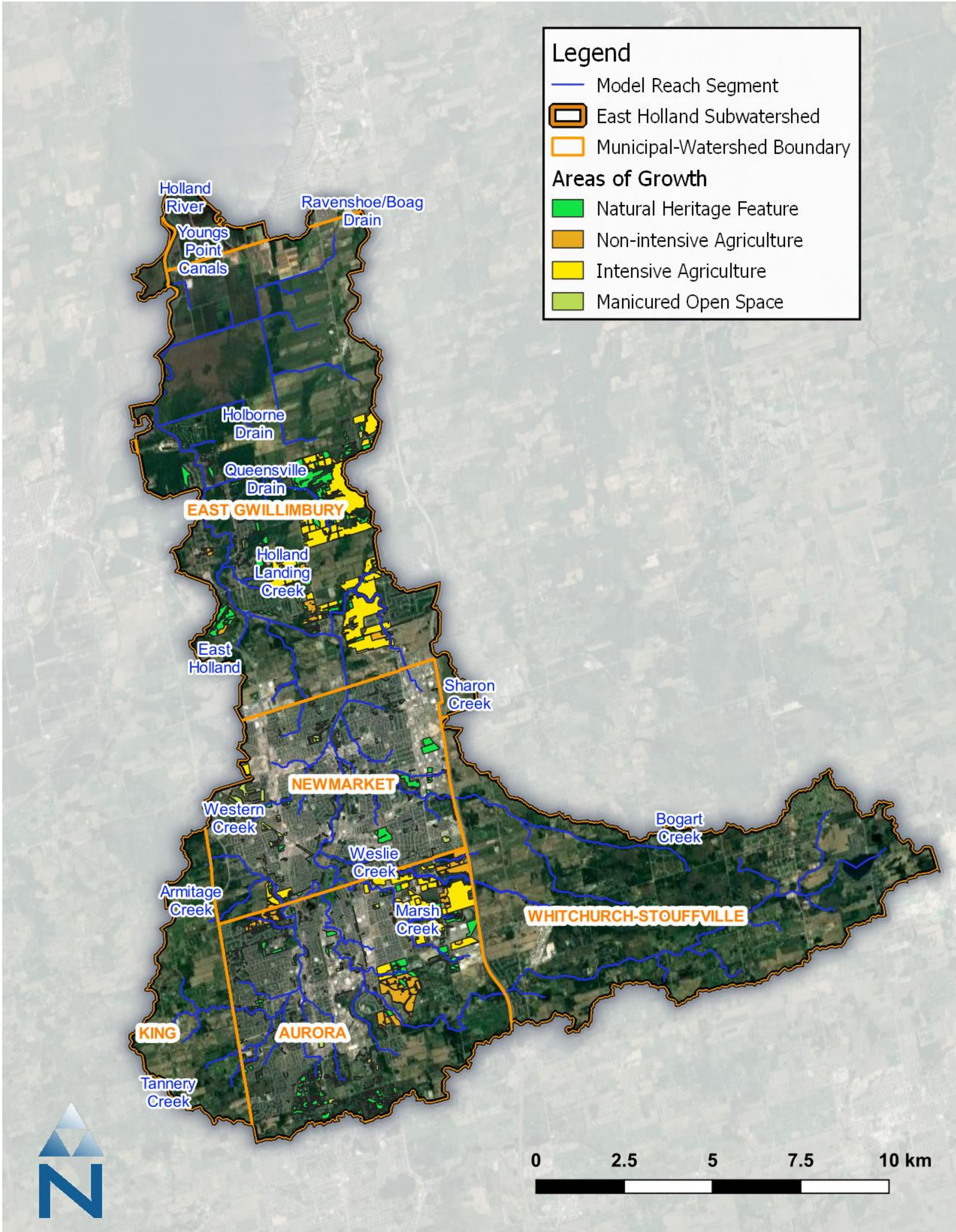


Figure 3-26: Official Plan areas of growth for undeveloped land uses. (Note: Official Plan lacked data for King and Whitchuch-Stouffville)

3.5.5. Watershed-scale Optimization

A watershed-scale decision support framework based on cost optimization allows governments and local planning agencies to coordinate watershed-scale investments to manage stormwater and achieve water quality goals. The innovative, tiered optimization approach utilized by SUSTAIN allows for evaluating the SCM cost-effectiveness for both individual and multiple, nested watersheds. The optimization with SUSTAIN was performed at two tiers – Tier 1 generates an optimization curves for each individual jurished and Tier 2 search across the upstream jurisheds to create a composite optimization curve. The jurisheds being searched depends on the assessment points, for example, searching all 314 jurisheds for a basin-wide solution, searching jurisheds upstream of a flood-prone area, or searching the jurisheds within a jurisdiction.

Figure 3-27 provides a conceptual graphic of 'N' number of jurisheds and their corresponding best solution curves are illustrated. Each of these curves are upstream of an assessment point in Tier 1 (center of the graphic). On the right-hand side of Figure 3-27, the Tier 1 best solutions are incorporated in the tier 2 search to meet the user-defined reduction target. Figure 3-28 (top) and Figure 3-28 (bottom) provide details on the Tier 1 and Tier 2 methodology for optimizing phosphorus reduction and flood reduction, respectively. For a watershed wide optimization of East Holland watershed, the optimization curve is composed of 6.3 million SUSTAIN runs. A complete Tier 1 and Tier 2 run takes approximately 20 hours when split across five high-performance modelling computers.

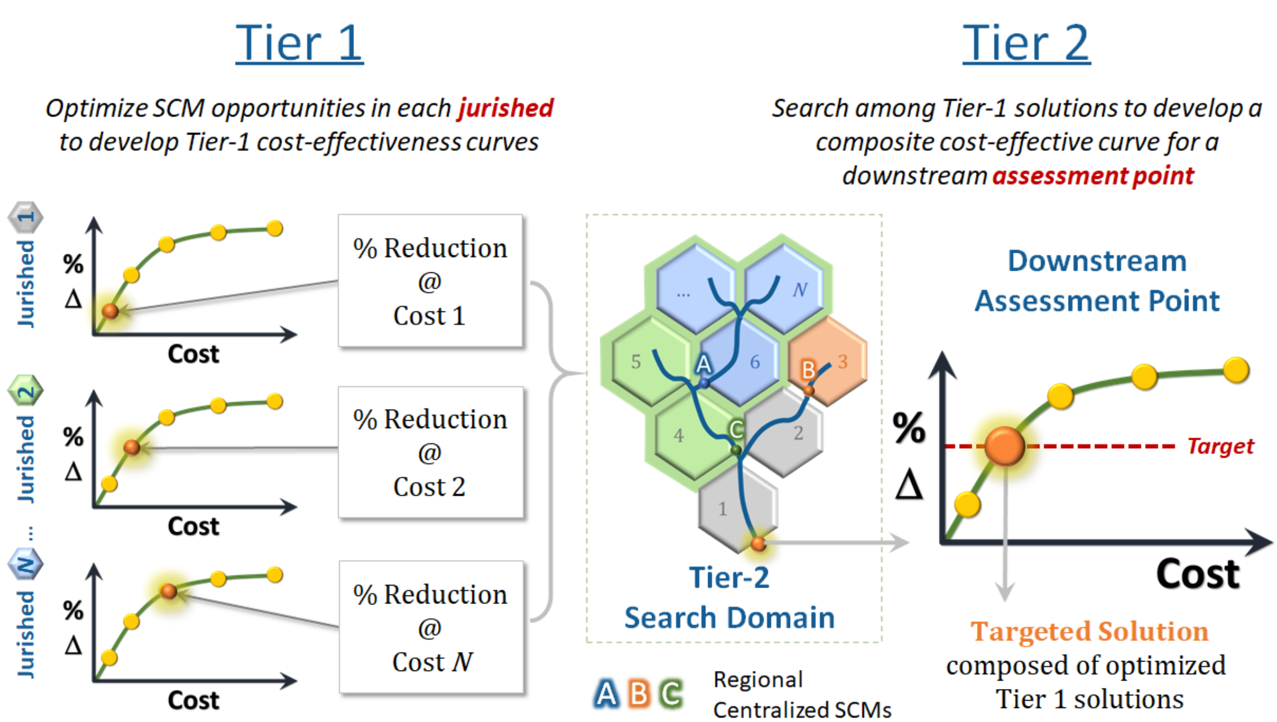
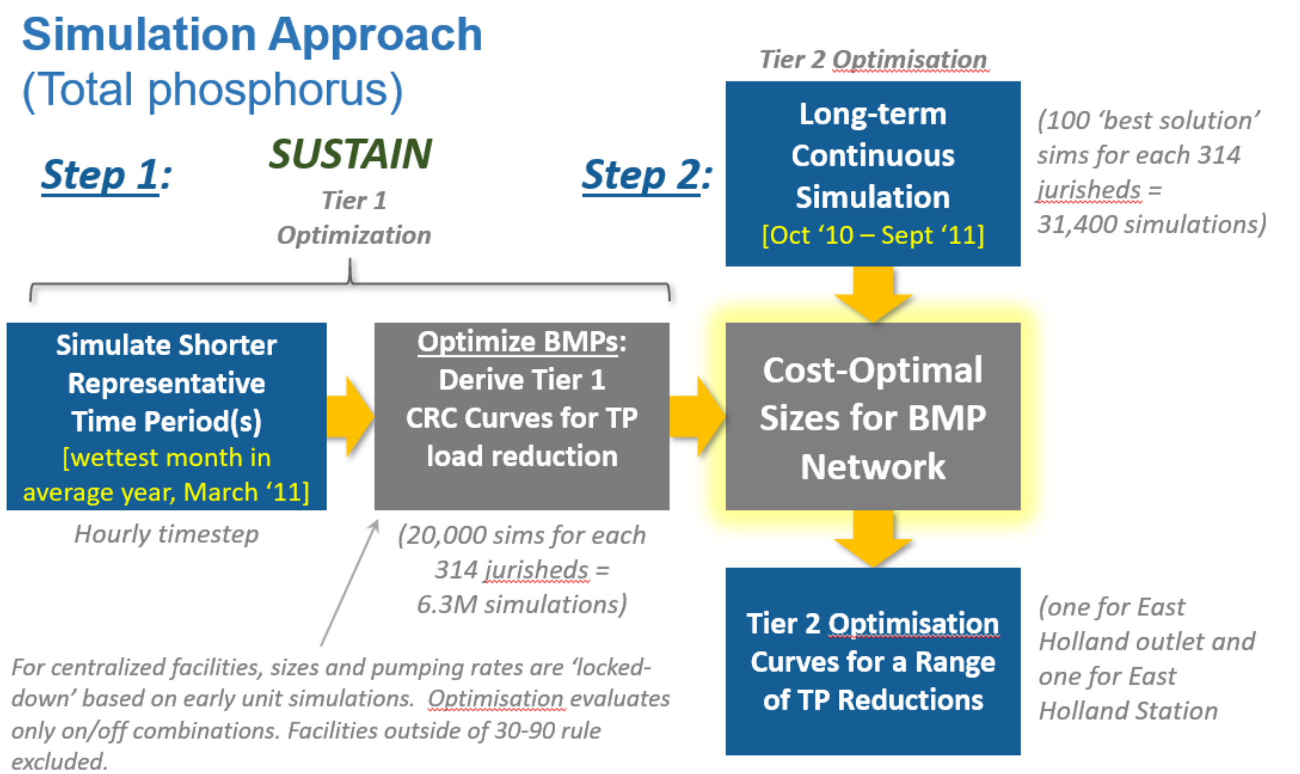


Figure 3-27: Conceptual representation of the two-tier optimization approach utilized in the East Holland river watershed



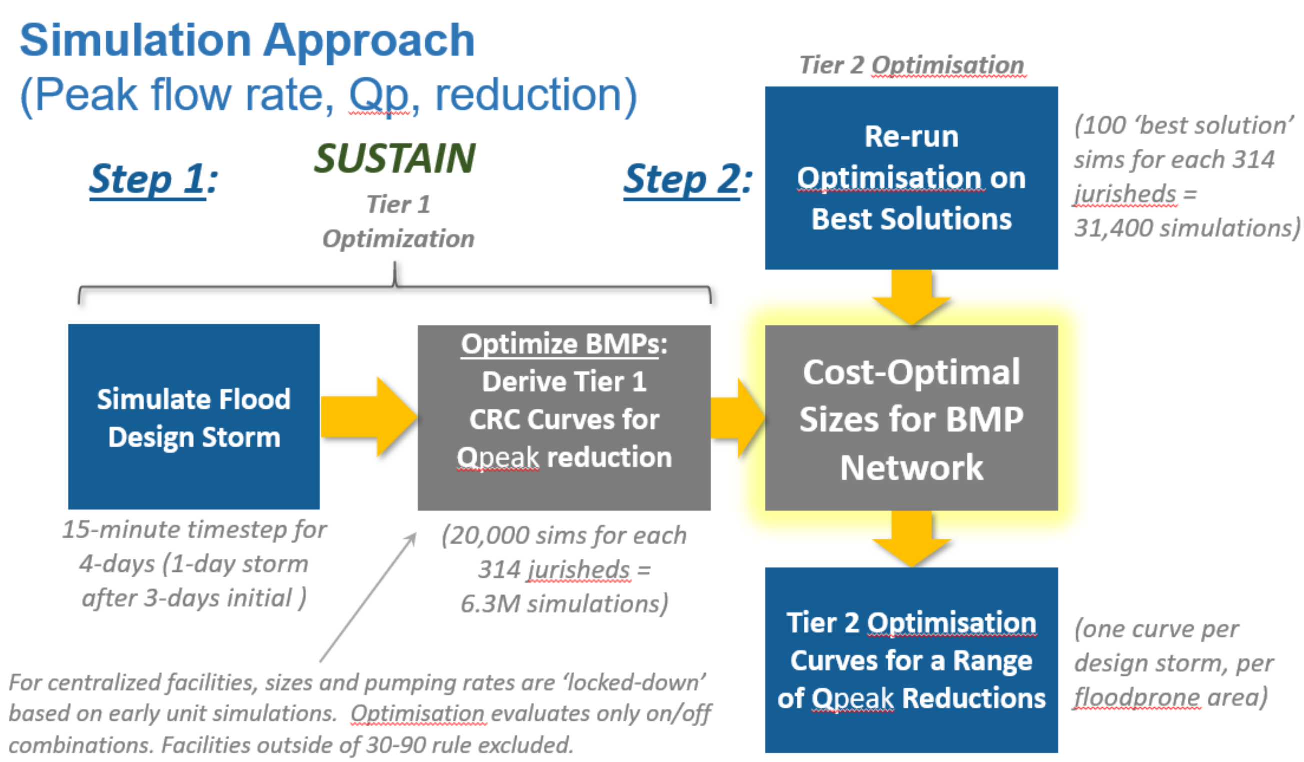


Figure 3-28: Illustration of Tier 1 and Tier 2 optimization methodology for assessing phosphorus reduction (top) / Illustration of Tier 1 and Tier 2 optimization methodology for assessing peak flow reduction for Flood Design Storm

3.5.5.1. Tier 1 Optimization

The first step in optimization is to assess the most cost effective SCM implementation solutions within each jurished using SUSTAIN, called Tier 1. As described in section 3.4.2.1, a single sub-catchment that is within two separate municipalities becomes two jurisheds identified with a unique numerical code. Establishing jurisheds allows for SCM optimization to occur within jurisdictional boundaries, these results can then be compared with optimization that is not constrained by jurisdictional boundaries and simply optimizes for the most cost-effective solutions across a watershed. The boundary condition for phosphorus reduction at Tier 1 was the wettest month in the average year – a subset of the annual average year was used to reduce run time. The boundary condition for the flood simulation was the same between Tier 1 and Tier 2, the 12-hour storms described in Section 3.5.4. Tier 1 simulations take approximately 18 hours when parallelized across five high performance modelling computers.

3.5.5.2. Inclusive Best Solution

Once the Tier 1 optimization has been completed, outputs are organized and arranged to form an inclusive set of best solutions. By identifying the best solutions, run time at Tier 2 can be reduced and the search space is only composed of the best implementation strategies within each jurished. Outputs from the first tier of optimization are a cloud of thousands (as many as 10,000) of unique SCM combinations described by cost and performance for each modeled jurished. Each SCM combination is a distinct blend of type and volume that represent a potential SCM implementation plan that can achieve a defined level of TP or peak flow reduction. Example output from a jurished is shown in Figure 3-29. Each gray dot in the plot is an evaluated SCM combination in the cloud. The jurished outputs with greatest cost-effectiveness are analyzed so that a cost-effectiveness curve can be identified for each (i.e., a set of 'best solutions'). The larger orange dots in Figure 3-30 are those identified as best solutions within a single jurished, representing the highest achievable performance at each cost interval. The simulation time to generate the best solutions for hundreds of jurisheds is approximately 30 minutes.

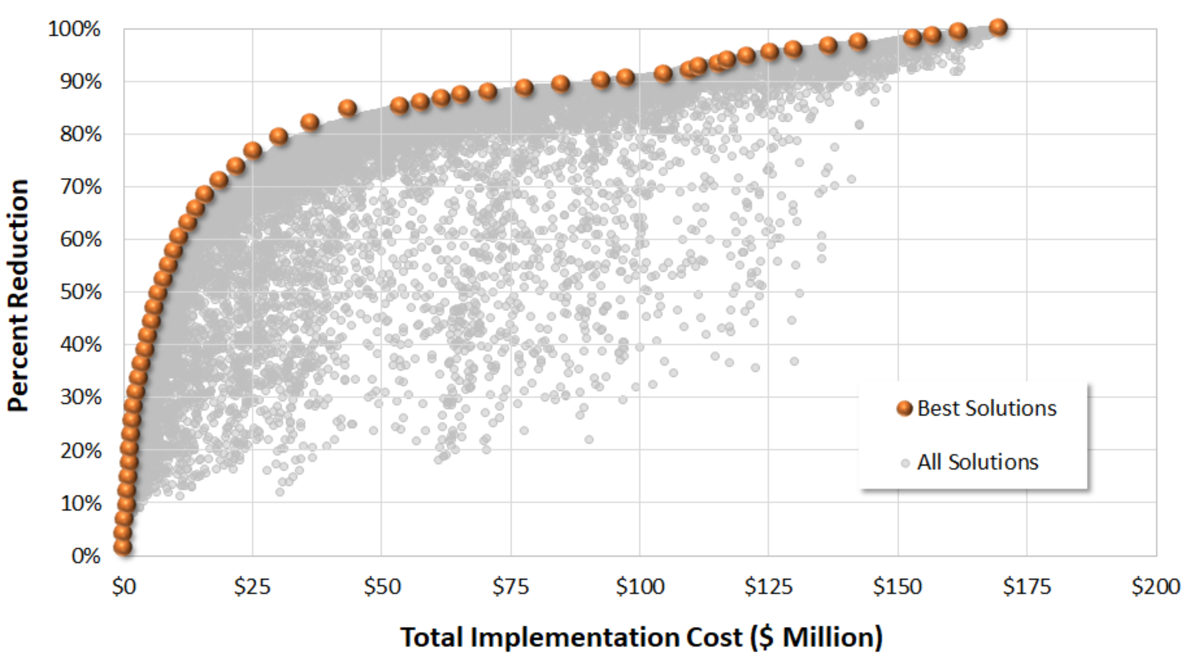
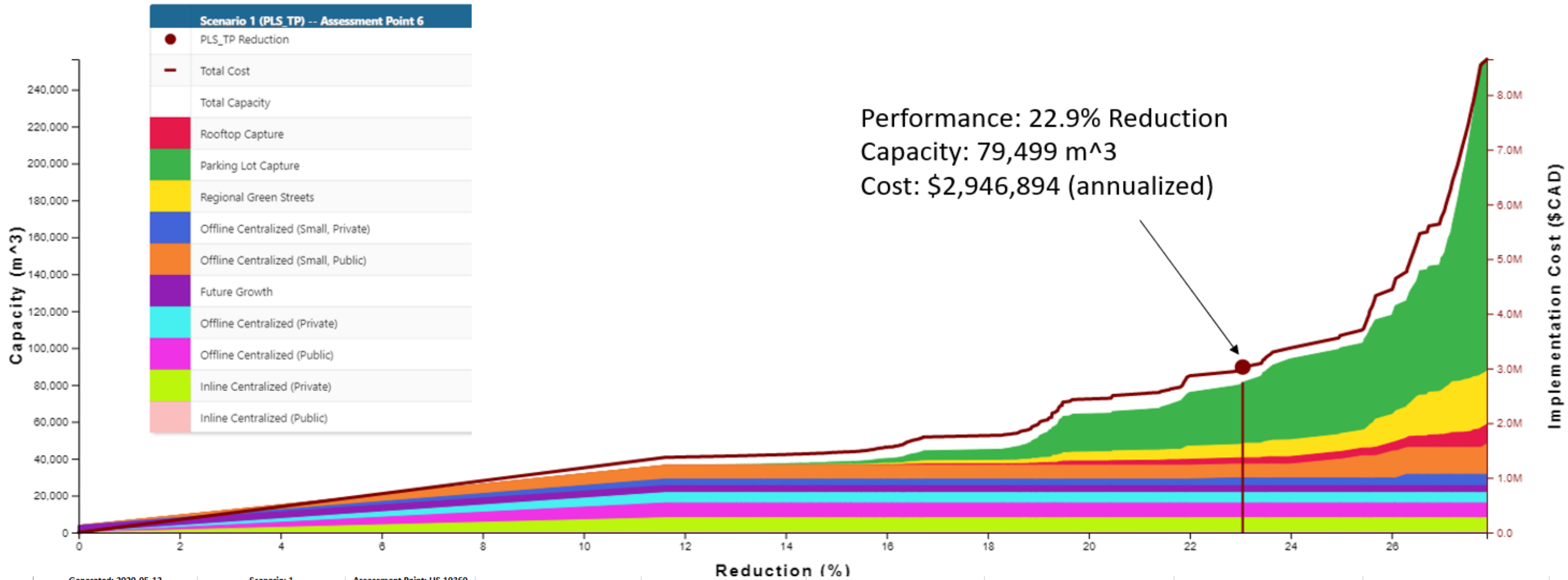


Figure 3-29: Example solutions for a single jurished and the advantage of cost-benefit optimization

3.5.5.3. Tier 2 Optimization

Each jurished's set of 'best solutions' represent the most cost-effective options within its boundary. However, when assessed at a regional scale, it may be more cost-effective to manage more aggressively in some jurisheds compared to others in order to meet downstream objectives. From this concept, a second tier of the optimization evaluates the set of best solutions from each jurished to optimize performance for a downstream point. This process balances the varying costs and benefits of all considered best solutions across the larger management area to identify a cost-optimal SCM strategy for each level of pollutant removal to meet downstream management objectives (either phosphorus reduction or peak flow reduction). The Tier 2 simulation time is approximately 2 hours.

The optimization results are summarized into optimization curves that contain the cost, capacity and reduction for each solution (Figure 3-30). Along the optimization curves, detailed implementation plans can be extracted that contain the optimal type and amount of SCMs selected for implementation within each jurished to meet the specified reduction target. For example, an emphasis for this report is the 'slice' that corresponds to 40% phosphorus reduction. The slice contains the 'recipe' of SCMs to achieve the 40% reduction upstream of the assessment point (either river outlet, East Holland Landing, or within a jurisdiction).



Generated: 2020-05-12	Scenario: 1	Assessment Point: US 10360						
Evaluation Factor: PLS_TP	Target Reduction: 40.47							
Capacity Units: m^3	Cost Units: $CAD, annualized	Footprint Units: m^2	Infiltration Trench w/ underdrain (A)	Infiltration Trench w/ underdrain (B)	Infiltration Trench w/ underdrain (C/D)	Infiltration Chamber w/ no underdrain (A)	Infiltration Chamber w/ no underdrain (B)	Infiltration Chamber w/ underdrain (C/D)
Jurished ID	Type	Total	LID1	LID2	LID3	LID4	LID5	LID6
105506	Capacity	619.1626	14.3739	0.0000	0.0000	61.9953	0.0000	56.1581
105506	Footprint	494.5	31.2	0.0	0.0	84.1	0.0	74.2
105506	Cost	29,558.39	1,815.00	0.00	0.00	1,929.02	0.00	2,057.70
105606	Capacity	59.4579	0.0000	0.0000	0.0000	3.8310	0.0000	50.0150
105606	Footprint	80.6	0.0	0.0	0.0	5.2	0.0	66.1
105606	Cost	2,774.08	0.00	0.00	0.00	855.61	0.00	1,918.47
105706	Capacity	45.2199	0.0000	0.0000	0.0000	0.0000	0.0000	41.9798
105706	Footprint	61.2	0.0	0.0	0.0	0.0	0.0	55.5
105706	Cost	1,736.36	0.00	0.00	0.00	0.00	0.00	1,736.36
105806	Capacity	191.9155	0.0000	0.0000	35.9385	0.0000	0.0000	154.6996
105806	Footprint	284.6	0.0	0.0	78.1	0.0	0.0	204.4
105806	Cost	7,094.48	0.00	0.00	2,803.40	0.00	0.00	4,291.08
105906	Capacity	53.6845	0.0000	0.0000	0.0000	0.0000	0.0000	51.7684
105906	Footprint	71.5	0.0	0.0	0.0	0.0	0.0	68.4
105906	Cost	1,958.21	0.00	0.00	0.00	0.00	0.00	1,958.21
106006	Capacity	0.2739	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
106006	Footprint	0.5	0.0	0.0	0.0	0.0	0.0	0.0
106006	Cost	0.00	0.00	0.00	0.00	0.00	0.00	0.00
106106	Capacity	4.7459	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
106106	Footprint	8.3	0.0	0.0	0.0	0.0	0.0	0.0
106106	Cost	0.00	0.00	0.00	0.00	0.00	0.00	0.00
106206	Capacity	752.3964	5.8185	0.0000	93.6793	4.8624	0.0000	473.9757
106206	Footprint	1200.8	12.6	0.0	203.7	6.6	0.0	626.2
106206	Cost	30,335.40	1,422.88	0.00	5,449.90	874.64	0.00	11,527.29
106306	Capacity	4076.0190	24.4701	0.0000	37.9470	0.0000	0.0000	569.1492
106306	Footprint	2773.2	53.2	0.0	82.5	0.0	0.0	752.0
106306	Cost	135,396.96	2,277.75	0.00	2,895.46	0.00	0.00	13,684.34
106406	Capacity	47.5841	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
106406	Footprint	77.0	0.0	0.0	0.0	0.0	0.0	0.0
106406	Cost	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 3-30: Example optimization curve and implementation plan for a sample 22.9% reduction slice

3.5.6. Climate change

The ability of SCMs to mitigate the effects of climate change were assessed. Climate change is expected to result in more extreme precipitation events in the East Holland River watershed[82]. The ability of SCMs to capture the increase in precipitation expected from climate change was evaluated for two time periods, 2021-2050 and 2051-2080. These time periods correspond to the same periods evaluated in the LSRCA Climate Change Adaptation Strategy[83]. For each period, future projection scenarios were based on two Representative Concentration Pathways (RCPs). The RCP 4.5 predicts a stabilization of carbon emissions by 2100 while RCP 8.5 represents a scenario in which carbon emissions continue to climb at historical rates. Although these are estimated future trajectories, comparisons to actual emissions levels suggest that observed emissions have been outpacing the RCP 8.5 scenario (Figure 3-31)

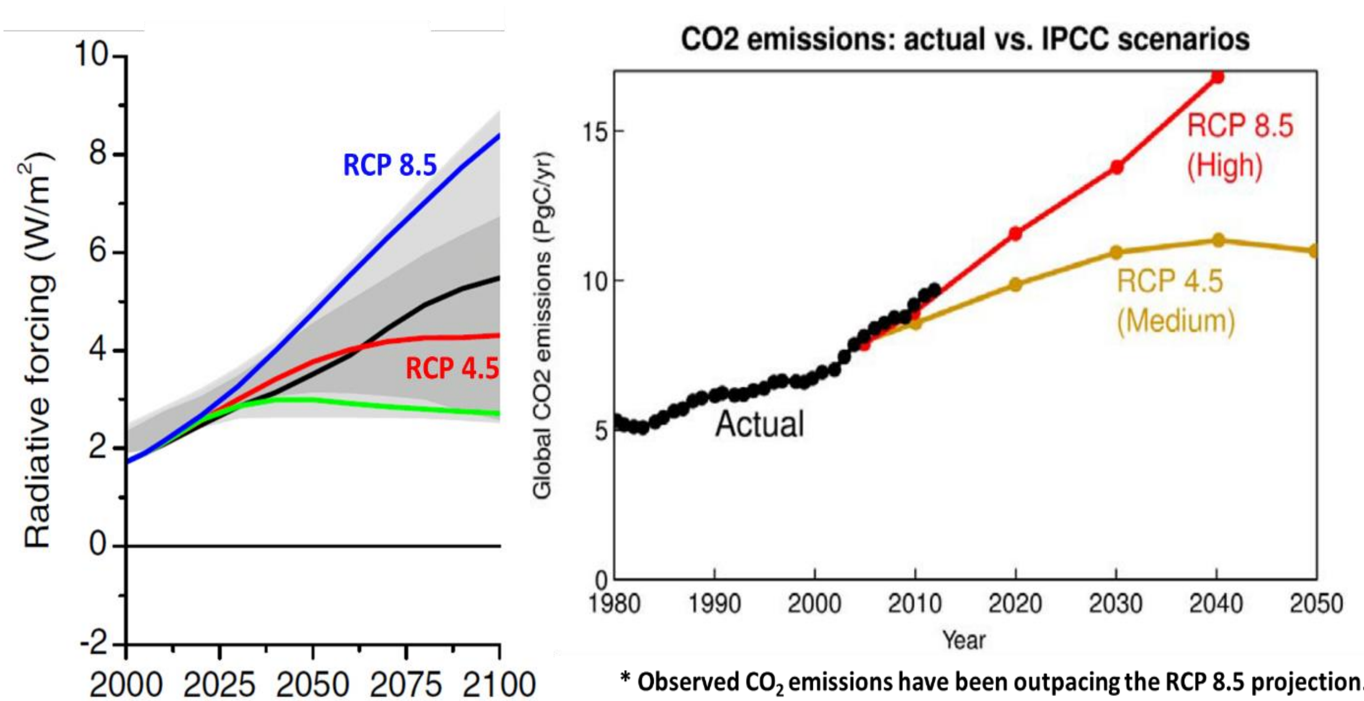


Figure 3-31: Selected representative Concentration Pathways for climate change analysis[84]

Estimates for precipitation events were obtained from the Intensity-Duration-Frequency Curves under Climate Change Tool – Version 4.0 (IDF_CC Tool)[85]. Biased-corrected predictions for the percent increase in total storm depths (Table 3-16) for the Oak Ridges Station (ID: 6155722), located in Aurora, were applied to design storm totals. For the climate change scenarios, these climate-change impacted hyetographs were routed through LSPC and SUSTAIN to estimate the mitigation of SCMs to increased peak flows for the following 4 projections:

- RCP 4.5 for period 2021-2050 and 2051-2080
- RCP 8.5 for period 2021-2050 and 2051-2080

Table 3-16: Percent increase in 12-hour storm depths for various return periods

RCP	2021 - 2050			
	10- year	25-year	50-year	100-year
Scenario 4.5	6.08%	10.42%	13.23%	15.69%
Scenario 8.5	8.05%	11.57%	11.31%	11.08%
RCP	2051 – 2080			
	10-year	25-year	50-year	100-year
Scenario 4.5	9.27%	10.07%	13.16%	15.84%
Scenario 8.5	14.51%	11.77%	14.41%	16.69%

4.0 Study Finding

The reporting of study findings is organized around the underlying study principles (see Section 2.1), as presented in the following subsections below.

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.

The Future State optimization methodology was used to create a watershed-wide strategy to reduce phosphorus loading from East Holland River into Lake Simcoe. Strategy development began with the total phosphorus objective rather than flooding because impaired water quality in Lake Simcoe poses a *basin-wide* challenge, while flood reduction is limited to *specific flood prone areas* (and not all municipalities reported flood-prone areas). The flooding analysis was integrated during both the opportunity screening (by emphasizing centralized project opportunities that provide both flood reduction and water quality benefits) and by evaluating the flood reduction co-benefits that would be achieved by the SCMs selected to achieve phosphorus reduction targets.

The output from the Future State/SUSTAIN optimization framework is an 'optimization curve' built upon millions of simulations that incorporate the data assembled during model configuration, specifically:

- opportunities and potential footprints for siting SCMs on public and private land;
- representative menu of SCMs and their typical designs;
- unit lifecycle costs for each SCM type; and
- areas where future growth is projected to occur.

As shown in Figure 4-1, an optimization curve represents a *range* of reductions from zero reduction (left end of x-axis) to maximum reduction that can be achieved with the available opportunities (right end of x-axis). Each optimization curve represents approximately 6.3 million SUSTAIN simulations[11] that consider the numerous

[11] 6.3 million simulations are comprised of 20,000 simulations for each of the 314 sub-catchments at Tier 1 plus 100 'best solution' simulations for each of the 314 sub-catchments at Tier 2

options for SCM combinations, locations and sizes. The colored bars of the curve reflect the storage capacity/size of different SCM types (shown in the y-axis on the left) and the red line reflect the corresponding annualized SCM lifecycle cost for those SCMs (y-axis on the right). The SCMs are included in the curve in order of declining cost-effectiveness, measured in terms of kilograms of phosphorus removed per dollar cost. SCMs providing most '*bang for the buck*' are included in the early, low reduction solutions to the left, while progressively more expensive SCMs are included in the later, highest reduction solutions (right end). Separate outputs are presented for two different assessment points: East Holland River outlet to Lake Simcoe and an upstream location at East Holland Landing.

From the optimization curves, implementation strategies that correspond to a target phosphorus reduction can be selected, as shown by the red dots in Figure 4-1. For East Holland River, the selected target is 40% reduction which is the Lake Simcoe-wide target from the Lake Simcoe Protection Plan[12]. The capacities and costs itemized in the legend of Figure 4-1 correspond to the 40% target – if a higher target reduction was selected the costs and capacities would be higher, and vice versa.

The outputs from the Future State model provide the first detailed economic feasibility assessment of achieving phosphorus reduction targets in the East Holland watershed. The solution for the East Holland Landing assessment point (bottom panel in Figure 4-1) is emphasized over the solution for the watershed outlet because it better reflects a potential phosphorus management strategy for municipalities in the watershed (more on this below). The output for East Holland Landing attainment represents a detailed implementation strategy for 190,000 m3 of structural SCM capacity at an annualized life-cycle cost of $6.5 million to achieve a 40% phosphorus reduction at East Holland Landing. Note this solution includes 'uptake' of SCMs on private land which would be achieved through market-based programs as discussed in later sections. A break down of these costs by municipalities is provided in section 4.3.3.

The implementation strategy is also presented as 'heat maps' to show the SCM locations across the watershed. The left panel is Figure 4-2: Implementation of SCMs to achieve phosphorus reduction at Holland Landing with public and private SCMs to achieve 40% reduction (left) and max reduction achievable with public-only siting of SCMs (right) presents the spatial representation of SCM implementation to achieve 40% phosphorus reduction at East Holland Landing (leveraging public and private lands [the right panel is discussed under the next subsection]). The sub-catchment polygons in Figure 4-2: Implementation of SCMs to achieve phosphorus reduction at Holland Landing with public and private SCMs to achieve 40% reduction (left) and max reduction achievable with public-only siting of SCMs (right) are colored on a gradient from white to red to indicate the level of distributed SCM implementation (managing parking lots, roofs and regional roads). The volumetric capacities (m^3) of distributed SCMs in each sub-catchment have been converted to the depth of runoff from the watershed that the distributed SCMs can capture. The green circles are locations of centralized SCM facilities, with the circle sized to reflect relative capacities of the centralized facilities.

The jurisdiction-by-jurisdiction implementation strategy for attaining 40% reduction at East Holland Landing is shown in Figure 4-3, organized by SCM type. The output in Figure 4-3 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 constraints. In addition, this output includes cost and capacity 'sharing' for jurisdictions that drain into centralized SCMs – for example, much

[12] For the Lake Simcoe-wide implementation strategy, the 40% target may not apply to each of the different sub-basins, as it may be more cost-effective to target different areas to achieve the overall 40% basin-wide reduction. The 40% target was simply used for East Holland River watershed as an initial target for demonstration.

of the centralized SCM capacity shown for Whitchurch-Stouffville, which is located 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. More discussion on jurisdictional-based accounting is provided in Section 4.3.

The potential footprints for SCMs to achieve 40% phosphorus reduction at East Holland Landing are illustrated in Figure 4-4. Both centralized SCM footprints (shown in red) and distributed SCM footprints (shown in purple) are illustrated. Note that, unlike centralized facilities, the distributed SCM footprints are 'potential' because distributed SCMs are optimized at a sub-catchment scale and the optimisation uses a *portion* of the available opportunity. The optimisation output provides a 'recipe' for distributed SCMs in each sub-catchment but does not prescribe the specific footprints. The actual implemented distributed SCM footprints would be determined by considering the available opportunities and in coordination with individual land owners. In contrast, centralized SCMs have specific locations, as shown in Figure 4-4. During implementation the *actual footprint within the located opportunity* would be determined in coordination with the land owner[13].

Detailed 'implementation recipes' for each municipality are presented in Appendix 6, which show sub-catchment-by-sub-catchment SCM capacities, along with heat maps and maps of potential SCM footprints. These recipes provide a 'trajectory' for an individual or preferable, shared approach to SCM implementation in the watershed to achieve phosphorus reduction targets. Over time, as the implementation program begins, more detailed stormwater Master Plans would be developed that include SCMs that have been investigated for feasibility and been subject to initial concept design. Economics of these implementation programs are further explored in Section 4.5.

Finally, further discussion is called for regarding the use of the East Holland Landing solution for implementation recipes. In comparison, the solution for the East Holland River outlet to Lake Simcoe (top panel in Figure 4-1) calls for almost double the annualized cost and capacity (350,000 m^3 of structural SCM capacity and $13.7 million annualized cost). Table 4-1 provides a detailed comparison of the solutions at the watershed outlet versus East Holland Landing. In review of the configuration of the Future State model and optimization curve outputs, the solution for the watershed outlet calls for so much more capacity and cost because the lower watershed is a high phosphorus-generating area due to agricultural lands, yet the identified opportunities for managing runoff originating for the lower watershed were much more limited and thus the 'burden' for phosphorus reduction largely falls on the more urbanized upstream areas.

To illustrate this finding, compare the top and bottom panels in Figure 4-1; they essentially show the same optimization curve, except the 40% reduction target is 'shifted' further to the right along the x-axis in the top panel for the watershed outlet, meaning higher capacity and cost. In the solution for the East Holland River outlet (top panel of Figure 4-1), the SCMs upstream of the agricultural areas achieve the reductions required to mitigate the phosphorus loading from the downstream areas; this is not considered an efficient strategy for basin-wide implementation.

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

[13] During Future State configuration, as described in Section 3.6.2, constraints were set regarding the maximum percentage of the opportunity that could be used for SCM footprints, but the actual footprint was not configured in detail.

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.

Finally, its important to note the optimization curve outputs in Figure 4-1 show a distinct ‘bend in the knee’ where the cost per unit reduction is much higher – for the East Holland solution in the bottom panel, this occurs around 45% reduction due to less effective SCM opportunities – which illustrates the importance of target selection on cost and feasibility. For example, a target reduction of 50% instead of 40% would lead to implementation of much less cost-effective SCMs. In essence, the solution for the watershed outlet forces implementation up the steep portion of the cost curve which is why increased costs (111% higher cost) are not proportional to the increased watershed area (27% more area).

Overall, the implementation recipes presented here demonstrate the utility of watershed-scale optimization to identify SCM implementation strategies. Without the optimization engine, traditional scenario modelling would be limited to a handful of configurations and would not fully explore the cost-effectiveness of many options for SCM implementation. The optimization outputs provide a balance between holistically covering the entire watershed while also providing detailed implementation recipes for hundreds of sub-catchments in the planning area.

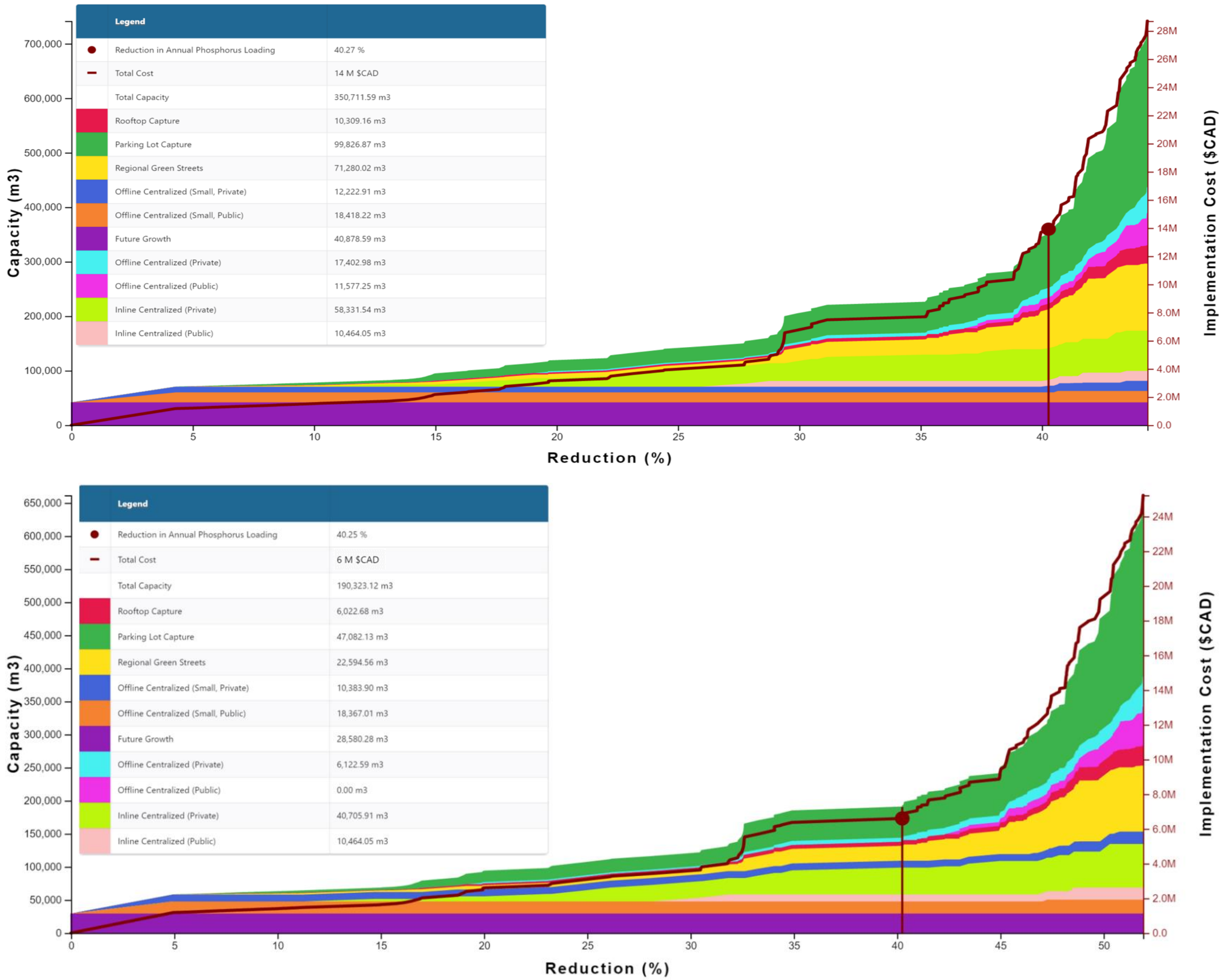


Figure 4-1: Optimized phosphorus reduction strategy at outlet to Lake Simcoe (*top*) and East Holland Landing (*bottom*) with publicly-sited SCMs and 80% uptake of private SCMs (Note: costs are annualized)

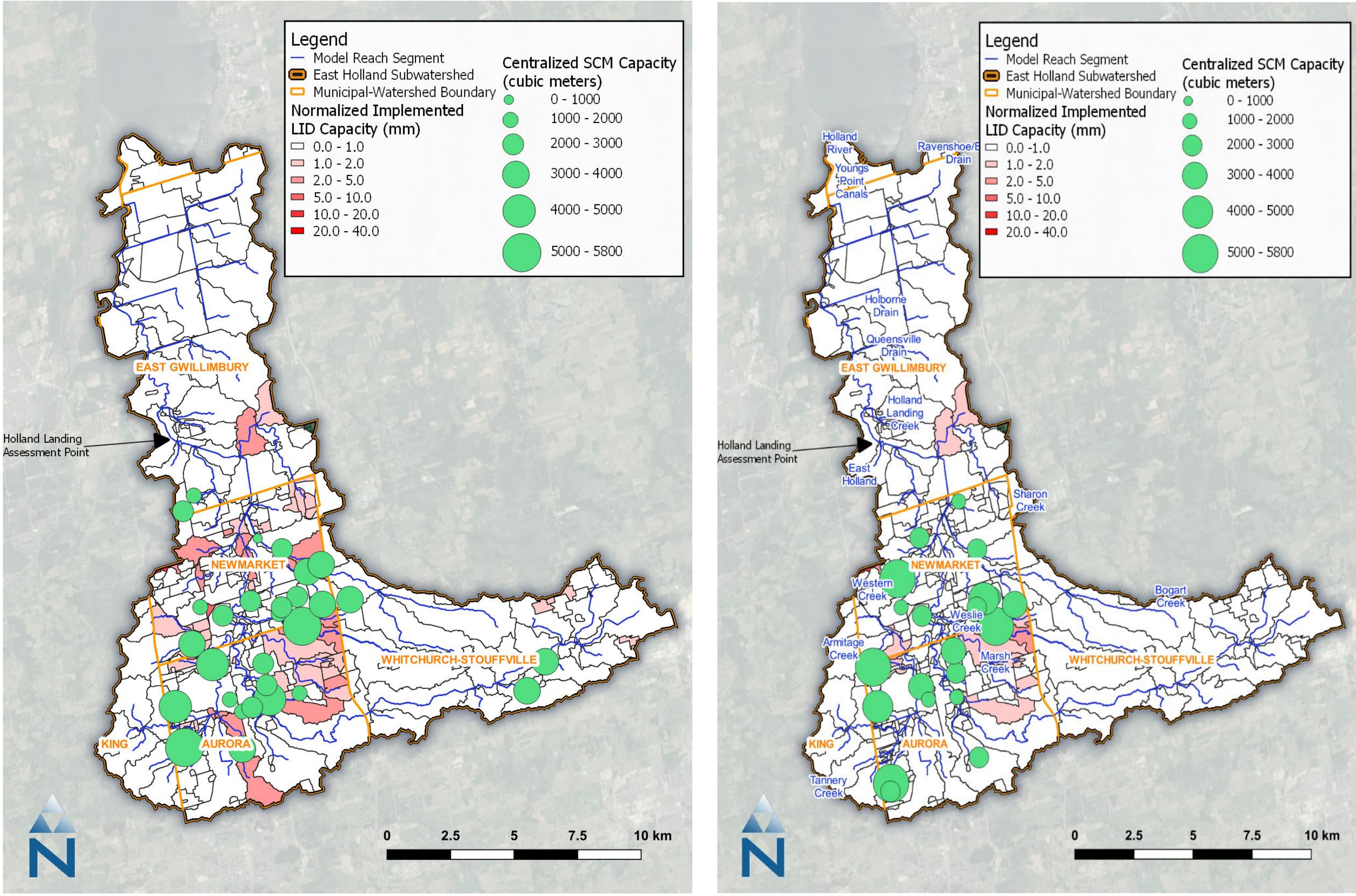


Figure 4-2: Implementation of SCMs to achieve phosphorus reduction at Holland Landing with public and private SCMs to achieve 40% reduction (left) and max reduction achievable with public-only siting of SCMs (right)

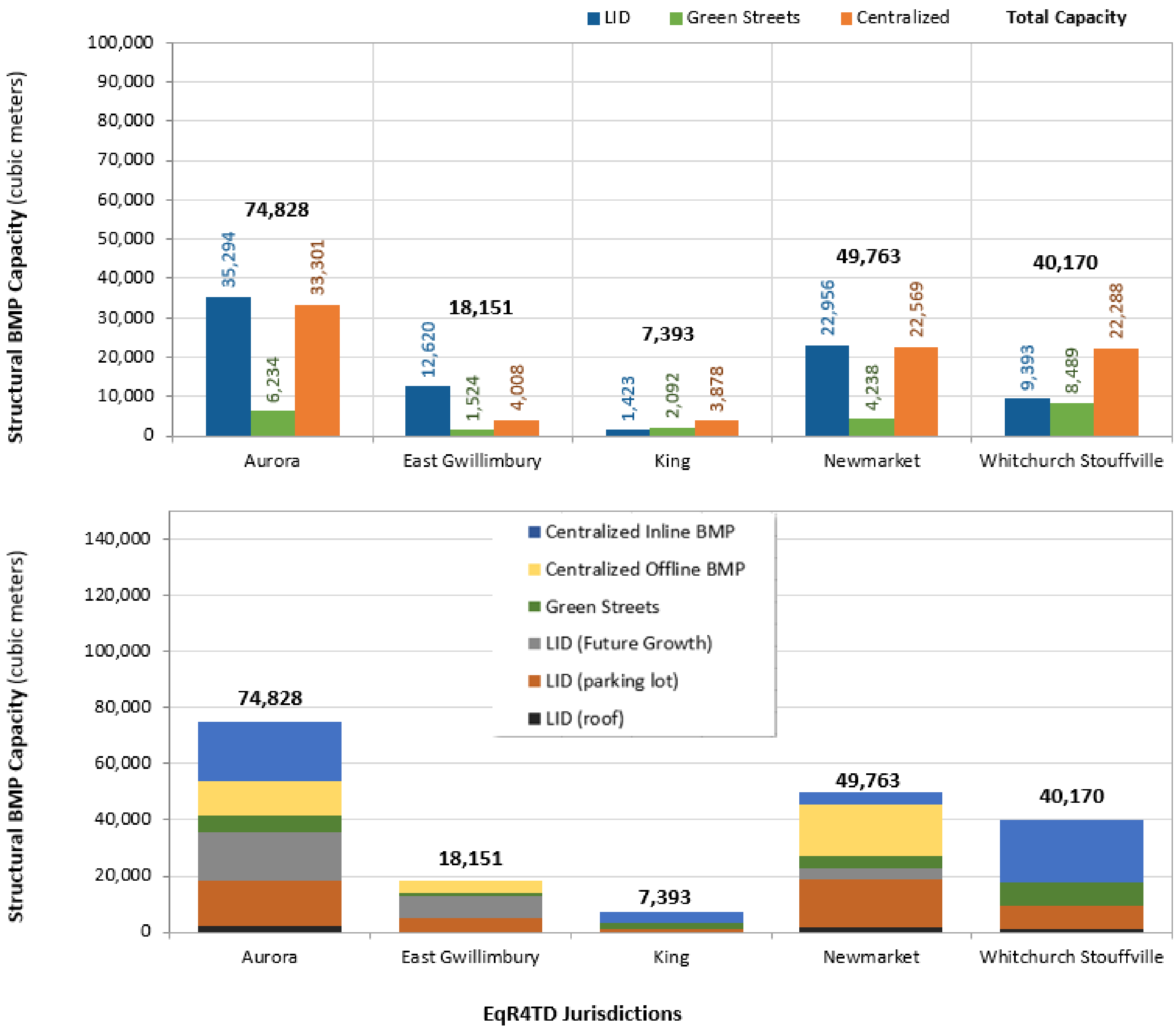


Figure 4-3: Summary of type and size of SCMs implemented on a watershed-wide basis and considering both public and private site opportunities to achieve a 40% phosphorus load reduction at Holland Landing

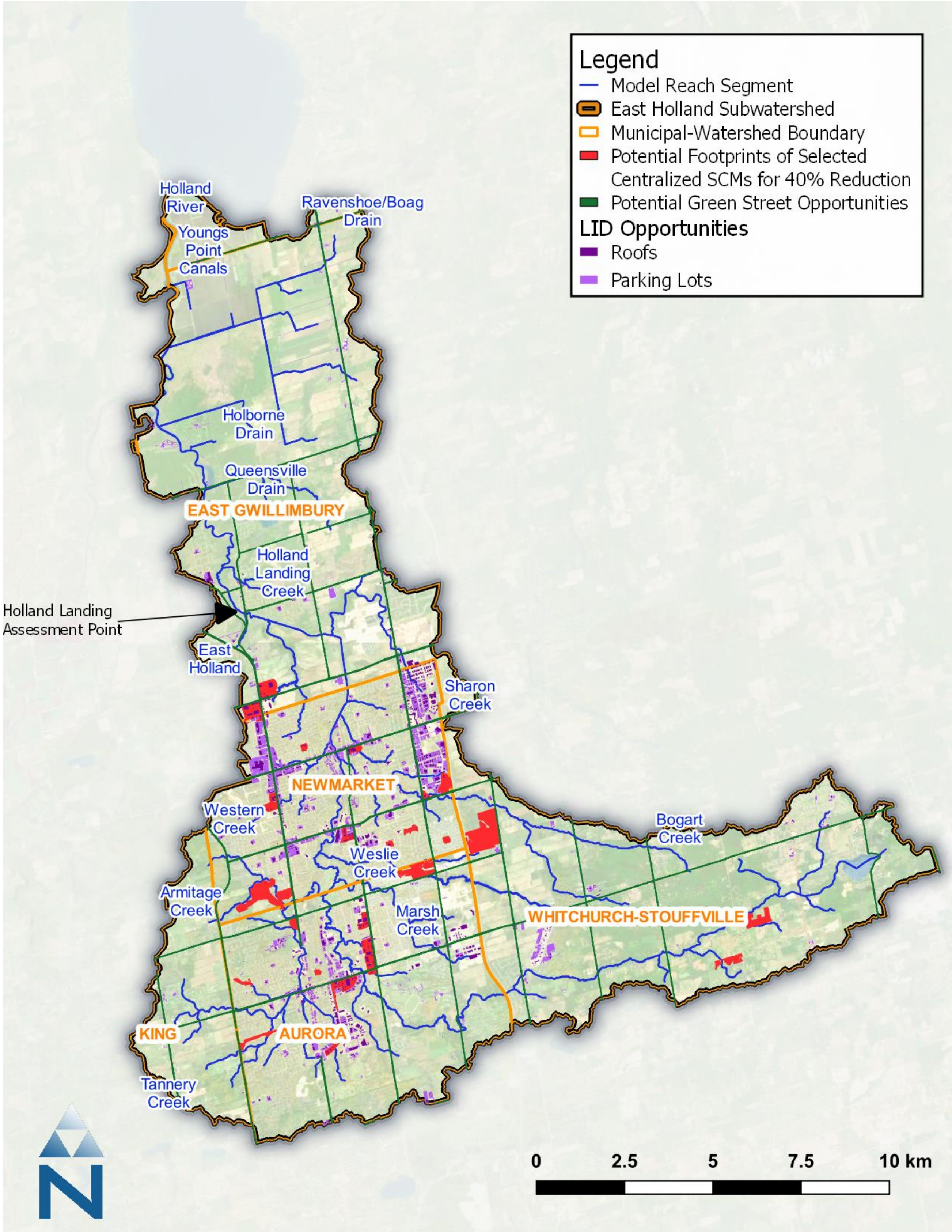


Figure 4-4: Potential SCM footprints to achieve 40% reduction at East Holland Landing considering both public and private site opportunities.

Table 4-1: Comparison of SCM implementation when achieving 40% phosphorus reduction at Holland Landing and at the East Holland river outlet to Lake Simcoe. (Note: costs are annualized)

SCM Type	Capacity		Footprint		Cost	
	Holland Landing	Outlet	Holland Landing	Outlet	Holland Landing	Outlet
Rooftop Capture	6,023	10,309	13,089	22,404	$306,620	$524,849
Parking Lot Capture	47,082	99,827	63,060	133,732	$1,063,446	$2,251,727
Green Streets	22,595	71,280	49,103	154,908	$1,956,155	$6,171,166
Future Growth	28,580	40,879	49,303	72,270	$0	$0
Offline Centralized (Small, Private)	10,384	12,223	5,408	6,365	$381,773	$485,675
Offline Centralized (Small, Public)	18,367	18,418	9,565	9,592	$675,279	$682,127
Offline Centralized (Private)	6,123	17,403	3,188	9,063	$225,102	$639,835
Offline Centralized (Public)	0	11,577	0	6,029	$0	$425,647
Inline Centralized (Private)	40,706	58,332	21,198	30,377	$1,496,587	$2,144,608
Inline Centralized (Public)	10,464	10,464	5,449	5,449	$384,720	$384,720
Total	**190,323**	**350,712**	**219,364**	**450,189**	**$6,489,682**	**$13,710,353**

4.2. Principle #2

In addition to municipal-owned properties, evaluating and utilizing private properties for structural SCMs will provide improved performance at greater cost-efficiency vs restricting consideration and siting of municipal SWM infrastructure exclusively to public land.

The implementation strategy presented for East Holland landing includes distributed and centralized SCMs that are sited on private land. Implementation of these SCMs would require marketplace instruments and programs that incentivize landowners to permit public agencies to site SCMs on their property. To allow the analysis during configuration of the Future State model and processing of its outputs, the public vs private SCMs were grouped separately to allow for comparison of 'business as usual' implementation scenarios that restrict SCMs to public land.

The findings show that if, in addition to evaluating municipal public parcels for siting SWM infrastructure, municipal stormwater planning staff evaluated suitable privately-owned parcels, 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.[14] The public-only scenarios do, however, include SCMs that would be implemented on private lands under municipally-enforced bylaws during projected future growth as was the case for scenarios discussed in the previous section.[15]

[14] 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. Separate arrangements with individual school boards would be required.

[15] Future growth SCMs are included with zero additional cost to municipalities, those costs would be borne by developers.

The public-only optimization solutions are shown in Figure 4-5. The outputs highlight that SCMs located on private property are an integral part of achieving phosphorus reduction targets in the East Holland River Watershed. If only public lands are considered, achieving a 40% reduction is not possible; the optimization curve maxes out at a 14.8% reduction at the East Holland Landing (Figure 4-1). This outcome summarizes the potential to manage runoff on public lands, the relative footprint of public lands vs the entire watershed is relatively small and thus most of the runoff would leave the watershed untreated even if opportunities on public land were used to their maximum potential.

The cost to achieve a 14.8% reduction was less expensive when private property was also considered. By comparing the bottom panel of Figure 4-1 with the bottom panel of Figure 4-5, the two scenarios can be compared. For a 14.8% reduction (the max reduction achievable with public SCMs), the annualized life cycle cost is $13.7-million per year when considering only public property, and $2 million per year when both public and private property was considered. Limiting opportunities to public land is therefore more than 5 times as expensive. When only public options are available, optimization is forced to implement less cost-effective options, including building larger capacity LID structures on public land and less effective centralized facilities.

Through this analysis, the existing programs in the watershed can be assessed in terms of their likely outcome for phosphorus reduction. The bottom panel in Figure 4-5 can be used as a projection of phosphorus reduction by two components of the existing programs: (1) implementation of LID during future growth and (2) constructing additional SCMs using the offset funding generated in the watershed. The offset funding is generated by a Phosphorus Offset Policy, which requires offset payments by developers to mitigate the phosphorus loading from that occur from new development. In addition to offset revenue, offset cost-savings would be generated through a reduction in the stormwater runoff and a corresponding reduction in municipal infrastructure costs. A percentage of those cost savings can be reallocated to incenting SCMs on private property.

The maximum revenue from the offset program is projected at $1 million annually for the East Holland watershed, in addition to the SCMs that are implemented during future growth.[16] The optimization curve in the bottom panel of Figure 4-5 shows that $1 million annual expenditure plus future growth SCMs would equate to approximately 5.6% reduction in phosphorus loading and 55,002 m3 of SCMs (of which 28,580 m3 [54%] is associated with future growth and 26,422 m3 is additional SCMs built and maintained using the annual $1 million offset revenue).

In summary, without programs to site SCMs on private land, the implementation program is greatly constrained and would not likely achieve the 40% reduction target. Due to limited opportunities on public land, a vast majority of the watershed would be untreated under a public-only scenario. Even for lower reduction targets (20%), where public-only vs public + private scenarios can be compared, the costs of a public-only approach are projected to be 50% higher because SCMs on private land provide highly cost-effective opportunities to mitigate phosphorus. That being said, under the 'business as usual' scenario with public only and $1 million in annual revenue from offset policies, existing programs provide a strong foundation for meeting reduction targets by achieving the initial 15% of the total 40% target.

Via the LSRCA's phosphorus and water budget offsetting policies, implementation of LID SCMs at optimal sites throughout the watershed can collectively help achieve water quality (P-load reductions) and hydrology (25 mm capture) targets under the LSPP. The effectiveness of the annual revenue from offsetting policies can be maximized by considering the highest 'bang for the buck' opportunities identified through optimization.

[16] SCMs for future growth were configured as sized to retain 25mm runoff. The Offset revenue would be in addition to those SCMs, in order to mitigate 100% of the phosphorus generation from the developed property.

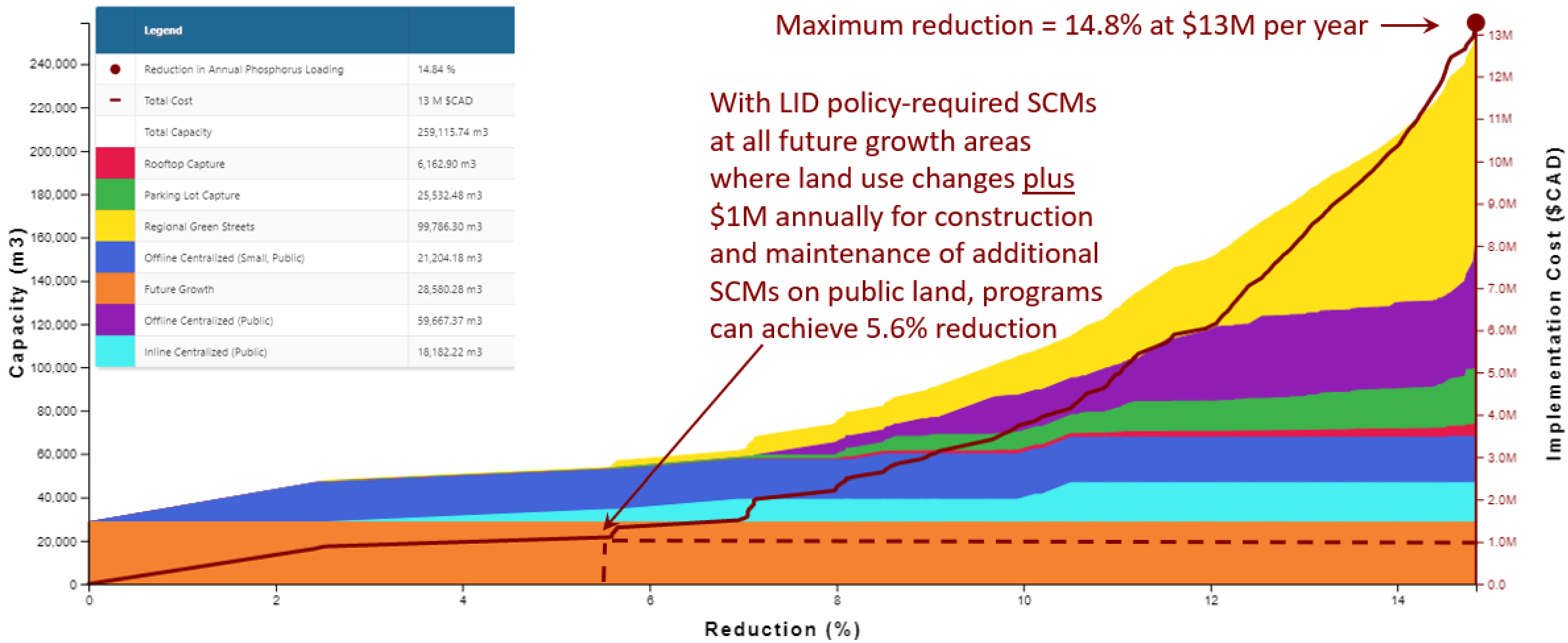


Figure 4-5: Optimized phosphorus reduction strategy at East Holland Landing using only publicly-sited SCMs. Costs are annualized. Note - the maximum available reduction is <40% target due to limited opportunities

4.3. Principle #3

Municipalities in a shared watershed have an equal responsibility for the health of the watershed in its entirety and co-operation for stormwater planning and management amongst municipalities in a common watershed will achieve optimal SWM system performance at greater cost-efficiency.

If municipalities in a common watershed co-operate in planning and managing an integrated SWM system, they could collectively achieve optimal performance – for meeting water quality and quantity objectives, improving watershed hydrology & resilience, `reducing flood risks & erosion, providing for greater adaptation to the impacts of climate change – at a greater cost-efficiency than by the current municipal boundary-based approach. To test this hypothesis, *jurisdictional* assessment points were introduced into the optimization problem formulation.

4.3.1. Allocating centralized SCM cost and capacity for jurisdictional versus basin-wide accounting

To quantify the differences in jurisdictional versus basin-wide strategies, the 'accounting' of cost and capacity, particularly for centralized SCMs, is a fundamental consideration. For centralized SCMs that are downstream of multiple jurisdictions, the accounting of financial responsibility and benefit 'credit' of which jurisdiction receives the pollutant or flow reduction[17] has a major effect on reported outcomes. For the jurisdictional accounting, optimization is constrained to the jurisdictional domains rather than generating solutions on a watershed basis (i.e., at the outlet to Lake Simcoe or at East Holland Landing[18]). For this approach, sub-watersheds are divided along jurisdictional boundaries to create 'jurisheds'[19].

The use of jurisheds allows the model to preserve the rules of hydrological connectivity and mass balance during simulation, while also providing a convenient way for management outcomes to be resampled and aggregated by jurisdiction. Distributed SCMs are smaller-scale opportunities that treat water within an individual jurished; however, centralized SCM are larger-scale opportunities located downstream of one or more jurisheds. As an illustration, Figure 4-6 presents hypothetical centralized SCM placement options (left panel) and associated treatments impacts by jurisdiction (right panel). The three possible centralized SCM placement configurations in the model are described as follows:

1) Centralized SCM footprint is located at a downstream outlet within a jurished and treats that jurished plus upstream drainage areas, as applicable;
2) Centralized SCM footprint is within one jurished, but treats stormwater routed from another jurished outlet, plus any upstream drainage areas, as applicable;
3) Centralized SCM footprint is located downstream of other centralized SCMs and treats stormwater from the intermediate drainage areas plus treated effluent from nested upstream centralized SCMs. Some stormwater water is treated multiple times.

Each of these three alternative configurations was handled with the jurisdictional-based optimization and the 'accounting' of cost and load reduction drive reporting of the differences between watershed-wide versus jurisdictional-based strategies. For purposes of accounting, the proportional inflow from different jurisheds into centralized SCMs was used to allocate cost and capacity upstream.

[17] The term 'benefit' is used to describe the 'credit' of pollutant of flow reduction that is attributable to an SCM. Crediting programs among jurisdictions would largely be based on the benefit provided by SCMs being built or cost shared.
[18] The sum of area footprint for the jurisdictional assessment points equals the total footprint area of the "basin-wide" assessment point at the mouth of East Holland River.
[19] The sum of the jurished areas within a jurisdictional boundary equals the area of the jurisdiction.

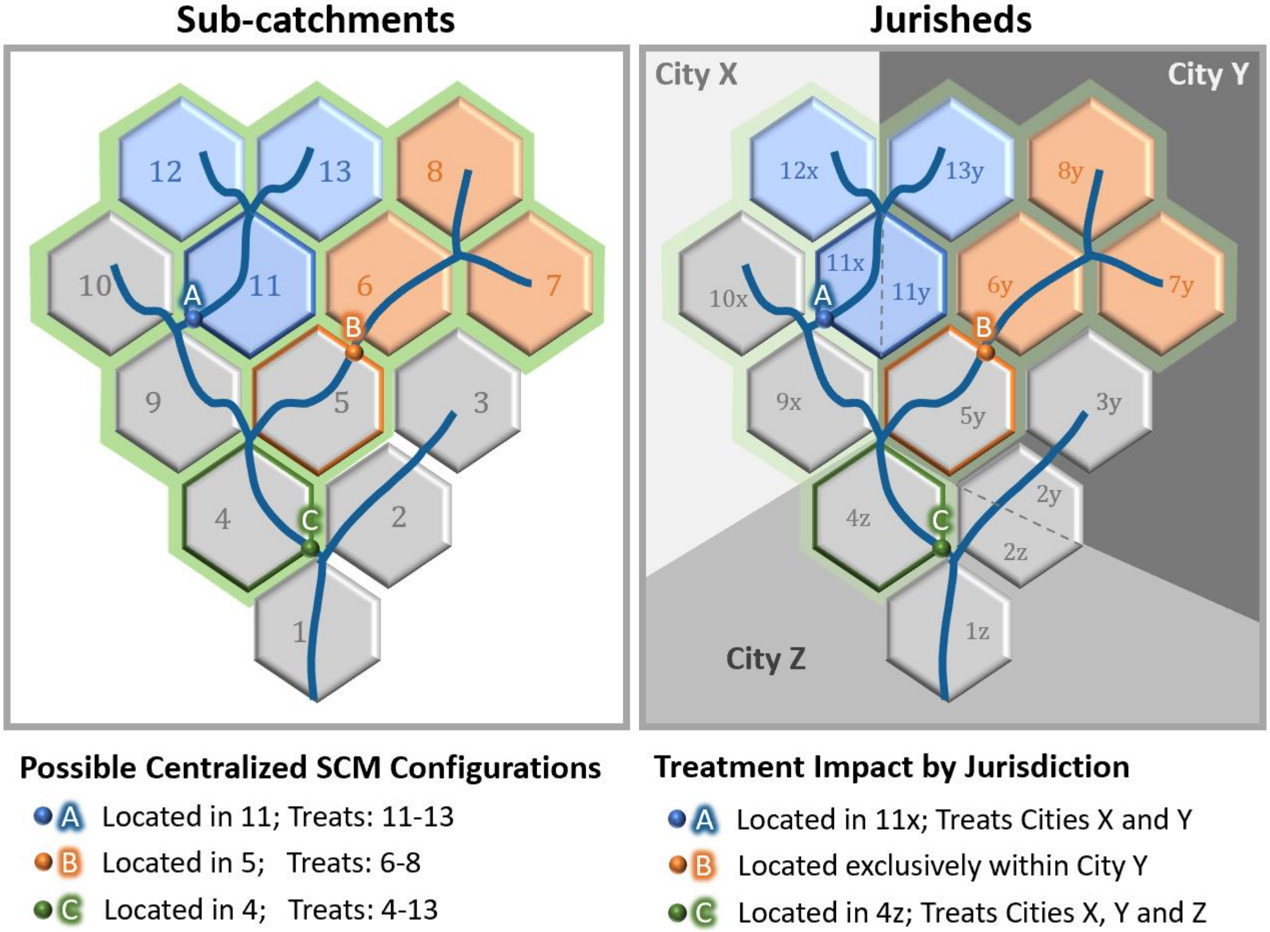


Figure 4-6: Possible centralized SCM placement configurations and treatment impacts by jurisdiction

Figure 4-7 presents the conceptual basin-wide versus jurisdictional accounting methodology. The basin-wide assessment point is shown in the left panel as the most downstream basin outlet. Three jurisdictional assessment points are shown in the right panel for Cities X, Y, and Z. Sub-watersheds 11 and 2 were divided by jurisdictional boundaries to create jurisheds 11x and 11y (divided between City X and Y), and jurisheds 2y and 2z (divided between City Y and Z). Three examples are discussed below to illustrate how cost and benefit accounting are handled for jurisdictional versus basin-wide optimization approaches.

First, consider centralized SCM A (blue dot). In both the basin-wide and jurisdictional scenarios, sub-catchments 11-13 are routed to SCM A for mass balance calculations; however, cost and benefit accounting between the two scenarios differs. For the basin-wide scenario both cost and benefit are shared between Cities X and Y proportional to inflow stormwater volume arriving at SCM A from each upstream city. Assuming equal inflow from each sub-watershed (conceptually simplified for illustrative purposes), both load reduction benefit and cost responsibility would be equally shared between Cities X and Y for SCM A because each city has half the drainage area of SCM A. City Z benefits from basin-wide and jurisdictional approaches as both reduce downstream pollutant loads.

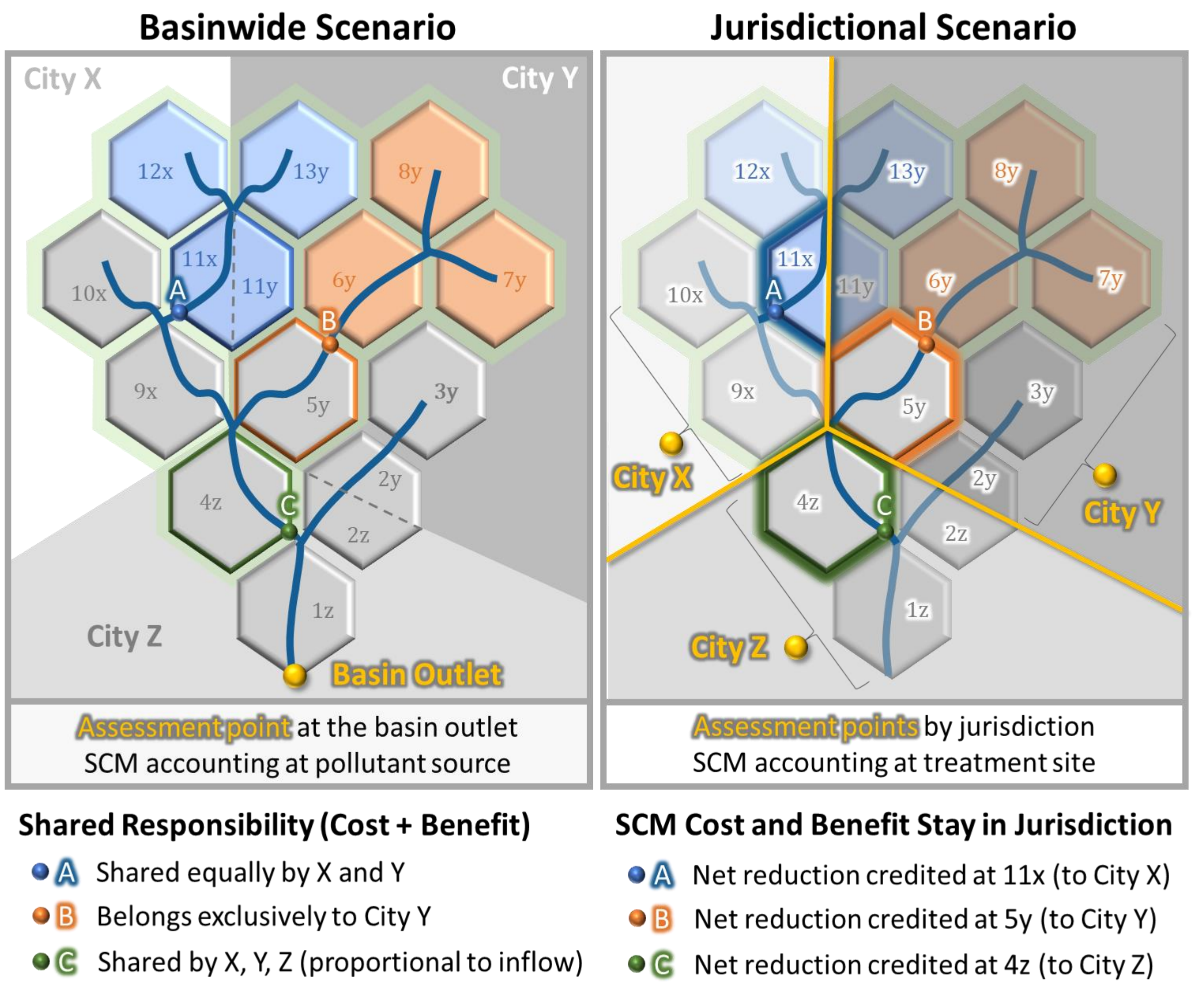


Figure 4-7: Conceptual basin-wide versus jurisdictional accounting methodology

Secondly, consider centralized SCM B (orange dot), which is wholly associated with City Y. Although the physical footprint is in 5y, it treats water from sub-watersheds 6-8. The basin-wide scenario applies the benefit of SCM B equally to sub-watersheds 6-8 only (not 5y), even though SCM B is physically located in 5y. However, the jurisdictional scenario credits the entire cost and benefit to jurished 5y even though no water originating from there is treated by SCM B. In this example, all jurisheds are located within the same jurisdiction so City Y will still receive full credit in the jurisdictional scenario. Nevertheless, it is possible for cases like this, where the footprint location is in a different jurished than where the cost and benefit credits are assigned, to extend across jurisdictional boundaries. The analysis focused on upstream jurisdictions working together to improve downstream conditions. The analysis does not consider the implications of downstream jurisdiction sharing the costs of implementation occurring upstream in other jurisdictions. The approach was limited to the contributing watershed of a SCM in order to adequately constrain the accounting framework based on quantifiable hydrological inputs, including the runoff and loading into an individual SCM that can be attributed to specific jurisdictions.

Finally, consider centralized SCM C (green dot). It is in City Z, but treats water from Cities X, Y, and Z. Effluent from SCM A and SCM B is also treated by SCM C (areas upstream of SCM A and B are therefore treated twice due to nesting). In this example, the contributing drainage area from Cities X and Y is much larger that of City Z. Assuming equal inflow from all sub-watersheds (conceptually simplified for illustrative purposes), it is possible for the net reduction achieved at SCM C (located in jurished 4z) to exceed the load originating from jurished 4z, resulting in a *negative* load in jurished 4z relative to the baseline load from 4z (because SCM C is reducing more load than originated in 4z, where its footprint is located). The watershed-wide scenario applies the benefit of SCM C to each upstream jurished in proportion to stormwater volume arriving at SCM C from each upstream jurished, and the over-reduction of SCM C relative to its jurished would not affect accounting. However, for the jurisdictional scenario, the total cost and benefit of SCM C would stay in jurished 4z — and no cost or benefit would be credited to upstream jurisdictions. In other words, Jurisdiction Z would receive all the benefit of the load reduction, but also be accounted 100% of the cost (even though its managing runoff from upstream jurisdictions). This represents an 'every jurisdiction for itself' accounting approach, but note the 'extra' benefit generated by SCM C could become available as a credit for purchase within a crediting marketplace. If there was no crediting or coordination, then the Jurisdiction X would be financially responsible for an SCM that is managing other jurisdictions' runoff.

4.3.2. Results of the jurisdictional versus basin-wide accounting analysis

For the East Holland River watershed, six jurisdictional assessment points, one for each municipality, were introduced into the optimization problem formulation.[20] Optimization curves were generated for each of those six municipal assessment points, and their respective 40% reduction slices extracted from each curve. Note the available SCM opportunity for the jurisdictional runs was the same as that used to optimize the basin-wide scenario at the mouth of East Holland River watershed[21]. Table 4-2 compares costs, capacities, and responses for the jurisdictional vs. the watershed-wide accounting scenarios. Figure 4-8 shows the relative distribution of cost and capacity for the jurisdictional vs. watershed-wide SCM solutions. The watershed-wide strategy *requires 30% less capacity and costs 27% less per year* than the jurisdictional scenario.

Table 4-2: Comparison of optimized jurisdictional vs. watershed-wide implementation strategies

Jurisdiction	Jurisdictional Strategy			Watershed-wide Strategy		
	Cost ($CAD Mil)	Capacity (m^3)	Percent P Reduction	Cost ($CAD Mil)	Capacity (m^3)	Percent P Reduction
Aurora	$2.76	87,515	55.6%	$3.83	103,573	50.9%
East Gwillimbury	$5.33	129,183	25.3%	$2.48	71,099	23.0%
Georgina	$0.29	5,360	7.6%	$0.09	1,907	6.9%
King	$0.86	13,376	27.7%	$0.78	14,621	82.0%
Newmarket	$8.38	241,274	40.1%	$3.41	94,641	26.7%
Whitchurch-Stouffville	$1.27	27,832	41.9%	$3.11	64,872	81.7%
Total	**$18.9**	**504,540**	**38.9%**	**$13.7**	**350,714**	**40.3%**
Percent Difference	*+38%*	*+44%*	--	*-27%*	*-30%*	--

[20] For the watershed-wide versus jurisdictional assessment, the optimization solution at the watershed outlet was used, rather than East Holland Landing, to allow for basin-wide accounting. The implementation recipe based on East Holland Landing, as presented in Appendix 6, is considered the most relevant implementation strategy for addressing phosphorus loading from municipalities in East Holland Watershed.

[21] The fact that SCM opportunities were assessed on a basin-wide scale before optimization means the jurisdiction versus basin-wide accounting outcomes may be a best-case scenario for the jurisdictional optimization. And typical 'every jurisdiction for itself' planning scenarios would have no coordination for finding the best SCM opportunities in the watershed, and cost inefficiencies would be even higher.

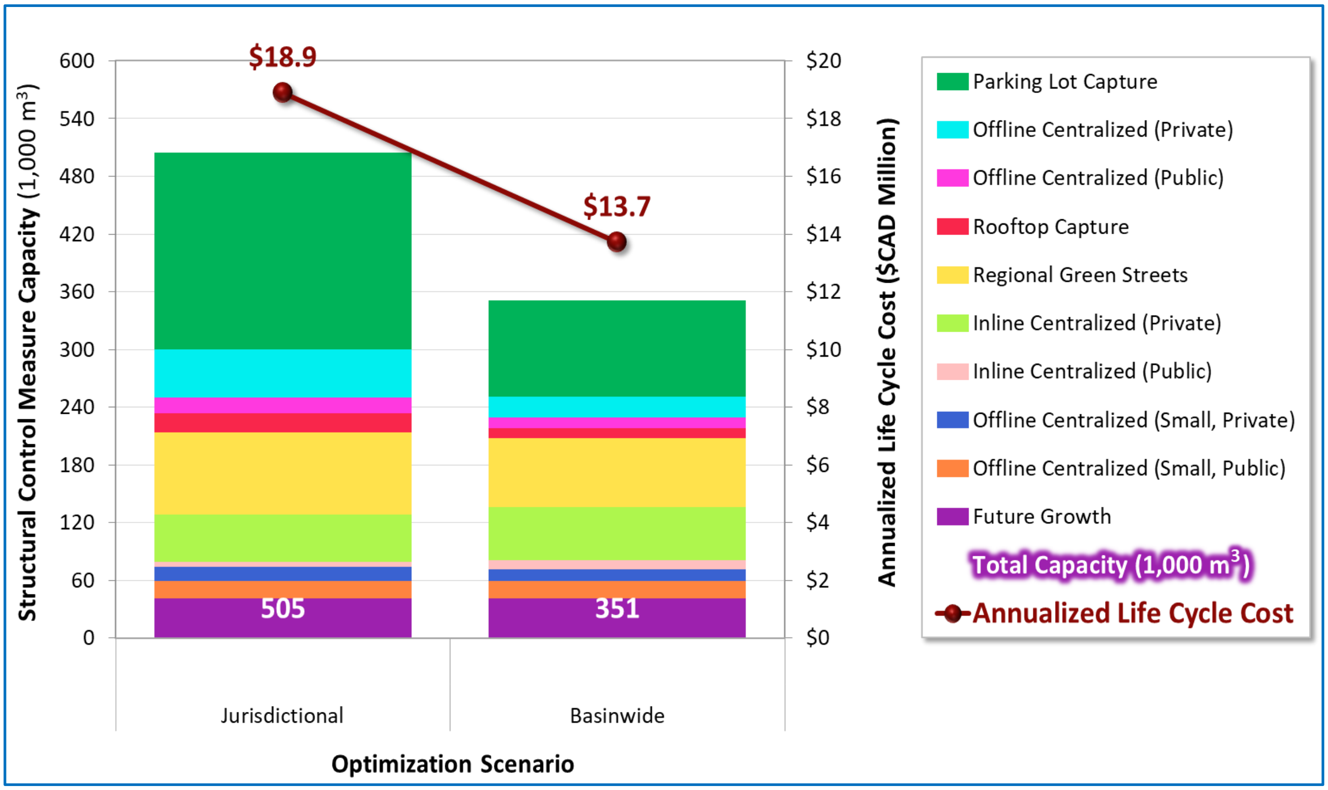


Figure 4-8: Optimized jurisdictional vs. basin-wide solutions for achieving 40% phosphorus load reduction in the East Holland river watershed

Further details on the jurisdictional versus watershed-wide accounting outcomes are presented as follows:

- Figure 4-9 shows a breakdown of jurisdiction versus watershed-wide strategies and corresponding SCM types within each jurisdiction.
- Table 4-3 is a comparison of baseline load vs. mitigated load for the watershed-wide and jurisdictional SCM implementation strategies.
- Figure 4-9 through Figure 4-11 present optimization curves for individual municipalities within the watershed. The curves represent each municipality 'going it alone' to achieve a 40% reduction of phosphorus loading from their jurisdiction.

As noted, the basin-wide scenario represents a 27% cost savings as compared to the jurisdictional scenario where each municipality individually strives to achieve a 40% phosphorus reduction; however, the comparison is not uniformly lower among the participating jurisdictions for a number of reasons (Figure 4-8), as follows:

First, some jurisdictions are opportunity-limited such that they cannot attain the 40% reduction target alone under the jurisdictional scenario (East Gwillimbury). For those jurisdictions, the maximum achievable solution is highlighted on the optimization curve (Figure 4-9 through Figure 4-11). When opportunity is limited, the selected plan extends into the steeper portion of the curve because less cost-effective options are selected, which drives up the overall implementation cost by jurisdiction. Jurisdictions such as East Gwillimbury are prime candidates for cost-sharing into upstream centralized SCMs rather than 'forcing' reductions to occur within their own jurisdiction.

Second, the centralized multi-jurisdictional SCMs were found to be the workhorses of the management strategies because of the economies of scale they provide for phosphorus load reduction. They collectively account for between 25% to 27% of the P load reduction between the two scenarios. Table 4-4 shows the reductions attributed to future growth and multi-jurisdictional SCMs for the jurisdictional vs. basin-wide solutions[22]. The location of the identified centralized SCM opportunities greatly affect the cost-effectiveness of implementation strategies (jurisdictions with few centralized SCM opportunities end up more expensive strategies, again East Gwillimbury is an example).

Third, future growth projections are not evenly distributed basin-wide. Aurora, East Gwillimbury, and Newmarket project 6.1%, 4.2%, and 3.3% P reduction from future growth, which collectively accounts for 3.7% of the basin-wide P load reduction (Table 4-4). The locations of future growth SCMs result in 'no cost' reduction to the jurisdictions, which affects the jurisdictional costs.

Figure 4-9 shows optimized jurisdictional vs. basin-wide solutions for the 40% solution, rolled up by jurisdictional assessment points—cost and benefit are also labeled above each bar. The jurisdiction-to-jurisdiction differences are an important discussion point – municipalities Newmarket and East Gwillimbury have much higher costs under the jurisdictional scenario, while Aurora and Whitchurch-Stouffville have lower costs. It may be counter-intuitive that a municipality could have less cost when not coordinating basin-wide, but the entire concept of basin-wide strategies is driven by the fact that some mitigation opportunities are cheaper in one area of the watershed versus another. When comparing unit reduction costs, as shown in 4-5, it is apparent that indeed Aurora and Whitchurch-Stouffville exhibit lower unit reduction costs than the basin-wide average. It's important to stress that these cost differences exist only because political boundaries have no correlation with watershed or sub-catchment boundaries and speak to the inequity of municipal boundary-based SWM. The difference in unit costs for Newmarket and Aurora, which are neighboring jurisdictions, is largely driven by the SCM opportunities in each jurisdiction – comparing the jurisdictional optimization curves (Figure 4-9) shows that Newmarket's solution is on the steepest section of the cost curve (red line) due to reliance on more expensive distributed SCMs (green streets and parking lot capture), while Aurora solution is on the flatter section of the cost curve which emphasizes centralized SCMs. This finding also shows the importance of the opportunity screening and cost assumptions during configuration of optimization. If additional centralized SCM (or other more cost-effective SCMs) opportunities were identified for East Gwillimbury or Newmarket, then the respective costs for each municipality could potentially be lower. The key outcome, despite the differences in cost resulting from SCM composition of the two scenarios, is the overall cost and capacity for the watershed-wide strategy is substantially lower than the jurisdictional scenario by 27% and 30%, respectively.

Finally, as mentioned above, the method for allocating centralized SCM cost and capacity will affect jurisdictional versus basin-wide results – in this scenario, sharing was based on inflow volume, Aurora and Whitchurch-Stouffville are responsible for the cost associated with the volume they contribute to downstream SCMs. If cost-allocation rules were based on phosphorus load rather than inflow volume, the cost distribution might differ.

[22] The modelling run used to generate Table 4-4 shows the *maximum achievable* reduction from future growth and regional centralized SCMs—distributed SCM impacts were not simulated for this run. Had they been simulated first, the net reduction from the regional centralized SCMs would have been partially offset by the distributed SCMs pre-treating the stormwater.

Table 4-3: Comparison of watershed-wide and jurisdictional-based SCM implementation strategies

Jurisdiction	Baseline P Load (kg/yr)	Jurisdictional		Basin-wide	
		Mitigated Load (kg/yr)	Reduction	Mitigated Load (kg/yr)	Reduction
Aurora	2,078	1,155	55.6%	1,058	50.9%
East Gwillimbury	2,274	576	25.3%	523	23.0%
Georgina	220	17	7.6%	15	6.9%
King	260	72	27.7%	213	82.0%
Newmarket	2,202	884	40.1%	589	26.7%
Whitchurch-Stouffville	1,055	442	41.9%	862	81.7%
Total	**8,090**	**3,146**	**38.9%**	**3,260**	**40.3%**

Table 4-4: Reduction attributed to future growth and multi-jurisdictional SCM reductions (assumes no reductions from distributed SCMs)

Jurisdiction	Baseline P Load (kg/yr)	Percent Reduction		
		Future Growth	Regional Centralized SCMs	
			Jurisdictional	Basin-wide
Aurora	2,078	6.1%	49.0%	61.9%
East Gwillimbury	2,274	4.2%	7.8%	6.2%
Georgina	220	0.0%	0.0%	0.0%
King	260	0.0%	7.8%	7.8%
Newmarket	2,202	3.3%	20.6%	14.8%
Whitchurch-Stouffville	1,055	0.0%	35.1%	41.9%
Total	**8,090**	**3.7%**	**27.4%**	**25.2%**

Table 4-5: Unit cost of phosphorus management by municipality for jurisdiction vs basin-wide strategies

Jurisdiction	Unit Cost of Management ($Mil/kg/yr)		Percent Difference
	Jurisdictional	Basin-wide	
Aurora	$0.054	$0.082	51.69%
East Gwillimbury	$0.209	$0.107	-48.62%
Georgina	$0.391	$0.140	-64.17%
King	$0.270	$0.082	-69.50%
Newmarket	$0.214	$0.131	-38.90%
Whitchurch-Stouffville	$0.065	$0.081	25.21%
Basin-wide	**$0.136**	**$0.095**	**-29.97%**

Color gradient:

Lowest	Low	Medium	High	Highest

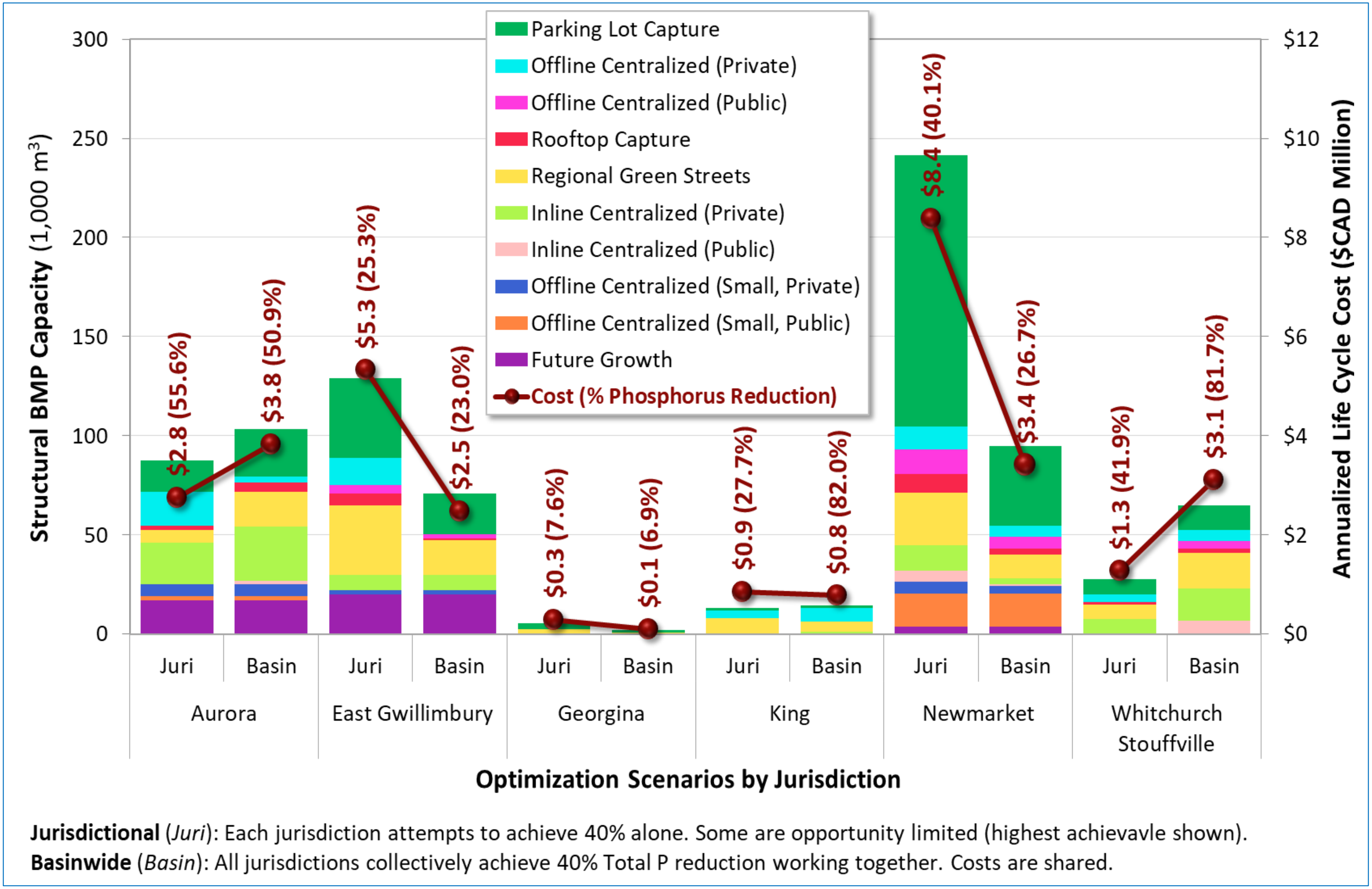


Figure 4-9: Optimized jurisdictional vs. basin-wide strategies for the 40% solution rolled up by jurisdictional assessment points

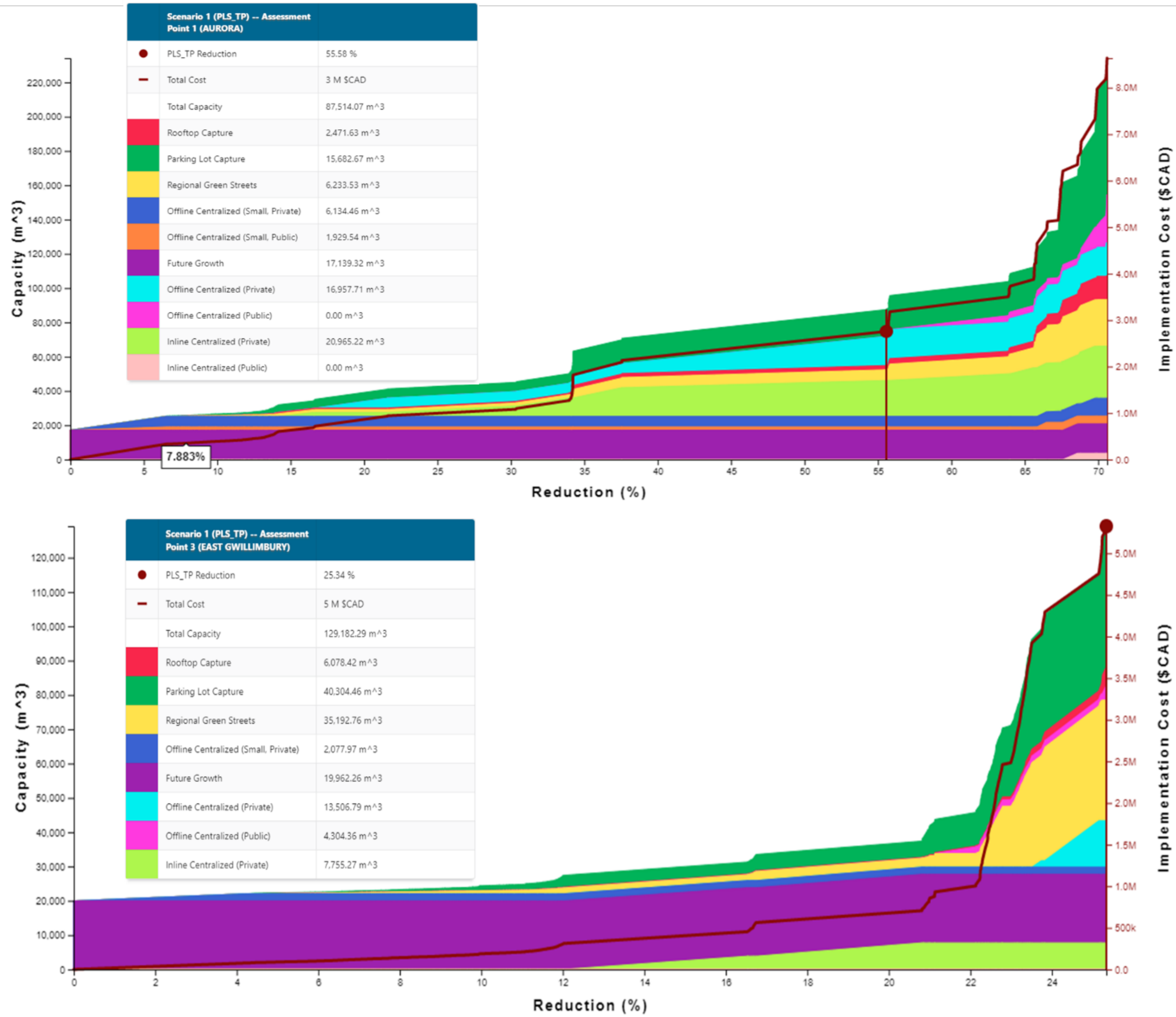


Figure 4-10: Optimized jurisdictional scenario curves for jurisheds in Aurora (top) and East Gwillimbury (bottom)

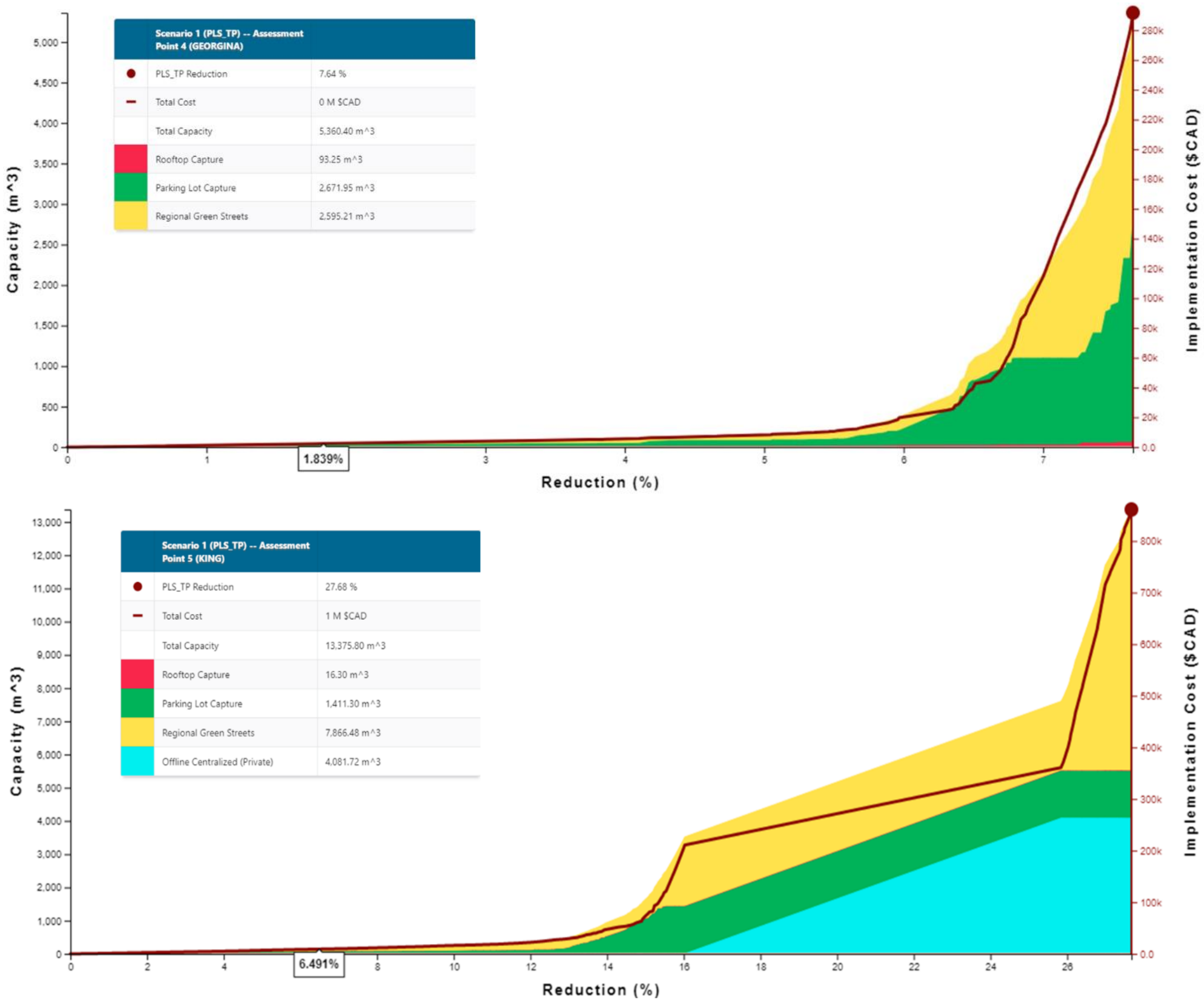
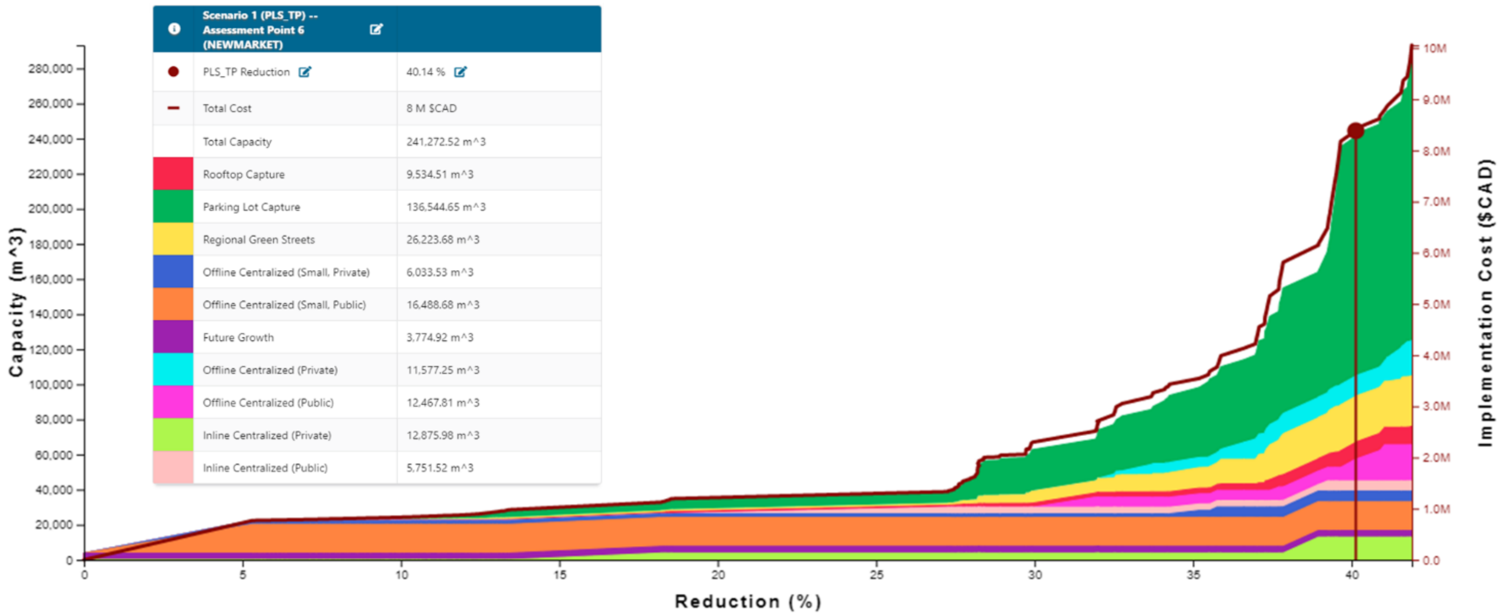


Figure 4-11: Optimized jurisdictional scenario curves for jurisheds in Georgina (top) and King (bottom)



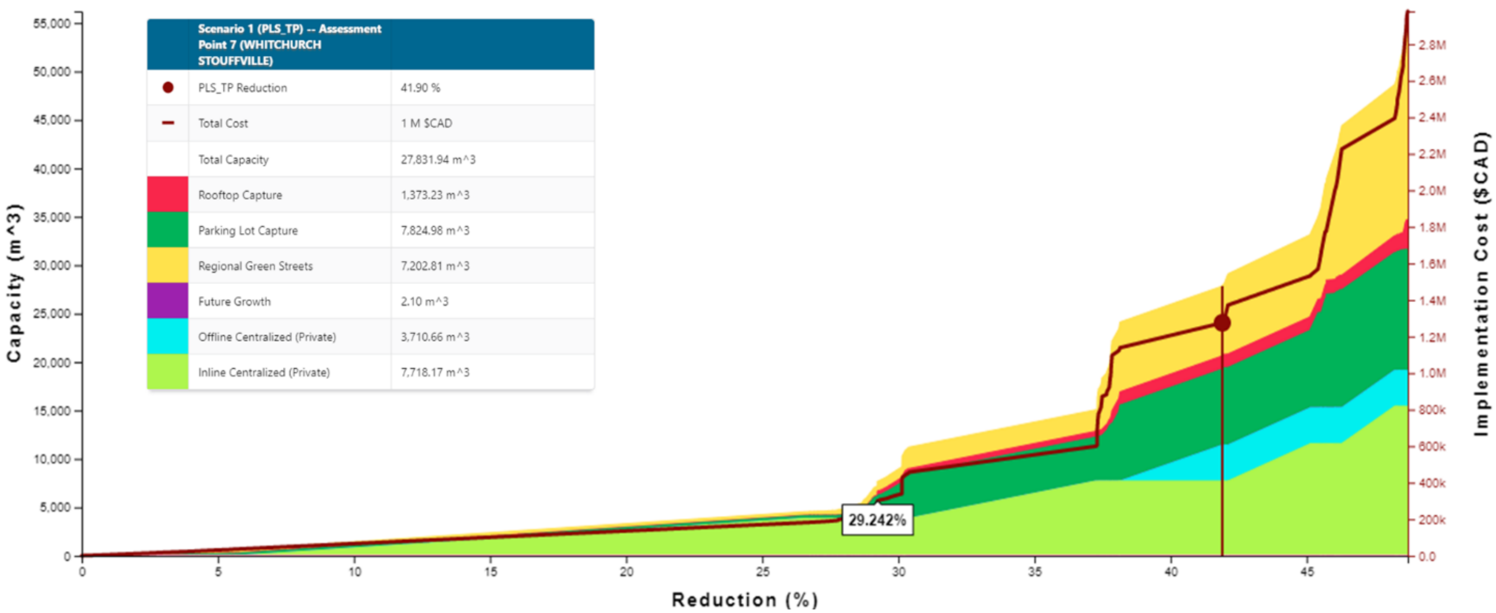


Figure 4-12: Optimized jurisdictional scenario curves for jurisheds in Newmarket (top) and Whitchurch-Stouffville (bottom)

4.3.3. Municipal budget perspective for cost allocation

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 System-wide SWM. Equitable cost sharing is an ultimate strategy for collective efficiency, but for the purposes of clarity and relevance, cost generated by SUSTAIN are presented with a municipal budgeting perspective.

The SUSTAIN output presents life-cycle costs evaluated over a 30-year time period assuming price inflation of 3% and a discount rate of 5%. From a municipal perspective, however, the composition of these costs is critical, since capital and O&M costs affect different municipal budgets. The costs presented below are based on assessment at East Holland Landing.

While SUSTAIN optimization utilized life cycle cost tools, the underlying calculation of the SCM costs allows their breakdown into capital costs and O&M. These costs are provided by municipality in Table 4-6 and Figure 4-13. The annual O&M costs include the cost of routine annual maintenance of the built assets.

Table 4-6: Breakdown of project costs by jurisdictions (total annualized costs, $1,000s) for 40% reduction assessed at Holland Landing

Community	Annualized Capital Cost	Annual OM Cost	Total Annual Life Cycle Cost
King	$255	$97	$352
East Gwillimbury	$416	$224	$640
Whitchurch–Stouffville	$1,126	$437	$1,563
Newmarket	$1,151	$534	$1,685
Aurora	$1,432	$667	$2,099
TOTAL	**$4,380**	**$1,959**	**$6,339**

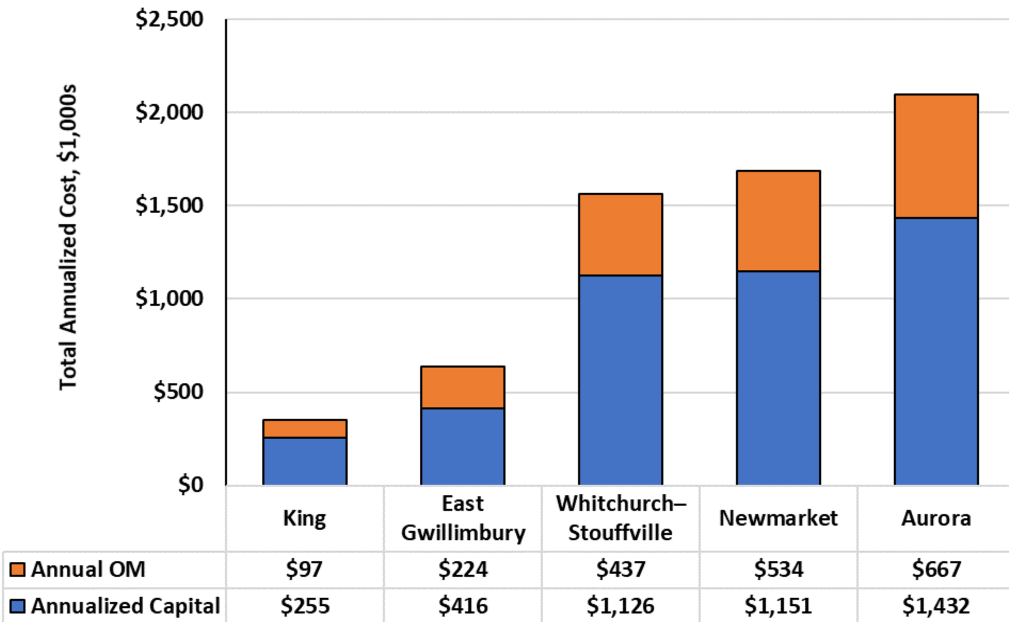


Figure 4-13: Project costs by jurisdiction

Capital costs in Figure 4-13 can be difficult to interpret because they are annualized over a 30-year period. They are converted to a total investment amount shown at 2020 price levels in Figure 4-14. Estimated O&M costs amount to 2.0% of these capital costs.

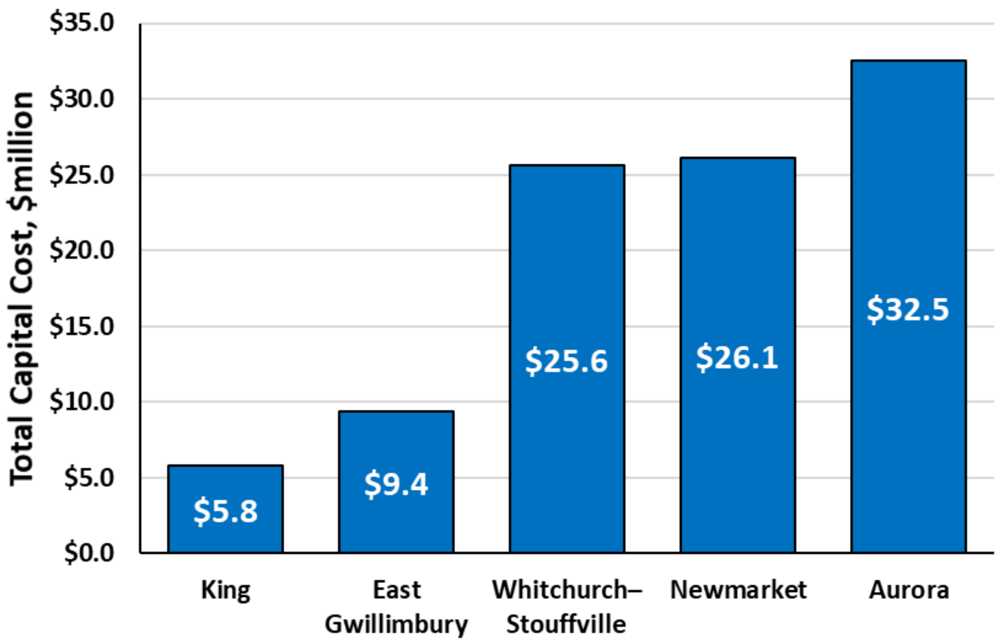
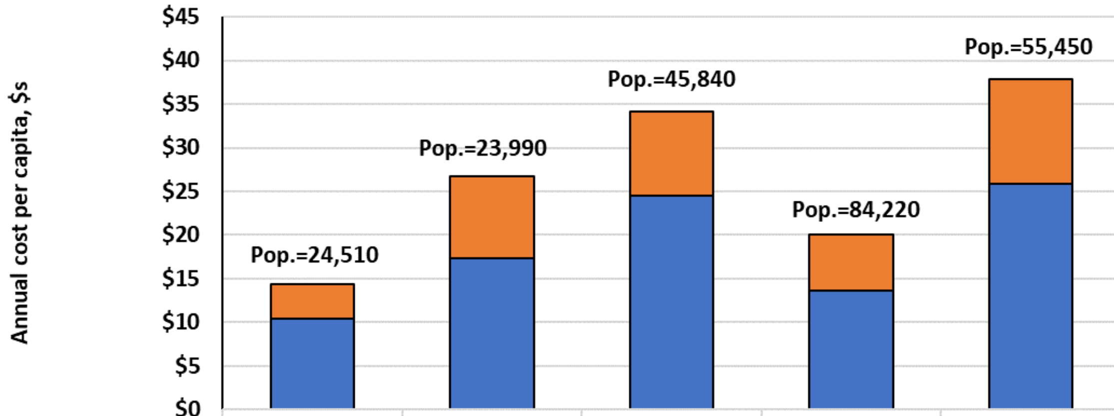


Figure 4-14: Total capital costs by jurisdiction

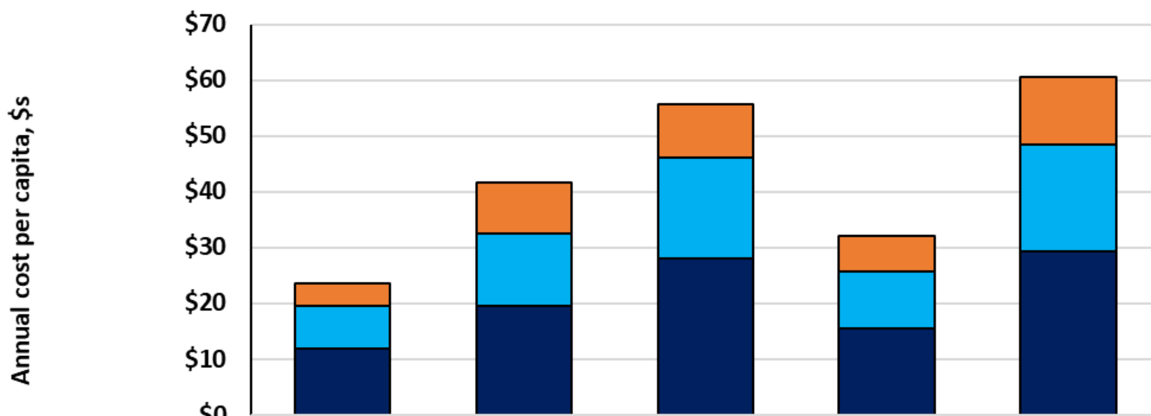
The plotted costs are displayed from lowest to highest in the Figures 4-13 and 4-14, but this ranking changes when population is taken into account (Figure 4-15).[23] Expressed in this way, the relative cost burden is much lower in Newmarket and higher in East Gwillimbury.



	King	East Gwillimbury	Whitchurch–Stouffville	Newmarket	Aurora
Annual OM	$4	$9	$10	$6	$12
Annualized Capital	$10	$17	$25	$14	$26

Figure 4-15: Per capita project costs by jurisdiction

Costs in 4-15 are still based on the 30-year life-cycle cost analysis which, in all likelihood, will not represent how these costs are presented in municipal budgets. Figure 4-16 considers what the municipal cost burden might look like on a per capita basis under the following assumptions: OM costs are as shown and capital costs are spread over a ten-year period with 50% financed out of current revenues and 50% financed by 20-year debt at a rate of 2.7%. These costs are higher than those shown in the preceding figure because capital costs are now spread out over a shorter period of time that is more representative of municipal capital financing practices.



	King	East Gwillimbury	Whitchurch–Stouffville	Newmarket	Aurora
OM	$4	$9	$10	$6	$12
Loan, 2.7%, 20 years	$8	$13	$18	$10	$19
Capital from curent	$12	$20	$28	$15	$29

[23] *Facts at a Glance*; York Region 2016 Census population by Local Municipality (downloaded May 31, 2020 from york.ca)

Figure 4-16: Per capita project cost burden on municipal budgets

4.4. Avoided Flood Damage Cost

As described in Section 3.1.3, 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 3-4).[24] 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[25]) and by evaluating the flood reduction co-benefits that would be achieved by the SCMs selected to achieve phosphorus reduction targets.

The SCMs for the optimization solution to achieve 40% phosphorus reduction at East Holland Landing were analyzed using hydrologic (LSPC) and hydraulic (HEC-RAS) modelling to quantify the flood reduction benefits. In other words, the SCMs that achieve a 40% P reduction were 'locked down' in SUSTAIN and their co-effectiveness for reducing peak flow and water level was estimated. These measures achieved a range of reductions across the six flood-prone areas, as discussed below. Figure 4-17 presents the cost curve for area 8 as an example. At the area 8, flood levels were predicted to be reduced by 3.6%. Appendix 6 contains detailed 'implementation recipes' for achieving these reductions.

[24] 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.

[25] 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.

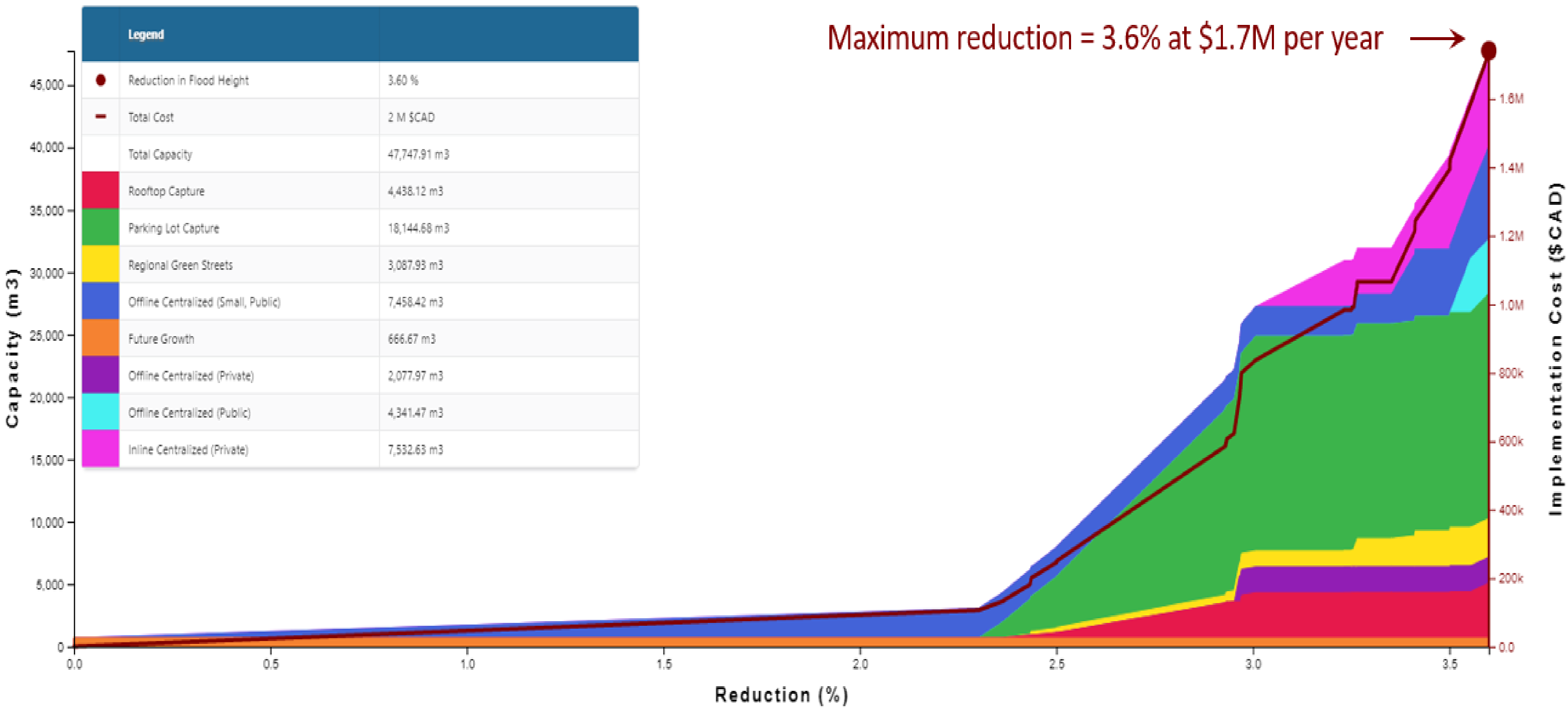


Figure 4-17: Optimized least cost curve for flood level reduction of design storms for Area 8.

To support this analysis, optimization curves for the flood design storms (10-, 25-, 50- and 100-year storms) were generated, and the corresponding water level reductions were determined using the HEC-RAS rating curves (Figure 4-18).[26] Rating curves show how flood elevation or stage increases with flood flow and reflects the impact of hydraulic characteristics of the stream channel and floodplain at a site. Generally, flood stage increases rapidly at lower flows confined to the channel. As discharge overflows the banks and accesses the floodplain, the rating curve becomes flatter – this is not unique to East Holland watershed. However, other factors, such as undersized culverts and bridges, and development within the floodplain can also impact and exacerbate flood conditions. Figure 4-18 presents a rating curve for the Gorham St to Srigley St Flood Prone area in Newmarket.

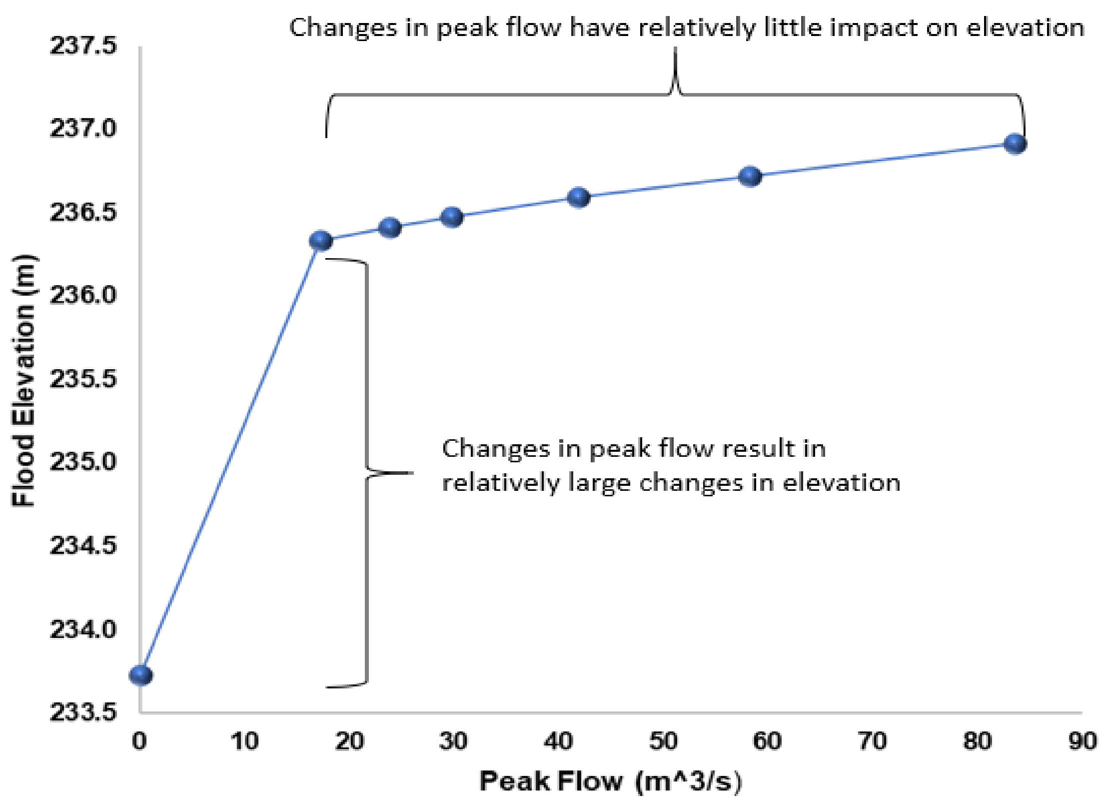


Figure 4-18: Example Rating Curve for the Gorham St to Srigley St flood-prone area in Newmarket

The estimates of flood reduction provided the basis for estimating flood damage reductions. They represent the *maximum potential* of the SCMs for reducing peak flows and water levels (Table 4-7). Overall, the ability for SCMs to reduce flooding impact is reduced as storms become larger and less frequent. However, channel and floodplain geometry play an important role in calculated reductions,

[26] Under these optimization simulations, the target for optimization was peak flow reduction at Tier 1 and volume reduction at Tier 2. These optimization outputs were independent of the phosphorus reduction optimization, except for the fact that centralized SCMs opportunities emphasized facilities that exhibited both water quality and flood reduction benefits.

therefore area 14 demonstrates increased flood reductions at the 100-year flood compared to smaller storms.

Table 4-7: Flood flow reductions with SCM implementation to reduce P-loading by 40% at East Holland Landing

Flood-prone Area*	Upstream area (km^2)	Min. Stream Elev. (m)	Baseline Flood			Flood after Mitigation			Impact on Flow (%)	Impact on flood elev. (%)
			Flow (m^3/s)	Flood Elev. (m)	Stream Depth (m)	Flow (m^3/s)	Flood Elev. (m)	Stream Depth (m)		
10-YEAR FLOOD										
Area 2	2.95	254.31	6.12	255.92	1.61	5.07	255.79	1.48	-17.2%	-8.1%
Area 5	28.61	250.22	32.75	251.93	1.71	26.18	251.64	1.42	-20.1%	-17.0%
Area 10	5.97	236.51	15.39	238.83	2.32	12.82	238.67	2.16	-16.7%	-6.9%
Area 8	24.16	233.73	29.75	236.48	2.75	22.95	236.42	2.69	-22.9%	-2.2%
Area 13	16.3	254.35	14.14	255.95	1.60	10.87	255.80	1.45	-23.1%	-9.4%
Area 14	4.51	256.47	8.40	258.16	1.69	6.91	257.98	1.51	-17.8%	-10.7%
25-YEAR FLOOD										
Area 2	2.95	254.31	9.44	256.13	1.82	7.88	256.06	1.75	-16.6%	-3.8%
Area 5	28.61	250.22	50.29	252.69	2.47	40.69	252.27	2.05	-19.1%	-17.0%
Area 10	5.97	236.51	20.90	239.00	2.49	17.51	238.92	2.41	-16.2%	-3.2%
Area 8	24.16	233.73	41.82	236.58	2.85	32.66	236.50	2.77	-21.9%	-2.8%
Area 13	16.3	254.35	22.09	256.17	1.82	17.57	256.07	1.72	-20.5%	-5.5%
Area 14	4.51	256.47	11.34	258.45	1.98	9.34	258.25	1.78	-17.6%	-10.1%
50-YEAR FLOOD										
Area 2	2.95	254.31	13.92	256.28	1.97	11.88	256.22	1.91	-14.7%	-3.0%
Area 5	28.61	250.22	67.28	252.89	2.67	56.09	252.77	2.55	-16.6%	-4.5%
Area 10	5.97	236.51	27.58	239.14	2.63	23.61	239.03	2.52	-14.4%	-4.2%
Area 8	24.16	233.73	58.20	236.71	2.98	46.88	236.62	2.89	-19.5%	-3.0%
Area 13	16.3	254.35	33.80	256.47	2.12	27.84	256.39	2.04	-17.6%	-3.8%
Area 14	4.51	256.47	15.01	258.81	2.34	12.64	258.57	2.10	-15.8%	-10.3%
100-YEAR FLOOD										
Area 2	2.95	254.31	19.15	256.38	2.07	17.22	256.37	2.06	-10.1%	-0.5%
Area 5	28.61	250.22	95.92	253.09	2.87	84.51	253.02	2.80	-11.9%	-2.4%
Area 10	5.97	236.51	36.70	239.38	2.87	33.01	239.29	2.78	-10.1%	-3.1%
Area 8	24.16	233.73	83.51	236.92	3.19	71.12	236.82	3.09	-14.9%	-3.1%
Area 13	16.3	254.35	48.26	256.65	2.30	42.52	256.58	2.23	-11.9%	-3.0%
Area 14	4.51	256.47	20.71	259.78	3.31	18.43	259.30	2.83	-11.0%	-14.5%

* FLOOD PRONE AREAS
Area 2 - Tannery Creek, South of Tyler Street at Temperance St
Area 5 - Tannery Creek, Aurora Heights Dr/Machell Park
Area 10 - Western Creek, Ontario St, East of Lorne Ave
Area 8 - Bogart Creek, Gorham St to Srigley St
Area 13 - Tannery Creek, Harriman Driveways
Area 14 - Tannery Creek, Kennedy St West Culvert

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).

The mitigation of peak flows generally did not translate to water level reductions at flood-prone sites in East Holland watershed (Table 4-7). The maximum *water level* reduction achieved for the 10-year storm was 17.0% compared to 14.5% for the 100-year storm. Overall, water level reductions were well below these levels, averaging 6.3% across all flood return periods and 4.5% for the 100-year flood.

The impact of reduced flooding on flood damages is depicted in Figure 4-19, using the example of Area 5 which plots damages against the return frequency of the flood flow for one of the flood prone areas. The x-axis of Figure 4-19 goes from large, infrequent storms to the left to smaller more frequent storms to the right. The 100, 50, 25, 10, and 5-year floods, have a 1%, 2%,4%, 10%, and 20% chance of occurring in any given year, respectively. The blue line represents existing conditions and the orange line, flood damages after SWM measures are implemented. During smaller storms, including the 10-year, damages do not occur during existing conditions. In the case depicted, flood damages up to the 20-year flood are eliminated, and damages for larger floods up to the 100-year flood are marginally reduced.

This reduction in damages, expressed in terms of average annual damages, is the value we consider when comparing the costs of conventional and green SWM measures to the benefits.

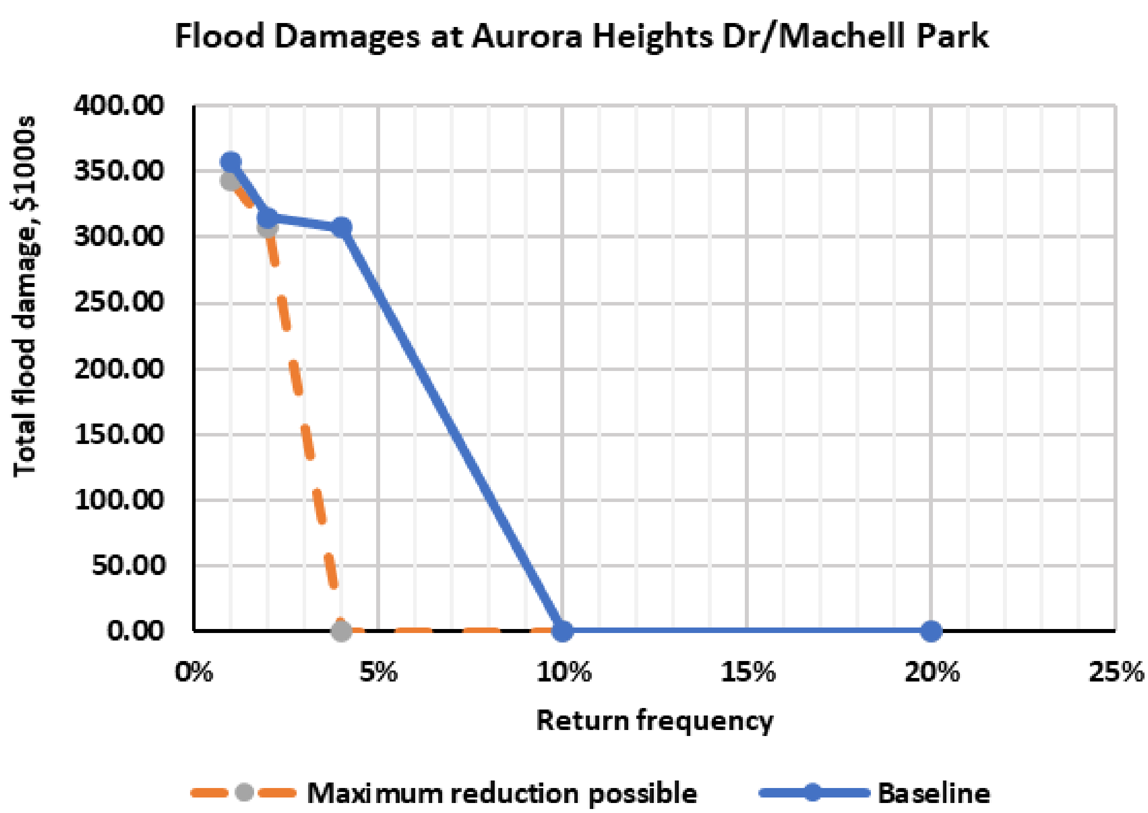


Figure 4-19: Flood damages by return frequency

Estimated flood damages for the five flood prone areas evaluated for this study are shown at flood frequencies ranging from 20% (5-year flood) to 1% (100-year flood) in Table 4-8. The estimated benefit from implementing SWM measures is the difference in average annual damages under existing conditions and with the SCMs for optimal phosphorus control in place; this amounts to $51,000 per year.

Table 4-8: Flood damages by return frequency

DAMAGE RETURN FREQUENCY	1%	2%	4%	10%	20%	Avg annual damage
BASELINE FLOOD DAMAGES - $1,000s						
AREA 2 - S. of Tyler Street at Temperance St	1,183.6	955.5	916.1	783.7	0.0	119.6
AREA 5 - Aurora Heights Dr/Machell Park	357.0	314.9	307.3	0.0	0.0	18.8
AREA 8 - Gorham St to Srigley St	2,339.0	2,166.7	1,911.6	1,613.6	0.0	249.7
AREA 10 - Ontario St, East of Lorne Ave	80.6	78.7	78.6	78.3	0.0	11.0
AREA 13 - Harriman Road driveways	133.4	0.0	0.0	0.0	0.0	0.67
TOTAL						399.1
MAXIMUM POSSIBLE REDUCTION - $1,000s						
AREA 2 - S. of Tyler Street at Temperance St	955.5	932.3	800.1	699.6	0.0	106.7
AREA 5 - Aurora Heights Dr/Machell Park	343.0	307.3	0.0	0.0	0.0	6.3
AREA 8 - Gorham St to Srigley St	2,255.5	1,911.6	1,613.6	1,492.4	0.0	223.9
AREA 10 - Ontario St, East of Lorne Ave	80.0	78.6	78.6	77.4	0.0	10.9
AREA 13 - Harriman Road driveways	133.4	0.0	0.0	0.0	0.0	0.7
TOTAL						348.5

4.5. Optimized SCM strategies: Mitigating the impacts of urbanization & climate change

The optimized distributed and centralized SCM strategy presented in the previous subsections provide water quality and peak flow reduction benefits as well as other co-benefits associated with SCM implementation. Benefits analyzed under *current state* involved current hydrological and pollutant loading impairments. For all municipal stormwater programs, the mitigation of *future* hydrology and pollutant loading is an important consideration due to climate change and urbanization.

Future rainfall conditions were simulated and the mitigation of climate change by the SCM strategy was quantified through peak flow reduction metrics. As described in Section 3.5.2., peak flow mitigation was used as the evaluation metric because projections of peak rainfall intensity were available from the Climate Change Tool – Version 4.0 (IDF_CC Tool[27])[lxxxvi], building upon the LSRCA Climate Change Adaptation Strategy[lxxxvii].

[27] Computerized web-based tool integrating a user interface with a GIS for the development of IDF curves under climate change. https://www.idf-cc-uwo.ca

The results of the climate change resiliency analysis, presented in Table 4-9 and Table 4-10, illustrate the SCM strategy can provide increased resiliency to climate change. Results are dependent on the characteristics of areas upstream of flood-prone sites, including their impervious areas and the presence of SCM opportunities. Table 4-9 provides an analysis of peak flow reductions for RCP 4.5 and 8.5 scenarios for the period from 2021-2050, while Table 4-10 provides this same information for the period from 2051 – 2080. Intuitively, the SCM strategy provides more flood mitigation during smaller storms compared to larger storms. In fact, the analysis forecasts that SCM implementation can mitigate 100% of the impact of climate change to the 10-year storm in certain flood-prone areas (far left shaded columns of Table 4-9 and Table 4-10). For the 50- and 100-year storms, the future peak flow mitigation ranges from 10% to 48% (right hand shaded columns).

Table 4-9: Climate change resiliency analysis for 2021-2050 period based on stress testing the SCM strategy to achieve 40% phosphorus reduction at East Holland Landing

2021-2050												
Site	RCP 4.5											
	10 yr			25 yr			50 yr			100 yr		
	Non-Mitigated % Peak Flow Change	Mitigated % Peak Flow Change	Percent of Climate Change Mitigated	Non-Mitigated % Peak Flow Change	Mitigated % Peak Flow Change	Percent of Climate Change Mitigated	Non-Mitigated % Peak Flow Change	Mitigated % Peak Flow Change	Percent of Climate Change Mitigated	Non-Mitigated % Peak Flow Change	Mitigated % Peak Flow Change	Percent of Climate Change Mitigated
Area 2	+12.0%	-5.2%	100.0%	+46.9%	+30.4%	35.2%	+52.2%	+37.6%	28.0%	+44.3%	+34.2%	22.8%
Area 5	+20.4%	0.3%	98.5%	+33.3%	+14.2%	57.3%	+66.1%	+49.5%	25.2%	+109.2%	+97.3%	10.9%
Area 8	+11.4%	-11.4%	100.0%	+38.6%	+15.8%	59.2%	+65.4%	+45.9%	29.8%	+90.7%	+75.8%	16.4%
Area 10	+10.3%	-6.5%	100.0%	+31.5%	+15.3%	51.5%	+48.5%	+34.1%	29.6%	+63.6%	+53.6%	15.8%
Area 13	+11.4%	-11.7%	100.0%	+52.3%	+31.9%	39.1%	+60.4%	+42.8%	29.2%	+55.5%	+44.5%	19.8%
Area 14	+10.7%	-7.1%	100.0%	+32.0%	+14.3%	55.2%	+57.2%	+41.4%	27.6%	+84.6%	+73.6%	13.0%
Site	RCP 8.5											
	10 yr			25 yr			50 yr			100 yr		
	Non-Mitigated % Peak Flow Change	Mitigated % Peak Flow Change	Percent of Climate Change Mitigated	Non-Mitigated % Peak Flow Change	Mitigated % Peak Flow Change	Percent of Climate Change Mitigated	Non-Mitigated % Peak Flow Change	Mitigated % Peak Flow Change	Percent of Climate Change Mitigated	Non-Mitigated % Peak Flow Change	Mitigated % Peak Flow Change	Percent of Climate Change Mitigated
Area 2	+18.0%	+0.8%	95.8%	+52.8%	+36.3%	31.3%	+44.7%	+30.0%	32.8%	+33.2%	+23.0%	30.5%
Area 5	+26.5%	+6.5%	75.7%	+38.1%	+19.1%	50.0%	+53.3%	+36.7%	31.2%	+67.8%	+55.9%	17.6%
Area 8	+15.9%	-7.0%	100.0%	+44.1%	+21.2%	51.8%	+53.6%	+39.2%	26.8%	+58.5%	+43.7%	25.4%
Area 10	+14.3%	-2.4%	100.0%	+35.7%	+19.5%	45.5%	+40.3%	+20.8%	48.3%	+42.3%	+32.2%	23.8%
Area 13	+17.5%	-5.6%	100.0%	+59.1%	+38.6%	34.6%	+51.2%	+33.6%	34.4%	+40.0%	+28.1%	29.7%
Area 14	+14.5%	-3.2%	100.0%	+36.5%	+18.8%	48.3%	+46.8%	+31.1%	33.7%	+54.2%	+43.3%	20.3%

Table 4-10: Climate change resiliency analysis for 2051-2080 period based on stress testing the SCM strategy to achieve 40% reduction at the East Holland Landing

2051-2080												
Site	RCP 4.5											
	10 yr			25 yr			50 yr			100 yr		
	Non-Mitigated % Peak Flow Change	Mitigated % Peak Flow Change	Percent of Climate Change Mitigated	Non-Mitigated % Peak Flow Change	Mitigated % Peak Flow Change	Percent of Climate Change Mitigated	Non-Mitigated % Peak Flow Change	Mitigated % Peak Flow Change	Percent of Climate Change Mitigated	Non-Mitigated % Peak Flow Change	Mitigated % Peak Flow Change	Percent of Climate Change Mitigated
Area 2	+22.2%	+5.0%	77.6%	+45.2%	+28.7%	36.6%	+52.0%	+37.3%	28.2%	+44.7%	+34.5%	22.7%
Area 5	+30.3%	+10.2%	66.2%	+31.9%	+12.8%	59.8%	+65.6%	+49.0%	25.4%	+110.7%	+98.8%	10.8%
Area 8	+18.9%	-4.0%	100.0%	+37.0%	+14.2%	61.7%	+64.9%	+45.4%	30.0%	+91.8%	+76.9%	16.2%
Area 10	+17.0%	+0.2%	98.7%	+30.3%	+14.1%	53.6%	+48.2%	+33.8%	29.8%	+64.3%	+54.3%	15.6%
Area 13	+21.9%	-1.2%	100.0%	+50.3%	+29.9%	40.6%	+60.0%	+42.4%	29.4%	+56.0%	+45.0%	19.6%
Area 14	+17.1%	-0.7%	100.0%	+30.6%	+13.0%	57.5%	+56.8%	+41.0%	27.8%	+85.6%	+74.6%	12.8%
Site	RCP 8.5											
	10 yr			25 yr			50 yr			100 yr		
	Non-Mitigated % Peak Flow Change	Mitigated % Peak Flow Change	Percent of Climate Change Mitigated	Non-Mitigated % Peak Flow Change	Mitigated % Peak Flow Change	Percent of Climate Change Mitigated	Non-Mitigated % Peak Flow Change	Mitigated % Peak Flow Change	Percent of Climate Change Mitigated	Non-Mitigated % Peak Flow Change	Mitigated % Peak Flow Change	Percent of Climate Change Mitigated
Area 2	+44.0%	+26.7%	39.2%	+53.8%	+37.3%	30.7%	+56.8%	+42.2%	25.8%	+46.5%	+36.4%	21.8%
Area 5	+46.7%	+26.6%	43.0%	+39.0%	+19.9%	48.9%	+74.7%	+58.0%	22.3%	+119.4%	+107.5%	10.0%
Area 8	+33.7%	+10.9%	67.8%	+45.1%	+22.2%	50.7%	+73.0%	+58.7%	19.7%	+98.3%	+83.5%	15.1%
Area 10	+29.9%	+13.2%	55.9%	+36.4%	+20.2%	44.6%	+53.7%	+34.3%	36.2%	+68.6%	+58.5%	14.7%
Area 13	+45.2%	+22.1%	51.1%	+60.2%	+39.8%	34.0%	+66.0%	+48.4%	26.7%	+58.7%	+46.8%	20.3%
Area 14	+29.4%	+11.6%	60.5%	+37.3%	+19.6%	47.3%	+64.0%	+48.2%	24.6%	+91.8%	+80.9%	12.0%

For the climate change resiliency analysis, it is important to note the stormwater control strategy includes bioretention implemented in future growth areas when land use changes occur. The analysis shows that increased rainfall intensity under climate change may greatly outsize the SCMs being implemented to control future growth. For example, review the columns labeled 'Non-Mitigated % Peak Flow Change' in Table 4-9 and Table 4-10 – the increases under the 50- and 100-year storms are projected to be 44% to 109% even for the conservative RCP 4.5 scenario 2021-2050. These peak flow increases are substantial and would require a sea change in infrastructure planning. Careful review of the climate change forecasts for design storms and the corresponding simulated peak flow increases is advised, as these projected peak flow increases would have dire consequences for both flood protection and water quality protection (particularly with respect to bank erosion). As proof of this, consider0 the flood damage estimates for existing conditions and moderate and high climate change (CC) scenarios (Table 4-11). Average annual flood damages are estimate to increase by as much as 14%. New SWM controls offset this impact for all but the high CC scenario for the period 2051-80.

Table 4-11: Average Annual Flood Damages ($1,000)

Category	Existing	Low CC scenario, 2021-50	Low CC scenario, 2051-80	High CC scenario, 2021-50	High CC scenario, 2051-80
Baseline	$399.1	$426.3	$436.1	$429.1	$455.4
Maximum reduction	$348.5	$396.4	$403.1	$390.8	$414.6
Reduction in damages	$50.6	$29.9	$33.0	$38.3	$40.9

4.6. Co-benefits

Management actions, both modelled (representative) and those to be targeted for future implementation, were qualitatively evaluated (see Section 3.4.2 for a description of the evaluation methodology) and rated. Structural and non-structural SCMs, both individually and collectively, provide co-benefits. In terms of the latter, qualitatively evaluating the co-benefits that accrue via a combination or network of SCMs – which, as evidence indicates, magnifies the potential benefits via expanded scale and cumulative impact – was beyond the purpose and scope of this study.

The representative centralized SCM is a hybrid pond/wetland. The distributed SCMs are infiltration trenches, infiltration chambers, bioretention and enhanced boulevard tree cell (an infiltration trench with a bioretention cell tree). The design parameters and applications for representative SCMs used in the optimization analysis are previously summarized in Table 3-6 and discussed in section 3.6.3.1. Table 4-9 below provides a summary of the co-benefits, identified via the leading jurisdictions research and literature review, for the representative SCMs. As the enhanced boulevard tree cell has both a bioretention chamber and an infiltration trench, the co-benefits summary table includes the addition of a tree with the design of both types of SCMs (bioretention and infiltration trench/chambers). A summary of the co-benefits identified for the management actions targeted for future scenario analysis and implementation is included in Appendix 7.

Table 4-12: Description of co-benefit by type

SCM TYPE	CO-BENEFITS	DESCRIPTION
HYBRID POND / WETLAND	Habitat and increased biodiversity	"Stormwater treatment wetlands can be important habitats", especially in urban and peri-urban areas with habitat loss and fragmentation.[88] Depending on design and construction, hybrid ponds/wetlands where levees have been set back allow the channel to meander and create floodplain ecosystem features, such as wetlands and forests that provide valuable habitat in urban areas.[89] Depending on design and construction, hybrid ponds/wetlands may provide wildlife habitat.[90] Stormwater ponds have similar levels of biodiversity to "unmanaged wetlands in urban areas"[91]
	Groundwater recharge	Moderate recharge with detainment and wetland components. Reduced recharge a detention pond/chamber extension has impermeable or compacted soils, a liner or permanent pool of water.[92]
	Erosion control	Hybrid ponds with extended detention constructed above can protect downstream channels from erosive flows.[93] Depending on design and construction, hybrid ponds/wetlands may provide flood control and control of the physical changes in a stream due to urban development[94] Designs with vegetation have plant root-zones that generally help maintain an oxidised sediment surface layer protecting sediment from erosion during a storm event.[95]
	Carbon sequestration	Depending on construction, vegetation used and the maintenance regime, engineered wetlands can remove CO_2 and CH_4, two greenhouse gases. CO_2 is removed from the atmosphere and stored below ground in the underlying matrix.[96],[97] Depending on plant selection and maintenance, accumulated high biomass that can serve as a carbon sink.[98] An assessment of retention ponds across different climatic zones, determined that they sequester carbon across all zones[99].
	Improved air quality	Depending on construction, vegetation types, location and area of green space, hybrid pond/wetland facilities may act as a "sink" for airborne chemicals.[100]
	Drinking source water quality	Depending on construction and applications to retain stormwater for longer periods of time (e.g., detention extension, dry pond, outlet sluice gate, etc.), significant removal of TSS, P, NH3, carbon and zinc can be achieved.[101,102]
	Reduced heat stress	Depending on construction and type of vegetation used and area of green space and pond surfaces, hybrid pond/wetland facilities can mitigate the heat island effect[103]
	Energy savings	Depending on construction, these facilities can reduce energy use for water treatment for CSOs. Depending on the area and type of vegetation used and surface area of ponds, may reduce urban heat island effect via evaporative cooling and reduction of surface albedo and in turn, lower demand for energy use of air conditioning.[104]
	Community enhancement & recreation	Depending on design and construction, hybrid ponds/wetlands may provide passive recreational and landscape value.[105] Proximity to parks results in increased physical activity amongst residents living within a quarter mile of a park and people living within one mile of the park were four times as likely to visit the park once a week or more, and had an average of 38% more exercise sessions per week than those living farther away.[106]
	Property values	Stormwater ponds in residential areas are increasingly managed as aesthetic amenities that add value to real estate.[107] A 2004 study determined that residential properties exposed to flooding are discounted in the market by an average of 2–5%, and 0–2% for properties subject to reduced flooding.[108] Stormwater detention improves downstream floodplain property value by 2% to 5%.[109] Well landscaped hybrid ponds/wetlands and bioswales can increase property values by 7%[110]
	Reduced demand on SW infrastructure	Depending on location, construction, sizing and vegetation used, may provide substantial detention of SW providing reduction of peak flow between 30% and 88%,[111] thereby significantly reducing downstream flows and burden on infrastructure. Often the area of land required for such an integrated, urbanised stormwater system is significantly less than the sum of the land areas required to meet individual design objectives.[112]

SCM TYPE	CO-BENEFITS	DESCRIPTION
BIORETENTION (includes addition of a tree)	Habitat and increased biodiversity	Depending on construction, bioretention can provide a wetland ecosystem.[113] A study of bird populations in urban green space found that even small urban parks provide habitat food for song bird populations.[114] Depending on construction, during dry seasons bioretention may provide the necessary conditions and space for animal and plant species to thrive[115]
	Groundwater recharge	Via infiltration and evapotranspiration of runoff volumes, bioretention systems also help to reduce pollutant loads to watercourses and recharge groundwater.[116] The water absorbs into the pavement, is filtered, and enters the underground aquifer.[117] Installations of under drains help the infiltrated water to recharge groundwater and augment base flows in local streams.[118]
	Erosion control	Depending on construction, bioretention facilities can mitigate downstream flooding and streambank erosion caused by changes in runoff and flows post development.[119,120] Retention-based approaches reduce streambank and bed erosion and reduce sediment discharges.[121]
	Carbon sequestration	Appropriate selection of vegetation for bioretention facilities can "effectively reduce GHG emissions over years by improving CO_2 absorption capacity".[122] Depending on type of vegetation and subsurface media, bioretention facilities can reduce CO_2 levels from emissions through direct carbon sequestration.[123,124] On an individual basis, urban trees store about four times more CO_2 than individual trees in forest stands urban trees because urban trees tend to grow larger and have relatively faster growth rates.[125] More than 100 new trees sequester nearly 11,000 pounds of carbon annually and reduce ambient temperatures. Because of the use of structural planting cells, the trees have an expected lifespan triple that of conventionally planted street trees.[126]
	Improved air quality	Depending on construction and types of vegetation used, bioretention facilities can improve air quality via uptake of airborne pollutants and capture of particulates.[127]
	Drinking source water quality	Depending on design and construction, bioretention facilities can remove greater than: 96% TSS and oil and grit, 98% lead, 70% TP, 9% nitrite and 20% ammonium, resulting in improved water quality and lower water treatment requirements.[128] Bioretention cells are typically sized to capture at least the first 0.5" of runoff, and are therefore effective in reducing concentrations of TSS, oil and grease, heavy metals, phosphorus, and to a lesser extent, nitrogen.[129]
	Reduced heat stress	Depending on construction and use, type and area of vegetation, bioretention has the "capacity to mitigate urban heat island effect to a noticeable degree".[130]
	Reduced energy use	Bioretention facilitates provide for "evaporative cooling and reduction of surface albedo", reducing the urban heat island effect and associated energy use for air conditioning.[131]
	Community value & recreation	Proximity to parks results in increased physical activity amongst residents living within a quarter mile of a park and people living within one mile of the park were four times as likely to visit the park once a week or more, and had an average of 38% more exercise sessions per week than those living farther away.[132] Well designed and maintained bioretention facilities improve local aesthetics, enhance recreational opportunities within communities and have the potential to reduce the transmission of local noise through sound absorption.[133] The vegetation in bioretention cells may reduce glare and act as a crash cushion for errant vehicles.[134]
	Property values	A 2004 study of the economic value of tree in Philadelphia found the value of homes in proximity to a newly planted 'sidewalk' tree increased by about 9%.[135] Bioretention for commercial facilities enables new construction or redevelopment to meet SWM and landscape requirements simultaneously, to provide a greater ROI.[136]
	Reduced demand on infrastructure	Bioretention instead of storm sewers/sand filters saved $250K along Anacostia River in Washington, DC and in Denver, CO., the cost of a 0.1-acre bioretention pond was 17% less than a conventional SCM.[137] Depending on design and construction, bioretention facilities can reduce water treatment requirements by removing greater than: 96% TSS and oil and grease, 98% lead, 70% TP, 9% nitrite and 20% ammonium.[138]

SCM TYPE	CO-BENEFITS	DESCRIPTION
INFILTRATION CHAMBERS & INFILTRATION TRENCHES (includes addition of a tree)	Habitat and increased biodiversity	Street trees and vegetation can support pollinators and other insects and provide a food source and nesting site for birds.[139] Street trees provide habitat-related benefits on an increasing scale to multiple types of urban wildlife including mammals, birds, and insects. Small-scale to larger scale habitat benefits are valuable in that they help improve the health and diversity of wildlife populations.[140]
	Groundwater recharge	Depending on construction (pre-treatment and/or treatment media), infiltration trenches provide reasonable groundwater recharge and base flow to near-by streams.[141] Although small trees 'have limited capacity to capture stormwater, integrating structures like tree pits into the urban landscape…can increase opportunities for infiltration' and recharge of groundwater.[142]
	Erosion control	Flow tests of the most intense design storm (the 25-yr, 6-hr) of infiltration trenches in Portland, OR measured peak flow reductions ranging from 63% to 100%, with an average reduction of 90% representing the significant potential for a reduction of erosive flow velocities in open channels.[143] Use of vegetation and other frictional surface material reduce runoff velocities and associated erosion.[144]
	Carbon sequestration	On an individual basis, urban trees store about four times more CO_2 than individual trees in forest stands urban trees because urban trees tend to grow larger and have relatively faster growth rates.[145] Trees sequester significant CO_2 from the air. By fixing carbon during photosynthesis and storing excess carbon as biomass, trees ack as a carbon sink.[146,147,148,149] More than 100 new trees sequester nearly 11,000 pounds of carbon annually and reduce ambient temperatures. Because of the use of structural planting cells, the trees have an expected lifespan triple that of conventionally planted street trees.[150]
	Improved air quality	Street trees absorb air pollutants at a rate 9 times greater than more distant trees and improve air quality by intercepting airborne contaminants at street level.[151] Automobile and truck exhausts – CO, VOCs, NOx, and particulate matter are reduced significantly from proximity to street trees and vegetation.[152]
	Drinking source water quality	Depending on construction and maintenance, infiltration trenches provide adequate treatment of road runoff, specifically TSS, heavy metals, phosphorus and, to a lesser extent, nitrogen.[153] a ROW infiltration trench with tree pit can remove up to 90% of pollutants from road runoff, protecting drinking source water quality.[154]
	Reduced heat stress	Trees and other vegetative cover used with infiltration trenches have low albedo (reflection) properties which reduce the urban heat island effect.[155]
	Energy savings	Although shade trees do not curtail peak loads immediately, they do promise reductions that will increase as trees grow larger, as such, street trees can provide future energy peak demand reductions.[156]
	Community enhancement & recreation	Communities that use vegetated trenches/swales to infiltrate road runoff have found that bioretention offers ancillary benefits like improved aesthetics.[157] Business districts having trees were characterized as being higher in visual quality and comfort. The "visual walls" that infiltration trenches with trees provide create a defined edge to sidewalks that allows motorists to better distinguish between the roadway and the pedestrian walkways.[158]
	Property values	In a 2010 study using a hedonic price model a sale price premium of \$968 was determined for "each green street treatment within 500 feet of a single-family home" of \$968.[159] A study of an urban streetscape planted with sidewalk trees in Silva cells, resulted in the "increased property values in the Uptown tax increment financing district by \$1.5 million (or 9%) from 2009 to 2010, a 31% increase from 2004".[160]
	Reduced demand on infrastructure	Green streets with infiltration trenches have been installed in Portland, OR since 2003 and are "more cost-effective in some cases than installing new sewer pipes because they avoid basement and creek flooding and the need for alterations to existing storm pipe infrastructure".[161] A California study found "a correlation between tree shade and better pavement performance. It also demonstrated the economic benefits of increased pavement durability and reduced maintenance costs associated with increased tree shade".[162]

As discussed in Section 3.4.2, a qualitative evaluation co-benefits produced by selected SCMs was undertaken to understand the potential value (environmental, social and economic) of individual management actions. A rating scale (Table 4-10) 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 1-4). 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. Table 4-10 summarizes the ratings for the representative SCMs used for the optimization analysis.

Table 4-13: Qualitative rating based on the capacity of a SCM to provide co-benefits

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 4-14: Qualitative rating of co-benefits for representative SMCs

STORMWATER CONTROL MEASURE	CO-BENEFITS														
	Biodiversity	Habitat for species	Supports pollinators	Groundwater recharge & base flow	Erosion control	CO_2 sequestration & storage	Air quality Improvement	Drinking source water quality	Reduced Heat Stress	Energy savings	Improved aesthetics	Increased recreational opportunities	Increased Property Value	Reduced demand on infrastructure	AVERAGE RATING
Decentralized SCMs															
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 SCMs															
Hybrid wetland/pond	¾	¾	¾	1	1	¾	½	1	¾	½	1	¾	¾	1	0.80

Comprehensive SWM, integrating green and grey infrastructure, natural assets and non-structural SCMs, provides multiple and cumulative benefits beyond flood mitigation and water quality protection. Given the significant co-benefits that would be realized by implementing the SCMs represented in this study, the potential aggregate co-benefits of integrating all other structural and non-structural SCMs (Section 4.5) are unquestionable and substantial. Subsequent to further optimization analysis of management options and the development of any implementation plan, an evaluation of the additional co-benefits will provide a more complete understanding of the added environmental, social and economic value of System-wide SWM.

4.7. Considerations & Implications

The study findings provide important insights into the jurisdictional-based approach to SWM as compared with the proposed, system-based approach. The optimization and economic analyses generated results with implications for multiple facets of SWM at both a local- and a macro-scale. The local-scale includes the East Holland study area specifically, and municipalities, watershed authorities/agencies and First Nation communities across Canada in general. At a macro-scale, the implications of the study findings are discussed within the Canadian context, specifically, the provincial and federal levels. However, it should be noted that the results of the study and the implications of System-wide SWM are relevant to external local, state and national jurisdictions.

4.7.1. East Holland watershed context

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 not confounded by the limitations of municipal boundaries. There are implications in taking such an approach to SWM in the East Holland but the substantial cost-savings; opportunities for innovation; alternative financing; market and economic development; improved water and air quality; reduced erosion and flooding; higher property values; 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. Finance and economics are major factors in investment decisions at the municipal-level and this fact is equally true for East Holland municipalities and the LSRCA. The combination of significant cost-savings, local economic stimulus and the potential of a regional SWM innovation hub are compelling reasons for area municipalities to work together to achieve System-wide SWM.

All resident municipalities benefit from their location in the East Holland watershed and connection to Lake Simcoe. The concept of Equitable Responsibility recognizes that a collaborative municipal approach to planning and management of stormwater on a watershed-wide basis represents an opportunity for sharing expertise and resources to create a cost-effective, future-ready system and a new vision for SWM. This said, it is well recognized that the study was undertaken to examine the potential of a new SWM paradigm to achieve sustainable, adaptive and cost-effective SWM. Although the findings from this study provide compelling evidence to support a move toward System-wide SWM, additional testing and analysis are recommended and discussed in section 5.0. In the interim period, municipalities must consider the implications of the optimization analysis for their individual municipal SWM budgets and budgeting process.

As evidenced by the study findings, greater cost-efficiencies are realized by managing stormwater at the watershed-scale versus the current municipal boundary-based approach. On a municipal basis, an unequal distribution of sites selected for SCMs is an expected outcome of optimization analysis. The concept of equitable responsibility is based on this understanding and on the fact that all watershed resident municipalities benefit equally from improved water quality, reduced risks of flooding and erosion and enhanced resilience to the impacts of rapidly changing land use and climate variability. This said, moving to System-wide SWM in the East Holland watershed will be an incremental process involving additional testing and analysis.

4.7.2. Overall context

The study generated evidence-based findings supporting the study principles, specifically:

1. Using an **optimization methodology** significantly enhanced understanding of the characteristics and processes influencing watershed hydrology and expanded 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, including climate change and planned land use changes.
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 SWM and represents a more equitable and fair process for all watershed resident municipalities and constituents.

Taken collectively, the stormwater planning and management practices set out in the study principles represent a new SWM framework – one that facilitates basin-scale system-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.

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. Table 4-11 provides a summary of the constraints, and opportunities at each of the functional areas at all three levels.

Table 4-15: Summary of constraints and opportunities by study principles

CATEGORY	LEVEL	CONSTRAINT	OPPORTUNITY
POLICY & GOVERNANCE	*Principle #1 – Optimization analysis.*		
	LOCAL[28]	• Optimization analysis is not identified in provincial policies or guidance, hence there are no municipal/watershed agency policies specifying or endorsing its use. • SWM/watershed planning are typically engineering-led exercises primarily focused on addressing problem areas or issues, such as flooding, degrading water quality and erosion, as opposed to jurisdiction-wide system optimization.	• Establish an interdepartmental planning mechanism for stormwater/integrated water management. • Inter-departmental collaboration is common in private industry and its successful functioning is achieved by requiring joint planning and management by relevant business units (departments). • Opportunity for municipalities and watershed agencies to implement a system-based approach to SWM/watershed management planning using an optimization methodology
	PROVINCIAL	• No policy, guidance or requirement for optimization analysis for SWM.	• Opportunity to update policies and require plans to demonstrate cost-efficient performance under multiple scenarios.
	FEDERAL	N/A	
	Principle #2 – Watershed-wide, co-operative stormwater planning and management by municipalities in a common watershed.		
	LOCAL	• Co-operation between municipalities and between municipalities and other local entities, specifically watershed authorities and Indigenous communities, is not an explicit part of their official functions. • Perceived loss of municipal autonomy and authority. • Concerns about potential legal, financial and administration complications. • The municipal governance model and associated municipal culture is based on delivery of services within the municipal boundary, therefore, co-operative planning and management of SWM between municipalities and between municipalities and other local entities is limited.	• Numerous mechanisms (e.g., *Intermunicipal Service* Agreements, *Intermunicipal Partnership Agreements* or *Third-party Delivery Agreements* with intermunicipal oversight) provide an informal means for cooperation for shared delivery/management of specific municipal functions such as SWM, but provides the necessary rules and parameters to ensure autonomy, fiscal management and effective administration. • Temporary and long-term intermunicipal collaboration agreements and management frameworks are used successfully by many municipalities in Canada (e.g., transit, water & wastewater services, emergency services, etc.) and could be adapted for cooperative, watershed-wide stormwater planning and management. • There is no legislation restricting or preventing intermunicipal collaboration on stormwater planning and management.
	PROVINCIAL	• Numerous provincial ministries and agencies have some level of oversight for municipal SWM – adding intermunicipal collaboration will create another level of complexity. • Policies to encourage watershed scale planning (BC) and collaboration (AB – not specific to SWM nor integrated watershed management, rather it applies only to shared planning, infrastructure and services amongst neighbouring municipalities with connecting borders) • With the exception of Alberta, there are no legislative requirements for intermunicipal collaboration and planning.	• Merging watershed planning, source water protection guidance, and SWM planning functions could reduce provincial programming and administrative costs while significantly enhancing opportunities to harmonize policies to meet multiple goals and for greater impact and improved efficiency. • Opportunities to integrate policy and oversight functions are significant – in most Canadian provinces the ministries having oversight of watershed planning are the same ministries with oversight for municipal SWM. • Opportunity for harmonization of environmental policies in related areas providing for improved co-ordination and management and greater cost-efficiency. • Guidance supporting intermunicipal collaboration for planning and managing stormwater on a sub-watershed-, watershed- or nested watershed-scale.
	FEDERAL	• No fiscal policies associated with federal funding (directly or indirectly) of municipal SWM emphasizing or promoting intermunicipal collaboration. • No fiscal policies associated with federal funding to support or incentivise watershed-scale planning and management by resident municipalities. • Limited harmonization of policy objectives across different ministries and agencies (e.g., infrastructure, agriculture, finance, environment, R&D, public safety, natural resources, etc.) resulting in programming and funding silos restricting opportunities for inter-organizational projects covering multiple functional areas (e.g., integrated watershed-scale SWM addressing Indigenous community infrastructure; adaptive agriculture; sustainable finance and climate change, etc.)	• Fiscal policy supporting intermunicipal cooperation for watershed-scale, integrated system stormwater planning, capital works and OM. • Funding incentive for SWM project proposals demonstrating intermunicipal cooperation, watershed-scale planning and integration of stormwater infrastructure (green and grey), natural assets and non-structural practices. • Harmonization of relevant policy objectives (e.g., green infrastructure, climate change adaptation and resiliency in agriculture, First Nation community infrastructure, source water protection, flood mitigation, P3s, asset management and natural asset valuation, fisheries and endangered species, carbon sequestration, etc.) across ministries and agencies for integrated programming.

[28] The term *local* is used to recognize that although municipalities have frontline responsibility for SWM within their boundaries, watershed management agencies/authorities and First Nation communities have a direct and vital role in watershed management and source water protection.

CATEGORY	LEVEL	CONSTRAINT	OPPORTUNITY
POLICY & GOVERNANCE	***Principle #3 - In addition to public property, evaluate and site SCMs on suitable privately-owned property and/or secure implementation of non-structural SWM measures.***		
	LOCAL	• No framework or policy for securing private property hosting of SCMs on private property owner participation in non-structural SWM practices. • Legal and risk concerns with siting of SWM infrastructure on private property coupled with no impelling requirement or need, have prevented serious exploration of potential policies, management framework, and legal mechanism. • Established policies and governance frameworks for public-private partnerships but typically used for large infrastructure projects, not local-level partnerships with private landowners. • Established policies and management system for green field development and construction of SWM infrastructure, but with post-construction assumption of infrastructure by municipality. • Primarily an ad hoc approach (i.e., not an established framework) to securing SCMs on private property via some form of incentive (e.g., reduced SWM fee) and/or by-law (e.g., mandatory downspout disconnection for properties with combined sewers).	• Established policies and management frameworks are potential models that could be adapted for private property hosting of SCMS. • The alternative energy grid model, wherein private property owners with solar installation or co-generation capacity provide energy to the public utility grid is a potential model that could be adapted for SWM. • Well established and legally tested municipal and provincial policies and associated management frameworks for municipal infrastructure (e.g., water supply and wastewater treatment) on private property provide a valuable precedent. • Potential opportunity to adapt municipal policies and management systems currently in place for P3s for larger scale infrastructure projects for local-level public-private partnerships (P3s) for individual properties. • Current municipal policies, regulations and management systems (legal, financial, planning, operations, etc.) provide the necessary framework to establish local-level agreements with individual property owners.
	PROVINCIAL	• Strong governance framework and policies for P3s for larger-scale projects, including P3s for the construction of water supply and wastewater infrastructure, but not adapted for local-level arrangements. • No apparent policies or guidance to support municipalities in developing local-level P3s with individual property owners. • Current SWM planning requirements do not address the potential nor process for municipalities to secure arrangements with private property owners to host SCMs.	• Current provincial policies are not an impediment to municipal-private property arrangements to host SCMs. • Opportunity to adjust existing P3 governance, policies and management mechanisms currently in place for larger-scale infrastructure projects for application to joint municipal-private property owner arrangements for hosting SCMS. • Opportunity to provide municipalities with guidance and support in developing local-level P3 arrangements (PES systems, lease agreements, joint ventures, infrastructure off-set grants, etc.) with individual property owners or a collective of property owners.
	FEDERAL	• Strong governance framework and polices supporting P3s for larger-scale infrastructure projects that are national, interprovincial and regional in scope. • No apparent policies pertaining to local-level P3s.	• Current federal policies are not an impediment to arrangements between municipalities and private property owners to host SCMs • Opportunity to modify policies related to water management infrastructure funding and financing to support local-level P3s between municipalities and private property owners.
FINANCE & ADMIN	***Principle #1 – Optimization analysis***		
	LOCAL	• No requirement for full life-cycle cost-efficiency analysis for SWM planning nor any requirement to demonstrate system-wide performance at greatest cost-efficiency and under multiple land use, climate, SCMs (e.g., distributed vs centralized, green and grey, natural assets, etc.), temporal and policy scenarios. • Additional SWM planning costs. • Administration challenge due to lack of expertise in optimization analysis.	• Opportunity to use optimization analysis to evaluate the cost-effectiveness of SWM strategies under multiple scenarios. • Optimization analysis identifies the most cost-efficient strategy to meet stormwater/watershed management objectives, consequently, any additional planning costs would be more than off-set by post-implementation savings. • Optimization analysis for SWM planning is becoming industry standard, public-domain models are available at no-cost, additional tools and training are available through multiple sources at little or no costs, and leading engineering stormwater/watershed management planning consultancies providing optimization analysis.

CATEGORY	LEVEL	CONSTRAINT	OPPORTUNITY
FINANCE & ADMINISTRATION	***Principle #1 – Optimization analysis (Cont'd.)***		
	PROVINCIAL	• No provision or mechanism for additional funding to municipalities, watershed agencies or indigenous communities for system-based stormwater/watershed management planning using optimization analysis. • Due to lack of in-house expertise in whole-system SWM and optimization analysis, there may be additional costs and resources required for ministry reviews of SWM/watershed management plans and capital funding submissions.	• Opportunity to support whole-system planning which will deliver optimal system performance that meets water quantity and quality targets, provide greater inherent adaptability and resilience, reduce life-cycle costs, and provide multiple economic, environmental and social co-benefits. • Optimization analysis is becoming industry standard; public-domain models are available at no-cost, additional tools and training are available through multiple sources at little or no cost, and leading engineering and stormwater/watershed management planning consultancies provide optimization analysis. • Once in-house know-how is established costs and associated administrative demands for plan reviews will be lower.
	FEDERAL	N/A	
	Principle #2 – Watershed-wide, co-operative stormwater planning and management by municipalities in a common watershed.		
	MUNICIPAL	• Municipal capital and operating budgets for stormwater infrastructure and asset management are based on SWM plans specific to the municipality. • Different financing mechanisms – property taxes, percentage or fixed charge on water bill (water supply & wastewater services) and property-based SWM fees – may be used by different municipalities in the same watershed. • Administrative functions for SWM are set up for delivery within an individual municipal management framework. • SWM funding submissions to provincial and federal ministries and associations are done on an individual municipal basis and may cover single projects or complete SWM plans.	• There are numerous intermunicipal agreements for cost-sharing for other services and projects such as social services, transportation, and water supply, that could be readily adapted for intermunicipal SWM. • Collaboration amongst municipalities in a common watershed for stormwater planning and management would not require changing individual municipal budgeting or SWM financing processes, however, significant cost savings via economies of scale, bundling for tenders (materials and services), reduced duplication of functions (e.g., modelling, data collection and analysis, etc.), and capacity building through shared expertise and resources would be realized. • Roles and responsibilities, shared functions and resources, costs and cost sharing, decision-making, dispute resolution, budgeting and financial management and administration, etc. are readily spelled out in an intermunicipal agreement. • Due to the cost savings and system efficiencies that can be achieved via intermunicipal SWM, joint funding proposals from multiple municipalities can be more attractive to public funding agencies and to private investors. • Greater investment capacity & enhanced credit worthiness makes it easier to secure grants/loans for infrastructure.
	PROVINCIAL	• Funding emphasis on larger scale or shovel-ready capital infrastructure projects. • Added complexity and associated costs and resources would be required to develop and administer intermunicipal agreements and integrated, watershed-scale stormwater planning and management. • Funding typically provided on a municipality-by-municipality basis for individual or multiple SWM capital projects. • No incentive, via targeted funding support for intermunicipal collaboration on stormwater planning and/or management. • No financial incentive for municipalities in shared watershed work together to identify and capitalize on opportunities to twin SWM planning with other planned infrastructure, development, environmental, undertakings (e.g., road reconstruction, public transit corridors, new utility installations, etc.)	• Incentivise intermunicipal collaboration for integrated, watershed-scale stormwater planning and management: ○ Establish dedicated funding and funding criteria for intermunicipal, watershed-scale SWM ○ Provide a funding bonus or preferential financing for joint funding proposals by watershed resident municipalities. ○ Set minimum thresholds [geographic (e.g., sub-watershed), population served, objectives to be met, etc. for project proposals) to encourage. ○ Fast-track SWM intermunicipal submissions for funding • Guidance and financial support for the process of developing an intermunicipal collaboration agreement to plan and/or implement integrated SWM infrastructure/systems. • Requirements, via prescribed life-cycle cost-efficiency analysis, for municipalities to demonstrate SWM plans will collectively meet watershed targets (e.g., water quality, flood mitigation, infiltration, peak flow, base flow, water balance, etc.). • Requirement that SWM plans/master plans must demonstrate they have identified opportunities to twin planned SWM works with other public or private sector infrastructure, development/re-development, road construction/re-construction and environmental (e.g., tree planting, wetland restoration, etc.) projects, completed supporting cost-efficiency analyses, and implemented a process to leverage identified opportunities.

CATEGORY	LEVEL	• CONSTRAINT	• OPPORTUNITY
FINANCE & ADMINISTRATION	***Principle #2 (Cont'd)***		
	FEDERAL	• Larger funding amounts are available for capital works with emphasis on shovel-ready projects. • Funding via transfer payments to provinces is often subject to provincial priorities and may be difficult to target intermunicipal SWM planning and projects. • Smaller amounts of funding are provided for the development of SWM plans and strategies vs capital works. • No funding requirements for intermunicipal collaboration for SWM planning. • No funding available for the development of intermunicipal collaboration agreements to support shared SWM/watershed planning and implementation.	• Opportunity to establish funding criteria and additional funding incentives for optimization-based, integrated SWM planning, specifically targeting system-based planning wherein green and grey infrastructure, natural assets and non-structural practices are integrated as a whole. • Funding provided directly or via national associations with qualifying criteria for intermunicipal/inter-organizational SWM/watershed planning and capital projects. • Broaden capital funding to enable municipalities, watershed management agencies, and aboriginal communities to finance, incentivise or otherwise support implementation of structural and non-structural SCMs on privately-owned property and to incorporate natural areas (e.g., wetlands, forests, grasslands, etc.) as SWM assets. • For SWM capital funding submissions, a pre-qualifying requirement that municipalities have completed an optimization analysis and identified the most cost-effective integrated strategy.
	Principle #3 - In addition to public property, evaluate and site SCMs on suitable privately-owned property and/or secure implementation of non-structural SWM measures.		
	LOCAL	• Budget and financial management system not set up for investing in SCMs located on private property nor for public-private financing arrangements with individual property owners. • Perceived financial risk associated with siting of SCMs on private property. • No examples in Canada of local-level P3-type financial arrangements with individual private property owners to host SCMs. • Incentives – stormwater fee credits, subsidies, and other market-based instrument – are typically used to encourage uptake of SCMs by private property owners vs. direct public-private contractual arrangements with individual property owners. • Potentially would require additional administrative resources.	• Opportunity to adapt existing financing and admin models currently in place for local P3 arrangements with private property owners, such as solar installations on individual private properties. • Need to evaluate other public-private instruments (e.g., PES mechanisms, lease arrangements, grants, etc.) for local public-private partnerships to determine effective financing vehicles to drive uptake. • Opportunity and need to examine the potential administrative and financial implications – cost, ROI, staffing, risk, etc. – of municipal-private property owner arrangements for structural/non-structural SCMs. • Private-property uptake SCMs has been proven to reduce the burden on municipal SWM infrastructure and the associated costs for upgrades and replacements generating significant cost-savings.[163,164,165,166] • In jurisdictions where private property participation in supported (e.g., Philadelphia, PA; Seattle, WA; Portland, OR; etc.) significant benefits to the local economy and co-benefits (e.g., reduced heat island effect, improved air quality, increased property values, etc.) have been realized.
	PROVINCIAL	• Current financial support and processes and administrative practices associated with public-private ventures are focused at larger scale infrastructure projects not local-level municipal-private property owner arrangements. • Financial and administrative implications and cost-benefits not understood and no apparent assessment has been undertaken. • Not on the radar. • Initiatives in jurisdictions outside Canada are often sited as examples of what could be implemented here, but many of these approaches are based on national and state-level policies, regulations and financial management systems that apply in a Canadian federal or provincial context.	• Opportunity to adapt existing financing and admin models currently in place for local P3 arrangements with private property owners, such as solar installations on individual private properties. • Opportunity to assess the value of pooling funding across ministries and departments where multiple objectives can be realized via local-level arrangements between municipalities and private property owners, such as community economic stimulus, source water protection, health & safety (improved air quality, reduced flooding and improved resilience to drought), carbon sequestration, improved agricultural practices, increased biodiversity, reduced water treatment costs and demands, reduced losses to cold water fisheries, etc.) • Opportunity to complete a cost-benefit evaluation of local-level P3 (or equivalent) arrangement between municipalities and private-property owners for implementation of SCMs on private property. • Opportunity to develop financing and admin processes tailored to Cdn. provinces that provide comparable economic, social and environmental benefits as those being realized by other jurisdictions.
	FEDERAL	• Current financing, and related functions, for public-private ventures is focused at larger scale infrastructure projects not local-level municipal-private property owner arrangements or the use of market-based economic instruments to secure uptake of SCMs on private property. • No funding or resources to support municipalities and watershed agencies in planning and implementing SWM strategies incorporating public-private financing arrangements to secure SCMs on private property.	• Opportunity to adapt existing financing and admin models currently in place for local P3 arrangements with private property owners, such as solar installations on individual private properties. • Opportunity to assess the value of pooling funding across ministries and departments where multiple objectives can be realized via local-level arrangements between municipalities and private property owners, such as community economic stimulus, source water protection, health & safety (improved air quality, reduced flooding and improved resilience to drought), carbon sequestration, improved agricultural practices, increased biodiversity, reduced water treatment costs and demands, reduced losses to cold water fisheries, etc.).

CATEGORY	LEVEL	CONSTRAINT	OPPORTUNITY
OPERATIONS	***Principle #1 – Optimization analysis.***		
	LOCAL	• Limited knowledge of optimization analysis and its value for integrated SWM/watershed planning. • Primary focus on compliance with provincial SWM planning requirements which do not include optimization analysis. • SWM plans are typically focused on addressing stormwater problem areas or issues (e.g., flooding, declining water quality, erosion, CSOs, new/re-development, replacing aged infrastructure, etc.) in order of priority, wherein cost analysis is an additional step used to compare pre-selected or preferred options vs. optimization analysis wherein costs are baked-in. • SWM planning typically an engineering-led technical process with limited involvement of senior economic, finance and market experts.	• There are significant of information, training and support for optimization-based SWM modelling and modelling tools in the public domain. • Optimization-based models are increasingly being used for SWM/integrated watershed planning by jurisdictions across the globe resulting in continuous improvements, increasing knowledge and expertise and greater access to open-domain and open-source models and supporting resources. • Opportunity for municipalities and watershed agencies/authorities to utilise an optimization methodology for SWM planning, which will enable them to: ○ determine the most cost-efficient strategy to address priority issues under multiple planning, climate and temporal scenarios ○ generate a strategy integrating existing and future green and grey infrastructure, non-structural SCMs, natural assets for optimal system performance at the greatest life-cycle cost-efficiency. ○ adapt and modify the SWM strategy to meet changing conditions, regulations, etc. • Opportunity to develop an interdisciplinary (e.g., economics and finance, markets, planning and development, asset management, climate change, etc.) approach to SWM planning enabling the development of a cross-functional strategy that meets multiple organizational objectives.
	PROVINCIAL	• Provincial review staff have limited exposure to optimization-based planning for stormwater/watershed management and may lack the necessary expertise to evaluate such plans.	• Opportunity for review staff to acquire the necessary expertise to review and evaluate stormwater and watershed management plans developed using an optimization methodology. • Opportunity to develop an interdisciplinary review process wherein ministry staff/divisions with expertise in relevant areas (e.g., economics and finance, markets, P3s, climate change, etc.) participate in the review and approval of SWM plans and watershed management plans.
	Principle #2 – Watershed-wide, co-operative stormwater planning and management by municipalities in a common watershed.		
	LOCAL	• No apparent example of *operationalized* intermunicipal/inter-agency collaboration for system-based, watershed-wide stormwater planning and management. • Concern over potential loss of operational autonomy and authority. • Perceived risk associated with a process for stormwater planning and management that has not been tried and tested. • Lack of common or shared approach to monitoring, the collection and application of data, and the SWM planning process amongst and between municipalities, watershed agencies and provincial ministries is a roadblock to intermunicipal/inter-agency stormwater/watershed management planning.	• Well established and functioning intermunicipal/inter-agency collaboration agreements in areas such as health and emergency services and water supply and wastewater treatment, demonstrate there is no loss of autonomy or additional risk involved with such an approach. • Opportunity for full-scale (watershed-wide) living lab research of operationalized intermunicipal collaboration on stormwater planning and implementation. • Co-ordination and standardization of SWM/integrated watershed planning practices (monitoring methodologies; type, format and collection of data; modelling, economic and valuation methodologies, etc.) amongst municipalities, watershed agencies/authorities and provincial ministries would enable comparative analyses, reduce costly duplication, streamline planning and decision-making, and provide cost-sharing opportunities.
	PROVINCIAL	• With the exception of Alberta[29], there is little if any provincial impetus or guidance for municipalities to operationalize a collaborative approach to SWM. • No apparent examples of provincial support or guidance for municipalities in a shared watershed to operationalize a co-operative approach to integrated stormwater planning and management watershed-wide.	• Opportunity to build and expand on existing provincial direction and guidance for intermunicipal collaboration to support the development and implementation of collaborative agreements for integrated stormwater planning and management amongst municipalities in shared watersheds.
	FEDERAL	N/A	

[29] The Province of Alberta's Municipal Government Act sets out requirements for intermunicipal collaboration frameworks to specify what and how services are planned, funded and delivered with other municipalities that share a common boundary

CATEGORY	LEVEL	CONSTRAINT	OPPORTUNITY
OPERATIONS	***Principle #3 - In addition to public property, evaluate and site SCMs on suitable privately-owned property and/or secure implementation of non-structural SWM measures.***		
	LOCAL	• Most municipal SWM and watershed agency staff have limited or no experience evaluating and incorporating SCMs on private property as part of an integrated municipal SWM system. • Additional resource requirements to evaluate, manage and monitor SCMs on private property. • Significant range in the experience and know-how of municipal and watershed agency staff with the use of green infrastructure, non-structural SCMs and natural assets for SWM. • Staff at most municipalities, and particularly staff responsible for SWM, have little or no experience with public-private service arrangements and market-based instruments. • Concerns over ensuring structural SCMs on private property are properly maintained and that upgrades and replacement of SWM assets are carried out.	• Opportunity to draw on the experience of leading jurisdictions that have made participation of private property owners in managing stormwater a key component of their integrated SWM strategies. • Opportunity to adapt public utility micro-grid operational models for green energy installation on private property. • Savings generated by private property SCMs reducing the need for upgrading, replacing or building additional municipal SWM infrastructure will more than off-set additional operational costs. • Local-level P3s, other public-private payment for service arrangements, and market-based instruments offer a significant opportunity for municipalities and watershed management agencies to realize cost-efficient SWM, stimulate local economic development, increase property values and thereby property tax revenue, reduce demand and associated costs for upgrading, replacing and new construction of SWM infrastructure, greening and improved liveability of neighbourhoods, and multiple other local- and regional-scale benefits. • There are well established models and practices for ensuring infrastructure located on private property is properly maintained and assets are upgraded or replaced as required.
	PROVINCIAL	• Provincial experience with public-private financial arrangements typically involves larger scale undertakings (e.g., infrastructure projects, provision of public services, etc.), consequently, ministries with oversight of municipal SWM and watershed management may lack the knowledge and experience to review and evaluate plans involving local-level P3s and to provide direction and guidance on such arrangements. • No apparent provincial direction, guidance or resources to promote or support municipalities or watershed agencies in planning and implementing local-level public-private financial arrangements for SCMs on private property.	• Opportunity to draw on the experience of leading state-level jurisdictions that have successfully supported municipalities and watershed agencies in planning and delivering SWM strategies wherein private property participation is an integral component. • Opportunity for provincial ministries with oversight responsibilities for stormwater and watershed management to provide direction, guidance and supporting resources and tools to assist municipalities and watershed agencies in planning and securing uptake of SCMs by private property owners via local-level P3 (or similar arrangements) and the use of market-based instruments.
	FEDERAL	• Macro-scale focus of P3 programming with no apparent guidance or support for local-scale arrangements between municipalities/watershed agencies and private property owners	• Opportunity to adapt the guidance, resources and tools developed by the US EPA to assist municipalities and watershed agencies in planning and implementing SWM strategies that incorporate local P3 (or similar arrangements) and the use of market-based economic instruments to secure uptake of SCMs on private property.

4.7.2.1. *Inter-municipal 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.[167,168]

4.7.2.2. *SCMs on private property*

Securing private property hosting of centralized and distributed SCMs will require the progressive use of market-based financial instruments. These progressive uses would include Payment for Ecological Services (PES), 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 areas with CSOs 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 quite low, typically below 6%, and therefore, have a very poor Return on Investment (ROI) value in terms of SWM.

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 (See Appendix 2 for more details on individual leading jurisdictions' SWM incentive programs). 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.

Designing and effectively using financial- and market-based instruments to target private property uptake of SCMs will require municipalities in the in the East Holland River watershed and across the country adopt innovative market-based strategies that work in a Canadian context. There are numerous examples – from leading SWM jurisdictions with proven financial and market incentive programs to the energy sector (public and private utilities), which has significant success using financial and market instruments to secure private property-owner hosting of renewable energy installations for back-up micro-grids and up-take of energy conservation measures. Not only have these undertakings generated notable returns on dollars invested, these returns are compounded and reflected in economic development at the local level

In Canada, multiple factors have impeded the adoption by municipalities of strategies to secure private property hosting of SCMs which may be summarized as follows:

- A misconception that policy and regulatory changes at the provincial and municipal levels of government would be required to allow publicly-owned SCMs on private property or public funding supporting privately-owned SCMs on private property. In fact, current provincial policies and legislation support public-private ventures, particularly as they pertain to infrastructure and the delivery of services for the public good. Typically, such arrangements between municipal governments and the private sector have focused on large scale capital projects rather than local-level initiatives.
- Concern that private property owners may not properly maintain SCMs thereby undermining their efficacy and associated (ROI) while at the same time creating an adversarial situation between the property owner and the municipality. There are many examples of SWM, energy generation, wastewater treatment, source water protection infrastructure located on private property – both privately-owned, publicly funded, and publicly-owned – with established contractual arrangements, often deeded and including claw-back provisions and other legal and financial mechanisms to ensure on-going upkeep of said assets. Success depends on contractual arrangements which are effective drivers for compliance. Furthermore, the perception that municipal O&M practices ensure the efficacy of SWM assets, consider that about 40% to 60% of municipal SWM assets are in 'fair', 'poor', 'very poor' or 'unknown' condition.[30]
- It is worth noting that municipal water infrastructure is located on every private property in Canada with the exception of those on well and septic systems. Private property owners are responsible for the cost to maintain, service and repair this infrastructure except in the case where actions by the municipality or issues within the system located on municipal property are the cause of the problem.
- A concern that a program to support SCMs on private property would create a costly administrative burden for municipalities. Again, case studies demonstrate that the ROI for municipalities is substantially greater with private property participation than without. The findings from this study affirm that securing private property hosting of SCMs on private property generates a 28% cost savings and 30% lower SCM capacity requirements. Consider that the East Holland River watershed could be considered a 'reverse watershed', in that the most urbanized areas are located in the mid- to upper-portions of the watershed versus the more common situation wherein the heavily developed areas are located at the base of the watershed, such as Barrie, Toronto, Halifax, Montreal, Vancouver, etc. In these heavily urbanized municipalities where the majority of property is privately-held, securing private property hosting of SCMs may well provide greater cost savings.

5.0 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.

[30] Federation of Canadian Municipalities; Canadian Infrastructure Report Card: Monitoring the State of Canada's Core Public Infrastructure (2019)

Table 5-1: 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. • 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.	**Watershed-wide, integration of centralized and distributed SCMs located on viable publicly-owned and privately-owned lands** • 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 $10.4-million).
Jurisdictional-based (planning and management of stormwater based on the political boundaries of individual municipalities) • $18.9-million annualized life-cycle cost to achieve 40% P-load target.	**Integrated, watershed-wide (collaborative approach to stormwater planning and management unrestrained by political boundaries)** • $13.7-million annualized life-cycle cost to achieve 40% P-load reduction target. • 28% cost savings and 30% lower SCM capacity requirements.

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:

1. **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.
    - Optimization modelling can screen a large number of potential management options, generate new alternatives that might otherwise have been overlooked and provide an intuitive means of trade-off analysis.[169]
    - While research will continue to evolve, we argue that process-based models—in combination with novel measurements and 'big data'—will be primary tools for projecting how the local-scale effects of LID extend to multiscale catchments, particularly in catchments with additional land cover types (e.g., forest, agriculture).[170]

2. 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.
    - Securing private property use of SCMs offers multiple benefits beyond improved performance and SWM infrastructure cost savings. Inducing additional private SCMs uptake in Philadelphia has conservatively injected $3.1 billion into the local economy, supporting about 1,000 jobs per year and generating $2 million per year in local tax revenues for the entire 25-year period.[171]
    - Portland, OR implemented a Grey to Green Initiative that includes an Ecoroof incentive program. To date there are more than 172 Ecoroofs in the city reducing runoff by an estimated 5168 m^3/ha.[172]
    - Onondaga County, N.Y., targets specific districts via grant funding to commercial properties that install SCMs. The initiative has eliminated an estimated 946,353 m^3 of CSOs.[173]

- Private property participation in the larger system improves SWM throughout the management area. While individual, isolated elements of a green infrastructure network all provide some benefit, a certain critical mass and connectivity potential are needed to effectively contribute ecosystem services to a network.[174]

3. 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.
   - Evolving SWM practices now reflect a more equitable approach that considers the protection of existing biophysical systems as well as people and property.[175] The individual SWM systems developed at the neighbourhood scale need to be integrated into a comprehensive drainage system within the watershed**.**[176]
   - Inter-municipal collaboration agreements 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.[177,178]
   - Stormwater systems designed on a watershed basis are more likely to be seen as a multi-functional resource that can contribute to the overall quality of the urban environment. Potential even exists to make the stormwater system a primary component of the civic framework of the community—elements of the public realm that serve to enhance a community's quality of life like public spaces and parks.[179]
   - An integrated, watershed-wide system incorporating green and grey infrastructure, non-structural practices such as planting cover crops, and natural assets as SCMs provides greater resiliency to the impacts of expanding urbanization and more frequent and severe weather events due to climate change. According to Stephane Hallegatte, Lead Economist, Global Facility for Disaster Reduction and Recovery, "We need protection which can fail gracefully,". "The advantage to a nature-based system is they tend not to fail in catastrophic fashion."[180]
   - Improved watershed-scale SWM can produce multiple downstream benefits, including 1) reduced frequency, area, and impact of flooding; 2) less costly public drainage infrastructure; 3) reduced pollution treatment; 4) reduced erosion and sedimentation; 5) improved water quality; 6) improved in-stream biological integrity and aesthetics; and 7) increased groundwater recharge.[181]
   - Location and spatial distribution of SCMs throughout the landscape contributes to the catchment-scale cumulative effectiveness of practices.[182]

5.1. 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.

5.1.1. Recommendations – Lake Simcoe Region

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

1) 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.

2) 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.)

3) Meet with senior representatives of the Chippewa of Georgina Island First Nation to discuss the study findings and explore opportunities for collaboration.

4) 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.

5) Identify strategic partnership opportunities for targeted pilot / living laboratory studies to evaluate and adapt processes and practices.

6) Develop guidance and training materials and tools to support area municipalities in the use of optimization analysis for SWM planning.

7) 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.).

5.1.2. 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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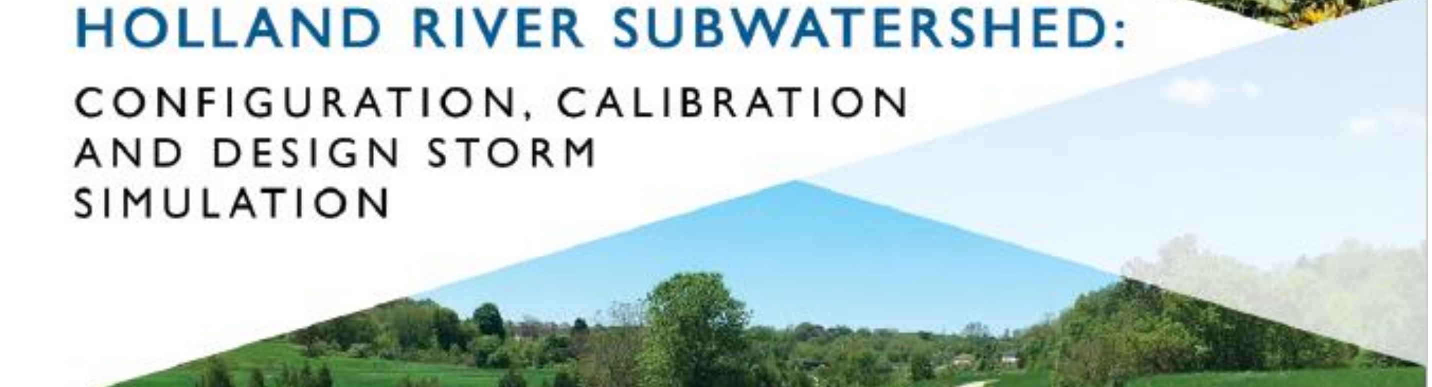
APPENDIX 1

CURRENT STATE MODELLING REPORT

EQR4TD PROJECT

CURRENT STATE MODEL FOR THE EAST HOLLAND RIVER SUBWATERSHED:

CONFIGURATION, CALIBRATION AND DESIGN STORM SIMULATION



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Tables

1 OVERVIEW

A 'Current State' model for the East Holland River watershed has been developed as a component of the project entitled "Equitable Responsibility for Transformative Design: Achieving sustainable watershed-scale stormwater management", or EqR4TD project. The EqR4TD project in an integrated sub-watershed study that seeks to evaluate the potential to optimize stormwater management (SWM) infrastructure performance at a greater cost-efficiency via systems-based stormwater planning, design and operation. The study takes a watershed-wide approach to determining the application of green and grey infrastructure and natural assets to realize improved water quantity and quality control and enhanced system resiliency. Looking beyond municipal boundaries, the study seeks to determine the most cost-effective and equitable solution for stormwater management infrastructure planning, including the design, construction and operation of capital projects, amongst municipalities within a common watershed.

The Current State model is one of two major components of a process-based modelling system being developed for the EqR4TD project (see Figure 1-1). The Current State model will serve as a boundary condition for an open source, process-based 'Future State' model which will be used to analyze scenarios and options for managing stormwater at a watershed-based, cross-jurisdictional scale. The overall modelling process for the Eq4RTD project is summarized in Figure 1-2– this report represents Step 1 in the figure and describes the initial development, calibration and application of the Current State model. In addition, Step 2 – 'Establish Hydrology Targets and Conditions' – is initiated within Section 5 of this report, which includes simulation of event-based flood control storm and comparison to outputs from a previously developed hydrologic model.

This report that follows is organized into four sections:

- Model background (Section 2)
- Model configuration (Section 3)
- Model calibration (Section 0)
- Design storm simulation (Section 5)

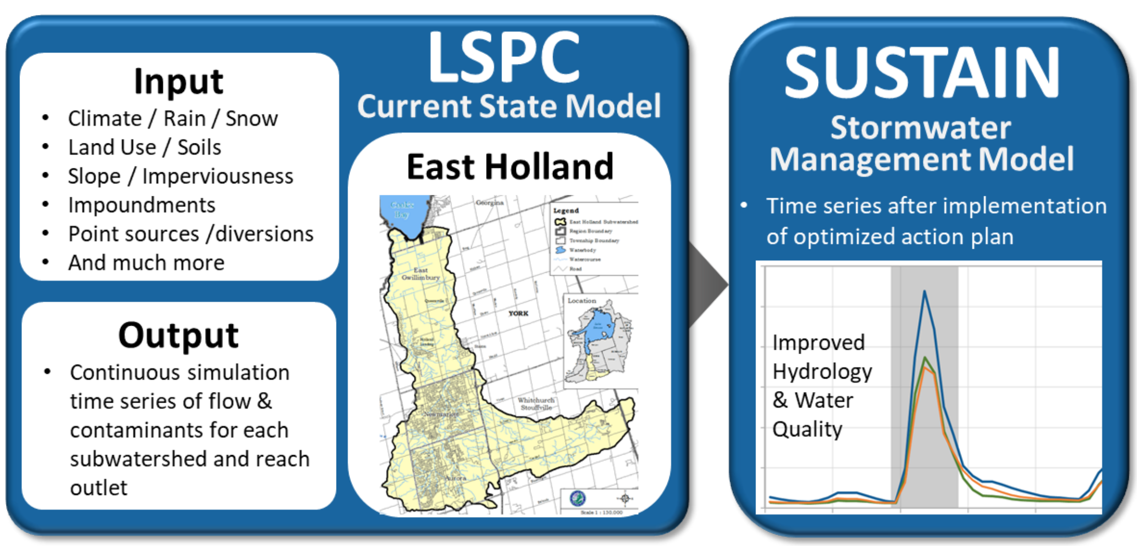


Figure 1-1. Overview of open source, process-based modelling system being developed for Eq4RTD project.

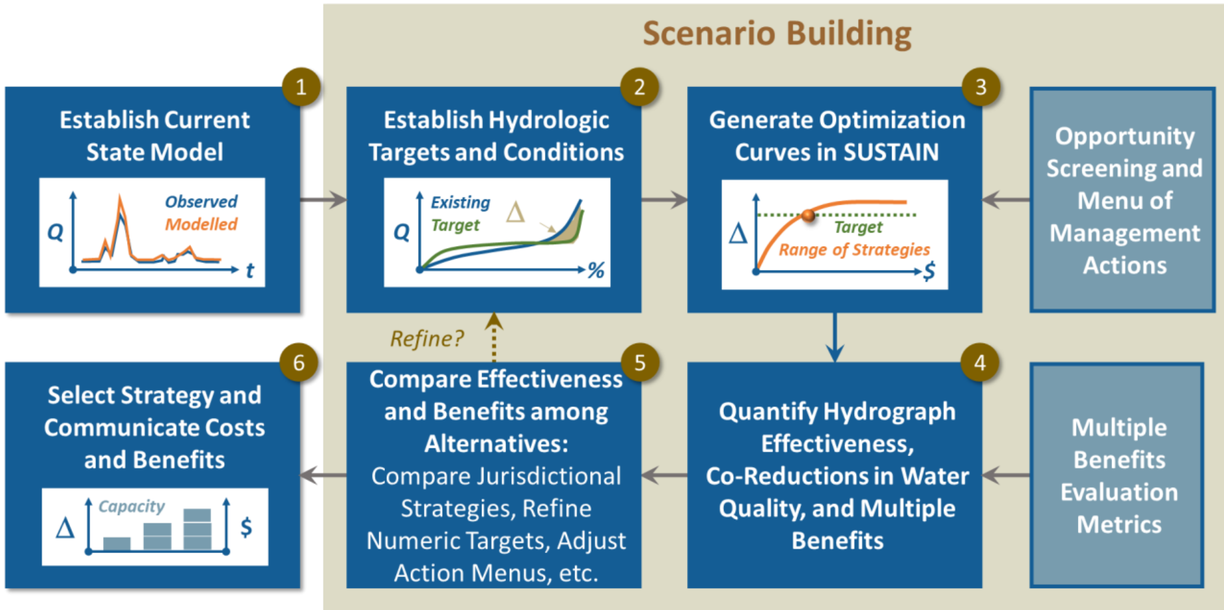


Figure 1-2. Overview of modelling process for Eq4RTD project for systems-based economic decision making

2 MODEL BACKGROUND

The hydrologic and water quality model selected for the baseline model of the East Holland River watershed is the Loading Simulation Program in C++ (LSPC) (Shen et al., 2004). The following sections provide background on the LPSC model and an overview of how LSPC is being applied for watershed planning.

2.1 LSPC Overview

LSPC is an open-source, process-based watershed modelling system developed by U.S. Environmental Protection Agency (EPA) for simulating watershed hydrology, sediment erosion and transport, and water quality processes from both upland contributing areas and receiving streams (the code for LSPC can be downloaded here: LSPC Code). A watershed model is essentially a series of algorithms for representing the interaction between meteorology and land surfaces, resulting in surface and subsurface flow that carry pollutants to streams. The LSPC model simulates flow accumulation in stream networks and the transport of pollutants, which may be deposited or scoured from the stream bed or may be sorbed or transformed due to various chemical and biological processes. LSPC is capable of dynamically simulating flow, sediments, nutrients, metals, dissolved oxygen, temperature, and other pollutants for pervious and impervious lands and waterbodies of varying order.

The algorithms of LSPC were developed from a subset of those in the Hydrologic Simulation Program FORTRAN (HSPF) (Bicknell et al. 1997). The hydrologic portion of HSPF/LSPC is based on the Stanford Watershed Model (Crawford and Linsley 1966), which was one of the pioneering watershed models. LSPC is built upon a relational database platform, making it easier to collate diverse datasets to produce robust representations of natural systems. LSPC integrates GIS outputs, comprehensive data storage and management capabilities, the original HSPF algorithms, and a data analysis/post-processing system into a convenient PC-based Windows environment.

Figure 2-1 is a generalized schematic of the underlying hydrology model (Stanford Watershed Model) used in LSPC. The schematic represents land-based processes for a single land unit in the model. The schematic shows the major processes that influence hydrology, which in turn influence water quality. The model configuration and calibration efforts determined the scale and parameterization for representation of process-based hydrology and water quality parameters in East Holland River watershed, as described in Section 3 and 0.

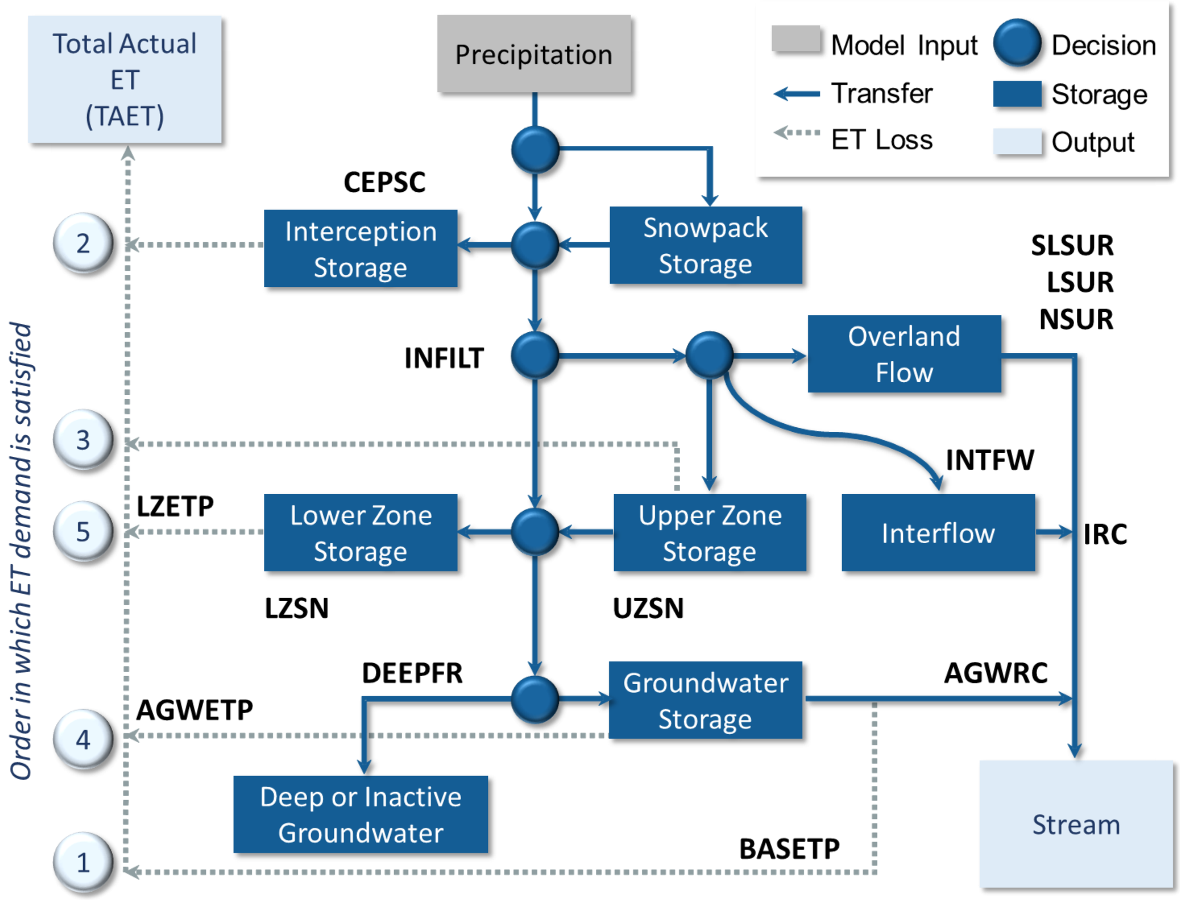


Figure 2-1. Hydrology model schematic for LSPC (based on Stanford Watershed Model).

2.2 Overview of Current State Model Development Process

The Current State model provides the 'baseline' for establishing existing hydrology and water quality conditions in the East Holland River watershed. The process to develop the Current State model has been iterative and adaptive – for example, over the last 7 months the modelling team has: incrementally increased the resolution of model thru incorporation of smaller subcatchment areas and additional land use types, incrementally incorporated data and findings from previous studies, and adjusted parameters to better match observed data. In the long-term, the vision for the Current State model is a 'living' platform that evolves as additional data are collected and lessons are learned from other efforts in the watershed. This long-term vision also foresees a Current State model that can inform future data acquisition efforts by highlighting gaps in model performance and corresponding factors that have the most impact on conditions in the East Holland River.

Figure 2-2 is a conceptual schematic of a model development cycle, which is conceptually represented as circular as opposed to linear. The cycle can be summarized in six interrelated steps:

1. **Assess Available Data**: these data are used for land representation, source characterization, meteorological boundary conditions and more.
2. **Delineate Project Extent**: which refers to model segmentation and discretization needed to simulate hydrology and water quality at temporal and spatial scales appropriate for supporting decisions across the watershed.
3. **Set Boundary Conditions**: refers to spatial and temporal model inputs, especially meteorological data, for establishing the conditions that drive variation in hydrology and water quality.
4. **Represent Processes:** these are the processes represented by the algorithms in the model, and selection of the processes to use for the application (e.g., which pollutants to simulate).
5. **Confirm Predictions** refers to adjustment of model rates and constants to mimic observed physical processes of the natural system, mostly through comparison to observational data.
6. **Assess Data Gaps**: modelled responses and/or poor model performance can indicate the influence of unrepresented physical processes in the modelled system. A well-designed model can be adapted for future applications as new information about the system becomes available. Depending on the study objectives, data gaps sometimes provide a sound basis for further data collection efforts to refine the model, which cycles back to Step 1.

These steps are organized into two primary efforts: model configuration (green boxes) and model calibration (blue), which are detailed in the following sections.

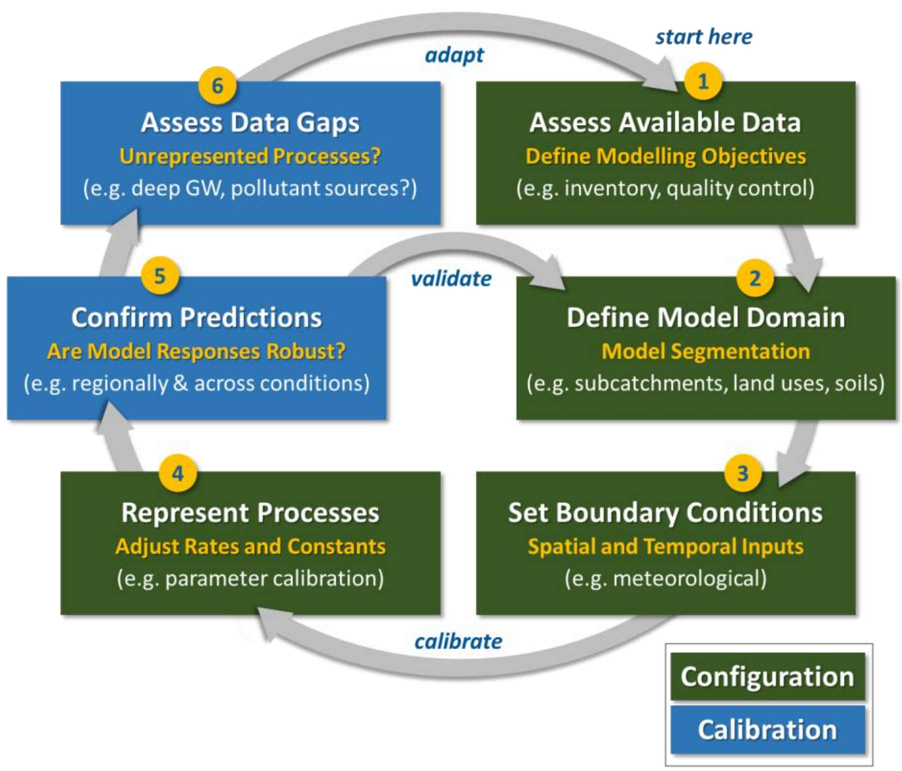


Figure 2-2. Conceptual schematic of the Current State model development cycle.

3 MODEL CONFIGURATION

Model configuration is the process by which all the key data are translated into the model for representation of the watershed's weather, land cover, infrastructure, and more. The organizational framework for LSPC is a relational database. By their very nature, both GIS and timeseries elements of watershed data are also organized in a relational database structure (i.e., spatial objects with tabular attributes)—configuration generally involves translating GIS and time series data from their 'native' format into the formats required for the LSPC database and LSPC input files.

Key elements of model configuration include: (1) weather, (2) subcatchment delineation, (3) hydrologic response units, (4) stream cross sections, and (5) pond representation. These elements are described in the subsection below.

3.1 Weather Boundary Conditions

The LSPC model requires input of hourly climate data as boundary conditions to run the snow, hydrology, and water quality modules. Precipitation and potential evapotranspiration drive the water balance of both the snow accumulation/melt and hydrology modules. Hourly air temperature is also central to the snow accumulation and melt processes, and both dew point temperature and solar radiation govern internal snowpack processes. Water quality simulation then relies indirectly on all the above because hydrology is a prerequisite for pollutant generation and transport. Table 3-1 presents a summary of the LSPC modules activated for the East Holland River watershed model and the specific climate data dependencies for each.

Meteorological data drive the modelled hydrologic processes. As shown in Figure 2-1, precipitation is the primary input to the water budget (top middle) and drives runoff due to rainfall (Overland Flow and Interflow). Total actual evapotranspiration (TAET, top left) and streamflow are the primary outputs in the water budget. Potential evapotranspiration (PET; not explicitly shown in the schematic) is another key meteorological boundary condition for the model. The interaction of model parameters will ultimately determine how much PET becomes TAET. The boundary condition time series drive these processes in LSPC.

Table 3-1. Summary of climate data input requirements by LSPC module

LSPC Module	Precipitation	Potential Evapotranspiration	Temperature	Dew Point	Wind Speed	Solar Radiation	Cloud Cover[1]
Snow Accumulation/Melt	●	●	●	●	●	●	--
Hydrology	●	●	--	--	--	--	--
Water Quality (GQUAL)	●	●	--	--	--	--	--

1. While not required for any of the modules described in the above table, cloud cover inputs were included in the LSPC watershed model to provide flexibility for enhancing the model.

Both daily and hourly climate data timeseries were collected from local sources surrounding the East Holland River watershed including stations monitored by the Lake Simcoe Region Conservation Authority (LSRCA) and Environment Canada. Interpolated datasets derived as part of the Environmental Flows (E-flows) hydrological study (LSRCA 2018a) were also provided by LSRCA and represent spatially averaged daily precipitation and potential evapotranspiration for the East Holland River watershed. As is often found with observed timeseries data, records from some stations were incomplete while others spanned limited time periods. The data were also provided at different temporal resolutions. Table 3-2 summarizes the data used as inputs to the LSPC model for the East Holland River watershed.

Table 3-2. Summary of input datasets detailing the data layer and source for developing climate timeseries

Station Name	Station ID or Filename	Data Source	Climate Parameters	Time Period
Observed Data				
Newmarket Office	LS0108	LSRCA	Hourly Precipitation	2/28/1999 – 9/30/2018
Toronto / Buttonville Airport	6158410 / 615HMAK	Environment Canada	Air Temperature, Wind Speed, Dewpoint Temperature, Solar Radiation, Cloud Cover	1/1/1999 – 9/30/2018 [1]
Model Derived / Interpolated Data				
Precipitation	*Interplolated_Average_Daily_ Watershed_Climate.csv*	LSRCA	Daily Precipitation	1/1/1999 – 9/30/2016
Potential Evapotranspiration	*EHO_GSFLOW_PET.csv*	LSRCA	Daily Potential Evapotranspiration	10/1/1994 – 9/30/2015 [1]

1: Potential evapotranspiration timeseries were computed using the Penman method through 9/30/2018 and scaled to match long-term seasonal average variability of EHO_GSFLOW_PET.csv.

These climate data were reviewed for completeness and screened for data gaps using annual summary statistics, seasonal summary statistics, and timeseries plots. Since the spatially interpolated precipitation dataset from the E-flows study is a modelled data product derived from observed data and was not accompanied with any quality flagging, this timeseries was considered complete and free of missing or impaired data. The interpolated daily precipitation timeseries was disaggregated to an hourly timestep using rainfall distributions from the Newmarket Office gage. Because that dataset ended in 2016, Newmarket Office data from 10/1/2016 through 9/30/2018 were appended to the disaggregated timeseries to extend the record by two years. Figure 3-1 presents an example monthly timeseries displaying the precipitation depths for the interpolated timeseries and the Newmarket Office timeseries (the period at the end of the record that was appended with the Newmarket gage can be seen on the right).

Potential evapotranspiration timeseries were calculated by applying the Penman method using hourly temperature, dew point, wind speed, and solar radiation data from the Toronto/Buttonville Airport gage (6158410 /615HMAK). Short gaps with missing input data from this gage were filled using linear interpolation between adjacent records. The computed PET timeseries were then scaled using monthly factors to match the daily PET totals from the EHO-GSFLOW timeseries provided by LSRCA (LSRCA 2018c). Finally, these data were translated to the required input format for the LSPC model.

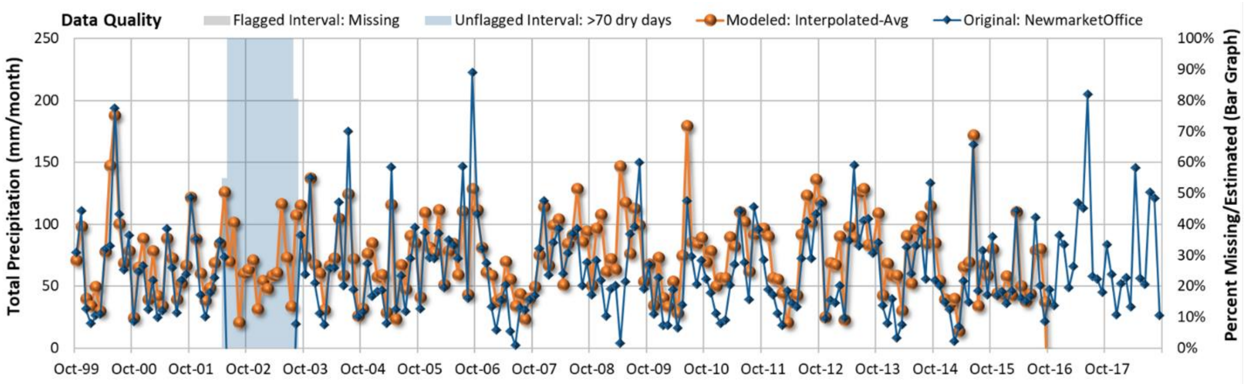


Figure 3-1. Observed precipitation at the Newmarket Office and the spatially interpolated Environment Canada precipitation (10/1/1999 through 9/30/2018).

3.2 Subcatchment Boundaries

A primary element of hydrologic model development is watershed delineation. Identifying watershed boundaries enables modellers to portray specific characteristics of the region's watersheds such as slope, land use, impervious cover, climatic variations, elevation, etc. to simulate the hydrology of the region. A fine resolution subcatchment delineation provides increased spatial resolution and model accuracy for predicting hydrologic characteristics within a watershed and allows for routing of flows and associated pollutant loads within each watershed.

Several datasets were already available as base layers for developing subcatchment delineations, specifically within the urban areas of Newmarket, East Gwillimbury (East Gwill), and Aurora, reflecting hydromodifications and routing which would not otherwise be captured through a delineation process based solely on elevation data. Table 3-3 presents a summary of the datasets used for developing the Current State subcatchment boundaries and routing. A key outcome of the effort is the representation of ponded vs unponded areas in East Holland River watershed.

Table 3-3. Summary of datasets used to develop Current State model subcatchment boundaries and routing.

Description	Source	Filename	Publication Date
Newmarket Pond Subcatchments	Newmarket	FCM_Stmwater_Mngt_Project_2019 NMKT_STORM_CATCHMENT_AREAS.shp	c. 2019
East Gwill Pond Subcatchments	East Gwill	SWM_FACILITY.shp	c. 2019
Aurora Pond Stormwatersheds	Aurora	Stormwatershed.shp	c. 2018
125-hectare Subcatchments	LSRCA	Catchment125Ha_10252018.shp	c. 2002

Creation of the subcatchment delineations began with combining the subcatchment layers from Newmarket and East Gwillimbury with the stormwatersheds layer from Aurora. Only Level-1 through Level-4 ponds in the Aurora stormwatersheds layer were incorporated into the delineations. Uncontrolled ponds were excluded. Remaining areas in the East Holland River watershed were filled in using the 125-hectare subcatchments layer created by LSRCA staff using digital elevation data c. 2002. Small slivers and holes in the aggregate subcatchment delineation layer were reviewed and filled by manually adjusting the boundaries to remove these sliver areas. At this step, the outer boundary of the entire East Holland River watershed was also reviewed and manually adjusted as necessary for continuity with the 125-hectare subcatchments.

Next, flow direction (i.e., routing) of pond-controlled subcatchments from Step 1 was determined by reviewing flow directions in LSRCA-provided subcatchment layers, augmented with manual review of aerial imagery and available GIS locations of ponds. Model stream segment centerlines within each subcatchment were established using flow lines accompanying the 125-hectare subcatchment layer. These stream segments were then augmented with flow accumulation lines generated by ArcHydro GIS plugin. The stream segments were cross referenced against known watercourse drainage areas to ensure consistency in routing within tributaries (i.e., headwater routing flows downstream rather than to an adjacent watercourse). Finally, checks were performed to compare the final delineations and stream segments against stormwater management plans, including the Lake Simcoe Protection Plan (LSPP) Comprehensive SWM master plans (CSWM-MPs), along with previous hydrologic models, including Visual-Otthymo-2 (VO2) currently used for flood-mapping in concert with the U.S. Army Corps of Engineers Hydrologic Engineering Center River Analysis System (HEC-RAS). No major inconsistencies were identified during this review. After completing these checks, a sequential set of subcatchment and reach IDs were assigned to each feature and used to establish the upstream-downstream routing table for LSPC. The subcatchment delineations and routing were provided to LSRCA staff for review following the same quality assurance and quality control procedures outlined above.

Table 3-4 summarizes the number of subcatchments within the East Holland River watershed model and Figure 3-2 depicts the delineated subcatchment organized by watercourse. The delineation process resulted in a total of 273 subcatchments. The East Holland River mainstem is the largest watercourse in the model both in terms of total area and number of subcatchments.

Table 3-4. Summary statistics of subcatchment delineations by tributary

Watershed	Total Area (sq. km.)	Subcatchments		
		Count	Mean Size (ha.)	Median Size (ha.)
Holland River	6.2	4	155.9	149.7
East Holland	88.8	106	83.7	32.1
Ravenshoe/Boag Drain	24.6	11	223.2	183.1
Queensville Drain	7.7	3	258.3	157.2
Holland Landing Creek	5.0	9	55.2	5.1
Western Creek	6.5	25	25.8	17.1
Armitage Creek	7.3	6	122.2	90.7
Tannery Creek	31.7	50	63.3	13.8
Marsh Creek	8.1	17	47.9	29.0
Weslie Creek	11.4	12	95.0	15.5
Bogart Creek	24.2	16	151.0	73.2
Sharon Creek	9.4	12	78.7	30.7
Holborne Drain	5.2	1	520.4	520.4
Youngs Point Canals	2.6	1	258.5	258.5
Total	**238.7**	**273**	--	--

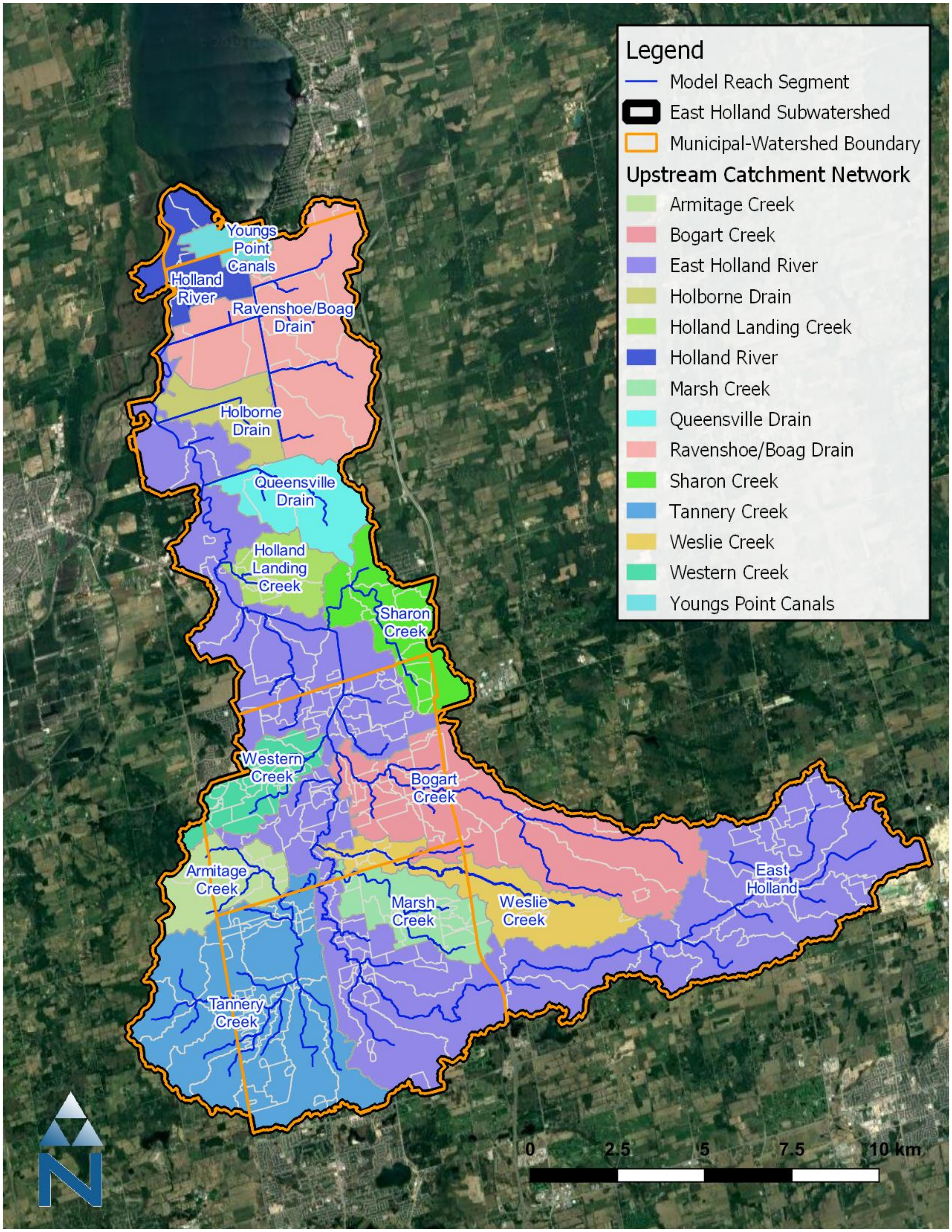


Figure 3-2. East Holland River watershed subcatchment delineations, reach segments, and watercourses.

3.3 Hydrologic Response Units

For each land unit, process-based parameters that reflect differences in geology, soils, vegetation, and land cover govern the rates and volumes of water at each stage throughout the schematic. Within LSPC, land units are parameterized as Hydrologic Response Units (HRUs), which are the core hydrologic modelling land units in the watershed model. Each HRU represents areas of similar physical characteristics attributable to certain processes. The HRU development process is driven by the major data types that are available and local knowledge of the major drivers of hydrology in the watershed. For East Holland River, four categories of land characteristic were used to create the HRUs: slope, soils, land cover, and geology. The areal combination of these primary landscape characteristics ultimately determined the number of meaningful HRU categories considered for the model. Some consolidation of HRUs was implemented to balance the need for spatial resolution with model simulation efficiency.

Figure 3-3 shows the organizational relationship of HRUs, subcatchments, and model parameterization. Secondary attributes are properties (e.g., impervious cover) that are summarized by HRU to estimate numerical values for the model.

The following subsections provide detailed methods for processing the four key categories of data to develop HRUs.

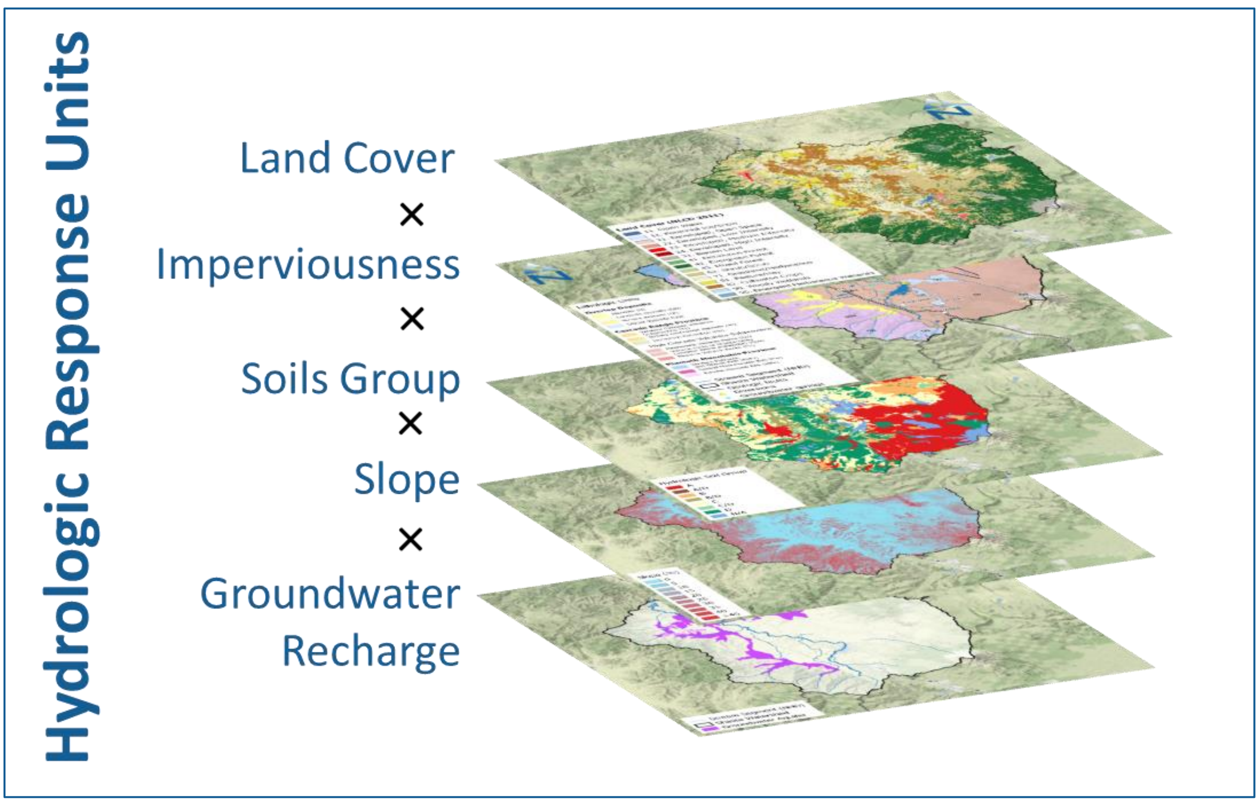


Figure 3-3. Key land characteristics used to create HRUs for the East Holland River

3.3.1 Elevation & Slope

A digital elevation model (DEM) is a raster-based dataset describing the elevation of the landscape across a regular grid. DEMs are useful for performing drainage studies in determining flow direction and are often used to derive the landscape slope, defined as elevation rise over run. LSRCA provided a 5-meter DEM grid covering the East Holland River watershed that was used to derive a similar raster grid describing the landscape slope. Table 3-5 presents the details of these two datasets.

Table 3-5. Summary of input datasets detailing data source and type

GIS Layer	Data Source	Description
Digital Elevation Model (DEM)	LSRCA	5m Raster (c. 2007)
Slope (derived from above DEM)	Paradigm Environmental (derived from above DEM)	5m Raster (c. 2019)

Figure 3-4 presents cumulative distribution function that shows the raw slope value as a percentage of total watershed area for the East Holland River watershed. This curve was used to segment slopes throughout the watershed and establish breakpoints between slope categories within the model HRUs.

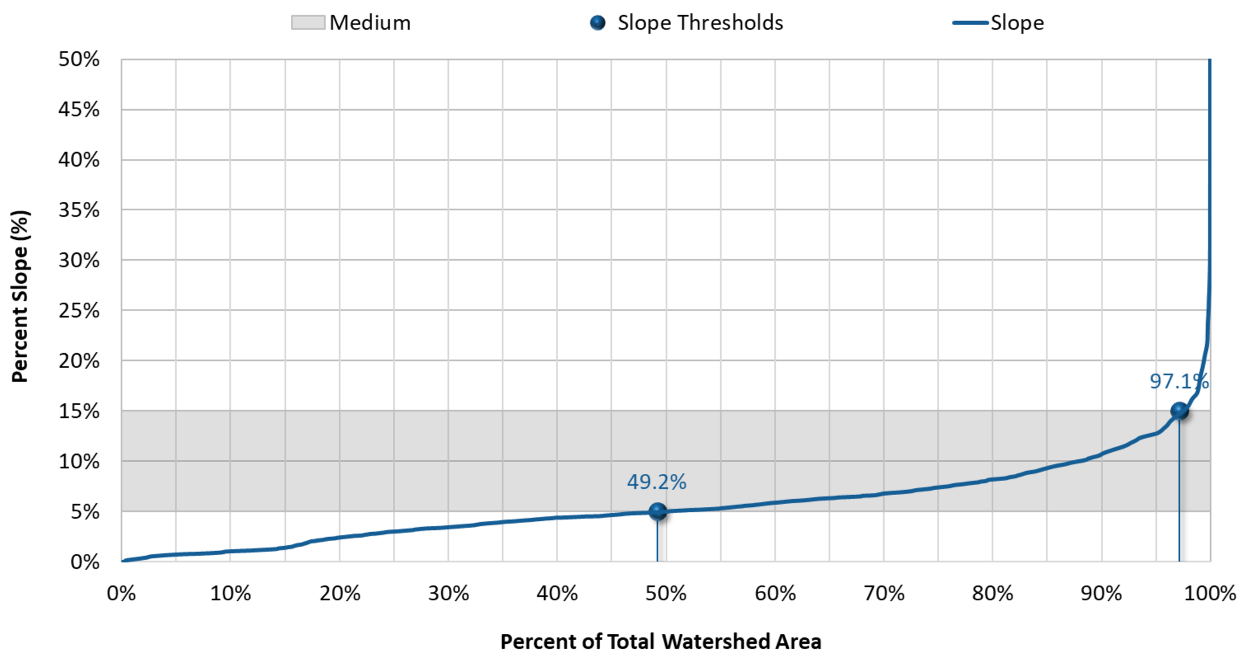


Figure 3-4. Cumulative distribution function that shows the raw slope value as a percentage of total watershed area for the East Holland River watershed.

Based on this analysis, the raw slope raster was reclassified into two groups (i.e., ≤5% and >5%) corresponding to *low* and *medium-high* slope areas, respectively. Areas greater than 15% which would have otherwise been classified as a separate *high* category were included with medium slopes in the medium-high category because three slope categories would have greatly increased the number of HRUs (and therefore simulation time) with little impact on predictions given the small portion of the watershed with high slopes. Figure 3-5 presents a map showing the spatial distribution of the classified slope categories for HRU development.

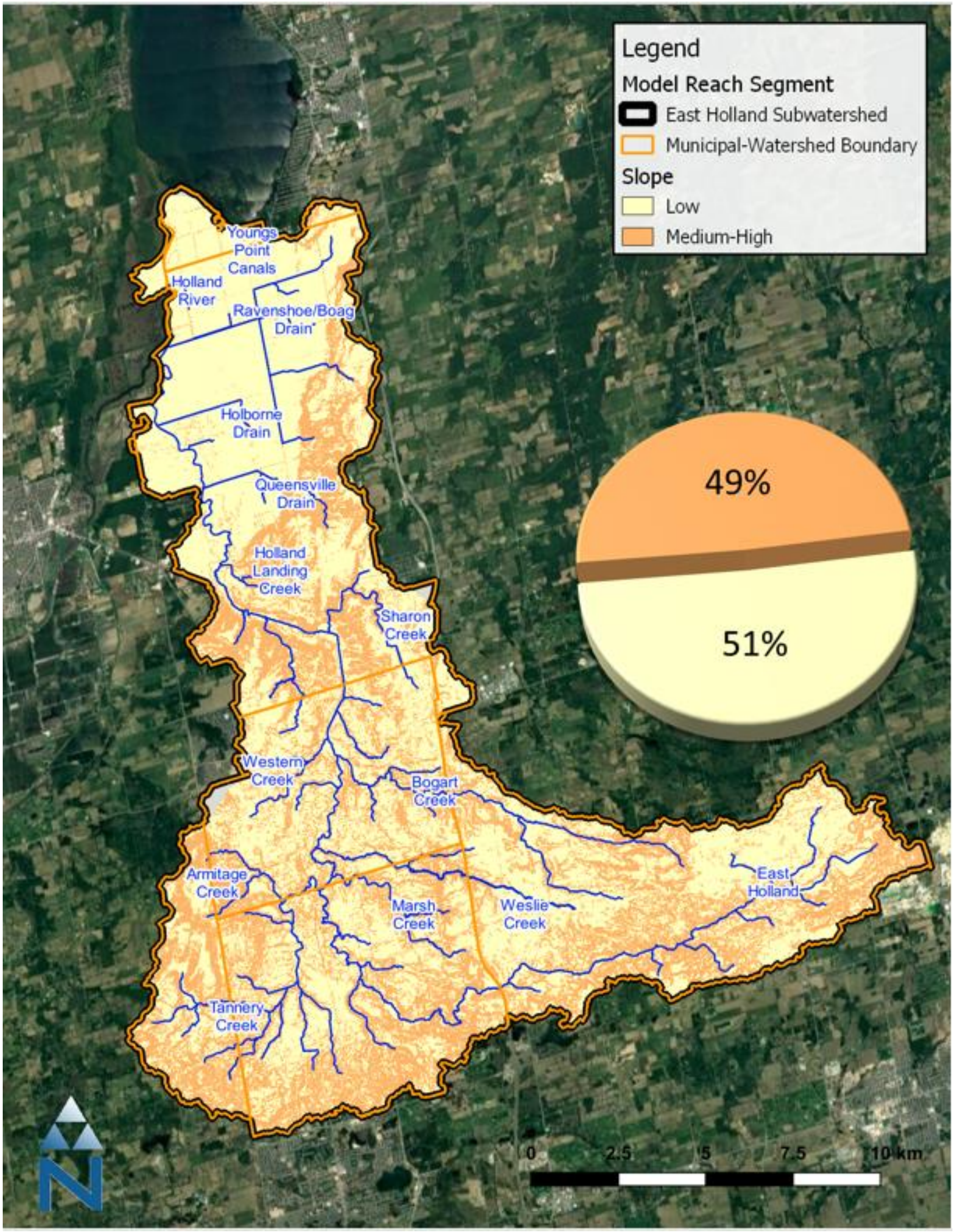


Figure 3-5. Map showing reclassified landscape slope groups for the East Holland River watershed.

3.3.2 Hydrologic Soil Groups

Hydrologic soil groups (HSG) are used to represent the relative amount of runoff that is generated from pervious land, based on effective infiltration rate. HSG-A generally has the lowest runoff potential whereas HSG-D has the highest runoff potential. These HSG classifications are used within the model as a basis for setting certain hydrologic parameters including infiltration rates. Soil characteristics of each hydrologic soil group are described in Table 3-6.

Table 3-6. NRCS Hydrologic soil group descriptions (NRCS 1986)

Hydrologic Soil Group	Description
A	Sand, Loamy Sand, or Sandy Loam
B	Silt, Silt Loam or Loam
C	Sandy Clay Loam
D	Clay Loam, Silty Clay Loam, Sandy Clay, Silty Clay, or Clay

Table 3-7 details the soils data used for HRU development, which were derived from two sources:

1. A Soil Survey Complex layer obtained from LSRCA (LSRCA 2018b). This soils dataset is composed of a GIS polygon layer of map units and a linked database with multiple layers of soil properties. This dataset contains an attributed named "HYDRO" for each polygon that contains information designating the HSG which is used to characterize soil runoff potential.
2. Upon initial review of the feature class attributes, large areas of Newmarket and Aurora were identified with an "Unknown" classification. Additional soil survey information published by the Canadian Soil Information Service under the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) was identified which contained additional information used to fill these missing classifications with a corresponding hydrologic soil group attributed (CANSIS 2018).

Table 3-7. Summary of input datasets detailing the data layer and source for developing soil groups

GIS Layer	Data Source	Description
Soil Survey Complex	LSRCA	Polygon (c. 2007)
Soil Survey of Canada	Ontario Ministry of Agriculture, Food and Rural Affairs	Polygon (c. 2018)

Figure 3-6 presents a map and table summarizing the HSG distribution for the watershed using the combined layer described above. Overall, no single soil group in the East Holland River watershed dominates the soils distribution. HSG-C makes up the largest portion of the watershed area, but only marginally larger than the area of HSG-A and HSG-B. HSG-D represents the smallest portion of the watershed area. While no single soil group dominates the overall soil makeup of the watershed, there are distinct spatial patterns where specific soils dominate the composition of distinct regions. The northern most portion of the watershed adjacent to Lake Simcoe along the downstream segment of the East Holland River has the highest prevalence of poorly draining HSG-D soils while the southeastern headwater areas have most of the rapidly draining HSG-A soils.

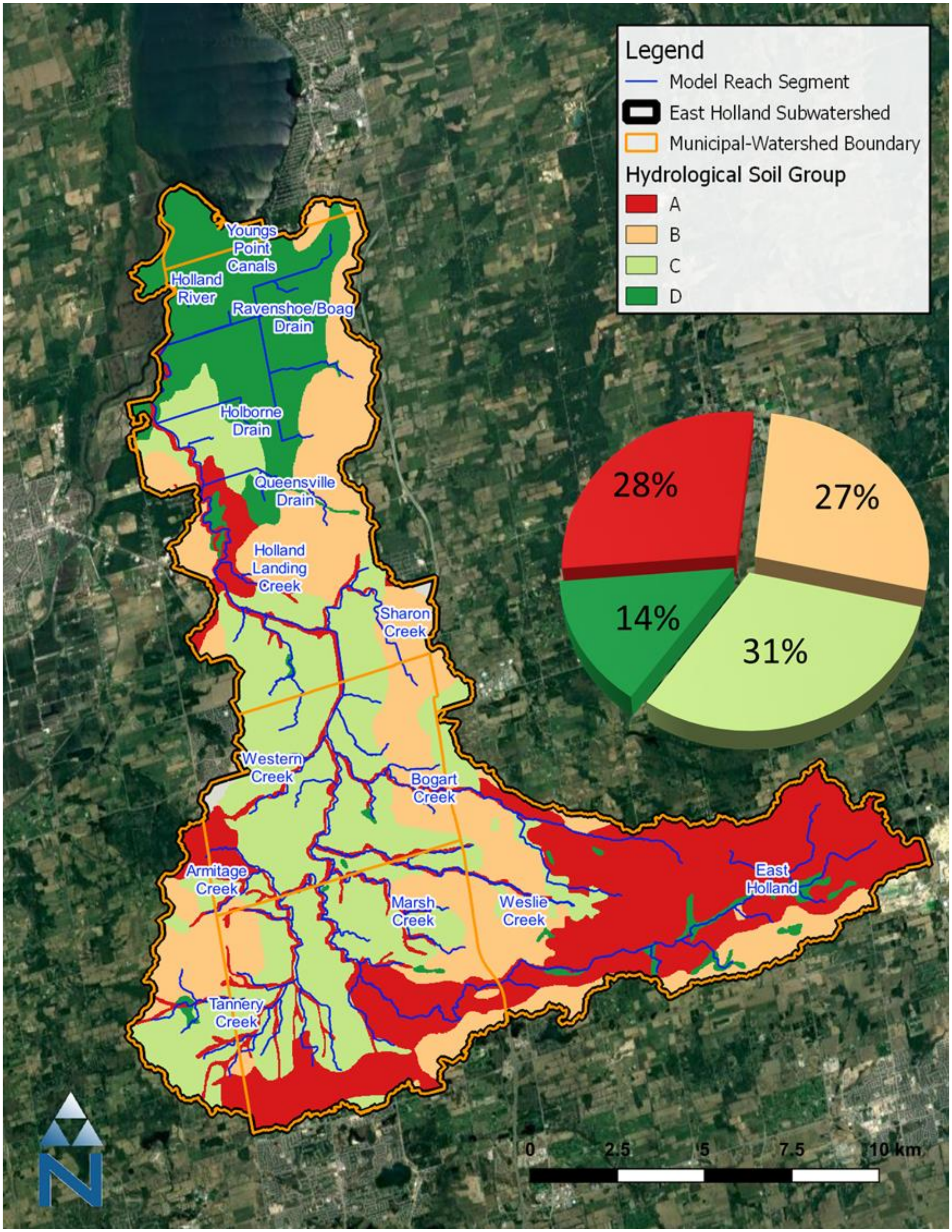


Figure 3-6. Soil survey hydrologic soil groups in the East Holland River watershed.

3.3.3 Seepage/Groundwater Recharge Areas

Processes impacting baseflow, interflow, and groundwater recharge were represented both on the land and within stream channels. On the land surface, geologic information was incorporated into the HRUs using data from the E-Flows study developed in 2018. Within the stream channel, in-stream losses were simulated based on groundwater flux information provided by the Oak Ridges Moraine Groundwater Program. The data was extracted from a coupled groundwater/surface water model built using GSFLOW, the integration of PRMS and MODFLOW maintained by the USGS.

The E-Flow modelling results were previously synthesized into map attributes categorizing *low* and *high* seepage/ground water recharge zones based on linear seepage coefficients (LSRCA 2018a). Figure 3-7 presents a map of the linear seepage coefficient adapted from the E-flows study with areas of high recharge aligning with the Oak Ridges Moraine in the south-southeastern portion of the watershed, which is a known flow sink. Land cover data, described below, was used to identify developed areas within the high recharge zone. Because stormwater from developed areas are generally managed through a system of curbs and gutters and storm drains, the opportunity for groundwater recharge is likely reduced. Therefore, developed areas within high recharge zones were reverted to a 'low recharge' classification. The need for this refinement was discovered through model calibration, because not doing so resulted in significant underprediction of runoff from those areas. Incorporation of this layer in the HRUs provided additional resolution within individual subcatchments for achieving the modelled flow balances in areas prone to groundwater losses.

The GSFLO data represented modelled groundwater interaction with the ground surface, all stream reaches (Strahler orders 1-6) and both Lake Wilcox and Musselman's Lake. Thirteen groundwater raster datasets were received from the Oak Ridges Moraine Groundwater Program. These datasets contained average daily groundwater flux (mm/d) by month and annual average groundwater flux (mm/yr). The data were at the resolution of 200x200 m pixels. Annual average groundwater flux ranged from -34,018 mm/yr (groundwater discharge) to +4,033 mm/yr (groundwater recharge). Figure 3-8 presents a summary of the data. The northern extent of the raster coverage did not include the entirety of the model watershed. Losses to groundwater were most pronounced in the area of the Oak Ridges Moraine. In these areas, a GIS analysis was conducted using a 200 m buffer on either side of the stream centerlines to calculate the annual average groundwater flux in the vicinity of the stream. A stream loss (mm/hr) was used as a calibration parameter to improve agreement between observed and predicted flows in the watershed upstream of the Vandorf gage. An initial value, based on analysis of the groundwater data, of 0.005 mm/hr was applied to the model reaches. During calibration this value was increased to 1.72 mm/hr to achieve improved results. The incorporation of groundwater losses to the Vandorf gage watershed resulted in improved representation of processes known to occur in the region. Further refinement of groundwater dynamics is possible in LSPC, including varying the loss rate seasonally. However, while such changes would result in increasing the complexity of the model, they are not expected to meaningfully improve the agreement between existing and predicted flows in the area. The relatively high rate of 1.72 mm/hr that was required to improve results suggests that the model was not very sensitive to the loss parameter. Additionally, observed discharge at the Vandorf gage were limited to approximately two years of data; a longer dataset could help to justify any seasonally-based adjustments to stream flow losses to groundwater.

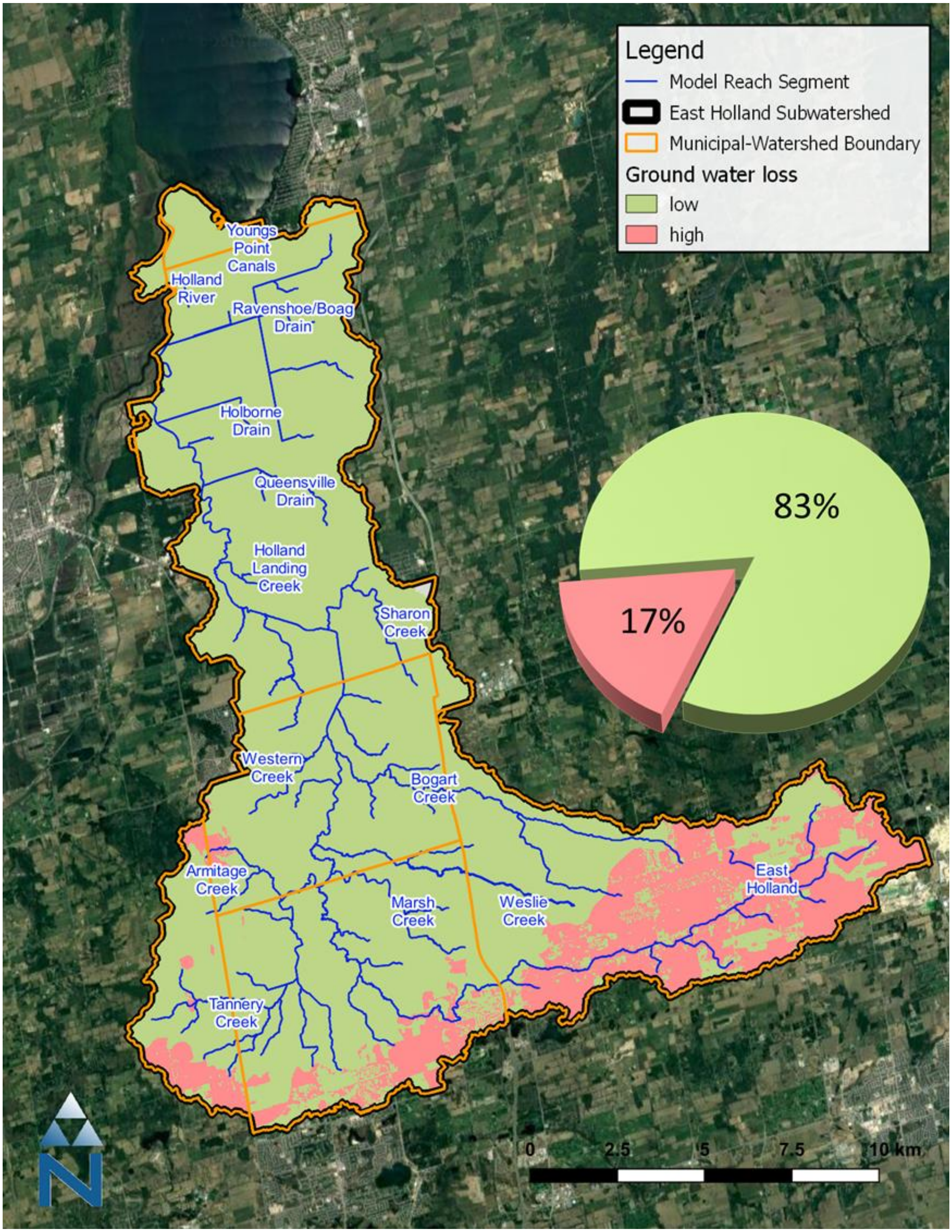


Figure 3-7. Adaptation of the linear seepage coefficient from the LSRCA E-Flows Study for designating low and high seepage groundwater seepage rates.

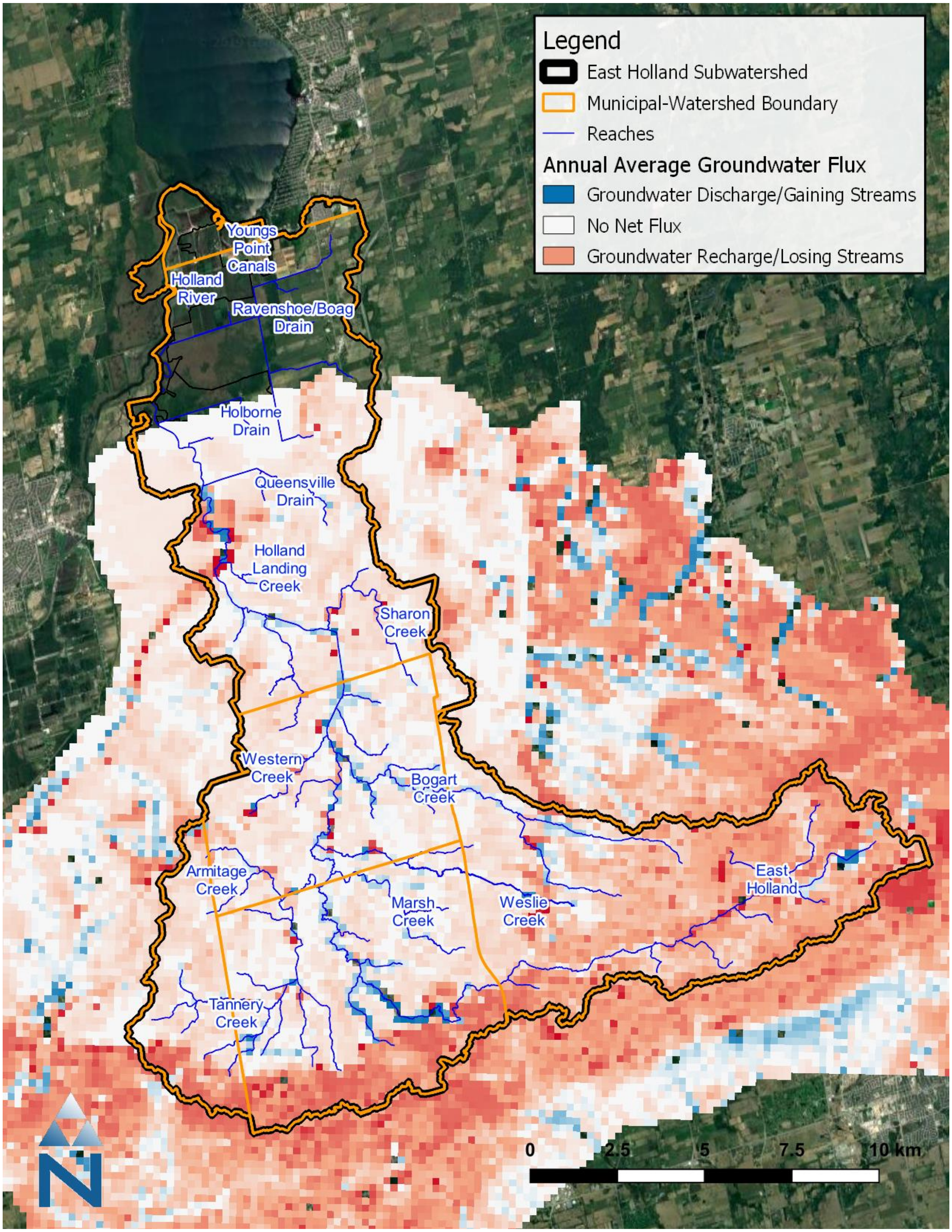


Figure 3-8. Average annual groundwater flux from GSFLOW data.

3.3.4 Land Cover and Use

Land cover and land use data are key base layers for HRU development. Land cover describes the physical characteristics that cover the landscape (e.g., forest, wetlands, development) while land use describes the programmatic nature of land cover (e.g., type of development, functional use of open space, zoning etc.). Table 3-8 presents the primary sources of land use and land cover data used to develop the East Holland River watershed HRUs.

Table 3-8. Summary of input datasets describing land use and land cover for the East Holland River watershed

GIS Layer	Data Source	Description
Land Cover & Surface Type	Lake Simcoe Region Conservation Authority	Polygon (c. 2017)
Ecological Land Classification Natural Heritage Areas	Lake Simcoe Region Conservation Authority	Polygon (c. 2014)

The Lake Simcoe Watershed land cover layer depicts a continuous coverage of the known land cover types and land use activities within the watershed. Land cover data are used by LSRCA to inform planning and management decisions throughout the East Holland River watershed and adjacent watersheds contributing to Lake Simcoe. This dataset was developed using the best available information from both LSRCA and the Ministry of Natural Recourses (MNR) and cross-referenced with orthophotography. Each polygon in this dataset is assigned a land use code and surface type which distinguishes building footprints, roads, etc. This layer also includes Natural Heritage land use designation categorizing critical natural areas.

Embedded within the land cover dataset is an attribute describing the surface type, which was used during HRU development to distinguish pervious from impervious surfaces. The land cover layer went through an update in 2017 to incorporate this attribute. Figure 3-9 shows a zoomed in view of the surface type designation in areas around the LSRCA office. Because of the high level of spatial detail provided in the dataset, this attribute was used directly to represent different types of impervious surfaces within HRU dataset. Inclusion of these surface types in the Current State watershed model establishes the ability to target future management options to specific land use and surface types.

The Natural Heritage category is based on the Ontario Ministry of Natural Resources' Ecological Land Classification (ELC) system, which applies a uniform approach for identifying, describing, naming, mapping and organizing landscape patterns and vegetation communities. All Natural-Heritage features are classified to the Community Series, which is determined by the type of vegetation that characterizes the community. Information in the Community Series includes community cover (open, shrub, or treed) and whether the community is herbaceous, deciduous, or mixed. Some areas in the Natural Heritage Category have been classified to the more refined level of Ecosite. The Ecosite level incorporates the same characteristics as Community Series, but also includes additional environmental features such as soils and geology. For HRU development, the Natural Heritage layer was further subdivided into open, shrub, and treed cover types.

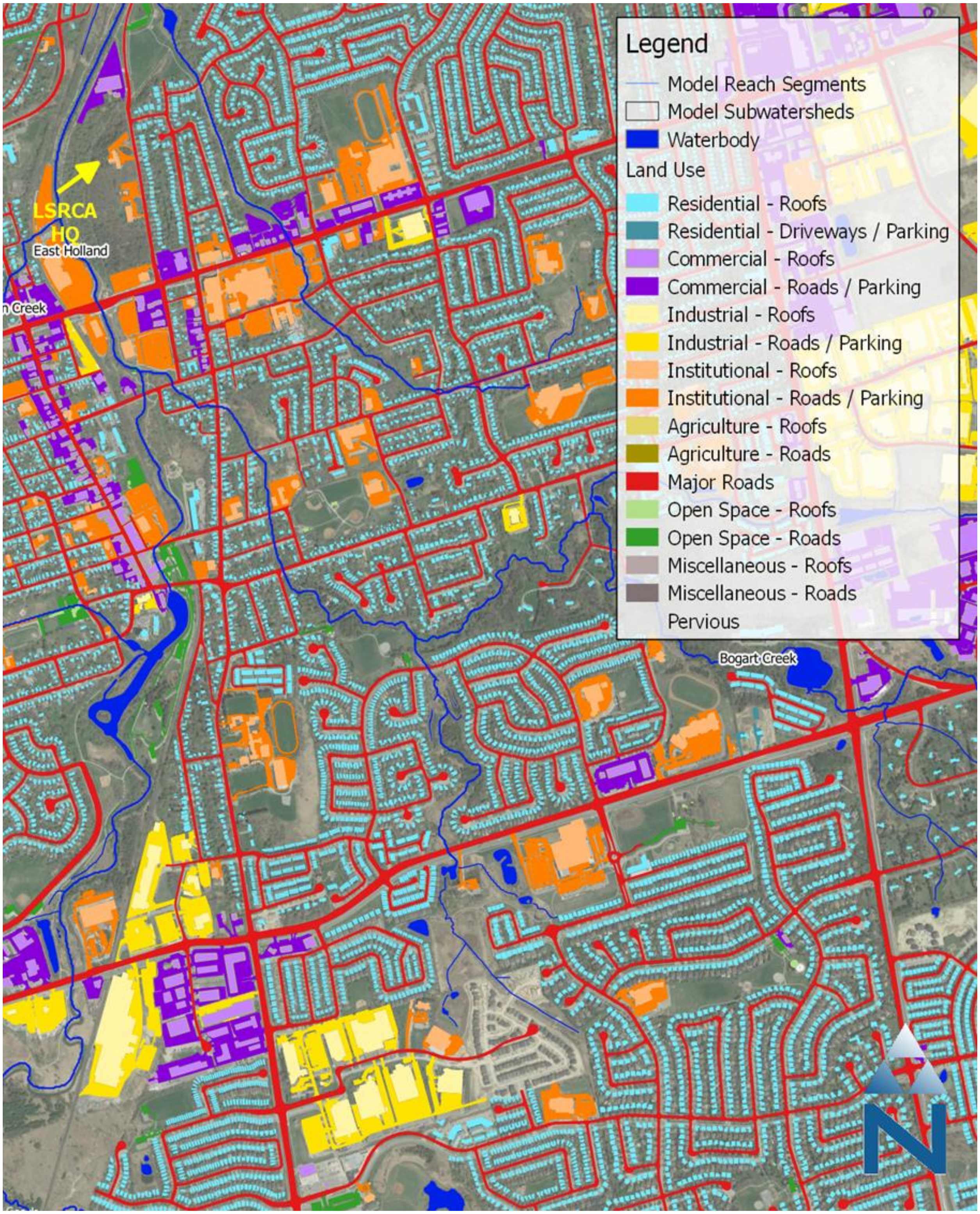


Figure 3-9. Zoomed in view of impervious surface categories derived from the land cover layer.

Figure 3-10 depicts a conceptual overlay of the three land cover components discussed in this section. The figure shows the relationship between the land cover components and describes the process for integrating these different components into a single layer describing land cover, land use, and surface type. In this schema, essentially all ELC Natural Heritage land use areas and impervious surface types are maintained. Remaining areas are then represented using the land use/zoning classification found in the land cover layer.

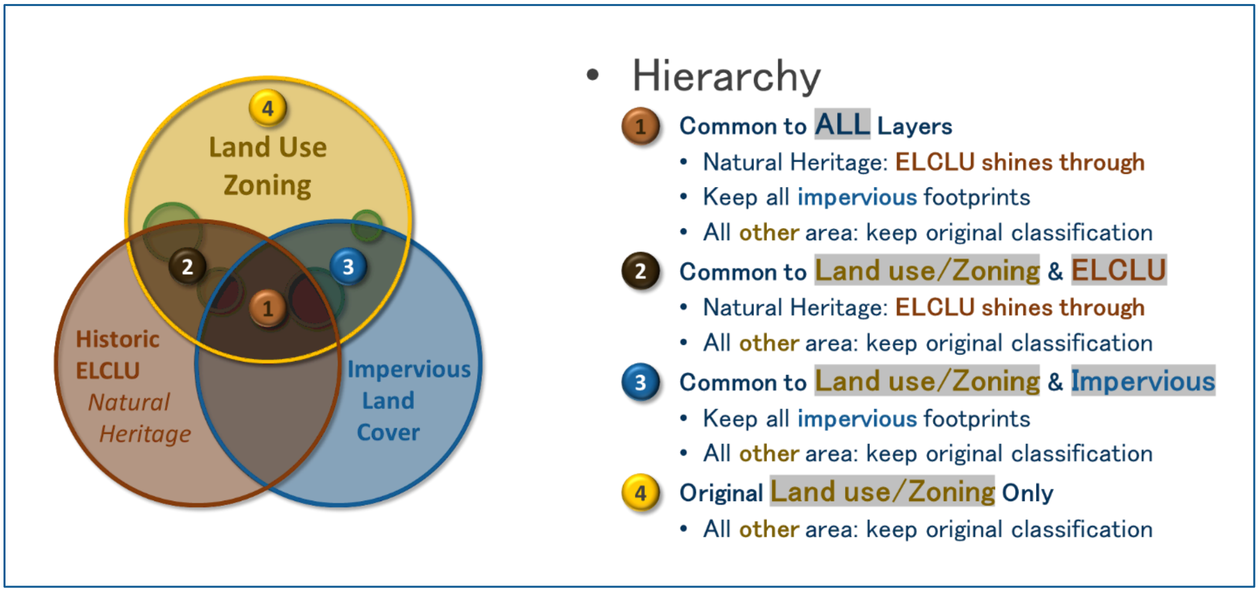


Figure 3-10. Conceptual diagram of HRU land cover reclassification process.

Figure 3-11 shows a combined, generalized land cover and land use map for the East Holland River watershed based on the two data sources discussed above. Natural Heritage areas are the dominant natural land cover classifications making up approximately 35% the total watershed area. Agriculture is the second most prominent category making up 28% of the total watershed area and Developed Pervious is the third most dominant making up approximately 25% of the total watershed area. When combined, these three categories together represent approximately 88% of the total watershed area for the East Holland River.

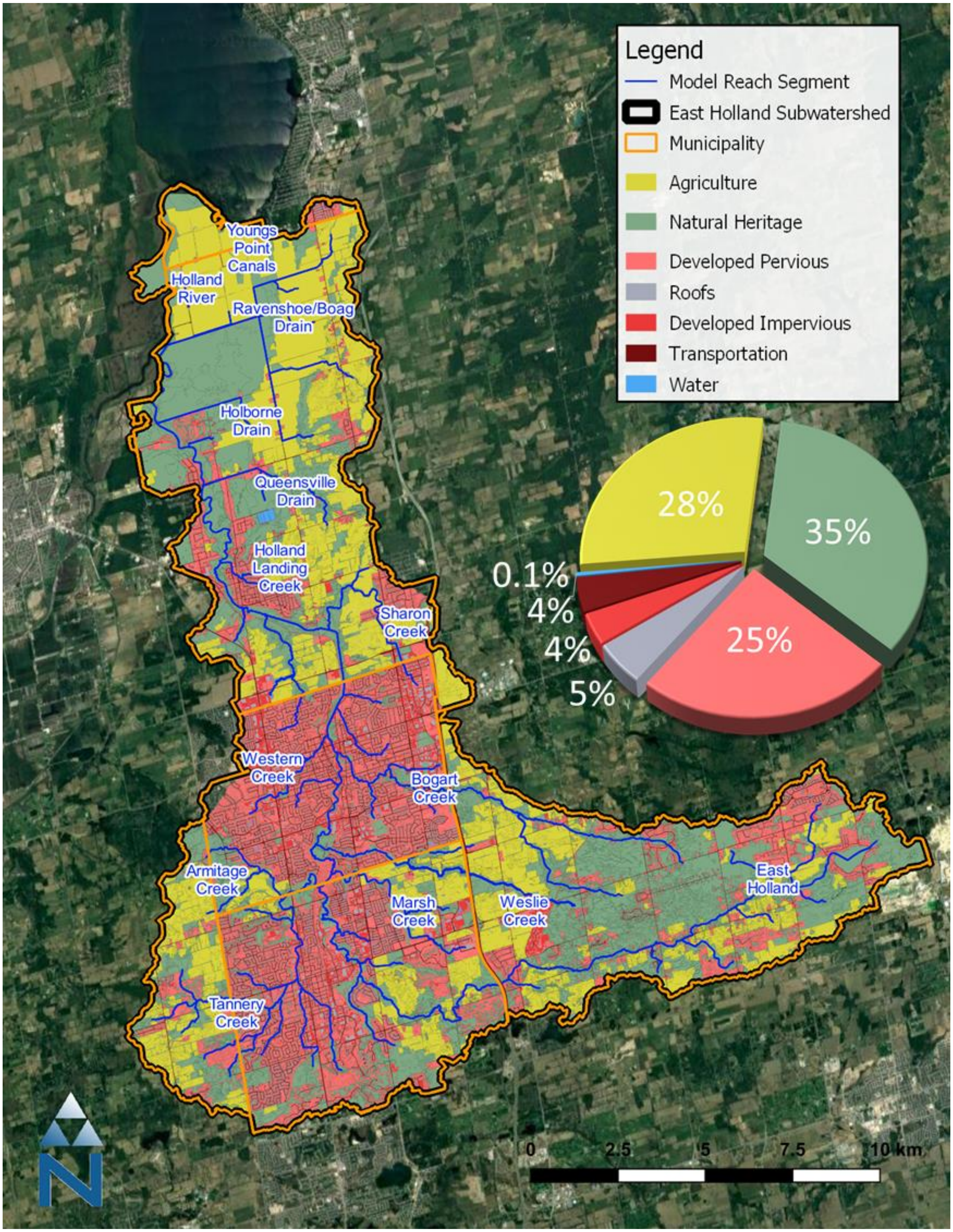


Figure 3-11. Combined major categories based on the land cover and land use datasets.

3.3.5 Final HRUs

Each of the four key spatial data elements discussed in the previous subsections (i.e., slope, soils, groundwater recharge, and land cover) were overlaid in GIS and classified into HRU groups that were assigned a unique HRU code to convert them into raster format. After overlaying each of these layers within a GIS raster framework, the resulting aggregate raster was reclassified into 89 unique categories for representation within the East Holland River watershed model. These 89 HRUs are used as the basis for the land representation in the model and provide the ability to uniquely parametrize both the hydrology and water quality processes (e.g., infiltration rates, pollutant loading rates, etc.). Final model HRUs are summarized in the Table 3-9 (breakdown of HRU components as a percentage of total watershed area) and Figure 3-12 (spatial distribution of HRUs across the watershed).

Table 3-9. Summary of HRU components expressed as a percent of total area for the East Holland River watershed

Order	LUC	Percent of Area	Soil Group (% Landuse Area)				Slope (% Landuse Area)			Groundwater Recharge	
			A	B	C	D	0-5	5-15	>15	Low	High
			1	2	3	4	1	2	3	1	2
1	Agriculture_High	22.7%	10.4%	39.6%	19.3%	30.7%	67.6%	32.3%	0.0%	85.7%	14.3%
2	Agriculture_Low	5.6%	33.7%	37.5%	24.7%	4.1%	30.2%	69.5%	0.3%	70.0%	30.0%
3	Natural_Heritage_Open	8.4%	35.7%	14.5%	25.1%	24.8%	52.5%	41.7%	5.8%	74.2%	25.8%
4	Natural_Heritage_Treed	17.5%	48.8%	21.3%	19.0%	10.9%	35.0%	57.9%	7.0%	58.4%	41.6%
5	Natural_Heritage_Shrub	8.9%	35.3%	25.0%	16.4%	23.3%	47.1%	50.0%	2.8%	69.5%	30.5%
6	Dev_Pervious	24.6%	29.3%	23.7%	45.1%	1.9%	38.6%	60.1%	1.3%	100.0%	0.0%
7	Dev_Roof	4.9%	21.1%	20.2%	57.6%	1.1%	69.5%	30.3%	0.1%	100.0%	0.0%
8	Dev_Residential_Low-Medium	0.5%	31.7%	32.1%	22.3%	13.9%	61.5%	37.9%	0.6%	100.0%	0.0%
9	Dev_Residential_Medium-High	0.1%	57.9%	14.9%	23.5%	3.7%	38.6%	58.5%	2.8%	100.0%	0.0%
10	Dev_Commercial	1.2%	4.9%	18.1%	76.7%	0.3%	92.5%	7.4%	0.1%	100.0%	0.0%
11	Dev_Industrial	1.5%	8.2%	35.4%	55.6%	0.8%	89.6%	10.4%	0.0%	100.0%	0.0%
12	Dev_Transportation	3.9%	22.4%	24.5%	51.0%	2.1%	61.7%	37.6%	0.8%	100.0%	0.0%
13	Water	0.1%	10.5%	14.4%	33.9%	41.2%	81.5%	17.9%	0.6%	95.4%	4.6%

*Totals do not always add to 100% due to rounding

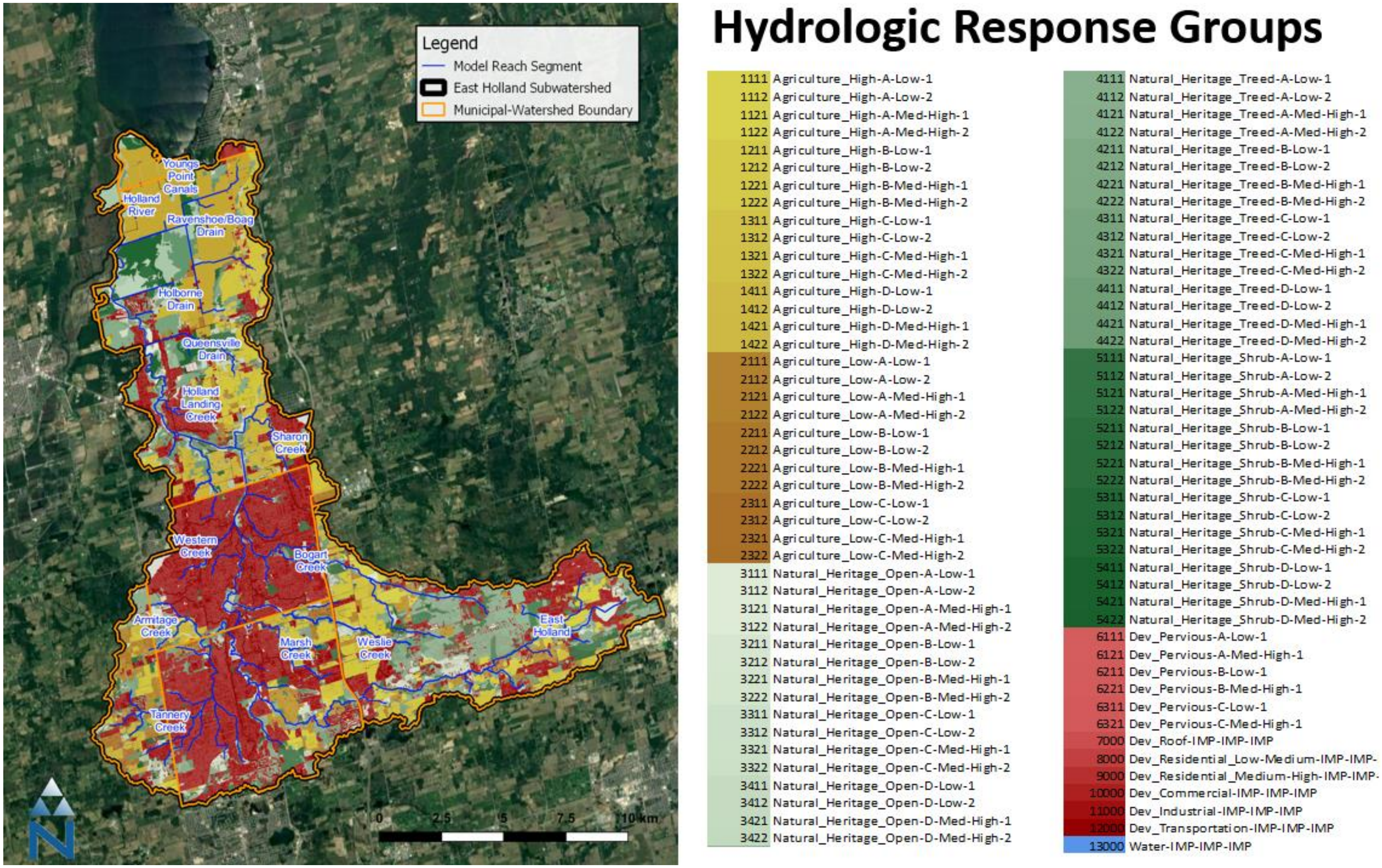


Figure 3-12. Map of LSPC model HRUs for the East Holland River watershed.

3.3.6 Directly Connected Impervious Area

Mapped impervious area (MIA) represents the birds-eye view of impervious cover over the landscape, as represented by available spatial layers. However, the Effective Impervious Area (EIA) is the portion of the MIA that contributes runoff, or which is directly connected to the conveyance systems within the LSPC model. Estimates of Directly Connected Impervious area (DCIA) are rarely available locally, and thus empirical algorithms are typically used to convert MIA to DCIA for input to LSPC.

EIA is derived as a function of DCIA, with other adjustments as needed to account for other structural and non-structural management practices in the flow network. Figure 3-13 illustrates the transitional sequence from MIA to DCIA. Runoff from impervious areas that are not connected to the drainage network may flow onto pervious surfaces, infiltrate, and become part of pervious subsurface and overland flow. Because segments are modelled as being parallel to one another in LSPC, this process can be approximated using a conversion of a portion of impervious land to pervious land. On the open landscape, runoff from disconnected impervious surfaces can overwhelm the infiltration capacity of adjacent pervious surfaces during large rainfall/runoff events creating sheet flow over the landscape—therefore, the MIA→EIA translation is not a direct linear conversion. Finding the right balance between MIA and EIA can be an important part of the hydrology calibration effort.

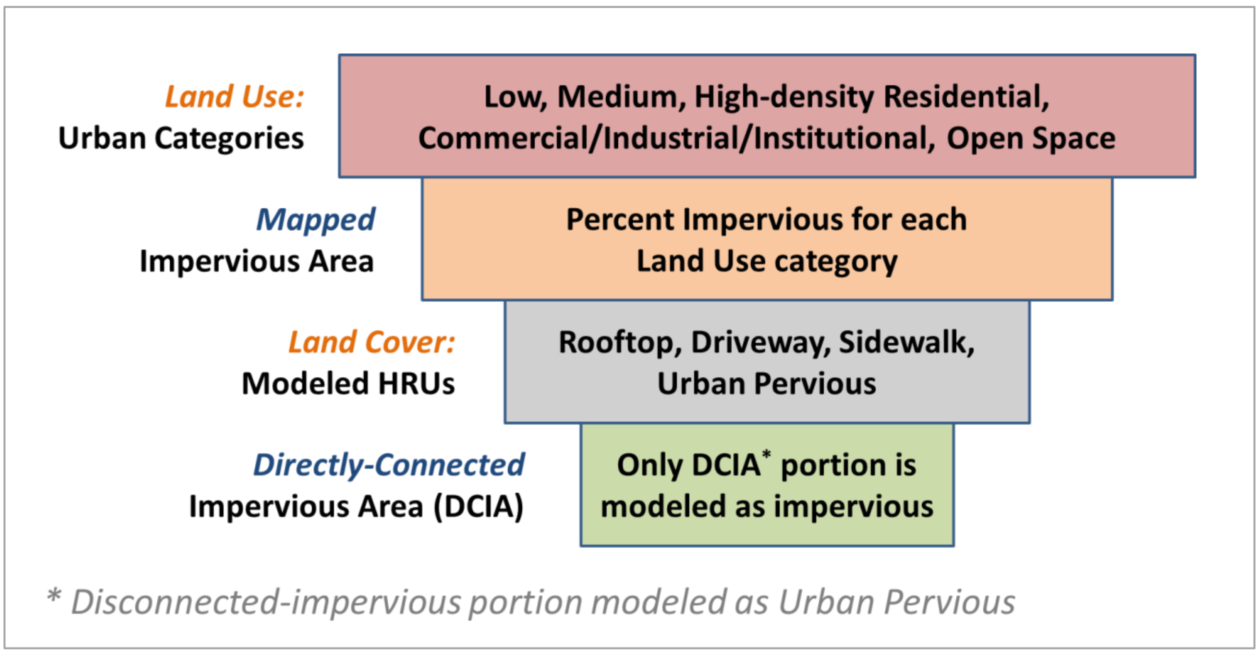


Figure 3-13. Translation Sequence from Mapped Impervious Area to Directly Connected Impervious Area.

The Sutherland Equations (2000) were the empirical relationships used for DCIA estimates in the LSPC model. This refinement is necessary to avoid an initial overestimation of impervious surfaces contributing runoff before initiating process-based model calibration. The Sutherland Equations, presented in Figure 3-14, show a strong correlation between the density of developed area and DCIA. The curve for high-density developed land trends closer to the line of equal value than the curve for less developed areas. Similarly, as the density of mapped impervious area approaches 1.0, the translation to DCIA also approaches 1.0. An estimate of EIA equal to MIA × DCIA based on the Sutherland Equations was used to adjust the MIA from the land cover GIS layers into EIA for use in the LSPC watershed model.

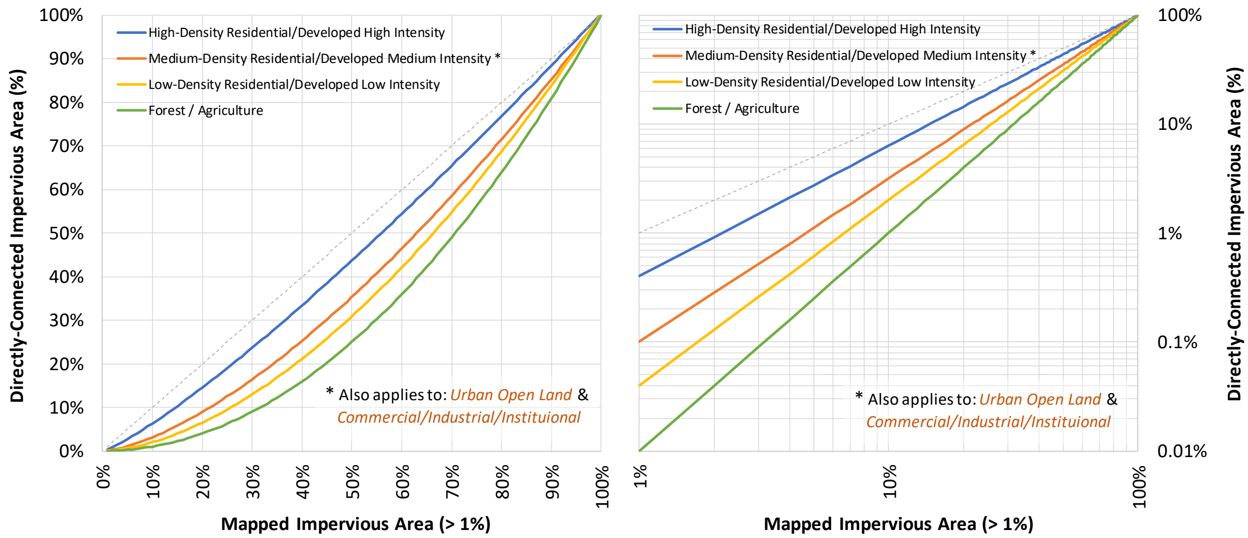


Figure 3-14. Relationships between Mapped and Directly Connected Impervious area (Sutherland 2000).

Table 3-10 presents a summary of land use in the East Holland watershed and the impact of applying the Southerland Equations to convert MIA into DCIA. The amount of MIA converted to DCIA ranged from a high of 100% for roads to a low of 1.5% for intensive agriculture. Overall, the total mapped impervious area in the East Holland Watershed was reduced by 0.3% in the conversion to DCIA.

Table 3-10. Impervious area summary by land use

LSRCA Land Cover and Surface Type Category	Area (ha)			DCIA:MIA	Percent of Area	
	Total	MIA	DCIA		MIA	DCIA
Active Aggregate	73	1.1	0.2	15.8%	1.5%	0.2%
Commercial	599	48.6	40.9	84.1%	66.4%	55.9%
Estate Residential	322	12.1	5.1	42.6%	16.5%	7.0%
Industrial	606	41.1	32.1	78.0%	56.1%	43.8%
Institutional	543	26.4	17.2	65.2%	36.0%	23.5%
Intensive Agriculture	5,456	0.5	0.0	1.5%	0.6%	0.0%
Manicured Open Space	982	2.3	0.6	26.2%	3.1%	0.8%
Natural Heritage Feature	8,210	0.0	0.0	--	--	--
Non-intensive Agriculture	1,395	2.5	0.2	5.9%	3.5%	0.2%
Rail	44	0.0	0.0	--	--	--
Road	939	73.2	73.2	100.0%	100.0%	100.0%
Rural Development	606	7.7	2.0	25.7%	10.5%	2.7%
Urban	4,005	14.6	6.9	47.0%	20.0%	9.4%
East Holland Watershed	**23,778**	**230**	**178**	**77.5%**	**1.0%**	**0.7%**

3.4 Stream Cross-Sections

Stream cross sections drive the relationship between flow and water depth and affect travel times across the watershed. Although they are not as important for estimating flow rates for hydrological simulation, accurate cross-sectional areas are important for estimating flow depths and velocities throughout the network, which strongly influence pollutant fate and transport modelling.

3.4.1 Cross-Sections Represented in LSPC

A Light Detecting and Ranging (LiDAR) based DEM was used to derive representative model cross-sections for 92 reaches (Figure 3-15). Creating cross sections from elevation data allow for improved predictions of sediment transport and flood frequency estimation through more robust modelling of velocity estimates and water surface elevations, respectively. Parallel lines were drawn at regular intervals on either side of the stream centerline. Line segments that were outside subcatchment boundaries were excluded from the analysis. The elevation data were sampled at 1-m intervals and average elevations for each line was calculated. A total of 201 lines with 1,000+ vertices per line were analyzed. A representative cross section for each stream segment was derived using the stream centerline as the zero datum.

3.4.2 Existing HEC-RAS model

A hydraulic model was previously developed for the East Holland watershed using the HEC-RAS software. HEC-RAS allows the user to perform hydraulic analysis to estimate peak flows and perform floodplain mapping for river systems. The Visual OTTHYMO 2.0 SR-1 (VO2) software package was used to develop event-based flood flows, derived from design storms, for input into HEC-RAS. HEC-RAS was then used to route the flood flows through the geometric representation of East-Holland river system and associated floodplains. Stream geometry in HEC-RAS is represented as stream cross-sections.

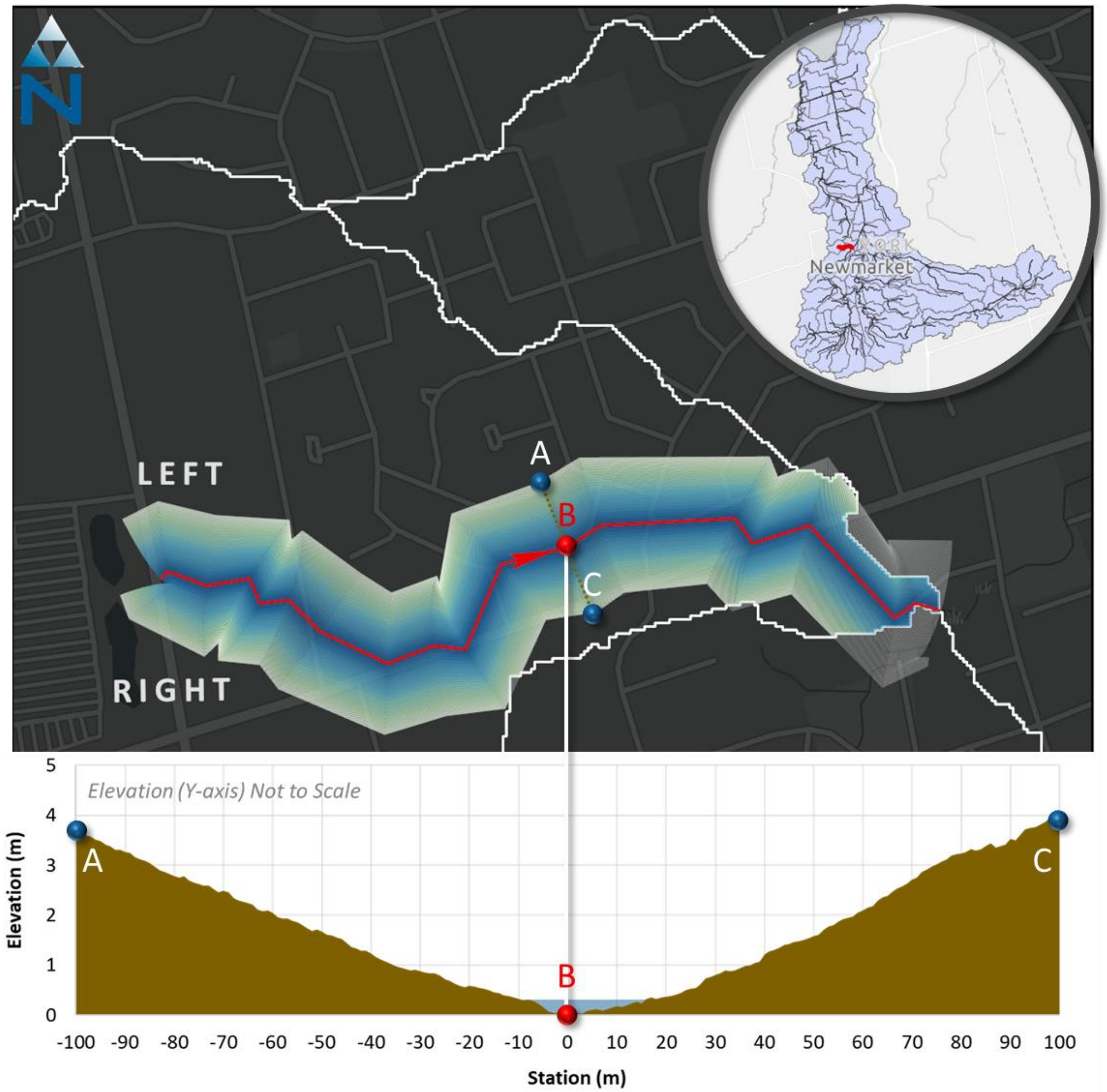


Figure 3-15. Example cross section derived from LiDAR-derived DEM.

3.5 Sediment and Phosphorus

Model representation of sediment builds upon the hydrology calibration and is also considered the primary mode of delivery for phosphorus in the study; therefore, erosion and sediment mobilization are the next steps in the top-down weight of evidence-based approach. Once that primary mode of pollutant delivery has been established, sediment-associated phosphorus is simulated. Throughout the water quality calibration process, intermediate checks, data sources, and references are consulted to ensure that assumptions are reasonable and error propagation is minimized.

Sediment sources and mobilisation processes vary with land cover (pervious/impervious) and soil type. Some sediment is associated with urban runoff, while some originates from rural areas, gullies, and stream channels. When calibrating to mixed instream sediment samples, it is helpful to characterize relative loadings from all sources. The advantage of an HRU-based approach is that it retains much of the resolution of spatial variability for model parameterization at the level of the smallest modelling unit (land unit). This minimizes the need to specify diverse combinations of model parameter groups at the subcatchment level. Sediment calibration was performed in three steps: (1) edge-of-field yield estimation and (2) boundary shear stress calculation within the channels, and (3) instream sediment transport.

Sediment is simulated differently on impervious and pervious surfaces; however, once generated from the land, the bulk edge-of-field sediment is split into sand/silt/clay portions as a function of the typical particle size distribution of the HRU by soil group. Figure 3-16 and Figure 3-17 are process diagrams illustrating sediment simulation processes for impervious and pervious land segments, respectively. The red-text labels within the figures describe the model parameters that influence the associated physical processes being represented.

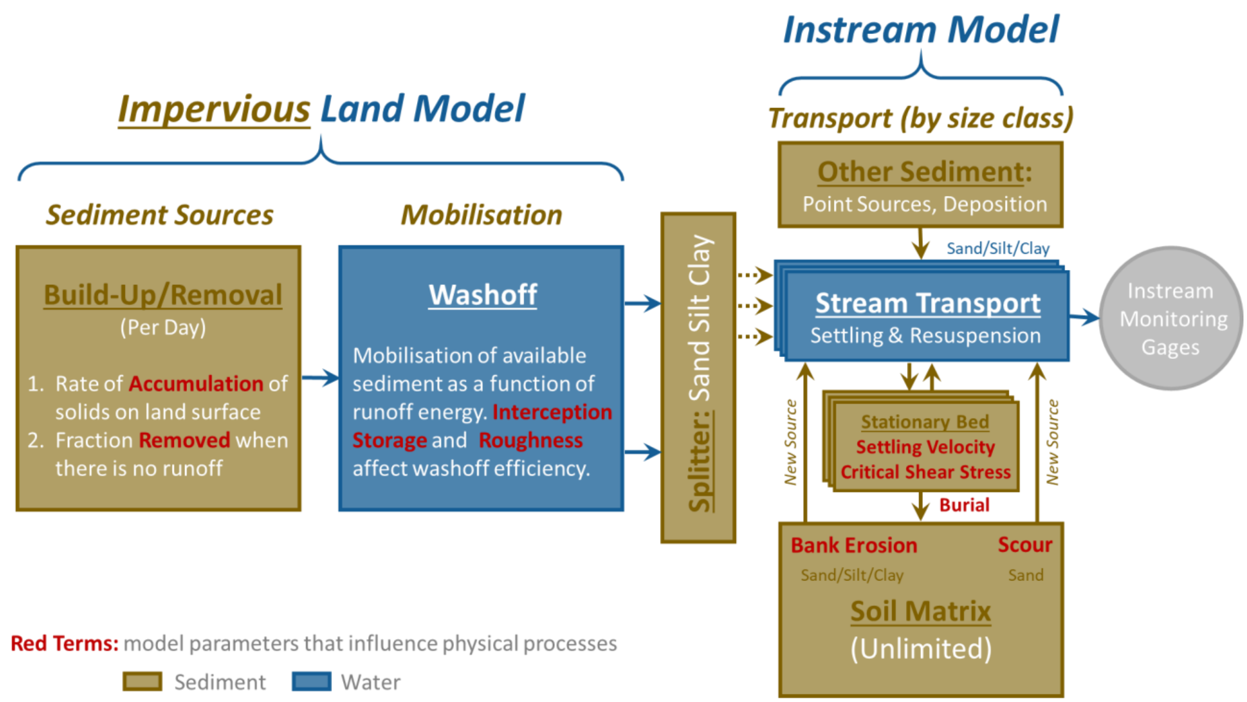


Figure 3-16. Sediment simulation process diagram for impervious surfaces upstream of instream transport.

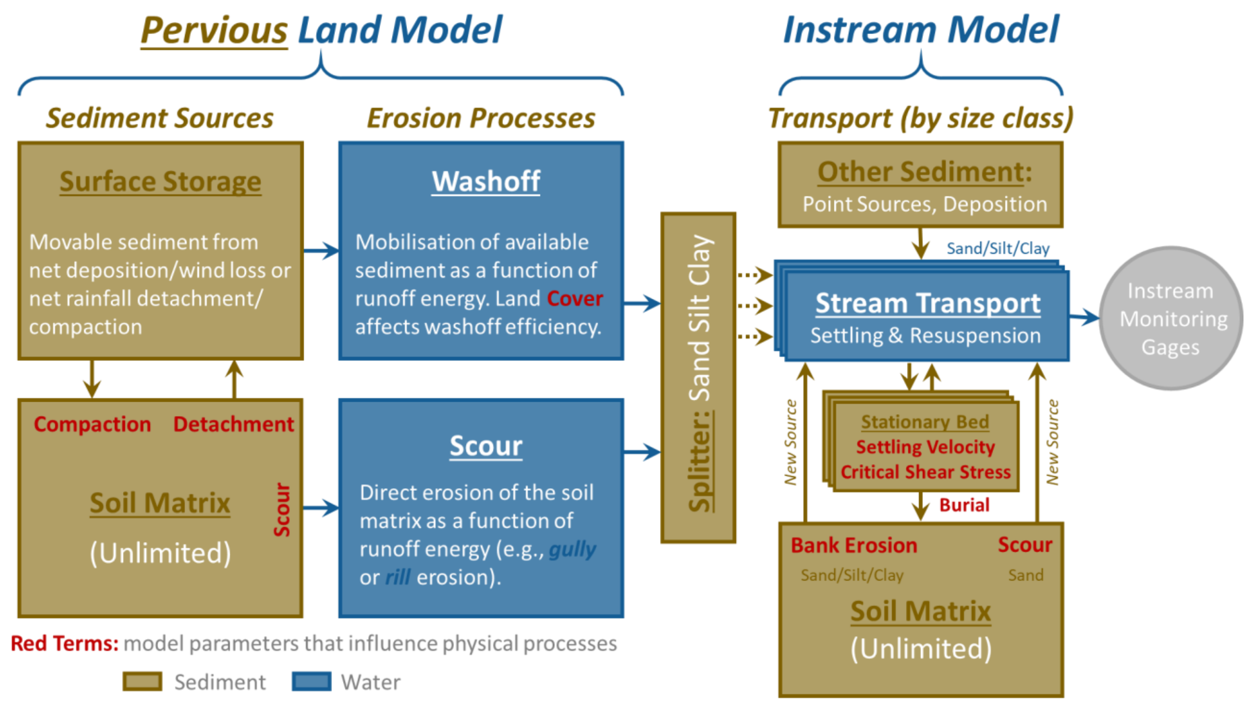


Figure 3-17. Sediment simulation process diagram for pervious surfaces upstream of instream transport.

3.5.1 Boundary Shear Stress

Boundary shear stress, the lateral force that water imposes on the channel cross-section (USEPA 2006), is a simulated hydraulic property of the channel. It is calculated as a function of the modelled streamflow, cross-sectional area (wetted perimeter), and slope of the stream channel. Although it is purely a hydraulic property of the stream channel, LSPC uses it to establish thresholds for sediment settling and resuspension.

As previously noted, sediment generated from the land is partitioned into sand, silt, and clay fractions by HRU before being routed to the stream segments (Figure 3-17). LSPC represents sediment transport processes (i.e., settling and resuspension) as a function of modelled shear stress. Shear stress is a function of stream channel geometry. A surface of channel boundary shear stress magnitude vs. slope and percent of time was generated using modelled cross-sections in the model (Figure 3-18). A total of 92 LiDAR-sampled cross sections and 18 other estimated routing segments were used to generate the surface (110 modelled channels altogether).

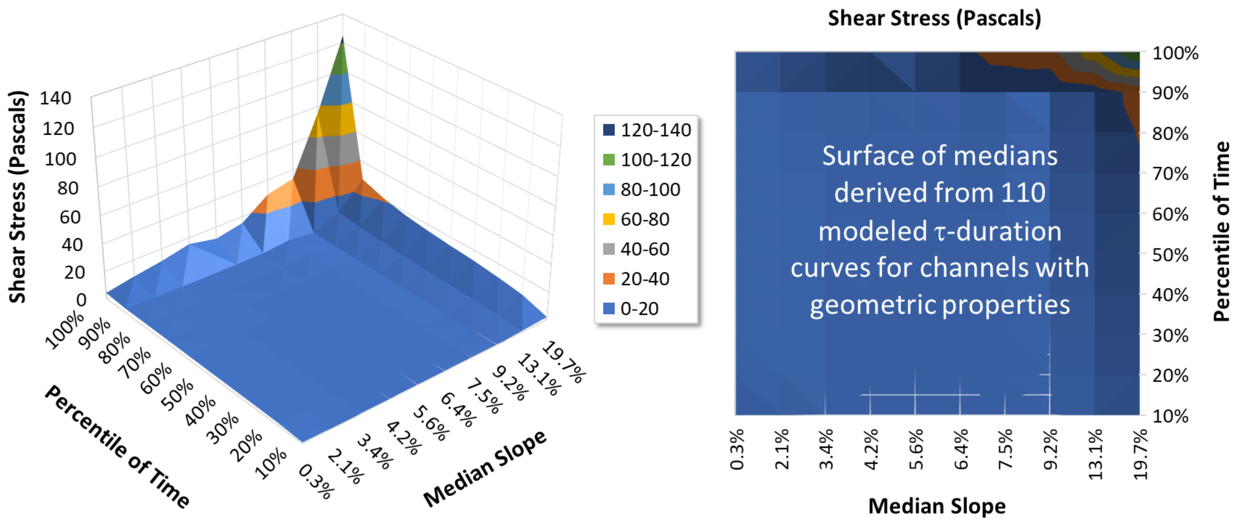


Figure 3-18. Surface of channel boundary shear stress vs. slope and percent of time (all modelled reaches).

For cohesive sediment (silt and clay), critical shear stress was estimated for each reach segment as summarized in Table 3-11. Sand movement is modelled using a user-specified power function of velocity. Both shear stress and velocity are derivative values computed as a function of flow volume and channel geometry. They are expressed as properties of silt and clay particles of median size and shape. Lighter particles are more easily resuspended than heavier particles and tend to remain in suspension longer than heavier particles. Streams with higher slopes and flow rates will tend to resuspend sediment more easily and more often, while streams with lower slopes and lower flow rates will tend to experience more sediment deposition. Figure 3-19 shows the selected critical shear stress values for silt and clay deposition and resuspension vs. median channel slope and percent of time. Figure 3-19 shows the percent of time that silt and clay particles spend in deposition, transport, and resuspension in the East Holland River watershed stream segments, as estimated from critical shear stress values. For pond segments, critical shear stress for deposition and resuspension were not applicable—sediment settled at the user-specified particle settling rate in still water.

Table 3-11. Calibrated critical sheer stress percentiles by sediment class

Sediment Class	Deposition	Resuspension
Sand	Power Function[1]	Power Function[1]
Silt	5 Pa	14 Pa
Clay	1 Pa	9 Pa

1: Sand transport is modelled using a power function on velocity (coefficient and exponent)

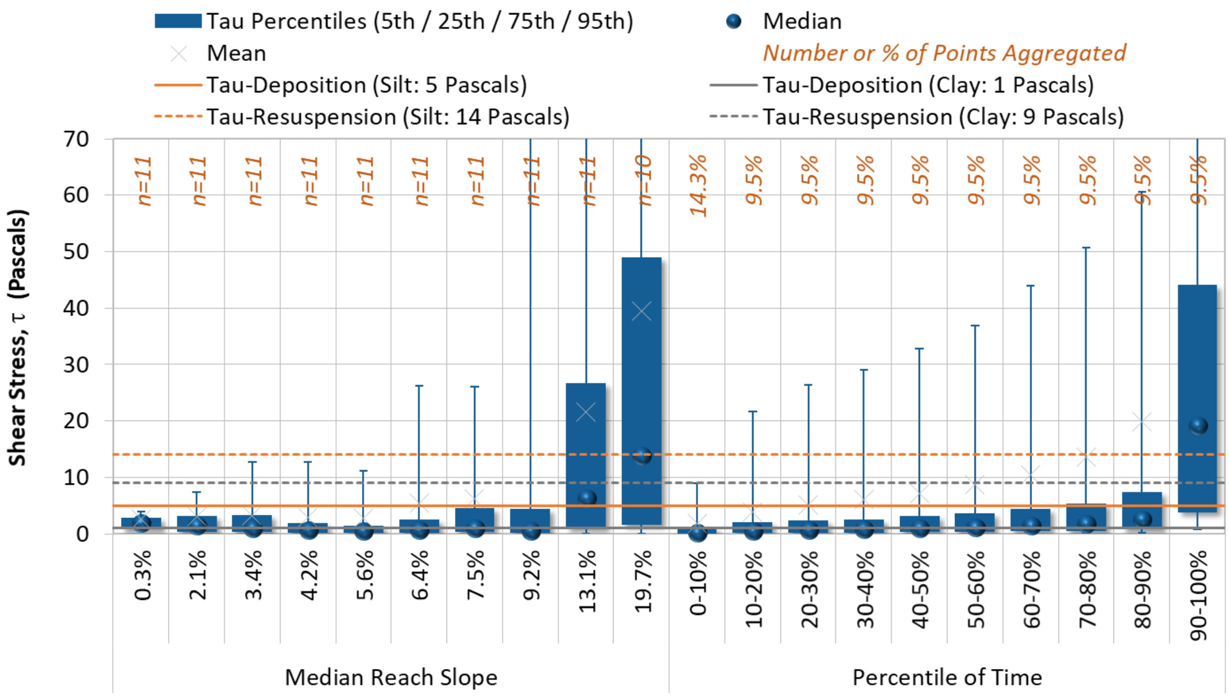


Figure 3-19. Estimated critical shear stress for deposition and resuspension vs. distribution of boundary shear stress by median reach slope and percent of time for all modelled reaches.

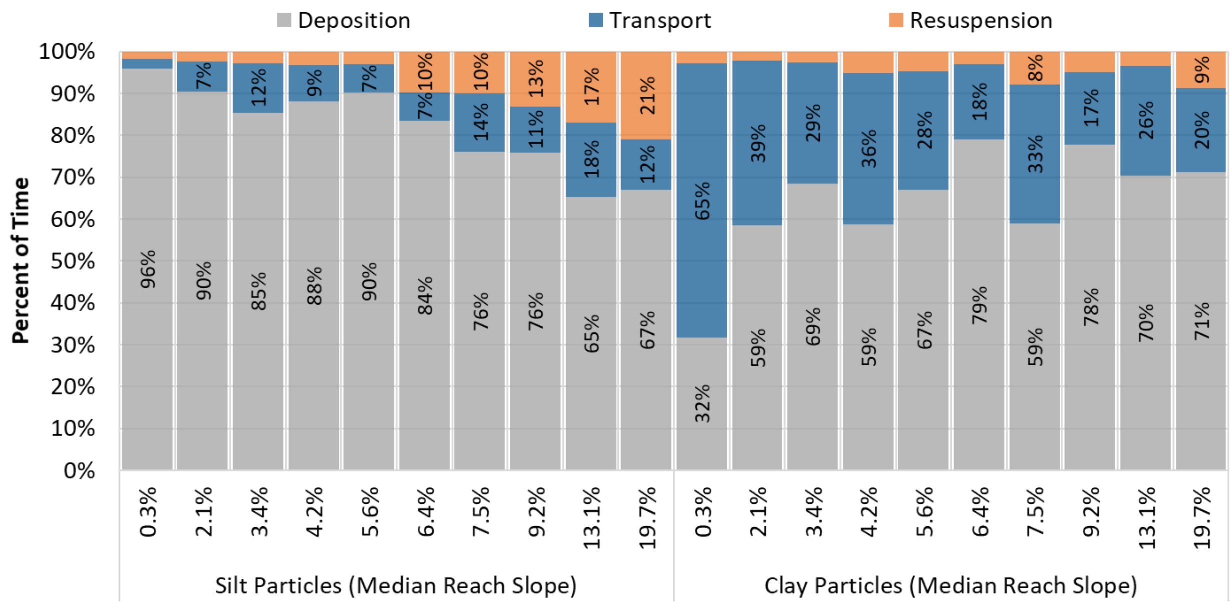


Figure 3-20. Percent of time that silt and clay particles spend in deposition, transport, and resuspension in the East Holland River watershed stream segments, as estimated from critical shear stress values.

3.5.2 Edge-of-Field Sediment and Phosphorus Yield Estimation

One of the key attributes of soil surveys typically reported is the K-factor, which is a measure of soil erodibility (i.e., detachment and runoff of sediment). This along with other factors impacts sediment loading by land use. Evaluations of surficial geology provides a basis for estimating erodibility since literature provides correlations between soil type and erosion potential (LSRCA 2010). Spatially correlated estimates of K-factor vs. HSG were not immediately available in the East Holland River watershed; however, analyses of similar data from experience using soil surveys from the United States (STATSGO/SSURGO) reveal some consistent correlations and trends between K-factor and HSG, which was spatially classified over the whole East Holland River watershed (CANSIS 2018). Clay soils, which are more resistant than sand and silt to detachment, tend to have relatively low K values (0.05 to 0.15). Likewise, coarse-textured sandy soils that are easily detached, but are not easily mobilized by runoff, also have low K values (0.05 to 0.2). Soils with moderate silt and loam content have moderate K values (0.2-0.4) because they are moderately susceptible to both detachment and runoff. Soils with high silt content are the most erodible of all soils (K > 0.4), because they are both easily detached and are associated with high rates of runoff. The analyses and calibration show that D soils were moderately erodible, while C soils were generally more erodible in both areas, suggesting that C soils should be parameterized as slightly more erodible than D soils, even though D soils produce more runoff than C soils. Hydrologic soil group (which also serves as a surrogate for soil erodibility), is estimated based on soil texture, as illustrated in Figure 3-21, shows estimated particle size distribution by hydrologic soil group and for impervious surfaces. As depicted in Figure 3-16 and Figure 3-17, these 'splitter' ratios were used to divide the modelled bulk edge-of-field sediment yield totals into sand/silt/clay portions by HRU for instream transport modelling.

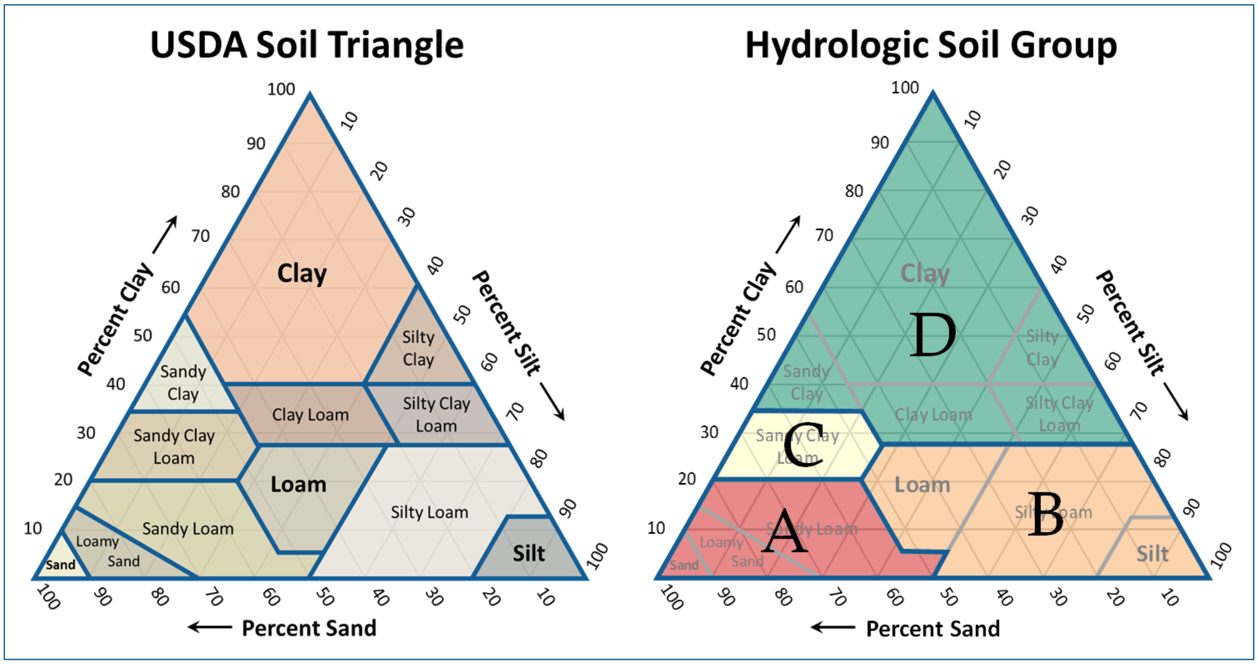


Figure 3-21. Standard USDA Soil Triangle with Hydrologic Soil Group mapping.

Table 3-12. Estimated particle size distribution by hydrologic soil group and for impervious surfaces

Hydrologic Soil Group	Sand	Silt	Clay
A	70%	10%	20%
B	20%	65%	15%
C	50%	20%	30%
D	60%	20%	20%
Impervious Surfaces	10%	70%	20%

3.6 Ponds Representation

Model subcatchment delineations presented in Section 3.2 were established using known stormwatershed and pond drainage areas from Newmarket, East Gwillimbury, and Aurora. A shapefile containing pond footprints, SWM_FACILITY, was used in conjunction with the 5m DEM to generate pond volumes to derive model stage-discharge relationships representing the impoundments. The volumes allow LSPC to simulate the effect of the ponds as impoundments. Volumes were developed for each pond by taking the maximum elevation from the 5m DEM at the pond edge and subtracting the mean elevation in the pond to find the average depth over the pond footprint. The average depth was then multiplied by the pond footprint using the following equation to estimate a storage volume:

$$\text{Estimated Pond Volume} = (\text{Max Elevation} - \text{Mean Elevation}) \times (\text{Pond Footprint})$$

Stage discharge relationships were incorporated for pond-controlled subcatchments within the East Holland River watershed model.

Figure 3-22 presents a schematic comparing LSPC representations of a standard reach and an impounded reach. Figure 3-23 presents a map of the East Holland River watershed depicting these pond-controlled (impounded) subcatchment drainage areas, locations of ponds, and reach segments represented by LiDAR cross sections. Of the 106 modelled stream segments within the model, 92 were derived from LiDAR. The other 14 segments within the network were initially derived from LiDAR sampling; however, the topography or curvature of those segments produced distorted cross-sections that were not suitable for use in the model. For those channels, a representative trapezoidal cross-section was estimated using a coarse regression relationship between the sampled cross-sections and the cumulative upstream drainage area.

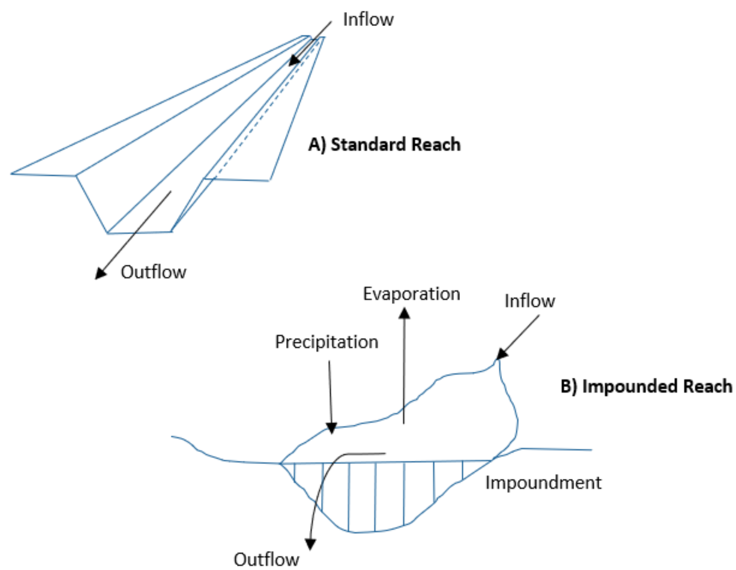


Figure 3-22. Schematic depicting a standard reach (A) and an impounded reach (B).

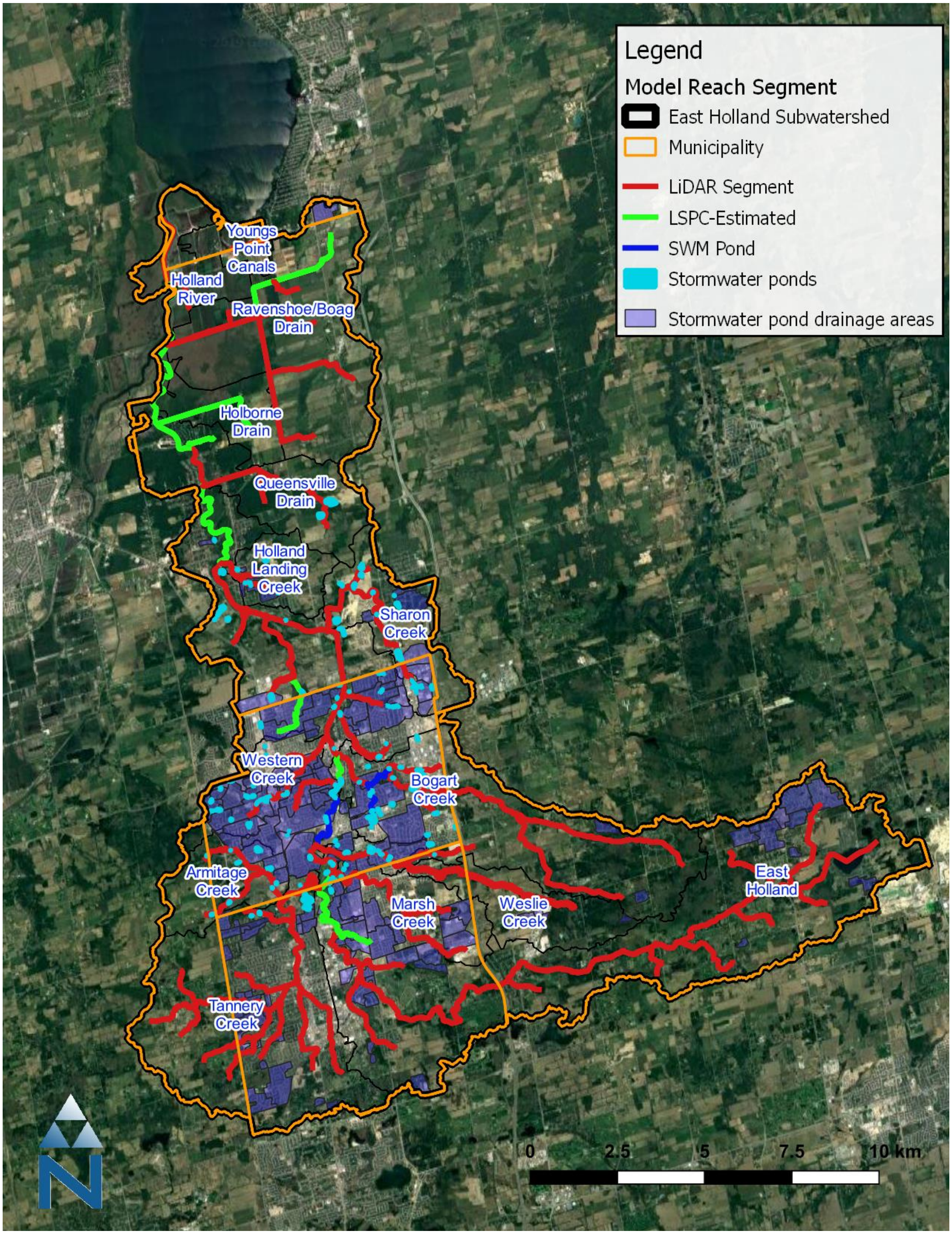


Figure 3-23. Map depicting ponds, pond controlled subcatchments, and reach segment representation for the East Holland River watershed.

3.7 Summary

The many datasets used to configure the LSPC model spanned years of effort by numerous programs by LSRCA and other organizations. The level of data quality for the East Holland River is generally considered quite high, and the level of resolution provided by the LSPC configuration is one of the highest developed to date by Paradigm for an LSPC model. A few notes on the configuration datasets are provided below:

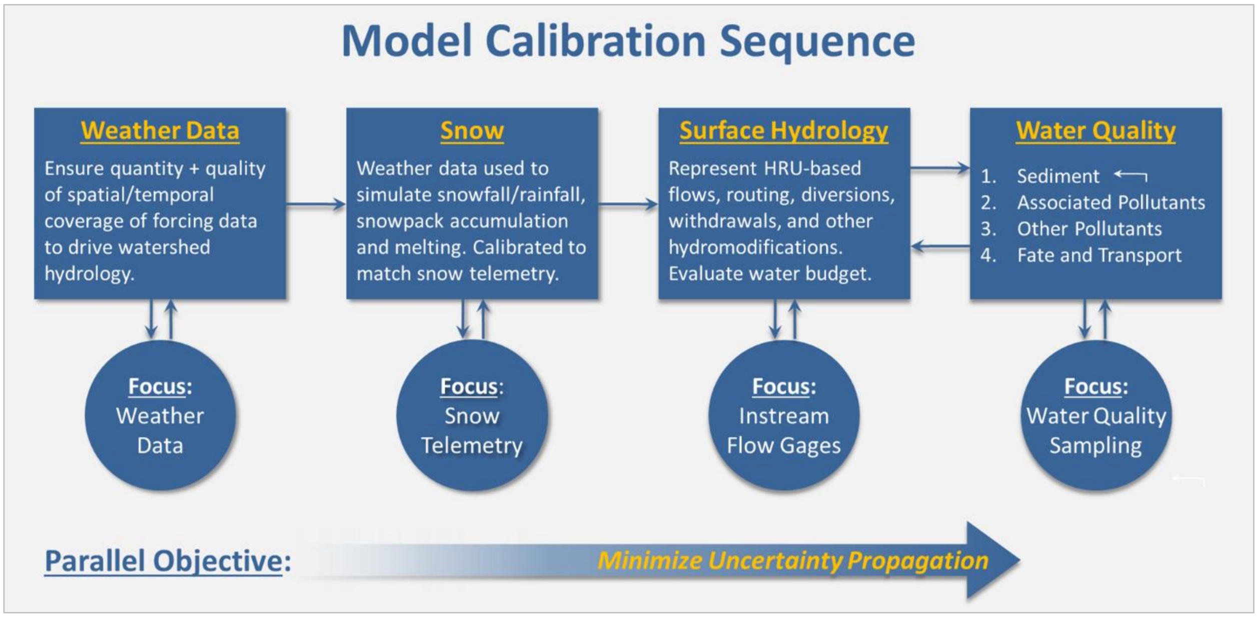
- Data about septic tanks and their condition could impact phosphorous loading estimates. There was very detailed information on the location of septic tanks, but estimates regarding their condition were not available, which led to the decision to not include septic tanks in the model configuration. Lack of information on septic condition is very common across watersheds where Paradigm has developed LSPC models.
- The pond data were challenging to compile and assemble. The resulting subcatchments are very high resolution. However, it is unclear whether all major ponds are represented as the layers received for pond footprints did not always align with subcatchment outlets from pond controlled subcatchments. Also, the quality of information on existing pond storage volume was relatively poor, which led to development of the LiDAR based approach. Over time, it is expected the pond inventory data will be improved and the LSPC configuration could be re-visited in the future. The level of information available on ponds for East Holland River was higher than any watershed that Paradigm has modelled with LSPC, and the level of resolution that ponds are represented in this LSPC model are higher than any other to date.
- Groundwater hydrology in the area is highly complex Existing groundwater modelling results in the Oak Ridges Moraine suggested the presence of losing streams. These streams were represented in LSPC by applying an hourly stream loss to model reaches in the area. This approach resulted in improved agreement between observed and predicted flows. While LSPC does allow for losses from one stream to become gains in another, this feature was not used in the present model. Additionally, the final rate of 1.72 mm/hr. was higher than what the groundwater modelling for the area would suggest. The differences are likely due to the limitations of the approach. The GSFLO and LSPC models were developed at different spatial and temporal scales. GSFLO used fixed 200x200 m cells while LSPC used much larger, variably sized subwatersheds. Additionally, LSPC was run at an hourly timestep while the output for GSFLO was daily or annual.

With the configured model, the LPSC calibration effort was initiated, as presented in the next section.

4 MODEL CALIBRATION

The East Holland River watershed modelling approach builds upon local data sources, research efforts, and follows internationally recognized modelling protocols and conventions. For example, the 2002 EPA guidance document on developing Quality Assurance Project Plans (QAPP) (USEPA 2002) for modelling refers to calibration as the configuration and refinement of the analytical instruments that will be used to generate analytical data to support the decision-making process. The "instrument" is the predictive tool (i.e., the model) that is to be developed and/or applied. Figure 4-1 has a generalized schematic describing the process for model calibration that aims to minimize the propagation of uncertainty, along with a summary of the modelled date ranges by data source (based on data availability and/or data quality). Figure 4-2 show the location of weather/snow telemetry gages. Figure 4-3 shows observed streamflow and water quality sampling locations.

Demonstrating model calibration is key to the model development process, as it forms the basis for establishing the degree of confidence and uncertainty in model predictions and the reliability of the model for making management decisions. Models are deemed acceptable when they can simulate field data within a reasonable range of statistical measures, as described in Section 4.4. After weather data and meteorological boundary conditions are well established, a top-down weight of evidence 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 co-located flow data. Figure 4-4 is a schematic showing the parameterization and calibration sequence for land hydrology and stream transport. Unit-area results from this step were summarized and compared relative to each other and against representative published literature values. This step provides an early opportunity to identify possible errors, anomalies, or other unrepresentative behavior prior to aggregation, instream routing, and transport. Next, outputs from land hydrology are aggregated and routed to the stream transport model. In some cases, other features such as SWM ponds, diversions, withdrawals, and point sources influence the water balance.



Data Sources	Station Name	Station ID	Modelled Date Range
Weather Data	Interpolated Rainfall + Newmarket Office	*Customized*	3/1/1999 – 9/30/2018
	Toronto Buttonsville Airport	615HMAK	1/1/1999 – 9/30/2018
Snow Telemetry	Sheppards Bush – Site 4, Aurora	4	10/1/2003 – 4/30/2018
Instream Flow Gages	Western Creek	LS0201	10/1/2015 – 9/30/2018
	Tannery Creek	LS0102	10/1/2003 – 9/30/2011
	East Holland River, East Holland Landing	02EC009	10/1/2003 – 9/30/2018
	East Holland River, Vandorf		10/1/2009 – 9/30/2011
Water Quality Sampling	Western Creek	LS0201	4/1/2015 – 12/31/2017
	Tannery Creek	3007700702	4/1/2008 – 12/31/2017
	East Holland River, East Holland Landing	02EC009	4/1/2008 – 12/31/2017

Figure 4-1. Data sources and calibration sequence to minimize propagation of error and uncertainty.

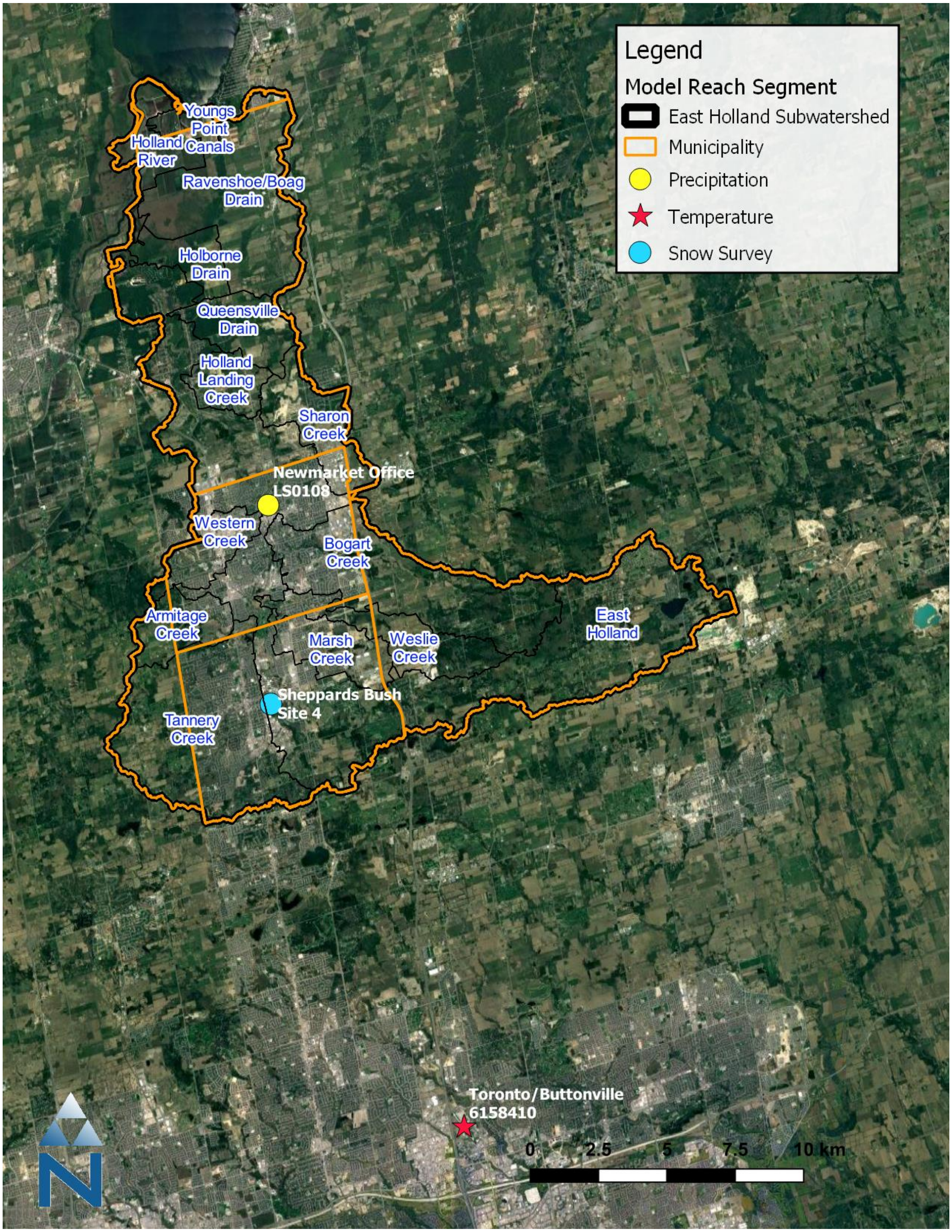


Figure 4-2. Climate data gages and snow telemetry sites used for model calibration.

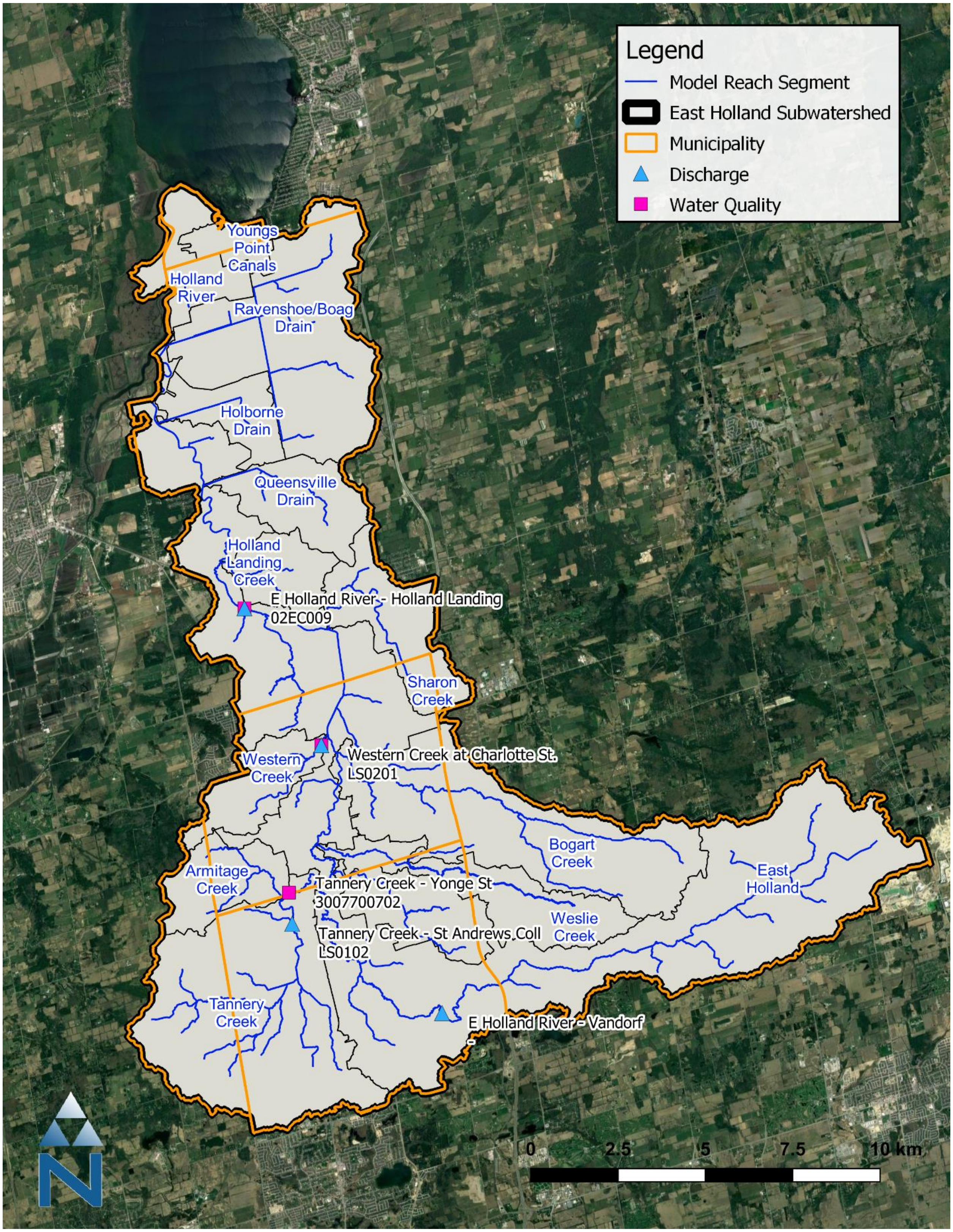


Figure 4-3. Observed streamflow and water quality sampling gages for model calibration.

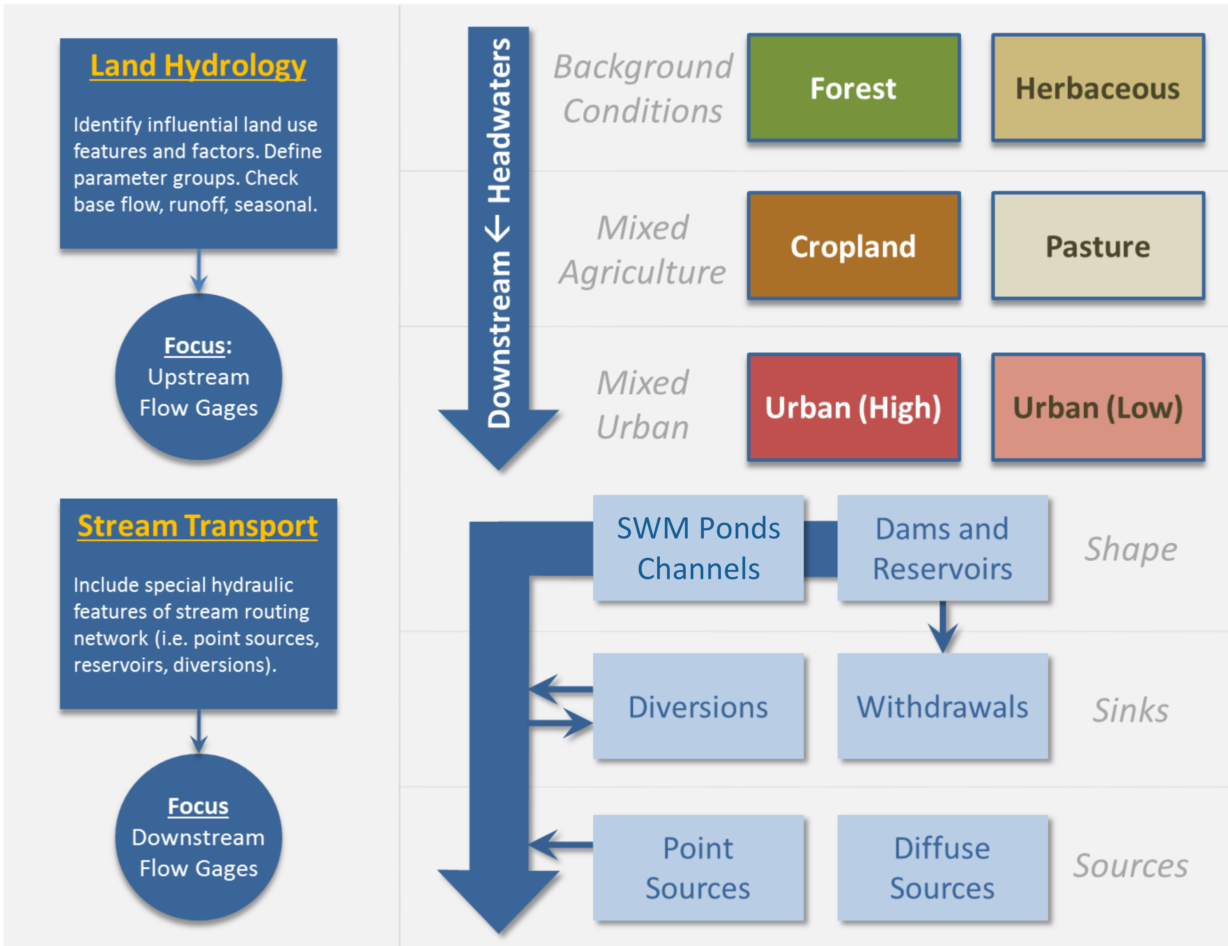


Figure 4-4. Model parameterization and calibration sequence for land hydrology and stream transport.

4.1 Hydrological–Trends Analysis

Before model calibration began, the observed sediment and phosphorus data at the three water quality calibration stations were paired with representative streamflow and rainfall data and sorted into seasonal, wet- and dry-weather, and antecedent moisture conditions to tease out predominant hydrological trends from the data. An objective of the model development effort is to parameterize the model in such a way as to replicate the trends inherent in the observed data, relative to hydrological conditions (i.e., wet and dry streamflow conditions and rainfall magnitude)—such a model is more representative of watershed conditions, and will ultimately be more sensitive to changes in management that are hydrologically based. Table 4-1 is an index of the hydrological-trends analysis evaluation panels.

Table 4-1. Index of hydrological-trends analysis evaluation panels

Pollutant	Figure Number	Assessment Location
Residual Particles (i.e., sediment)	Figure 4-5	East Holland River – Holland Landing
	Appendix A	Tannery Creek – Yonge St
	Appendix A	Western Creek
Total Phosphorus	Figure 4-6	East Holland River – Holland Landing
	Appendix A	Tannery Creek – Yonge St
	Appendix A	Western Creek

Each of the evaluation panels has six graphs that highlight variability in median observed concentration for the following conditions:

1. Upper Left (Annual Trends): Changes over time
2. Upper Right (Monthly Trends): Seasonal variability over all the years
3. Middle Left (Rainfall Depth): Variability with increasing rainfall depth
4. Middle Right (Streamflow): Variability with increasing streamflow
5. Lower Left (Wet Weather by Antecedent Dry Days): Assessment of first-flush levels
6. Lower Right (Dry Weather by Dry Days): Variability by number of dry days

Hydrological-trends analysis provides context and justification for model parameterization. The analysis illustrates how hydrology drives sediment and how sediment drives phosphorus. Below is a summary of the trends observed and recommendations for model parameterization:

- Both sediment and phosphorus exhibit similar seasonal, wet-weather, and dry-weather trends, confirming an association between sediment and phosphorus. Sediment will be modelled as sediment associated.
- During dry weather conditions, the East Holland River gage has higher median sediment and total phosphorus concentrations than Western Creek and Tannery Creek, suggesting that the land use distribution, point source discharges, or changes in groundwater may be contributing to those elevated dry weather concentrations. Additionally, instream processes may impact concentrations during periods in which stream flows are low and organic loading is high.
- There is a strong first-flush signature in both sediment and total phosphorus at all gages. The highest median concentrations occur for samples taken with 7-14 antecedent dry days. This trend is most pronounced at the Western Creek gage, which has the highest developed HRU drainage area distribution. This suggests that a build-up/washoff approach is a reasonable and representative process for simulating sediment and phosphorus from urban sources.
- Both sediment and phosphorus exhibit a non-linear increase in median concentration with increasing streamflow, suggesting that sediment scour is a process at play from pervious HRU sources
- Conversely, median sediment concentrations generally show a steady decline over time with increasing number of dry days. This confirms a wet-weather signature in both sediment and phosphorus loading trends.

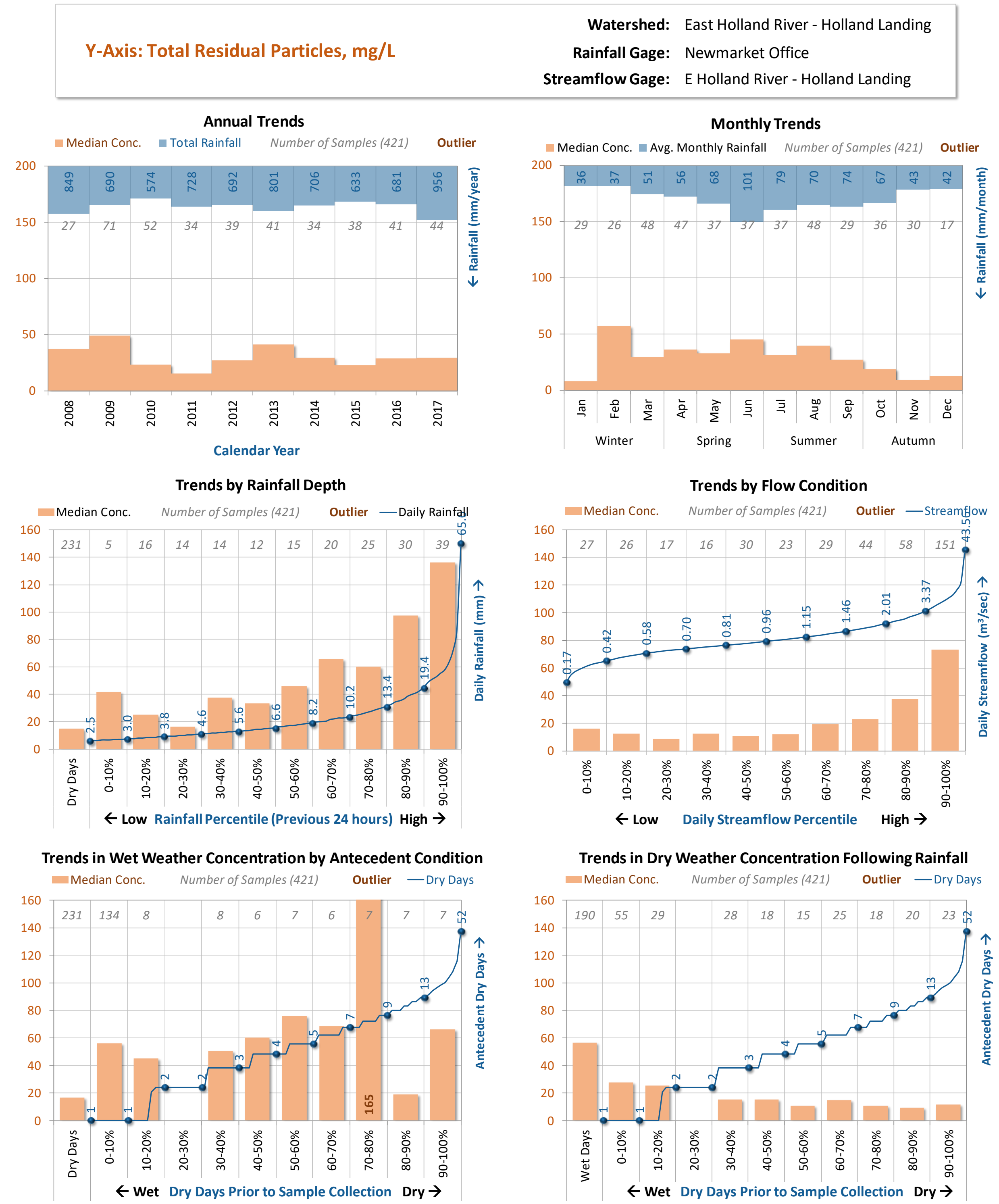


Figure 4-5. Hydrological Trends Analysis for East Holland River – Holland Landing: Total Residual Particles (sediment), mg/L.

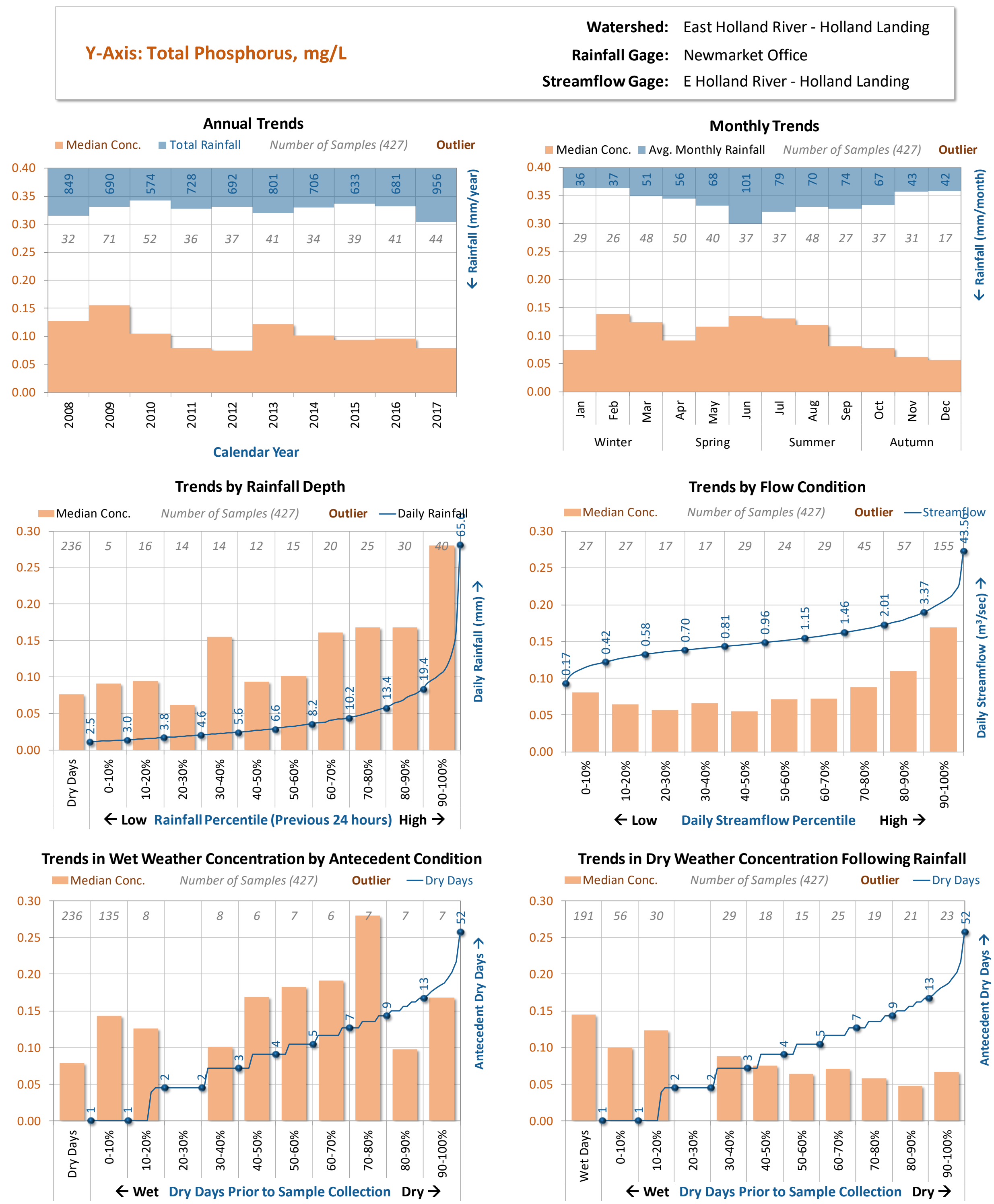


Figure 4-6. Hydrological Trends Analysis for East Holland River – Holland Landing: Total Phosphorus, mg/L.

4.2 Additional Data to Augment Calibration

In addition to long-term monitoring observations at the 3 calibration gages, two excel spreadsheets containing observed phosphorus concentrations from stormwater and groundwater sampling efforts in Holland Landing were received and utilized during model calibration.

4.2.1 Pollutograph Sampling at Holland Landing

LSRCA provided a high-resolution phosphorus monitoring dataset from Holland Landing in East Holland River, with 921 samples collected between 3/5/2011 and 5/31/2012. Figure 4-7 presents the time series of phosphorous concentration and loading at East Holland during the period based on the intensive sampling, which included 'pollutograph' monitoring where multiple samples are collected over discrete storm events. These data were used to investigate the LSPC simulation of phosphorous concentrations intra-storm event, across the rising and receding limbs of the hydrographs. The data were also used to calculate annual loading rates, as described in Section 4.6.3.

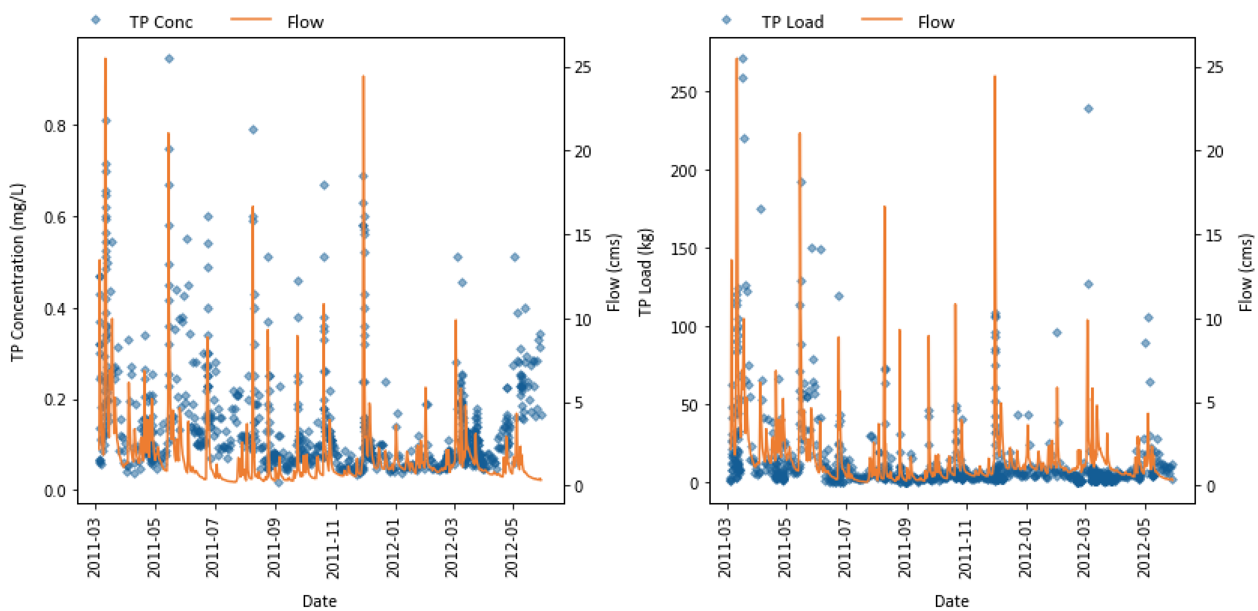


Figure 4-7. Time series of total phosphorous concentration (left) and loading rate (right) at East Holland River between 3/5/2011 and 5/31/2012.

4.2.2 Groundwater Sampling in East Holland Watershed

LSRCA provided a groundwater dataset contains 28 samples (20 for Total Phosphorus and 8 for Dissolved Phosphorus) collected between 8/5/2004 and 10/25/2018 as shown in Figure 4-8. The LSPC model for the East Holland watershed generates phosphorus loading as a function of sediment erosion and washoff; however, a background concentration is also used to represent periods when flow is baseflow-dominated. Observed groundwater phosphorus levels, along with dry-weather instream concentrations, were used to establish representative background concentrations during dry weather. Roy and Malenica (2013) found widespread occurrence of elevated (>0.1 mg/L) groundwater phosphorus concentrations near Lake Simcoe's Kempenfelt Bay, which provides some justification for spatial variation in the model. Based on the provided groundwater data and literature, LSPC TP groundwater concentrations were set to range from 0.005 mg/l in natural heritage areas to

0.1 mg/l in high intensity agricultural areas (since agriculture is a dominant land use in the vicinity of where observed groundwater concentrations were approximately 0.1 mg/l).

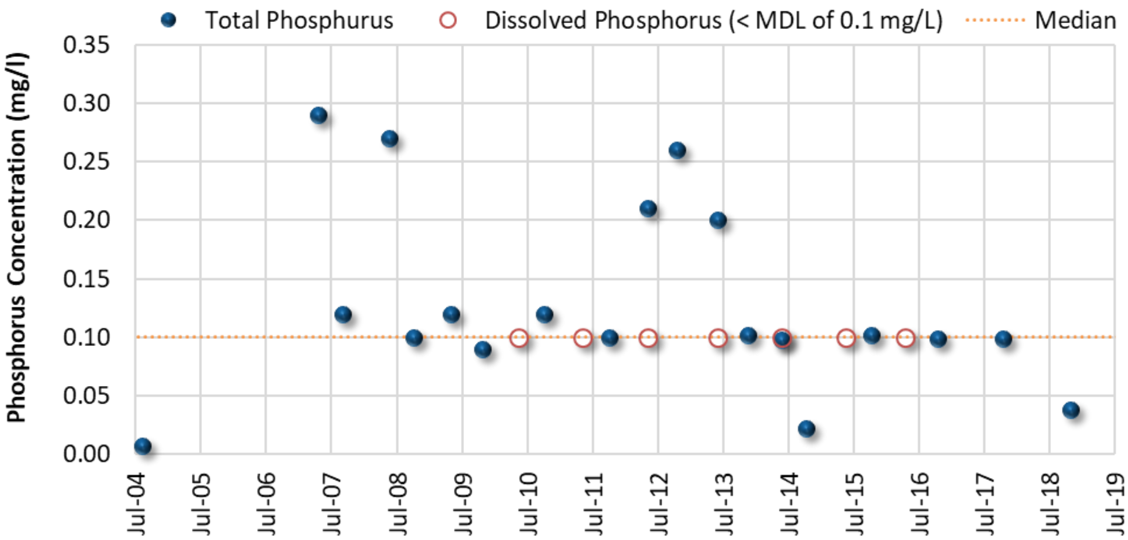


Figure 4-8. Phosphorus concentrations in groundwater sampled near Holland Landing.

4.3 Snow Calibration

Snowfall and snowmelt are important components of the water budget in the East Holland River watershed. Snowpack accumulation impacts hydrology and water quality by acting as a reservoir that stores precipitation that arrives as snowfall and releases it as a surface inflow when it melts. Snowfall and snowpack are not set in LSPC as a boundary condition; instead LSPC uses an energy balance method to simulate snowfall (Bicknell et al. 1997; Tetra Tech 2017). The energy balance uses air temperature to determine when precipitation arrives as snowfall, and solar radiation, dewpoint temperature, and wind speed to determine when the snowpack melts. Heat is transferred into or out of the snowpack through net radiation heat, convection of sensible heat from the air, latent heat transfer by moist air condensation on the snowpack, rain, and conduction from the ground beneath the snowpack. Melting occurs when the liquid portion of the snowpack exceeds the snowpack's holding capacity. The melted snow returns to the system as a lateral inflow to the associated land segment. The fate of that water depends on surface conditions and soil moisture content.

Observed snow data for model calibration were available at the Sheppards snowpack monitoring station in Aurora, Ontario. The Sheppards gage is within the East Holland River watershed, as previously shown in Figure 4-2. Data collected between 2003 and 2018 spanning several winter cycles with varying amounts of snowfall were used for model calibration. Within those 15 years, water year 2012 had the least amount of snowfall, while water year 2014 had the most. The LSPC model calibrated very well for snowfall using disaggregated daily precipitation from E-Flows "interpolated" dataset and other atmospheric weather data from the Environment Canada gage at Toronto Buttonville. This further validated the robustness of those data products in capturing a representative volume of precipitation for the East Holland River watershed. Figure 4-9 is a plot of modelled vs. observed snowpack for the 15-year period between water years 2004 and 2018. Visual assessment of the continuous modelled vs. grab-sample observed snowpack depths shows strong agreement in temporal variation. The model consistently predicted the relative magnitude and duration of snowpack across the wide range of snow conditions over the 15-year period. Figure 4-10 is an aggregated-annualized rollup over the 15-year calibration period, with computed statistics comparing the central tendency of snowpack and volume over that period. The data were resampled in this way to calculate statistics for assessing model performance because the observed snowpack measurements were grab samples. On average, the percent difference between modelled and observed snowpack is less than 4 percent. The percent difference between modelled and observed peak snowpack is less than 12 percent.

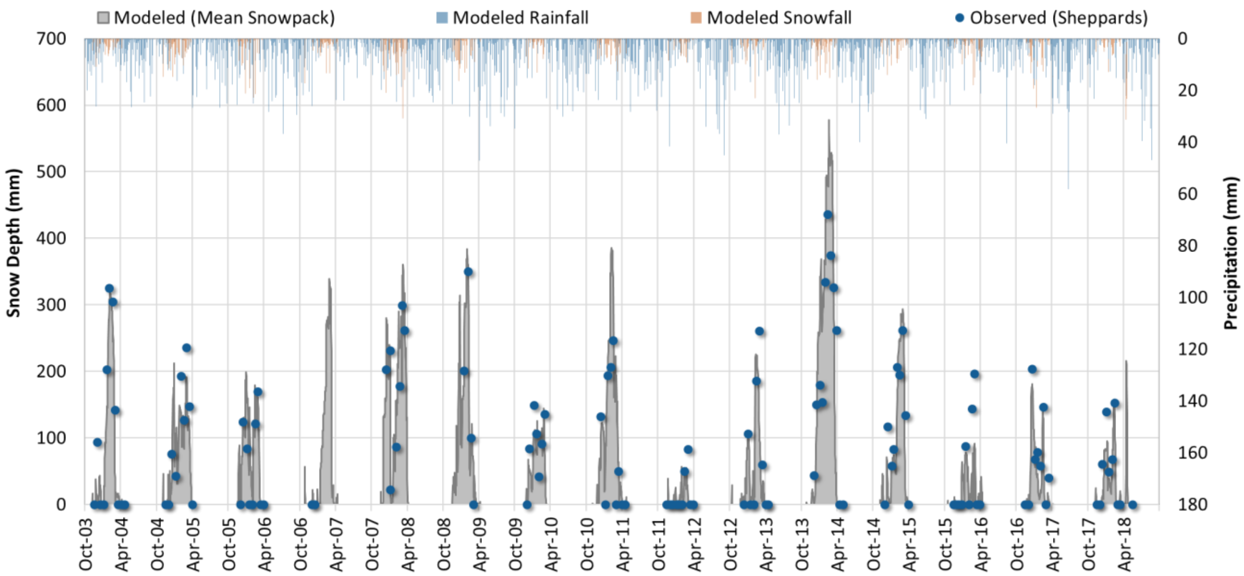


Figure 4-9. Modelled vs. observed daily snowpack depth at Sheppards, Aurora (2004-2018).

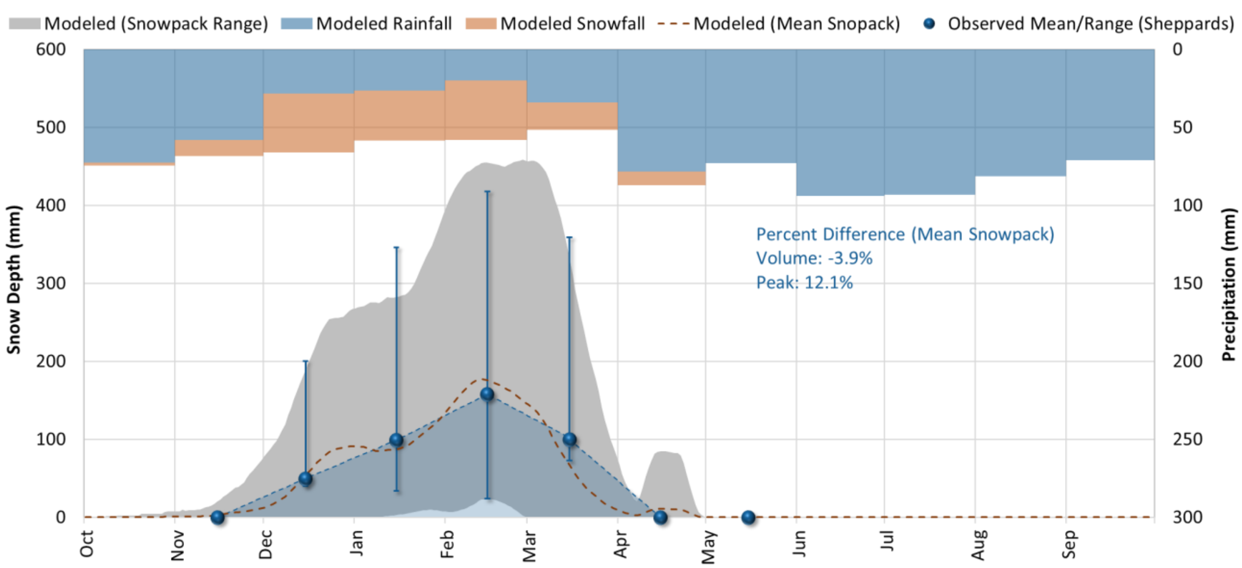


Figure 4-10. Aggregated-annualized observed vs. modelled snowpack depth at Sheppards, Aurora (2004-2018).

The SNOW module uses the observed air temperature to determine when precipitation falls as snowfall vs. rainfall. An optimized value of -0.55 Degrees C was used as the threshold that triggers snowfall in the model. Figure 4-11 is a plot of observed air temperature vs. modelled rainfall/snowfall distribution over the 15-year calibration period. Figure 4-12 is an aggregated version of the same information presented as an annualized summary. It shows that on average, the season for snowfall begins in early to mid-October and lasts through April. The peak periods for snowfall (relative to rainfall) are in mid-December and early to mid-February. The months of December through February see a mix of snowfall and rain-on-snow events that influence snowpack depths over the landscape.

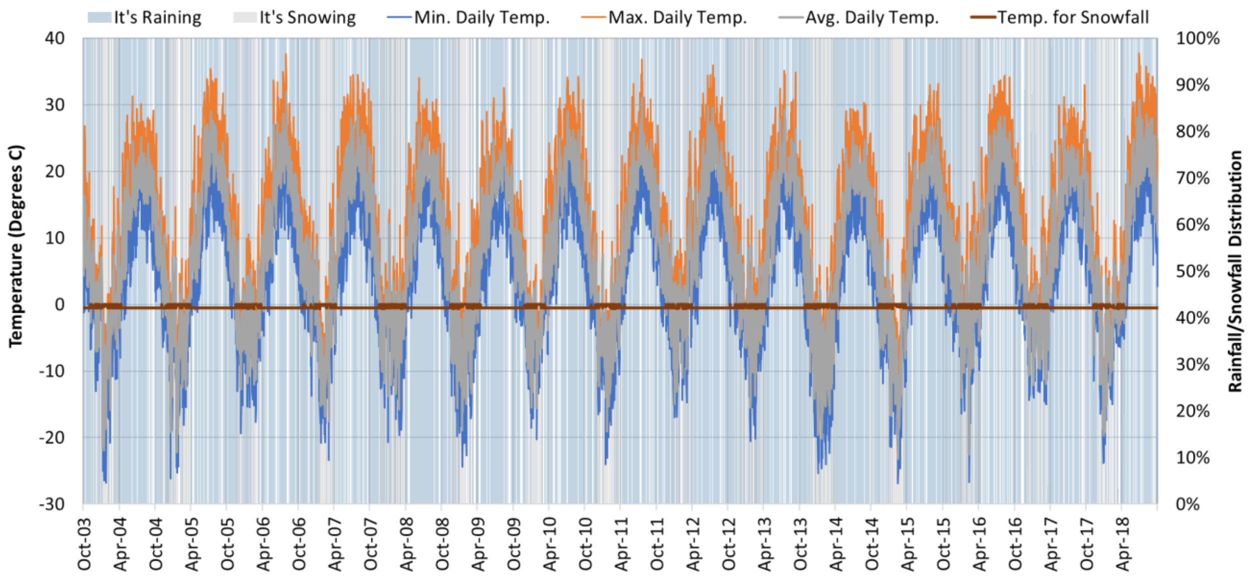


Figure 4-11. Observed daily temperature at Buttonville vs. modelled rainfall/snowfall at Sheppards, Aurora.

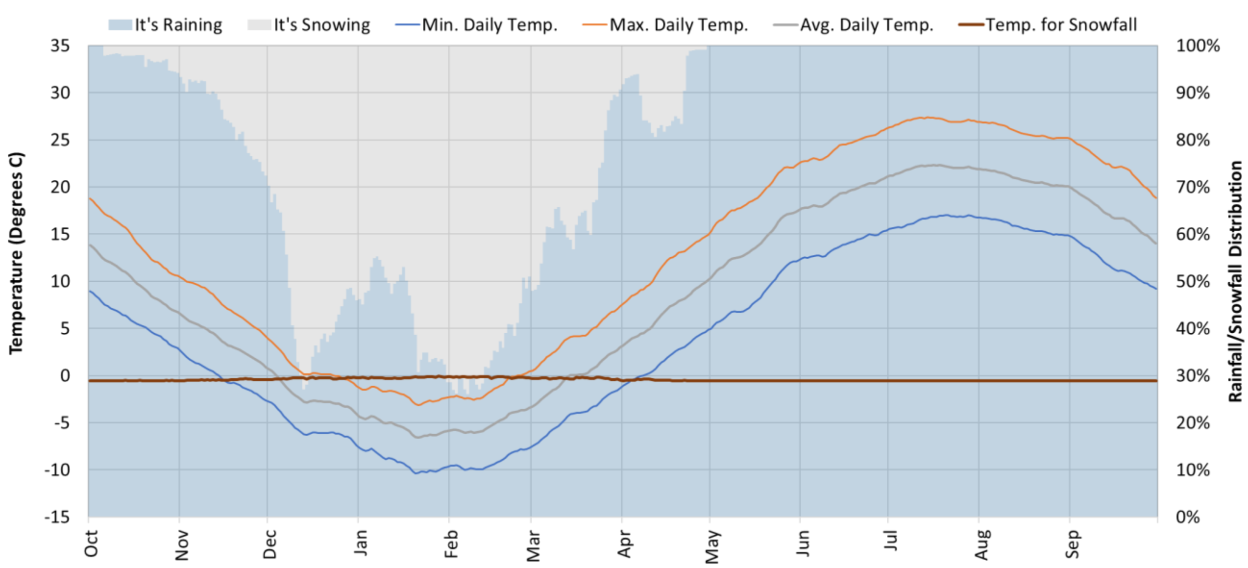


Figure 4-12. Aggregated-annualized temperature variation vs. modelled rainfall/snowfall at Sheppards, Aurora (2004-2018).

4.4 Metrics for Model Evaluation

Calibration was assessed using a combination of visual assessments and computed statistical evaluation metrics. Visual assessment involved reviewing panels of simulated vs observed graphical outputs, which are presented in the following sections, and review of the simulated conditions during the pollutograph sampling period (2011-2012) at Holland Landing. For statistical assessment of model performance, agreement between LPSC outputs and observed data was assessed using performance metrics based on those recommended by Moriasi et al. (2015). These performance metrics are considered highly conservative, and it is very rare to receive "Very Good" evaluations across all metrics – "Satisfactory" is a significant outcome. The metrics are used as a weight of evidence approach to evaluate whether model performance is reasonable.

The performance metrics are based on three statistics, the percent bias (PBIAS), the coefficient of determination (R^2), and the Nash-Sutcliffe model efficiency (NSE) as follows:

- PBIAS quantifies systematic overprediction or underprediction of observations. A bias towards underestimation is reflected in positive values of PBIAS while a bias towards overestimation is reflected in negative values. Low magnitude values of PBIAS indicate better fit, with a value of 0 being optimal.
- The coefficient of determination (R^2) describes the degree of collinearity between simulated and measured data. The correlation coefficient is an index that is used to investigate the degree of linear relationship between observed and simulated data. R^2 describes the proportion of the variance in observed data that is explained by a model. Values for R^2 range from 0 to 1, with 1 indicating a perfect fit. Values greater than 0.70 indicate acceptable model performance (Donigian 2000). The R^2 metric was calculated and presented within graphical 1-to-1 evaluation panels.
- The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information"; Nash and Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. Values for NSE can range between $-\infty$ and 1, with NSE = 1 indicating a perfect fit.

For each metric, the resulting value was compared to performance thresholds, which differ for hydrology and water quality (see Figure 4-13 and Figure 4-14). The Moriasi et al. (2015) thresholds for nutrients were applied to sediment as well to simplify the analysis and reporting (metrics for the two pollutants are very similar). The performance thresholds established by Moriasi et al. (2015) were modified based on performance criteria established by Donigian (2000) to account for targeted 'bins' of conditions based on season and flow rate. Moriasi et al. (2015) only provided metrics for evaluation of all conditions across the model time series. Donigian (2000) included metrics for model predictions within flow regimes, such as the highest 10% of flows and baseflow. The thresholds by Donigian (2000) essentially shifted the categories one column to the left, so that the threshold within a smaller bin for Very Good was the same as Good when considering all the data within a single pool. This approach was applied to the Moriasi et al. 2015 to maintain reasonable performance metrics within the smaller bins of flow regime and season. Moriasi et al. (2015) anticipated adjustments to their thresholds: "these [thresholds] can be adjusted within acceptable bounds based on additional considerations, such as quality and quantity of available measured data, spatial and temporal scales, and project scope and magnitude, and updated based on the framework presented herein."

Performance Metric	Hydrologic Condition	Comparison Type	Performance Thresholds for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
R-squared (R^2)	All Flows	Compare All Observed vs Simulated Daily Flow Rates that Occur During Selected Season-Condition	> 0.85	0.75 - 0.85	0.60 - 0.75	≤ 0.60	Based on Moriasi et al. (2015)
	Seasonal Flows		> 0.75	0.60 - 0.75	0.60 - 0.50	≤ 0.50	
	Highest 10% of Flows						
	Lowest 50% of Flows						
	Storm Flows						
	Baseflows						
Nash-Sutcliffe Efficiency (E)	All Flows		> 0.80	0.70 - 0.80	0.50 - 0.70	≤ 0.50	
	Seasonal Flows		> 0.70	0.50 - 0.70	0.40 - 0.50	≤ 0.40	
	Highest 10% of Flows						
	Lowest 50% of Flows						
	Storm Flows						
	Baseflows						
Percent bias (PBIAS, %)	All Flows		+/- 5	5 - 10	10 - 15	> 15	
	Seasonal Flows		> 10	10 - 15	15 - 25	> 25	
	Highest 10% of Flows						
	Lowest 50% of Flows						
	Storm Flows						
	Baseflows						

Figure 4-13. Summary of performance metrics used to evaluate model hydrology calibration.

	Condition	Performance Thresholds for WQ Simulation			
		Very Good	Good	Satisfactory	Unsatisfactory
R-squared	All Conditions (Combined)	>0.7	0.60 - 0.70	0.30 - 0.60	<0.30
	Seasonal and High/Low Flows	>0.60	0.30 - 0.60	0.20 - 0.30	<0.20
Nash-Sutcliffe Efficiency (E)	All Conditions (Combined)	>0.65	0.50 - 0.65	0.35 - 0.50	<0.35
	Seasonal and High/Low Flows	>0.50	0.35 - 0.50	0.25 - 0.35	<0.25
Percent Bias (PBIAS, %)	All Conditions (Combined)	<15	15 - 20	20 - 30	>30
	Seasonal and High/Low Flows	<20	20 - 30	30 - 40	>40

Based on Moriasi et al. (2015), Hydrologic and Water Quality Models: Performance Measures and Evaluation Criteria. Transactions in American Society of Agricultural and Biological Engineers, Volume 58(6): 1763 - 1785.

Figure 4-14. Summary of performance metrics used to evaluate model water quality calibration.

4.5 Hydrology

A phased weight-of-evidence approach was used for hydrology calibration. An initial set of HRU model parameters were derived and stratified by HRU with guidance from the BASINS Technical Note 6: *Estimating Hydrology and Hydraulic Runoff Parameters* (USEPA 2000). The goal was to characterize the relative hydrological response of the various HRU combinations of land cover, soil type, and slope such that the routed aggregate response of the model was representative of observed trends at the flow monitoring gages. The model was then refined to represent SWM ponds and their drainage areas, plus groundwater seepage based on the groundwater model results. After representing all the physical characteristics of the watershed, model parameters were fine-tuned so that the calculated error statistics fell within the targeted model performance ranges.

Observed data from four gages were used for model calibration. Model calibration locations included the gages at Western Creek, Tannery Creek, East Holland River at Vandorf, and the East Holland River at Holland Landing. Additionally, data summaries and water balance results from the E-flows study (LSRCA 2018a) were used to benchmark the model calibration in the upstream Oak Ridges Moraine portion of the watershed. As summarized in Figure 4-15, some of the observed streamflow data were flagged as impaired or estimated. Model calibration focused on periods with observed data that were minimally flagged. The model was calibrated at the three upstream gages (Western Creek, Tannery Creek, East Holland River at Vandorf) and validated at the downstream location (East Holland River at Holland Landing). The evaluation periods at the Western Creek, Tannery Creek and East Holland River at Vandorf calibration gages focused on the periods of highest quality. The East Holland River gage was selected for model validation because (1) it had the highest data quality of all gages, (2) it spanned the longest continuous time period, and (3) drained a diverse range of HRUs (Table 4-2). The three smaller calibration watersheds are also upstream tributaries of the East Holland River gage. Because of the significant impact of the Oak Ridges Moraine on watershed hydrology, the model was also compared against water budget estimates from the E-flows study for areas upstream of the Vandorf gage.

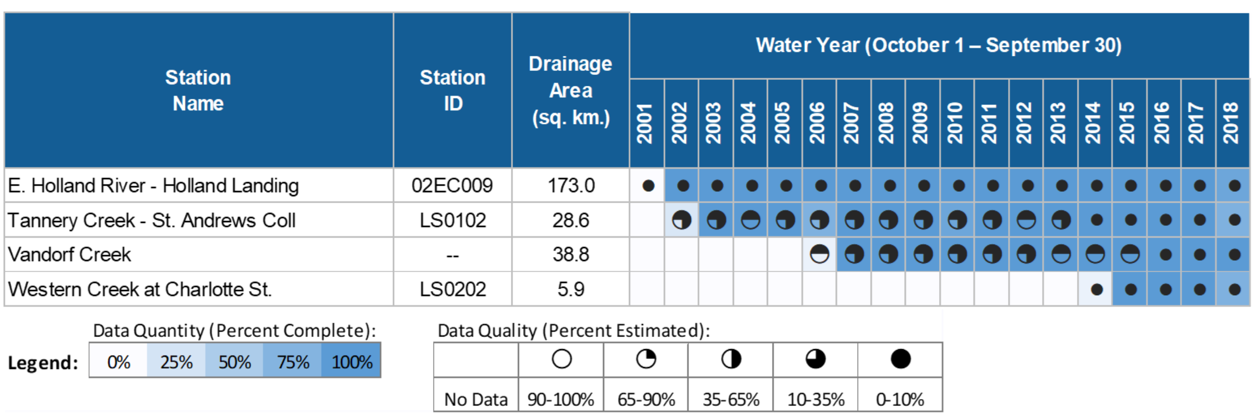


Figure 4-15. Temporal summary of observed streamflow quantity/quality in the East Holland River watershed.

Table 4-2. HRU distribution upstream of calibration/validation gages

Gage	Land Cover		Area (ha)	Total	Hydrologic Soil Group				Slope		Recharge	
					A	B	C	D	<5%	>5%	Low	High
Vandorf Creek	Ag.	High	658	16%	49%	50%	--	2%	53%	47%	10%	90%
		Low	387	10%	75%	23%	3%	--	13%	87%	25%	75%
	Dev.	Impervious	145	4%	--	--	--	--	--	--	--	--
		Pervious	986	24%	70%	25%	5%	--	36%	64%	100%	--
	Natural Heritage	Open	344	9%	73%	13%	--	13%	45%	55%	8%	92%
		Shrub	415	10%	75%	22%	--	3%	33%	67%	9%	91%
		Treed	1,095	27%	79%	12%	--	9%	34%	66%	7%	93%
Western Creek at Charlotte St. (LS0201)	Ag.	High	9	1%	--	0%	100%	--	100%	--	100%	--
		Low	--	0%	--	--	--	--	--	--	--	--
	Dev.	Impervious	162	25%	--	--	--	--	--	--	--	--
		Pervious	362	56%	23%	0%	77%	--	58%	42%	100%	--
	Natural Heritage	Open	13	2%	83%	--	17%	--	8%	92%	23%	77%
		Shrub	56	9%	3%	90%	7%	--	93%	7%	86%	14%
		Treed	45	7%	94%	0%	6%	--	2%	98%	18%	82%
Tannery Creek, St. Andrews College (LS0102)	Ag.	High	271	9%	11%	29%	58%	2%	22%	78%	61%	39%
		Low	252	9%	9%	41%	50%	--	8%	92%	70%	30%
	Dev.	Impervious	332	12%	--	--	--	--	--	--	--	--
		Pervious	1,298	45%	32%	14%	54%	--	27%	73%	100%	--
	Natural Heritage	Open	174	6%	49%	5%	45%	1%	12%	88%	42%	58%
		Shrub	186	6%	33%	24%	42%	1%	14%	86%	60%	40%
		Treed	349	12%	38%	28%	31%	2%	7%	93%	54%	46%
East Holland River, Holland Landing (02EC009)	Ag.	High	2,794	16%	20%	45%	35%	1%	52%	48%	72%	28%
		Low	1,174	7%	38%	35%	27%	--	27%	73%	66%	34%
	Dev.	Impervious	1,935	11%	--	--	--	--	--	--	--	--
		Pervious	5,890	34%	30%	21%	50%	--	40%	60%	100%	--
	Natural Heritage	Open	1,125	6%	53%	14%	28%	5%	30%	70%	54%	46%
		Shrub	1,346	8%	53%	27%	19%	2%	28%	72%	52%	48%
		Treed	3,103	18%	62%	16%	18%	4%	23%	77%	44%	56%

*Totals do not always add to 100% due to rounding

4.5.1 Hydrology Calibration Evaluation

The hydrology calibration results in a series of graphical outputs called 'calibration panels' and statistical metrics as described in Section 4.4. The calibration outputs are a result of a series of iterative parameter adjustments based on investigation into model performance compared to observations. The selected parameters for both hydrology and water quality are presented in Appendix B. The hydrology calibration outputs (both graphical outputs and tabular statistical performance metrics) are presented as a series of panels in Appendix C.

Summary results of model performance metrics for all stations by season and flow regime are presented in Table 4-3 and Table 4-4, respectively. Table 4-3 summarizes simulated versus modelled daily flow for the entire model simulation period (All) and for each season. Table 4-4 summarizes the simulated versus modelled flow for the entire simulation period (All) as well as days categorized as storm flow or baseflow and for weekly peak and low flows. Based on the weight-of-evidence approach and the large number of metrics that received 'Satisfactory' or better, the model is considered reasonably calibrated and well-performing for East Holland River watershed. Some notable station by station observations include:

- Western Creek had the best performance across seasons and flow regimes. Western Creek is the most representative 'developed' watershed in terms of the relative HRU distribution. Western Creek hydrology performance metrics exhibited Satisfactory or better for every metric considered, and a majority being Good or Very Good.
- Agreement between observed and predicted flows was lowest at East Holland River at Vandorf. In addition, in the hydrologically complex Oak Ridges Moraine area that contributes to the Vandorf gage, the calibration for Vandorf was limited by the relatively short modelling period (Figure 4-1). Model results at Vandorf station did not capture the full magnitude of a relatively large observed discharge occurring in the spring of 2009 (Appendix C) which contributed to lower calibration performance.
- Overall, the model achieved performance that was satisfactory or better for most metrics across seasons. However, summer flows tended to be overpredicted as shown by the results for RME (Table 4-5) and PBIAS (Table 4-8).

Figure 4-16 through Figure 4-18 show an example hydrology 'calibration panel' for the East Holland River at Holland Landing gage. Daily and monthly simulated flows generally appear in agreement with observations. Seasonal changes in flow are evident, with the autumn and winter generally characterized by steady or rising streamflow, the highest flows occurring in spring, and flows steadily decreasing through the summer (Figure 4-17). The flow duration curve (Figure 4-18) presents discharge vs. percent of time that discharge is equaled or exceeded. The area under the curve represents the average daily flow and the value located at the 50% value is the median daily flow. Quantitative assessments of model performance for East Holland River at Holland Landing are presented in Table 4-5 through Table 4-8. These tables represent additional details on model performance for each calibration gage.

Table 4-3. Hydrologic Performance Evaluation Across All Stations by Season.

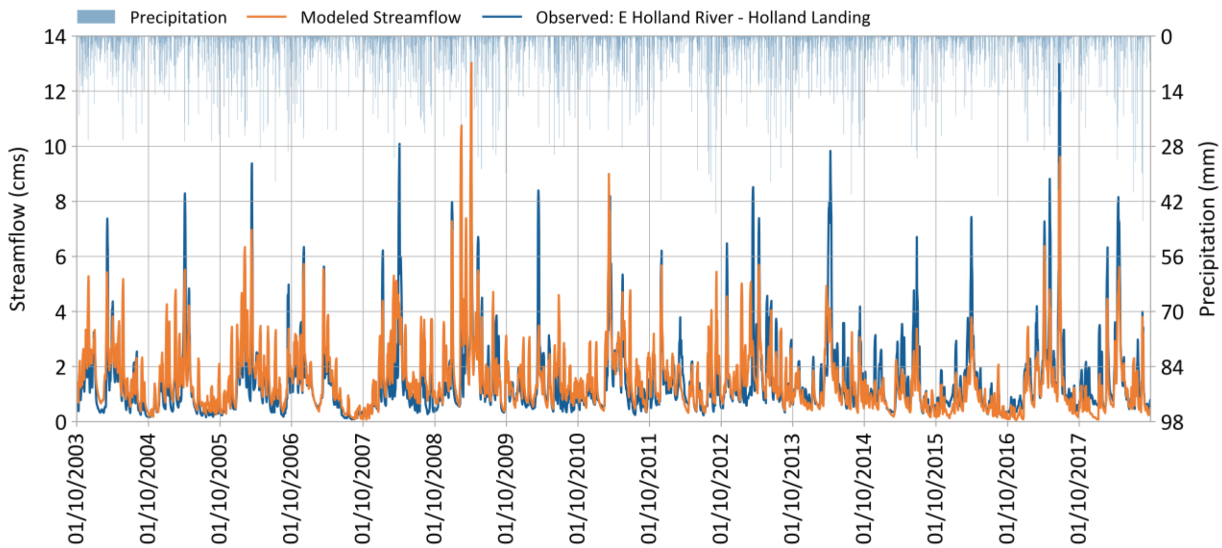
Hydrology Monitoring Locations	Performance Metrics (Seasonal)														
	PBIAS					R-squared					Nash-Sutcliffe E				
	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall
Tannery Creek - St Andrews Coll	- Good	- Very Good	- Very Good	+ Very Good	- Good	Satisfactory	Good	Good	Very Good	Satisfactory	Satisfactory	Good	Good	Very Good	Good
Western Creek at Charlotte St.	- Good	+ Very Good	- Very Good	- Good	- Satisfactory	Very Good	Good	Very Good	Satisfactory	Very Good	Very Good	Good	Very Good	Good	Good
East Holland River - Vandorf	+ Good	- Unsatisfactory	+ Good	+ Unsatisfactory	+ Good	Unsatisfactory	Good	Unsatisfactory	Satisfactory	Satisfactory	Satisfactory	Good	Unsatisfactory	Unsatisfactory	Satisfactory
East Holland River - Holland Landing	+ Very Good	+ Very Good	- Very Good	+ Satisfactory	+ Very Good	Satisfactory	Satisfactory	Good	Good	Very Good	Satisfactory	Good	Very Good	Good	Very Good

Very Good | Good | Satisfactory | Unsatisfactory
+ Positive | - Negative

Table 4-4. Hydrologic Performance Evaluation Across All Stations by Flow Regime.

Hydrology Monitoring Locations	Performance Metrics (Flow Regime)														
	PBIAS					R-squared					Nash-Sutcliffe E				
	All	Highest	Storms	Lowest	Baseflow	All	Highest	Storms	Lowest	Baseflow	All	Highest	Storms	Lowest	Baseflow
Tannery Creek - St Andrews Coll	- Good	- Very Good	- Very Good	- Satisfactory	- Very Good	Satisfactory	Unsatisfactory	Good	Unsatisfactory	Good	Satisfactory	Unsatisfactory	Good	Unsatisfactory	Good
Western Creek at Charlotte St.	- Good	+ Very Good	- Very Good	- Satisfactory	- Very Good	Very Good	Good	Very Good	Very Good	Very Good	Very Good	Good	Very Good	Very Good	Very Good
East Holland River - Vandorf	+ Good	+ Very Good	+ Very Good	- Good	+ Satisfactory	Unsatisfactory	Unsatisfactory	Satisfactory	Unsatisfactory	Very Good	Satisfactory	Unsatisfactory	Good	Satisfactory	Very Good
East Holland River - Holland Landing	+ Very Good	+ Very Good	+ Very Good	+ Good	+ Satisfactory	Satisfactory	Good	Good	Satisfactory	Satisfactory	Satisfactory	Good	Good	Satisfactory	Satisfactory

Very Good | Good | Satisfactory | Unsatisfactory
+ Positive | - Negative



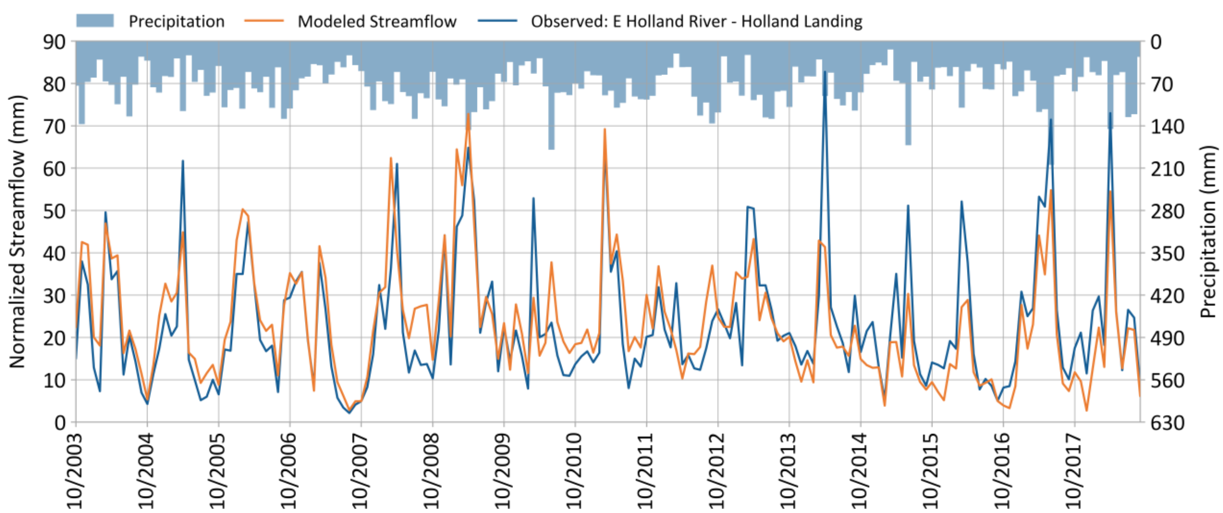


Figure 4-16. Simulated vs. observed daily (top) and monthly (bottom) streamflow comparisons at East Holland River - Holland Landing (02EC009).

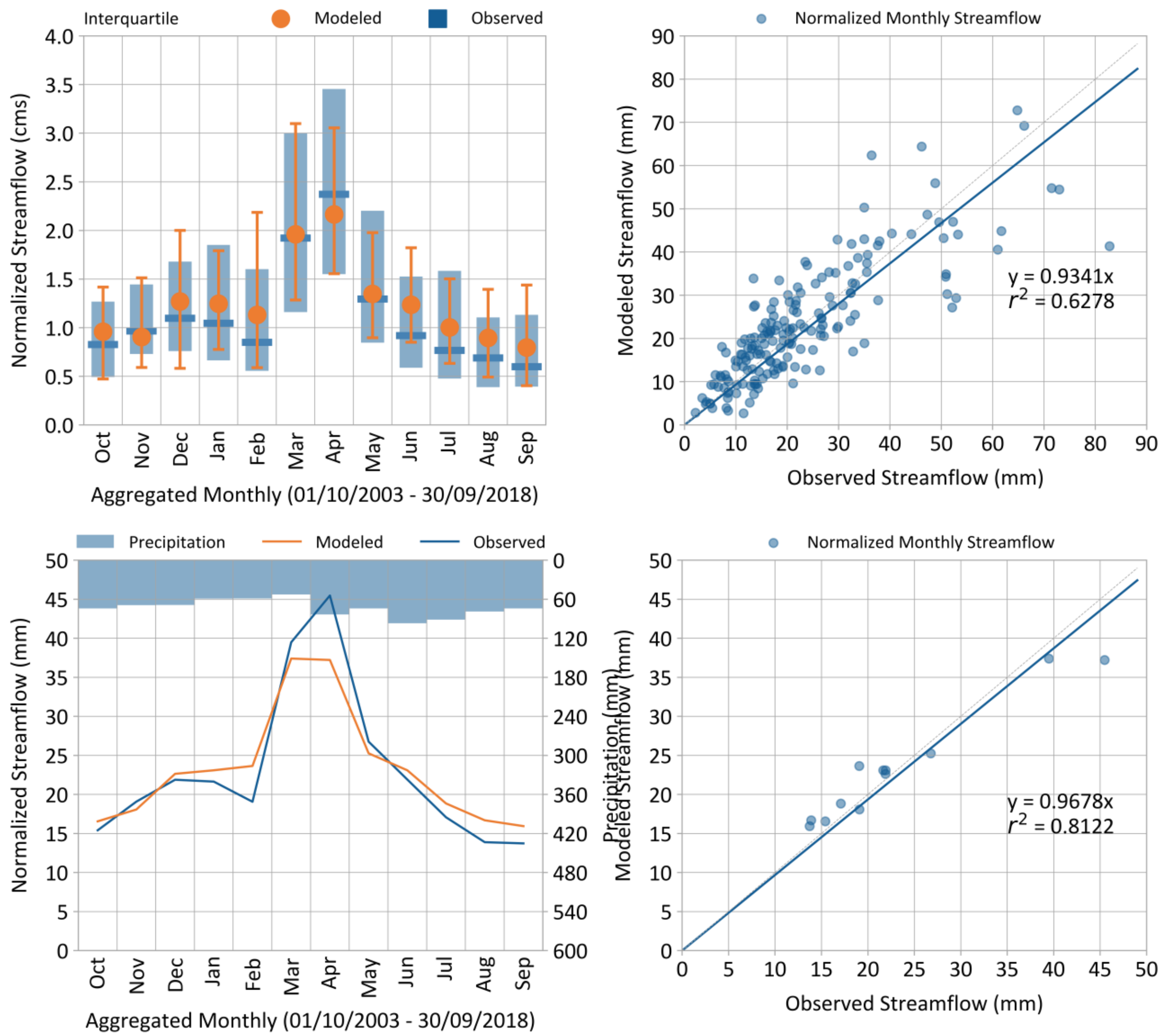


Figure 4-17. Simulated vs observed monthly (top) and average monthly (bottom) streamflow comparisons at East Holland River - Holland Landing (02EC009).

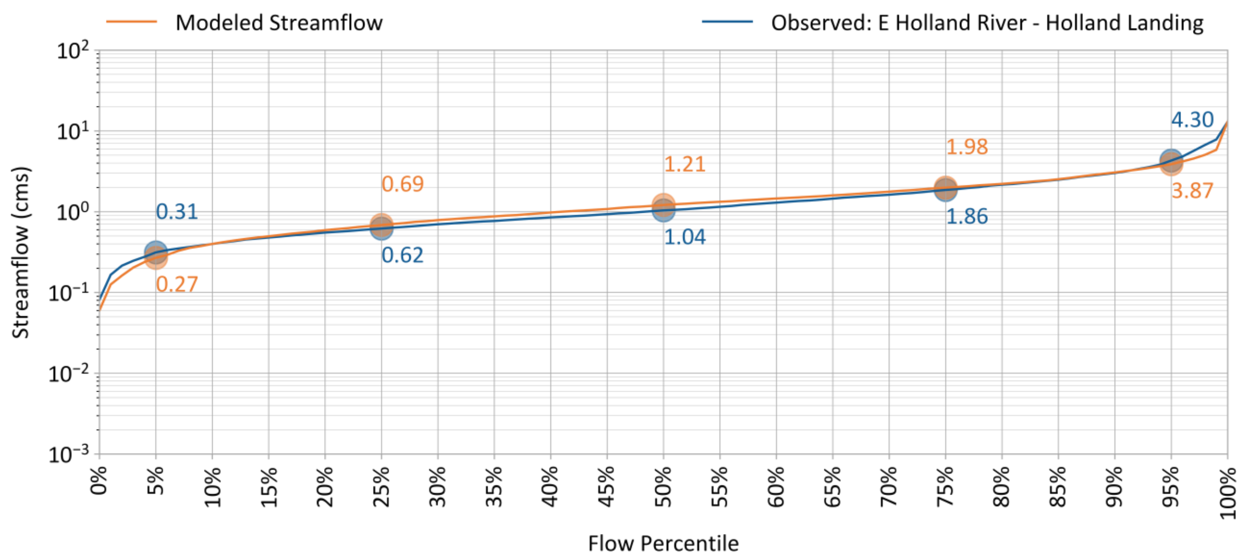


Figure 4-18. Flow duration curve at East Holland River – Holland Landing (02EC009).

Table 4-5. Hydrology Calibration Performance Results for Relative Mean Error at E Holland River - Holland Landing (Station ID: 02EC009).

	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation)				
Calibration Metrics *(01/10/2003 - 30/09/2018)*	**Relative Mean Error**				
	All Seasons	**Winter**	**Spring**	**Summer**	**Fall**
Total Annual Volume	1.1%	4.9%	-9.1%	15.2%	1.6%
Highest Weekly Flows	1.7%	-5.9%	-6.8%	23.1%	6.2%
Lowest Weekly Flows	10.9%	17.7%	3.8%	31.0%	-0.1%
Storm Volume	-11.0%	-15.1%	-19.9%	2.1%	-1.6%
Baseflow Volume	4.7%	11.3%	-6.0%	19.9%	2.4%
Baseflow Recession Rate	1.5%	2.5%	2.0%	1.4%	-0.6%

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
Relative Mean Error	Total Annual Volume	Compare Observed vs Simulated Total Volume across Simulation Period for Selected Season-Conditions	≤5%	5 - 10%	10 - 15%	>15%	Donigian et al. (1984), Lumb et al. (1984), and Donigian (2000)
	Highest Weekly Flows		≤10%	10 - 15%	15 - 25%	>25%	
	Lowest Weekly Flows		≤10%	10 - 15%	15 - 25%	>25%	
	Annual Storm Volume		≤10%	10 - 15%	15 - 25%	>25%	
	Seasonal Storm Volume		≤15%	15 - 30%	30 - 50%	>50%	
	Baseflow Volume		≤10%	10 - 15%	15 - 25%	>25%	
	Baseflow Recession Rate		≤3%	3 - 5%	5 - 10%	>10%	

Table 4-6. Hydrology Calibration Performance Results for R-Squared at E Holland River - Holland Landing (Station ID: 02EC009).

Calibration Metrics (01/10/2003 - 30/09/2018)	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation) R-Squared (R^2)				
	All Seasons	Winter	Spring	Summer	Fall
All Conditions	0.69	0.59	0.73	0.63	0.79
Highest Weekly Flow Rates	0.62	0.54	0.71	0.49	0.81
Lowest Weekly Flow Rates	0.51	0.28	0.7	0.47	0.57
Days Categorized as Storm Flow	0.69	0.6	0.73	0.63	0.8
Days Categorized as Baseflow	0.57	0.42	0.71	0.61	0.69

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
R-Squared (R^2)	All Conditions	Compare Observed vs Simulated Rates that Occur During Selected Season-Conditions	>0.85	0.75 - 0.85	0.60 - 0.75	≤0.60	Moriasi et al. (2015)
	Seasonal Flows		>0.75	0.60 - 0.75	0.50 - 0.60	≤0.50	
	Highest Weekly Flow Rates						
	Lowest Weekly Flow Rates						
	Days Categorized as Storm Flow						
	Days Categorized as Baseflow						

Table 4-7. Hydrology Calibration Performance Results for Nash-Sutcliffe Efficiency at E Holland River - Holland Landing (Station ID: 02EC009).

	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation)				
Calibration Metrics *(01/10/2003 - 30/09/2018)*	**Nash-Sutcliffe Efficiency (E)**				
	All Seasons	**Winter**	**Spring**	**Summer**	**Fall**
All Conditions	0.69	0.57	0.71	0.55	0.78
Highest Weekly Flow Rates	0.61	0.52	0.7	0.3	0.81
Lowest Weekly Flow Rates	0.42	-0.06	0.68	-0.35	-0.23
Days Categorized as Storm Flow	0.69	0.57	0.7	0.55	0.78
Days Categorized as Baseflow	0.47	-0.04	0.68	0.3	0.34

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
Nash-Sutcliffe Efficiency (E)	All Conditions	Compare Observed vs Simulated Flow Rates that Occur During Selected Season-Conditions	>0.80	0.70 - 0.80	0.50 - 0.70	≤0.50	Moriasi et al. (2015)
	Seasonal Flows		>0.70	0.50 - 0.70	0.40 - 0.50	≤0.40	
	Highest Weekly Flow Rates						
	Lowest Weekly Flow Rates						
	Days Categorized as Storm Flow						
	Days Categorized as Baseflow						

Table 4-8. Hydrology Calibration Performance Results for Percent Bias at E Holland River - Holland Landing (Station ID: 02EC009).

Calibration Metrics *(01/10/2003 - 30/09/2018)*	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation) — Percent Bias (PBIAS)				
	All Seasons	Winter	Spring	Summer	Fall
All Conditions	1.1%	4.9%	-9.1%	15.2%	1.6%
Highest Weekly Flow Rates	1.7%	-5.9%	-6.8%	23.1%	6.2%
Lowest Weekly Flow Rates	10.9%	17.7%	3.8%	31.0%	-0.1%
Days Categorized as Storm Flow	0.3%	3.9%	-9.7%	13.7%	1.2%
Days Categorized as Baseflow	18.0%	27.1%	4.5%	39.2%	9.0%

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
Percent Bias (PBIAS)	All Conditions	Compare Observed vs Simulated Flow Rates that Occur During Selected Season-Conditions	<5%	5% - 10%	10% - 15%	>15%	Moriasi et al. (2015)
	Seasonal Flows		<10%	10% - 15%	15% - 25%	>25%	
	Highest Weekly Flow Rates						
	Lowest Weekly Flow Rates						
	Days Categorized as Storm Flow						
	Days Categorized as Baseflow						

4.6 Water Quality

A phased weight-of-evidence approach was used for water quality calibration. An initial set of HRU model parameters were derived based on Paradigm's previous nutrient modelling projects, which incorporate a variety of literature values and the results of model calibration in other watersheds. The water quality calibration effort including two major components: (1) evaluation of resulting pollutant yields and event mean concentrations (EMCs) when compared to literature values and observations studies (Section 4.6.1) and (2) comparison to instream concentrations using graphical panels and statistical performance metrics (Section 4.6.2). The LSPC parameters resulting from calibration are detailed in Appendix B.

4.6.1 Unit-Area Loads and Concentrations

Modelled sediment and phosphorus EMCs and yields were summarized by HRU and evaluated to assess if the relative loading by land cover, soil group, slope, and groundwater recharge zone were reasonably representative. Because the model configuration reflects physical characteristics of the land surface, such as slope and soil type, and spatial variability, the goal of model calibration is to parameterize sediment properties to capture the relative range of variability between sources as a function of those physical characteristics of the watershed.

Export coefficients are functions expressing aggregated pollution generation per unit area and unit time for a land use while EMCs represent a flow-weighted composite concentration of a runoff event. While these values represent important statistical characteristics of nonpoint source loads and water quality, they are proxies for the physical processes driving water quality. While the results of process based, continuous simulation in LSPC may be *summarized* into export coefficients and EMCs, they are generally not used as parameters in the models themselves—instead, the process-based modelled time series outputs are aggregated to the same spatial/temporal scales for comparison. In addition, the resulting EMCs and yields from LSPC are across a range of values, they are not singular values as most empirical models.

4.6.1.1 Total suspended solids

Total suspended solids is an important water quality constituent, as it affects the delivery of many of pollutants including phosphorous. As discussed at the beginning of Section 4, the water quality calibration began with sediment before addressing phosphorous. Figure 4-19 and Figure 4-20 show the variability of modelled responses by HRU for total suspended sediment. The edge-of-field loads were also aggregated and normalized by subcatchment to assess the range of spatial variability in the modelled response across the East Holland River watershed, which results in a 'heat map' of yields (Figure 4-21). Developed areas had the highest median unit-area sediment loading while agricultural had the highest single value (>2,500 kg/ha/yr.), although its median was lower than developed. The Oak Ridges Moraine portion of the watershed had high variability in EMCs but exported notably less sediment than the rest of the watershed. This result is likely due to the low runoff potential in the area. While overland flow does not occur often in the Oak Ridges Moraine, when it does, it carries the accumulated sediment that has been detached and accumulated on the landscape. Among impervious surfaces, roads had the highest simulated unit-area loading, followed by residential, commercial and industrial—rooftops had the lowest unit-area sediment loads. Although developed land had the highest median unit-area loading rate, the estimated range of variability was not as high as the high-intensity agricultural areas.

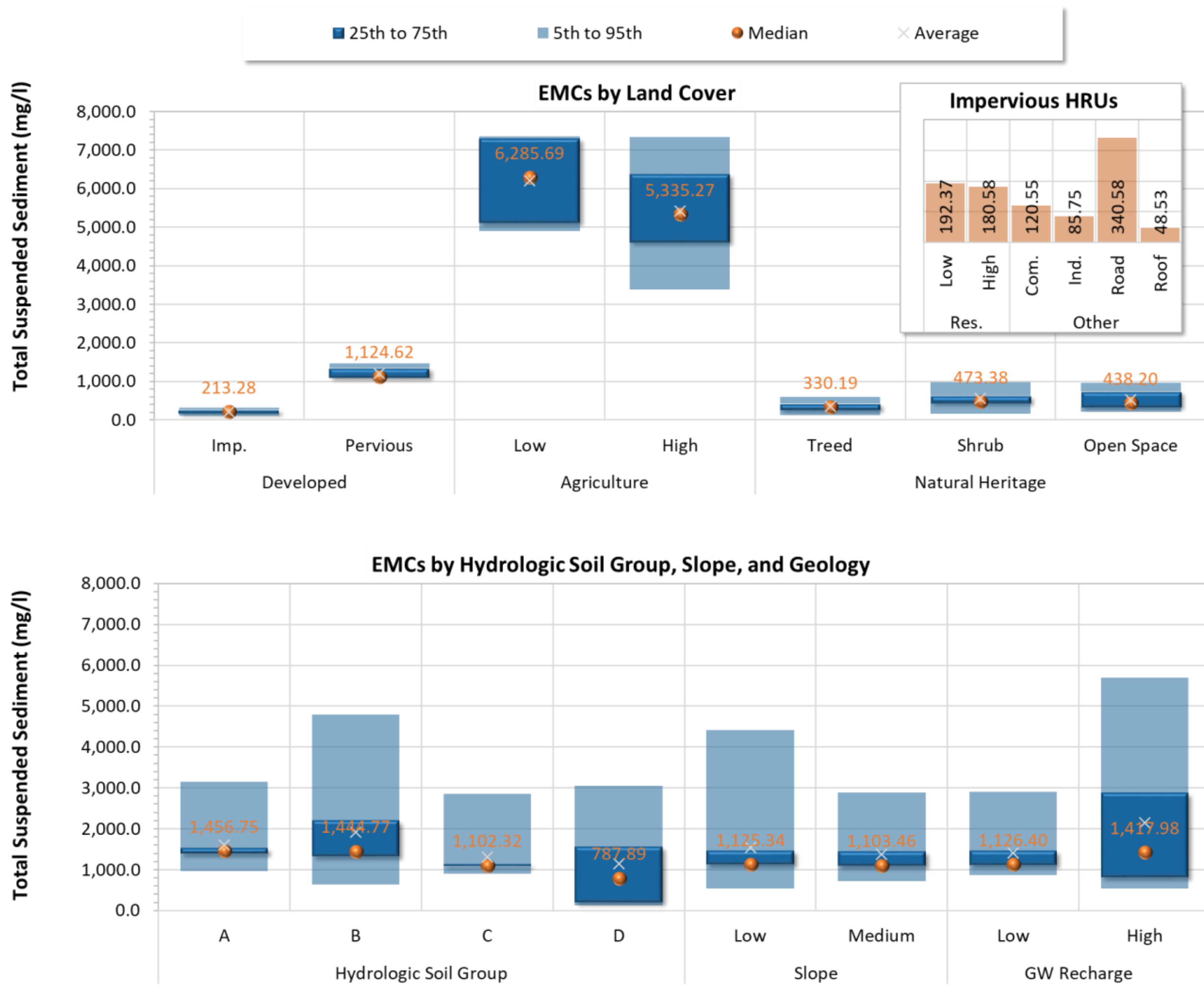


Figure 4-19. Modelled sediment concentrations by HRU in the East Holland River watershed.

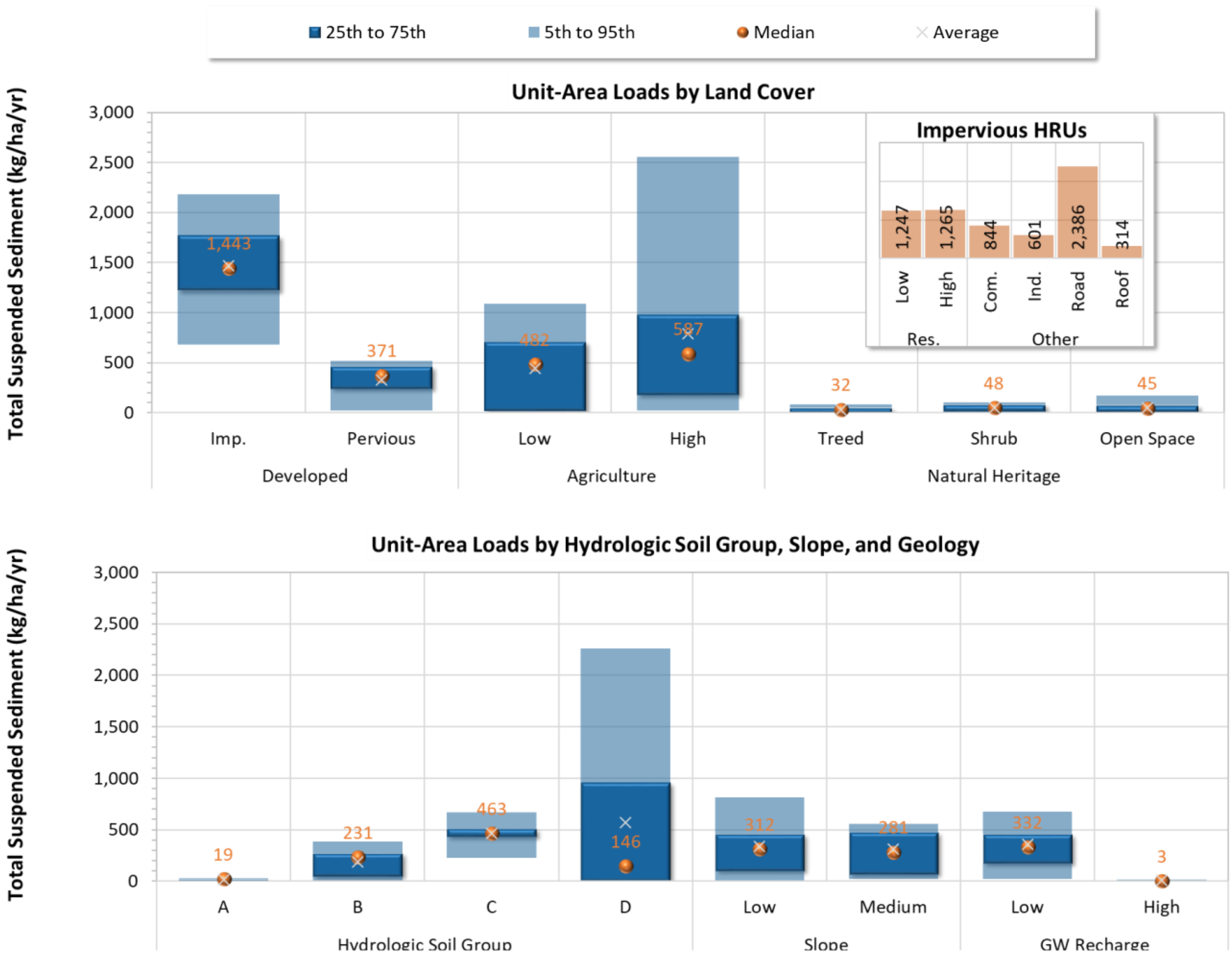


Figure 4-20. Modelled unit-area sediment loads by HRU in the East Holland River watershed.

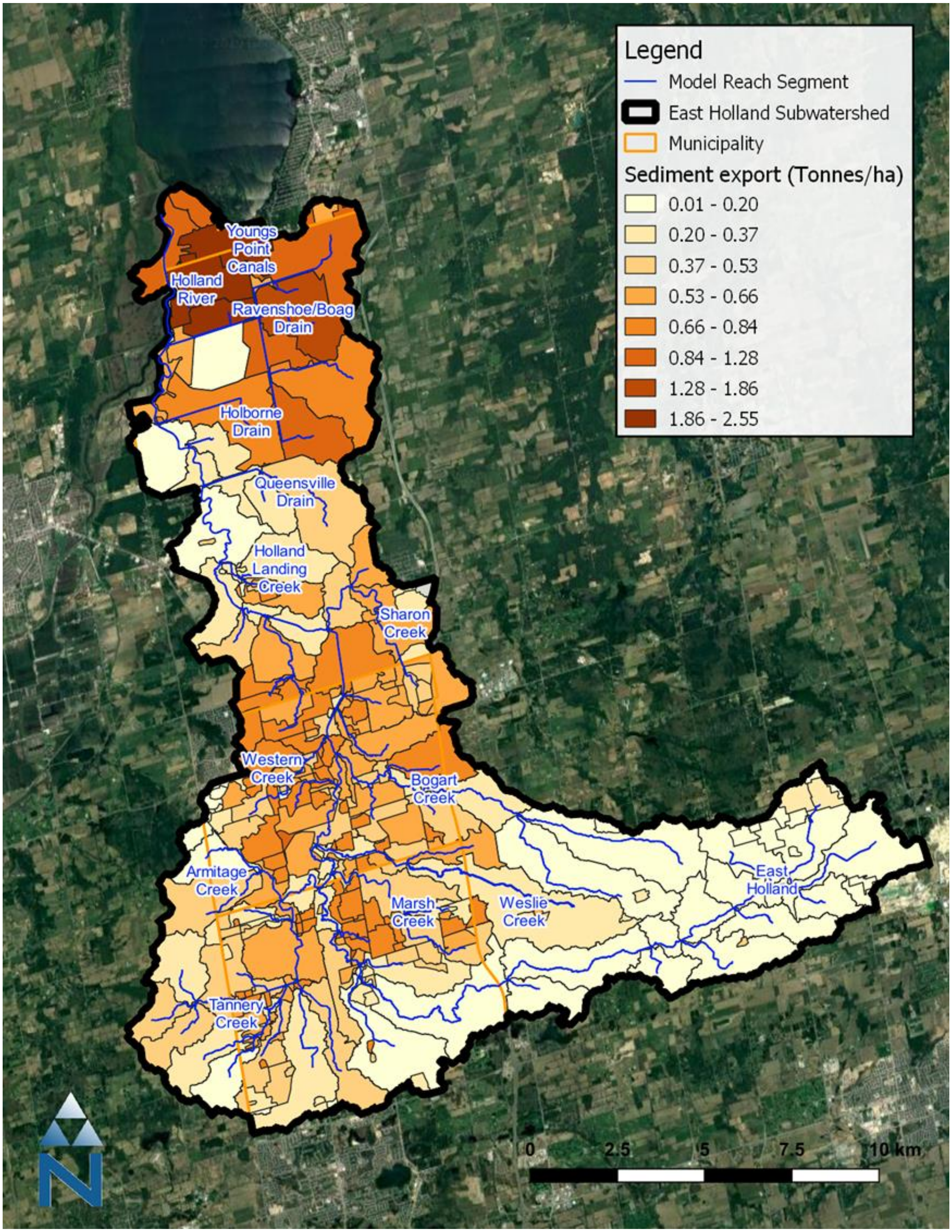


Figure 4-21. Modelled annual sediment loads by subcatchment in the East Holland River watershed.

4.6.1.1 Total phosphorous

Total phosphorus associated with surface runoff was modelled in LSPC as a sediment-associated pollutant. The approach used potency factors, which are mass concentrations (g-P/kg-sediment), to define how much phosphorus was associated with sediment. Potency factors were specified for sediment originating from washoff and scour sources for each HRU. The driving factors influencing phosphorus export from an HRU are the hydrologic response (i.e., runoff, which varies by land use, soil type, slope, and groundwater recharge potential), density of vegetation cover, the specified potency factors, and the erodibility, expressed as the K factor, of the soils in the HRU. Figure 4-22 and Figure 4-23 show the variability of modelled responses by HRU for total phosphorus. Phosphorus follows the same general trends as sediment. Agricultural areas have the highest EMCs and the Oak Ridges Moraine had the lowest loads. Figure 4-24 presents aggregates edge-of-field phosphorus loads normalized by subcatchment. Phosphorus loadings are concentrated in developed areas as well as agricultural areas near the Holland marsh.

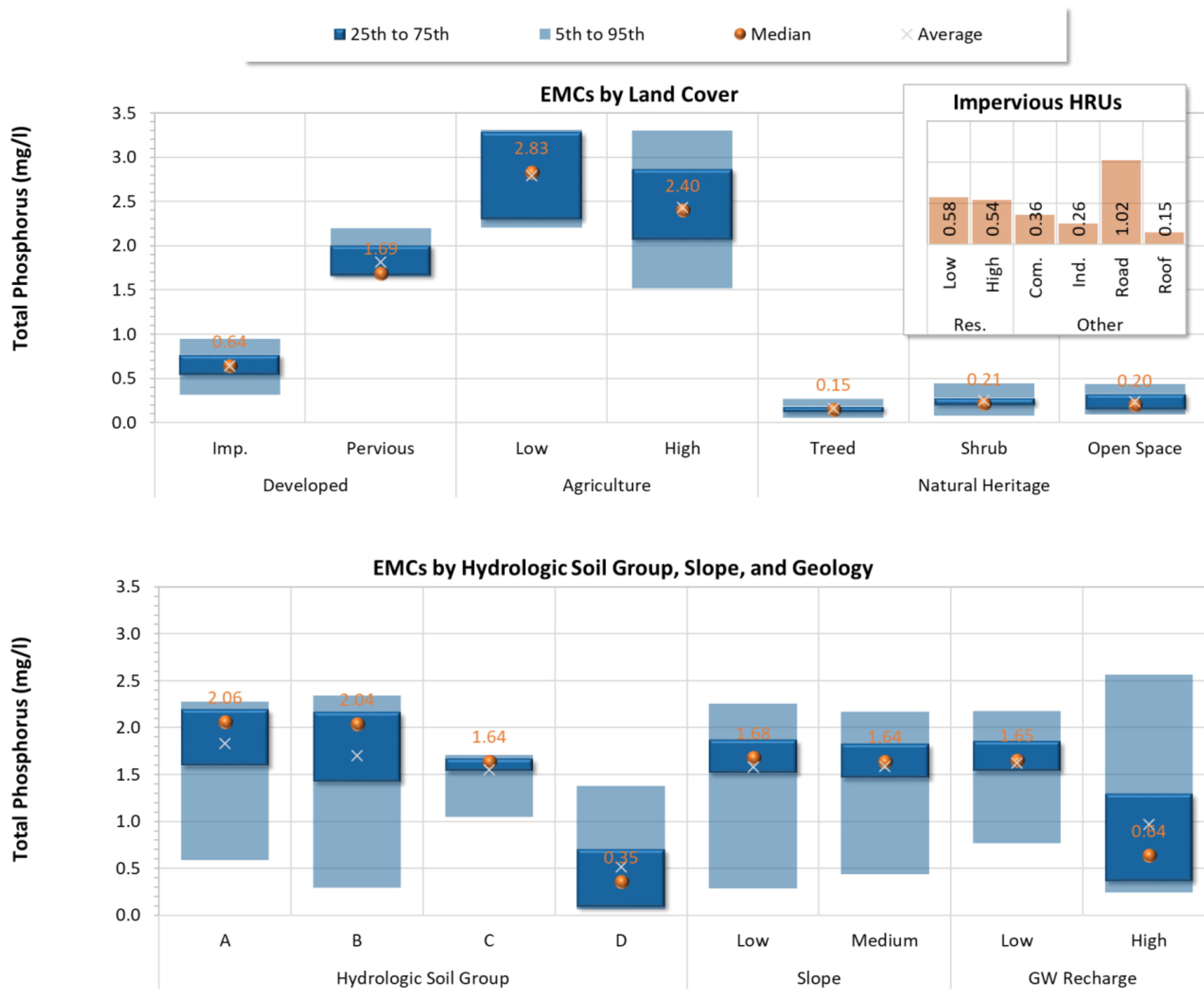


Figure 4-22. Modelled TP concentrations by HRU in the East Holland River watershed.

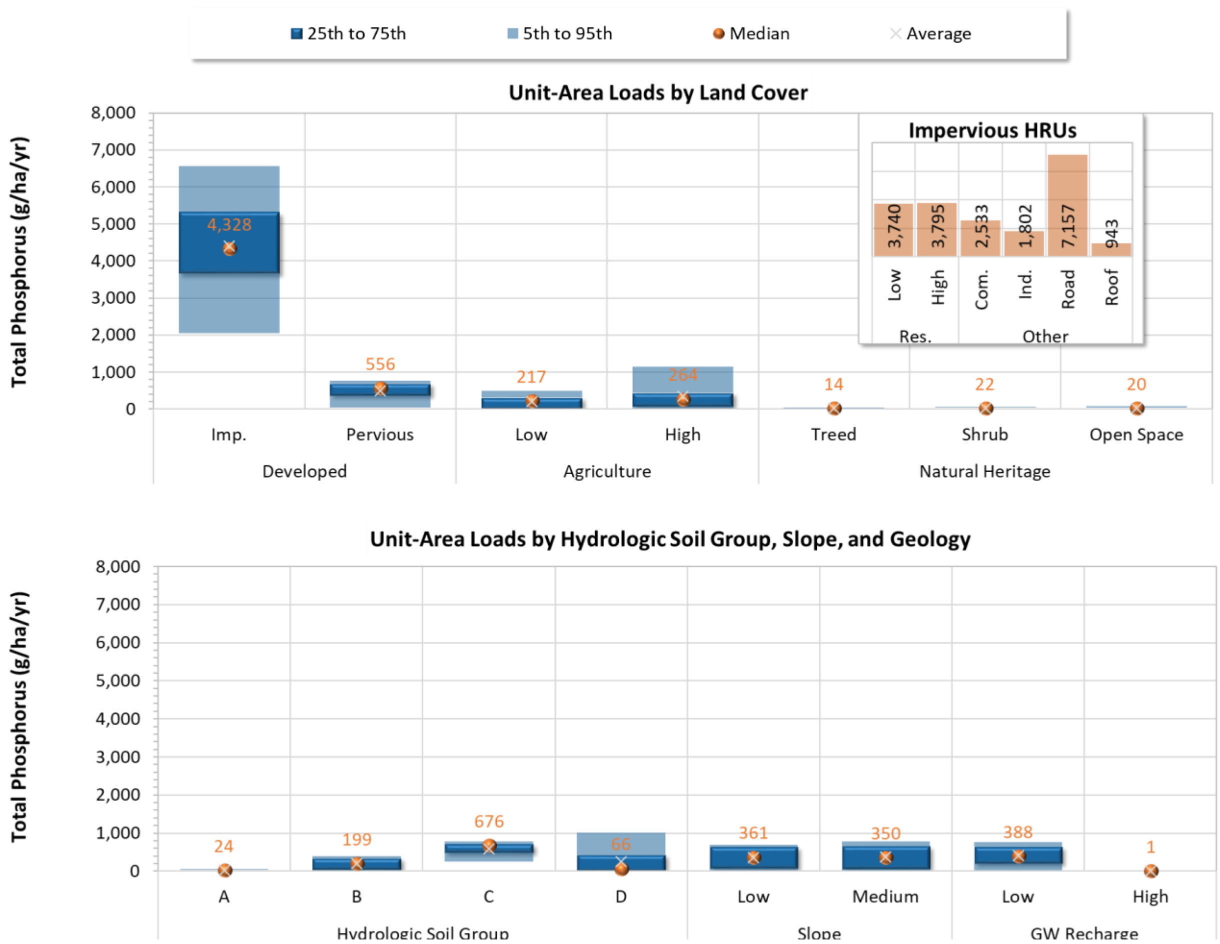


Figure 4-23. Modelled unit-area TP loads by HRU in the East Holland River watershed

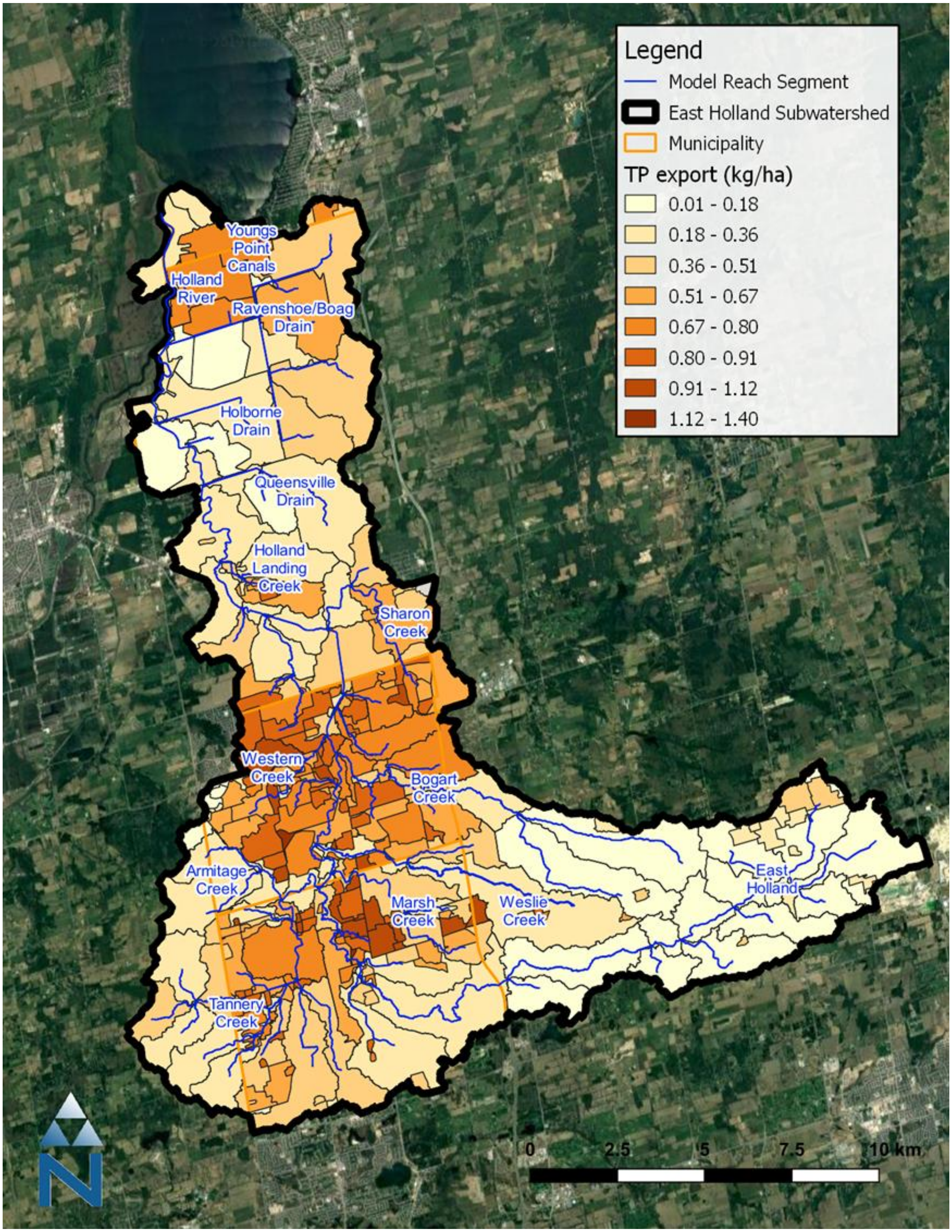


Figure 4-24. Modelled annual total phosphorus loads by subcatchment in the East Holland River watershed.

For phosphorous, an extensive comparison to literature values was performed and leveraged for model adjustments. For East Holland watershed, this step was particularly important because no 'end of pipe' data were available to assess phosphorous concentrations prior to mixing in the stream environment. The parameterization based on literature was essentially used in lieu of end-of-pipe data. However, the calibration to instream concentrations (as described in the next subsection) were weighed much more heavily than the literature estimates.

LSPC is a physically-based model that uses algorithms accounting for the kinetic energy of rainfall/runoff on the land and shear stress within a channel to simulate sediment erosion/washoff and transport. Other modelling approaches to estimating phosphorus export in the East Holland watershed have included land use export coefficients (Hutchinson Environmental Sciences Ltd., et al., 2012) and EMCs (Auger & Van Seters, 2018). These key literature sources, described below, were used for evaluation of LSPC simulated yields and EMCs:

- The export coefficients used in the Phosphorus Budget Tool (Hutchinson Environmental Sciences Ltd., et al., 2012) were derived from The Canadian Nutrient and Water Evaluation Tool (CANWET) and were calibrated using three years of observed data (The Louis Berger Group, 2010). CANWET is an adaptation of the Generalized Watershed Loading Functions (GWLF) model (Haith et al., 1992) and has been considered a simplification of HSPF (Ahmed et al., 2013; Singh et al., 2012). Alternatively, LSPC is directly derived from HSPF algorithms. CANWET was used to simulate dissolved and solid-phase loading from rural land uses and build/washoff from urban areas. Rural dissolved nutrient export was calculated by multiplying runoff, computed using the Curve Number method, by user-defined dissolved concentrations of nitrogen and phosphorus for specific land uses. Rural solid-phase loading was estimated by applying user-defined nutrient potency factors (mg/kg) by sediment yield. Similar to LSPC, CANWET uses algorithms representing the Universal Soil Loss Equation, including estimates of soil erodibility. Urban nutrient export was calculated based on general accumulation and wash off relationships. Buildup (kg/ha/d) of nutrients on urban land was washed off using a first-order function applied to runoff volumes (Haith et al., 1992). Table 4-9 presents a summary LSPC total phosphorus loadings for various land uses compared to those used in the Phosphorus Budget Tool (PTool) (Hutchinson et al., 2012), which were estimated using CANWET, as well as those found in the literature for comparison. Figure 4-25 presents a graphical comparison of LSPC unit area phosphorus loads to those from the P Tool as well as those found in the literature. Load values and literature sources from Figure 4-25 are presented in Table 4-10.
- The LID Treatment Train Tool (LID TTT) was developed by LSCRA, Credit Valley Conservation (CVC) and Toronto and Region Conservation Authority (TRCA) to help developers and other stakeholder implement sustainable stormwater practices. The LID TTT uses EMCs. Seasonal effects can have considerable influence on the observed EMCs reported by various studies; these influences are often not represented in the mean or median summaries (Auger and Van Seters, 2018). An HSPF model using EMCs was developed for the City of Toronto Wet Weather Flow Management Master Plan. Calibration involved adjusting initial measured EMC values for urban areas within their uncertainty estimates to improve agreement between observed and predicted average in-stream concentrations at the mouth of six major tributaries (D'Andrea et al., 2004). Default land cover EMCs in the LID TTT are derived from monitoring studies on paved surfaces, STEP water quality data for roofs, HSPF calibrated EMCs for landscaped areas and row crops, and International Stormwater BMP data base data for open space, forests, and wetlands (Auger & Van Seters, 2018). Table 4-11 compares LSPC total phosphorus EMCs to those used in the LID TTT, as well as those found in the literature. Figure 4-26 presents a graphical comparison of LSPC EMCs to those from the LID TTT. EMC values and literature sources from Figure 4-26 are presented in Table 4-12.

For many parameters, the yield and EMCs from LSPC were higher than shown in P-Tool and LID TTT – however, the balance to calibrate to instream concentrations tipped the scales. For example, if the LID TTT parameters were matched directly, the LSPC model would greatly underpredict phosphorous concentrations at the instream calibration stations. Compared to the other literature values (gray bars in Figure 4-25 and Figure 4-26**Error! Reference source not found.**), LSPC is well within range for most land use categories and shows general agreement in terms of yield and EMCs.

Table 4-9. Total phosphorus loading comparison for LSPC and P-Tool

	TP export coefficient (kg/ha/yr)		
TP Tool Landuse	**P-Tool ***	**LSPC**	**LSPC Landuse**
Cropland	0.36	0.51	Intensive Ag
Hay-Pasture	0.12	0.26	Non-intensive ag
Sod Farm/ Golf Course	0.24	0.53	Manicured Open Space
Commercial/Industrial	1.82	1.59	Commercial
		1.05	Industrial
High intensity residential	1.32	0.61	Estate residential
		0.56	Urban
		0.91	Institutional
Low-intensity development	0.13	0.60	Rural development
Quarry	0.08	NA	NA
Unpaved Road	0.83	NA	NA
NA	NA	7.16	Road
Forest	0.10	0.02	Natural Heritage
Transition	0.16		
Wetland	0.10		
Open Water	0.26	NA	NA
NA	NA	0.35	Active Aggregate
NA	NA	0.44	Rail

*From Hutchinson et al., 2012, Table 2

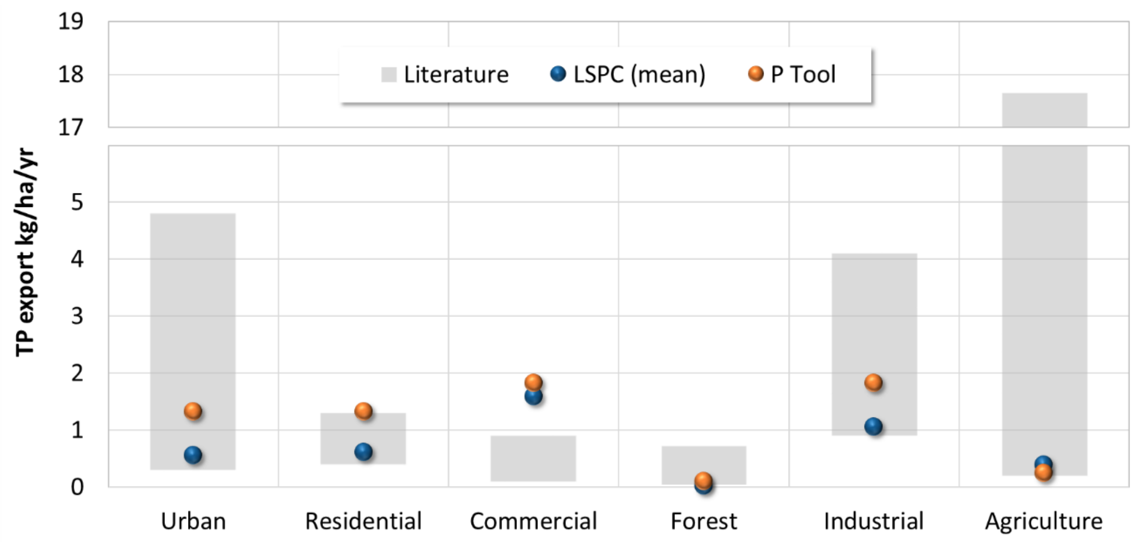


Figure 4-25. Comparison of LSPC mean unit-area total phosphorus loads to the P Tool and literature values.

Table 4-10. Unit-area total phosphorus load comparisons between LSPC and literature

Literature Source	Location	Land Use					
		Urban	Residential	Commercial	Forest	Industrial	Agricultural
Beaulac and Reckhow. 1982	US	-	-	-	-	-	0.20 - 17.64
Novotny, 2003	US	0.3-4.8	0.4-1.3	0.1-0.9	-	0.9-4.1	-
Dillon and Kirchner, 1975	ON, CAN	-	-	-	0.042 - 0.72	-	-
LSPC	--	0.56	0.61	1.59	0.02	1.05	0.39
Ptool	--	1.32	1.32	1.82	0.10	1.82	0.24

Table 4-11. Comparison of LSPC and LID TTT EMCs

LID TTT Landcover	LID TTT EMCs	LSPC EMCs	LSPC Landcover
Paved Surface	0.23	0.59	All Impervious areas
Roof	0.09		
Landscaped Area	0.32	1.75	Residential pervious areas
		1.70	Commercial pervious areas
		1.71	Institutional pervious areas
		1.81	Industrial pervious areas
		1.85	Rural urban pervious areas
		1.75	Urban pervious areas
Row Crop	0.2	1.71	Intensive Ag pervious areas
		2.42	Non-intensive Ag pervious areas
Open Space/Parkland	0.2	1.75	Manicured open space pervious areas
Forest	0.2	0.11	Natural heritage pervious areas
Wetland	0.2		

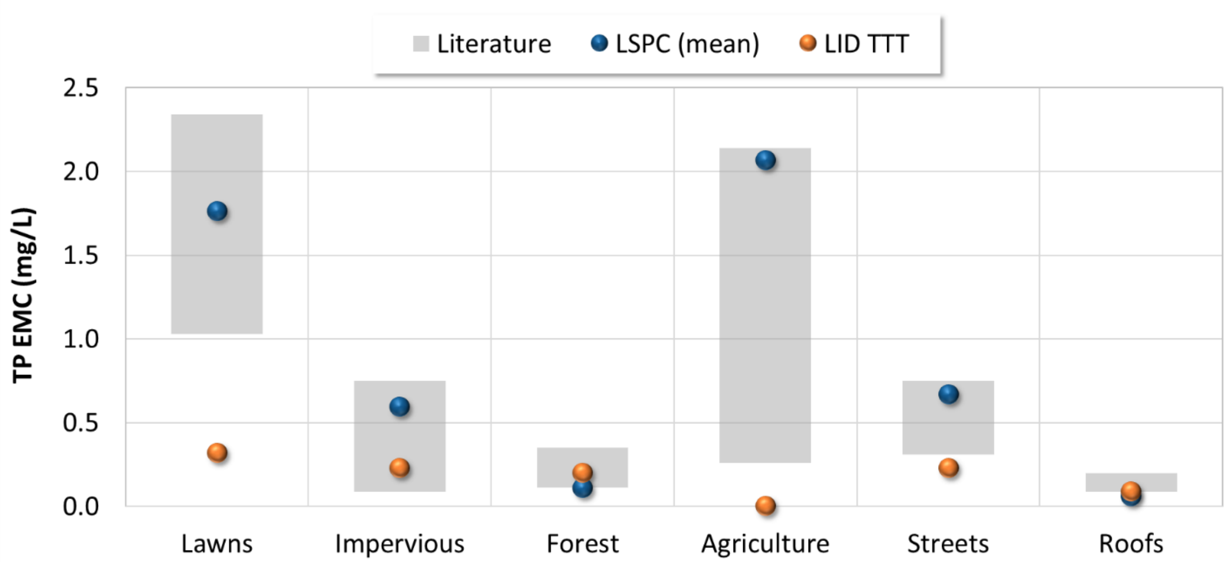


Figure 4-26. Comparison of LSPC total phosphorus EMCs to the LID TTT and literature values.

Table 4-12. Literature used for the total phosphorus EMC comparisons

Source	Landuse				
	Location	Lawns	Impervious/ Urban	Forest	Agriculture
Lin, 2004	WI,US	-	-	0.112	0.262
Lin, 2004	NC, US	-	0.27	0.35	2.14
Waschbusch et al., 1999	WI, US.	1.03-2.34	0.09 - 0.75	-	-
LSPC		1.75	0.59	0.11	2.06
Ptool		0.32	0.23	0.2	0.2

4.6.2 Instream Sediment and Phosphorus Calibration Evaluation

Sediment and phosphorus calibrations were evaluated together because of the associated nature in which they were parameterized. Like hydrologic calibration, both visual and statistical comparisons are helpful in understanding how well modelled results agree with observations. The key difference in water quality observations (compared to flow measurements) is they are instantaneous samples from a single location of the cross section and depth profile. LSPC outputs fully-mixed average concentrations at each timestep. Unlike flow data, there is not a continuous time series for comparison to the LSPC outputs. Fundamentally, the instantaneous water quality samples are a 1:1 comparison to LSPC time series and thus the ‘observed’ water quality datasets intrinsically have more error and uncertainty compared to streamflow measurements.

A robust, statistical evaluation of sediment and phosphorus prediction is presented in Table 4-13 through Table 4-16. These tables evaluate model performance using a suite of metrics (Figure 4-13) across seasons and flow regimes for each of the water quality calibration gages. The assessment incuded samples over the entire simulation period, for high and low flows, and for days categorized as storm flow and base flows. As described in Section 4.4, these performance metrics are considered highly conservative, and it is very rare to receive “Very Good” evaluations across all metrics – “Satisfactory” is a significant outcome. The metrics are used as a weight of evidence approach to evaluate whether model performance is reasonable.

- With the exception of NSE, every metric achieved a Satisfactory of better for the All category at all stations for *either* concentration or load for both sediment and phosphorous. This is a great outcome for the water quality calibration and shows the LSPC model is reasonably calibrated for sediment and phosphorous and can provide a reliable baseline for Future State simulations.
- Most assessments using PBIAS were satisfactory or higher, suggesting that the model does not tend towards a systematic bias towards over- or under-prediction. Agreement between observations and predictions tended to be better for loads than for concentrations (Figure 4-28).
- Results for R^2 also suggest that the model performed reasonably well in establishing a linear relationship between model results and observations, meaning the model is generally predicting responses of sediment and total phosphorous to dynamic watershed conditions.
- Performance at low flows is worse when compared to elevated flows, meaning the model is not fully capturing baseflow dynamics. This is expected, as fluctuations in low flows are not in response to processes that are well captured by LSPC. Causes of low flow fluctuations may include minor discharges and groundwater dynamics. LSPC was not coupled to a groundwater model, and spatial variations in groundwater quality are not well characterized by available data. Most water quality observations occurred during high flows (Figure 4-27). Evenly distributed samples

across all flow regimes would be beneficial for calibration purposes, however, given the nature of regional water quality sampling, such datasets are rarely available.

- The NSE metric shows the poorest performance grading. During periods of unsatisfactory NSE results, the residual variance (the variance in the differences between observations and predictions) is larger than the variance of the observed data. NSE is very sensitive to extreme values and also reflects the timing of simulated versus observed values. There is potential that using a single rain gage for the entire watershed affected the predicted timing of pollutant concentrations and loads. The majority of satisfactory or higher results for NSE occurred when assessing sediment and phosphorus loads by season rather than flow regime.

An example set of calibration panels is shown in Figure 4-27 through Figure 4-30 and Table 4-17 through Table 4-22 for total phosphorus at the East Holland River – Holland Landing station. Appendix D and E present a completed set of plots for sediment and total phosphorus for the calibration gages, respectively. Station-by-station performance varied, sediment concentration calibration appears to be strongest at Holland Landing while sediment loading, and phosphorus concentration and loading calibration appears strongest at Western Creek.

Table 4-13. Water Quality Calibration. Statistical performance metric results for sediment concentration by season and flow regime

Performance Metrics (Seasonal)

Water Quality Monitoring Locations	PBIAS					R-squared					Nash-Sutcliffe E				
	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall
East Holland River - Holland Landing	- (VG)	- (S)	+ (VG)	- (VG)	+ (S)	(S)	(G)	(G)	(S)	(G)	(U)	(U)	(U)	(U)	(U)
Tannery Creek - Yonge St	+ (U)	+ (VG)	+ (VG)	+ (U)	+ (U)	(S)	(VG)	(G)	(G)	(G)	(U)	(U)	(U)	(U)	(U)
Western Creek	- (U)	- (U)	- (G)	+ (G)	- (VG)	(S)	(U)	(VG)	(G)	(S)	(S)	(U)	(VG)	(S)	(U)

Performance Metrics (Flow Regime)

Water Quality Monitoring Locations	PBIAS					R-squared					Nash-Sutcliffe E				
	All	Top 25%	Storms	Low 50%	Baseflow	All	Top 25%	Storms	Low 50%	Baseflow	All	Top 25%	Storms	Low 50%	Baseflow
East Holland River - Holland Landing	- (VG)	- (VG)	- (VG)	+ (VG)	+ (S)	(S)	(S)	(G)	(U)	(S)	(U)	(U)	(U)	(U)	(U)
Tannery Creek - Yonge St	+ (U)	+ (U)	+ (U)	- (U)	+ (U)	(S)	(G)	(G)	(U)	(U)	(U)	(U)	(U)	(U)	(U)
Western Creek	- (U)	- (U)	- (G)	+ (U)	- (U)	(S)	(U)	(G)	(U)	(U)	(S)	(U)	(G)	(U)	(U)

Very Good (VG) | Good (G) | Satisfactory (S) | Unsatisfactory (U)

+ Positive | - Negative

Table 4-14. Water Quality Calibration. Statistical performance metric for sediment load by season and flow regime

Performance Metrics (Seasonal)

Water Quality Monitoring Locations	PBIAS					R-squared					Nash-Sutcliffe E				
	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall
East Holland River - Holland Landing	+ (S)	- (VG)	+ (U)	+ (VG)	+ (S)	(S)	(G)	(VG)	(G)	(G)	(U)	(G)	(S)	(U)	(U)
Tannery Creek - Yonge St	+ (VG)	- (G)	- (U)	+ (U)	+ (S)	(G)	(VG)	(VG)	(VG)	(G)	(U)	(U)	(S)	(U)	(U)
Western Creek	- (S)	- (G)	- (S)	- (VG)	- (VG)	(VG)	(G)	(VG)	(VG)	(VG)	(VG)	(U)	(VG)	(VG)	(VG)

Performance Metrics (Flow Regime)

Water Quality Monitoring Locations	PBIAS					R-squared					Nash-Sutcliffe E				
	All	Top 25%	Storms	Low 50%	Baseflow	All	Top 25%	Storms	Low 50%	Baseflow	All	Top 25%	Storms	Low 50%	Baseflow
East Holland River - Holland Landing	+ (S)	+ (G)	+ (G)	+ (U)	+ (U)	(S)	(S)	(G)	(U)	(G)	(U)	(U)	(S)	(U)	(U)
Tannery Creek - Yonge St	+ (VG)	+ (VG)	+ (VG)	- (U)	+ (U)	(G)	(G)	(VG)	(U)	(G)	(U)	(U)	(U)	(U)	(U)
Western Creek	- (S)	- (G)	- (G)	- (G)	- (U)	(VG)	(G)	(VG)	(U)	(VG)	(VG)	(S)	(VG)	(U)	(VG)

Very Good (VG) | Good (G) | Satisfactory (S) | Unsatisfactory (U)

+ Positive | - Negative

Table 4-15. Water Quality Calibration. Performance metrics for total phosphorus concentration by season and flow regime

Performance Metrics (Seasonal)

Water Quality Monitoring Locations	PBIAS					R-squared					Nash-Sutcliffe E				
	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall
East Holland River - Holland Landing	- (Satisfactory)	- (Unsatisfactory)	- (Very Good)	- (Very Good)	+ (Very Good)	(Unsatisfactory)	(Satisfactory)	(Satisfactory)	(Unsatisfactory)	(Satisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)
Tannery Creek - Yonge St	+ (Unsatisfactory)	+ (Very Good)	- (Very Good)	+ (Unsatisfactory)	+ (Unsatisfactory)	(Satisfactory)	(Unsatisfactory)	(Satisfactory)	(Good)	(Good)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)
Western Creek	- (Very Good)	- (Satisfactory)	+ (Very Good)	+ (Good)	- (Very Good)	(Satisfactory)	(Unsatisfactory)	(Very Good)	(Good)	(Good)	(Unsatisfactory)	(Unsatisfactory)	(Very Good)	(Unsatisfactory)	(Unsatisfactory)

Performance Metrics (Flow Regime)

Water Quality Monitoring Locations	PBIAS					R-squared					Nash-Sutcliffe E				
	All	Top 25%	Storms	Low 50%	Baseflow	All	Top 25%	Storms	Low 50%	Baseflow	All	Top 25%	Storms	Low 50%	Baseflow
East Holland River - Holland Landing	- (Satisfactory)	- (Good)	- (Good)	- (Good)	- (Good)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)
Tannery Creek - Yonge St	+ (Unsatisfactory)	+ (Unsatisfactory)	+ (Unsatisfactory)	- (Good)	+ (Satisfactory)	(Satisfactory)	(Satisfactory)	(Good)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)
Western Creek	- (Very Good)	- (Very Good)	- (Very Good)	- (Satisfactory)	- (Unsatisfactory)	(Satisfactory)	(Unsatisfactory)	(Good)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)

Very Good | Good | Satisfactory | Unsatisfactory

\+ Positive | - Negative

Table 4-16. Water Quality Calibration. Performance metrics for total phosphorus load by season and flow regime

Performance Metrics (Seasonal)

Water Quality Monitoring Locations	PBIAS					R-squared					Nash-Sutcliffe E				
	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall	All	Winter	Spring	Summer	Fall
East Holland River - Holland Landing	- (Unsatisfactory)	- (Unsatisfactory)	- (Satisfactory)	- (Very Good)	- (Very Good)	(Satisfactory)	(Good)	(Very Good)	(Good)	(Good)	(Unsatisfactory)	(Satisfactory)	(Good)	(Satisfactory)	(Unsatisfactory)
Tannery Creek - Yonge St	- (Satisfactory)	- (Unsatisfactory)	- (Unsatisfactory)	+ (Unsatisfactory)	- (Very Good)	(Satisfactory)	(Good)	(Good)	(Good)	(Good)	(Unsatisfactory)	(Unsatisfactory)	(Satisfactory)	(Unsatisfactory)	(Unsatisfactory)
Western Creek	- (Very Good)	+ (Good)	- (Very Good)	+ (Good)	+ (Good)	(Very Good)	(Good)	(Very Good)	(Very Good)	(Very Good)	(Good)	(Unsatisfactory)	(Very Good)	(Very Good)	(Satisfactory)

Performance Metrics (Flow Regime)

Water Quality Monitoring Locations	PBIAS					R-squared					Nash-Sutcliffe E				
	All	Top 25%	Storms	Low 50%	Baseflow	All	Top 25%	Storms	Low 50%	Baseflow	All	Top 25%	Storms	Low 50%	Baseflow
East Holland River - Holland Landing	- (Unsatisfactory)	- (Satisfactory)	- (Satisfactory)	+ (Satisfactory)	- (Very Good)	(Satisfactory)	(Satisfactory)	(Good)	(Unsatisfactory)	(Good)	(Unsatisfactory)	(Unsatisfactory)	(Satisfactory)	(Unsatisfactory)	(Unsatisfactory)
Tannery Creek - Yonge St	- (Satisfactory)	- (Good)	- (Good)	- (Unsatisfactory)	+ (Unsatisfactory)	(Satisfactory)	(Satisfactory)	(Good)	(Unsatisfactory)	(Good)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)	(Unsatisfactory)
Western Creek	- (Very Good)	+ (Very Good)	+ (Very Good)	- (Unsatisfactory)	- (Unsatisfactory)	(Very Good)	(Good)	(Very Good)	(Unsatisfactory)	(Very Good)	(Good)	(Good)	(Very Good)	(Unsatisfactory)	(Very Good)

Very Good | Good | Satisfactory | Unsatisfactory

\+ Positive | - Negative

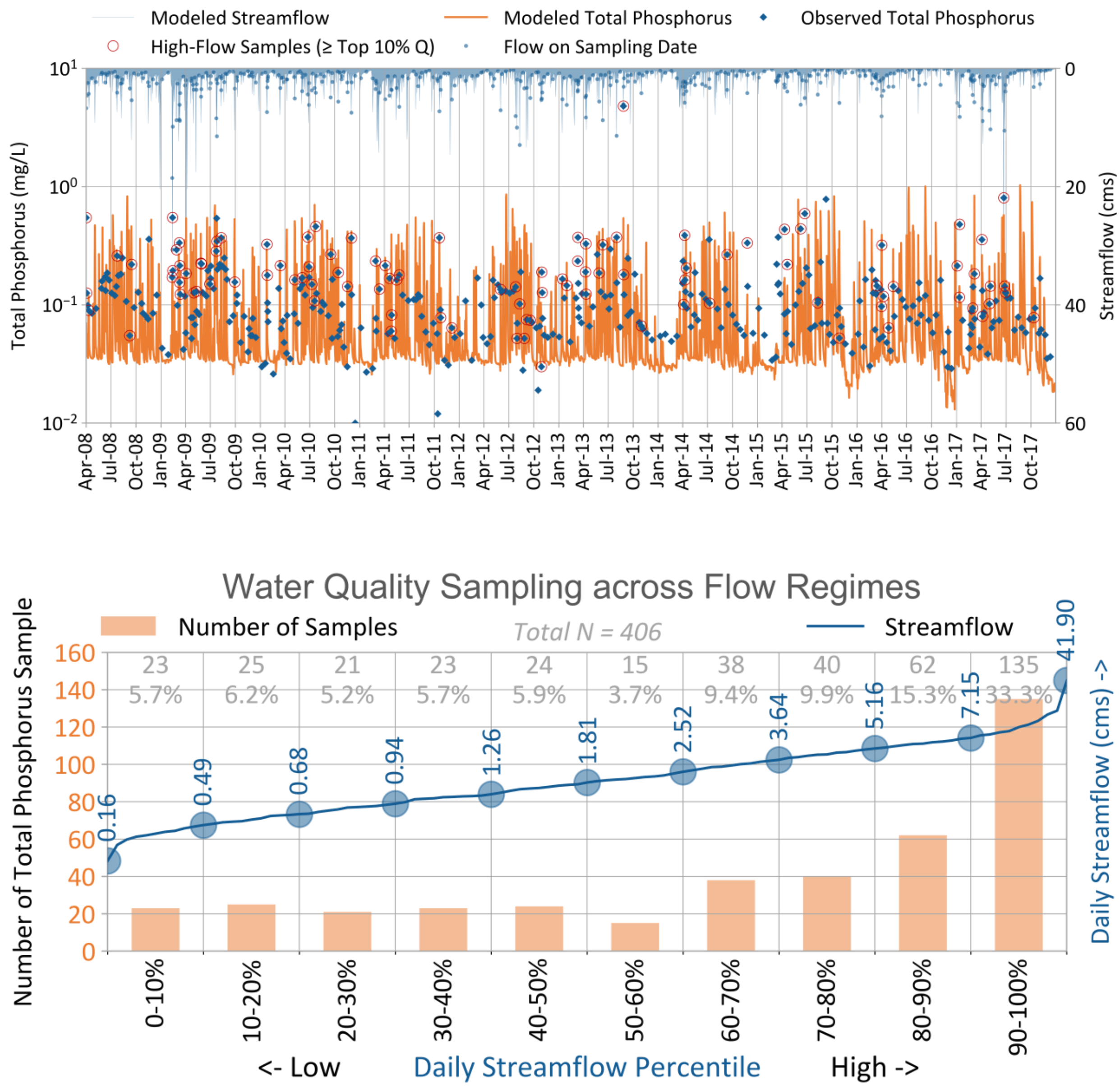


Figure 4-27. East Holland River - Holland Landing (02EC009) – Total phosphorus calibration: Simulated daily vs. observed grab sample concentration time series (top) and flow duration with total phosphorus sampling (bottom).

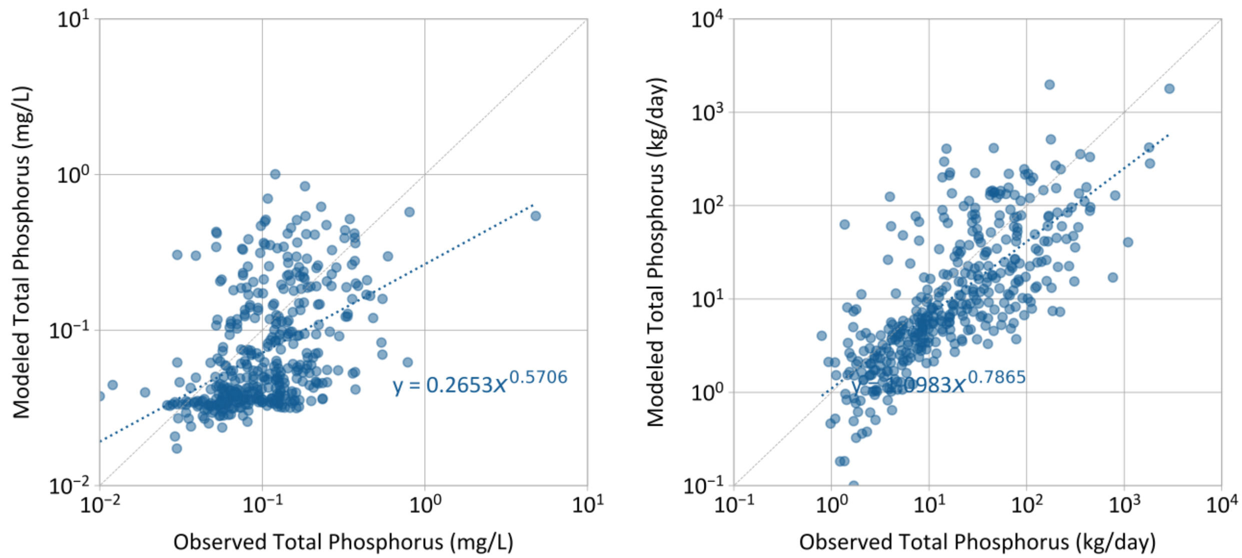


Figure 4-28.East Holland River - Holland Landing (02EC009)-Total phosphorus calibration: Simulated vs. observed daily total phosphorus daily concentrations (left) and loading rates (right).

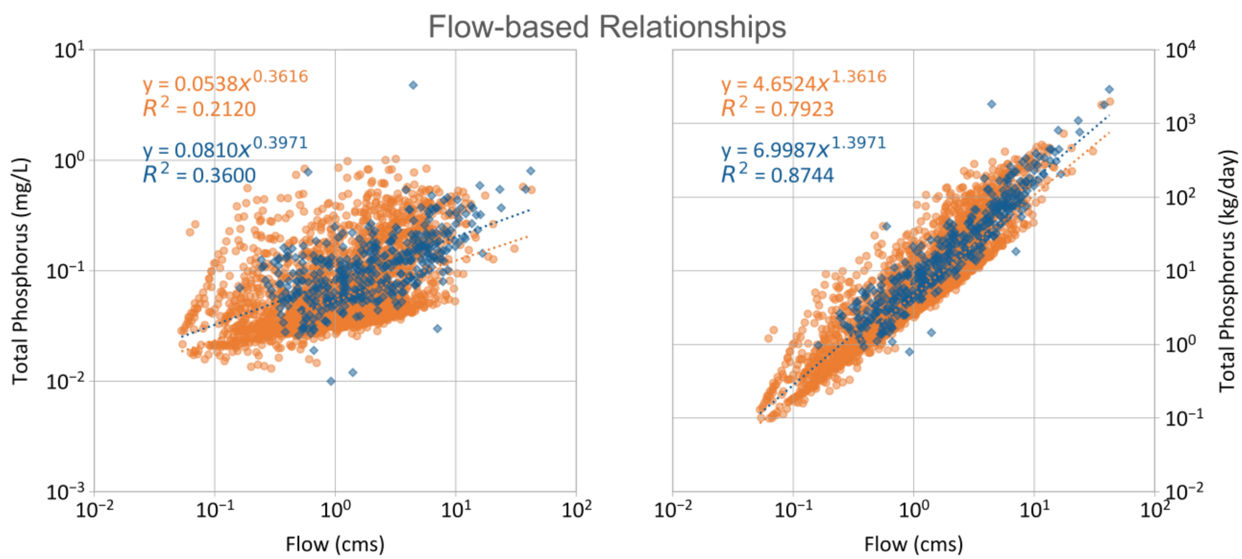


Figure 4-29. Holland River – Holland Landing (02EC009) Total Phosphorus Calibration: Total Phosphorus samples across flow regimes.

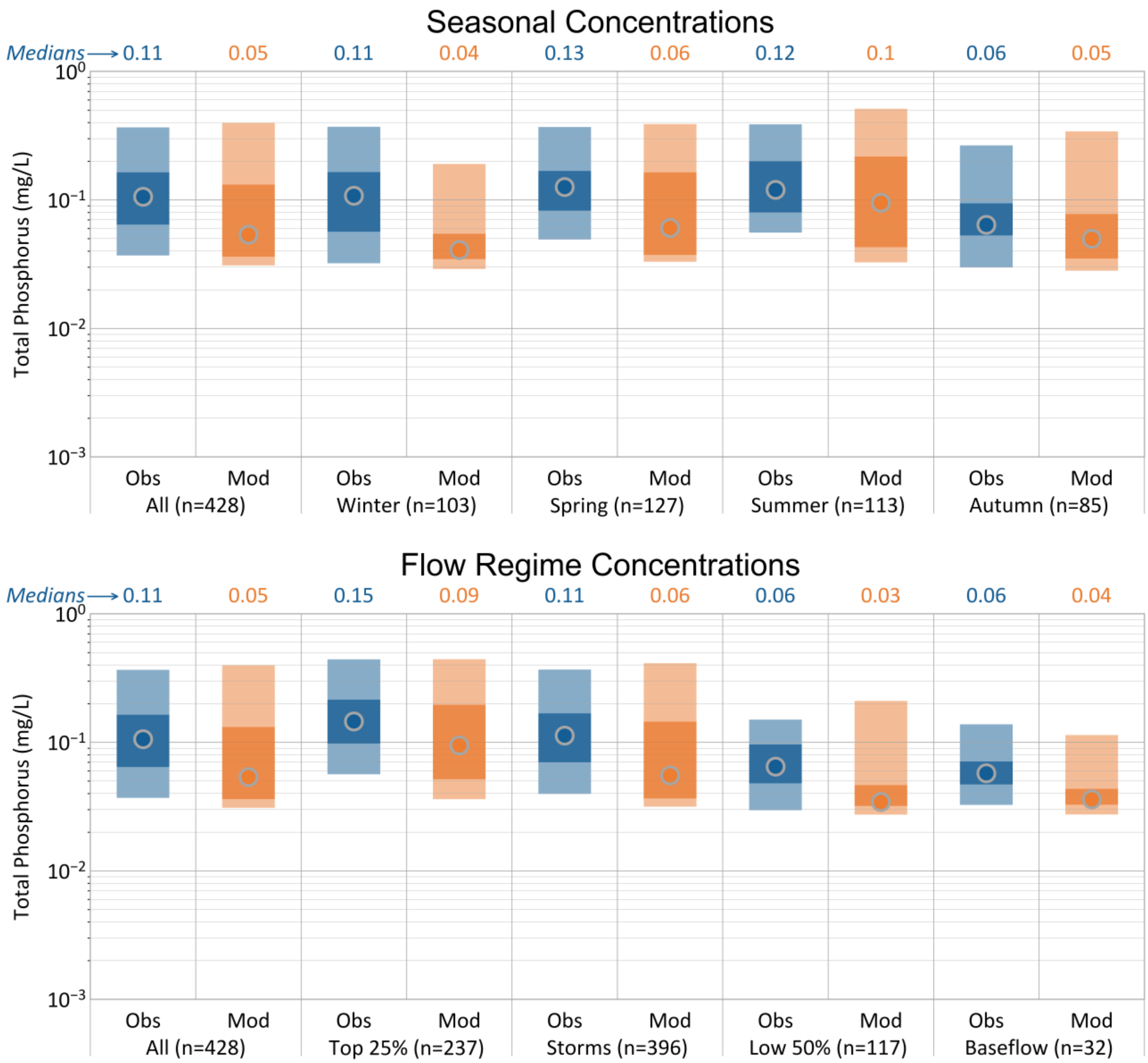


Figure 4-30. Holland River – Holland Landing (02EC009) Total Phosphorus Calibration: Simulated vs. observed daily total phosphorus concentrations by season and flow regime.

Table 4-17. Holland River – Holland Landing (02EC009) Total Phosphorus Calibration: PBIAS calibration metrics for total phosphorus concentration

Condition during Sample Collection *(04/01/2008 - 12/31/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration)									
	Percent Bias (PBIAS)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	-20.2%	406	-43.8%	95	-19.3%	123	-15.8%	105	3.2%	83
Samples on Days with Highest 25% of Flows	-21.1%	217	-43.8%	61	-12.3%	79	-21.2%	48	2.3%	29
Samples on Days with Lowest 50% of Flows	-26.7%	116	-34.1%	21	-55.6%	23	-18.8%	42	5.5%	30
Samples on Storm Volume Days	-20.2%	376	-44.0%	87	-18.5%	116	-16.8%	100	4.6%	73
Samples on Baseflow Volume Days	-20.4%	30	-40.2%	8	-43.5%	7	43.3%	5	-15.6%	10

Percent Bias (PBIAS)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	<15%	15% - 20%	20% - 30%	>30%	Moriasi et al. (2015)
Seasonal and High/Low Flows	<20%	20% - 30%	30% - 40%	>40%	

Table 4-18. Holland River – Holland Landing (02EC009) Total Phosphorus Calibration: PBIAS calibration metrics for total phosphorus load

Condition during Sample Collection *(04/01/2008 - 12/31/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Load (Observed Daily Load vs Daily Simulated Load)									
	Percent Bias (PBIAS)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	-33.2%	406	-59.9%	95	-30.2%	123	-19.7%	105	-2.6%	83
Samples on Days with Highest 25% of Flows	-36.7%	217	-60.7%	61	-31.3%	79	-28.6%	48	-9.0%	29
Samples on Days with Lowest 50% of Flows	37.7%	116	-9.8%	21	-0.4%	23	81.9%	42	36.7%	30
Samples on Storm Volume Days	-33.4%	376	-59.9%	87	-30.3%	116	-20.2%	100	-2.8%	73
Samples on Baseflow Volume Days	-1.4%	30	-53.4%	8	-13.3%	7	254.2%	5	12.7%	10

Percent Bias (PBIAS)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	<15%	15% - 20%	20% - 30%	>30%	Moriasi et al. (2015)
Seasonal and High/Low Flows	<20%	20% - 30%	30% - 40%	>40%	

Table 4-19. Holland River – Holland Landing (02EC009) Sediment Calibration: R^2 calibration metrics for total phosphorus concentration

Condition during Sample Collection *(04/01/2008 - 12/31/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) R-Squared (R^2)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.21	406	0.25	95	0.27	123	0.09	105	0.24	83
Samples on Days with Highest 25% of Flows	0.14	217	0.09	61	0.3	79	0.0	48	0.13	29
Samples on Days with Lowest 50% of Flows	0.02	116	0.01	21	0.01	23	0.01	42	0.02	30
Samples on Storm Volume Days	0.2	376	0.23	87	0.26	116	0.08	100	0.21	73
Samples on Baseflow Volume Days	0.08	30	0.16	8	0.0	7	0.13	5	0.16	10

R-Squared (R^2)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.70	0.6 - 0.70	0.30 - 0.60	<0.30	Moriasi et al. (2015)
Seasonal and High/Low Flows	> 0.60	0.30 - 0.60	0.20 - 0.30	<0.20	

Table 4-20. Holland River – Holland Landing (02EC009) Total Phosphorus Calibration: R^2 calibration metrics for total phosphorus load

Condition during Sample Collection *(04/01/2008 - 12/31/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Load (Observed Daily Load vs Daily Simulated Load) R-Squared (R^2)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.55	406	0.57	95	0.62	123	0.5	105	0.5	83
Samples on Days with Highest 25% of Flows	0.24	217	0.3	61	0.4	79	0.03	48	0.18	29
Samples on Days with Lowest 50% of Flows	0.14	116	0.19	21	0.26	23	0.19	42	0.03	30
Samples on Storm Volume Days	0.54	376	0.52	87	0.61	116	0.49	100	0.51	73
Samples on Baseflow Volume Days	0.37	30	0.64	8	0.96	7	0.62	5	0.06	10

R-Squared (R^2)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.70	0.6 - 0.70	0.30 - 0.60	<0.30	Moriasi et al. (2015)
Seasonal and High/Low Flows	> 0.60	0.30 - 0.60	0.20 - 0.30	<0.20	

Table 4-21. Holland River – Holland Landing (02EC009) Sediment Calibration: NSE calibration metrics for total phosphorus concentration

Condition during Sample Collection *(04/01/2008 - 12/31/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Concentration (Observed Instantons Grab Sample Concentration vs Average Daily Simulated Concentration) — Nash-Sutcliffe Efficiency (E)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	-0.65	406	-0.74	95	-1.03	123	-1.18	105	-0.35	83
Samples on Days with Highest 25% of Flows	-0.98	217	-2.41	61	-0.43	79	-1.07	48	-0.68	29
Samples on Days with Lowest 50% of Flows	-1.54	116	-0.67	21	-6.0	23	-2.84	42	-2.44	30
Samples on Storm Volume Days	-0.74	376	-0.84	87	-1.03	116	-1.23	100	-0.46	73
Samples on Baseflow Volume Days	-1.17	30	-2.11	8	-3.78	7	-24.88	5	-0.0	10

Nash-Sutcliffe Efficiency (E)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.65	0.50 - 0.65	0.35 - 0.50	<0.35	Moriasi et al. (2015)
Seasonal and High/Low Flows	>0.50	0.35 - 0.50	0.25 - 0.35	<0.25	

Table 4-22. Holland River – Holland Landing (02EC009) Total Phosphorus Calibration: NSE calibration metrics for total phosphorus load

Condition during Sample Collection *(04/01/2008 - 12/31/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Load (Observed Daily Load vs Daily Simulated Load) — Nash-Sutcliffe Efficiency (E)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.35	406	0.28	95	0.35	123	0.33	105	0.13	83
Samples on Days with Highest 25% of Flows	-0.54	217	-1.04	61	-0.12	79	-1.01	48	-0.49	29
Samples on Days with Lowest 50% of Flows	-2.23	116	-1.01	21	-7.59	23	-1.55	42	-6.54	30
Samples on Storm Volume Days	0.3	376	0.21	87	0.34	116	0.29	100	0.06	73
Samples on Baseflow Volume Days	-0.07	30	-0.15	8	-0.28	7	-5.32	5	-1.22	10

Nash-Sutcliffe Efficiency (E)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.65	0.50 - 0.65	0.35 - 0.50	<0.35	Moriasi et al. (2015)
Seasonal and High/Low Flows	>0.50	0.35 - 0.50	0.25 - 0.35	<0.25	

4.6.3 Evaluation of Pollutograph Sampling at Holland Landing

Sub-daily storm samples from a 365-day monitoring study in East Holland River at Holland Landing (Figure 4-7) were also compared against hourly modelled TP timeseries during model calibration to assess how well the model predicted phosphorus levels under different conditions. As shown in Figure 4-31 and Figure 4-32, comparison of modelled vs. observed instream TP generally had better agreement during wet weather (i.e., top 10% of modelled streamflow) than for the lower 90% of modelled flows. Concentrations were about 40% to 300% higher for the top 10% of flows compared to the bottom 90% of flows. In general, spring, summer and fall had the best match when comparing concentrations associated with the top 10% of modelled flows, while winter tended to underpredict instream TP. This finding suggests to SWM managers that although the current state model predictions are representative of TP export from land during storms, there are still relatively high TP levels in baseflow loads to the lake that may need to be addressed through other management strategies.

To better understand the seasonal variability summarized above, selected sub-daily storm intervals were evaluated. Findings of this assessment are summarized as follows:

- Figure 4-33 shows model performance over the three wettest consecutive 3-day periods in the sampled record. Because sediment detachment is a function of rainfall intensity, the model shows the most pronounced response when rainfall intensity is highest. As seen in the upper panel, rainfall volume alone does not translate into higher phosphorus levels in runoff—intensity is a major driver. In the middle panel, the model follows the general rise and fall of the pollutograph but does not reach the highest peaks. The lower panel models a response for one of the most intense 1-hour intervals, but the comparison suggests that perhaps that peak was a localized rainfall event that did not occur at that time and location. Nevertheless, the range of responses across the three wettest 3-day periods encapsulates the range of observed phosphorus concentrations among the three intervals evaluated demonstrating that the model is responsive to intense rainfall runoff events.
- Figure 4-34 shows model performance for three other events with notable rainfall totals that all have less than a 24-hour duration. The model generally performed best for those types of events. In order from top to bottom, the panels show fall (28 mm), summer (17.8 mm), and spring (11.5 mm) storms. The peak intensities of the fall and summer storms appear to align in such a way as to produce good agreement in the resulting estimated phosphorus concentration. The lower panel (spring storm) also shows a reasonably good fit; however, the slight misalignment of concentrations suggests that the localized rainfall distribution may have been different than the modelled storm.
- Figure 4-35 shows two events where the level of phosphorus concentrations observed in the stream do not appear to correlate well with the amount of precipitation that was simulated. Both events occurred in early-to-mid March, a typical time for snowmelt. The modelled runoff volume and/or energy associated with the snowmelt event may not be as representative during snowmelt periods. Also, the coupling of the current snow module with the sediment and water quality may not be as representative for capturing this process because soluble P originating from surface soil and plant residues may be a larger portion of total P than particulate P during snowmelt. Furthermore, the model is not currently able to simulate snow removal/relocation. Moving snow from treated paved surface to unpaved surfaces changes the chemical composition of the snowpack and the melting rate and delivery, which may be responsible in for part of the elevated and attenuated TP levels that consistently occur during the winter months.

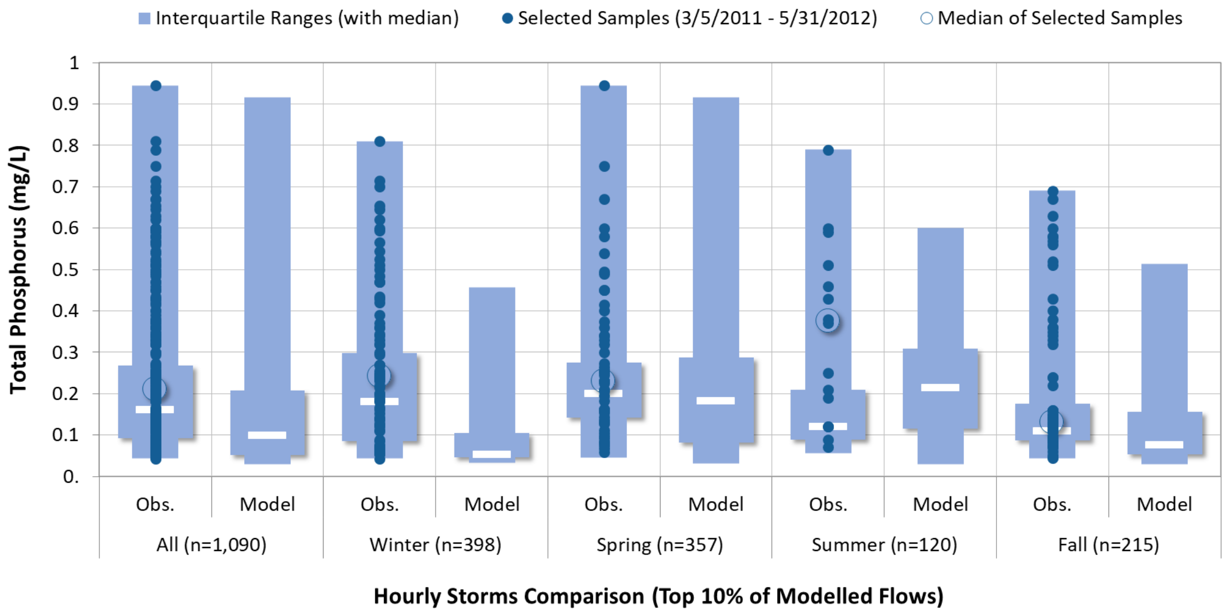


Figure 4-31. Modelled vs. observed wet-weather total phosphorus concentrations for top 10% of modelled flows at East Holland Landing.

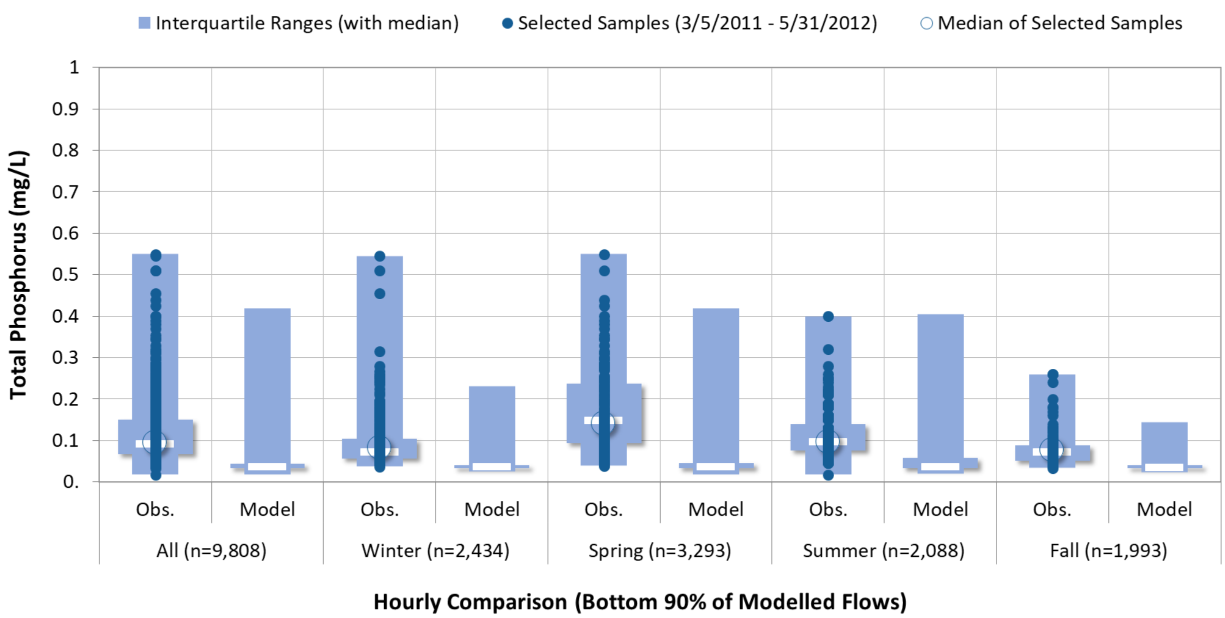


Figure 4-32. Modelled vs. observed total phosphorus concentrations for bottom 90% of modelled flows at East Holland Landing.

- Conversely, Figure 4-36 shows two winter events where the modelled phosphorus is higher than the observed phosphorus. Although this is not common, those results suggest that the model occasionally overpredicts phosphorus for some wet-weather events, which may also be related to snowfall/snowmelt predictions.If precipitation is simulated as snowfall, the energy associated with it does not detach or mobilize sediment; however, if it arrives as rainfall or snowmelt, sediment can be detached and/or mobilized. Although the model is well calibrated for snowfall at macroscale comparison, there may be small localized variations that were not fully characterized. Insights gained suggest that possible refinements to the coupling of the snow module with the sediment and water quality modules to address (1) snowpack relocation and (2) snowpack water quality may help to better characterize pollutant storage, mobilization, and transport associated with snowmelt.

Overall, the pollutograph sampling at East Holland served as a valuable dataset for gaining insight to model performance.

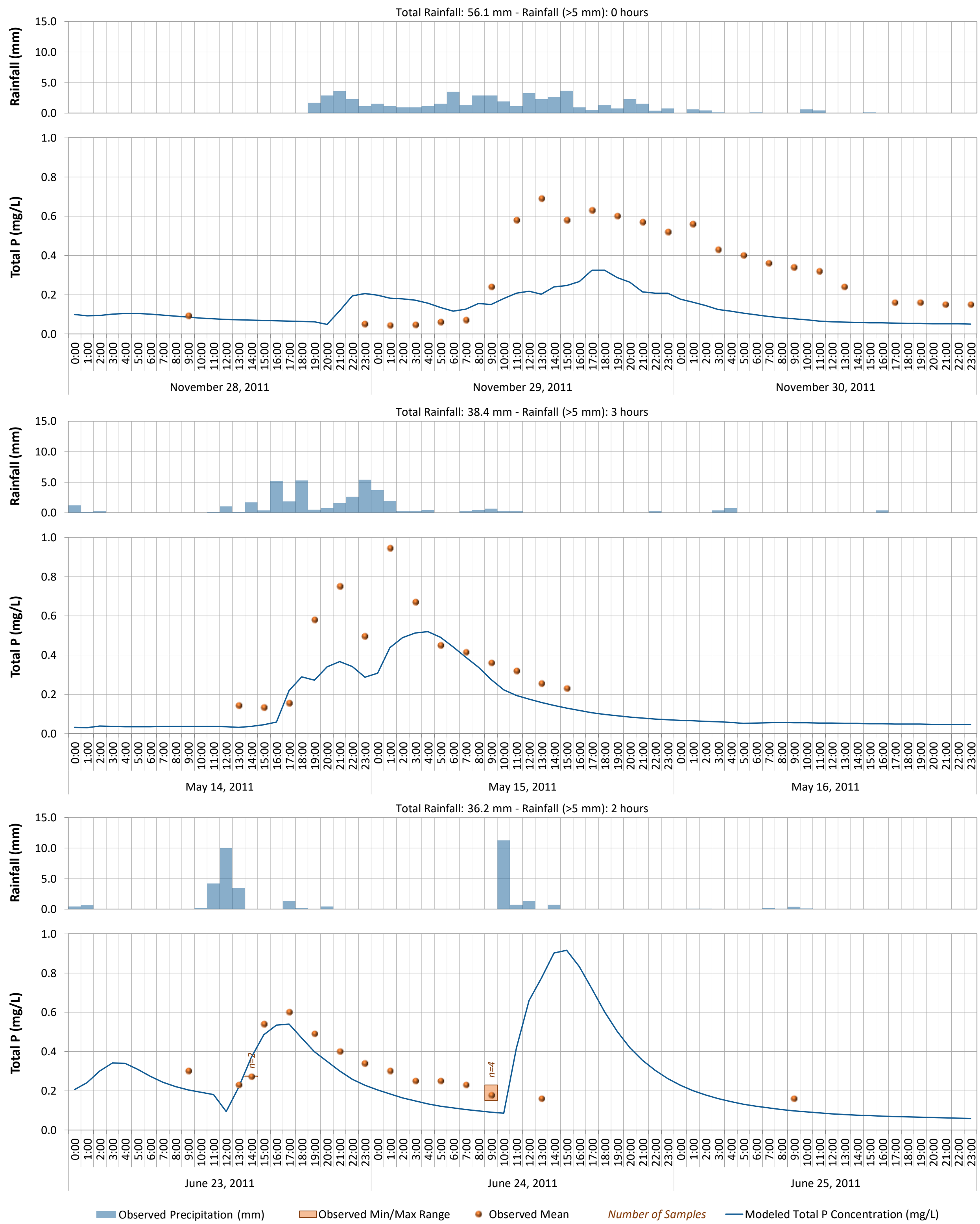


Figure 4-33. Modelled vs. observed total phosphorus pollutographs for 3 wettest consecutive 3-day periods – East Holland River, East Holland Landing.

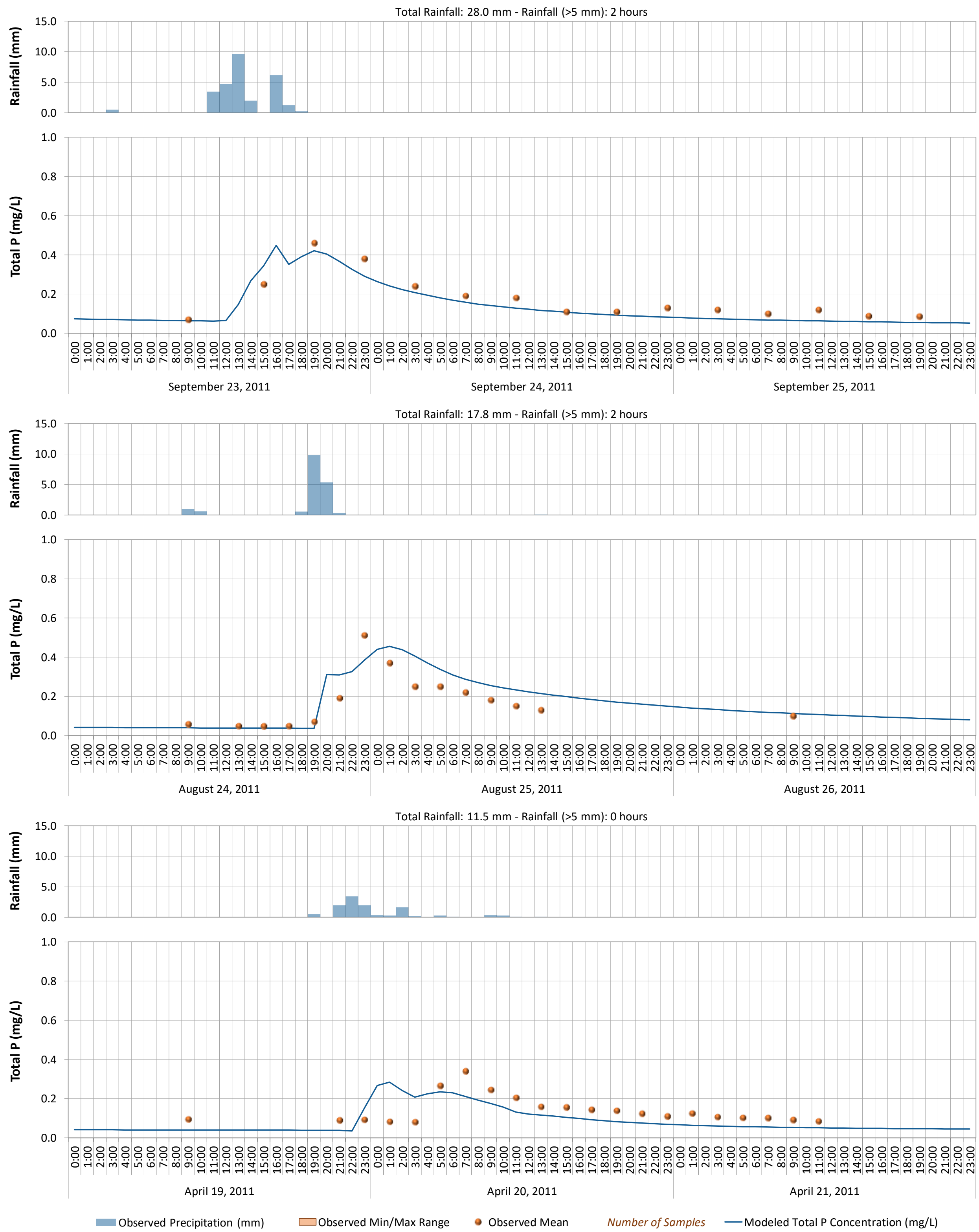


Figure 4-34. Modelled vs. observed total phosphorus pollutographs for 3 events (< 24-hour duration) – East Holland River, East Holland Landing.

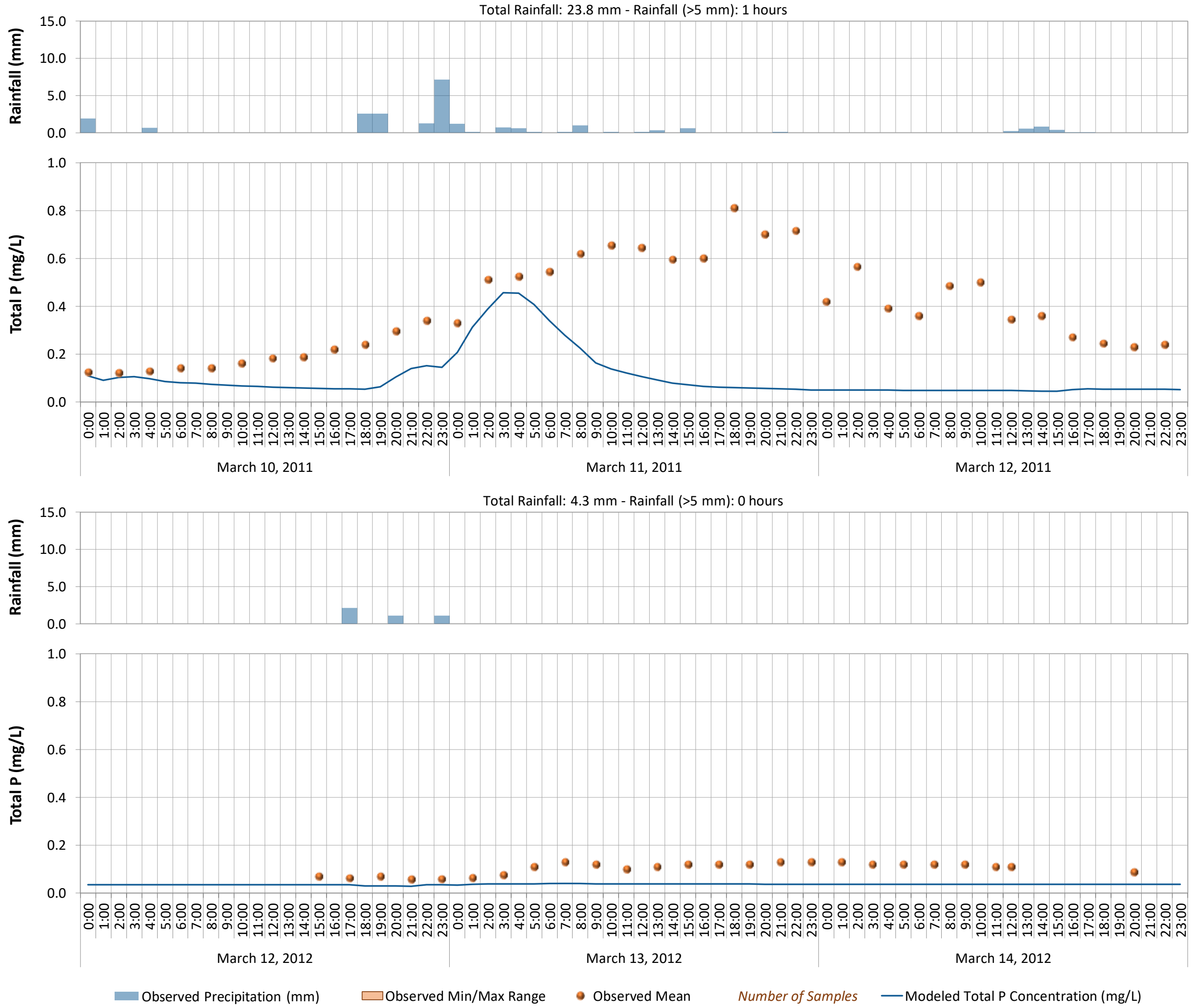


Figure 4-35. Modelled vs. observed total phosphorus pollutographs (2 March events) – East Holland River, East Holland Landing.

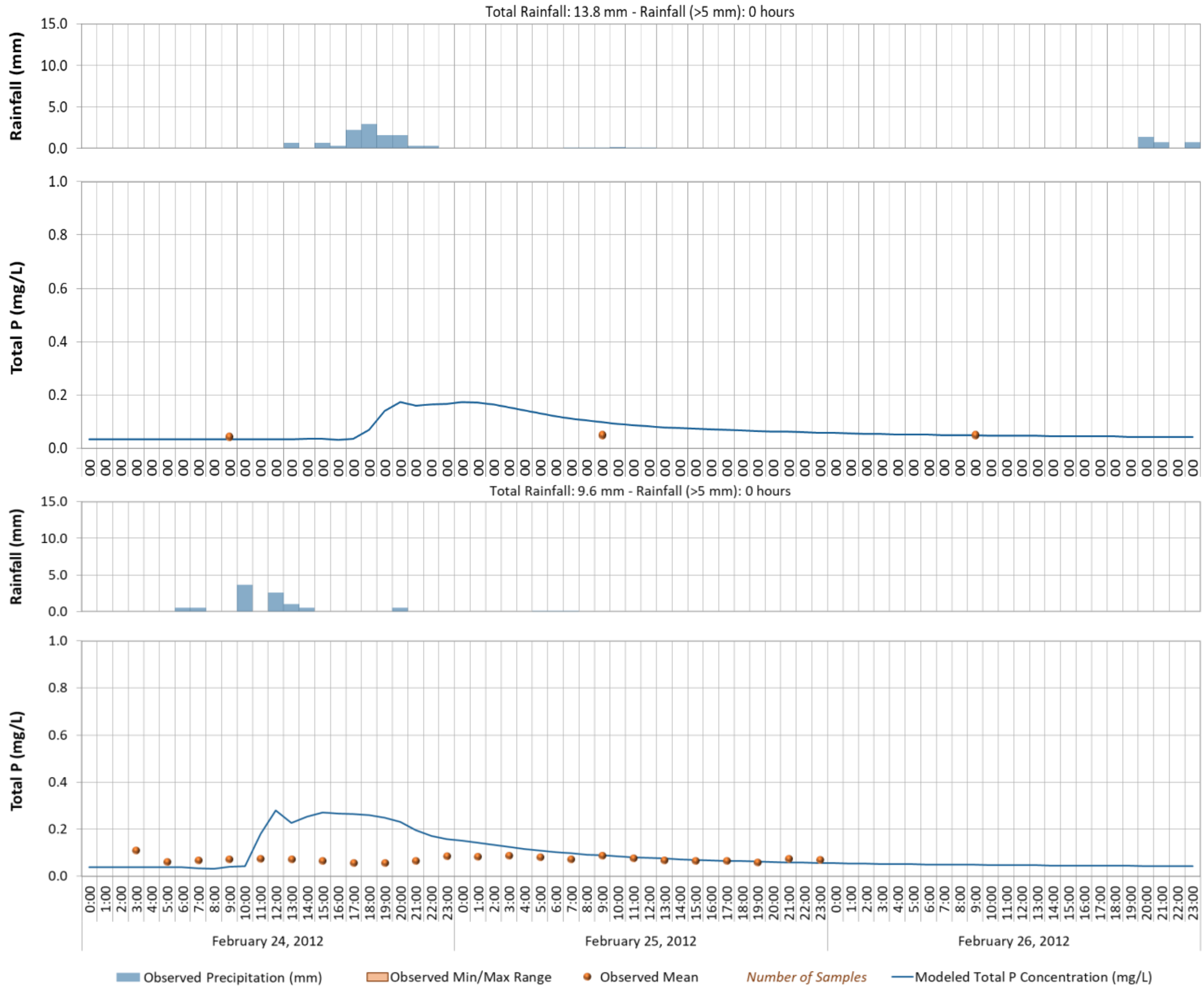


Figure 4-36. Modelled vs. observed total phosphorus pollutographs for 2 winter/snowfall events – East Holland River, East Holland Landing.

4.6.4 Evaluation of Watershed-Wide Nutrient Loading to Lake Simcoe

The final evaluation of water quality performance was comparison of LPSC outputs for watershed-wide phosphorous loading to Lake Simcoe to other available estimates. Evaluations included the following comparisons to available literature and data:

- A recent Lake Simcoe phosphorus load report (LSRCA, 2017) estimated that the 2012/2013 - 2014/2015 average annual export rate was 45-120 $kg/km^2/year$ for the East Holland River watershed. According to LSPC, predicted average annual edge-of-field TP export over the 9-year simulation was 39 $kg/km^2/year$ while the predicted average annual loading delivered to Lake Simcoe was 36 $kg/km^2/year$.
- Comparisons were also made to previous modelling performed during an Assimilative Capacity Study (ACS) for Lake Simcoe (LSRCA 2010). The ACS used the CANWET watershed model and the associated algorithms for dissolved and solid-phase nutrient export from rural lands and buildup and washoff from urban lands. The LSPC model predicted higher annual average TP loading to Lake Simcoe, 8,584 kg per year compared to 6,090 kg per year (Table 4-23). Regarding sources, LSPC parameterizes agriculture and groundwater as having relatively more TP loading compared to other sources when compared to CANWET. The LSPC modelled phosphorus loading from groundwater ranges from 15.7% to 23.1% of the total load (depending on whether interflow outflow is considered as part of groundwater), while CANWET estimated 2.5% of the load. Based on the weight-of-evidence, including groundwater sampling and observed pollutographs, the higher loading from groundwater simulated by LSPC appears to be justified.
- The pollutograph sampling conducted by LSRCA at Holland Station between March 2011 and May 2012 (see Section 4.2.1) provides an approximately 1-year evaluation window to estimate observed loading. As shown in Table 4-24. the LSPC outputs during the monitoring period were compared and used to estimate watershed-wide loading to Lake Simcoe. The watershed-wide estimate used the simple ratio that 72% of the East Holland watershed is upstream of Holland Landing station. Based on the sub-sampled evaluation periods, the estimated annual loading to Lake Simcoe ranged between 8,825 kg per year and 17,556 kg per year based on monitoring data and 7,361 kg per year and 11,021 kg per year based on LPSC outputs. The variation during the period for the monitoring period appears to be due to elevated baseflow concentrations between March and May 2012 which substantially increased loading rates at Holland Station. This observation illustrates the importance of baseflows when estimated impacts on Lake Simcoe.

Table 4-23. Relative/percent phosphorus loading by land use, total edge-of-field, and delivered load.

Source (LSRCA 2010)	LSRCA, 2010	LSPC, 2019	HRU Analogue (LSPC 2019)
Hay/Pasture	2.63%	1.39%	Agriculture_Low
Crop Land	8.34%	15.77%	Agriculture_High
Other	3.75%	0.87%	Natural Heritage
Low-Intensity Development	0.43%	4.09%	Dev_Residential_Low_Medium
High-Intensity Development	82.35%	54.76%	Dev_Residential_Medium_High Dev_Commercial Dev_Industrial Dev_Transportation
Groundwater	2.50%	7.43%	Interflow Outflow
		15.69%	Groundwater Outflow
Edge-of-Field Load (kg/yr)	**6,090**	**9,315**	**Edge-of-Field Load (kg/yr)**
Delivered Load (kg/yr)	**n/a**	**8,584**	**Delivered Load (kg/yr)**

Table 4-24. Observed vs. modelled phosphorus results for March 2011 to May 2012 period at Holland Landing

Period	Observed			Modelled		
	Average Daily TP Load (kg/day)	Total P Load (kg)	Corresponding Watershed-wide Estimate (kg) *	Average Daily P Load (kg/day)	Total P Load (kg)	Corresponding Watershed-wide Estimate (kg)*
03/05/2011 - 05/30/2012	28.29	12,816	17,556	17.76	8,046	11,021
03/05/2011 - 03/04/2012	30.46	11,150	15,273	20.60	7,540	10,328
05/31/2011 - 05/30/2012	17.60	6,442	8,825	14.68	5,374	7,361

* Based on dividing the loading at Holland Station by 72% to represent the areal watershed-wide loading

The watershed-wide evaluation also included analysis of 'delivery' of sediment and phosphorous to Lake Simcoe. The delivery outputs by LSPC illustrate are a key advantage of process-based modelling over empirical models – the actual downstream impact of edge-of-field discharges can be assessed based on routing, fate and transport. In the field, discharges distant from the stream are likely to have less impact than discharges proximal to the stream due to settling and other attenuation factors. Figure 4-37 and Figure 4-38 show modelled edge-of-field unit-area load (left panel) and resulting impact/delivery to Lake Simcoe (right panel) by subcatchment for sediment and phosphorus, respectively. For any given subcatchment, the delivery ratio is the fraction of pollutant that originates within the subcatchment that is delivered to Lake Simcoe through stream transport. The paired maps illustrate the aggregation of HRU yield and instream fate and transport. As previously noted, the high-recharge areas in the Oak Ridges Moraine produce less runoff and have the lowest unit-area loads. Conversely, agricultural areas near Lake Simcoe are simulated to have the highest unit area sediment loads while developed areas in the middle portion of the watershed have the highest unit-area phosphorus load. In terms of the percent of sediment and phosphorus load delivered to Lake Simcoe, subcatchments discharging to the East Holland River downstream of Holland landing appear to have the most efficient pathway (i.e., have the highest delivery ratios). Phosphorus is associated with fine particles (silts and clays); therefore, areas with a higher distribution of fine particles also have higher delivery ratios. Areas with existing modelled SWM ponds and the Oak Ridges Moraine region appear to experience the most attenuation (i.e., they have the lowest delivery ratios).

Analysis of the delivery heat maps included the following findings:

- Annual TP export ranged from near 0 to 1.4 kg/ha (Figure 4-38, left panel). The highest TP export was in the subcatchments nearest the lake; these areas are low-lying agriculture areas that experience high groundwater levels. Winter et al. (2002) found that the highest mean annual export of TP to Lake Simcoe occurred from these areas. The right panel of also demonstrates the water quality benefits of the stormwater ponds within the East Holland River Watershed as well as the effect of the Oak Ridges Moraine on TP delivery to Lake Simcoe. The relatively high permeability of that landform results in less runoff and therefore less TP delivered to the lake.
- Sediment export from subcatchments ranged from nearly 0 to 2.6 tonnes/ha (Figure 4-37**Error! Reference source not found.**, left panel). Sediment export was highest in

subcatchments near the lake and in the highly developed areas around Newmarket and Aurora. The sediment delivery ratio, which is the portion of exported sediment delivered to the lake, ranged from 0 to 100% (Figure 4-37, right panel). The right panel of Figure 4-37 also demonstrates the effectiveness of the stormwater ponds that were modelled in the East Holland River watershed. Several of the subcatchments draining to those ponds have the lowest sediment delivery ratio in the watershed because the upstream sediment load from those ponds is largely trapped and settles within the ponds.

Overall, the comparison to available literature and monitoring data suggests that LSPC loading estimates of total phosphorous inputs from East Holland watershed to Lake Simcoe are in range. While the comparison to the CANWET model suggests LSPC loadings are relatively high, comparison to observed pollutograph data support the LSPC predictions might actually under-predict loading. LSPC loading predictions are also on the low end of estimates by the 2017 Lake Simcoe loading report. Finally, the delivery ratio analysis generated with LSPC can provide a tool moving forward to support source assessment, as it differentiates between high-load and high-impact areas of the watershed.

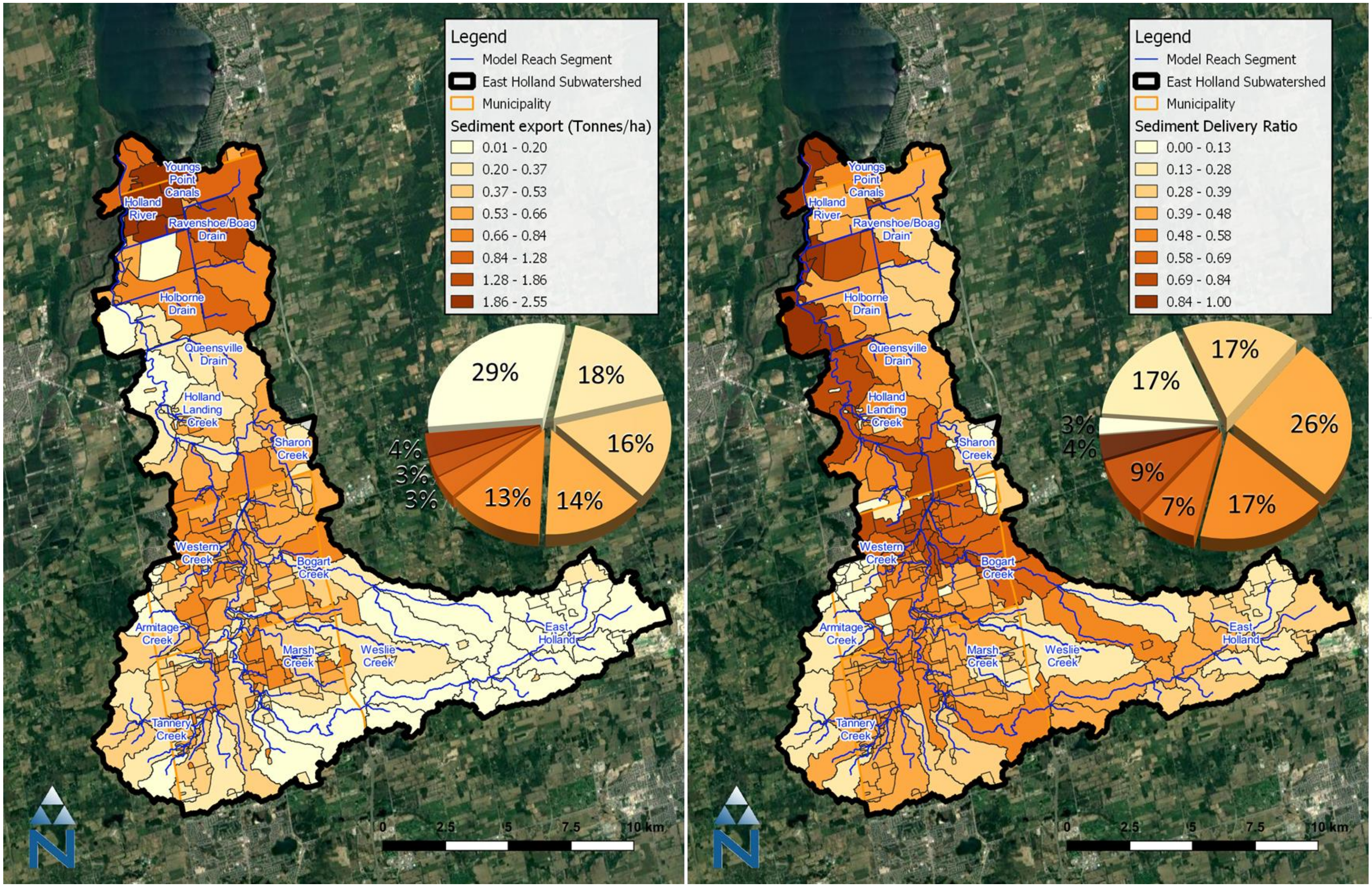


Figure 4-37. Edge-of-field sediment load (left panel) and percent delivered load to Lake Simcoe (right panel) by subcatchment.

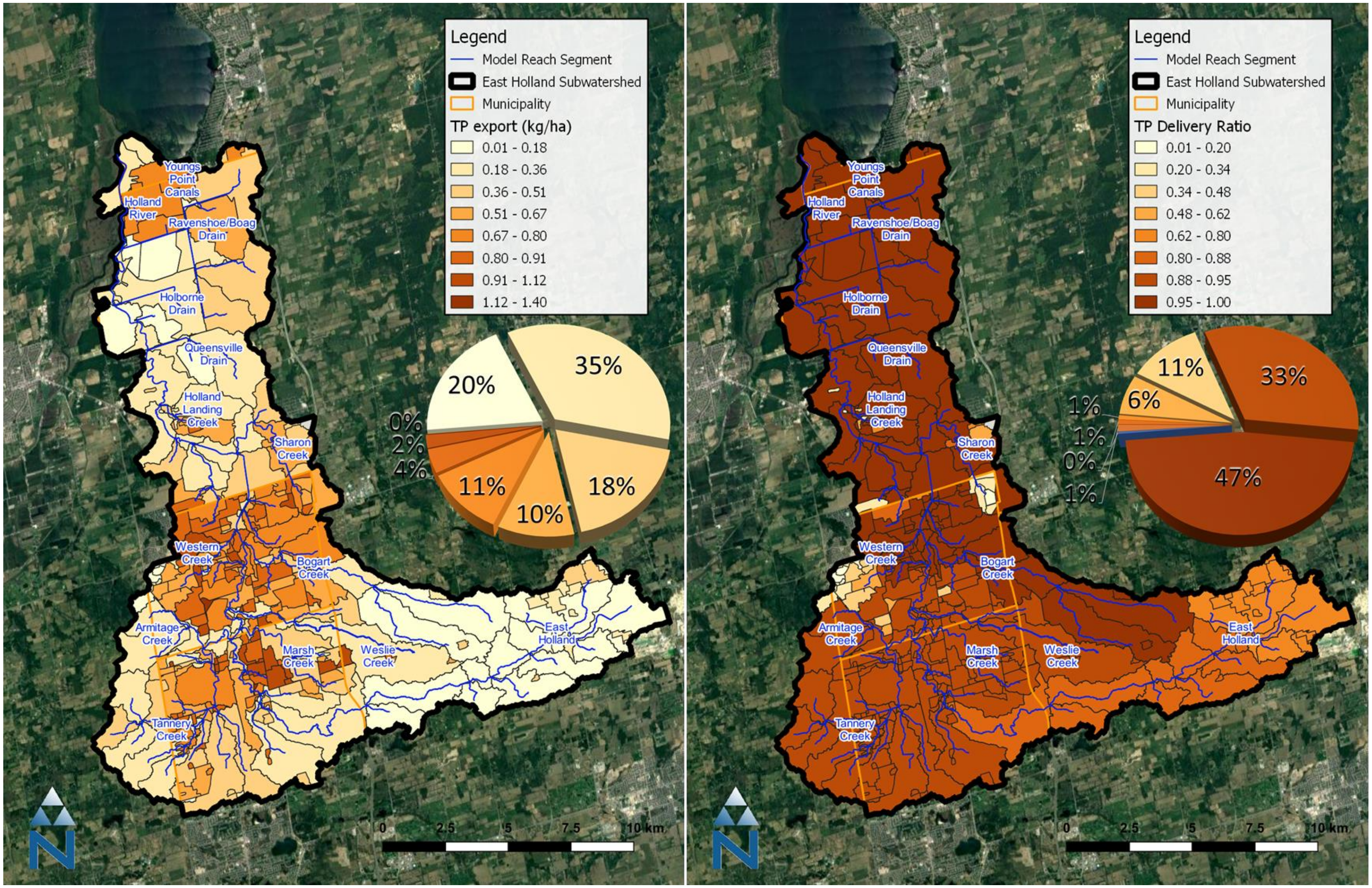


Figure 4-38. Edge-of-field total phosphorus load (left panel) and percent delivered load to Lake Simcoe (right panel) by subcatchment.

4.7 Discussion of Calibration Performance

Two important objectives of the 'Current State' modelling effort for the EqR4TD project are to provide representative runoff timeseries at the HRU level to be used as boundary conditions for Future State modelling including: (1) simulation of the benefit of distributed and regional SWM practices modelled in SUSTAIN and (2) peak flow estimates for flood modelling and linkage to HEC-RAS. In addition, outside of the EqR4TD project, the Current State model generated for East Holland could potentially provide a starting point for a modelling framework that could support Lake Simcoe-wide assessment and tracking of offset programs to mitigate phosphorous. For all of the above application, robust simulation of *storm runoff conditions* and mitigation by SWM practices is a top priority.

The calibrated LSPC model is reasonably calibrated or well-calibrated for storm conditions. The Current State model achieved 'Very Good' metrics for both the 'Highest 10% of Flows' and seasonal storm volume predictions achieved 'Very Good' across all seasons, suggesting that model simulation of rainfall runoff is representative of measured conditions for an urban/peri-urban watershed. Furthermore, for the calibration assessments, the LSPC model performance at Western Creek is excellent. Western Creek is the most representative station for developed/impervious areas within East Holland watershed. While East Holland River at Holland Station is the most downstream station, more emphasis was placed on Western Creek for parameter setting. The Western Creek watershed also has the highest resolution data of existing SWM ponds.

The comparison of observed versus simulated pollutographs provided important insight that can inform phosphorus management. While SWM implementation can help address the phosphorus loading from land resulting from overland flow, there are relatively high baseflow concentrations in the East Holland River that contribute to the nutrient loading to Lake Simcoe. The calibrated LSPC performs reasonably well in predicting the rainfall-driven export of total phosphorus and can be used to assess the benefit of SWM implementation. This is evident by the agreement in storm pollutographs, the statistical metrics used to assess performance, as well as the simulated loadings and EMCs that are comparable to literature values and other modeling efforts. However, a holistic approach to nutrient management should not only include stormwater flows but acknowledge the sustained loading from groundwater. Robust prediction of groundwater-driven nutrient loading would likely require further investigation, ranging from seasonal parameter setting to coupling LSPC to a dynamic groundwater quality model. Finally, the other important source of nutrients to Lake Simcoe is loading from agricultural lands – both surface runoff and interflow. A holistic approach to phosphorous mitigation would include both rural and urban programs.

For all modelling projects, there are areas where the model performance could be improved, as follows:

- The groundwater representation in LSPC is relatively coarse, making it challenging to reflect complex hydrological trends in areas where groundwater strongly impacts hydrology. Existing annual groundwater modelling results were used to calibrate in-stream losses upstream of the Vandorf gage for which the contributing area is almost entirely reflective of Oak Ridges Moraine hydrology. Performance metrics across all stations reveal seasonal and flow regime differences in model performance for the Vandorf calibration (Table 4-3). Future studies can incorporate code changes to LSPC to allow for seasonal variations for in-stream losses.
- Among the other calibration stations, some flow regime metrics (R^2 and NSE) for Tannery Creek scored 'Unsatisfactory', while the same metrics were good or better for PBIAS. Figure C-1 (Appendix C) shows that some observed peaks were underpredicted and some extremely low flows were overpredicted. The poorer results for R^2 and NSE are likely due to both metrics sensitivity to extreme values. The good agreement shown in the PBIAS results suggest there

is not systemic bias of the central tendency of the high and low flows to be larger or smaller than their observed counterparts.

- The NSE metric generally reported worse performance than other metrics. As discussed previously, assessing model performance, the comparison between observed and predicted is inherently challenging because a daily average fully mixed model output is being compared to an instantaneous concentration from a single point in the cross section. For NSE, because the differences in modeled and predicted values are squared, the metric suggests an overestimation of the model performance during peak flows/concentrations and an underestimation during low flow/concentration conditions. For hydrology, sediment and phosphorous, the % difference in modelled and predicted values is highest at low flows/concentrations (as reflected by PBIAS) which could lead to lower NSE values. The performance of NSE, which is more influenced by the timing of simulated vs observed values, could be impacted by the use of a single weather station across the entire watershed. Overall, because a suite of metrics was used to assess performance, calibration to achieve improvements in one metric can result in poorer performance in another metric. Therefore model calibration must balance the weight of evidence provided by the suite of metrics to determine when satisfactory performance has been achieved, meaning NSE metrics alone do not reflect the model performance.
- Consideration of seasonal parameters in urban areas could also benefit model performance. Within the urban area, differences were observed in seasonal total volume between the spring and summer. For example, the spring/summer imbalances observed in appear to be systematic in the watershed because the model performs similarly at the other two gages. It could be associated with thawing of a frozen upper soil layer. Frozen ground may limit infiltration at the onset of the spring thaw. Upper zone nominal storage is one parameter that can be varied seasonally to reflect a reduced capacity in the spring, which then opens in the summer.

Overall, the Current State LSPC model developed for the EqR4TD project provides a powerful tool for assessment of Future State mitigation strategies and may also support a variety of other programs for East Holland watershed and Lake Simcoe watershed.

5 DESIGN STORM SIMULATION

Analysis of flow rates and water levels during large storm events will be an important element of the Eq4RTD project. Although LSPC can predict water levels, it is primarily a hydrologic model and does not account for backwater effects and in-channel structures that impact water levels. As such, there are discussions around linking LSPC to HEC-RAS to simulate the mitigation of elevated water levels for optimized management actions. LPSC coupled with SUSTAIN would provide the hydrologic boundary condition for the baseline condition and mitigated conditions, and HEC-RAS would estimate the corresponding water levels pre- and post-mitigation. As an early step, as described in this section, LSPC was used to simulate the runoff and peak flows from design storm conditions, which were compared to the peak flows estimated by an existing VO2 hydrologic model that has already been linked to HEC-RAS by LSRCA. This section describes the initial results of conducting design storm simulations with LSPC and comparison to outputs from VO2.

In 2005, LSRCA conducted a hydrologic and hydraulic modelling study for the West/East Holland rivers and the Maskinonge River watersheds with VO2 and HEC-RAS (LSRCA 2005). Goals of this study included calibrating and validating watershed hydrologic models, evaluating flood peak flows at key locations, and evaluating the impact of future land use changes on peak flow rates. The study evaluated both the AES and SCS design storm distribution and three different durations (6, 12, 24-hour) as candidate design storms. Based on comparison of peak flows the 12-hour SCS design storm was considered as most appropriate because of the watershed's geography and with consideration of travel time through the network (LSRCA 2005).

While both LSPC and the VO2/HEC-RAS models can estimate peak flows, several important differences exist between the two modelling approaches. LSPC is a continuous simulation model which converts rainfall to runoff using algorithms based on Philips equation (Tetra Tech, 2017). The VO2 approach was event based and used the Curve Number approach to convert rainfall to runoff (CCL, 2005). Calibration of the continuous LSPC model compared to the VO2 model involved different objectives. Hydrologic calibration for LSPC focused on several metrics, including total volume, the weekly peak and low flows, annual and seasonal storm volume, as well as baseflow characteristics. The metrics were calibrated over a 15-year period and accounted for snowmelt. The VO2 model focused on calibrating runoff volume and peak flow for four discrete precipitation events. Additionally, antecedent soil moisture conditions can also have a large impact on peak flows. The VO2 approach calibrated curve numbers using an antecedent precipitation index based on the precipitation occurring over the preceding 10 days of each calibration event. Since the LSPC model was already calibrated, antecedent conditions were accounted for by simulating each design storm in LSPC, then simulating 10 dry days, then simulating the design storm again and using the peak flows from that final day.

5.1 Design Storm Simulation

Using the 12-hour SCS Type-II storm distribution selected, a return period peak flow analysis was performed for the 2, 5, 10, 25, 50, and 100-year storm events for key floodplain mapping locations of interest throughout the East Holland River watershed. This simulation covered the entire watershed's network and was based on the following key assumptions (LSRCA 2005):

- All on-line and off-line reservoirs, lakes and stormwater management facilities in place.
- Average antecedent moisture condition (AMC II) at the start of the simulation.
- The 12-hour 1:2 to 1:100-year SCS Type II design storms.
- No areal reduction factor applied.

Table 5-1 presents a summary of the six design storms and Figure 5-1 presents an example of the 5-year 12-hour SCS storm distribution. Each of the six storms was represented using the same storm distribution (i.e., timing and proportion of peak were the same) scaled to the total storm depth presented in Table 5-1.

Table 5-1. Summary of the 12-hour, SCS Type-II return period design storms evaluated

Design Storm	Total Depth (mm)	Peak 15-minute Depth (mm)
2-year, 12-hour	42.00	13.86
5-year, 12-hour	54.40	17.95
10-year, 12-hour	62.70	20.69
25-year, 12-hour	73.10	24.12
50-year, 12-hour	80.80	26.66
100-year, 12-hour	88.50	29.20

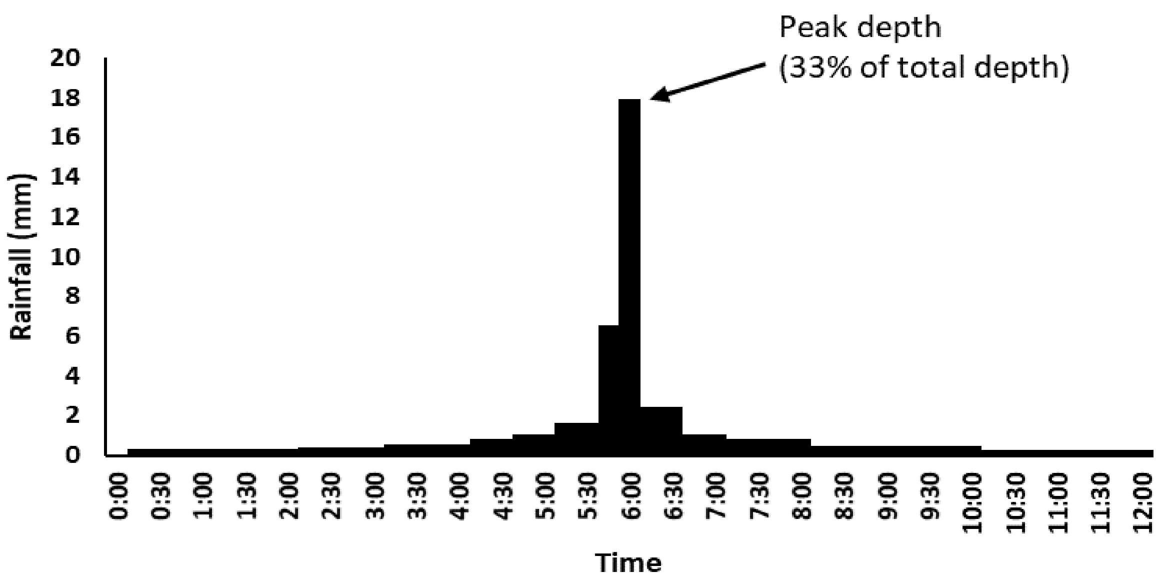


Figure 5-1.Example hyetograph of the 5-year, 12-hour SCS Type-II storm distribution.

A similar design storm analysis was performed using the LSPC watershed model for each of the six design storms listed in Table 5-1. Peak flow rates as predicted by VO2 for the six storms were extracted from the HEC-RAS model and accompanying report, which were compared to the LSPC peak flow rates. The LSPC design storm simulations were performed using 15-minute data and comparison of the peak flow evaluated only the single, maximum flow rate generated during the storm.

5.2 Comparison between LSPC– and VO2– Predicted Peak Flows

Flood-prone locations for this study were identified through a review of stream and stormwater management plans as well as discussions with municipalities and the region. Flood-prone areas were located in the municipalities of Newmarket and Aurora (Figure 5-2) based on feedback from municipalities and review of their review of stormwater and stream management master plans (Newmarket's Comprehensive Stormwater Management Master Plan and Aurora's Stream Management Master Plan & Tannery Creek Flood Relief Study). These locations were used for the LSPC-VO2 comparison, as shown in Table 5-2. Generally, the LSPC Current State model was able to bracket the peak flow results extracted from the VO2 model with underprediction of the peak for some storms and overprediction of the peak for other storms. Figure 5-3 presents a visual comparison for the LSPC and VO2 peak flows for the 100-year storm.

Note that none of the hydrologic calibration criteria presented in Figure 4-13 are directly applicable to this type of model comparison; however, annual storm volume and seasonal storm volume criteria allow up to 15% and 30% deviation from the observed data for maintaining a performance rating of *Good* or better. These metrics do not apply when comparing an event-based model to a continuous simulation model – but if the same 15% to 30% deviation tolerance was applied to the VO2-LSPC comparison, it would result in several simulations having *Very Good* or *Good* performance ratings. The largest percent differences of +135.9% and +127.6% would be within the *Poor* category. Area 10 and Area 8, located on Bogart Creek and the East Holland River, respectively, generally had the largest error across all storms. The LSPC results for the East Holland River tended to overpredict flows compared to VO2, especially as the storm size grew larger. Alternatively, LSPC results for Tannery Creek locations generally underpredicted results compared to VO2, although agreement tended to improve for larger storms.

The LSPC vs VO2 results were extremely sensitive to assumptions about initial conditions in the stream for the LSPC simulations. This is an important assumption that should be evaluated whenever a continuous-simulation model is used to predict single-storm events. The model results presented in the tables above assume 10 days of dry conditions for all streams prior to routing runoff from the design storms. The sensitivity of this assumption was tested by assuming completely dry streams (i.e., zero water depth) in all streams prior to routing the design storm runoff. For those runs, the model generally underpredicts the VO2 peak flows. Although using average annual water depth performed well at two locations, LSPC overpredicted runoff for the largest events at the Tannery Creek outlet. The LSPC hydrology calibration for Tannery Creek focused on the period between 10/1/2003 and 9/30/2010 because of data quality concerns at the gage for the period after water year 2010; therefore, the data used to calibrate VO2 and LSPC may differ slightly. The model sensitivity tests suggest that the LSPC design storm simulation could be "calibrated" to better match the VO2 peak flows by adjusting antecedent dry conditions and initial water depth in the stream at LSPC simulation beginning – however, this exercise has not been carried out at this time VO2 peak flows are not necessarily more reliable or accurate and should not necessarily drive the Future State analysis. As the Future State simulation is carried out, the methodology to assess the effect of mitigation will be determined – either to apply % peak flow reductions by mitigation to the VO2 boundary condition or use the LSPC boundary condition directly. If the decision is to use the VO2 condition, then further adjustment of LSPC peak flows to VO2 predictions can be conducted by adjusting the LPSC simulation initial conditions.

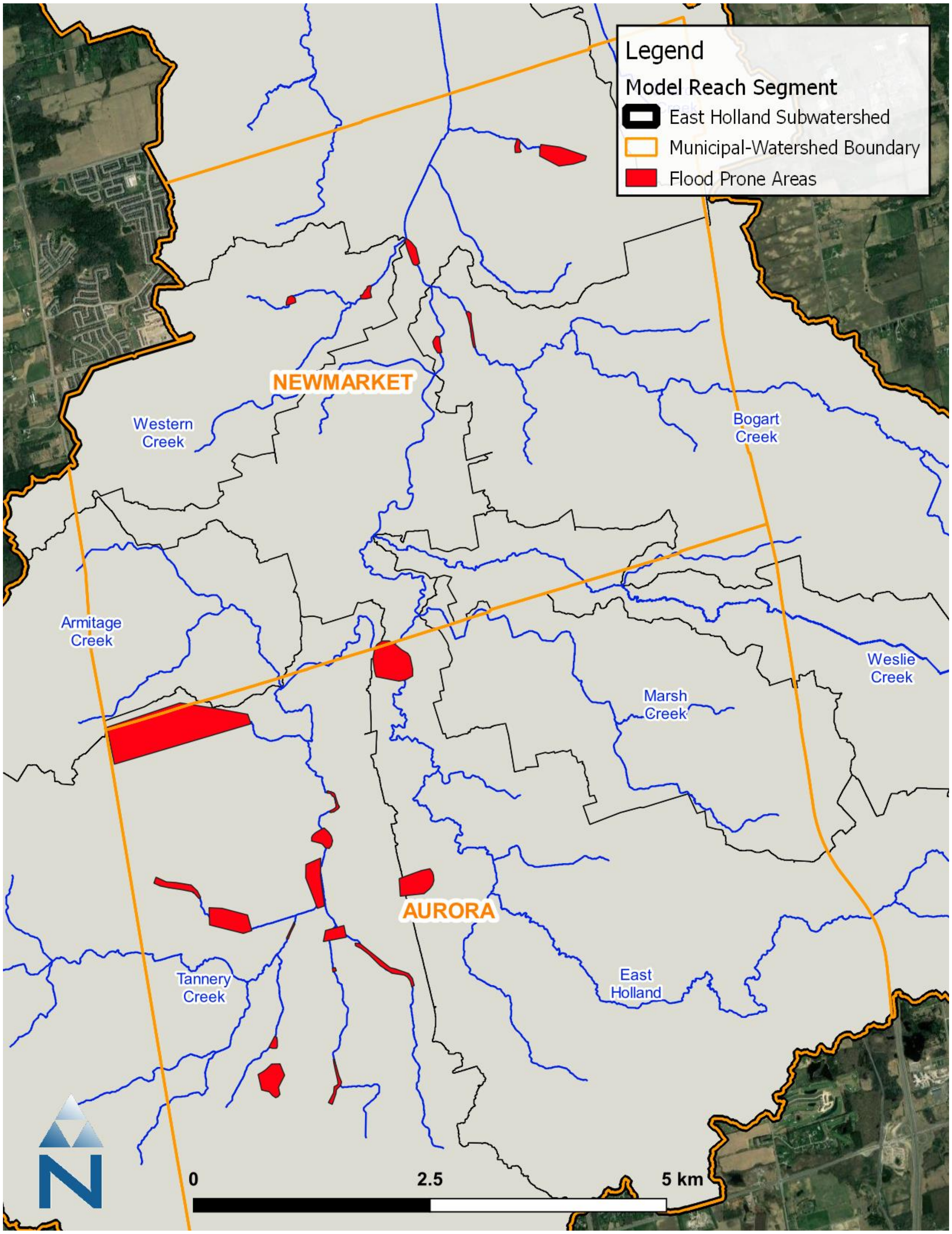


Figure 5-2. Flood-prone areas in East Holland watershed based on feedback from municipalities.

Table 5-2. Design storm peak comparisons for East Holland Watershed using VO2 vs LSPC

Waterbody	Flood-prone Location	ID	Municipality	LSPC SWID	Up-steam drainage area (km²)	Peak Discharge (m³/s) [according to hydrologic model]																	
						100 year			50 year			25 year			10 year			5 year			2 year		
						VO2	LSPC	% Diff	VO2	LSPC	% Diff	VO2	LSPC	% Diff	VO2	LSPC	% Diff	VO2	LSPC	% Diff	VO2	LSPC	% Diff
Bogart Creek	Gorham St to Srigley St	Area 10	Newmarket	12340	24.16	35.40	83.51	135.9%	30.00	58.20	94.0%	24.50	41.82	70.7%	17.80	29.75	67.1%	13.00	23.91	84.0%	7.60	17.30	127.6%
East Holland River	St. Andrews Valley golf club	Area 8	Aurora	11520	52.73	28.60	51.69	80.8%	23.70	39.07	64.8%	19.20	30.68	59.8%	14.00	21.93	56.6%	10.70	17.54	63.9%	6.30	12.92	105.1%
	Water St to Civic Dr (Doug Duncan Dr)	Area 11	Newmarket	10810	116.62	111.70	200.92	79.9%	96.10	149.51	55.6%	80.50	110.77	37.6%	60.30	70.05	16.2%	45.80	47.33	3.3%	27.30	29.98	9.8%
	North of Davis Dr, East of Tannery Mall - Ice Jam	Area 14	Newmarket	10800	141.14	131.10	245.07	86.9%	112.30	185.19	64.9%	94.20	138.29	46.8%	70.90	83.67	18.0%	54.10	58.64	8.4%	32.20	37.58	16.7%
Tannery Creek	South of Tyler Street at Temperance St	Area 2	Aurora	11510	2.95	16.40	19.15	16.8%	14.40	13.92	-3.3%	12.40	9.44	-23.9%	9.40	6.12	-34.8%	7.70	4.77	-38.0%	5.20	3.29	-36.8%
	South of Aurora Heights to Wellington St W	Area 5	Aurora	11420	1.46	11.90	14.22	19.5%	9.90	9.55	-3.5%	7.10	6.45	-9.2%	5.00	4.31	-13.8%	3.60	3.41	-5.2%	2.30	2.44	6.3%
	North of St Johns Sideroad	Area 9	Aurora	11090	1.59	4.87	8.12	66.7%	4.12	5.38	30.7%	3.56	3.65	2.5%	2.85	2.52	-11.5%	2.32	2.03	-12.7%	1.53	1.44	-6.0%
	North and South of Glass Dr - at Holman Cresent and Child Dr	Area 1	Aurora	11350	2.96	13.30	22.81	71.5%	11.40	16.73	46.7%	9.60	11.82	23.2%	7.00	8.16	16.6%	4.80	6.51	35.6%	2.80	4.72	68.7%
	Aurora Heights Dr/ Machell Park	Area 7	Aurora	11170	28.61	74.40	95.92	28.9%	63.80	67.28	5.5%	52.50	50.29	-4.2%	38.90	32.75	-15.8%	29.10	23.97	-17.6%	17.20	16.51	-4.0%
	Fleury Park/YRDSB	Area 4	Aurora	11180	17.87	41.70	60.84	45.9%	35.50	42.31	19.2%	29.80	27.96	-6.2%	22.20	18.16	-18.2%	15.90	14.11	-11.3%	8.80	9.98	13.4%
	Culverts at Dunning Ave, Royal Rd, Cousins Dr, Gurnett St, & 15085 Yonge St	Area 17	Aurora	11510	2.95	16.40	19.15	16.8%	14.40	13.92	-3.3%	12.40	9.44	-23.9%	9.40	6.12	-34.8%	7.70	4.77	-38.0%	5.20	3.29	-36.8%
	Harriman Road driveways	Area 18	Aurora	11190	16.30	33.00	48.26	46.2%	28.10	33.80	20.3%	23.40	22.09	-5.6%	18.00	14.14	-21.4%	13.40	10.91	-18.6%	7.40	7.71	4.1%
	Kennedy St West Culert	Area 19	Aurora	11480	4.51	16.20	20.71	27.8%	14.20	15.01	5.7%	11.40	11.34	-0.5%	9.20	8.40	-8.7%	7.30	6.87	-6.0%	5.10	5.02	-1.6%
	Yonge St and Batson Dr Culvert	Area 20	Aurora	11170	28.61	74.40	95.92	28.9%	63.80	67.28	5.5%	52.50	50.29	-4.2%	38.90	32.75	-15.8%	29.10	23.97	-17.6%	17.20	16.51	-4.0%
	Richardson Dr houses and David Rd, Jones Ct, and Murray Dr culverts	Area 21	Aurora	11480	4.51	16.20	20.71	27.8%	14.20	15.01	5.7%	11.40	11.34	-0.5%	9.20	8.40	-8.7%	7.30	6.87	-6.0%	5.10	5.02	-1.6%
	Devlin Place Culvert	Area 22	Aurora	11350	2.96	16.50	22.81	38.2%	13.90	16.73	20.3%	10.80	11.82	9.5%	8.00	8.16	2.0%	5.40	6.51	20.6%	3.00	4.72	57.5%
Western Creek	Ontario St, East of Lorne Ave	Area 13	Newmarket	10560	5.97	42.50	36.70	-13.6%	37.30	27.58	-26.1%	32.30	20.90	-35.3%	25.80	15.39	-40.3%	21.00	12.42	-40.9%	13.50	9.01	-33.3%

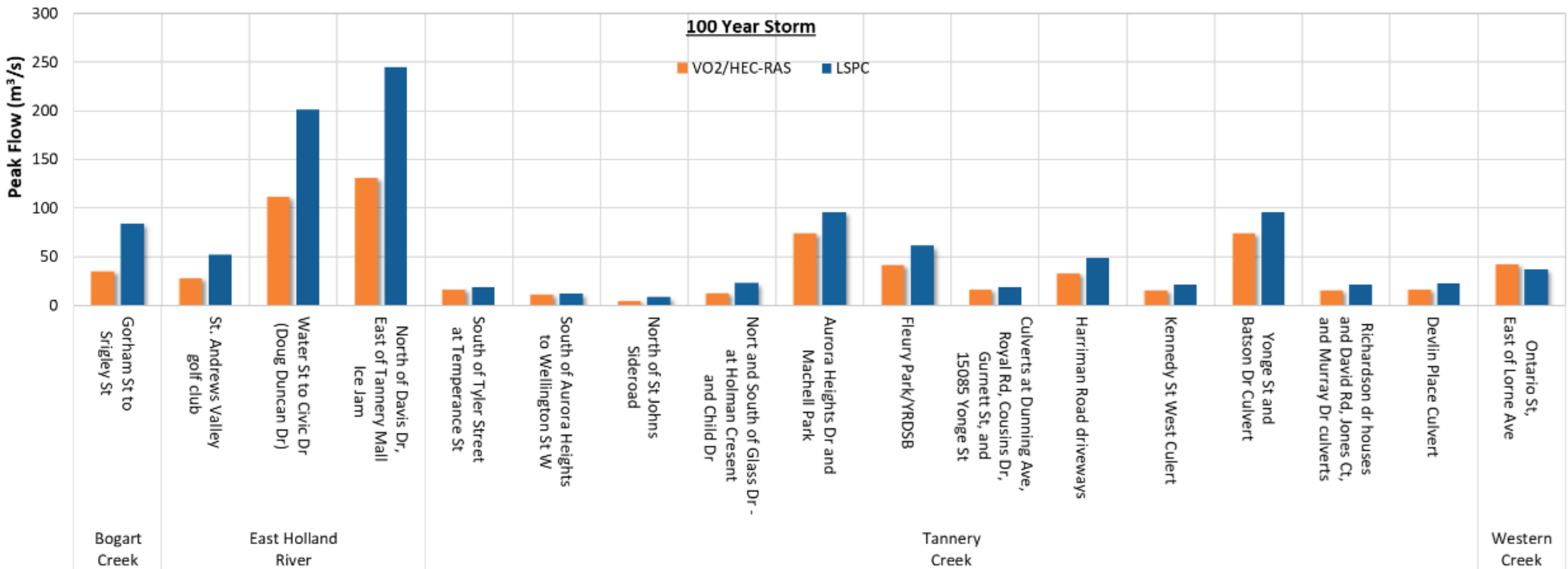


Figure 5-3. Comparison of VOC/HEC-RAS and LSPC 100-year peak flows for flood-prone areas.

5.3 Discussion

These initial results find no major limitation with applying the LSPC model as the hydrologic boundary condition for HEC-RAS. Comparisons between VO2 and LSPC are promising. The approach to flood mitigation modelling will be based on the relative (percent) difference in peak flows as predicted by LSPC, which will then be applied either to the VO2-predicted peak flows or the LSPC flow directly. A perfect match between LSPC and VO2 is not necessarily required to achieve the goals of the flood simulation modelling.

During the Future State assessment, the strengths of VO2, LSPC and HEC-RAS models can be leveraged in concert to derive valuable information regarding the ability of proposed stormwater management practices to mitigate flooding in the East Holland River watershed. LPSC coupled with SUSTAIN can be used to provide the hydrologic boundary condition for a baseline and mitigated conditions. The respective peak flows can then be routed through HEC-RAS to estimate the corresponding peak flows and water levels pre- and post-mitigation. The relative changes in water levels can then be applied either to the VO2 flows or directly to the LSPC flows to assess the benefits of mitigation based on the established HEC-RAS regulatory flood depths and floodplain extents. The methodology for the Future State assessment will be determined in coming months.

6 CONCLUSIONS

The Current State model presented in this report is the culmination of many data collection programs and will provide the key 'baseline' by which strategies can be developed for the EqR4TD project. In many ways, the LSPC model has 'converted' existing data into a living tool that can evolve and be adapted over time as new data are collected. Overall, the level of resolution of the East Holland River model is quite high, its performance is satisfactory for watershed-scale planning decisions. Outputs from the LSPC model will be a powerful tool for driving policy and economic decisions through the EqR4TD project. The LSPC model may also provide an important starting point for other regional programs related to Lake Simcoe watershed protection.

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APPENDIX A: TRENDS ANALYSIS

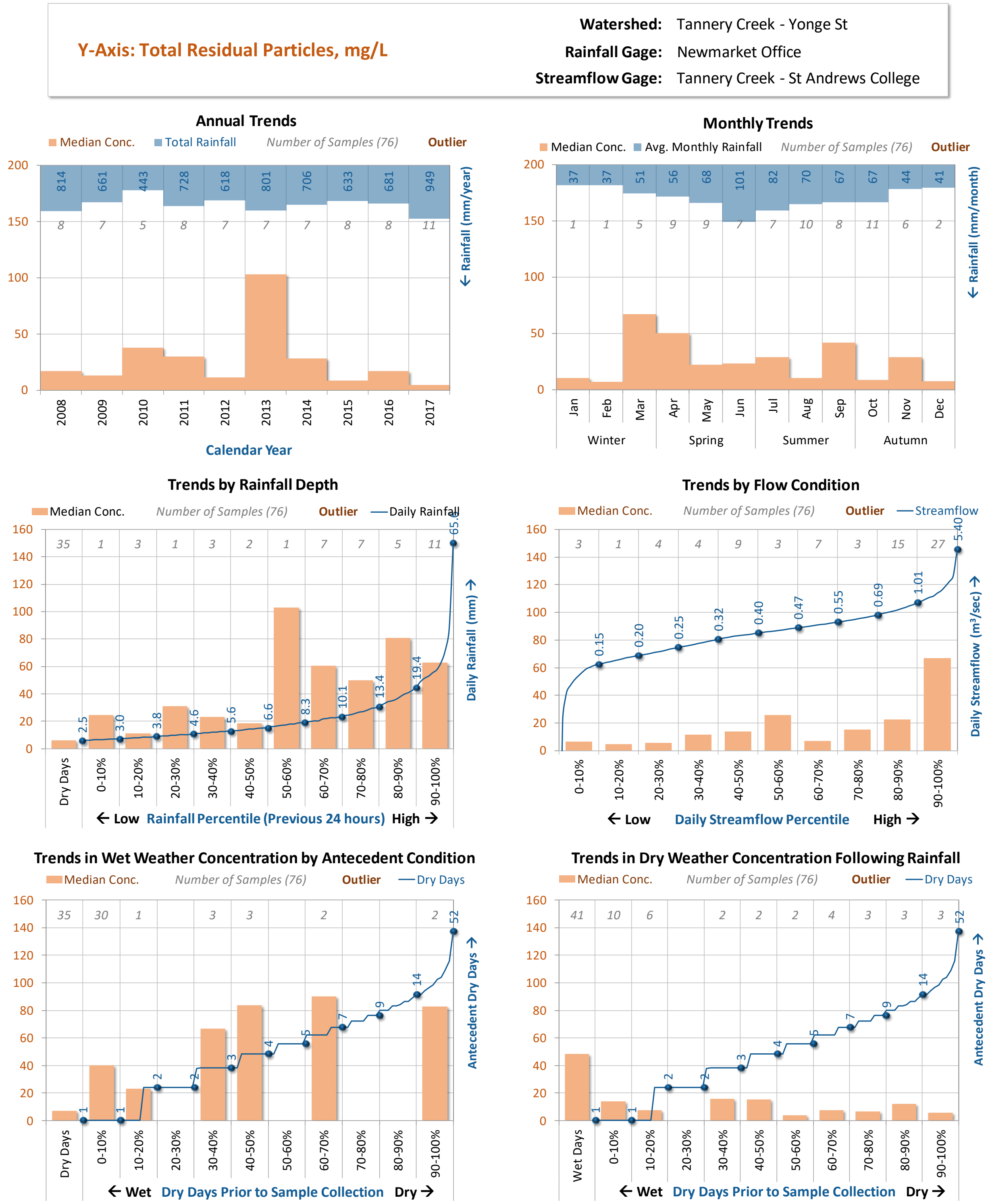


Figure A-1. Tannery Creek – Yonge St: Total Residual Particles, mg/L.

Figure A-2. Western Creek: Total Residual Particles, mg/L.

Y-Axis: Total Phosphorus, mg/L		
	Watershed:	Tannery Creek - Yonge St
	Rainfall Gage:	Newmarket Office
	Streamflow Gage:	Tannery Creek - St Andrews College

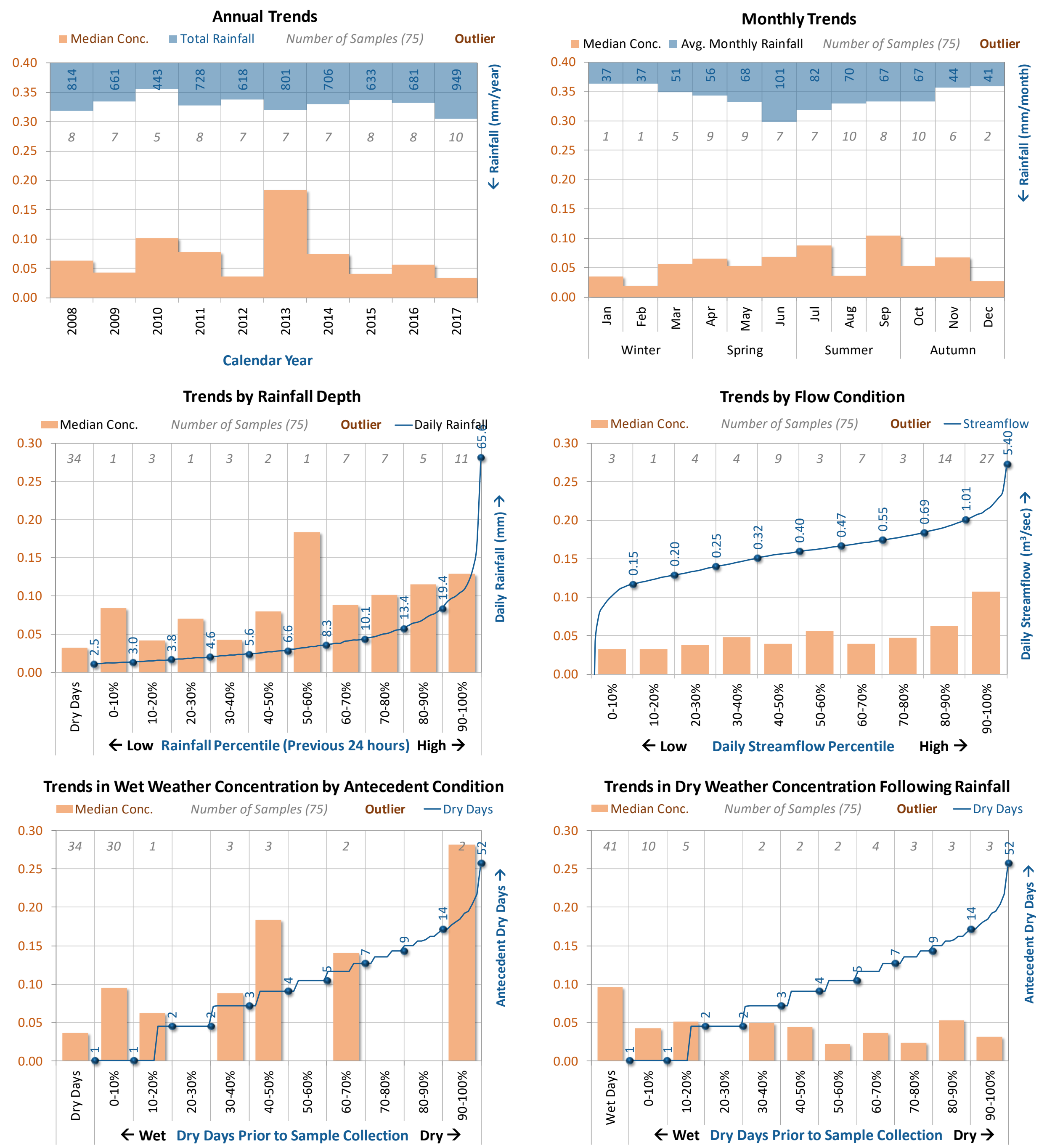


Figure A-3. Tannery Creek – Yonge St: Total Phosphorus, mg/L.

Y-Axis: Total Phosphorus, mg/L	**Watershed:**	Western Creek
	Rainfall Gage:	Newmarket Office
	Streamflow Gage:	E Holland River - Holland Landing

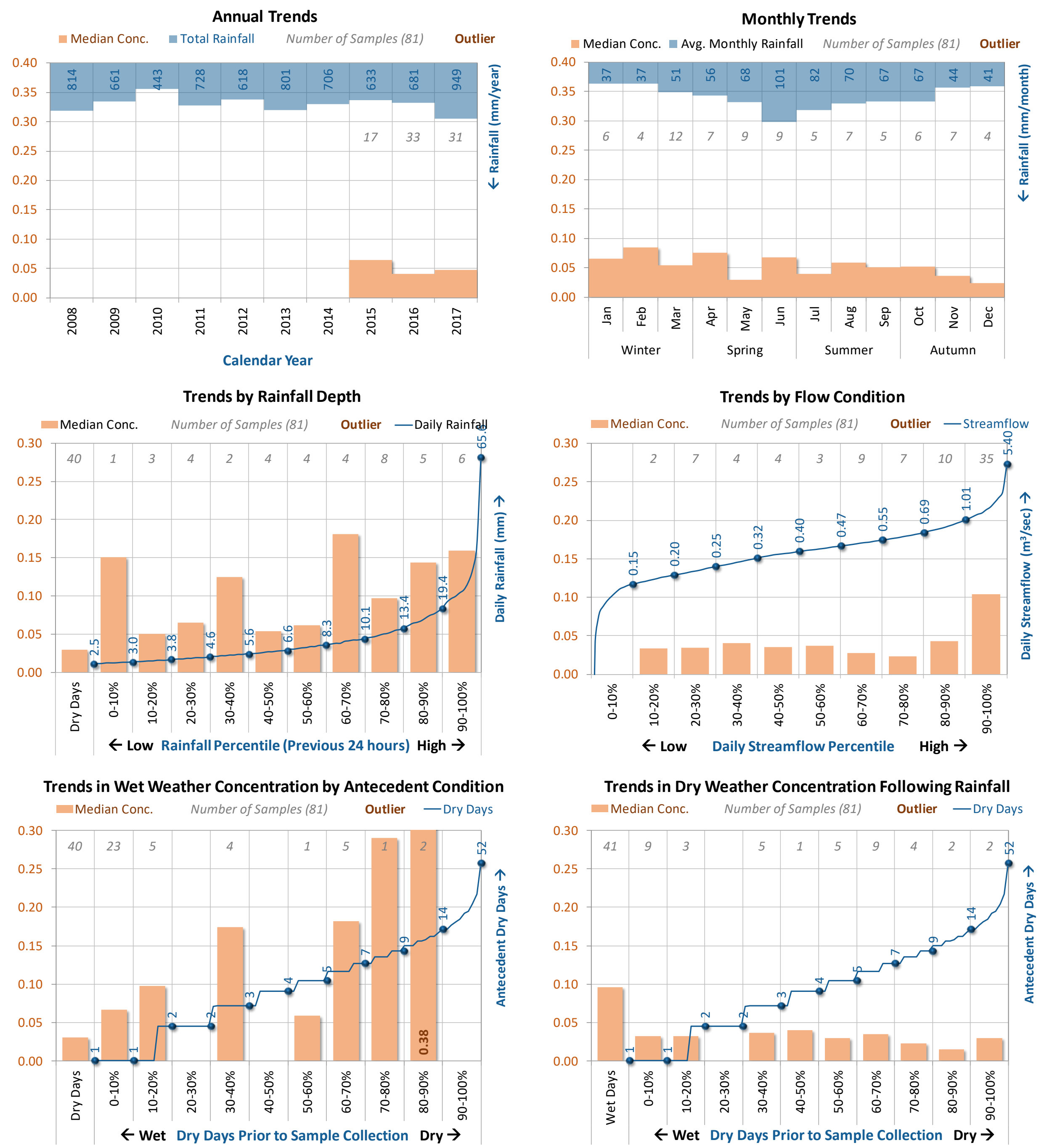


Figure A-4. Western Creek: Total Phosphorus, mg/L.

APPENDIX B: CALIBRATION PARAMETER TABLES

Table B-1 and Table B-2 describe the LSPC hydrology and snow parameters, respectively, and lists the values selected for the final calibration. Parameters that vary by HRU are presented as a range.

Table B-1. Summary of hydrology calibration parameters

Parameter	Description	Unit	Value
LZSN	Lower Zone Nominal Soil Moisture Storage	inches	9.0
INFILT	Index to Infiltration Capacity	in/hr	0.01-0.4
KVARY	Variable groundwater recession	1/inches	0.0
AGWRC	Base groundwater recession	none	0.92 – 0.985
CEPSC	Interception storage capacity	inches	0.05 – 0.25
UZSN	Upper zone nominal soil moisture storage	inches	0.4 - 0.9
NSUR	Manning's n (roughness) for overland flow	none	0.05 – 0.3
INTFW	Interflow inflow parameter	none	2.0
IRC	Interflow recession parameter	none	0.3 – 0.7
LZETP	Lower zone ET parameter	none	0.4 – 0.7
PETMAX	Temp below which ET is reduced	deg. F	40
PETMIN	Temp below which ET is set to zero	deg. F	35
INFEXP	Exponent in infiltration equation	none	2
INFILD	Ratio of max/mean infiltration capacities	none	2
DEEPFR	Fraction of GW inflow to deep recharge	none	0.0
BASETP	Fraction of remaining ET from baseflow	none	0.0
AGWETP	Fraction of remaining ET from active GW	none	0

Table B-2. Summary of snow calibration parameters

Parameter	Description	Unit	Value
forest	Fraction forest cover (winter transpiration)	none	0.2 – 0.5
iceflag	Ice formation in the snowpack is simulated	none	1
fzg	Parameter that adjusts for the effect of ice (in the snowpack) on infiltration	none	1
fzgl	Lower limit of *inffac* as adjusted by ice in the snowpack	per inch	0.1
lat	Latitude of the pervious land segment	degrees	43.5
melev	Mean elevation of LAND above sea level	feet	836
shade	Fraction of LAND shaded from solar radiation	none	0.5
snowcf	Precipitation-to-snow multiplier	none	1
covind	Maximum snowpack (water equivalent) at which the entire LAND is covered with snow	inches	1
rdcsn	Density of cold, new snow relative to water (snow falling at temps below freezing)	none	0.15
tsnow	Air temperature below which precipitation will be snow, under saturated conditions	deg. F	31
snoevp	Adapts sublimation equation to field conditions	none	0.1

Parameter	Description	Unit	Value
ccfact	Adapts snow condensation/convection melt equation to field conditions	none	0.5
mwater	Maximum water content of the snowpack, in depth of water per depth of water	in/in	0.03
mgmelt	Maximum rate of snowmelt by ground heat, in depth of water per day	in/day	0.01

Table B-3 and Table B-4 describe the LSPC edge-of-field sediment and total phosphorus model parameters, respectively, and lists the values selected for the final calibration. Parameters that vary by HRU are presented as a range.

Table B-3. Summary of sediment calibration parameters

Parameter	Description	Unit	Value
KRER	Coefficient in the soil detachment equation	complex	0.2 – 0.8
JRER	Exponent in the soil detachment equation	none	2
COVER	Fraction land surface protected from rainfall	none	0.3 – 0.95
KSER	Coefficient in the sediment washoff equation	complex	0.08 – 0.2
JSER	Exponent in the sediment washoff equation	none	1.8 – 2.0
KGER	Coefficient in soil matrix scour equation	complex	0.0
JGER	Exponent in the matrix soil scour equation, which simulates gully erosion	none	2.0
ACCSDP	Solids accumulation rate on the land surface	lb/ac-day	0.0001 – 0.0005
REMSDP	Fraction of solids removed per day	per day	0.05
SMPF	Supporting management practice factor	none	1.0
AFFIX	Fraction by which detached sediment storage decreases each day as a result of soil compaction	none	0.1
NVSI	Rate at which sediment enters detached storage from the atmosphere	lb/ac-day	0
SAND	Fraction of sediment which is sand	none	0.1 – 0.7
SILT	Fraction of sediment which is silt	none	0.1 – 0.7
CLAY	Fraction of sediment which is clay	none	0.15 – 0.3
SED_SURO	Background concentration associated with surface runoff	mg/l	0
SED_IFWO	Background concentration associated with interflow outflow	mg/l	0
SED_AGWO	Background concentration associated with groundwater outflow	mg/l	0.2

Table B-4. Summary of total phosphorus calibration parameters

Parameter	Description	Unit	Value
POTFW	Pollutant washoff potency factor	lb/ton-sediment	2.0 – 15.0
POTFS	Pollutant scour potency factor	lb/ton-sediment	0.0
POTFC	Pollutant background concentration potency factor	lb/ton-sediment	0.0
SOQC	Pollutant concentration in surface runoff	mg/l	0.0
IOQC	Pollutant concentration in interflow outflow	mg/l	0.0075 – 0.06
AOQC	Pollutant concentration in groundwater outflow	mg/l	0.005 – 0.04
ACQOP	Pollutant accumulation rate on surface	lb/ac-day	0
SQOLIM	Pollutant maximum storage	lb/ac	0
WSQOP	Rate of surface runoff that removes 90% of stored pollutant per hour	in/hr	0
ADDC	Pollutant atmospheric dry deposition flux	lb/ac-day	0
AWDC	Pollutant atmospheric wet deposition conc	mg/l	0

Table B-5 and Table B-6 present the LSPC instream sediment and total phosphorus model parameters, respectively, and lists the values selected for the final calibration.

Table B-5. Summary of instream transport parameters for sediment

Parameter	Description	Unit	Sand	Silt	Clay
SEDFG	Sediment flag indicating sediment class	none	0	1	2
SEDO	Initial sediment conc in fluid phase	mg/l	0.8	0.8	0.8
SEDFRAC	Initial sediment fractions (by weight) in the bed material	none	0.1	0.7	0.2
DB50/D	Median diameter of the non-cohesive sediment (sand) / effective diameter of the cohesive particles (silt and clay)	inches	0.00984	0.00063	0.00004
W	Corresponding fall velocity of the particle in still water	in/sec	0.78740	0.00394	0.00001
RHO	Density of the particles	gm/cm^3	2.5	2.2	2
KSAND	Coefficient in the sandload power function formula	none	0.35	--	--
EXPSND	Exponent in the sandload power function formula	none	3.2	--	--
TAUCD	Critical bed shear stress for deposition	lb/ft^2	--	0.509850	0.101970
TAUCS	Critical bed shear stress for scour of the cohesive particle	lb/ft^2	--	1.427580	0.917730
M	Erodibility coefficient of the cohesive particle	$lb/ft^2/day$	0	1	1
BURIAL	Burial rate of the sediment particle	in/day	0	0	0

Table B-6. Summary of instream transport parameters for total phosphorus

Parameter	Description	Unit	Value
QSDFG	No sediment associated pollutant flag	none	0
INI_COND	Initial instream concentration at start of simulation	mg/l	0
DECAY	General first-order instream loss rate of qual by reach group	per day	0.0
TCDECAY	Temperature correction coefficient for first-order decay of qual	none	1
ADDC	Atmospheric dry deposition flux	lb/ac-day	0
AWDC	Atmospheric wet deposition conc	mg/l	0
POTBER	Scour potency factor for stream bank erosion	lb/ton-sediment	4

APPENDIX C: HYDROLOGY CALIBRATION PANELS

Tannery Creek – St Andrews Coll
Station ID: LS0102
01/10/2003 – 30/09/2011

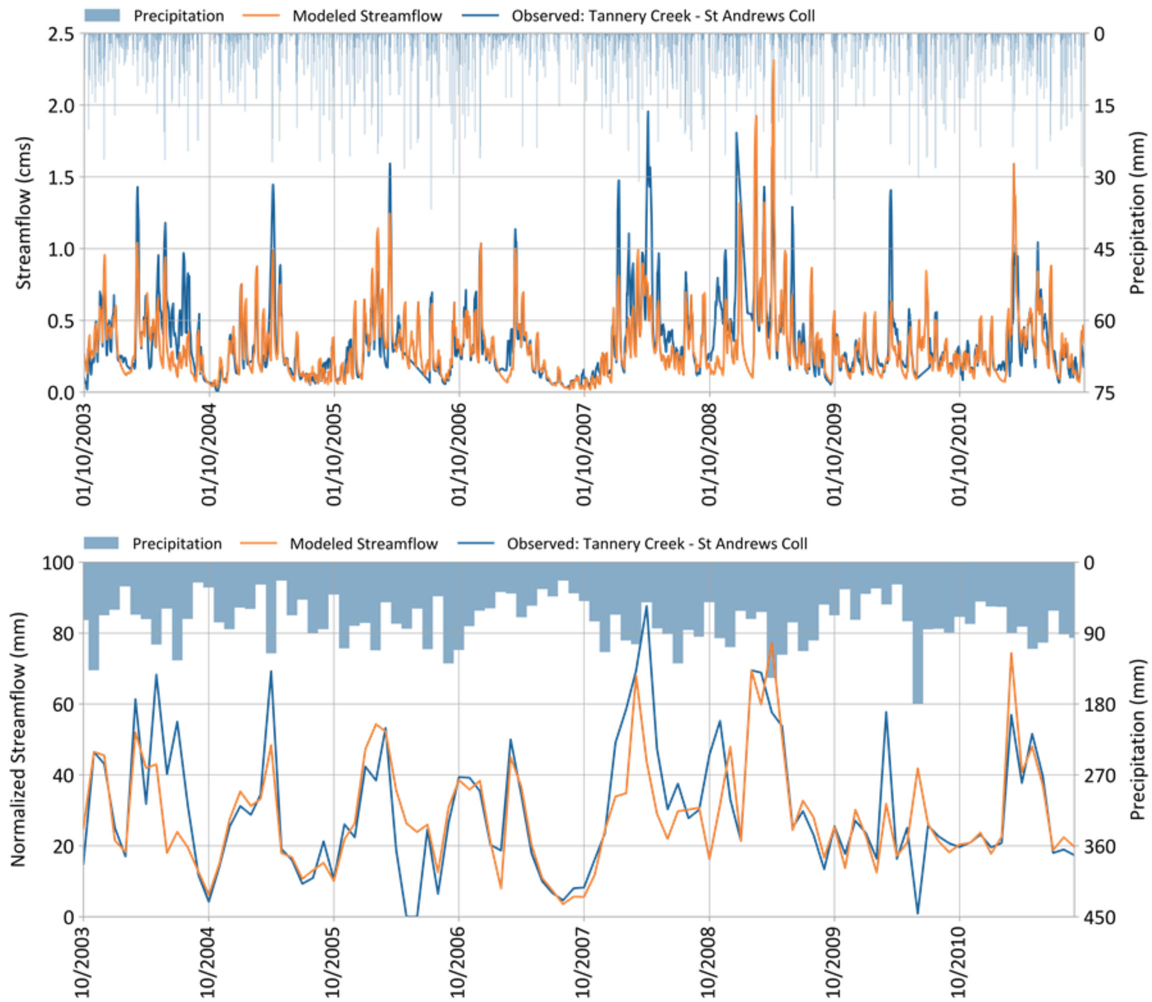


Figure C-1. Simulated vs. observed daily (top) and monthly (bottom) streamflow comparisons at Tannery Creek - St Andrews Coll (Station ID: LS0102).

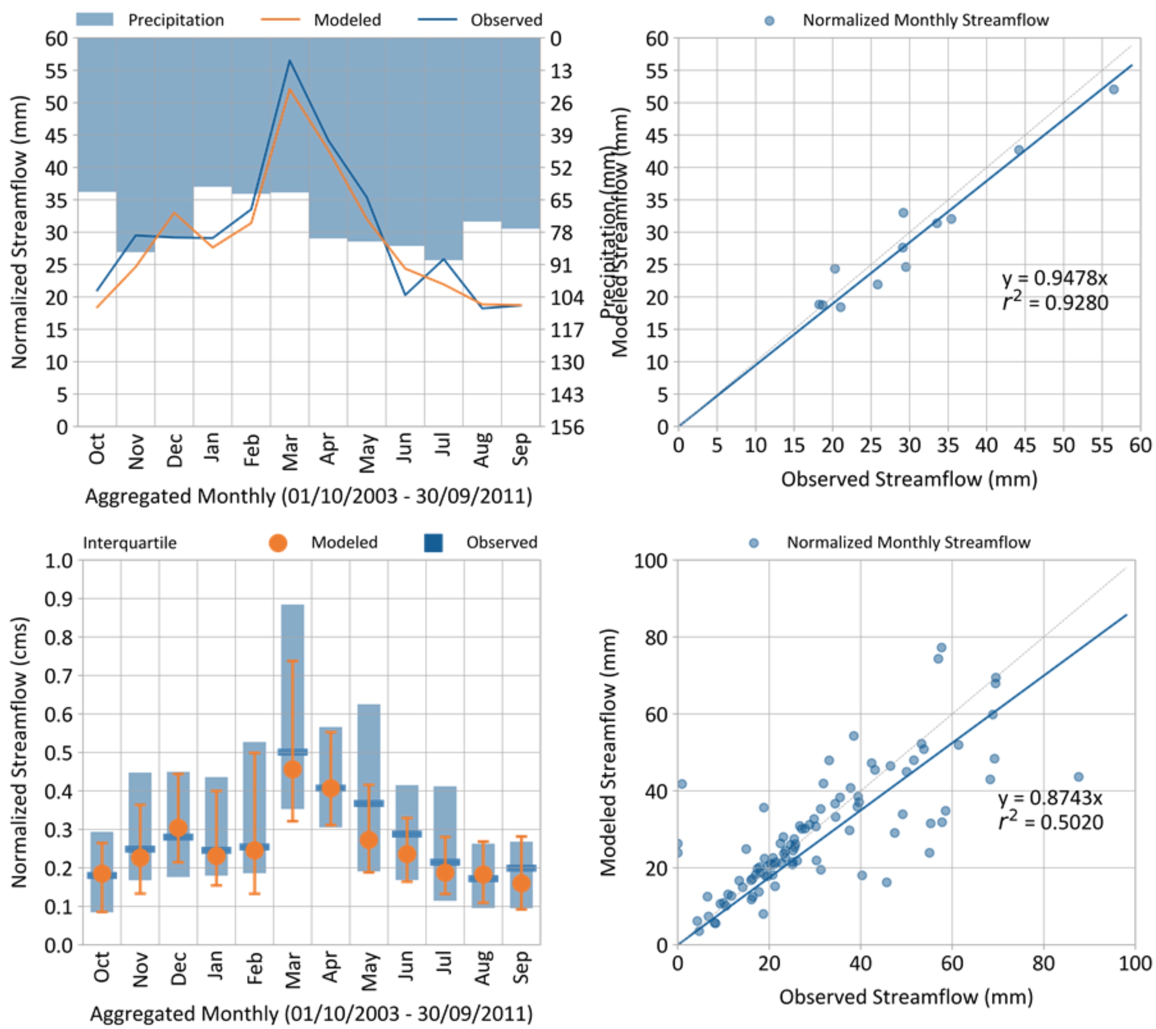


Figure C-2. Simulated vs observed monthly (top) and average monthly (bottom) streamflow comparisons at Tannery Creek - St Andrews Coll (Station ID: LS0102).

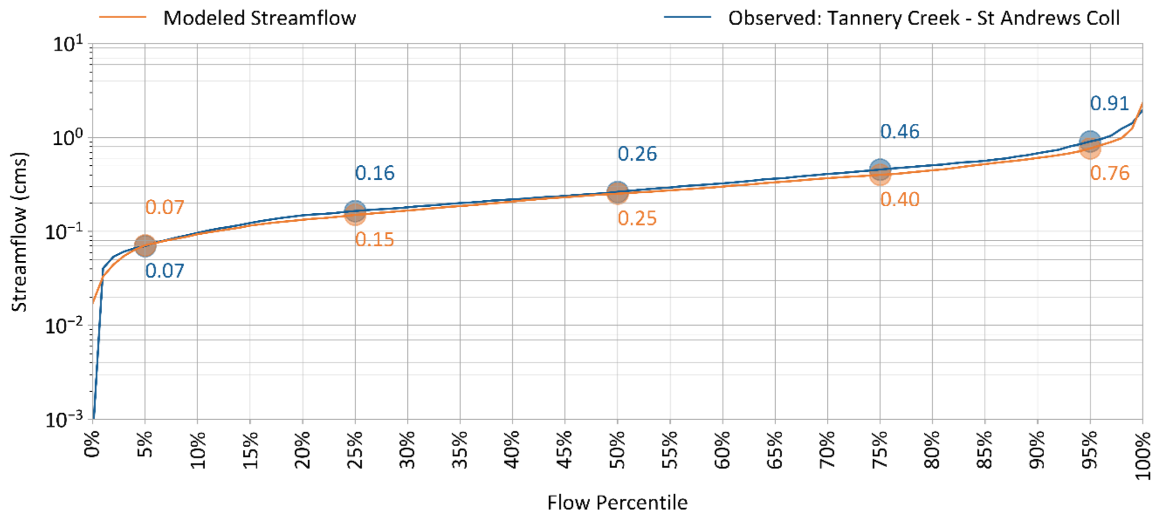


Figure C-3. Flow Duration Curve for Daily Flow at Tannery Creek - St Andrews Coll (Station ID: LS0102).

Table C-1. Relative Mean Error for Predicted vs Observed Volumes at Tannery Creek - St Andrews Coll (Station ID: LS0102).

Calibration Metrics (01/10/2003 - 30/09/2011)	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation) Relative Mean Error				
	All Seasons	Winter	Spring	Summer	Fall
Total Annual Volume	-6.9%	-5.9%	-9.0%	0.1%	-10.2%
Highest Weekly Flows	-4.5%	-6.6%	-2.4%	16.0%	-10.8%
Lowest Weekly Flows	-15.1%	-8.9%	-15.9%	-12.4%	-22.8%
Storm Volume	-5.5%	-7.3%	-3.2%	7.1%	-11.3%
Baseflow Volume	-7.1%	-5.8%	-9.7%	-0.7%	-10.0%
Baseflow Recession Rate	0.5%	1.6%	-0.3%	-0.2%	0.4%

Performance:	Very Good	Good	Satisfactory	Unsatisfactory

Reference: Donigian et al. (1984), Lumb et al. (1984), and Donigian (2000)

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
Relative Mean Error	Total Annual Volume	Compare Observed vs Simulated Total Volume across Simulation Period for Selected Season-Conditions	≤5%	5 - 10%	10 - 15%	>15%	Donigian et al. (1984), Lumb et al. (1984), and Donigian (2000)
	Highest Weekly Flows		≤10%	10 - 15%	15 - 25%	>25%	
	Lowest Weekly Flows		≤10%	10 - 15%	15 - 25%	>25%	
	Annual Storm Volume		≤10%	10 - 15%	15 - 25%	>25%	
	Seasonal Storm Volume		≤15%	15 - 30%	30 - 50%	>50%	
	Baseflow Volume		≤10%	10 - 15%	15 - 25%	>25%	
	Baseflow Recession Rate		≤3%	3 - 5%	5 - 10%	>10%	

Table C-2. R-Squared for Predicted vs Observed Volumes at Tannery Creek - St Andrews Coll (Station ID: LS0102).

Calibration Metrics *(01/10/2003 - 30/09/2011)*	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation) R-Squared (R^2)				
	All Seasons	Winter	Spring	Summer	Fall
All Conditions	0.67	0.63	0.64	0.83	0.58
Highest Weekly Flow Rates	0.43	0.37	0.31	0.38	0.58
Lowest Weekly Flow Rates	0.41	0.16	0.58	0.74	0.24
Days Categorized as Storm Flow	0.67	0.63	0.64	0.84	0.59
Days Categorized as Baseflow	0.6	0.56	0.64	0.7	0.43

Performance: Very Good | Good | Satisfactory | Unsatisfactory

Reference: Moriasi et al. (2015)

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
R-Squared (R^2)	All Conditions	Compare All Observed vs Simulated Daily Flow Rates that Occur During Selected Season-Conditions	>0.85	0.75 - 0.85	0.60 - 0.75	≤0.60	Moriasi et al. (2015)
	Seasonal Flows Highest Weekly Flow Rates Lowest Weekly Flow Rates Days Categorized as Storm Flow Days Categorized as Baseflow		>0.75	0.60 - 0.75	0.50 - 0.60	≤0.50	

Table C-3. Nash-Sutcliffe Efficiency for Predicted vs Observed Volumes at Tannery Creek - St Andrews Coll (Station ID: LS0102).

Calibration Metrics (01/10/2003 - 30/09/2011)	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation) Nash-Sutcliffe Efficiency (E)				
	All Seasons	Winter	Spring	Summer	Fall
All Conditions	0.64	0.59	0.58	0.82	0.55
Highest Weekly Flow Rates	0.25	0.15	-0.49	-0.14	0.53
Lowest Weekly Flow Rates	0.32	-0.25	0.51	0.7	0.07
Days Categorized as Storm Flow	0.64	0.59	0.58	0.83	0.56
Days Categorized as Baseflow	0.53	0.43	0.55	0.61	0.36

Performance: Very Good | Good | Satisfactory | Unsatisfactory

Reference: Moriasi et al. (2015)

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
Nash-Sutcliffe Efficiency (E)	All Conditions	Compare All Observed vs Simulated Daily Flow Rates that Occur During Selected Season-Conditions	>0.80	0.70 - 0.80	0.50 - 0.70	≤0.50	Moriasi et al. (2015)
	Seasonal Flows		>0.70	0.50 - 0.70	0.40 - 0.50	≤0.40	
	Highest Weekly Flow Rates						
	Lowest Weekly Flow Rates						
	Days Categorized as Storm Flow						
	Days Categorized as Baseflow						

Table C-4. Percent Bias for Predicted vs Observed Volumes at Tannery Creek - St Andrews Coll (Station ID: LS0102).

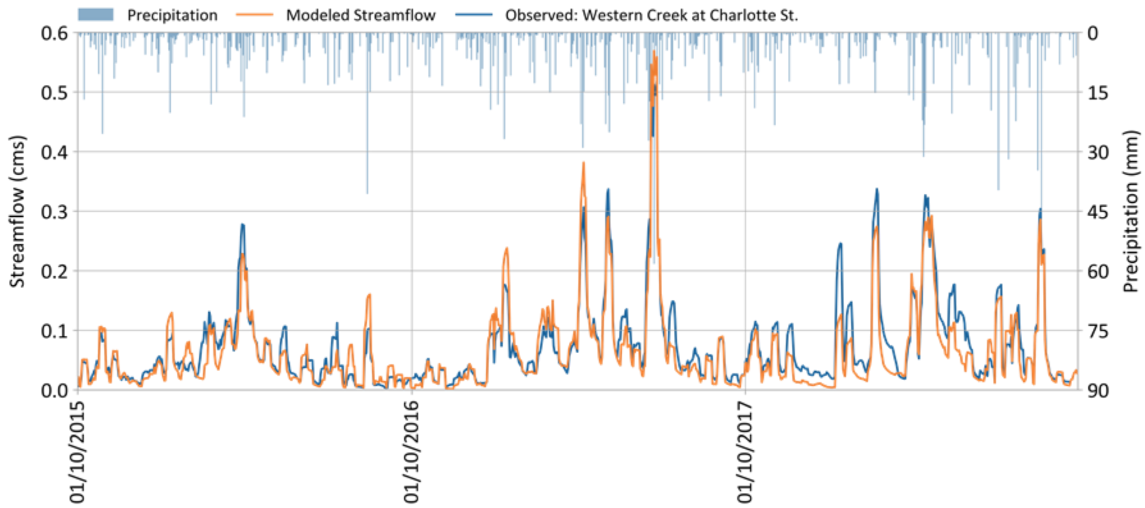
Calibration Metrics (01/10/2003 - 30/09/2011)	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation) Percent Bias (PBIAS)				
	All Seasons	Winter	Spring	Summer	Fall
All Conditions	-6.9%	-5.9%	-9.0%	0.1%	-10.2%
Highest Weekly Flow Rates	-4.5%	-6.6%	-2.4%	16.0%	-10.8%
Lowest Weekly Flow Rates	-15.1%	-8.9%	-15.9%	-12.4%	-22.8%
Days Categorized as Storm Flow	-7.3%	-6.3%	-9.6%	-0.4%	-10.1%
Days Categorized as Baseflow	-3.3%	-0.0%	-3.6%	4.2%	-10.7%

Performance: Very Good | Good | Satisfactory | Unsatisfactory

Reference: Moriasi et al. (2015)

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
Percent Bias (PBIAS)	All Conditions	Compare All Observed vs Simulated Daily Flow Rates that Occur During Selected Season-Conditions	<5%	5% - 10%	10% - 15%	>15%	Moriasi et al. (2015)
	Seasonal Flows		<10%	10% - 15%	15% - 25%	>25%	
	Highest Weekly Flow Rates						
	Lowest Weekly Flow Rates						
	Days Categorized as Storm Flow						
	Days Categorized as Baseflow						

Western Creek at Charlotte St.
Station ID: LS0201
01/10/2015 - 30/09/2018



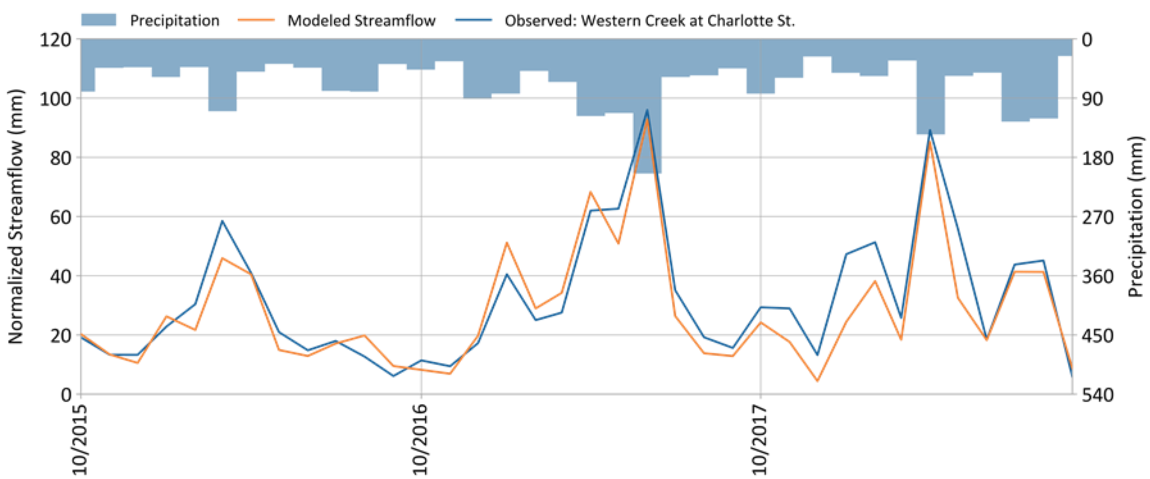


Figure C-4. Simulated vs. observed daily (top) and monthly (bottom) streamflow comparisons at Western Creek at Charlotte St. (Station ID: LS0201).

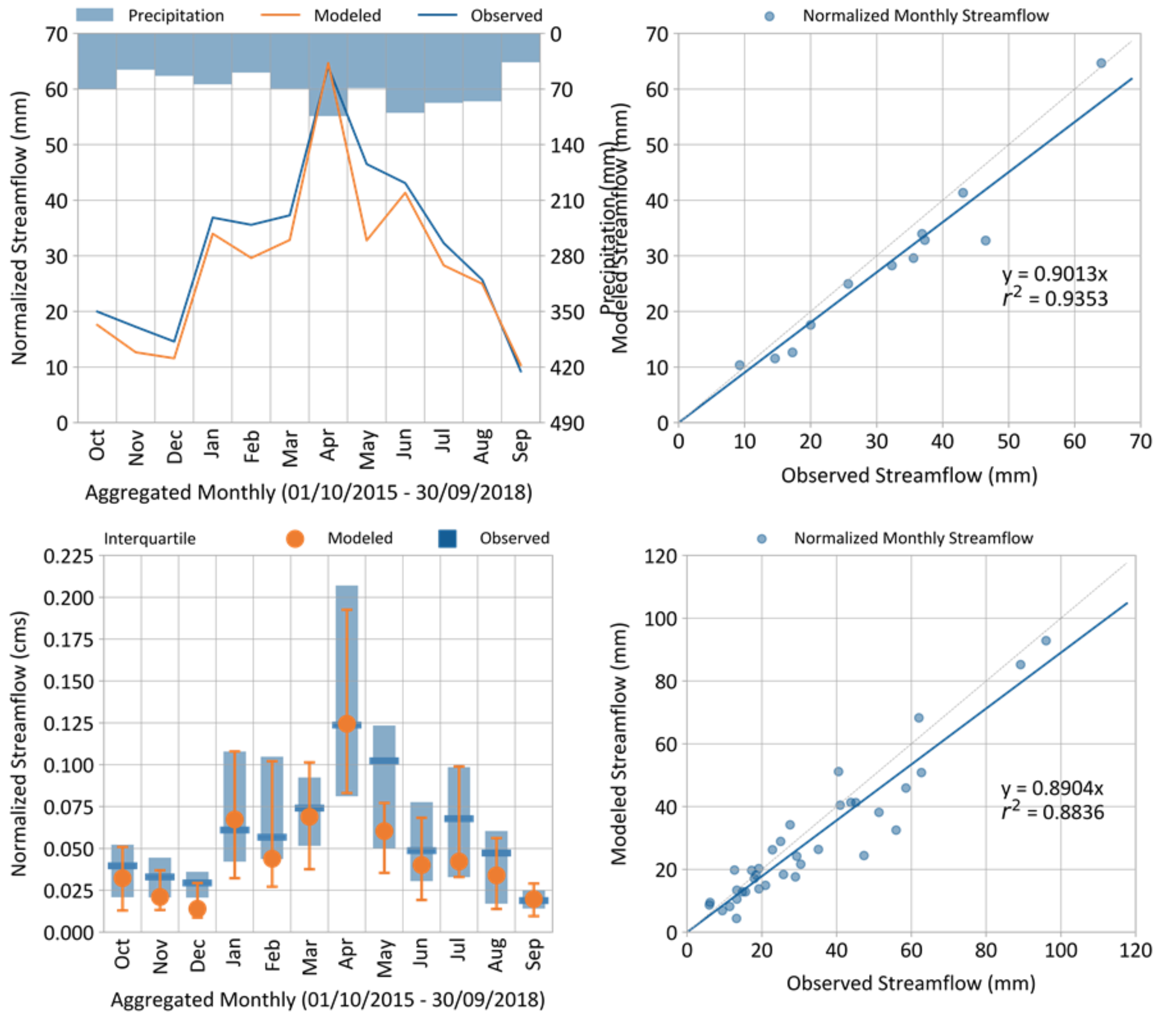


Figure C-5. Simulated vs observed monthly (top) and average monthly (bottom) streamflow comparisons at Western Creek at Charlotte St. (Station ID: LS0201).

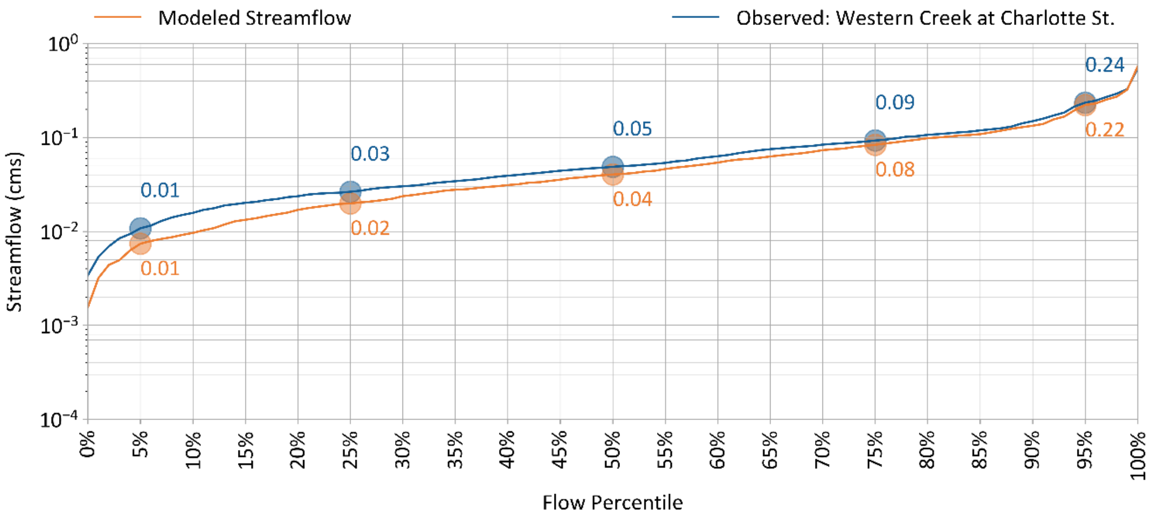


Figure C-6. Flow Duration Curve for Daily Flow at Western Creek at Charlotte St. (Station ID: LS0201).

Table C-5. Relative Mean Error for Predicted vs Observed Volumes at Western Creek at Charlotte St. (Station ID: LS0201).

Calibration Metrics *(01/10/2015 - 30/09/2018)*	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation) – Relative Mean Error: All Seasons	Winter	Spring	Summer	Fall
Total Annual Volume	-7.6%	7.1%	-7.6%	-13.6%	-20.7%
Highest Weekly Flows	2.7%	8.4%	6.1%	6.4%	-13.4%
Lowest Weekly Flows	-16.6%	13.4%	-18.3%	-21.8%	-49.0%
Storm Volume	-0.4%	8.2%	-8.2%	-3.6%	4.8%
Baseflow Volume	-8.7%	6.9%	-7.5%	-15.5%	-24.8%
Baseflow Recession Rate	-0.7%	0.2%	-0.9%	1.6%	-2.6%

Performance: Very Good | Good | Satisfactory | Unsatisfactory

Reference: Donigian et al. (1984), Lumb et al. (1984), and Donigian (2000)

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation: Very Good	Good	Satisfactory	Unsatisfactory	Reference
Relative Mean Error	Total Annual Volume	Compare Observed vs Simulated Total Volume across Simulation Period for Selected Season-Conditions	≤5%	5 - 10%	10 - 15%	>15%	Donigian et al. (1984), Lumb et al. (1984), and Donigian (2000)
	Highest Weekly Flows		≤10%	10 - 15%	15 - 25%	>25%	
	Lowest Weekly Flows		≤10%	10 - 15%	15 - 25%	>25%	
	Annual Storm Volume		≤10%	10 - 15%	15 - 25%	>25%	
	Seasonal Storm Volume		≤15%	15 - 30%	30 - 50%	>50%	
	Baseflow Volume		≤10%	10 - 15%	15 - 25%	>25%	
	Baseflow Recession Rate		≤3%	3 - 5%	5 - 10%	>10%	

Table C-6. R-Squared for Predicted vs Observed Volumes at Western Creek at Charlotte St. (Station ID: LS0201).

Calibration Metrics (01/10/2015 - 30/09/2018)	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation) R-Squared (R^2)				
	All Seasons	Winter	Spring	Summer	Fall
All Conditions	0.89	0.7	0.96	0.59	0.79
Highest Weekly Flow Rates	0.69	0.64	0.73	0.1	0.78
Lowest Weekly Flow Rates	0.78	0.65	0.82	0.81	0.5
Days Categorized as Storm Flow	0.87	0.7	0.95	0.56	0.8
Days Categorized as Baseflow	0.95	0.85	0.98	0.73	0.76

Performance: Very Good | Good | Satisfactory | Unsatisfactory

Reference: Moriasi et al. (2015)

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
R-Squared (R^2)	All Conditions	Compare All Observed vs Simulated Daily Flow Rates that Occur During Selected Season-Conditions	>0.85	0.75 - 0.85	0.60 - 0.75	≤0.60	Moriasi et al. (2015)
	Seasonal Flows		>0.75	0.60 - 0.75	0.50 - 0.60	≤0.50	
	Highest Weekly Flow Rates						
	Lowest Weekly Flow Rates						
	Days Categorized as Storm Flow						
	Days Categorized as Baseflow						

Table C-7. Nash-Sutcliffe Efficiency for Predicted vs Observed Volumes at Western Creek at Charlotte St. (Station ID: LS0201).

Calibration Metrics (01/10/2015 - 30/09/2018)	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation) Nash-Sutcliffe Efficiency (E)				
	All Seasons	Winter	Spring	Summer	Fall
All Conditions	0.87	0.66	0.94	0.53	0.67
Highest Weekly Flow Rates	0.52	0.4	0.52	-1.12	0.72
Lowest Weekly Flow Rates	0.72	0.56	0.67	0.75	-0.36
Days Categorized as Storm Flow	0.85	0.67	0.93	0.5	0.67
Days Categorized as Baseflow	0.93	0.45	0.97	0.62	0.62

Performance:	Very Good	Good	Satisfactory	Unsatisfactory

Reference: Moriasi et al. (2015)

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
Nash-Sutcliffe Efficiency (E)	All Conditions	Compare All Observed vs Simulated Daily Flow Rates that Occur During Selected Season-Conditions	>0.80	0.70 - 0.80	0.50 - 0.70	≤0.50	Moriasi et al. (2015)
	Seasonal Flows Highest Weekly Flow Rates Lowest Weekly Flow Rates Days Categorized as Storm Flow Days Categorized as Baseflow		>0.70	0.50 - 0.70	0.40 - 0.50	≤0.40	

Table C-8. Percent Bias for Predicted vs Observed Volumes at Western Creek at Charlotte St. (Station ID: LS0201).

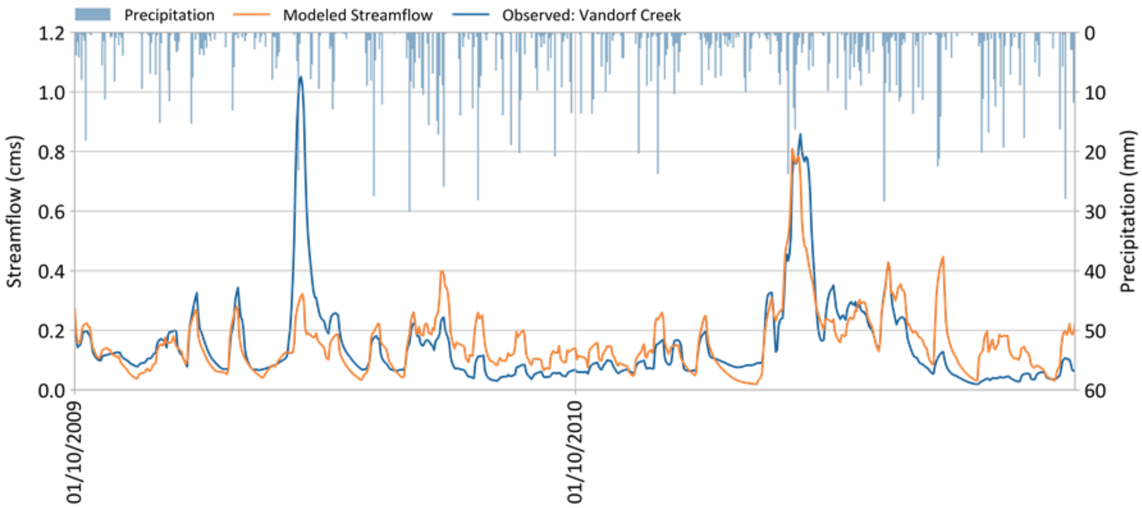
Calibration Metrics (01/10/2015 - 30/09/2018)	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation)				
	Percent Bias (PBIAS)				
	All Seasons	Winter	Spring	Summer	Fall
All Conditions	-7.6%	7.1%	-7.6%	-13.6%	-20.7%
Highest Weekly Flow Rates	2.7%	8.4%	6.1%	6.4%	-13.4%
Lowest Weekly Flow Rates	-16.6%	13.4%	-18.3%	-21.8%	-49.0%
Days Categorized as Storm Flow	-8.4%	4.9%	-8.2%	-13.1%	-21.0%
Days Categorized as Baseflow	-3.0%	21.9%	-4.7%	-19.1%	-18.9%

Performance:	Very Good	Good	Satisfactory	Unsatisfactory

Reference: Moriasi et al. (2015)

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
Percent Bias (PBIAS)	All Conditions	Compare All Observed vs Simulated Daily Flow Rates that Occur During Selected Season-Conditions	<5%	5% - 10%	10% - 15%	>15%	Moriasi et al. (2015)
	Seasonal Flows		<10%	10% - 15%	15% - 25%	>25%	
	Highest Weekly Flow Rates						
	Lowest Weekly Flow Rates						
	Days Categorized as Storm Flow						
	Days Categorized as Baseflow						

Vandorf Creek
Station ID: Vandorf
01/10/2009 – 30/09/2011



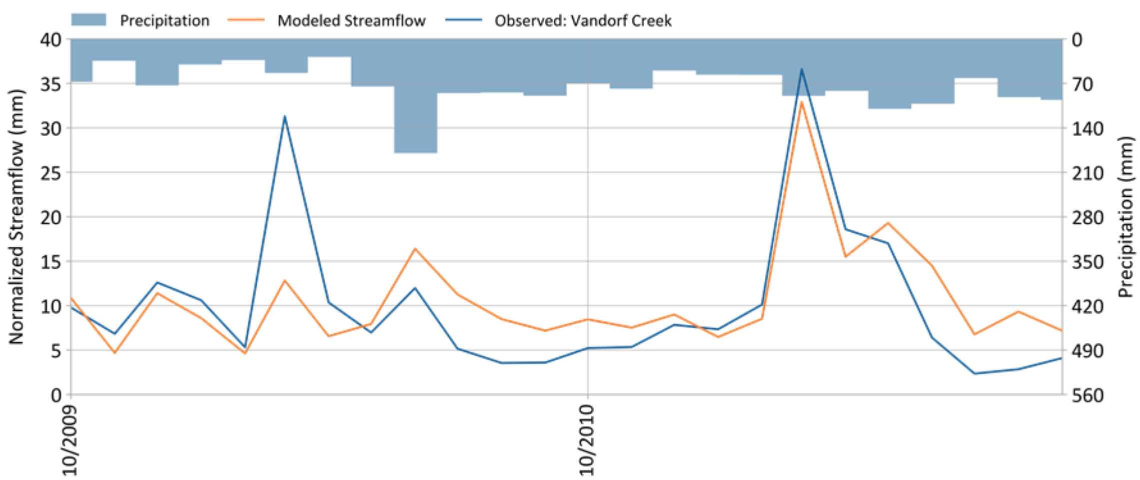


Figure C-7. Simulated vs. observed daily (top) and monthly (bottom) streamflow comparisons at Vandorf Creek (Station ID: Vandorf).

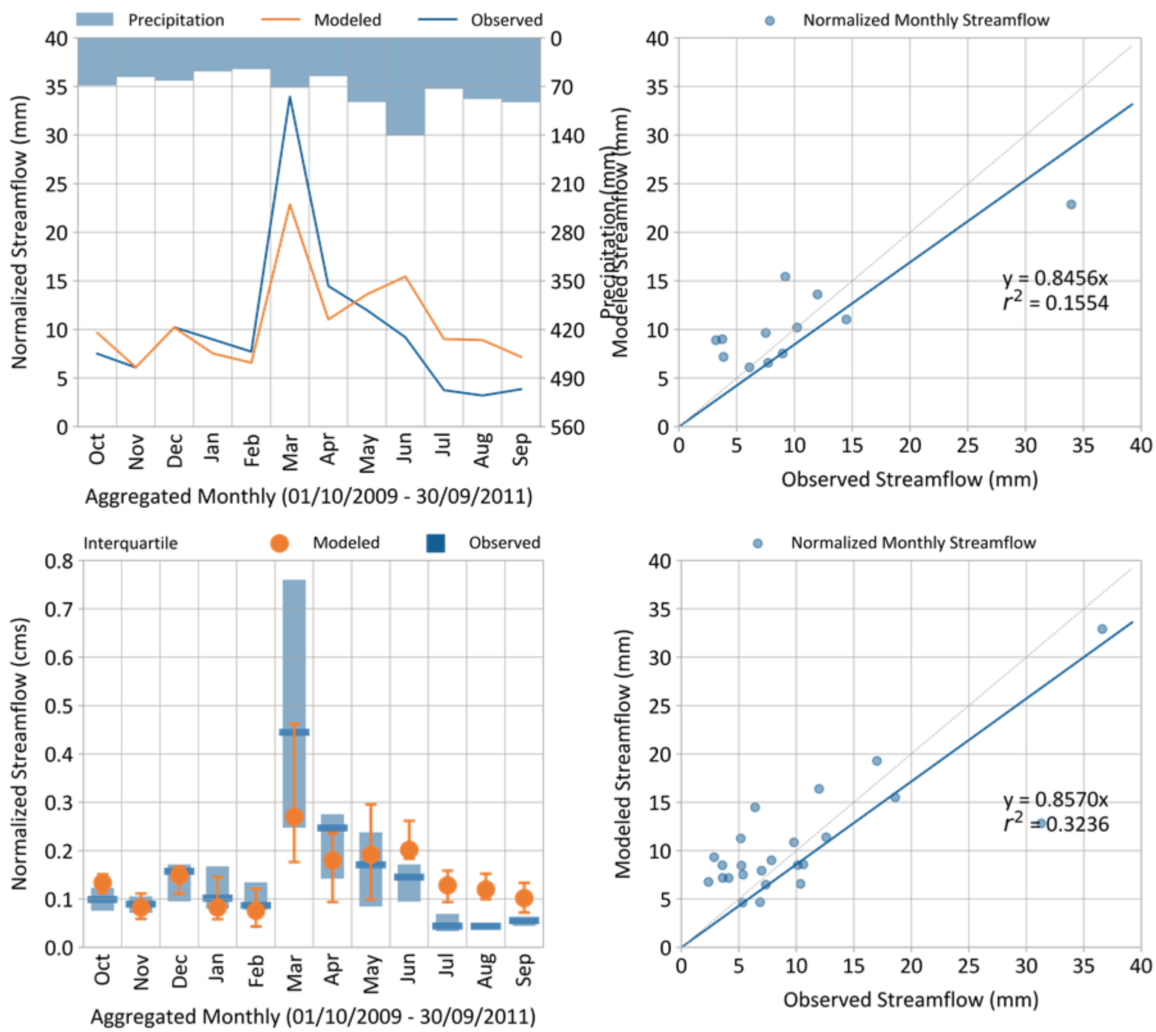


Figure C-8. Simulated vs observed monthly (top) and average monthly (bottom) streamflow comparisons at Vandorf Creek (Station ID: Vandorf).

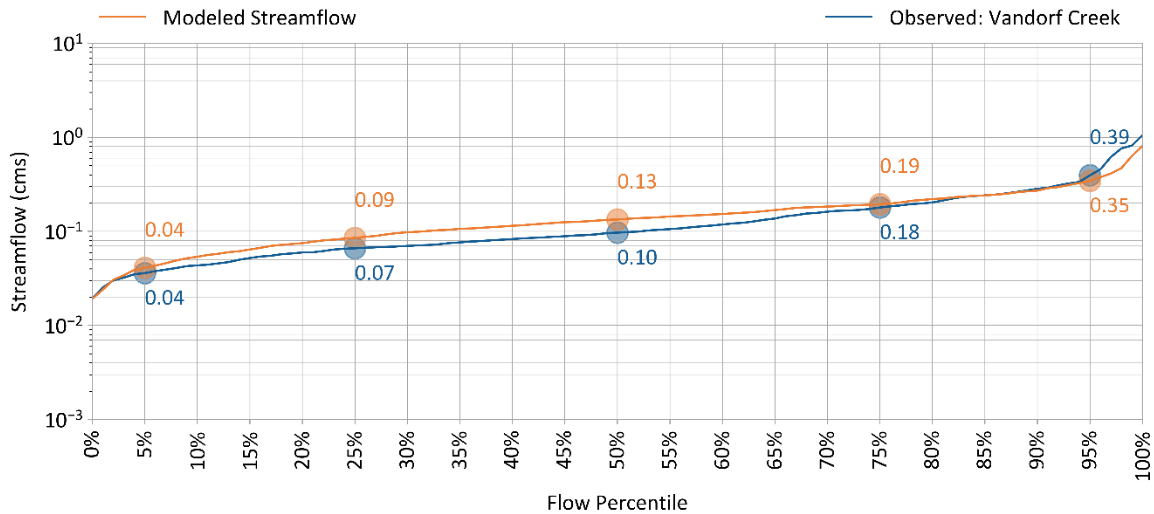


Figure C-9. Flow Duration Curve for Daily Flow at Vandorf Creek (Station ID: Vandorf).

Table C-9. Relative Mean Error for Predicted vs Observed Volumes at Vandorf Creek (Station ID: Vandorf).

Calibration Metrics *(01/10/2009 - 30/09/2011)*	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation) — Relative Mean Error: All Seasons	Winter	Spring	Summer	Fall
Total Annual Volume	6.3%	-27.0%	12.4%	132.2%	10.2%
Highest Weekly Flows	2.2%	-20.2%	-2.1%	58.8%	16.8%
Lowest Weekly Flows	-6.4%	-14.5%	-19.0%	46.4%	2.0%
Storm Volume	9.9%	-36.1%	34.3%	160.1%	28.2%
Baseflow Volume	6.0%	-26.0%	10.7%	129.7%	8.8%
Baseflow Recession Rate	-0.3%	1.4%	-1.3%	-0.7%	-0.8%

Performance: Very Good | Good | Satisfactory | Unsatisfactory

Reference: Donigian et al. (1984), Lumb et al. (1984), and Donigian (2000)

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation: Very Good	Good	Satisfactory	Unsatisfactory	Reference
Relative Mean Error	Total Annual Volume	Compare Observed vs Simulated Total Volume across Simulation Period for Selected Season-Conditions	≤5%	5 - 10%	10 - 15%	>15%	Donigian et al. (1984), Lumb et al. (1984), and Donigian (2000)
	Highest Weekly Flows		≤10%	10 - 15%	15 - 25%	>25%	
	Lowest Weekly Flows		≤10%	10 - 15%	15 - 25%	>25%	
	Annual Storm Volume		≤10%	10 - 15%	15 - 25%	>25%	
	Seasonal Storm Volume		≤15%	15 - 30%	30 - 50%	>50%	
	Baseflow Volume		≤10%	10 - 15%	15 - 25%	>25%	
	Baseflow Recession Rate		≤3%	3 - 5%	5 - 10%	>10%	

Table C-10. R-Squared for Predicted vs Observed Volumes at Vandorf Creek (Station ID: Vandorf).

Calibration Metrics *(01/10/2009 - 30/09/2011)*	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation) — R-Squared (R^2): All Seasons	Winter	Spring	Summer	Fall
All Conditions	0.54	0.62	0.39	0.55	0.59
Highest Weekly Flow Rates	0.47	0.48	0.41	0.37	0.71
Lowest Weekly Flow Rates	0.45	0.44	0.48	0.43	0.35
Days Categorized as Storm Flow	0.52	0.6	0.38	0.56	0.59
Days Categorized as Baseflow	0.79	0.87	0.64	0.48	0.59

Performance: Very Good | Good | Satisfactory | Unsatisfactory

Reference: Moriasi et al. (2015)

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation: Very Good	Good	Satisfactory	Unsatisfactory	Reference
R-Squared (R^2)	All Conditions	Compare All Observed vs Simulated Daily Flow Rates that Occur During Selected Season-Conditions	>0.85	0.75 - 0.85	0.60 - 0.75	≤0.60	Moriasi et al. (2015)
	Seasonal Flows; Highest Weekly Flow Rates; Lowest Weekly Flow Rates; Days Categorized as Storm Flow; Days Categorized as Baseflow		>0.75	0.60 - 0.75	0.50 - 0.60	≤0.50	

Table C-11. Nash-Sutcliffe Efficiency for Predicted vs Observed Volumes at Vandorf Creek (Station ID: Vandorf).

Calibration Metrics (01/10/2009 - 30/09/2011)	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation) Nash-Sutcliffe Efficiency (E)				
	All Seasons	Winter	Spring	Summer	Fall
All Conditions	0.54	0.53	0.04	-11.27	0.44
Highest Weekly Flow Rates	0.33	0.27	0.27	-0.31	0.62
Lowest Weekly Flow Rates	0.45	0.41	0.42	-0.58	0.19
Days Categorized as Storm Flow	0.52	0.51	0.0	-10.7	0.43
Days Categorized as Baseflow	0.77	0.87	0.57	-26.87	0.46

Performance: Very Good | Good | Satisfactory | Unsatisfactory

Reference: Moriasi et al. (2015)

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
Nash-Sutcliffe Efficiency (E)	All Conditions	Compare All Observed vs Simulated Daily Flow Rates that Occur During Selected Season-Conditions	>0.80	0.70 - 0.80	0.50 - 0.70	≤0.50	Moriasi et al. (2015)
	Seasonal Flows; Highest Weekly Flow Rates; Lowest Weekly Flow Rates; Days Categorized as Storm Flow; Days Categorized as Baseflow		>0.70	0.50 - 0.70	0.40 - 0.50	≤0.40	

Table C-12. Percent Bias for Predicted vs Observed Volumes at Vandorf Creek (Station ID: Vandorf).

	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation)				
Calibration Metrics *(01/10/2009 - 30/09/2011)*	**Percent Bias (PBIAS)**				
	All Seasons	**Winter**	**Spring**	**Summer**	**Fall**
All Conditions	6.3%	-27.0%	12.4%	132.2%	10.2%
Highest Weekly Flow Rates	2.2%	-20.2%	-2.1%	58.8%	16.8%
Lowest Weekly Flow Rates	-6.4%	-14.5%	-19.0%	46.4%	2.0%
Days Categorized as Storm Flow	5.4%	-28.3%	13.6%	129.4%	9.7%
Days Categorized as Baseflow	18.0%	-7.9%	-1.6%	160.9%	15.5%

Performance: Very Good | Good | Satisfactory | Unsatisfactory

Reference: Moriasi et al. (2015)

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
Percent Bias (PBIAS)	All Conditions	Compare All Observed vs Simulated Daily Flow Rates that Occur During Selected Season-Conditions	<5%	5% - 10%	10% - 15%	>15%	Moriasi et al. (2015)
	Seasonal Flows		<10%	10% - 15%	15% - 25%	>25%	
	Highest Weekly Flow Rates						
	Lowest Weekly Flow Rates						
	Days Categorized as Storm Flow						
	Days Categorized as Baseflow						

E Holland River – Holland Landing
Station ID: 02EC009
01/10/2003 – 30/09/2018

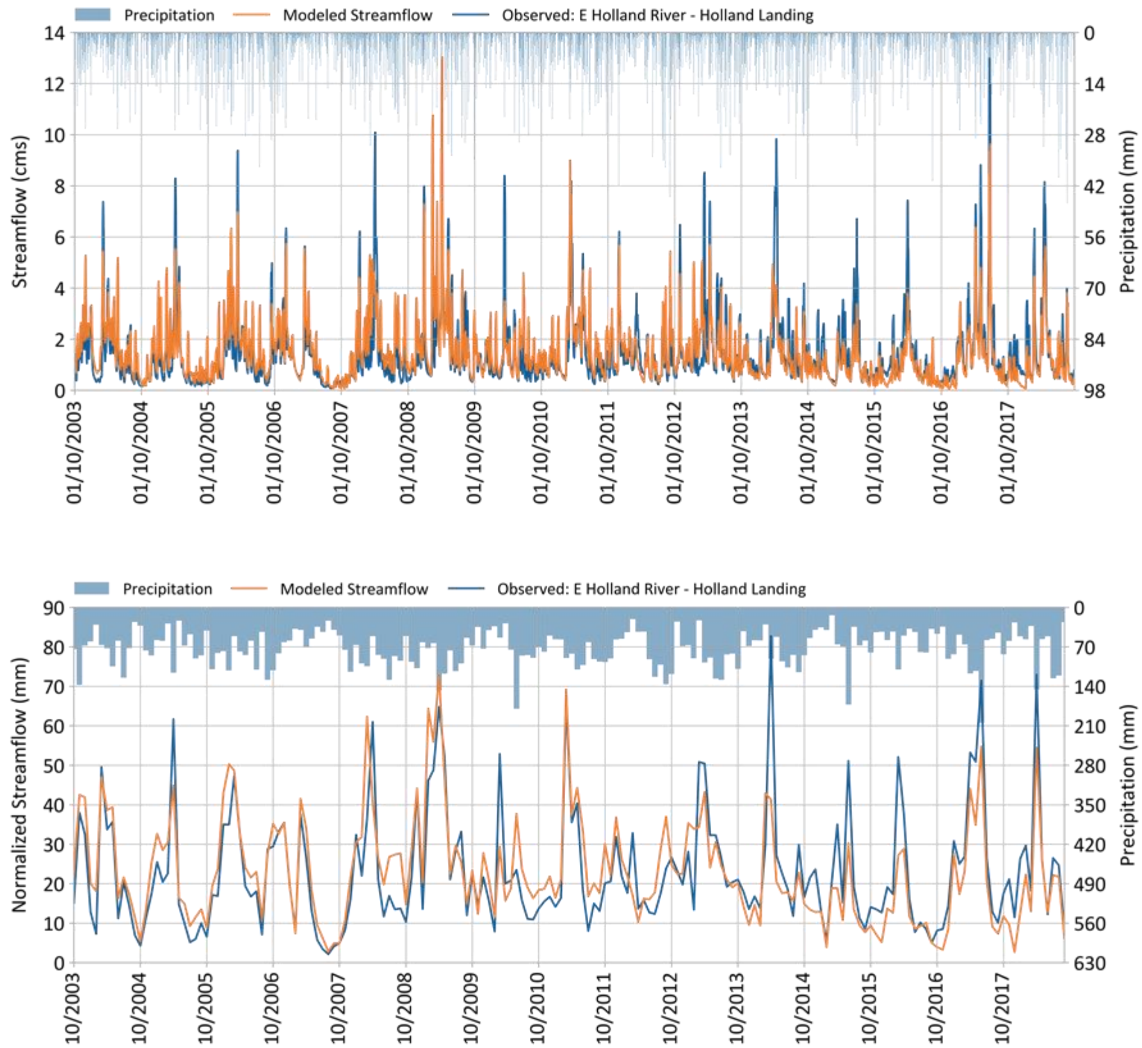


Figure C-10. Simulated vs. observed daily (top) and monthly (bottom) streamflow comparisons at E Holland River - Holland Landing (Station ID: 02EC009).

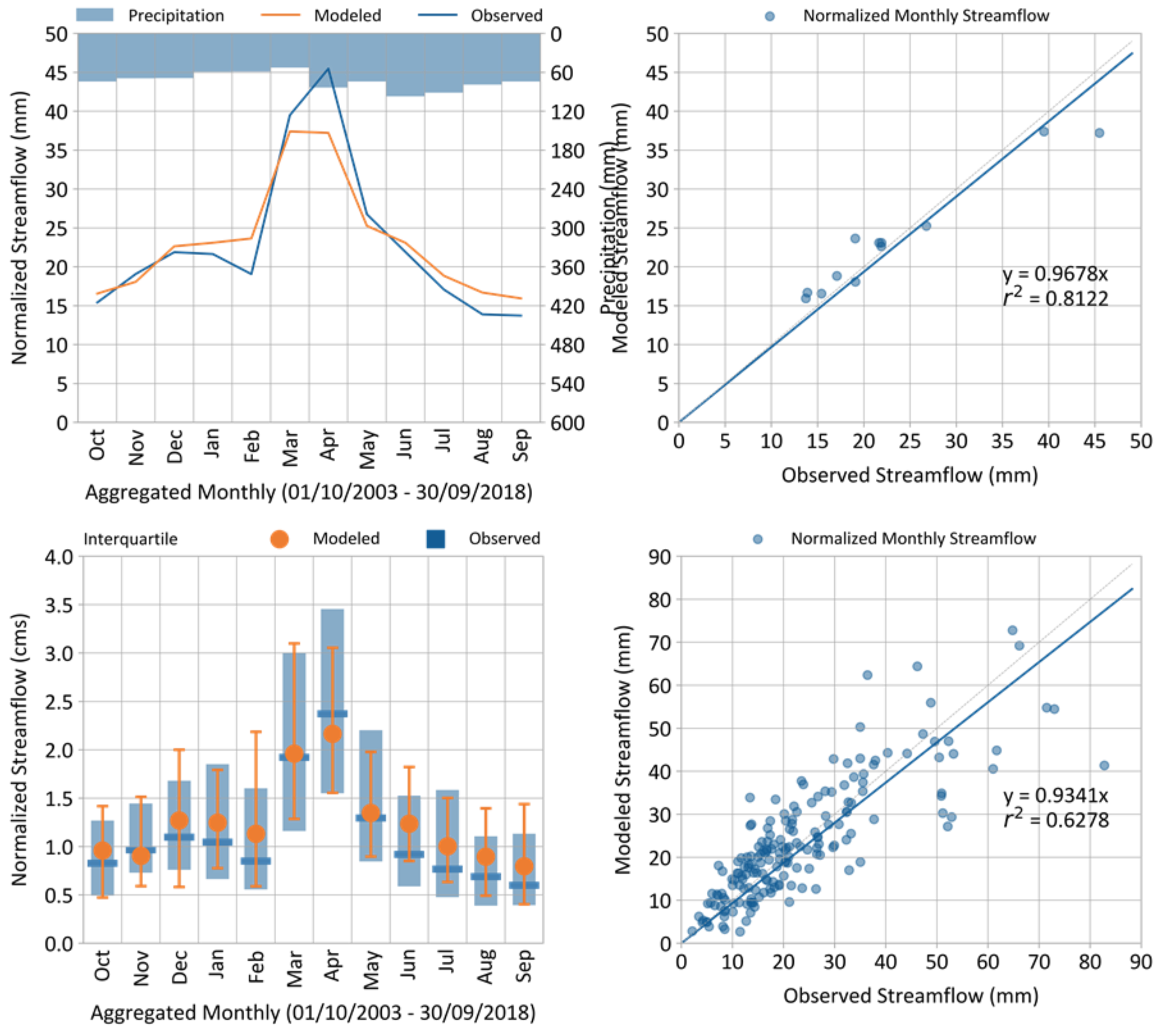


Figure C-11. Simulated vs observed monthly (top) and average monthly (bottom) streamflow comparisons at E Holland River - Holland Landing (Station ID: 02EC009).

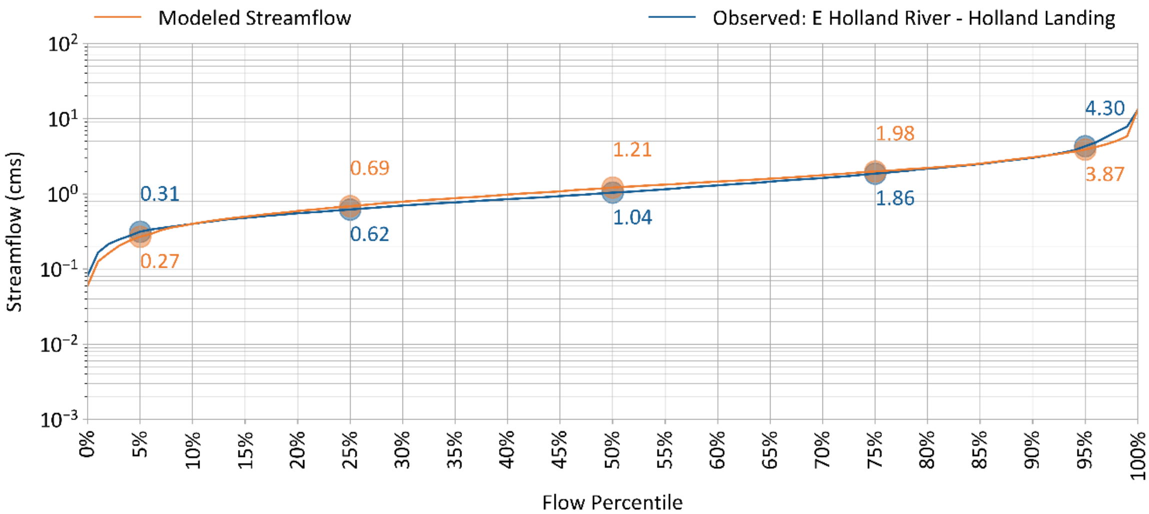


Figure C-12. Flow Duration Curve for Daily Flow at E Holland River - Holland Landing (Station ID: 02EC009).

Table C-13. Relative Mean Error for Predicted vs Observed Volumes at E Holland River - Holland Landing (Station ID: 02EC009).

Calibration Metrics *(01/10/2003 - 30/09/2018)*	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation) Relative Mean Error				
	All Seasons	Winter	Spring	Summer	Fall
Total Annual Volume	1.1%	4.9%	-9.1%	15.2%	1.6%
Highest Weekly Flows	1.7%	-5.9%	-6.8%	23.1%	6.2%
Lowest Weekly Flows	10.9%	17.7%	3.8%	31.0%	-0.1%
Storm Volume	-11.0%	-15.1%	-19.9%	2.1%	-1.6%
Baseflow Volume	4.7%	11.3%	-6.0%	19.9%	2.4%
Baseflow Recession Rate	1.5%	2.5%	2.0%	1.4%	-0.6%

Performance: Very Good | Good | Satisfactory | Unsatisfactory

Reference: Donigian et al. (1984), Lumb et al. (1984), and Donigian (2000)

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
Relative Mean Error	Total Annual Volume	Compare Observed vs Simulated Total Volume across Simulation Period for Selected Season-Conditions	≤5%	5 - 10%	10 - 15%	>15%	Donigian et al. (1984), Lumb et al. (1984), and Donigian (2000)
	Highest Weekly Flows		≤10%	10 - 15%	15 - 25%	>25%	
	Lowest Weekly Flows		≤10%	10 - 15%	15 - 25%	>25%	
	Annual Storm Volume		≤10%	10 - 15%	15 - 25%	>25%	
	Seasonal Storm Volume		≤15%	15 - 30%	30 - 50%	>50%	
	Baseflow Volume		≤10%	10 - 15%	15 - 25%	>25%	
	Baseflow Recession Rate		≤3%	3 - 5%	5 - 10%	>10%	

Table C-14. R-Squared for Predicted vs Observed Volumes at E Holland River - Holland Landing (Station ID: 02EC009).

Calibration Metrics (01/10/2003 - 30/09/2018)	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation) R-Squared (R^2)				
	All Seasons	Winter	Spring	Summer	Fall
All Conditions	0.69	0.59	0.73	0.63	0.79
Highest Weekly Flow Rates	0.62	0.54	0.71	0.49	0.81
Lowest Weekly Flow Rates	0.51	0.28	0.7	0.47	0.57
Days Categorized as Storm Flow	0.69	0.6	0.73	0.63	0.8
Days Categorized as Baseflow	0.57	0.42	0.71	0.61	0.69

Performance:	Very Good	Good	Satisfactory	Unsatisfactory

Reference: Moriasi et al. (2015)

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
R-Squared (R^2)	All Conditions	Compare All Observed vs Simulated Daily Flow Rates that Occur During Selected Season-Conditions	>0.85	0.75 - 0.85	0.60 - 0.75	≤0.60	Moriasi et al. (2015)
	Seasonal Flows		>0.75	0.60 - 0.75	0.50 - 0.60	≤0.50	
	Highest Weekly Flow Rates						
	Lowest Weekly Flow Rates						
	Days Categorized as Storm Flow						
	Days Categorized as Baseflow						

Table C-15. Nash-Sutcliffe Efficiency for Predicted vs Observed Volumes at E Holland River - Holland Landing (Station ID: 02EC009).

Calibration Metrics *(01/10/2003 - 30/09/2018)*	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation) — Nash-Sutcliffe Efficiency (E)				
	All Seasons	Winter	Spring	Summer	Fall
All Conditions	0.69	0.57	0.71	0.55	0.78
Highest Weekly Flow Rates	0.61	0.52	0.7	0.3	0.81
Lowest Weekly Flow Rates	0.42	-0.06	0.68	-0.35	-0.23
Days Categorized as Storm Flow	0.69	0.57	0.7	0.55	0.78
Days Categorized as Baseflow	0.47	-0.04	0.68	0.3	0.34

Performance: Very Good | Good | Satisfactory | Unsatisfactory

Reference: Moriasi et al. (2015)

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
Nash-Sutcliffe Efficiency (E)	All Conditions	Compare All Observed vs Simulated Daily Flow Rates that Occur During Selected Season-Conditions	>0.80	0.70 - 0.80	0.50 - 0.70	≤0.50	Moriasi et al. (2015)
	Seasonal Flows Highest Weekly Flow Rates Lowest Weekly Flow Rates Days Categorized as Storm Flow Days Categorized as Baseflow		>0.70	0.50 - 0.70	0.40 - 0.50	≤0.40	

Table C-16. Percent Bias for Predicted vs Observed Volumes at E Holland River - Holland Landing (Station ID: 02EC009).

	Observed vs Simulated Calibration Performance for Runoff Volumes (Simulated vs Observed Total Volume for Condition-Season across Simulation)				
Calibration Metrics *(01/10/2003 - 30/09/2018)*	**Percent Bias (PBIAS)**				
	All Seasons	**Winter**	**Spring**	**Summer**	**Fall**
All Conditions	1.1%	4.9%	-9.1%	15.2%	1.6%
Highest Weekly Flow Rates	1.7%	-5.9%	-6.8%	23.1%	6.2%
Lowest Weekly Flow Rates	10.9%	17.7%	3.8%	31.0%	-0.1%
Days Categorized as Storm Flow	0.3%	3.9%	-9.7%	13.7%	1.2%
Days Categorized as Baseflow	18.0%	27.1%	4.5%	39.2%	9.0%

Performance: Very Good | Good | Satisfactory | Unsatisfactory

Reference: Moriasi et al. (2015)

Performance Metric	Hydrological Condition	Comparison Type	Performance Threshold for Hydrology Simulation				Reference
			Very Good	Good	Satisfactory	Unsatisfactory	
Percent Bias (PBIAS)	All Conditions	Compare All Observed vs Simulated Daily Flow Rates that Occur During Selected Season-Conditions	<5%	5% - 10%	10% - 15%	>15%	Moriasi et al. (2015)
	Seasonal Flows; Highest Weekly Flow Rates; Lowest Weekly Flow Rates; Days Categorized as Storm Flow; Days Categorized as Baseflow		<10%	10% - 15%	15% - 25%	>25%	

APPENDIX D: TSS CALIBRATION PANELS

East Holland River – Holland Landing
Station ID: 02EC009
01/04/2008 – 31/12/2017

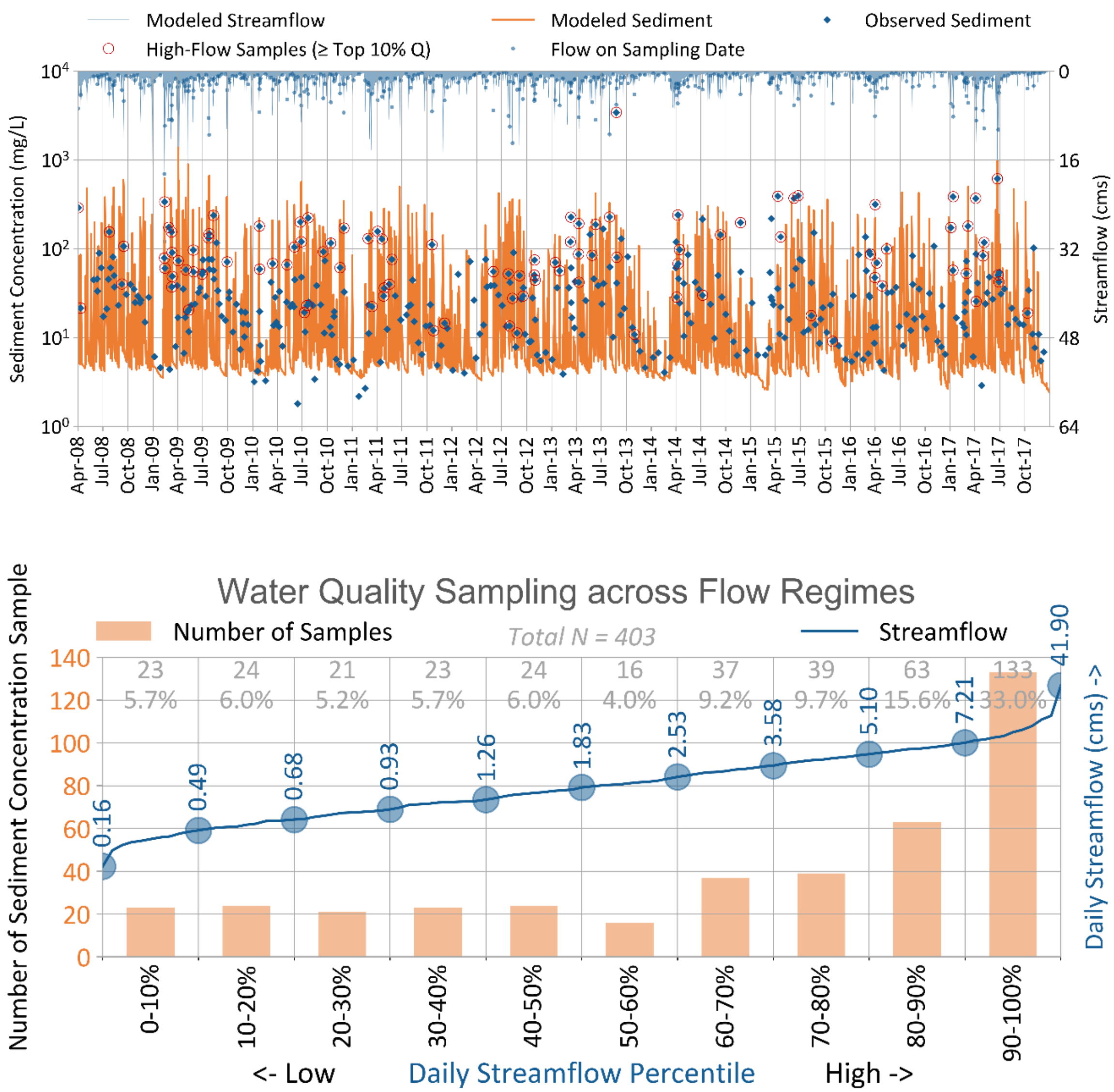


Figure D-1. East Holland River - Holland Landing (02EC009) - TSS calibration: Simulated daily vs. observed grab sample concentration time series (top) and flow duration with TSS sampling (bottom)

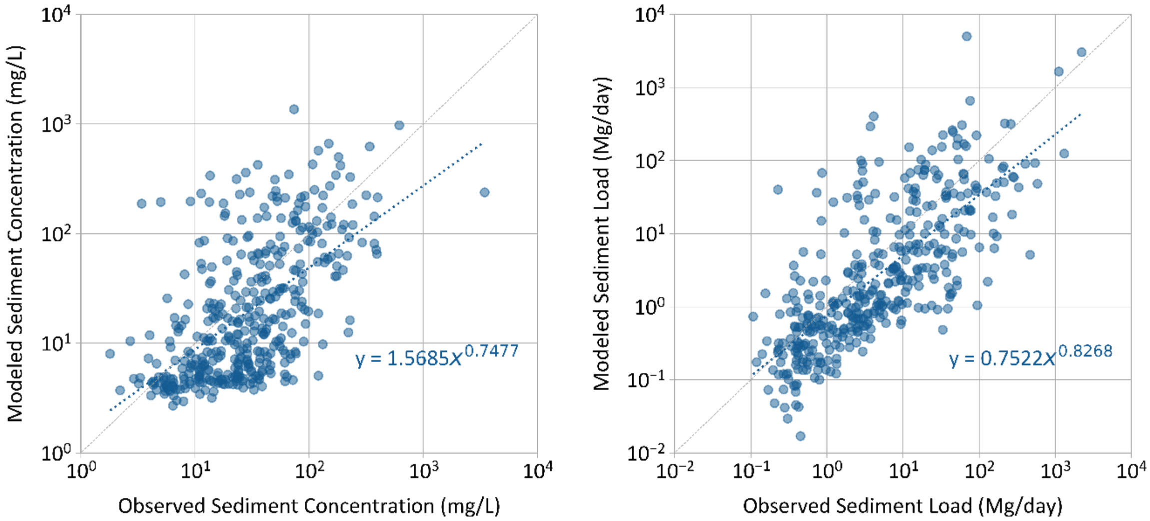


Figure D-2. East Holland River - Holland Landing (02EC009) - TSS calibration: Simulated vs. observed daily TSS concentrations (left) and loading rates (right)

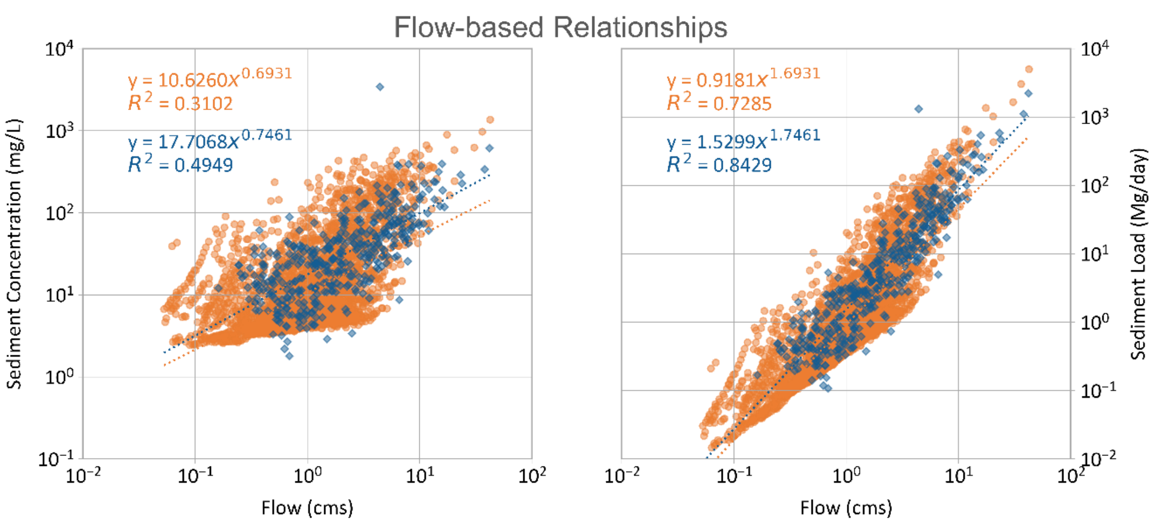


Figure D-3. East Holland River - Holland Landing (02EC009) - TSS calibration: Flow-based relationships for simulated and observed daily concentrations (left) and loading rates (right). Note: the R^2 values here are not relevant to calibration performance

Figure D-4. Holland River – Holland Landing (02EC009) - TSS calibration: Simulated vs. observed concentrations by season (top) and flow regime (bottom)

Table D-1. East Holland River - Holland Landing (02EC009) - TSS calibration: PBIAS statistical metrices for East Holland River - Holland Landing

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for TSS Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) — Percent Bias (PBIAS)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	-1.5%	403	-30.2%	95	5.2%	118	-0.8%	107	31.8%	83
Samples on Days with Highest 25% of Flows	-4.8%	216	-29.2%	61	10.4%	77	-10.8%	49	21.8%	29
Samples on Days with Lowest 50% of Flows	0.2%	115	-39.3%	21	-57.5%	22	43.5%	42	35.2%	30
Samples on Storm Volume Days	-2.1%	374	-29.8%	87	5.1%	112	-2.6%	102	32.7%	73
Samples on Baseflow Volume Days	39.0%	29	-52.8%	8	9.0%	6	255.4%	5	13.5%	10

Percent Bias (PBIAS)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	<15%	15% - 20%	20% - 30%	>30%	Moriasi et al. (2015)
Seasonal and High/Low Flows	<20%	20% - 30%	30% - 40%	>40%	

Table D-2. East Holland River - Holland Landing (02EC009) - TSS calibration: R^2 statistical metrices for East Holland River - Holland Landing

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for TSS Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) — R-Squared (R^2)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.35	403	0.45	95	0.41	118	0.21	107	0.34	83
Samples on Days with Highest 25% of Flows	0.24	216	0.34	61	0.38	77	0.02	49	0.2	29
Samples on Days with Lowest 50% of Flows	0.03	115	0.0	21	0.02	22	0.0	42	0.04	30
Samples on Storm Volume Days	0.33	374	0.42	87	0.4	112	0.21	102	0.3	73
Samples on Baseflow Volume Days	0.27	29	0.15	8	0.18	6	0.65	5	0.59	10

R-Squared (R^2)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.70	0.6 - 0.70	0.30 - 0.60	<0.30	Moriasi et al. (2015)
Seasonal and High/Low Flows	> 0.60	0.30 - 0.60	0.20 - 0.30	<0.20	

Table D-3. East Holland River - Holland Landing (02EC009)-TSS calibration: NSE statistical metrices for East Holland River - Holland Landing

	Observed vs Simulated Calibration Performance for TSS Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration)									
Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Nash-Sutcliffe Efficiency (E)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	-0.23	403	0.07	95	-0.48	118	-0.86	107	-0.25	83
Samples on Days with Highest 25% of Flows	-0.68	216	-1.11	61	-0.42	77	-1.0	49	-0.41	29
Samples on Days with Lowest 50% of Flows	-1.62	115	-0.59	21	-3.29	22	-6.31	42	-2.41	30
Samples on Storm Volume Days	-0.28	374	0.03	87	-0.49	112	-0.9	102	-0.35	73
Samples on Baseflow Volume Days	-2.1	29	-1.44	8	-10.39	6	-26.42	5	-0.26	10

Nash-Sutcliffe Efficiency (E)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.65	0.50 - 0.65	0.35 - 0.50	<0.35	Moriasi et al. (2015)
Seasonal and High/Low Flows	>0.50	0.35 - 0.50	0.25 - 0.35	<0.25	

Table D-4. East Holland River - Holland Landing (02EC009) - TSS calibration: PBIAS statistical metrices for East Holland River - Holland Landing

	Observed vs Simulated Calibration Performance for TSS Load (Observed Daily Load vs Daily Simulated Load)									
Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Percent Bias (PBIAS)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	23.4%	403	-10.7%	95	45.3%	118	8.6%	107	30.8%	83
Samples on Days with Highest 25% of Flows	21.0%	216	-10.6%	61	45.2%	77	0.3%	49	17.7%	29
Samples on Days with Lowest 50% of Flows	179.5%	115	-7.0%	21	27.9%	22	389.0%	42	183.4%	30
Samples on Storm Volume Days	23.3%	374	-10.5%	87	45.2%	112	8.1%	102	30.3%	73
Samples on Baseflow Volume Days	99.7%	29	-60.9%	8	94.8%	6	854.3%	5	83.6%	10

Percent Bias (PBIAS)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	<15%	15% - 20%	20% - 30%	>30%	Moriasi et al. (2015)
Seasonal and High/Low Flows	<20%	20% - 30%	30% - 40%	>40%	

Table D-5. East Holland River - Holland Landing (02EC009) - TSS calibration: R^2 statistical metrices for East Holland River - Holland Landing

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for TSS Load (Observed Daily Load vs Daily Simulated Load) R-Squared (R^2)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.55	403	0.59	95	0.61	118	0.5	107	0.49	83
Samples on Days with Highest 25% of Flows	0.29	216	0.42	61	0.42	77	0.04	49	0.2	29
Samples on Days with Lowest 50% of Flows	0.09	115	0.08	21	0.06	22	0.23	42	0.01	30
Samples on Storm Volume Days	0.54	374	0.55	87	0.6	112	0.5	102	0.49	73
Samples on Baseflow Volume Days	0.36	29	0.51	8	0.83	6	0.75	5	0.26	10

R-Squared (R^2)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.70	0.6 - 0.70	0.30 - 0.60	<0.30	Moriasi et al. (2015)
Seasonal and High/Low Flows	> 0.60	0.30 - 0.60	0.20 - 0.30	<0.20	

Table D-6. East Holland River - Holland Landing (02EC009) - TSS calibration: NSE statistical metrices for East Holland River - Holland Landing

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for TSS Load (Observed Daily Load vs Daily Simulated Load) Nash-Sutcliffe Efficiency (E)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.33	403	0.39	95	0.29	118	0.24	107	0.08	83
Samples on Days with Highest 25% of Flows	-0.48	216	-0.78	61	-0.2	77	-0.94	49	-0.42	29
Samples on Days with Lowest 50% of Flows	-2.41	115	-0.93	21	-3.8	22	-3.21	42	-6.75	30
Samples on Storm Volume Days	0.3	374	0.35	87	0.28	112	0.21	102	0.02	73
Samples on Baseflow Volume Days	-0.52	29	-0.33	8	-1.64	6	-8.7	5	-1.96	10

Nash-Sutcliffe Efficiency (E)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.65	0.50 - 0.65	0.35 - 0.50	<0.35	Moriasi et al. (2015)
Seasonal and High/Low Flows	>0.50	0.35 - 0.50	0.25 - 0.35	<0.25	

Western Creek
Station ID: LS0201
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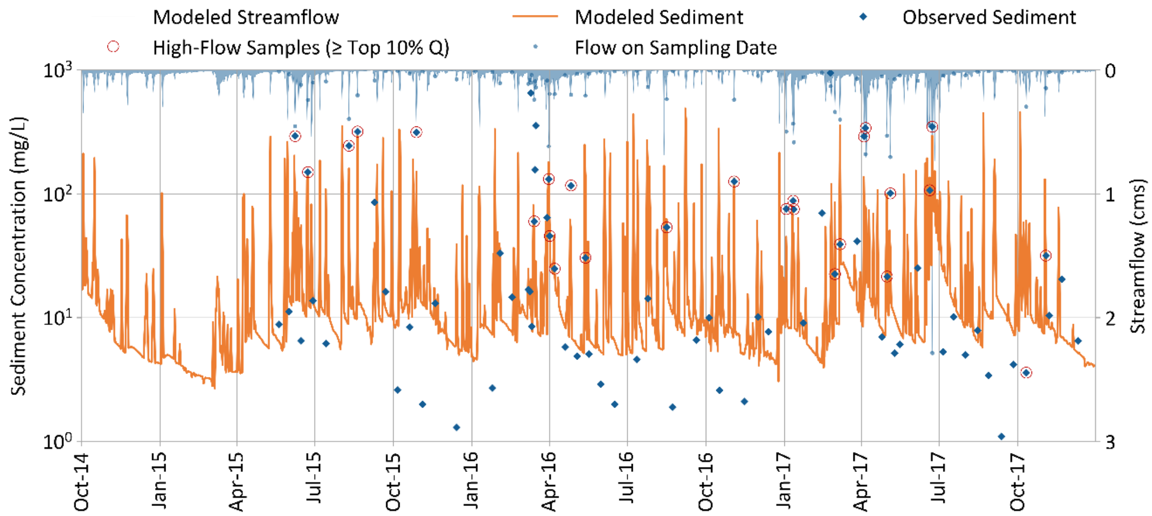


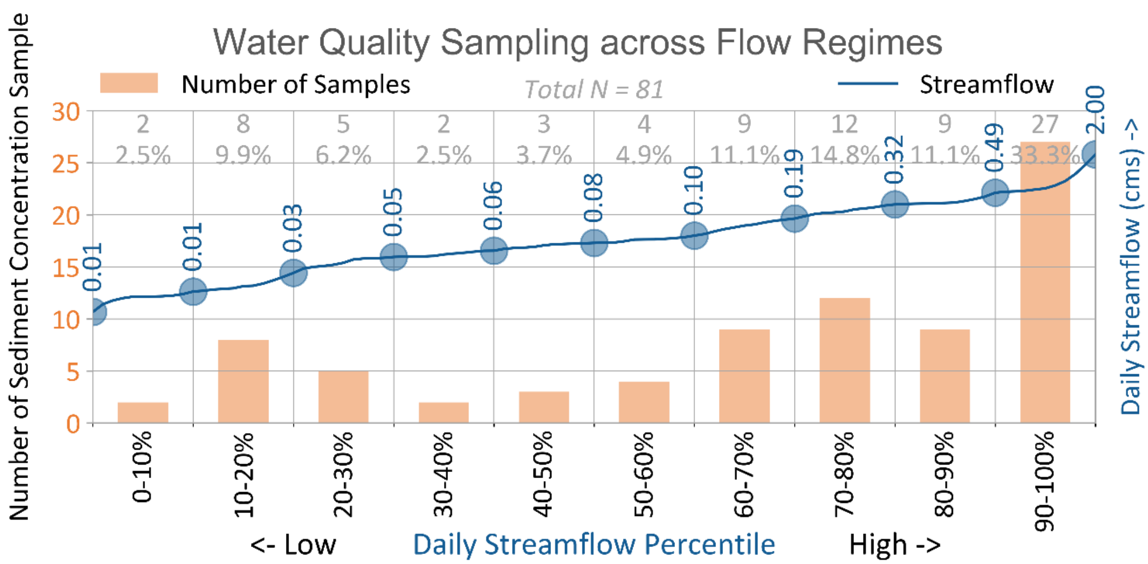


Figure D-5. Western Creek (LS0201) - TSS calibration: Simulated daily vs. observed grab sample concentration time series (top) and flow duration with TSS sampling (bottom)

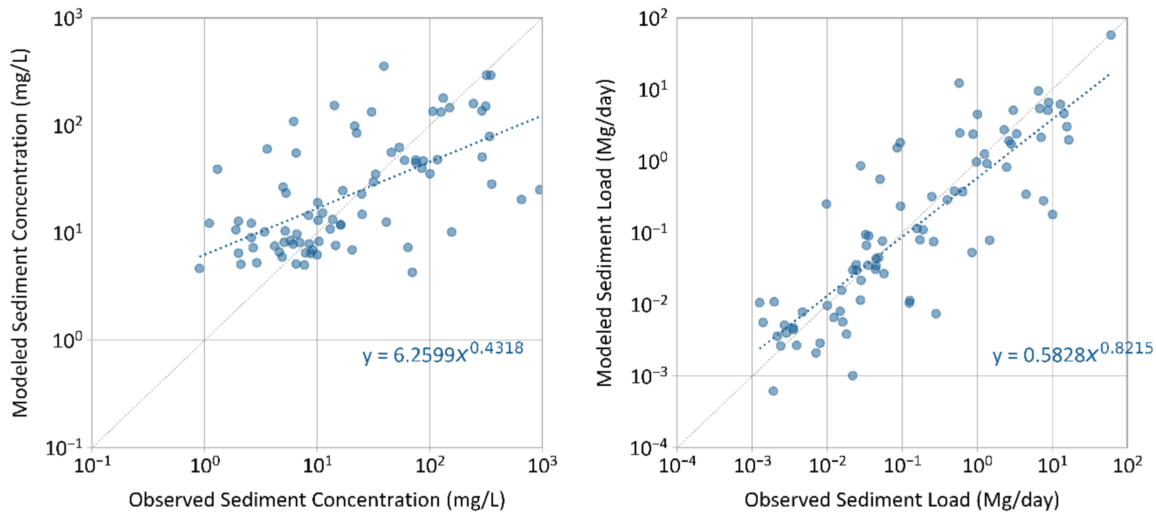


Figure D-6. Western Creek (LS0201) - TSS calibration: Simulated vs. observed daily TSS concentrations (left) and loading rates (right)

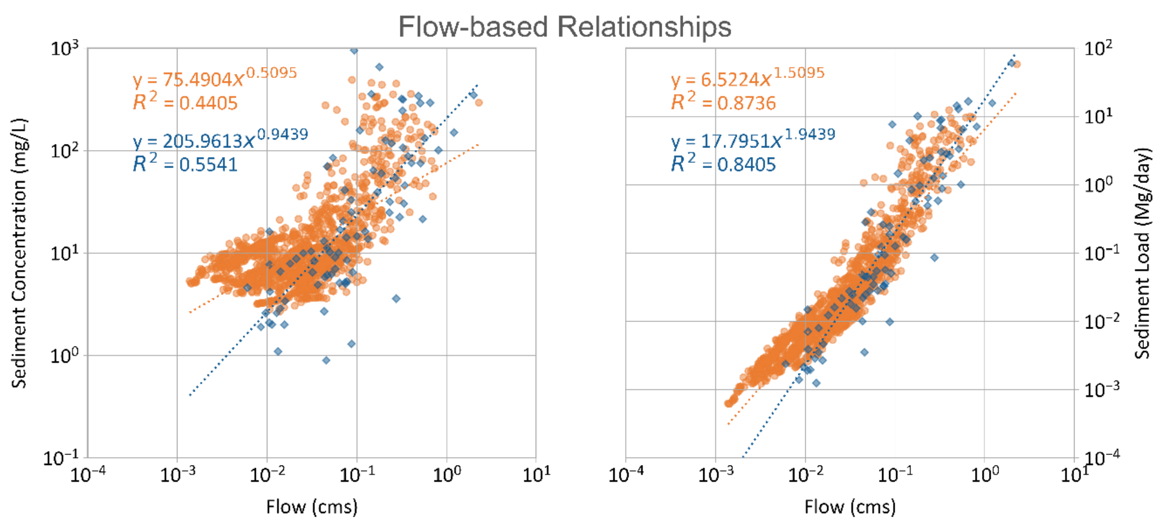


Figure D-7. Western Creek (LS0201) - TSS calibration: Flow-based relationships for simulated and observed daily concentrations (left) and loading rates (right). Note: the R^2 values here are not relevant to calibration performance

Figure D-8. Western Creek (LS0201) - TSS calibration: Simulated vs. observed concentrations by season (top) and flow regime (bottom)

Table D-7. Western Creek (LS0201) - TSS calibration: PBIAS statistical metrices for Western Creek

Condition during Sample Collection *(01/10/2014 - 31/12/2017)*	Observed vs Simulated Calibration Performance for TSS Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) — Percent Bias (PBIAS): All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	-37.1%	81	-64.5%	22	-28.8%	25	21.4%	17	-7.6%	17
Samples on Days with Highest 25% of Flows	-40.9%	44	-65.0%	17	-30.6%	16	12.2%	6	-13.2%	5
Samples on Days with Lowest 50% of Flows	54.3%	20	N/A	0	N/A	3	64.8%	8	50.7%	9
Samples on Storm Volume Days	-25.7%	73	-44.9%	18	-31.4%	24	19.9%	15	-9.3%	16
Samples on Baseflow Volume Days	-87.6%	8	N/A	4	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

Percent Bias (PBIAS)	Performance Threshold for WQ Simulation: Very Good	Good	Satisfactory	Unsatisfactory	Reference
All Conditions (Combined)	<15%	15% - 20%	20% - 30%	>30%	Moriasi et al. (2015)
Seasonal and High/Low Flows	<20%	20% - 30%	30% - 40%	>40%	

Table D-8. Western Creek (LS0201) - TSS calibration: R^2 statistical metrices for Western Creek

Condition during Sample Collection *(01/10/2014 - 31/12/2017)*	Observed vs Simulated Calibration Performance for TSS Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) — R-Squared (R^2): All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.37	81	0.14	22	0.7	25	0.53	17	0.3	17
Samples on Days with Highest 25% of Flows	0.12	44	0.02	17	0.4	16	0.7	6	0.51	5
Samples on Days with Lowest 50% of Flows	0.03	20	N/A	0	N/A	3	0.07	8	0.05	9
Samples on Storm Volume Days	0.42	73	0.16	18	0.76	24	0.52	15	0.3	16
Samples on Baseflow Volume Days	0.07	8	N/A	4	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

R-Squared (R^2)	Performance Threshold for WQ Simulation: Very Good	Good	Satisfactory	Unsatisfactory	Reference
All Conditions (Combined)	>0.70	0.6 - 0.70	0.30 - 0.60	<0.30	Moriasi et al. (2015)
Seasonal and High/Low Flows	> 0.60	0.30 - 0.60	0.20 - 0.30	<0.20	

Table D-9. Western Creek (LS0201) - TSS calibration: NSE statistical metrices for Western Creek

Condition during Sample Collection *(01/10/2014 - 31/12/2017)*	Observed vs Simulated Calibration Performance for TSS Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) — Nash-Sutcliffe Efficiency (E): All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.35	81	-0.14	22	0.69	25	0.26	17	0.1	17
Samples on Days with Highest 25% of Flows	-0.01	44	-0.97	17	0.4	16	0.36	6	0.07	5
Samples on Days with Lowest 50% of Flows	-1.13	20	N/A	0	N/A	3	-1.21	8	-1.28	9
Samples on Storm Volume Days	0.4	73	-0.16	18	0.75	24	0.28	15	0.13	16
Samples on Baseflow Volume Days	0.07	8	N/A	4	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

Nash-Sutcliffe Efficiency (E)	Performance Threshold for WQ Simulation: Very Good	Good	Satisfactory	Unsatisfactory	Reference
All Conditions (Combined)	>0.65	0.50 - 0.65	0.35 - 0.50	<0.35	Moriasi et al. (2015)
Seasonal and High/Low Flows	>0.50	0.35 - 0.50	0.25 - 0.35	<0.25	

Table D-10. Western Creek (LS0201) - TSS calibration: PBIAS statistical metrices for Western Creek

Condition during Sample Collection *(01/10/2014 - 31/12/2017)*	Observed vs Simulated Calibration Performance for TSS Load (Observed Daily Load vs Daily Simulated Load) — Percent Bias (PBIAS): All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	-27.7%	81	-23.1%	22	-33.1%	25	-13.5%	17	-4.1%	17
Samples on Days with Highest 25% of Flows	-28.1%	44	-23.0%	17	-33.1%	16	-18.1%	6	-3.1%	5
Samples on Days with Lowest 50% of Flows	-23.7%	20	N/A	0	N/A	3	-3.4%	8	-31.6%	9
Samples on Storm Volume Days	-24.8%	73	-3.4%	18	-33.4%	24	-13.5%	15	-4.1%	16
Samples on Baseflow Volume Days	-88.9%	8	N/A	4	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

Percent Bias (PBIAS)	Performance Threshold for WQ Simulation: Very Good	Good	Satisfactory	Unsatisfactory	Reference
All Conditions (Combined)	<15%	15% - 20%	20% - 30%	>30%	Moriasi et al. (2015)
Seasonal and High/Low Flows	<20%	20% - 30%	30% - 40%	>40%	

Table D-11. Western Creek (LS0201) - TSS calibration: R^2 statistical metrices for Western Creek

Condition during Sample Collection *(01/10/2014 - 31/12/2017)*	Observed vs Simulated Calibration Performance for TSS Load (Observed Daily Load vs Daily Simulated Load) R-Squared (R^2)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.73	81	0.46	22	0.89	25	0.78	17	0.65	17
Samples on Days with Highest 25% of Flows	0.42	44	0.26	17	0.72	16	0.78	6	0.62	5
Samples on Days with Lowest 50% of Flows	0.04	20	N/A	0	N/A	3	0.0	8	0.11	9
Samples on Storm Volume Days	0.74	73	0.47	18	0.92	24	0.78	15	0.64	16
Samples on Baseflow Volume Days	0.6	8	N/A	4	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

R-Squared (R^2)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.70	0.6 - 0.70	0.30 - 0.60	<0.30	Moriasi et al. (2015)
Seasonal and High/Low Flows	> 0.60	0.30 - 0.60	0.20 - 0.30	<0.20	

Table D-12. Western Creek (LS0201) - TSS calibration: NSE statistical metrices for Western Creek

Condition during Sample Collection *(01/10/2014 - 31/12/2017)*	Observed vs Simulated Calibration Performance for TSS Load (Observed Daily Load vs Daily Simulated Load) Nash-Sutcliffe Efficiency (E)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.71	81	0.12	22	0.89	25	0.73	17	0.53	17
Samples on Days with Highest 25% of Flows	0.35	44	-0.81	17	0.71	16	0.66	6	0.33	5
Samples on Days with Lowest 50% of Flows	-0.44	20	N/A	0	N/A	3	-0.42	8	-0.68	9
Samples on Storm Volume Days	0.72	73	0.1	18	0.91	24	0.72	15	0.5	16
Samples on Baseflow Volume Days	0.57	8	N/A	4	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

Nash-Sutcliffe Efficiency (E)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.65	0.50 - 0.65	0.35 - 0.50	<0.35	Moriasi et al. (2015)
Seasonal and High/Low Flows	>0.50	0.35 - 0.50	0.25 - 0.35	<0.25	

Tannery Creek – Yonge St
Station ID: 3007700702
01/04/2008 – 31/12/2017

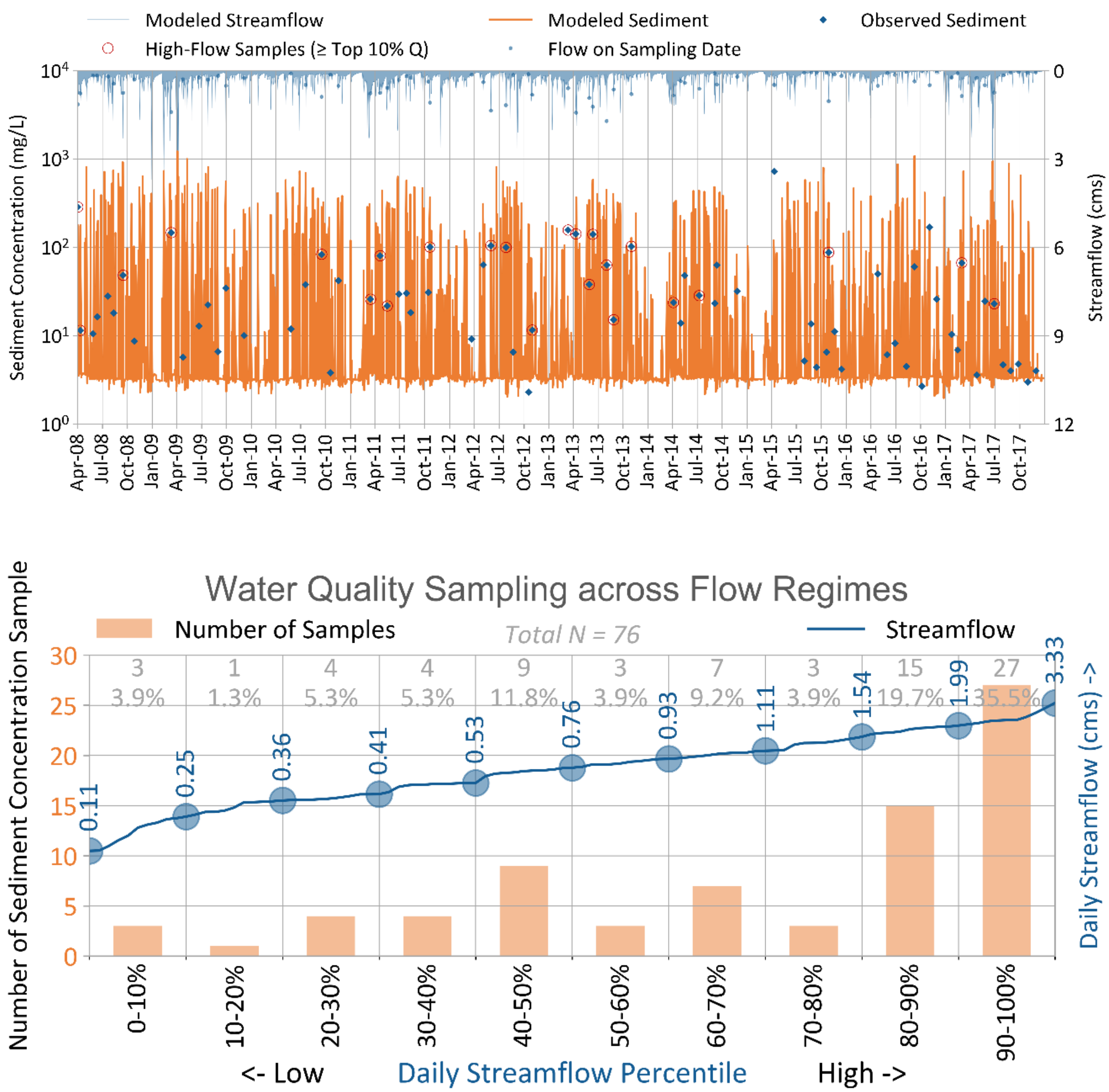


Figure D- 9. Tannery Creek - Yonge St (3007700702) - TSS calibration: Simulated daily vs. observed grab sample concentration time series (top) and flow duration with total TSS sampling (bottom)

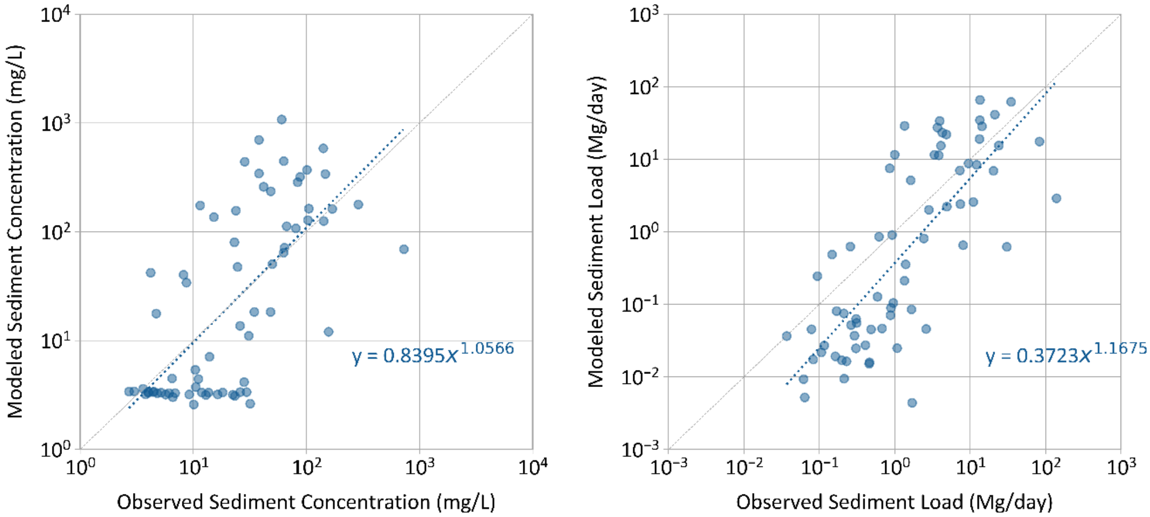


Figure D-10. Tannery Creek - Yonge St (3007700702) - TSS calibration: Simulated vs. observed daily TSS concentrations (left) and loading rates (right)

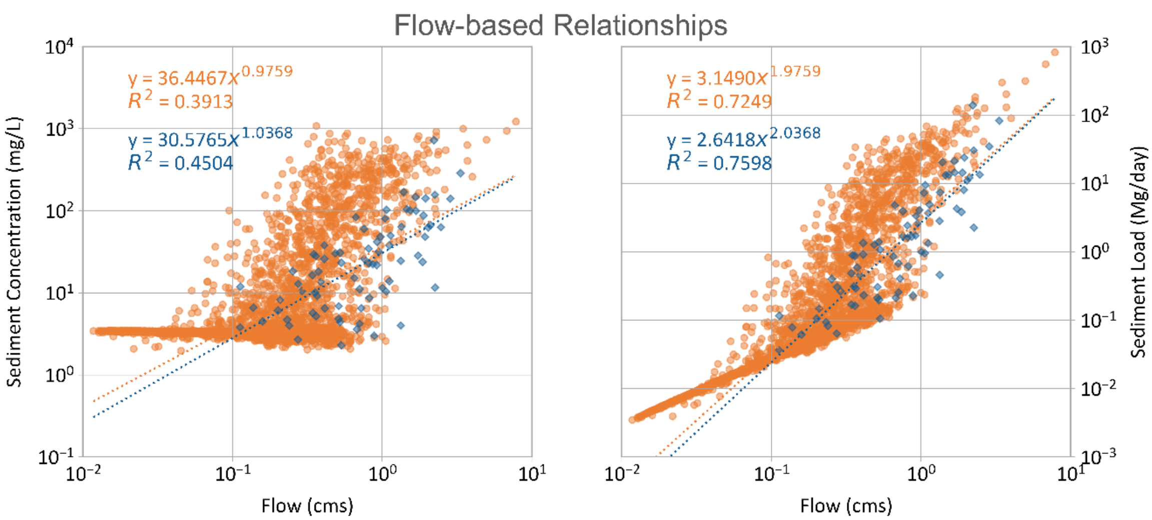
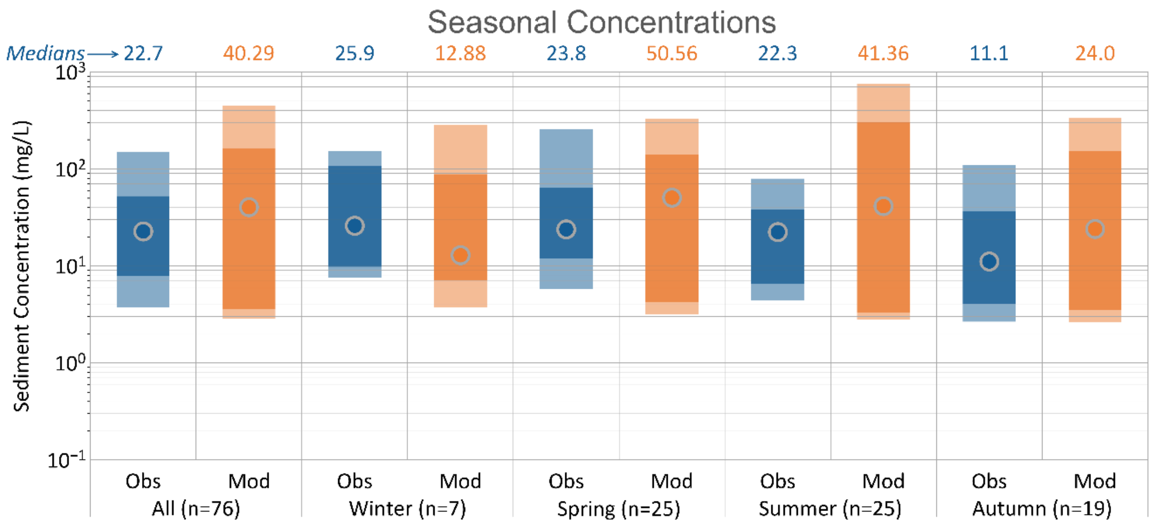


Figure D-11. Tannery Creek - Yonge St (3007700702) - TSS calibration: Flow-based relationships for simulated and observed daily concentrations (left) and loading rates (right). Note: the R^2 values here are not relevant to calibration performance



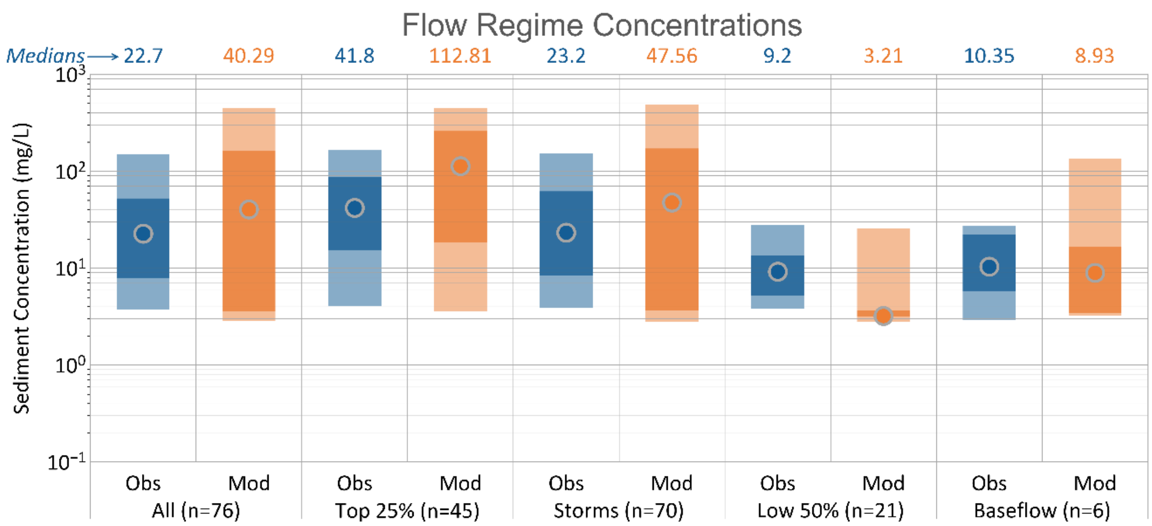


Figure D-12. Tannery Creek - Yonge St (3007700702) - TSS calibration: Simulated vs. observed concentrations by season (top) and flow regime (bottom)

Table D-13. Tannery Creek - Yonge St (3007700702) - TSS calibration: PBIAS statistical metrices for Tannery Creek - Yonge St

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for TSS Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) Percent Bias (PBIAS)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	112.5%	76	15.9%	7	18.3%	25	418.3%	25	108.7%	19
Samples on Days with Highest 25% of Flows	112.3%	45	N/A	4	21.4%	17	482.1%	10	121.9%	14
Samples on Days with Lowest 50% of Flows	-47.7%	21	N/A	1	-37.2%	8	-56.9%	9	N/A	3
Samples on Storm Volume Days	111.4%	70	22.0%	5	9.8%	24	439.6%	23	108.9%	18
Samples on Baseflow Volume Days	165.2%	6	N/A	2	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

Percent Bias (PBIAS)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	<15%	15% - 20%	20% - 30%	>30%	Moriasi et al. (2015)
Seasonal and High/Low Flows	<20%	20% - 30%	30% - 40%	>40%	

Table D-14. Tannery Creek - Yonge St (3007700702) - TSS calibration: R^2 statistical metrices for Tannery Creek - Yonge St

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for TSS Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) R-Squared (R^2)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.47	76	0.62	7	0.43	25	0.49	25	0.55	19
Samples on Days with Highest 25% of Flows	0.36	45	N/A	4	0.29	17	0.23	10	0.49	14
Samples on Days with Lowest 50% of Flows	0.02	21	N/A	1	0.05	8	0.07	9	N/A	3
Samples on Storm Volume Days	0.5	70	0.55	5	0.51	24	0.55	23	0.53	18
Samples on Baseflow Volume Days	0.02	6	N/A	2	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

R-Squared (R^2)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.70	0.6 - 0.70	0.30 - 0.60	<0.30	Moriasi et al. (2015)
Seasonal and High/Low Flows	> 0.60	0.30 - 0.60	0.20 - 0.30	<0.20	

Table D-15. Tannery Creek - Yonge St (3007700702) - TSS calibration: NSE statistical metrices for Tannery Creek - Yonge St

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for TSS Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) — Nash-Sutcliffe Efficiency (E)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	-0.29	76	0.05	7	-0.12	25	-1.63	25	0.17	19
Samples on Days with Highest 25% of Flows	-0.46	45	N/A	4	-0.12	17	-9.33	10	-0.05	14
Samples on Days with Lowest 50% of Flows	-2.66	21	N/A	1	-6.49	8	-2.3	9	N/A	3
Samples on Storm Volume Days	-0.26	70	0.02	5	0.04	24	-1.63	23	0.08	18
Samples on Baseflow Volume Days	-2.06	6	N/A	2	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

Nash-Sutcliffe Efficiency (E)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.65	0.50 - 0.65	0.35 - 0.50	<0.35	Moriasi et al. (2015)
Seasonal and High/Low Flows	>0.50	0.35 - 0.50	0.25 - 0.35	<0.25	

Table D-16. Tannery Creek - Yonge St (3007700702) - TSS calibration: PBIAS statistical metrices for Tannery Creek - Yonge St

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for TSS Load (Observed Daily Load vs Daily Simulated Load) — Percent Bias (PBIAS)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	3.6%	76	-22.4%	7	-44.6%	25	241.4%	25	30.0%	19
Samples on Days with Highest 25% of Flows	0.1%	45	N/A	4	-44.5%	17	232.6%	10	32.9%	14
Samples on Days with Lowest 50% of Flows	-73.1%	21	N/A	1	-65.1%	8	-78.2%	9	N/A	3
Samples on Storm Volume Days	1.8%	70	-22.4%	5	-47.9%	24	245.9%	23	30.2%	18
Samples on Baseflow Volume Days	292.0%	6	N/A	2	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

Percent Bias (PBIAS)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	<15%	15% - 20%	20% - 30%	>30%	Moriasi et al. (2015)
Seasonal and High/Low Flows	<20%	20% - 30%	30% - 40%	>40%	

Table D-17. Tannery Creek - Yonge St (3007700702) - TSS calibration: R^2 statistical metrices for Tannery Creek - Yonge St

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for TSS Load (Observed Daily Load vs Daily Simulated Load) R-Squared (R^2) All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.61	76	0.66	7	0.63	25	0.64	25	0.59	19
Samples on Days with Highest 25% of Flows	0.42	45	N/A	4	0.33	17	0.26	10	0.55	14
Samples on Days with Lowest 50% of Flows	0.12	21	N/A	1	0.02	8	0.1	9	N/A	3
Samples on Storm Volume Days	0.63	70	0.67	5	0.68	24	0.69	23	0.58	18
Samples on Baseflow Volume Days	0.31	6	N/A	2	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

R-Squared (R^2)	Performance Threshold for WQ Simulation: Very Good	Good	Satisfactory	Unsatisfactory	Reference
All Conditions (Combined)	>0.70	0.6 - 0.70	0.30 - 0.60	<0.30	Moriasi et al. (2015)
Seasonal and High/Low Flows	> 0.60	0.30 - 0.60	0.20 - 0.30	<0.20	

Table D-18. Tannery Creek - Yonge St (3007700702) - TSS calibration: NSE statistical metrices for Tannery Creek - Yonge St

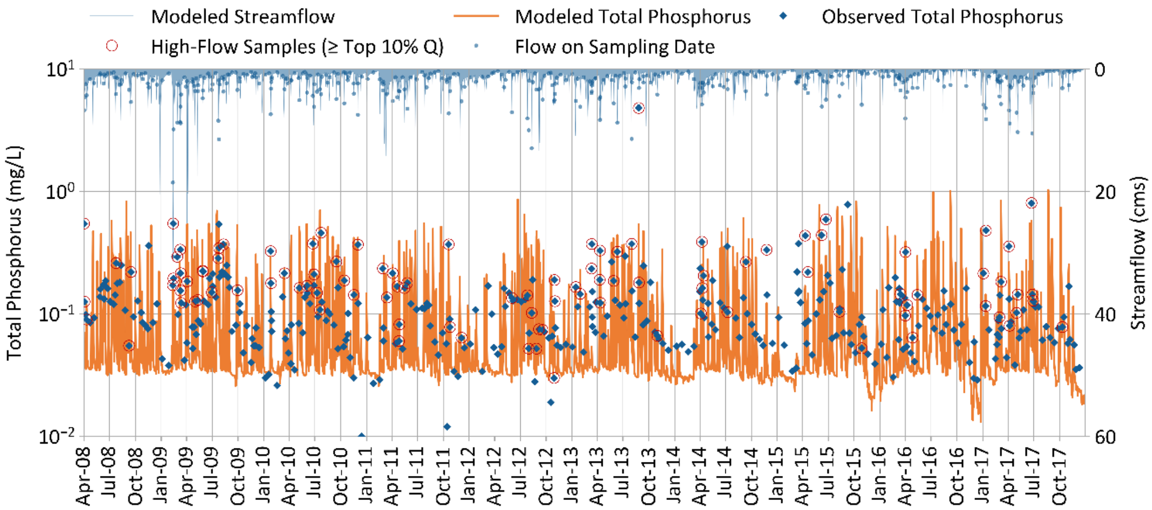
Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for TSS Load (Observed Daily Load vs Daily Simulated Load) Nash-Sutcliffe Efficiency (E) All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	-0.21	76	-0.29	7	0.32	25	-0.82	25	-0.66	19
Samples on Days with Highest 25% of Flows	-0.83	45	N/A	4	-0.09	17	-3.2	10	-1.84	14
Samples on Days with Lowest 50% of Flows	-3.28	21	N/A	1	-4.89	8	-3.36	9	N/A	3
Samples on Storm Volume Days	-0.21	70	-0.62	5	0.37	24	-0.85	23	-0.78	18
Samples on Baseflow Volume Days	-2.13	6	N/A	2	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

Nash-Sutcliffe Efficiency (E)	Performance Threshold for WQ Simulation: Very Good	Good	Satisfactory	Unsatisfactory	Reference
All Conditions (Combined)	>0.65	0.50 - 0.65	0.35 - 0.50	<0.35	Moriasi et al. (2015)
Seasonal and High/Low Flows	>0.50	0.35 - 0.50	0.25 - 0.35	<0.25	

APPENDIX E: TOTAL PHOSPHOROUS CALIBRATION PANELS

East Holland River – Holland Landing
Station ID: 02EC009
01/04/2008 – 31/12/2017



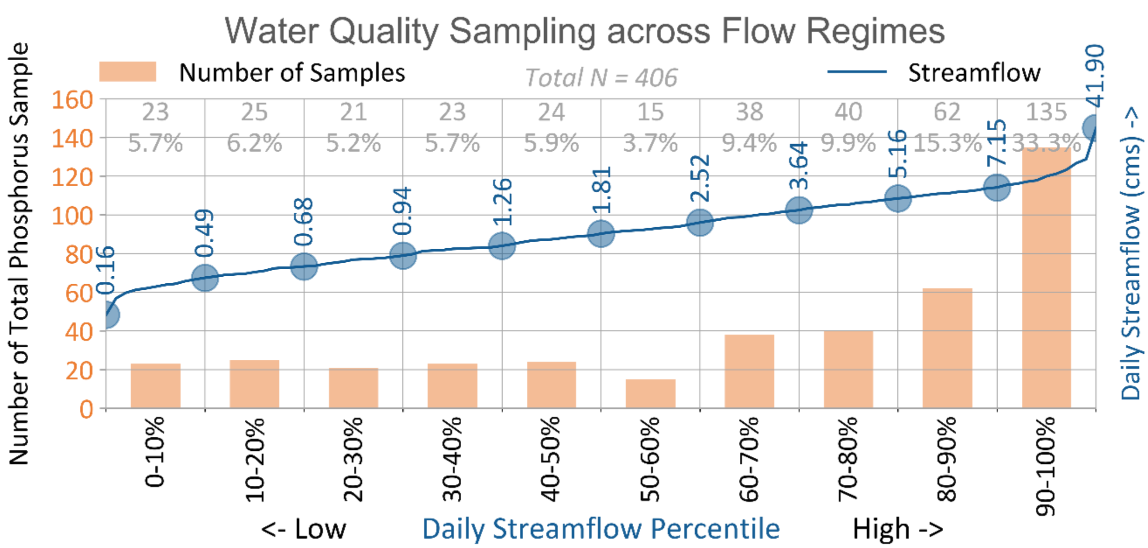


Figure E-1. East Holland River - Holland Landing (02EC009) - Total phosphorus calibration: Simulated daily vs. observed grab sample concentration time series (top) and flow duration with total phosphorus sampling (bottom)

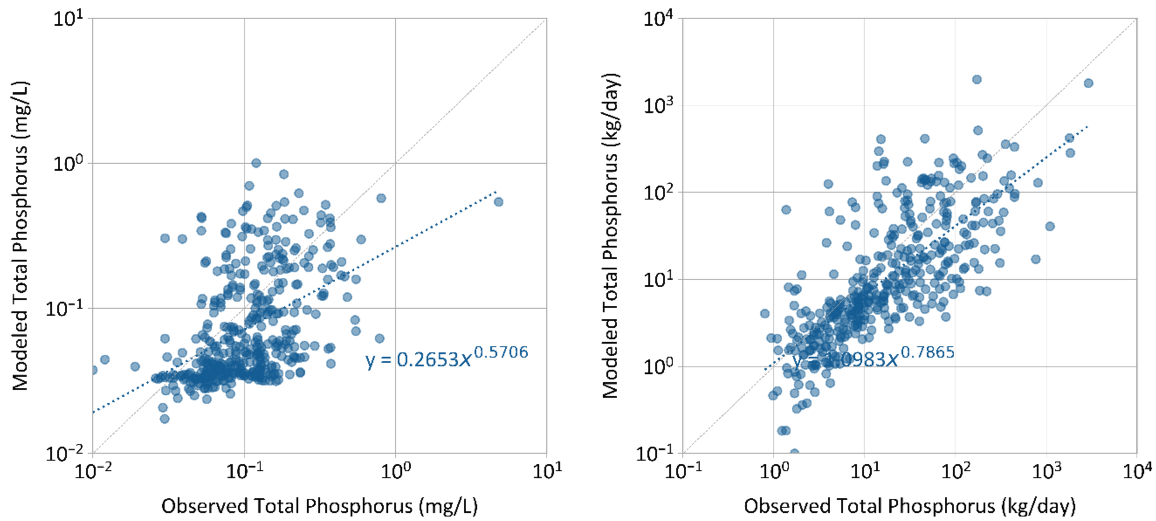


Figure E-2. East Holland River - Holland Landing (02EC009) - Total phosphorus calibration: Simulated vs. observed daily total phosphorus concentrations (left) and loading rates (right)

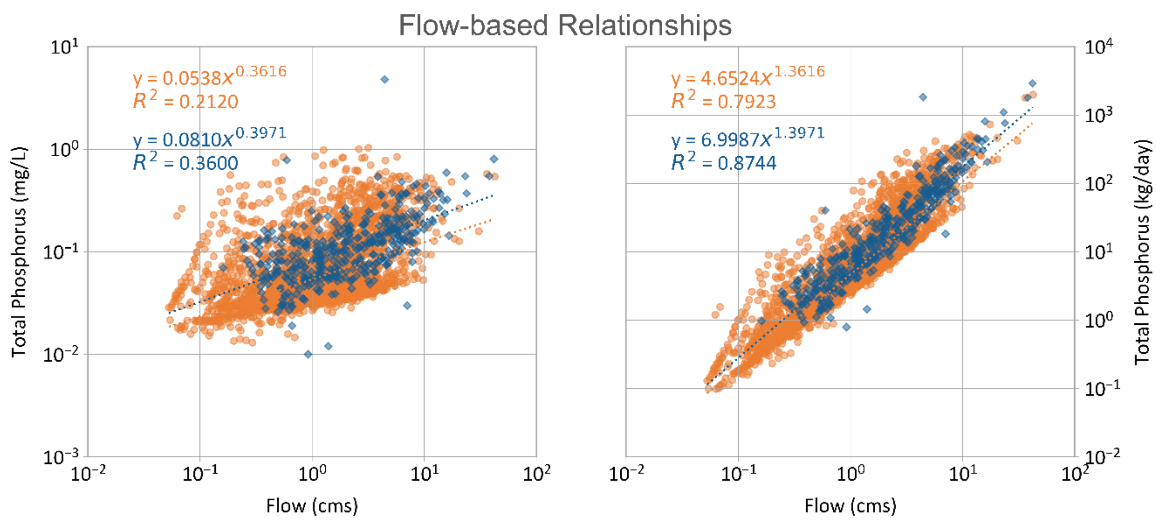


Figure E-3. East Holland River - Holland Landing (02EC009) - Total phosphorus calibration: Flow-based relationships for simulated and observed daily concentrations (left) and loading rates (right). Note: the R^2 values here are not relevant to calibration performance

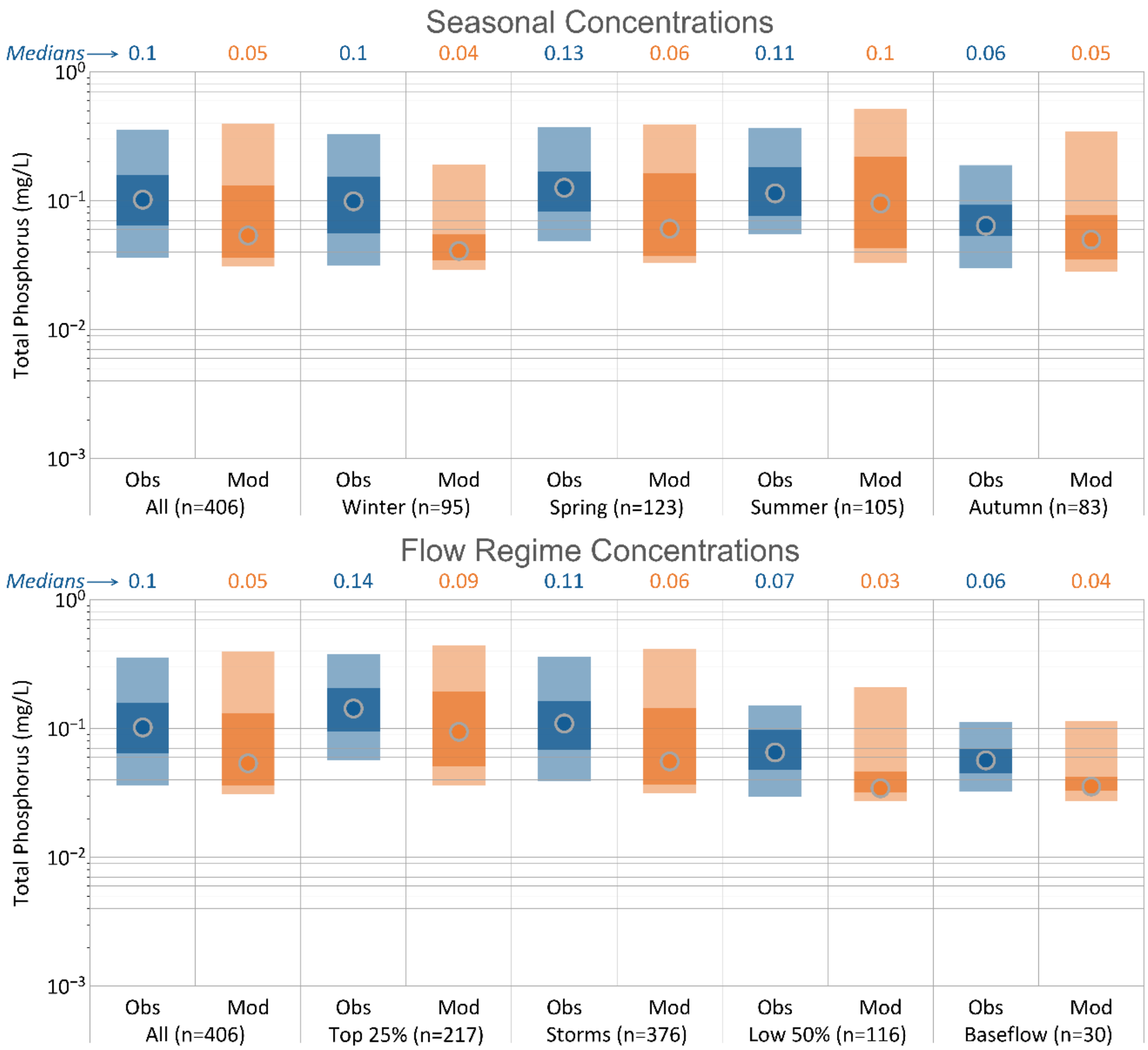


Figure E-4. Holland River – Holland Landing (02EC009) - Total phosphorous calibration: Simulated vs. observed concentrations by season (top) and flow regime (bottom)

Table E-1. East Holland River - Holland Landing (02EC009) - Total phosphorus calibration: PBIAS statistical metrices for East Holland River - Holland Landing

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) — Percent Bias (PBIAS)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	-20.2%	406	-43.8%	95	-19.3%	123	-15.8%	105	3.2%	83
Samples on Days with Highest 25% of Flows	-21.1%	217	-43.8%	61	-12.3%	79	-21.2%	48	2.3%	29
Samples on Days with Lowest 50% of Flows	-26.7%	116	-34.1%	21	-55.6%	23	-18.8%	42	5.5%	30
Samples on Storm Volume Days	-20.2%	376	-44.0%	87	-18.5%	116	-16.8%	100	4.6%	73
Samples on Baseflow Volume Days	-20.4%	30	-40.2%	8	-43.5%	7	43.3%	5	-15.6%	10

Percent Bias (PBIAS)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	<15%	15% - 20%	20% - 30%	>30%	Moriasi et al. (2015)
Seasonal and High/Low Flows	<20%	20% - 30%	30% - 40%	>40%	

Table E-2. East Holland River - Holland Landing (02EC009)-Total phosphorus calibration: R^2 statistical metrices for East Holland River - Holland Landing

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) — R-Squared (R^2)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.21	406	0.25	95	0.27	123	0.09	105	0.24	83
Samples on Days with Highest 25% of Flows	0.14	217	0.09	61	0.3	79	0.0	48	0.13	29
Samples on Days with Lowest 50% of Flows	0.02	116	0.01	21	0.01	23	0.01	42	0.02	30
Samples on Storm Volume Days	0.2	376	0.23	87	0.26	116	0.08	100	0.21	73
Samples on Baseflow Volume Days	0.08	30	0.16	8	0.0	7	0.13	5	0.16	10

R-Squared (R^2)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.70	0.6 - 0.70	0.30 - 0.60	<0.30	Moriasi et al. (2015)
Seasonal and High/Low Flows	> 0.60	0.30 - 0.60	0.20 - 0.30	<0.20	

Table E-3. East Holland River - Holland Landing (02EC009) - Total phosphorus calibration: NSE statistical metrices for East Holland River - Holland Landing

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) — Nash-Sutcliffe Efficiency (E)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	-0.65	406	-0.74	95	-1.03	123	-1.18	105	-0.35	83
Samples on Days with Highest 25% of Flows	-0.98	217	-2.41	61	-0.43	79	-1.07	48	-0.68	29
Samples on Days with Lowest 50% of Flows	-1.54	116	-0.67	21	-6.0	23	-2.84	42	-2.44	30
Samples on Storm Volume Days	-0.74	376	-0.84	87	-1.03	116	-1.23	100	-0.46	73
Samples on Baseflow Volume Days	-1.17	30	-2.11	8	-3.78	7	-24.88	5	-0.0	10

Nash-Sutcliffe Efficiency (E)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.65	0.50 - 0.65	0.35 - 0.50	<0.35	Moriasi et al. (2015)
Seasonal and High/Low Flows	>0.50	0.35 - 0.50	0.25 - 0.35	<0.25	

Table E-4. East Holland River - Holland Landing (02EC009) - Total phosphorus calibration: PBIAS statistical metrices for East Holland River - Holland Landing

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Load (Observed Daily Load vs Daily Simulated Load) — Percent Bias (PBIAS)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	-33.2%	406	-59.9%	95	-30.2%	123	-19.7%	105	-2.6%	83
Samples on Days with Highest 25% of Flows	-36.7%	217	-60.7%	61	-31.3%	79	-28.6%	48	-9.0%	29
Samples on Days with Lowest 50% of Flows	37.7%	116	-9.8%	21	-0.4%	23	81.9%	42	36.7%	30
Samples on Storm Volume Days	-33.4%	376	-59.9%	87	-30.3%	116	-20.2%	100	-2.8%	73
Samples on Baseflow Volume Days	-1.4%	30	-53.4%	8	-13.3%	7	254.2%	5	12.7%	10

Percent Bias (PBIAS)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	<15%	15% - 20%	20% - 30%	>30%	Moriasi et al. (2015)
Seasonal and High/Low Flows	<20%	20% - 30%	30% - 40%	>40%	

Table E-5. East Holland River - Holland Landing (02EC009) - Total phosphorus calibration: R^2 statistical metrices for East Holland River - Holland Landing

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Load (Observed Daily Load vs Daily Simulated Load) R-Squared (R^2)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.55	406	0.57	95	0.62	123	0.5	105	0.5	83
Samples on Days with Highest 25% of Flows	0.24	217	0.3	61	0.4	79	0.03	48	0.18	29
Samples on Days with Lowest 50% of Flows	0.14	116	0.19	21	0.26	23	0.19	42	0.03	30
Samples on Storm Volume Days	0.54	376	0.52	87	0.61	116	0.49	100	0.51	73
Samples on Baseflow Volume Days	0.37	30	0.64	8	0.96	7	0.62	5	0.06	10

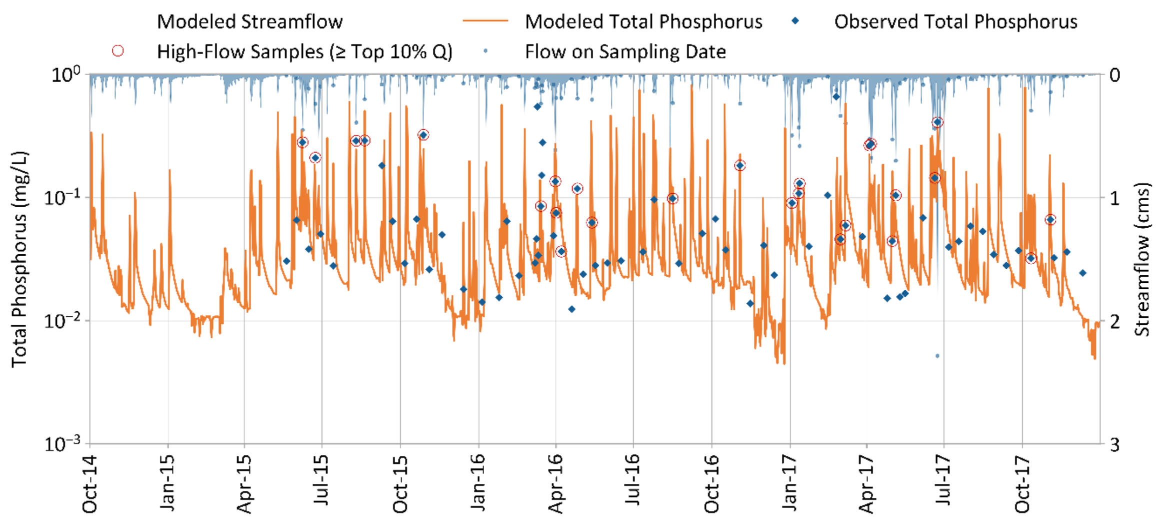
R-Squared (R^2)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.70	0.6 - 0.70	0.30 - 0.60	<0.30	Moriasi et al. (2015)
Seasonal and High/Low Flows	> 0.60	0.30 - 0.60	0.20 - 0.30	<0.20	

Table E-6. East Holland River - Holland Landing (02EC009) - Total phosphorus calibration: NSE statistical metrices for East Holland River - Holland Landing

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Load (Observed Daily Load vs Daily Simulated Load) Nash-Sutcliffe Efficiency (E)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.35	406	0.28	95	0.35	123	0.33	105	0.13	83
Samples on Days with Highest 25% of Flows	-0.54	217	-1.04	61	-0.12	79	-1.01	48	-0.49	29
Samples on Days with Lowest 50% of Flows	-2.23	116	-1.01	21	-7.59	23	-1.55	42	-6.54	30
Samples on Storm Volume Days	0.3	376	0.21	87	0.34	116	0.29	100	0.06	73
Samples on Baseflow Volume Days	-0.07	30	-0.15	8	-0.28	7	-5.32	5	-1.22	10

Nash-Sutcliffe Efficiency (E)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.65	0.50 - 0.65	0.35 - 0.50	<0.35	Moriasi et al. (2015)
Seasonal and High/Low Flows	>0.50	0.35 - 0.50	0.25 - 0.35	<0.25	

Western Creek
Station ID: LS0201
01/10/2014 – 31/12/2017



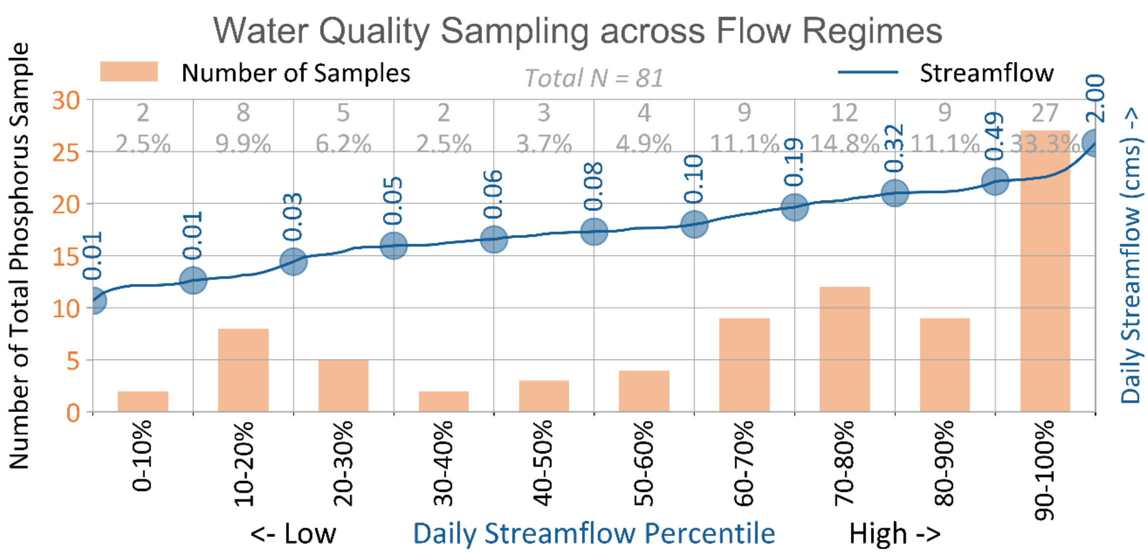


Figure E-5. Western Creek (LS0201) - Total phosphorus calibration: Simulated daily vs. observed grab sample concentration time series (top) and flow duration with total phosphorus sampling (bottom)

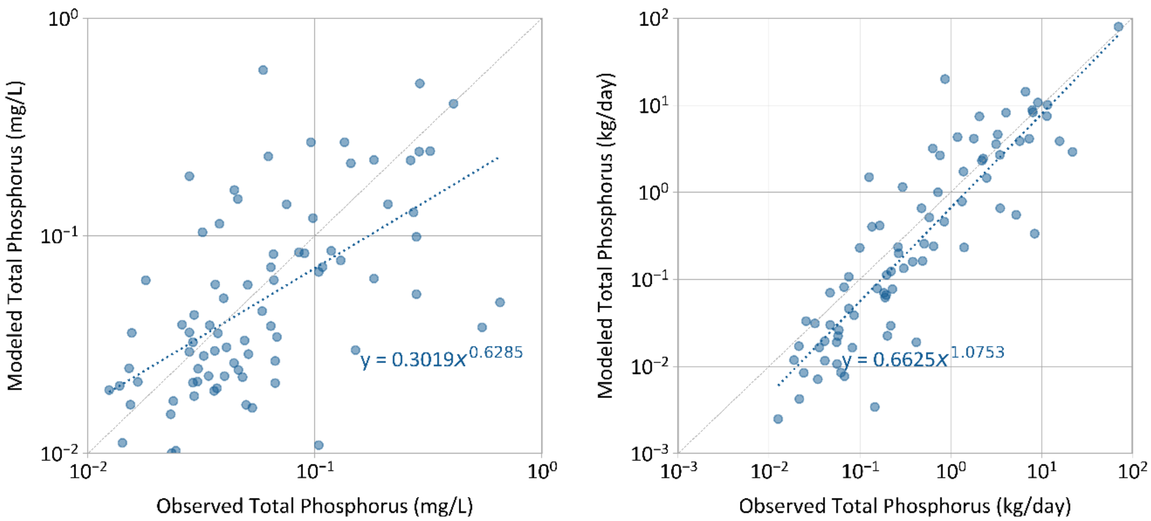


Figure E-6. Western Creek (LS0201) - Total phosphorus calibration: Simulated vs. observed daily total phosphorus concentrations (left) and loading rates (right)

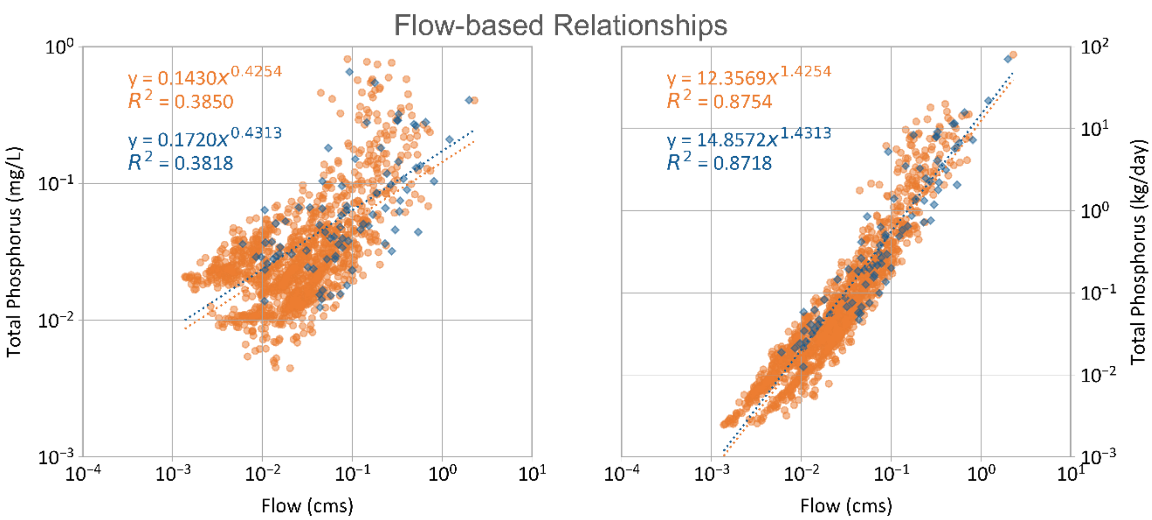


Figure E-7. Western Creek (LS0201) - Total phosphorus calibration: Flow-based relationships for simulated and observed daily concentrations (left) and loading rates (right). Note: the R^2 values here are not relevant to calibration performance

Table E-7. Western Creek (LS0201) - Total phosphorus calibration: PBIAS statistical metrices for Western Creek

Condition during Sample Collection *(01/10/2014 - 31/12/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) — Percent Bias (PBIAS): All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	-9.7%	81	-35.3%	22	0.8%	25	20.3%	17	-8.3%	17
Samples on Days with Highest 25% of Flows	-6.7%	44	-34.3%	17	0.5%	16	41.8%	6	12.6%	5
Samples on Days with Lowest 50% of Flows	-30.4%	20	N/A	0	N/A	3	-27.7%	8	-33.6%	9
Samples on Storm Volume Days	-1.1%	73	-12.0%	18	-2.4%	24	21.1%	15	-8.5%	16
Samples on Baseflow Volume Days	-66.7%	8	N/A	4	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

Percent Bias (PBIAS)	Performance Threshold for WQ Simulation: Very Good	Good	Satisfactory	Unsatisfactory	Reference
All Conditions (Combined)	<15%	15% - 20%	20% - 30%	>30%	Moriasi et al. (2015)
Seasonal and High/Low Flows	<20%	20% - 30%	30% - 40%	>40%	

Table E-8. Western Creek (LS0201) - Total phosphorus calibration: R^2 statistical metrices for Western Creek

Condition during Sample Collection *(01/10/2014 - 31/12/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) — R-Squared (R^2): All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.35	81	0.1	22	0.64	25	0.45	17	0.45	17
Samples on Days with Highest 25% of Flows	0.16	44	0.02	17	0.36	16	0.76	6	0.74	5
Samples on Days with Lowest 50% of Flows	0.07	20	N/A	0	N/A	3	0.06	8	0.09	9
Samples on Storm Volume Days	0.4	73	0.1	18	0.67	24	0.43	15	0.45	16
Samples on Baseflow Volume Days	0.08	8	N/A	4	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

R-Squared (R^2)	Performance Threshold for WQ Simulation: Very Good	Good	Satisfactory	Unsatisfactory	Reference
All Conditions (Combined)	>0.70	0.6 - 0.70	0.30 - 0.60	<0.30	Moriasi et al. (2015)
Seasonal and High/Low Flows	> 0.60	0.30 - 0.60	0.20 - 0.30	<0.20	

Table E-9. Western Creek (LS0201)-Total phosphorus calibration: NSE statistical metrices for Western Creek

Condition during Sample Collection *(01/10/2014 - 31/12/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) — Nash-Sutcliffe Efficiency (E)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.1	81	-0.59	22	0.61	25	0.04	17	0.13	17
Samples on Days with Highest 25% of Flows	-0.15	44	-1.04	17	0.31	16	0.53	6	0.46	5
Samples on Days with Lowest 50% of Flows	-1.36	20	N/A	0	N/A	3	-2.99	8	-1.0	9
Samples on Storm Volume Days	0.14	73	-0.81	18	0.65	24	-0.07	15	0.13	16
Samples on Baseflow Volume Days	-0.13	8	N/A	4	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

Nash-Sutcliffe Efficiency (E)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.65	0.50 - 0.65	0.35 - 0.50	<0.35	Moriasi et al. (2015)
Seasonal and High/Low Flows	>0.50	0.35 - 0.50	0.25 - 0.35	<0.25	

Table E-10. Western Creek (LS0201)-Total phosphorus calibration: PBIAS statistical metrices for Western Creek

Condition during Sample Collection *(01/10/2014 - 31/12/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Load (Observed Daily Load vs Daily Simulated Load) — Percent Bias (PBIAS)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	-0.2%	81	22.4%	22	-11.9%	25	20.3%	17	23.5%	17
Samples on Days with Highest 25% of Flows	0.1%	44	23.6%	17	-11.8%	16	18.6%	6	31.3%	5
Samples on Days with Lowest 50% of Flows	-65.8%	20	N/A	0	N/A	3	-58.4%	8	-71.6%	9
Samples on Storm Volume Days	2.2%	73	43.5%	18	-12.4%	24	20.4%	15	23.8%	16
Samples on Baseflow Volume Days	-71.3%	8	N/A	4	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

Percent Bias (PBIAS)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	<15%	15% - 20%	20% - 30%	>30%	Moriasi et al. (2015)
Seasonal and High/Low Flows	<20%	20% - 30%	30% - 40%	>40%	

Table E-11. Western Creek (LS0201)-Total phosphorus calibration: R^2 statistical metrices for Western Creek

Condition during Sample Collection *(01/10/2014 - 31/12/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Load (Observed Daily Load vs Daily Simulated Load) — R-Squared (R^2)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.77	81	0.51	22	0.88	25	0.82	17	0.81	17
Samples on Days with Highest 25% of Flows	0.54	44	0.35	17	0.72	16	0.79	6	0.8	5
Samples on Days with Lowest 50% of Flows	0.13	20	N/A	0	N/A	3	0.01	8	0.22	9
Samples on Storm Volume Days	0.78	73	0.51	18	0.9	24	0.81	15	0.8	16
Samples on Baseflow Volume Days	0.69	8	N/A	4	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

R-Squared (R^2)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.70	0.6 - 0.70	0.30 - 0.60	<0.30	Moriasi et al. (2015)
Seasonal and High/Low Flows	> 0.60	0.30 - 0.60	0.20 - 0.30	<0.20	

Table E-12. Western Creek (LS0201)-Total phosphorus calibration: NSE statistical metrices for Western Creek

Condition during Sample Collection *(01/10/2014 - 31/12/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Load (Observed Daily Load vs Daily Simulated Load) — Nash-Sutcliffe Efficiency (E)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.6	81	-0.18	22	0.87	25	0.64	17	0.3	17
Samples on Days with Highest 25% of Flows	0.36	44	-0.77	17	0.72	16	0.69	6	0.69	5
Samples on Days with Lowest 50% of Flows	-3.5	20	N/A	0	N/A	3	-4.27	8	-3.1	9
Samples on Storm Volume Days	0.6	73	-0.26	18	0.89	24	0.58	15	0.31	16
Samples on Baseflow Volume Days	0.5	8	N/A	4	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

Nash-Sutcliffe Efficiency (E)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.65	0.50 - 0.65	0.35 - 0.50	<0.35	Moriasi et al. (2015)
Seasonal and High/Low Flows	>0.50	0.35 - 0.50	0.25 - 0.35	<0.25	

Tannery Creek - Yonge St
Station ID: 3007700702
01/04/2008 - 31/12/2017

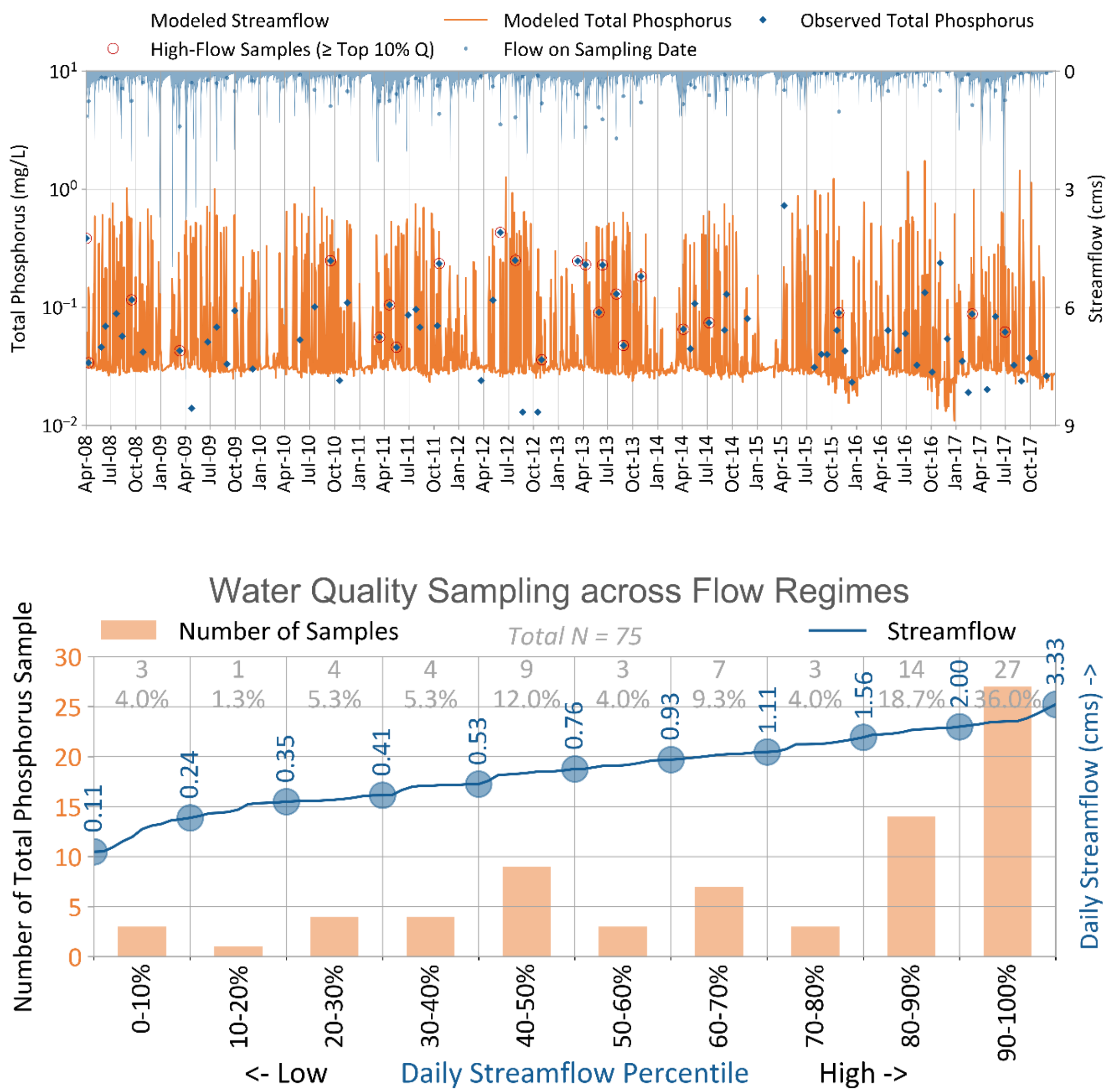


Figure E-8. Tannery Creek - Yonge St (3007700702) - Total phosphorus calibration: Simulated daily vs. observed grab sample concentration time series (top) and flow duration with total phosphorus sampling (bottom)

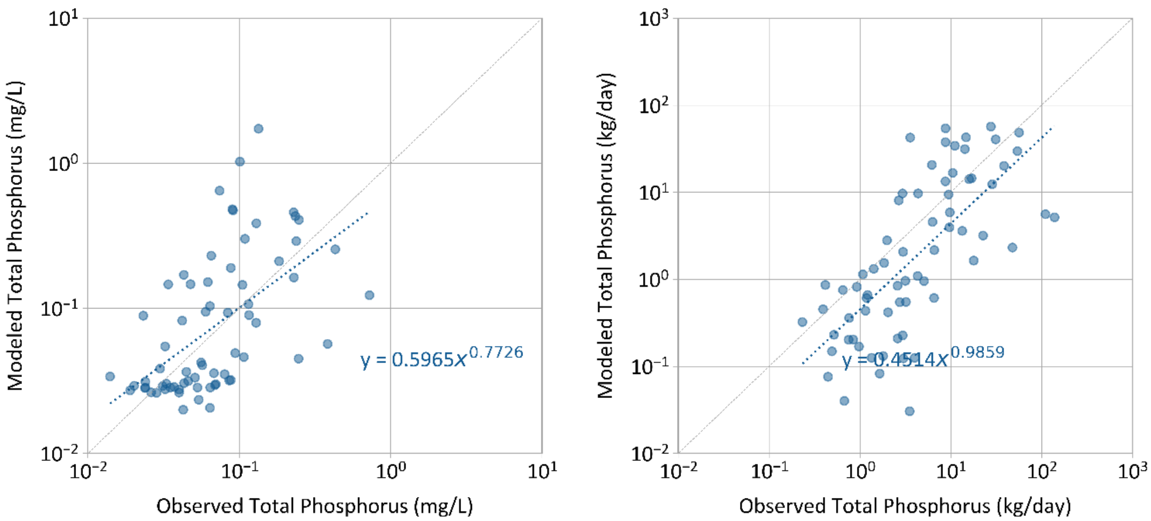


Figure E-9. Tannery Creek - Yonge St (3007700702) - Total phosphorus calibration: Simulated vs. observed daily total phosphorus concentrations (left) and loading rates (right)

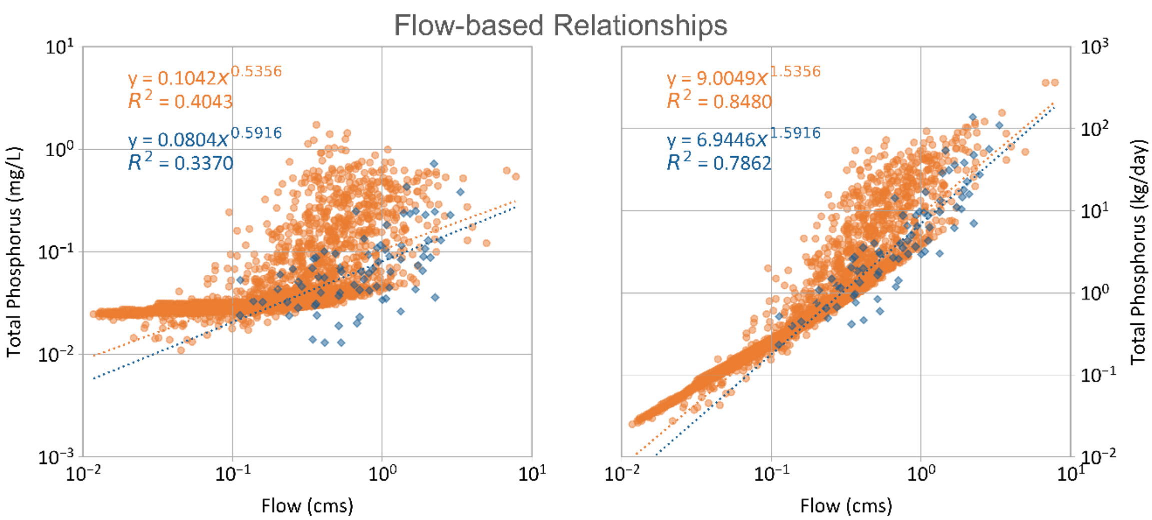


Figure E-10. Tannery Creek - Yonge St (3007700702) - Total phosphorus calibration: Flow-based relationships for simulated and observed daily concentrations (left) and loading rates (right). Note: the R^2 values here are not relevant to calibration performance

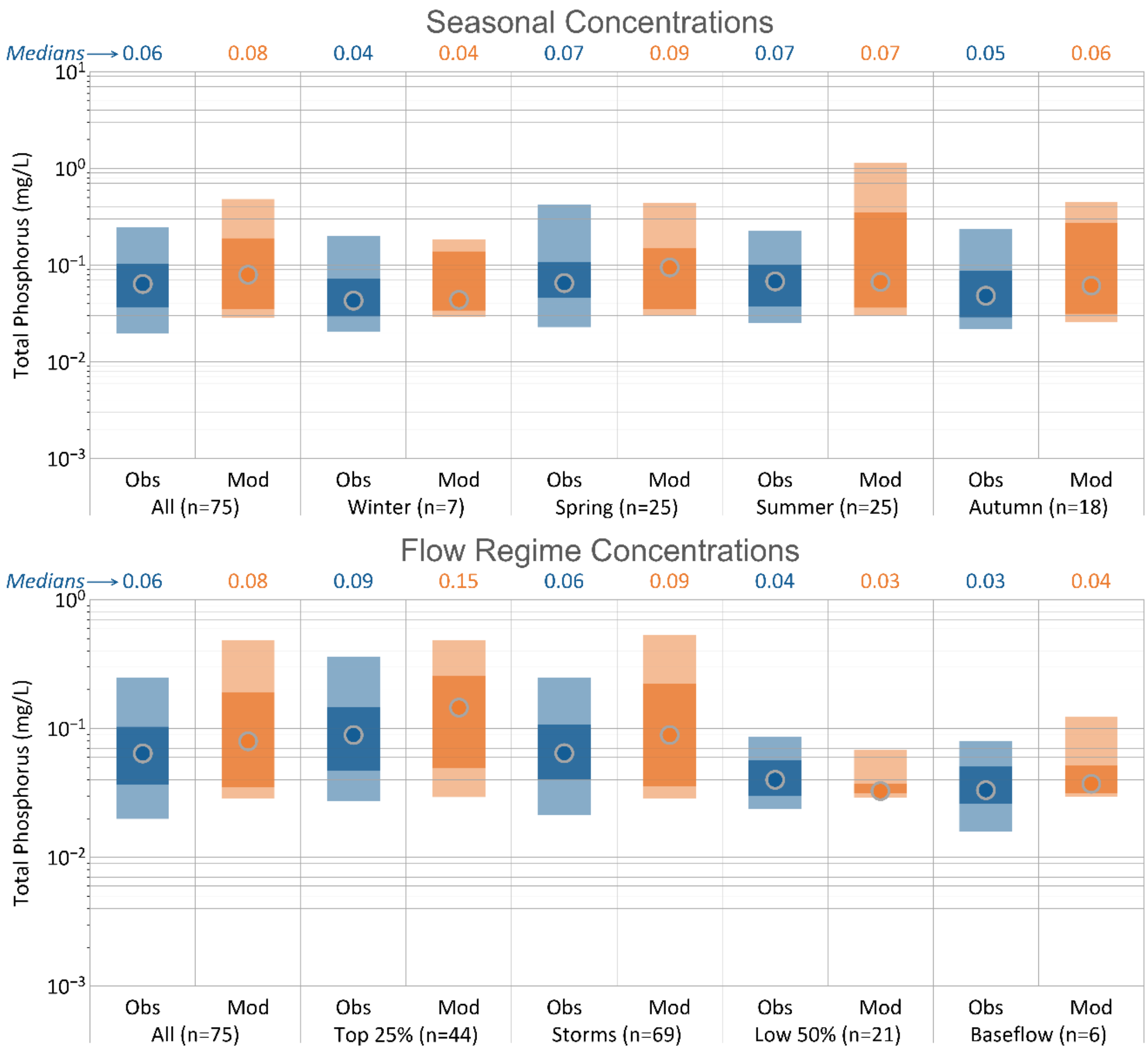


Figure E-11. Tannery Creek - Yonge St (3007700702) - Total phosphorus calibration: Simulated vs. observed concentrations by season (top) and flow regime (bottom)

Table E-13. Tannery Creek - Yonge St (3007700702) - Total phosphorus calibration: PBIAS statistical metrices for Tannery Creek - Yonge St

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) — Percent Bias (PBIAS): All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	52.9%	75	4.6%	7	-8.5%	25	158.3%	25	59.1%	18
Samples on Days with Highest 25% of Flows	55.6%	44	N/A	4	-5.9%	17	194.9%	10	68.2%	13
Samples on Days with Lowest 50% of Flows	-20.4%	21	N/A	1	-25.6%	8	-24.8%	9	N/A	3
Samples on Storm Volume Days	53.5%	69	6.9%	5	-12.0%	24	169.9%	23	58.5%	17
Samples on Baseflow Volume Days	35.7%	6	N/A	2	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

Percent Bias (PBIAS)	Performance Threshold for WQ Simulation: Very Good	Good	Satisfactory	Unsatisfactory	Reference
All Conditions (Combined)	<15%	15% - 20%	20% - 30%	>30%	Moriasi et al. (2015)
Seasonal and High/Low Flows	<20%	20% - 30%	30% - 40%	>40%	

Table E-14. Tannery Creek - Yonge St (3007700702) - Total phosphorus calibration: R^2 statistical metrices for Tannery Creek - Yonge St

Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Observed vs Simulated Calibration Performance for Total Phosphorus Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration) — R-Squared (R^2): All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.33	75	0.12	7	0.25	25	0.4	25	0.51	18
Samples on Days with Highest 25% of Flows	0.2	44	N/A	4	0.15	17	0.11	10	0.48	13
Samples on Days with Lowest 50% of Flows	0.04	21	N/A	1	0.01	8	0.03	9	N/A	3
Samples on Storm Volume Days	0.34	69	0.07	5	0.3	24	0.43	23	0.51	17
Samples on Baseflow Volume Days	0.01	6	N/A	2	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

R-Squared (R^2)	Performance Threshold for WQ Simulation: Very Good	Good	Satisfactory	Unsatisfactory	Reference
All Conditions (Combined)	>0.70	0.6 - 0.70	0.30 - 0.60	<0.30	Moriasi et al. (2015)
Seasonal and High/Low Flows	> 0.60	0.30 - 0.60	0.20 - 0.30	<0.20	

Table E-15. Tannery Creek - Yonge St (3007700702) - Total phosphorus calibration: NSE statistical metrices for Tannery Creek - Yonge St

	Observed vs Simulated Calibration Performance for Total Phosphorus Concentration (Observed Instantaneous Grab Sample Concentration vs Average Daily Simulated Concentration)									
Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	**Nash-Sutcliffe Efficiency (E)**									
	All Seasons	**n =**	**Winter**	**n =**	**Spring**	**n =**	**Summer**	**n =**	**Fall**	**n =**
All Conditions	-0.2	75	-0.26	7	0.03	25	-1.0	25	0.05	18
Samples on Days with Highest 25% of Flows	-0.61	44	N/A	4	-0.09	17	-4.96	10	-0.33	13
Samples on Days with Lowest 50% of Flows	-0.27	21	N/A	1	-0.7	8	-0.39	9	N/A	3
Samples on Storm Volume Days	-0.23	69	-0.44	5	0.1	24	-0.98	23	-0.1	17
Samples on Baseflow Volume Days	-0.91	6	N/A	2	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

Nash-Sutcliffe Efficiency (E)	**Performance Threshold for WQ Simulation**				**Reference**
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.65	0.50 - 0.65	0.35 - 0.50	<0.35	Moriasi et al. (2015)
Seasonal and High/Low Flows	>0.50	0.35 - 0.50	0.25 - 0.35	<0.25	

Table E-16. Tannery Creek - Yonge St (3007700702) - Total phosphorus calibration: PBIAS statistical metrices for Tannery Creek - Yonge St

	Observed vs Simulated Calibration Performance for Total Phosphorus Load (Observed Daily Load vs Daily Simulated Load)									
Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	**Percent Bias (PBIAS)**									
	All Seasons	**n =**	**Winter**	**n =**	**Spring**	**n =**	**Summer**	**n =**	**Fall**	**n =**
All Conditions	-25.4%	75	-46.5%	7	-57.0%	25	58.7%	25	-2.2%	18
Samples on Days with Highest 25% of Flows	-28.5%	44	N/A	4	-57.1%	17	52.4%	10	0.1%	13
Samples on Days with Lowest 50% of Flows	-51.9%	21	N/A	1	-50.7%	8	-56.0%	9	N/A	3
Samples on Storm Volume Days	-26.2%	69	-48.8%	5	-58.7%	24	61.2%	23	-2.0%	17
Samples on Baseflow Volume Days	49.5%	6	N/A	2	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

Percent Bias (PBIAS)	**Performance Threshold for WQ Simulation**				**Reference**
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	<15%	15% - 20%	20% - 30%	>30%	Moriasi et al. (2015)
Seasonal and High/Low Flows	<20%	20% - 30%	30% - 40%	>40%	

Table E-17. Tannery Creek - Yonge St (3007700702) - Total phosphorus calibration: R^2 statistical metrices for Tannery Creek - Yonge St

	Observed vs Simulated Calibration Performance for Total Phosphorus Load (Observed Daily Load vs Daily Simulated Load)									
Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	R-Squared (R^2)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	0.52	75	0.42	7	0.56	25	0.59	25	0.5	18
Samples on Days with Highest 25% of Flows	0.29	44	N/A	4	0.22	17	0.2	10	0.57	13
Samples on Days with Lowest 50% of Flows	0.14	21	N/A	1	0.07	8	0.22	9	N/A	3
Samples on Storm Volume Days	0.52	69	0.37	5	0.6	24	0.61	23	0.49	17
Samples on Baseflow Volume Days	0.49	6	N/A	2	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

R-Squared (R^2)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.70	0.6 - 0.70	0.30 - 0.60	<0.30	Moriasi et al. (2015)
Seasonal and High/Low Flows	> 0.60	0.30 - 0.60	0.20 - 0.30	<0.20	

Table E-18. Tannery Creek - Yonge St (3007700702) - Total phosphorus calibration: NSE statistical metrices for Tannery Creek - Yonge St

	Observed vs Simulated Calibration Performance for Total Phosphorus Load (Observed Daily Load vs Daily Simulated Load)									
Condition during Sample Collection *(01/04/2008 - 31/12/2017)*	Nash-Sutcliffe Efficiency (E)									
	All Seasons	n =	Winter	n =	Spring	n =	Summer	n =	Fall	n =
All Conditions	-0.22	75	-0.17	7	0.33	25	-0.48	25	-1.22	18
Samples on Days with Highest 25% of Flows	-1.34	44	N/A	4	-0.26	17	-1.64	10	-4.29	13
Samples on Days with Lowest 50% of Flows	-2.8	21	N/A	1	-1.89	8	-3.28	9	N/A	3
Samples on Storm Volume Days	-0.27	69	-0.66	5	0.35	24	-0.51	23	-1.48	17
Samples on Baseflow Volume Days	-0.9	6	N/A	2	N/A	1	N/A	2	N/A	1

*N/A: Metric not calculated for n < 5

Nash-Sutcliffe Efficiency (E)	Performance Threshold for WQ Simulation				Reference
	Very Good	Good	Satisfactory	Unsatisfactory	
All Conditions (Combined)	>0.65	0.50 - 0.65	0.35 - 0.50	<0.35	Moriasi et al. (2015)
Seasonal and High/Low Flows	>0.50	0.35 - 0.50	0.25 - 0.35	<0.25	

APPENDIX 2

LEADING JURISDICTIONAL RESEARCH

Leading Jurisdictions Research: Part 1

	JURISDICTION	PRACTICE DESCRIPTION
GOVERNANCE	Auckland, NZ	• Auckland Council is implementing integrated management of freshwater and land development planning in whole catchments”. https://www.aucklandcouncil.govt.nz/environment/looking-after-our-waterways/Pages/wai-ora-healthy-waterways.aspx
	Alberta, CA	• The Alberta Municipal Act provides for the development of an Inter-municipal Collaboration Framework (ICF) between municipalities sharing a common border. An ICF is intended to: ◦ provide for integrated and strategic planning, delivery and funding of intermunicipal services ◦ allocate scarce resources efficiently in the providing local services ◦ ensure municipalities contribute funding to services that benefit their residents
	Greater Vancouver Regional District, BC	• GVRD led a process to establish integrated watershed planning amongst municipalities (Cities of Vancouver, Burnaby, Coquitlam and Port Moody) in the Brunette River watershed. • Focus on integration of SWM and land use planning to protect the Brunette River, an inter-municipal watershed. • All five municipalities committed to a vision, goals and objectives for catchments within the Brunette River basin.
	Capital Regional District, BC	• The CRD established an Integrated Watershed Management Program (IWMP) works with municipalities, First Nations and watershed communities to monitor quality and stormwater, develop regulatory tools and codes of practice, restore key areas within harbours and watersheds and promote BMPs
	Prince George’s County, Maryland	• Implemented a public-private partnership model referred to as a Community-Based Public-Private Partnership (CBP3), for the management of stormwater county-wide. • CBP3 is a pay-for-performance service delivery model that delegates project selection, design, construction and Operations and Maintenance (O&M) responsibility to the private partner. https://www.epa.gov/G3/prince-georges-county-maryland-clean-water-partnership & https://www.corvias.com/sites/default/files/Insights/Prince_Georges_County_CWP_05-2017.pdf
	Okanagan Regional Districts, BC	• Establishment of the Okanagan Basin Water Board (OBWB), including a legislative framework setting out the authority, objectives, purpose, membership and representation and cost sharing measures between regional districts for watershed planning and management.
	New York City, New York	• The Department of Environmental Protection (DEP) established an Office of Green Infrastructure to facilitate and oversee implementation of GI on public and private property throughout the City

	JURISDICTION	PRACTICE DESCRIPTION
POLICIES, PLANS & REGULATIONS	Metro Vancouver & Conquitlam, BC	• Developed a Regional Growth Strategy that covers part of the Partington Creek watershed that is planned for greenfield development. Over the next 20 years, what is now forested land will be developed to accommodate about 12,000 people in what is described as a “new town centre” • Implement a watershed planning, land development planning, and financial modelling for the Partington Creek watershed greenfield development. • This deviates from the current approach to land development, which is to first develop land use plans and then engage civil engineers to mitigate the impacts of development.
	Coquitlam, BC	• Council amended the City’s Official Community Plan (OCP to require that Neighbourhood Plans take into account watershed conditions and needs. This means that Integrated Watershed Management Plan (IWMP) objectives will be realized through Neighbourhood Plan policies
	Philadelphia, Pennsylvania	• Updated their stormwater regulations in 2015 to address SWM in new developments, specifically**,** new developments are now required to handle more water, slow stormwater more effectively, and improve pollutant reduction. Specific requirements for water quality and water quantity targets that must be met are imbedded in the regulation http://www.phillywatersheds.org/stormwaterregulations • Implemented policy and planning changes to enable expedited development approvals review for those projects that meet specific ‘green’ standards for SWM • **Green Roof Density Bonus Ordinance:** This ordinance allows for increased density in properties zoned for a low-density multi-family residential and neighborhood commercial corridors if a qualifying green roof covers at least 60% of the building’s roof area. https://www.pwdplanreview.org/upload/pdf/Green_Roof_Density_Bonus_Factsheet_20160624.pdf http://planphilly.com/uploads/media_items/brown-green-roof-density-bonus.original.pdf
	Lancaster, Pennsylvania	• Developed and implemented a “Green Infrastructure Plan” setting out the implementation of city-wide GI for SWM in five- and twenty-five-year timeframes.
	Greater Los Angles County, California	• Led by the Los Angles Flood Control District, developed an Integrated Regional Watershed Plan. • The purpose of the initiative was to tackle the problem of multiple organizations operating is silos with single-focused visions and solutions and SWM projects addressing single-purpose issues. • This plan defines a direction for the “sustainable management of water resources” in the Region. The plan includes about 2,000 projects and involves “hundreds of local agencies, all working cooperatively to develop cost-effective solutions for the Region’s water resource needs.” • The partnership is described as a new model of integrated regional planning to address competing water demands, water supply reliability and financing of projects. https://dpw.lacounty.gov/wmd/irwmp/docs/IRWMPBookletBinder.pdf

POLICIES, PLANS & REGULATIONS

JURISDICTION	PRACTICE DESCRIPTION
New York City, New York	• The NYC Department of Environmental Protection (DEP) developed "hybrid plan" for combined sewer overflows using grey infrastructure (where cost effective) in combination with GI. • DEP committed to spend $1.5 billion on green infrastructure and stimulate another $900 million in private green infrastructure investment by 2030. • The DEP's Office of Green Infrastructure developed design standards for various types of green infrastructure. These design standards and procedures apply to City properties and are intended to streamline the development of contract plans and drawings, and reduce the timeline and costs associated with design and approval processes
Seattle, Washington	• The City set up "Open Space Seattle 2100" Guidance Committee to develop guiding principles for open space planning and to establish Green Infrastructure Plans for 2025 and 2100. • Process led to the development of a Green Stormwater Infrastructure (GSI) Strategy • In 2013, a City Council Resolution established GSI as a critical aspect of a sustainable drainage system and challenged Seattle to rely on GSI to manage stormwater runoff whenever possible. The Resolution and associated Exec Order also set a community-wide implementation reduction target for runoff and a 2020 goal of managing 400M gallons of stormwater annually with GSI.
Washington, Connecticut	• Established maximum lot coverage requirements within its zoning regulations to limit impervious cover. • The ordinance states: "In residential districts, the maximum land coverage for all buildings and structures (principal and accessory uses) including paved, impervious, or traveled surfaces shall not exceed: a. 15% of the total land area for lots less than two acres, b. 0.3 acres for lots between two and three acres (about 12%), and c. 10% for lots three acres and larger." • The ordinance limits imperviousness in business districts to a maximum of 25%. • In all cases, lot coverage is defined as: "the percentage of the lot, which is covered by structures
Towns of Exeter, Stratham & Newfields, New Hampshire	• Developed a framework for integrated water management to facilitate a watershed-based approach to managing water quality issues.
Toronto, Ontario	• **Green Streets Technical Guidelines**: Provides direction for the planning, design, integration and maintenance of a range of green infrastructure • The guidelines provide direction for the planning, design, integration and maintenance of a range of green infrastructure options appropriate for Toronto street types and conditions • GI and Vegetation Selection Tools to identify "site specific GI options that are viable for implementation as part of a street retrofit or reconstruction project and then determine plant species that would be context appropriate (where applicable)".
Portland, Oregon	• **Green Streets Policy**: a citywide Green Streets Policy and Resolution was developed and approved by City Council, processes were formalized for permitting and integration of Green Streets into city plans, and a fund was established to support construction of green street facilities. • The goal is to promote and incorporate the use of green street facilities in public and private development.

PROGRAMMES & PRACTICES

JURISDICTION	PRACTICE DESCRIPTION
Onondaga County, New York	**Green Projects & Streets:** A new GIS map tool to familiarize the community with GI projects that have been constructed. • https://socpa.maps.arcgis.com/apps/Shortlist/index.html?appid=a797dbe56ce745c2920e3c9e7d827d2b
Philadelphia, Pennsylvania	• **Expedited Reviews** for obtaining stormwater approvals. Two types of reviews are available: 1. **Disconnection Green Review:** Redevelopment projects must disconnect 95% or more of the post-construction impervious area within the project's Limits of Disturbance (LOD) using DIC to comply with PCSM Requirements. 2. **Surface Green Review:** New Development & Redevelopment projects that can demonstrate that 100% of post-construction impervious area within the project's LOD is managed by Disconnected Impervious Cover (DIC) and/or bio infiltration/bioretention SMPs to comply with PCSM Requirements are eligible. http://www.phillywatersheds.org/doc/Expedited%20Review%20Handout_20150706.pdf • **The Green Infrastructure Living Laboratory** project collects data from green infrastructure that has been constructed on private property. Via the partnership with the Living Laboratory, the City can weigh in on experimental designs and offer perspective about key needs. The outcomes of experiments and monitoring are used to inform design guidance and policy: "…monitoring data collected by the GILL team from a water reuse cistern at Drexel is a great example. We will use that case study as guidance for designers at PWD Philadelphia Water Dept)." • Data collected by GILL serves as a feedback loop to the Water Department's green stormwater infrastructure Design Team. http://www.govtech.com/fs/infrastructure/Real-Time-Data-Helps-Philadelphia-Improve-Green-Design.html
Franklin, Massachusetts	• Best Practices guidebook for green infrastructure to expedite permitting requirements for developers. • Established a four-step process for site plan and subdivision applications that begins with an existing site conditions map and an initial pre-development meeting, where developers are offered guidance on how to meet multiple permit requirements and community planning objectives. Through this process, LID and green infrastructure strategies are coordinated with other project requirements early in the planning process.
Pima County, Arizona	• Provide green infrastructure guidance, which includes standard engineering drawings, vegetation list, and BMP sizing guidance. • Plan submittal checklists for GI and water balance are provided to ensure that all details are provided in submittals to speed up plan reviews. Inspection checklists help ensure that long-term maintenance of GI facilities is completed as needed.
Canada: Alternative Land Use Services (ALUS)	• ALUS works with farmers to establish and maintain GI projects that produce ecosystem services for Canadian communities • Assist farmers to restore wetlands, reforest, install riparian buffer, manage sustainable drainage systems, create pollinator habitat and establish other ecologically beneficial project on their properties. • Provides Payment for Ecological Services (PES) annually to ensure the ongoing stewardship of each ALUS project
Philadelphia, Pennsylvania	• **Stormwater Credits Explorer Map:** For non-residential properties, this tool allows the user to sketch out ideas of up to 5 different types of "stormwater tools", including green roofs, rain gardens and permeable pavers, to determine effectiveness and feasibility of different approaches. • As Stormwater Tools are added or removed, the application updates the monthly stormwater charge for that property. Users can rapidly get a sense of the feasibility and effectiveness of adding stormwater infrastructure systems. http://water.phila.gov/swexp/explore/

Leading Jurisdictions Research – Part 2

JURISDICTION	INITIATIVE – DESCRIPTION
Portland, Oregon	**SWM Utility:** Portland finances stormwater management services by collecting public utility fees on developed property, and system development charges (SDCs) on new development. http://www.portlandoregon.gov/bes/article/402775 1. Residential Users – Fees are applied using the following categories a. Single Family and Duplexes b. 3-Plex and 4-Plex Residences 2. Developments of 5 or More Units Non-Residential Users 3. Discounts • Clean River Rewards: User fee discounts of as much as 100% of the monthly stormwater management charge for private on-site facilities that manage stormwater runoff, and 100% of the monthly on-site stormwater management charge for Drainage District residents and businesses. At the end of April 2014, a total of 35,813 utility ratepayers with active accounts have registered for stormwater discounts: 34,480 single family residential ratepayers (accounting for a total of 76,511,888 square feet of impervious area managed for stormwater) and 1,333 multifamily, commercial, and industrial ratepayers (accounting for a total of 69,393,012 square feet of impervious area managed for stormwater). http://www.portlandoregon.gov/bes/article/390568 - Summary of the program http://www.portlandoregon.gov/bes/article/402804 - Detailed program document **Marketing:** **Green Streets Program**: a citywide Green Streets Policy and Resolution was developed and approved by City Council, processes were formalized for permitting and integration of Green Streets into city plans, and a fund was established to support construction of green street facilities. **Green Streets Policy**: The goal is to promote and incorporate the use of green street facilities in public and private development. Key Program Elements: • Infrastructure Projects in the Right of Way will incorporate green street facilities into all City of Portland funded development, redevelopment or enhancement projects as required by the City's Stormwater Management Manual. If a green street facility is not incorporated into the Infrastructure Project, or only partial management is achieved, then an off-site project or off-site management fee will be required. • Any City of Portland funded development, redevelopment or enhancement project, that does not trigger the Stormwater Manual but requires a street opening permit or occurs in the right of way, shall pay into a "% for Green" Street fund. The amount shall be 1% of the construction costs for the project. Green Streets Policy:http://www.portlandoregon.gov/shared/cfm/image.cfm?id=154231 Green Streets Resolution: http://www.portlandoregon.gov/shared/cfm/image.cfm?id=154232 **% For Green Program**: The City of Portland requires all public and private development projects to manage stormwater on-site to the extent possible. Some right-of-way projects do not trigger application of this requirement. A percentage of the budget of these projects goes to the % for Green Program to help fund green infrastructure projects throughout the city. Two funding sources are combined to fund % for Green projects: • City right-of-way projects not required to meet the Stormwater Management Manual (SWMM) requirements • Off-site management fees collected when a private development cannot meet the SWMM requirements due to site conditions • Funds may not be used on a project to meet SWMM requirements, but may be used for projects that go above & beyond the requirements. http://www.portlandoregon.gov/bes/article/465399

Portland, Oregon (Cont'd)	**ECO Roof Floor Area Ratio Bonus Option**: The amount of FAR bonus allowed to a developer depends on the percentage of eco roof coverage in relation to the building footprint. • 10% – 30% coverage earns 1 sq ft of additional floor area per square foot of eco roof / 30% - 60% coverage earns 2 sq ft / 60% or greater earns 3 sq ft. http://www.portlandoregon.gov/bes/article/474490 **Wet Weather Program**: consists of numerous individual projects and activities at locations throughout the City. The goal is to reduce the peak volume of stormwater entering the combined system and manage SW to reduce pollutant concentrations. Funding for projects is in whole or in part by EPA grants. Proposed projects are in five main categories: *Water quality-friendly streets and parking lots*, *Downspout disconnections*, *Eco-roofs*, *Monitoring and feasibility studies*, and *Educational efforts* http://www.portlandoregon.gov/bes/article/62175 **Treebate Program**: Treebate is an incentive to plant yard trees at Portland residences. Homeowners can receive a credit to water/sewer utility bill for half the purchase price per tree up to $15 (small), $25 (medium) or $50 (large) depending on mature tree size and stormwater management potential. http://www.portlandoregon.gov/bes/article/314187?#eligible **Downspout Disconnection**: In targeted neighborhoods, the City pays homeowners $53 for each downspout they disconnect themselves, or will do the work for free. http://www.portlandoregon.gov/bes/article/127466 **Stormwater Management Plan** (Jan 2011): The plan identifies Best Management Practices (BMP's) to be implemented to meet the requirements of Portland's Municipal Stormwater Permit. http://www.portlandoregon.gov/bes/article/126117 **Stormwater Management Plan - Public Involvement**: Outreach and education of the public promotes environmental stewardship, pollution prevention, and sustainable stormwater management. The following Strategies have been implemented (see pages 13- 18 of the Stormwater Management Plan): **Community Stewardship Grants Program**: in place since 1995, provides up to $10,000 per project to citizens and organizations to encourage watershed protection. Projects must be within the City of Portland, promote citizen involvement in watershed stewardship, and benefit the public. From 1995 through June 2011, the program allocated over $948,000 to 198 projects. **Clean Rivers Education Programs:** free water quality classroom and field science education programs for grades K through 12 within the City of Portland. The Goal is to provide outreach to approximately 15,500 K-12students annually' **Regional Coalition for Clean Rivers and Streams**: a group of agencies and municipalities in the Portland/Vancouver metro area dedicated to educating the public about the impacts of stormwater runoff. The coalition develops an annual region wide public awareness campaign that can reach more than 1.4 million people living in the four-county area. **Watershed Education and Stewardship**: The watershed-based approach stresses comprehensive, multi-objective watershed management through inter-jurisdictional coordination within each watershed. Each program includes public education and stewardship **Publication & Signage**: Examples include water bill inserts, plant posters with stormwater pollution prevention messages, eco roof question and answer fact sheets, landscape swale posters, a "Stormwater Cycling" brochure and map for a self-guided tour of demonstration projects, erosion control information for street tree plantings, and educational materials for community meetings and events. **Stormwater Management Facilities – Operation & Maintenance Guide for Private Property Owners**: Property owners are legally responsible for inspecting and maintaining the stormwater management facilities on their sites. Required maintenance is outlined in the operations and maintenance (O&M) plan for the facility. This handbook supplements the O&M Plan. http://www.portlandoregon.gov/bes/article/54730 **Maintaining Your Stormwater Management Facility - Home Owner Handbook**: http://www.portlandoregon.gov/bes/article/54728 **Policy:** • Ordinance to establish rates for stormwater management services, Sept, 2012: http://www.portlandoregon.gov/bes/article/413237 • Portland Stormwater Management Manual, January 2014: This document outlines stormwater management requirements and the related regulations and policies. http://www.portlandoregon.gov/bes/article/474043 • Stormwater Management Program for the period 2011-2016: This document outlines the goals and mandates of the program. http://www.portlandoregon.gov/bes/article/126117

Minneapolis, Minnesota	**Fee Structure:** The Stormwater Utility Fee was established in 2005. The stormwater utility fee is based on impervious area and is charged on a per unit basis. Each ESU (Equivalent Stormwater Unit) is 1,530 square feet of impervious area on a property. The impervious area was calculated based on the size of the property, as well as the current use. Single family properties are billed based on: High – 1.25 ESU / Medium – 1.00 ESU / Low – 0.75 ESU Additional details of the fee structure: **http://www.minneapolismn.gov/www/groups/public/@clerk/documents/webcontent/wcms1p-118065.pdf** **Storm Water Fund 2014 Budget Financial Plan**: The Storm Water Fund is comprised of the Storm Water Collection and Street Cleaning programs. The Fund accounts for street cleaning and the design, construction, and maintenance of the City's storm drain system. A portion of the Storm Water Fund is used for sanitary water interceptor and treatment services. The Fund also accounts for the Combined Sewer Overflow program. 2014 budget information: **http://www.ci.minneapolis.mn.us/www/groups/public/@finance/documents/webcontent/wcms1p-113436.pdf** **The Stormwater Credit system:** provides up to 50% credit (reduction) in your stormwater utility fee for management tools/practices that address stormwater quality, and 50% or 100% credit (reduction) in your stormwater utility fee for management tools/practices that address stormwater quantity. Maximum credits are cumulative and cannot exceed 100% credit. **http://www.ci.minneapolis.mn.us/publicworks/stormwater/fee/stormwater_fee_stormwater_mngmnt_feecredits** **Stormwater Quantity Credit Program:** only those properties that can demonstrate the capacity to handle a 10-year or 100-year rain event can receive a stormwater quantity credit. Property owners must have their applications certified by a state licensed engineer or landscape architect. Property owners can apply for either the "Standard Quantity Reduction Credit" or the "Additional Quantity Reduction Credit." http://www.ci.minneapolis.mn.us/publicworks/stormwater/fee/stormwater_fee_stormwaterquantitycredits **Marketing:** **Public Education and Outreach**: Water quality education programs are required as part of the National Pollution Discharge Elimination System (NPDES) permit. These programs are funded through the MPRB and the City of Minneapolis. **http://www.ci.minneapolis.mn.us/publicworks/stormwater/stormwater_outreach** **Policy:** **Stormwater Fee Ordinance**: **http://www.minneapolismn.gov/www/groups/public/@council/documents/webcontent/convert_263412.pdf** **Stormwater Management for Development and Re-development Ordinance:** The ordinance establishes requirements for projects with land disturbing activities on sites greater than one (1) acre, including phased or connected actions, and for existing stormwater devices. • An option is reserved for only those sites that demonstrate that performance of on-site stormwater management is not feasible. With approval of the City Engineer, the Ordinance allows developers to contribute to the construction of a regional stormwater facility in lieu of on-site treatment/management. **http://www.ci.minneapolis.mn.us/publicworks/stormwater/dev/index.htm** **Permeable Pavement Zoning Code Amendment**: **http://www.minneapolismn.gov/www/groups/public/@council/documents/webcontent/convert_275393.pdf** **Vegetation Management Policy**: **http://www.ci.minneapolis.mn.us/www/groups/public/@citycoordinator/documents/webcontent/wcms1p-132021.pdf** **Water Resource Ordinances**: Table B-2 on page 31 of the report contains a summary of Minneapolis ordinances that help protect water resources in the City. The table also references related ordinances and state laws. **http://www.minneapolismn.gov/www/groups/public/@publicworks/documents/webcontent/convert_281304.pdf** **Local Surface Water Management Plan:** The City of Minneapolis completed its LSWMP in October, 2006. **http://www.minneapolismn.gov/www/groups/public/@publicworks/documents/webcontent/convert_253419.pdf** **Comparison of SWMP and LSWMP**: The Storm Water Management Program (SWMP) document is a federal requirement. There are many similarities between these two documents. The SWMP specifically focuses on stormwater runoff. The LSWMP has a broader view of surface water management in the City and includes water resource management activities, including management of the sanitary sewer collection system and other surface water management activities. The LSWMP was adopted in 2006 and ultimately was incorporated into the City's comprehensive plan.

Philadelphia, Pennsylvania	**Fee Structure:** **Residential Stormwater Charge:** Residential customers pay a standard amount based on the average surface area of impervious cover on residential properties throughout the city. SWMS charge is NOT based on monthly water consumption. The SWMS Charge is based on two parameters: the average Gross Area square footage and the average Impervious Area square footage for all residential properties. The average Gross Area for a residential property is 2,110 square feet. The average Impervious Area for a residential property is 1,050 square feet. Based on this average Gross Area and Impervious Area values, a uniform monthly charge has been defined for all residential properties. All Residential Properties are charged a monthly SWMS charge and a monthly Billing and Collection charge. http://www.phila.gov/water/wu/stormwater/Pages/ResidentialSWBilling.aspx **Non-Residential Stormwater Charge**: the cost to manage stormwater is based on the specific square footage of impervious area covering the property and the total square footage of the property. http://www.phila.gov/water/wu/Stormwater%20Resources/scaa_manual.pdf - page 34 of the document http://www.phila.gov/water/wu/stormwater/Pages/NonResidentialStormwaterBilling.aspx **Stormwater Management Service(SWMS) Charges Transition**: effective July 1, 2010, PWD is transitioning from an equivalent meter based SWMS Charge to a parcel area based SWMS Charge. See page 58 of the report: http://www.phila.gov/water/PDF/PWDRegulationsRev02.07.14.pdf **SWMS Charge CAP**: The objective of the SWMS Charge CAP is to enable stormwater customers to mitigate the annual fiscal year increase on their monthly SWMS Charge due to the transition from a meter based to a parcel area-based charge. http://www.phila.gov/water/wu/Stormwater%20Resources/scaa_manual.pdf - See page 13 of the document: **Stormwater Billing Map Viewer**: This web application lets users explore parcels on an interactive map, including high resolution ortho-photography, transparent overlays of impervious surfaces, and tools to make approximate measurements of length and area. http://www.phila.gov/water/swmap/#eyJhZ3NNYXAiOsSAem9vbcSIMCwieMSIMjcwNTI2Ny4yOTA4ODE1xJF5xJQ1MzY2MS4wMDc4NjQxMn3EkW1lYXN1cmXEiMSAY29udHJvbEFjdGl2xL06bnVsbMS1ImxlZ2VuZMS%2BIkFlcmlhbDIwMTDEiGbFoHNlxJFwdl9kYXRhLTHEiMWDdWV9fQ%3D%3D **Stormwater Credits Program**: offers Non-residential and Condominium customers (with at least 500 square feet of gross area) the opportunity to reduce their total SWMS Charge. Three classes of credits are available and depending on the types of SMPs present on the property and whether the customer holds a valid industrial NPDES permit for the site, a parcel may be eligible for all three classes of credits: 1. Impervious Area Stormwater Credit (IA Credit): 2. Tree canopy cover 3. Roof leader/downspout disconnections 4. Pavement disconnections 5. Green Roofs 6. Porous Pavement **Gross Area Stormwater Credit (GA Credit)** – Two options available: 1) Management of the First Inch of Runoff (Impervious Area Only) and 2) Credit Based on NRCS-CN (Open Space Only) **National Pollutant Discharge Elimination System (NPDES) Credit** for industrial stormwater discharge activities - customer must demonstrate that the parcel is subject to an active NPDES Permit for industrial stormwater discharge activities http://www.phila.gov/water/wu/Stormwater%20Resources/scaa_manual.pdf - See page 16 of the document

Philadelphia, Pennsylvania (Cont'd)	**Marketing:** **Stormwater Management Incentives Program**: offers non-residential property owners low-interest financing to stimulate investment in and utilization of stormwater best management practices which reduce a parcel's contribution of stormwater to the City's system. https://business.phila.gov/Documents/SMIP_information.pdf http://www.phila.gov/water/wu/Stormwater%20Grant%20Resources/SMIPFactSheet.pdf **Greened Acre Retrofit Program:** provides stormwater grants to contractors, companies or project aggregators who can build large-scale stormwater retrofit projects across multiple properties. Additionally, upon completion of the project, participating property owners (or customers) will be eligible for credits against their stormwater charges. http://www.phila.gov/water/wu/Stormwater%20Grant%20Resources/GARPFactSheet.pdf http://www.phila.gov/water/wu/Stormwater%20Grant%20Resources/GARPSeminar1.pdf **Green Roof Tax Credits:** The credit is for 25% of the cost of installing the green roof, up to $100,000. http://philadelphiaretail.com/pdf/GreenRoofTaxCredit.pdf http://www.phila.gov/Revenue/Tax%20Credits/taxcredit_greenroof_overview.pdf **Basement Protection Program**: This Program provides eligible residents with free installation of backwater valves and modifications to downspouts that help prevent sewage back up in their basements. http://www.phillywatersheds.org/watershed_issues/flooding/basement_backup_protection http://www.phillywatersheds.org/doc/BPP_Summary_Application_2.pdf **Stormwater Management Guidance Manual**: created to assist developers in meeting the requirements of the Philadelphia Stormwater Regulations. http://www.pwdplanreview.org/StormwaterManual.aspx **Green Guide for Property Management**: A guide to help commercial property owners reduce stormwater fees through innovative green projects on their properties. http://www.phila.gov/water/wu/Stormwater%20Resources/PWD_GreenGuide.pdf **Homeowner's Guide to Stormwater Management**: guide provides actions homeowners can take to improve stormwater management on their property or in the community. http://www.phila.gov/water/wu/Stormwater%20Resources/Homeowners_Guide_Stormwater_Management.pdf **Green Streets Design Manual**: http://www.phillywatersheds.org/what_were_doing/gsdm **Free Assistance Program**: The Philadelphia Water Department provides free assistance through site inspections and design recommendations for green retrofits that allow customers to obtain stormwater credits. This program minimizes the up-front costs to customers for preliminary evaluation and concept design, including evaluation of available credits. **Policy:** **Stormwater Regulation Ordinance:** http://www.phillyriverinfo.org/WICLibrary/StormwaterRegulations.pdf **Green Roof Tax Ordinance:** http://www.phila.gov/Revenue/Tax%20Credits/taxcredit_greenroof_overview.pdf

Downers, Illinois	**Fee Structure:** **Residential -** The stormwater fee is based on the total amount (in square footage) of impervious area on each parcel. Fees are expressed in Equivalent Runoff Units (ERU). One ERU is equal to 3,300 square feet of impervious area, which is the average for a single-family residential property in the Village. Property owners and tenants are jointly responsible for paying the bills. Utility bill payments will be applied toward the stormwater utility fee first, then to any water charges. Outstanding utility bill balances that remain unpaid for 45 days may result in the shut-off of water service. The Village may also place a lien against the property. **Stormwater Permit Fees & Securities Commercial and Non-Single Family Development**: http://www.downers.us/public/docs/permits/SWM%20Fees%20Commercial%202015.pdf **Stormwater Permit Fees & Securities Single-Family, Single-Lot Residential**: http://www.downers.us/public/docs/permits/SWM%20Fees%20Single%20Family%202015.pdf **Stormwater and Flood Plain Fees**: http://www.downers.us/public/docs/code/UserFee.pdf - see page 13 of the document **Marketing:** **Incentive Program**: a one-time reduction in the stormwater utility fee, applied to a customer's account balance. It is offered to assist property owners with the cost of materials, construction and installation of qualifying stormwater facilities. **http://www.downers.us/res/stormwater-management/stormwater-utility** **Credit Program**: A credit is an ongoing reduction in the amount of stormwater fees assessed to a parcel in recognition of on-site systems, facilities, or other actions taken to reduce the impact of stormwater runoff, in compliance with the Stormwater Credit and Incentive Manual.

Control Activity	Stormwater Credit
Site Run-off Rate Reduction (detention basin)	Up to 20%
Volume Reduction (retention basin, permeable pavement, cisterns, etc.)	Up to 20%
Water Quality (BMPs)	Up to 10%
Direct Discharge (outside and downstream of the Village's stormwater system)	Up to 50%
Education (the allowable education credit will be $3.00 per student taught per year)	Up to 100%
Partnership (provide land/facilities to Village to manage stormwater)	Up to 100%

http://www.downers.us/res/stormwater-management/stormwater-utility

Stormwater Credit and Incentive Manual: http://www.downers.us/public/docs/Stormwater_%20Management/CREDITINCENTIVEMANUAL2015.pdf

Stormwater Improvement Cost-Share Program: offers financial assistance to residents seeking to make stormwater improvements on their private property. To qualify, the proposed improvement must mitigate existing flooding conditions such as structural flooding of a house/garage or non-structural flooding over multiple properties. Flooding conditions must be present on more than one property to receive reimbursement. Once the qualifying criteria are met, reimbursement of up to $1,500 is available for each participating property. The maximum reimbursement per project is $10,000.

http://www.downers.us/res/stormwater-management/stormwater-improvement-cost-share-program

Stormwater Improvement Fund: created in 2008 to pay for projects in the *Watershed Infrastructure Improvement Plan*. The revenue sources for this Fund include *Issuance of General Obligation* (GO) bonds, a 1 /4 cent of the *Home Rule Sales Tax*, property taxes and *Detention Variance* fees collected on certain building permits

In 2008, the first round of GO Bonds was issued in the amount of $25 million. Depending on the status of future budgets and market conditions, the Village hopes to issue additional GO Bonds in 2011 and 2014, each in the amount of $25 million, to complete all High Priority projects in the WIIP.

http://www.downers.us/govt/village-budget/watershed-infrastructure-improvement-plan-wiip

Downners, Illinois (Cont'd)	**Policy:** Stormwater and Flood Plain Ordinance: http://www.downers.us/public/docs/code/Chapter26.pdf - see page 25 Stormwater & Flood Plain Ordinance Update (Dec 2014): The purpose of this item is to introduce changes to the Municipal Code that would lower the threshold for providing on-site stormwater storage for new development. The substantive changes to the Ordinance include Section 26.1001, the reduction of the threshold by which new development would be required to provide on-site stormwater storage from 2,500 square feet of new impervious surface to 500 square feet of new impervious surface. http://www.downers.us/public/docs/agendas/2014/12-02-14/ORD00-05763-SWREGS.pdf Fee In Lieu Programs for Developers: http://www.downers.us/public/docs/code/Chapter26.pdf - see page 63 of the Municipal Code Trees and Shrubs Ordinance: http://www.downers.us/public/docs/code/Chapter24.pdf 2014 Stormwater Project Analysis: includes a new approach for prioritizing stormwater capital improvement projects that is consistent with the Village's fee-based stormwater utility. The goal of this new approach is to establish a minimum service level standard for stormwater management such that the stormwater system will safely convey and store 95% of all rainfall events. http://www.downers.us/govt/village-budget/stormwater-project-analysis-report-2014 http://www.downers.us/public/docs/Stormwater_%20Management/Final%20Report%20only%20%286-19-2014%29.pdf

Halifax, Nova Scotia	**Fee Structure –** Charges are separated into two segments: **Site Related Flow Charge**: Effective July 1, 2017 residential properties are billed based on the actual amount of impervious area, with properties placed in tiers. **Stormwater Right-of-Way Charge:** On September 5, 2017, Regional Council approved a new billing approach for the municipality's Right of Way (ROW) Stormwater charge and set a flat annual rate for all properties receiving stormwater service from Halifax Water (both residential and commercial inside the Halifax Water stormwater boundary). Effective July 1, 2018 the annual charge is $40. https://www.halifax.ca/home-property/halifax-water/stormwater-services **Stormwater Credit Program:** In order to qualify for the credit program, the private stormwater management system for the property must match the post-development peak flow rate with the pre-development peak flow rate for, at minimum, the 1:5-year storm event. Non-Residential Customers that demonstrate their Site Related Flows are detained on their property or an adjacent property, as part of an overall stormwater management plan, are eligible to receive a credit. Stormwater credits are renewed annually and are contingent upon maintenance of the site. Eligible credits (30-50%) are applied against stormwater bills. https://www.halifax.ca/sites/default/files/documents/home-property/water/Non_Residential_Customer_Stormwater_Credit_Manual_%20July_1_2017.pdf

Seattle, Washington	**Fee Structure** Seattle charges a drainage fee on all properties in the City, with the exception of certain exempt properties. Drainage fees do not appear on utility bills. Seattle uses King County as its billing agent for the drainage fee. The drainage fee is shown on King County property tax statements as *Surface Water Management* (SWM) or Drainage. The method for calculating the drainage fee depends on the size and type of property owned. Single family and duplex properties smaller than 10,000 square feet are assigned to drainage rate categories based on the size of the parcel. All properties in a given rate category pay the same flat rate. This rate is also equal to the total bill, or charge. For example, parcels between 3,000 and 4,999 square feet will be subject to an annual drainage charge of $234.87 in 2014 while parcels between 5,000 and 6,999 square feet will all be subject to an annual drainage charge of $318.92 in the same year All other properties, including single family/duplex properties 10,000 square feet and larger, are assigned to rate categories based on how much impervious surface is contained on the parcel. Each rate category is assigned a rate which is multiplied by the parcel area (in 1,000s of square feet) to calculate the total charge, or bill. **Low Impact Rates**: apply to large residential and commercial parcels with significant amounts of highly pervious surface, such as forested land, unmanaged vegetated areas such as pasturelands and meadows and athletic fields designed with specific drainage characteristics. This highly pervious surface must cover a continuous area of at least one-half an acre, although this coverage may span more than one parcel. Low impact rates are available for the Undeveloped (0-15 percent impervious), Light (16-35 percent impervious) and Medium (36-65 percent impervious) rate categories. http://www.seattle.gov/util/MyServices/Rates/DrainageRates/UnderstandingYourBillFAQ/index.htm **Credits and Discounts:** **Low Impact Rates**: Discounts of 20 to 41 percent are applied to the rate for undeveloped natural areas of 0.5 acres or greater containing sufficient amounts qualifying “highly infiltrative” surface (i.e. forested areas, unmanaged grasslands, etc.). Certain athletic facilities with engineered designs that mimic the stormwater retention benefits of these large natural areas are also eligible for low impact rates. http://www.seattle.gov/util/MyServices/Rates/DrainageRates/RateSchedule/index.htm **Stormwater Facility Credit Program**: program offers credits of up to 50 percent for privately-owned systems that slow down stormwater flow and/or provide water quality treatment for run-off from impervious areas, thus lessening the impact to the City’s stormwater system, creeks, lakes or Puget Sound. Stormwater systems are structures such as vaults, rain gardens, permeable pavements and filtration systems. http://www.seattle.gov/util/groups/public/@spu/@ssw/documents/webcontent/spu01_006501.pdf **Marketing:** **Residential Rain Wise Program**: Provides technical support, education/outreach to assist homeowners, landscapers and property managers in understanding low impact development techniques such as site design, pervious paving, vegetation retention, sustainable landscape practices, and other natural drainage solutions. http://www.seattle.gov/util/groups/public/@spu/@drainsew/documents/webcontent/01_025302.pdf **Rain Wise Rebate Program**: provides rebates to private landowners (at their request and if eligible) for the installation of rain gardens and cisterns to reduce stormwater runoff from their private properties. In target areas, qualifying properties may be eligible to receive a rebate of up to $3.50 for each square foot of runoff controlled using a rain garden and/or cistern, both forms of green infrastructure. http://www.seattle.gov/util/groups/public/@spu/@usm/documents/webcontent/02_008093.pdf **The King County 2012 Surface Water Management Rate Study**: assesses changes to program requirements and funding availability under the County’s surface water management fee. In particular, the study focuses on revising the existing rate adjustment (“discount”) program for non-residential parcels. The intent is to offer direct incentives to landowners to encourage them to better control stormwater runoff and improve water quality on private property. http://www.kingcounty.gov/environment/wlr/surface-water-mgt-fee/2012-rate-study.aspx

Seattle, Washington (Cont'd)	**Policy:** **Green Stormwater Infrastructure Program** – In July 2013, City Council unanimously passed Resolution 31549, with key components: • Green Stormwater Infrastructure (GSI) should be relied upon to manage stormwater wherever possible • Target to manage 700MG annually with GSI by 2025 • City Departments shall collaborate with Office of Sustainability & Environment (OSE) to produce Implementation Strategy for meeting new target **Executive Order**: 2013-01 Citywide Green Stormwater Infrastructure Goal & Implementation Strategy: An Executive Order directing City departments to coordinate to develop an implementation strategy for managing 700 million gallons of stormwater annually with green stormwater infrastructure approaches by 2025. To be considered Green Stormwater Infrastructure, it must provide a function in addition to stormwater management such as water reuse, providing greenspace and/or habitat in the City. http://clerk.seattle.gov/~scripts/nph-brs.exe?s1=green+stormwater+infrastructure&s3=&s2=&s4=&Sect4=AND&l=20&Sect2=THESON&Sect3=PLURON&Sect5=CFCF1&Sect6=HITOFF&d=CFCF&p=1&u=%2F~public%2Fcfcf1.htm&r=1&f=G **Seattle Stormwater Code Ordinance**: http://clerk.ci.seattle.wa.us/~scripts/nph-brs.exe?s1=&s3=&s4=123105&s2=&s5=&Sect4=AND&l=20&Sect2=THESON&Sect3=PLURON&Sect5=CBORY&Sect6=HITOFF&d=ORDF&p=1&u=%2F~public%2Fcbor1.htm&r=1&f=G **Seattle Stormwater Code**: http://www.seattle.gov/dpd/codesrules/codes/stormwater/default.htm https://www.municode.com/library/wa/seattle/codes/municipal_code?searchRequest={%22searchText%22:%22SMC%2023.66%22,%22pageNum%22:1,%22resultsPerPage%22:25,%22booleanSearch%22:false,%22stemming%22:true,%22fuzzy%22:false,%22synonym%22:false,%22contentTypes%22:%5B%22CODES%22%5D,%22productIds%22:%5B%5D}&nodeId=TIT22BUCOCO_SUBTITLE_VIIISTCO **Requirements for Green Stormwater Infrastructure to the Maximum Extent Feasible for Single-Family Residential and Parcel Based Projects**: http://www.seattle.gov/dpd/codes/dr/DR2012-15.pdf **Requirements for Green Stormwater Infrastructure to the Maximum Extent Feasible for Roadway, Trail, and Sidewalk Projects**: http://www.seattle.gov/dpd/codes/dr/DR2012-16.pdf **The Right-of-Way Improvement Manual**: Chapter 6.4, provides information on rules specific to the use of GSI Facilities within the Right-of-way (ROW). http://www.seattle.gov/transportation/rowmanual/manual/6_4.asp **OTHER:** **City of Seattle - Stormwater Low Impact Development Practices:** A 10- page paper that examines Seattle's success with GSI. http://www.seattle.gov/util/groups/public/@spu/@usm/documents/webcontent/spu02_020004.pdf

Washington, DC

Fee Structure:

There are two utility charges that apply: The Impervious Surface Area Charge (IAC) and the Stormwater Fee. Both fees relate to improving the District's water quality. However, the Stormwater Fee and the DC Impervious Surface Area Water Charge address separate pollution control requirements.

IAC Charge: DC Water implemented the IAC charge in 2009 to recover the cost of the $2.6 billion federally mandated Combined Sewer Overflow Long Term Control Plan to control overflow into the waterways. This includes building large metro sized tunnels to store overflow until it can be treated at the wastewater treatment plant. The charge is based on a property's contribution of rainwater to the District's sewer system. Because charges are based on the amount of impervious area on a property, owners of large office buildings, shopping centers and parking lots will be charged more than owners of modest residential dwellings. All residential and non-residential customers are billed for CRIAC.

Residential: Includes condominium or apartment units where each unit is served by a separate line and is individually metered; multi-family structures of less than 4 units where all are served by a single service line that is master metered; and single-family dwellings. There is a six-tiered rate for residential customers. The tiers were developed in order to bill residential customers more equitably, based on the size of their properties.

Non- Residential: The fee is based on the total amount of impervious service area at a property. The total amount of impervious area is converted to ERU's and reduced to the nearest 100 sq feet.

http://www.aoba-metro.org/uploads/docs/2012/FINAL%20912012%20%20UTILITY%20COMMITTEEE%20UPDATED%20UNDERSTANDING%20DC%20WATER%20BILL%20Presentation-1.pdf

http://www.dcwater.com/customercare/iab.cfm

Stormwater Fee: The federal government requires that the District controls pollution from stormwater runoff. The stormwater fee provides a dedicated funding source to pay for these pollution control efforts. This fee helps to pay for green roofs, rain gardens, tree planting, street sweeping, and other activities that help keep waterways clean. Effective May 1, 2009, the stormwater fee collected from each District of Columbia retail water and sewer customer shall be based upon the Equivalent Residential Unit (ERU). An ERU is defined as 1,000 sq ft of impervious area of real property. A program to assist Low income residents with water bills is under development. The Department of the Environment (DDOE) manages the fee program.

http://www.dcregs.dc.gov/Gateway/RuleHome.aspx?RuleID=474056

Residential: A residential customer means a single-family dwelling used for domestic purposes, a condominium or apartment unit where each unit is served by a separate service line and is individually metered and the unit is used for domestic purposes, or a multifamily structure of less than four apartment units where all the units are served by a single service line that is master metered. Residential customers shall be assessed ERUs for the square feet of impervious surface on the property, as follows:

a) 0.6 ERUs for 100 to 600 square feet of impervious surface
b) ERU for 700 to 2,000 square feet of impervious surface
c) 2.4 ERUs for 2,100 to 3,000 square feet of impervious surface
d) ERUs for 3,100 to 7,000 square feet of impervious surface
e) 8.6 ERUs for 7,100 to 11,000 square feet of impervious surface
f) 13.5 ERUs for 11,100 square feet or more of impervious surface.

Non-Residential: All non-residential customers shall be assessed ERU(s) based upon the total amount of impervious area on each lot. This total amount of impervious area shall be converted into ERU(s), reduced to the nearest 100 square feet. Non-residential customers shall include all customers not within the residential class.

Impervious-only properties: are properties that have not, prior to May 1, 2009, had metered water/sewer service and require the creation of new customer accounts for billing of stormwater fees. (i.e., parking lots). The DC Water and Sewer Authority, pursuant to the Water and Sewer Authority Establishment and Department of Public Works Reorganization Act of 1996, effective April 18, 1996 (D.C. Law 11-111, §§ 203(3), (11) and 216; D.C. Code §§ 34-2202.03(3), (11)), shall establish accounts for and bill these impervious-only properties for stormwater fees pursuant to its regulations in 21 DCMR Chapter 41

http://www.dcregs.dc.gov/Gateway/RuleHome.aspx?RuleID=474056

Washington, DC (Cont'd)	**Stormwater Fee Discount Program, 2013**: The RiverSmart Rewards program provides District property owners and tenants who install systems that retain stormwater runoff, with discounts of up to 55% on its stormwater fee. Customers who are awarded RiverSmart Rewards will automatically be enrolled in the Clean Rivers Impervious Area Charge (IAC) Incentive Program, which offers a discount of up to 4% on the IAC. http://ddoe.dc.gov/release/district-establishes-new-stormwater-fee-discount-program **RiverSmart Homes Program**: Targets single family homes. Offers incentives to District of Columbia homeowners interested in reducing stormwater pollution from their properties. Homeowners receive up to $1,200 to adopt one or more of the following landscape enhancements: Shade tree planting, rain barrels, rain gardens, pervious pavers, bay scaping. http://ddoe.dc.gov/service/riversmart-homes-overview and http://ddoe.dc.gov/service/riversmart-rebates **RiverSmart Communities Program**: Targets larger Properties (ie apartments, condominiums and businesses). There are two options available to participate in the Communities Program: • Option 1: Rebate (open city-wide): offers rebates of up to 60% of the project cost of specific LID practices to multi-family residences such as condominiums, co-ops, apartments, small locally-owned businesses and houses of worship. This program is open city-wide. • Option 2: Design/Build (restricted to priority watersheds). Properties in designated high-priority watersheds will be considered for fully funded design/build LID projects. http://ddoe.dc.gov/service/riversmart-communities **RiverSmart Rewards**: property owners can earn a discount of up to 55% off the Stormwater Fee when they reduce stormwater runoff by installing green infrastructure (GI) such as green roofs, bioretention, permeable pavement, and rainwater harvesting systems. DC Water also offers a similar incentive program for its customers to earn a discount of up to 4% off the Clean Rivers Impervious Area Charge (IAC). Using one application, District residents, businesses, and property owners can apply for discounts through RiverSmart Rewards and the Clean Rivers IAC Incentive Program. Discounts are based on the stormwater retention volume achieved and are posted to DC Water bills. http://ddoe.dc.gov/riversmartrewards **RiverSmart Roof Tops Rebate**: The 2014-2015 green roof rebate program will provide base funding of $10 per square foot, and up to $15 per square foot in targeted sub-watersheds. There is no cap on the size of projects eligible for the rebate. Properties of all sizes including residential, commercial and institutional are encouraged to apply. For buildings with a footprint of 2,500 square feet or less, funds are available to defray the cost of a structural assessment. Additional funding may be available for features that further advance environmental goals. http://ddoe.dc.gov/greenroofs **RiverSmart Schools Program**: In addition to installing new schoolyard greenspace, the RiverSmart Schools program provides teachers with the training they need to use their conservation site with confidence to teach lessons based on the DCPS Standards. The gardens serve as a permanent outdoor learning tool that can enhance many areas of study. This year, funding is available for five schools with a minimum of $3,500 and up to $70,000 in gardening and classroom resources, plus additional technical assistance and in-kind support. http://ddoe.dc.gov/page/riversmart-schools-application **Stormwater Retention Credit Trading (SRC)** The program allows land-constrained developers to meet part of their mandated stormwater retention requirements by purchasing credits from offsite projects that reduce stormwater runoff, like rain gardens, green roofs, permeable pavement and other green infrastructure practices. Credits can be sold on the open market to those who need them to meet regulatory requirements**.** http://encouragecapital.com/wp-content/uploads/2016/03/DC-Stormwater-Press-Release.pdf Large development projects must install runoff-reducing green infrastructure (GI) if they trigger the District of Columbia's stormwater management regulations. This requirement, called the Stormwater Retention Volume (SWRv), is calculated by determining the volume of stormwater runoff from the regulated site. Projects with high compliance costs may be able to reduce costs by using Stormwater Retention Credits (SRCs). Each project must meet 50% of the required SWRv on-site, but DOEE offers the flexibility to meet the remaining 50% off-site through the use SRCs. **DC's Stormwater Retention Credit Trading Program:** https://doee.dc.gov/src The Washington Retention Credit Program is also discussed in this report: https://www.iisd.org/sites/default/files/publications/stormwater-markets-concepts-applications.pdf - see page 18

Washington, DC (Cont'd)	**DOEE rolled out two new elements of its SRC program (2017):** 1. **Price Lock Program:** Eligible SRC generators have the option to sell SRCs to DOEE at fixed prices. SRC generators can participate without losing the option to sell to another buyer. The option to sell to DOEE effectively constitutes a price floor in the SRC market and offers certainty about the revenue from an SRC-generating project. "We generally hear that investors want predictable investments that aren't tied to market swings," (Matthew Espie, Stormwater Program Manager at DOEE. "The main way we're providing confidence to investors is through the reserved money in the Price Lock program" https://doee.dc.gov/service/faq-src-price-lock-program 2. **Aggregator Startup Grants:** The Grant provides funds (up to $75,000) to support SRC-generating businesses as they evaluate sites for the feasibility of GI retrofits https://doee.dc.gov/node/1283461 **Environmental Impact Bond** In September 2016, DC Water issued a $25 million Environmental Impact Bond (EIB) to finance the construction of green infrastructure to manage stormwater runoff. http://www.quantifiedventures.com/dc-water/ **The Project:** https://www.dcwater.com/sites/default/files/Green%20Infrastructure%20Executive%20Summary.pdf **Marketing:** **Grants for LID Rebates & Environmental Education**: program of incentivizing low impact development (LID) implementation on private property in the District and to assist DDOE in providing a meaningful watershed education experiences for every student enrolled in District public schools. The total amount available for this initiative is approximately $1,310,000.00. http://ddoe.dc.gov/release/grants-lid-rebates-environmental-education **Rain Barrel and Cistern Rebate**: Homeowners can purchase and install up to two rain barrels or cisterns and receive $50 to $500 back by submitting an application, receipt, and pictures of the installed barrel. The rebate amount is dependent on volume: $1 per gallon stored. http://ddoe.dc.gov/service/riversmart-rebates **Tree Rebate**: provides rebates to individuals who purchase and plant a tree on private property, residential or commercial. There is no maximum number of rebates per property. 40 species noted for their large canopy and environmental benefits qualify for rebates up to $100 per tree. Small and medium canopy trees are eligible for rebates up to $50 per tree, as long as the tree reaches 15' tall and wide at maturity. http://caseytrees.org/programs/planting/rebate/ **Rain Garden, Pervious Paver, and Impervious Surface Removal Rebate**: The rebate is based on how many square feet of impervious area is treated with rain garden or pervious pavers/impervious surface removal. The rebate will reimburse homeowners $1.25 per impervious square foot treated. The minimum square footage that must be treated is 400 square feet (a $500 rebate). The maximum rebate is $1,000 or treating 800 square feet or more of impervious surface. http://ddoe.dc.gov/service/riversmart-rebates **The Clean Marinas Program**: is a partnership among the District Department of the Environment/Watershed Protection Division, the National Park Service/National Capital Region (NPS), and marinas in the District. It is a voluntary program through which marina operations become more environmentally responsible and marina managers educate the boating public on environmentally responsible boating practices. http://ddoe.dc.gov/service/reduce-stormwater-runoff **Green Jobs Grant**: Stormwater Retention Best Management Practice Maintenance Training Course: Funds are available for non-profit organizations or educational institutions to develop a training course for District residents to learn the specific skills required for maintenance of stormwater retention Best Management Practices (BMPs). The amount available for the project in this RFA is approximately $150,000. http://ddoe.dc.gov/node/831062 **Grants for Demonstration of Innovative Green Practices**: on-going program of incentivizing Low Impact Development (LID) Green Infrastructure (GI) implementation District on properties and to participate, in whole or in part, in demonstrations of innovative LID-GI practices on private and public spaces. The amount available for the projects in this RFA is approximately $2,110,000 http://ddoe.dc.gov/node/468782

Washington, DC (Cont'd)	**Policy:** **Stormwater Management Laws and Regulations**: A comprehensive listing and associated links for all regulations pertaining to stormwater management. http://dcregs.dc.gov/Gateway/ChapterHome.aspx?ChapterNumber=21-5 **2013 Stormwater Management Rule and Guidebook**: http://ddoe.dc.gov/swregs : the purpose is to enhance transparency and effectiveness of the stormwater plan review process for regulated and voluntary projects. The new database will also streamline participation in the Stormwater Retention Credit and RiverSmart Rewards programs, which incentivize installation of runoff-reducing Green Infrastructure. http://ddoe.dc.gov/node/951112 **Other:** Sustainable DC Omnibus Amendment Act of 2014: The components of this legislation address the challenges as prioritized in the Sustainable DC Plan including: growing jobs and the economy, improving health and wellness, ensuring equity and diversity, and **protecting the District's climate and the environment**. http://www.georgetownclimate.org/resources/sustainable-dc-omnibus-amendment-act-of-2014-washington-dc and, http://www.sustainabledc.org/in-dc/legislation/

Onondaga County, Syracuse, New York	**Non-Residential Stormwater Incentives – Grant Programs** **Save The Rain Green Improvement Fund (GIF):** GIF grant funding offers assistance to applicants installing GI technologies as an aspect of the development, redevelopment, and/or retrofitting of certain classes of privately-owned properties (commercial, business, and not-for-profit owned properties) in specific geographical locations. Since its inception (2010), GIF has provided over $11.2 million in funding to local green infrastructure projects on private property. **2018 Program Details:** http://savetherain.us/wp-content/uploads/2018/06/2018_GIFApplication_051618.pdf **Suburban Green Infrastructure Program (SGIP):** The purpose of the program to support the development of green infrastructure and stormwater mitigation techniques on public property within the Onondaga County sanitary sewer district but outside of the City of Syracuse. Funding is aimed at municipal entities within Onondaga County that are planning projects to reduce inflow and infiltration to the sanitary sewer system. All eligible projects must be on municipally-owned property within the Onondaga County sewer system. http://savetherain.us/sgip/ **Rain Barrel, Tree Planting and Vacant Lot Programs are also available:** http://savetherain.us/vacant-lot-program/ **Onondaga County's Save the Rain Program:** https://www.dec.ny.gov/chemical/112591.html

Burlington, Vermont	**Fee Structure:** The stormwater fee is based on impervious area and is charged on a per unit basis. Each ISU (Impervious surface unit) is 1,000 square feet of impervious area on a property. Single family, duplex, triplex homes, as well as seasonal and mobile homes pay a flat fee based on the average amount of impervious associated with these parcel types. Other types of properties (commercial parcels and vacant lots) are assessed a fee based on the amount of impervious surface on the parcel. Non-residential properties are eligible to apply for up to 50% credit on their stormwater bill if they can document that they have implemented stormwater management practices on their property. **Stormwater Credit Manual**: Fee credit program for directly assessed properties. The credit program is not yet available for those properties with a flat fee. Multiple credits can be given to eligible properties. The total credit given to any property shall not exceed 50% of the stormwater user fee for that property, and in no event shall a property pay a stormwater user fee less than the flat fee for a detached single-family home. **Water Quantity Reduction Credits**: available to properties whose peak stormwater runoff rate is restricted and/or controlled through onsite structural control facilities such as detention and retention ponds or chambers. If a higher level of detention is provided than required by the Vermont Stormwater Manual, then additional credits may be granted. The credit will be granted for the portion of impervious area that drains to the BMP. The maximum water quantity credit is 50%. Approved water quantity reduction credits can be applied in addition to any other approved credits. **Water Quality Treatment Credits**: offered to properties that discharge a portion of the runoff to approved structural BMPs which significantly reduce pollutants in stormwater runoff. The goal for water quality practices is for the removal of 80% total suspended solids (TSS) for 90% of all Vermont storms, estimated as a 0.9 inch/24-hour event. Approved water quality credits can be applied in addition to any other approved credits. The maximum water quality credit for a property is 25% reduction in stormwater user fees for BMPs with 80% TSS removal. Credit for BMPs with lower TSS removals shall be prorated using the following formula: % Credit = 0.31 x (Estimated % TSS Removal). The credit will be granted for the portion of impervious area that drains to the BMP. **Non-Structural Practices**: In some instances, the ability to strictly meet the requirements may not be possible, feasible or desired in an urban landscape. As such, the City encourages the use of alternative management practices and technologies as a way to both satisfy the requirements of this Division, to give flexibility to design and to encourage Green Infrastructure (green), Best Management Practices (BMP), Low Impact Design (LID) or other innovative practices that satisfy the requirements. Such practices include but are not limited to, green roofs, alternative detention practices, water reuse, including stormwater use, infiltration practices, including pervious and porous pavements and pavers. Application of Non-Structural Practice Credits are identical to those offered under Water Quantity Credits and Water Quality Credits. **Water Education Credit**: Approval of the credit application will result in a 10% credit to the assessed stormwater fee. http://www.burlingtonvt.gov/sites/default/files/DPW/Stormwater/Stormwater%20Credit%20Manual.pdf **Marketing:** **Stormwater Friendly Driveways**: A stormwater friendly driveway can reduce the amount of coverage calculated for zoning permit purposes and may allow property owners to construct additional building space elsewhere on their lot. Currently "strip driveways" provide this benefit, but soon other stormwater drive types may provide up to 50% coverage credit if proposed amendments to zoning regulations are approved in early 2014. http://www.burlingtonvt.gov/DPW/Stormwater-Friendly-Driveways **Let it Rain: Stormwater Best Management Practice Grants**: Private and public property owners are eligible for funds through this program. This includes all residents, non-profits, businesses, corporations, churches, private schools, homeowner associations, lake associations and municipal entities located within the Vermont portion of the Lake Champlain Basin. Available funds for initiatives: Downspout Disconnection - up to $20 / Rain Barrel - up to $25 / Rain Garden - up to $250 / Cistern - up to $500 / Permeable Pavers - up to $1 per sq ft / Other - dependent on practice http://www.burlingtonvt.gov/DPW/Get-Involved **Adopt-a-Drain Program**: encourages community awareness of stormwater management. http://www.burlingtonvt.gov/DPW/ADOPT-A-DRAIN

Burlington, Vermont (Cont'd)	**Policy:** **Wastewater, Stormwater and Pollution Control Ordinance** – Chapter 26 The Burlington City Council adopted a revised Chapter 26, December 15, 2008. The effective date is April 1, 2009. http://www.codepublishing.com/vt/burlington/?Burlington26/Burlington26.html The wastewater sections of Chapter 26 will be revised to reflect the decision to pursue municipal delegation of wastewater permitting. Wastewater permits are presently administered by the state. Beginning July 1, 2007, every parcel of land came under the authority of the state's on-site wastewater & potable water supply system program. As a result, a state permit is needed for most repairs, upgrades, and new construction of on-site wastewater treatment and disposal facilities, and connections to municipal water distribution and wastewater collection systems. Delegation of the state's regulatory program means that the state would transfer administration of its wastewater systems permit program to the city if the city makes a request in writing and meets specific criteria. http://www.burlingtonvt.gov/sites/default/files/DPW/Stormwater/Stormwater%20Taskforce%20Report.pdf –page 2 Chapter 26 contains standards for construction site erosion control. The standards are basically split between large and small projects. Large projects include all "major impact," "subdivision," and "planned unit developments" as defined in the City's Comprehensive Development Ordinance. Small projects are all others with at least 400 square feet area of disturbed earth involved in the construction process. Chapter 26 also contains standards for post-construction stormwater management plans. All projects that result in greater than or equal to ½ acre of clearing, grading, construction or land disturbance activity, and create greater than or equal to ½ acre of impervious surface are required to have a post-construction stormwater management plan. Chapter 26 includes provision for City administration of wastewater permits upon delegation by the State of Vermont. Previously, all wastewater permits were issued by the State of Vermont DEC Wastewater Division. City administration of wastewater permits will allow one stop shopping for applicants upon implementation. http://www.burlingtonvt.gov/sites/default/files/DPW/Stormwater/Stormwater%20FAQs.pdf **Burlington Comprehensive Development Ordinance:** http://www.burlingtonvt.gov/PZ/CDO **Backwater Valve Ordinance:** http://www.burlingtonvt.gov/assets/0/122/318/303/2180/8f0253c9-5b37-4627-b9e7-ee875e73d98e.pdf **Other:** **Stormwater Infrastructure Mapping Update Project**: Locations of all known manholes, catch basins, water valves and hydrants have been collected. A database associated with GIS mapped features allows better prioritization of maintenance activities. http://www.burlingtonvt.gov/DPW/Stormwater-Infrastructure-Mapping-Update-Project

St Paul, Minnesota	**In-lieu Fee Program (2018):** The primary objective of the Minnesota's In-Lieu Fee program (ILF) is to provide high quality and sustainable mitigation (replacement) to offset the loss of aquatic resource functions resulting from authorized impacts. The ILF will provide high quality mitigation credit through strategic site selection based on a watershed approach that incorporates stakeholder input. http://www.bwsr.state.mn.us/wetlands/in-lieu_fee/In-Lieu_Fee_Program_Prospectus.pdf The fee-in-lieu project is a research investigation that will inform the design of a shared green infrastructure district. It plans for a model in which, rather than building individual stormwater facilities onsite, property developers would pay a certain fee that would be pooled together by the city to develop district-based green infrastructure. **See Minneapolis – St Paul below for a district-level approach to SWM** http://www.govtech.com/fs/news/St-Paul-Minn-Modernizes-Stormwater-Infrastructure.html

New York City, New York	**Green Infrastructure Grant Program:** Applicable for private property owners in combined sewer areas of New York City. The program provides funding for green infrastructure projects that manage the first inch of rainfall, including blue roofs, rain gardens, green roofs, porous pavement and rainwater harvesting. Private property owners in combined sewer areas are eligible for the grants of up to $5 million. In order to ensure that the green infrastructure is well-maintained, grantees must sign a covenant that requires twenty years of maintenance. Since its introduction in 2011, the Grant Program has sought to strengthen public-private partnerships and public engagement in regards to the design, construction and maintenance of green infrastructure on private property. As of 2016, the Grant Program has committed more than $13 million to 33 private property owners to build green infrastructure projects in combined sewer areas. https://www1.nyc.gov/html/dep/html/stormwater/nyc_green_infrastructure_grant_program.shtml **Green Roof Policy Bill Proposed for NYC**: On January 28th, 2019 City Council held a hearing to decide on two pieces of proposed green roof legislation: whether green roofs and solar panels should be mandatory on certain New York City roofs, and, if the green roof tax abatement should be increased from $5.23 per square foot to $15 per square foot (60% of most med-large NYC green roof installations). https://www.urbanstrong.com/nyc-green-roof-policy-bill-proposed/ **Prior to March 2018:** NYC offered a property tax abatement to building owners to install green roofs. The one-time abatement is based on dollar amount per sq ft and is limited to the lesser of $200,000 or the building's annual tax. The program was suspended in 2018. https://www.urbanstrong.com/financial-incentives-solar-green-roofs-nyc/ The original **Green Roof Program**: https://www1.nyc.gov/assets/buildings/pdf/green_roof_tax_abatement_info.pdf **Article: *Expanding Green Roofs in New York City: Towards a Location-Specific Tax Incentive*** (a 2018 paper that examines the failure of New York's Tax abatement program and suggests a different strategy) "*In this Article, we suggest a strategy to help get around the budgetary dispute. Specifically, we propose that New York City increase the size of the tax abatement offered to property owners in targeted areas where green roofs are deemed most advantageous- perhaps those neighborhoods that are most vulnerable to the effects of stormwater runoff – while decreasing, or even eliminating, the abatement offered to properties located elsewhere. Moving towards a location-specific subsidy of this sort would allow the City to increase the impact of the tax incentive without increasing the total funding allocated to the program. Not only would the higher rate likely encourage increased utilization of the funding that has already been allocated to the program, but the roofs that are subsidized would be located in areas where they confer greater societal value*." https://www.nyuelj.org/wp-content/uploads/2018/06/Spiegel-Feld-Sherman-Green-Roofs-Draft-Final.pdf

Baltimore, Maryland	**Environmental Impact Bond (EIB)** A new EIB project (2018) totaling $10 million in green infrastructure is coming to the port city of Baltimore, the Chesapeake Bay Foundation (CBF) announced in a press release. Four million dollars in funding will come from state funds and the collection of city stormwater fees. The introduction of EIBs will allow Baltimore's Department of Public Works to take a bigger bite into green infrastructure. A further six million dollars' worth of infrastructure projects will be funded through EIBs, with Kresge Foundation and other funders yet to be named acting as the private investors. CBF and its partner, impact investment advisor Quantified Ventures (QV), are helping the city to design the plan. https://www.baltimoresun.com/news/maryland/baltimore-city/bs-md-bay-city-green-20180325-story.html The Green Infrastructure Environmental Impact Bond project being conducted by CBF, with our contractor Quantified Ventures, is funded by a generous one-to-one grant from an anonymous donor that is being matched in part by The Kresge Foundation and The Abell Foundation. http://www.cbf.org/how-we-save-the-bay/programs-initiatives/environmental-impact-bonds.html

Atlanta, Georgia	**Environmental Impact Bond** Through a creative financing opportunity won by the Department of Watershed Management (DWM), funding will support the improvement of resilience projects in Westside neighborhoods prone to flooding. Eight green infrastructure projects were proposed for funding at an estimated cost of $12.9 million https://www.prnewswire.com/news-releases/atlantas-department-of-watershed-management-wins-environmental-impact-bond-challenge-for-green-infrastructure-and-resilience-projects-on-the-citys-westside-300619657.html

Philadelphia, Pennsylvania	**Non-residential Stormwater Regulation (**Philadelphia began following updated stormwater regulations July 1, 2015) New developments are now required to handle more water, slow stormwater more effectively, and improve pollutant reduction. New, specific requirements for water quality and water quantity are identified in a chart on the following link: http://www.phillywatersheds.org/stormwaterregulations **Non-residential Stormwater Incentives – Expedited Review** Two types of reviews are available: 1. **Disconnection Green Review:** (Formerly named Green Project Review) Redevelopment projects exempt from the Channel Protection and Flood Control requirements are eligible for Disconnection Green Review. Projects must disconnect 95% or more of the post-construction impervious area within the project's limits of disturbance (LOD)using DIC to comply with PCSM Requirements. 2. **Surface Green Review:** New Development and Redevelopment projects that can demonstrate that 100% of post-construction impervious area within the project's LOD is managed by DIC and/or bio infiltration/bioretention SMPs to comply with PCSM Requirements are eligible. http://www.phillywatersheds.org/doc/Expedited%20Review%20Handout_20150706.pdf **Non-residential Impervious Area (IA) Reductions Credit**: Customers on a *Non-residential* or *Condominium* parcel with at least five-hundred (500) square feet of gross area are eligible to apply for credits in the following five categories: Tree Canopy Cover, Roof Leader/Downspout Disconnections, Pavement Disconnections, Green Roofs, and Porous Pavement • To be eligible for IA Credit, the customer must demonstrate applicable management of the first inch of runoff from impervious areas on a property via infiltration and/or detention & slow release and/or volume reduction and filtration. https://rrstormwater.com/city-philadelphia **Impervious Area Reduction Exemption:** Applicants having difficulty meeting the Channel Protection and/or Flood Control requirements using only DIC and bio-infiltration/bio-retention SMPs should investigate options to achieve a 20% reduction in impervious area from predevelopment to post development conditions, which exempts projects from both requirements. http://www.phillywatersheds.org/doc/Expedited%20Review%20Handout_20150706.pdf **Non-Residential Stormwater Incentives – Grant Programs:** **Stormwater Management Incentives Program** (SMIP) and the **Greened Acre Retrofit Program** (GARP) to reduce the price for qualified non-residential Philadelphia Water Customers and contractors to design and install stormwater best management practices. Competitive applications limit the request to no more than $100,000 per impervious acre managed. **The Stormwater Management Incentives Program (SMIP**) - grant program providing direct financial assistance to property owners for design and construction of SMPs. **The Greened Acre Retrofit Program (GARP)** provides funding to project aggregators or companies to construct stormwater retrofit projects on private property in the combined sewer area. https://www.pidcphila.com/images/uploads/product/Stormwater_Grants_Manual.9.14.15.pdf **The Greened Acre Retrofit Program (GARP),** encourages contractors or design / construction firms to compete for limited public grant funding by aggregating the lowest-cost retrofit opportunities available on private land. The availability of public dollars through GARP is intended to create a competitive green infrastructure market that can help source low-cost stormwater management, while also generating a potentially new line of business for engineering/design/construction firms. Private property owners in Philadelphia also benefit from GARP, as its funding provides a means for private property owners to reduce the impervious area on their parcels and thereby reduce their monthly stormwater management fees. Note: the above paragraph is an excerpt from a 15-page report that examines some of the challenges with adoption of the GARP program, 2016: https://www.nrdc.org/sites/default/files/spurring_entrepreneurship_and_innovation_in_stormwater_markets.pdf

	Any property is eligible to pursue and install retrofits; however, only non-residential, condominium, and multi-family properties with more than 4 units are eligible to receive stormwater credits. https://www.phila.gov/water/PDF/SWRetroManual.pdf
Philadelphia, Pennsylvania (Con't)	**Green Roof Business Tax Credits:** provides businesses a rebate for 50% of green roof costs up to $100,000. https://www.phila.gov/services/payments-assistance-taxes/tax-credits/green-roof-tax-credit/ **Green Roof Density Bonus Ordinance:** This ordinance allows for increased density in properties zoned for a low-density multi-family residential and neighborhood commercial corridors if a qualifying green roof covers at least 60% of the building's roof area. https://www.pwdplanreview.org/upload/pdf/Green_Roof_Density_Bonus_Factsheet_20160624.pdf **The Ordinance:** http://planphilly.com/uploads/media_items/brown-green-roof-density-bonus.original.pdf **Stormwater Credits Explorer Map:** This tool appears easy to use & provides a generic cost estimate to install GI & the resultant decrease in stormwater charge. The drawing function is a little sticky, but the concept is excellent and provide property owners with a quick estimate of ROI for GI. The application turns any non-residential property into a canvas where a user can sketch out ideas of up to 5 different types of "Stormwater Tools", including Green Roofs and Rain Gardens, Permeable Pavers and different types of storage basins. The tools enable users to lay out potential changes while keeping realistic limits for that given property. As Stormwater Tools are added or removed, the application updates the monthly stormwater charge for that property. Users can rapidly get a sense of the feasibility and effectiveness of adding stormwater infrastructure systems. http://water.phila.gov/swexp/explore/ **Big Green Map Captures Scale of Philly's Growing Green Infrastructure Network:** http://phl-water.maps.arcgis.com/apps/webappviewer/index.html?id=c5d43ba5291441dabbee5573a3f981d2 **Community Engagement** **Soak it up Adoption Program:** A community-level grant program. Grants are available on an annual basis up to $5,000. The amount awarded is contingent on the number of sites adopted as well as the level of public engagement proposed. Program is open to Philadelphia based non-profit organizations representing a specific community. Essentially this program is about engaging citizen participation in the management of GI. Private property is ineligible. https://www.pidcphila.com/product/soak-it-up-adoption-program http://www.phillywatersheds.org/sites/default/files2/SIU%20Adoption_FAQ.pdf **Residential Homeowners Incentive Program**: Residential property owners currently pay a flat stormwater charge and are not eligible for credits. A **Rain Check Program** is available for residential customers. Rain Check includes a free rain barrel giveaway and installation, or a small-scale stormwater intervention for a reduced cost. A downspout planter which usually costs $800 will be installed by PWD for $100, or for a rain garden or permeable pavers, PWD will pay up to $2,000. https://www.pwdraincheck.org/en/stormwater-tools-home **Green Infrastructure Living Laboratory (GILL):** A Partnership between the Philadelphia Water Department (PWD)and Drexel University's Sustainable Water Resource Engineering Lab to regularly monitor (use sensors) green infrastructure in order to utilize city storm water more efficiently. The GILL project collects data from green infrastructure that has been constructed on private property. Philadelphia's Green City, Clean Waters program can only be successful if investments are made in both public and private property. The more information gathered about private systems — in particular, green roofs and cisterns — the better the evaluation of which projects are working and are most effective in capturing stormwater. Through the partnership, the city can weigh in on experimental designs and offer perspective about key needs. The outcomes of experiments and monitoring are used to inform design guidance and policy… "…monitoring data collected by the GILL team from a water reuse cistern at Drexel is a great example. We will use that case study as guidance for designers at PWD. It also demonstrates that there is a capacity for water reuse that can meet our design requirements for stormwater management."

	The data collected by GILL can serve as a constant feedback loop to the Water Department's green stormwater infrastructure design team. http://www.govtech.com/fs/infrastructure/Real-Time-Data-Helps-Philadelphia-Improve-Green-Design.html

Prince George County, Maryland	**Community-Based Public-Private Partnership (CBP3)** In 2015, PG County entered into the 30-year "Clean Water Partnership" with Corvias, which is a pay-for-performance service delivery model that delegates project selection, design, construction and O&M responsibility to the private partner. Under the agreement, the county provides Corvias with funds to retrofit 2,000 acres over a three-year project period, in which the county provides oversight, and Corvias serves as the program manager, handling procurement of subcontractors to ensure projects are executed in line with the scope, schedule and costs. After each project is completed, the Maryland Environmental Service, an independent state agency, inspects and certifies work as completed, and then monitors subsequent O&M work. In this particular case, private sector financing was not the primary driver of the partnership. Following the EPA's Community-Based PPP (CBP3) model, the private sector was engaged to meet regulatory requirements in an economically efficient manner, to bring in expertise in GI design, to transfer knowledge to public sector employees, and to provide additional local economic and community benefits. The overall effort is expected to install 46,000 GI elements – including rain gardens, permeable pavement and green roofs – by 2025. The agreement requires that Corvias meet socioeconomic targets as well, with goals for participation of country residents, and goals of 30–40 percent for subcontracting to local small, minority, veteran, disabled and women-owned businesses. See pg. 32: https://www.preventionweb.net/files/61829_181107engagingtheprivatesectoringi.pdf **The Clean Water Partnership** is the first-ever CBP3 model to address stormwater management at such a large scale. Under the terms of the 30-year agreement, the county has committed to invest $100 million during the initial three years of the partnership. The funding covers the planning, design and construction of green infrastructure to retrofit 2,000 acres of impervious surfaces. Additionally, there is an option in the partnership to retrofit an additional 2,000 acres after the initial 3-year term if the county is satisfied with the progress of private entity. https://www.epa.gov/G3/prince-georges-county-maryland-clean-water-partnership https://www.corvias.com/sites/default/files/Insights/Prince_Georges_County_CWP_05-2017.pdf **Prince George's County Clean Water Partnership:** https://thecleanwaterpartnership.com/wp-content/uploads/2016/06/PGC-CBP3-Clean-Water-Partnership.pdf **Master Program Agreement** for the Urban Stormwater Retrofit Program Public-Private Partnership between Prince George's County and Corvias: https://thecleanwaterpartnership.com/wp-content/uploads/2017/10/CR-099-2014-Corvias-MPA-MMA-Legislative-Approval.pdf **Counter opinion on the merits of public-private partnerships for SWM:** *Public-Private Partnerships for Stormwater: Are We Sacrificing Innovation and Quality for Lower Costs***?** (pertinent to Prince George County, Maryland) https://www.cwp.org/public-private-partnerships-stormwater-sacrificing-innovation-quality-lower-costs

Chester, Pennsylvania	**Community-based Public-Private Partnership (CBP3):** In 2017, generated a **Vision** is to plan, implement and manage a 350-acre integrated Green Stormwater Infrastructure (GSI) urban retrofit program with $50 million investment, including a long-term (20-30 year) operation and maintenance program. The effort will support greater greening efforts in the region, generating hundreds of jobs and significant small business growth for this historically impoverished, overly burdened, urbanized community. https://www.corvias.com/news/cbp3-drive-economic-growth http://www.chestercity.com/wp-content/uploads/2017/05/Chester_CCBP3_Announce_FactSheet_v5.pdf **Challenges and Issues with the CBP3 System**: *This system will destroy the city of Chester* https://www.delcotimes.com/news/this-system-will-destroy-the-city-of-chester/article_cb9769b4-4f03-5da7-90a8-f0e7c7307cd8.html http://www.delconewsnetwork.com/news/region/chester-stormwater-authority-receives-m-in-loans/article_dcb241e4-b24a-5a6b-8122-da6eac99798c.html

The Ramsey-Washington Metro Watershed District, Minnesota	**Property Tax Levy to Fund Green Infrastructure**: The Ramsey-Washington Metro Watershed District (RWMWD) is located in the Eastern Twin Cities metropolitan area. The watershed encompasses approximately 41,600 acres and includes 18 lakes, 5 streams, and hundreds of wetlands. Land use in the watershed is generally developed, and includes industrial, commercial, and residential land. Green Infrastructure funding has come from a special property tax on all properties within the watershed. The EFC has worked with RWMWD to share their approach and successes with state water bankers from across the country interested in lending funds for these types of programs. Not surprisingly, the bankers were interested in how they will be paid back and were impressed with the stability and capacity of the watershed improvement tax. http://efc.web.unc.edu/2014/10/08/bottom-financing-options-green-infrastructure-will-approach/ Approximately 95 percent of the District's funds for implementing capital projects, programs, and other operations are raised through a property tax levy. This tax is an ad valorem tax (a tax on all taxable parcels in the District, based on property value). As a guiding principle, the District intends to restrict its annual levy to a property tax rate of approximately 0.025 percent, or about $25 per $100,000 of property value. From 2006 through 2015, the District's annual levy ranged from approximately $3M to $6M. This tax rate will allow the District's levy to grow at approximately the same rate as the increase in property values. https://www.rwmwd.org/wp-content/uploads/RWMWD-Strategic-Overview.pdf - see tab, page 26 The RWMWD is currently focusing much of its efforts on reducing dissolved Phosphorus as well as chlorides from road salt. Reduction in imperviousness is essential in achieving these goals. Green infrastructure is being used to retrofits streets, parking lots and site drainage. The District is working on pooling funds in order to take advantage of financing opportunities. Options being investigated include an "Impervious Surface Reduction Opportunities Fund" or a "Distributed Green Infrastructure Fund." State Revolving Fund (SRF) money has successfully been used for partial funding of previous District projects. Opportunities to expand this role of the SRF are being explored. https://efc.sog.unc.edu/sites/default/files/RWMWD_MN_GI%20Case%20Study.pdf Stewardship Grants (Residential & Commercial): available to install and maintain a variety of BMP's designed to filter and reduce runoff, protect groundwater, restore native ecosystems, prevent flooding and lessen the effects of drought. • **Installation Grants** of up to $15,000 for homeowners or $100,000 for ICI. Funding covers 50-100 percent of the project, depending on type and location. • **Maintenance:** For new projects, they will reimburse up to 50 percent of annual maintenance costs with a maximum of $5,000 over five years. https://www.rwmwd.org/get-involved/stewardship-grants/

St Paul, Minneapolis	**Towerside District** Stormwater: A New Model of Green Infrastructure Towerside is the region's first designated innovation district. This 370-acre area is envisioned as a high-intensity, high density mixes of places and spaces where working, living and innovation come together. A coalition of public, private and nonprofit partners is working to establish Towerside as a replicable model for sustainable urban redevelopment. Key to this model is the use of district-wide systems for stormwater management, energy, parking, parks and other amenities. This "first-of-its-kind district stormwater system" is the result of a voluntary agreement between four private developers (owning adjacent properties) to manage stormwater runoff jointly rather than separately. This shared "district" approach to stormwater management will save the property owners money while creating more effective, cost-efficient and eco-friendly stormwater treatments. The MWMO facilitated the agreement between the landowners and is providing $1.3 million to supplement the owners' investment in stormwater infrastructure. The district system design integrates infrastructure to facilitate sustainability and resilience for the community while adding new public amenities like green space. The stormwater system is also a component of the larger redevelopment of Fourth Street, which is known as "Green Fourth." The result of this effort is the Towerside District Stormwater System, which comprises a pair of biofiltration basins connected to a 206,575-gallon underground storage tank. Together, these features capture, treat and hold stormwater runoff from an approximately 8-acre area so that the water can be reused. https://www.mwmo.org/management/planning/towerside-district-stormwater-management/

	https://www.mwmo.org/projects/towerside-district-stormwater-system/

Montgomery County, Maryland	**Residential/Commercial Rebate Program for Stormwater Control:** **RainScapes Program** for residential, commercial and institutional property owners who implement efforts to help control stormwater runoff. The maximum per property rebate has been increased to $7,500 per residential property, and $20,000 for properties owned by commercial entities, institutions, homeowner associations or non-profit organizations. Once a RainScapes project is installed, residents can apply for a reduction to their property tax bill in the form of a credit for maintaining their project. Since the launch of the RainScapes Rewards Rebate Program 11 years ago, 987 rebates have been distributed totaling $511,481.63. **Types of projects (i.e., green roof, permeable pavers etc.) can be found here along with rebate amounts for each project type.** https://www.montgomerycountymd.gov/water/Resources/Files/rainscapes/Rebate-Table.pdf **The program:** https://www.montgomerycountymd.gov/water/rainscapes/rebates.html

Shepherd Creek Watershed, Cincinnati, Ohio	**Using Economic Incentives to Manage Stormwater Runoff in the Shepherd Creek Watershed: A study of reverse auctions by the US EPA** https://nepis.epa.gov/Exe/ZyNET.exe/P1002Q4G.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2006+Thru+2010&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C06thru10%5CTxt%5C00000006%5CP1002Q4G.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL **Reverse Auction:** A reverse auction modifies the application and approval process by soliciting offers from proponents. The latter enters a bid that describes the LID technology that they wish to implement as well as the amount of financial compensation required. The administering agency selects approved projects based on both the efficacy of measures proposed and the extent of financial assistance requested. This system could achieve greater SW control for the same budget if requests come in below what would be administered under prescribed compensation programs.

APPENDIX 3

TIER 1 AND TIER 2 MANAGEMENT MEASURES

& MANAGEMENT MEASURES EVALUATION MATRIX

Tier 1 (Existing development) and Tier 2 (Proposed development) Management Measures

MANAGEMENT CATEGORY		MANAGEMENT MEASURES													
		Bioretention	Perforated Pipes	Permeable Pavement	Infiltration Chambers	Boulevard Silva Cells	Green Roofs	Oil-grit separator	Land Retirement	Constructed Wetlands	Rural Forestry	Afforestation	SWM Ponds (Wet)	SWM Ponds (Dry)	Hybrid Wet Ponds/Wetlands
Regional / Municipal	Right-of-Way	1	1		2	1		2							
	Public facilities	1	2	1	1	2									
	Centralized devices on public land	2								1			2	1	1
Low-Medium Density Residential	Impervious	1	2	1											
	Pervious/grass space					1						1	2	2	2
Medium-High Density Residential	Impervious	1	2	1	1		2	2							
	Pervious/grass space	1			2	2						1			
Industrial, Commercial & Institutional	Impervious	1	2	1	1		2	2							
	Pervious/green space	1	2		2	2						1			2
Agricultural / Farm	Marginal lands	1								1	1				2
	Crop lands	1							1						

New development & re-development only

By assigning a number of 1, 2 or 3 in the corresponding cell, please indicate the three priority Management Strategies (top row) for each Management Category (left column).

Please do not rate more than 3 Management Strategies for each Management Category.

MANAGEMENT CATEGORY **CURRENT STATE (Existing Development)**		**MANAGEMENT STRATEGY**																	
		Bioretention	Perforated Pipes	Permeable Pavement	Infiltration Chambers	Boulevard Tree Pits	Rain Gardens	Green Roofs	Oil-grit separator	Downspout Disconnect	Roof-top Storage	Cisterns	Land Retirement	Constructed Wetlands	Rural Forestry	Afforestation	SWM Ponds (Wet)	SWM Ponds (Dry)	Hybrid Wet Ponds/Wetlands
Regional / Municipal	Regional Right-of-Way	◆	◆	◆	◆	◆			◆										
	Municipal Right of Way																		
	Public Facilities	◆	◆	◆	◆	◆		◆	◆		◆	◆					◆	◆	◆
	Centralized Devices on Public Land																		
Low-Medium Density Residential	Roof top						◆			◆									
	Impervious/driveway			◆															
	Pervious/grass space					◆	◆												
Medium-High Density Residential	Roof top						◆			◆									
	Impervious/driveway/parking lots	◆		◆	◆				◆										
	Pervious/grass space	◆			◆	◆	◆									◆			
Industrial, Commercial & Institutional	Roof top									◆	◆								
	Parking lots	◆		◆	◆				◆										
	Pervious/green space	◆	◆		◆	◆										◆			◆
Agricultural / Farm	Marginal lands	◆												◆	◆				◆
	Crop lands	◆											◆						

Equitable Responsibility for Transformative Design – Management Measure Evaluation Form (Proposed Development)

By assigning a number of 1, 2 or 3 in the corresponding cell, please indicate the three priority Management Strategies (top row) for each Management Category (left column).

Please do <u>not</u> rate more than 3 Management Strategies for each Management Category.

MANAGEMENT CATEGORY FUTURE STATE (Proposed Development)		MANAGEMENT STRATEGY																	
		Bioretention	Perforated Pipes	Permeable Pavement	Infiltration Chambers	Boulevard Tree Pits	Rain Gardens	Green Roofs	Oil-grit separator	Downspout Disconnect	Roof-top Storage	Cisterns	Land Retirement	Constructed Wetlands	Rural Forestry	Afforestation	SWM Ponds (Wet)	SWM Ponds (Dry)	Hybrid Wet Ponds/Wetlands
Regional / Municipal	Regional Right-of-Way	♦	♦	♦	♦	♦			♦										
	Municipal Right of Way	♦	♦	♦	♦	♦			♦										
	Public Facilities	♦	♦	♦	♦	♦		♦	♦		♦	♦					♦	♦	♦
	Centralized Devices on Public Land				♦									♦			♦	♦	♦
Low-Medium Density Residential	Roof top						♦			♦		♦							
	Impervious/driveway			♦															
	Pervious/grass space					♦	♦									♦	♦	♦	♦
Medium-High Density Residential	Roof top						♦	♦	♦	♦	♦	♦							
	Impervious/driveway/parking lots	♦		♦	♦				♦										
	Pervious/grass space	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦
Industrial, Commercial & Institutional	Roof top							♦	♦	♦	♦	♦							
	Parking lots	♦		♦	♦				♦										
	Pervious/green space	♦	♦		♦	♦										♦	♦	♦	♦

* Includes greenfield, in-fill and re-development

APPENDIX 4

MANAGEMENT MEASURE DEFINITIONS

Management Measure Definitions

Bioretention – A shallow excavated surface depression designed to capture and infiltrate some or all of the stormwater. Contains a storage layer, filter media, mulch, and planted with selected vegetation. Includes bioswales.

Perforated Pipes – Long infiltration trenches or linear soak-a-ways that are designed for both conveyance and infiltration of stormwater runoff. Can be used in place of conventional storm sewer pipes where topography, water table depth, and runoff quality conditions are suitable. Also known as pervious pipe systems, exfiltration systems and percolation drainage systems.

Permeable Pavement – Alternative to traditional pavement, allows precipitation falling on the surface to infiltrate through the surface into an underlying stone reservoir and, where suitable conditions exist, into the native soil. Includes permeable interlocking concrete pavers, plastic or concrete grid systems, pervious concrete, and pervious asphalt.

Infiltration Chambers – Below-ground chambers with permeable bottoms, designed to temporarily hold stormwater and allow it to slowly seep into the ground.

Boulevard Tree Pits – Includes Silva Cells (has storage but not a drainage course layer). Silva Cells use soil volume to support large tree growth and provides stormwater management through absorption, evapotranspiration, and interception.

Rain Gardens – planted installations designed to capture surface runoff in an amended soil. Usually used to capture roof, lawn, and driveway runoff from low to medium density residential lots.

Green Roofs – roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane.

Oil-Grit Separator – Systems designed to remove trash, debris, and some amount of sediment, oil, and grease from stormwater runoff based on the principles of sedimentation for the grit and phase separation for the oil.

Downspout Disconnect – residents disconnect downspouts from the municipal sewer system and redirecting roof runoff to a pervious surface, most commonly a lawn.

Roof-top Storage – using flat building roofs (generally large flat commercial and industrial rooftops) to store runoff to reduce peak flow rates to storm sewer systems

Cisterns – tank used to store rainwater (typically roof runoff) for later use.

Land Retirement – rural cropland left fallow for at least part of the year. Usually involves compensation (payment) to the landowner/farmer.

Constructed Wetland – converting land into a vegetated area such as a marsh or swamp where the soil is saturated for part of the year, used to treat and store stormwater. May offer added pollutant removal benefits due to enhanced biological uptake and filtration effects of the vegetation.

Rural Forestry – tree planting on rural lands.

Afforestation – the process of planting tracks for areas of trees on land that have limited trees or are void of trees

SWM Ponds (Wet) – Wet stormwater management ponds have a permanent pool of water, designed to reduce peak flows and provide both water quality and quantity control. Added storage allows more time for sediment and contaminants to settle out as water is gradually released to nearby streams.

SWM Ponds (Dry) – Flood control structures used to accommodate occasional excess overflow, can be integrated into the landscape as useful, accessible public space.

Hybrid Wet Pond/Wetlands – consist of a wet pond element and a wetland element, connected in series. The deep water component will be least impacted by winter/spring conditions and the wetland component provides enhanced biological removal during summer months.

APPENDIX 5

Cost Function Report: Proposed Cost Curves

Contents

INTRODUCTION

This report documents findings of work completed on the costs of SWM measures. Cost relationships are provided for capital, operating and maintenance (OM) and total costs. OM and total costing are presented as the net present value of costs over a 30-year time horizon estimated at a nominal discount rate of 5% and annual inflation of 3%.

These relationships are formulated as cost functions that vary in complexity based on the measure in question. The following equations represent the range of cost relationships presented below, where X represents a measure of project scale and a and b are coefficients:

	Unit cost (U)	Total Cost (T)
Simple	U = a	T = a*X
Linear	U = a + b/X	T = a*X +b
Exponential	$U = aX^b$	$T = aX^{b+1}$

The project scale variable, X, in these equations is the surface area of the measure in question in most cases; for example, the area occupied by an infiltration chamber installation or a rain garden. For three SWM measures--cisterns, wet ponds and dry ponds—X is a measure of volume.

In the case of measures having a linear cost function, a simplified total cost function is determined by setting X at a representative scale, X': T = a'*X where a' = (a + b/X').

Cost functions are presented for 17 measures in this report. For 9 of the measures, cost functions are based on conceptual design and costing using the STEP costing tool. This tool enables pre-feasibility level costing of SWM measures based on basic information on cost drivers such as drainage area, soil type and performance targets. Costs developed with the tool are converted into parametric cost curves using regression analysis. Goodness of fit statistics for the regressions are not provided below but plots are provided of costs determined with the STEP tool and the costs estimated with the regression equation. In most cases, r^2 values exceeded 0.99 and the lowest was 0.97.[1] Coefficients generated using regression analysis are reported to 5 significant digits.

Costing for the 6 remaining measures is based on simple conceptual designs and costing, previously published cost curves or actual cost date provided by area municipalities.

Significant property value differentials exist across watershed municipalities. These costs are not accounted for in the cost functions and must be added to project costs to provide total costs. Land values are provided in the following table:[2]

	Newmarket + Aurora	**E. Gwillimbury + Stouffville**
Agricultural land	na*	$31/ m^2$
ICI-RES	$706/m^2$	$124/ m^2$

* Only one observation, insufficient to estimate a representative Ag. value

[1] Full regression results are available upon request.
[2] Equitable Responsibility for Transformative Design: *Analysis Of Land Value Data*, 24 July 2019

The report provides final cost curves to be used with the SUSTAIN model. The cost functions may be revised in the future in response to new cost data or reviews of the STEP costing tool.

COSTING FOR MEASURES INCLUDED IN THE STEP COSTING TOOL

BIORETENTION

Bioretention (BR) design based on drainage area (DA), soil infiltration rate (IR), and the design type (a function of IR). A required storage volume per unit DA determines the surface area.

ASSUMED DESIGN:

- Square bioretention area adjacent to paved area, bordered by curb with curb inlets.
- Drainage area to surface area ratio = 15:1
- Water Quality Volume Requirement = 45 m^3/ha
- Options: (1) No underdrain, Native soil infiltration rate >=15 mm/hr; (2) With underdrain, Native soil infiltration rate <15 mm/hr
- Filter media = designed bioretention soil, Filter Media Depth = 0.75 m, Mulch depth = 0.075 m.
- 50 mm clear stone storage zone below filter media with a partial infiltration design, void ratio = 0.40, clear stone depth based on design maximum drainage period, infiltration rate divided by a safety factor of 2.5 and the stone void ratio
- Design ponding depth = 0.2 m, overflow connection to an existing manhole.
- Excludes land cost

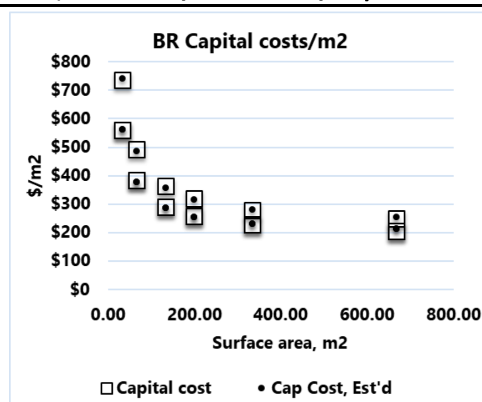
Storage volume: (1) No underdrain: 0.43 m^3 per m^2 of surface area; (2) With underdrain: 0.65 m3 per m2 of surface area

COST COEFFICIENTS (linear cost function based on facility surface area, m2: cost/m2 = a + b/SA)

CAPITAL

Unit costs, $/m2 (plotted to the left)	
No underdrain	194.71 + 12,328 * (1/area)
With underdrain	230.75 + 17,020 * (1/area)
Total costs ($s)	
No underdrain	12,328 + 194.71 * area
With underdrain	17,020 + 230.75 * area
Simplified total cost*	
No underdrain	219.36 * area
With underdrain	264.79 * area

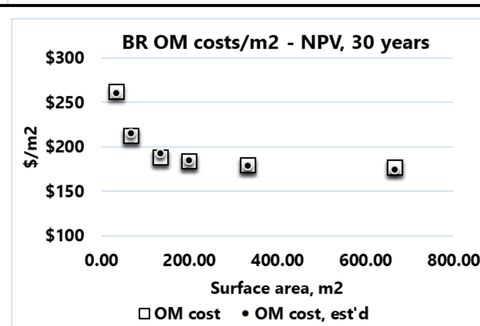
*area set to 500 m2 to determine coefficient value



OPERATING AND MAINTENANCE

Unit costs, $/m2 (plotted to the left)	
With & without underdrain	169.56 + 3,038.9 * (1/area)
Total costs ($s)	
With & without underdrain	3,038.9 + 169.56 * area
Simplified total cost*	
With & without underdrain	175.64 * area

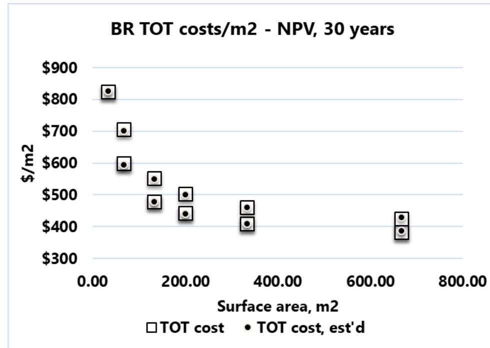
*area set to 500 m2 to determine coefficient value



TOTAL LIFE CYCLE COSTS

Unit costs, $/m2 (plotted to the left)	
No underdrain	364.27 + 15,367 * (1/area)
With underdrain	400.31 + 20,059 * (1/area)
Total costs ($s)	
No underdrain	15,367 + 364.27 * area
With underdrain	20,059 + 400.31 * area
Simplified total cost*	
No underdrain	395.00 * area
With underdrain	440.43 * area

*area set to 500 m2 to determine coefficient value



PERFORATED PIPES

Perforated pipes (PPi, called infiltration trench in STEP tool) – design based on DA, IR, and rainfall capture target (R). An estimate of required storage volume determines the length of the perforated pipe.

ASSUMED DESIGN:

- One inlet location (manhole), Trench Depth = 1.0 m, Trench width = 1.0 m.
- Drainage area to surface area ratio = 20:1
- Rainfall capture target = 25 mm
- Options: (1) Clean drainage only, no pre-treatment; (2) Includes road drainage, pre-treatment with an oil grit separator (OGS)
- 50 mm clear stone storage zone, void ratio = 0.40,
- Trench length based on storage volume required for rainfall capture and storage capacity of stone.
- Excludes land cost

Storage volume = 0.44 m3 /m2 surface area

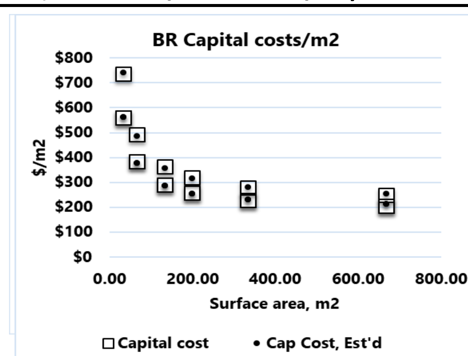
Add $100 to the **total** capital cost and NPV cost for residential applications to account for the cost of redirecting downspouts (see downspout redirect below).

COST COEFFICIENTS (linear cost function based on facility surface area, m2: cost/m2 = a + b/SA)

CAPITAL

Unit costs, $/m2 (plotted to the left)
320.66 + 11,374 * (1/area)
Total costs ($s)
11,374 + 320.66 * area
Simplified total cost*
343.41 * area

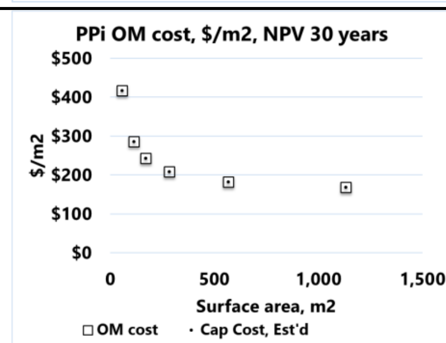
*area set to 500 m2 to determine coefficient value



OPERATING AND MAINTENANCE

Unit costs, $/m2 (plotted to the left)
156.06 + 14,731 * (1/area)
Total costs ($s)
14,731 + 156.06 * area
Simplified total cost*
185.52 * area

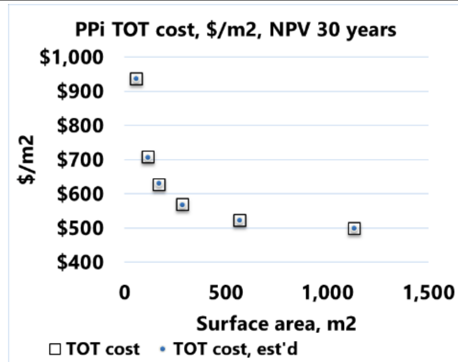
*area set to 500 m2 to determine coefficient value



TOTAL LIFE CYCLE COSTS

Unit costs, $/m2 (plotted to the left)
476.72 + 26,105 * (1/area)
Total costs ($s)
26,105 + 476.72 * area
Simplified total cost*
528.93 * area

*area set to 500 m2 to determine coefficient value



PERMEABLE PAVEMENT

Permeable pavement (PPa) are design based on total and impermeable DA, IR, and R. An estimate of required storage volume determines the depth of the storage bed. An underdrain is added if there is poor soil drainage (<15 mm/hr).

ASSUMED DESIGN:

- No drainage from outside the treated parking lot area.
- Options: (1) With underdrain, native soil infiltration rate <15 mm/hr; (2) No underdrain, Native soil infiltration rate >=15 mm/hr
- Rainfall capture target = 56 mm
- Minimum sub-base depth (50 mm dia clear stone) = 0.2 m*
- Base depth (20 mm clear stone) = 0.1 m, Bedding depth (2-5 mm stone) = 0.05 m, Underdrain Diameter = 150 m, Height of pavers = 80 mm.
- Storage zone void ratio = 0.40.
- Excludes land cost.

Storage volume = 0.22 m3 per m2 of surface area (150 mm underdrain has minimal impact on storage volume)

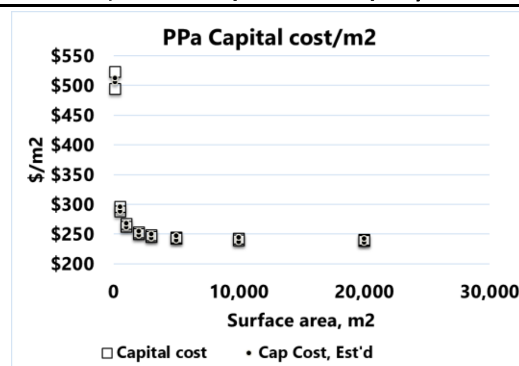
* Costs do not change until R is increased to >89 mm since the minimum sub-base depth of 0.2 m provides enough storage for up to this amount of rain.

COST COEFFICIENTS (linear cost function based on facility surface area, m2: cost/m2 = a + b/SA)

CAPITAL

Unit costs, $/m2 (plotted to the left)	
No underdrain	234.86 + 27,088 * (1/area)
With underdrain	241.73 + 27,088 * (1/area)
Total costs ($s)	
No underdrain	27,088 + 234.86 * area
With underdrain	27,088 + 241.73 * area
Simplified total cost*	
No underdrain	240.27 * area
With underdrain	247.15 * area

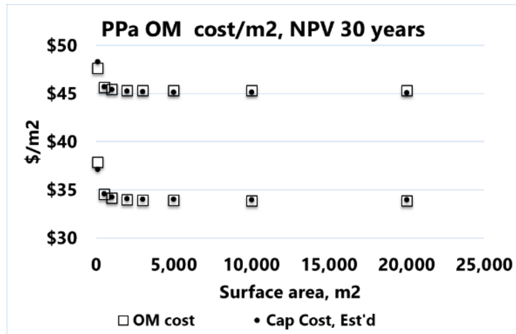
*area set to 500 m2 to determine coefficient value



OPERATING AND MAINTENANCE

Unit costs, $/m2 (plotted to the left)	
No underdrain	33.955 + 321.19 * (1/area)
With underdrain	45.101 + 321.19 * (1/area)
Total costs ($s)	
No underdrain	321.19 + 33.95 * area
With underdrain	321.19 + 45.10 * area
Simplified total cost*	
No underdrain	34.019 * area
With underdrain	45.165 * area

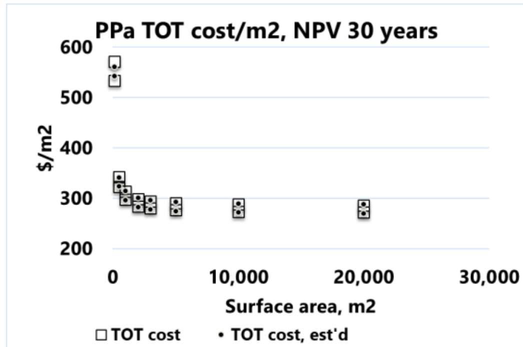
*area set to 500 m2 to determine coefficient value



TOTAL LIFE CYCLE COSTS

Unit costs, $/m2 (plotted to the left)	
No underdrain	268.81 + 27,410 * (1/area)
With underdrain	286.83 + 27,410 * (1/area)
Total costs ($s)	
No underdrain	27,410 + 268.81 * area
With underdrain	27,410 + 286.83 * area
Simplified total cost*	
No underdrain	274.29 * area
With underdrain	292.31 * area

*area set to 500 m2 to determine coefficient value



INFILTRATION CHAMBER

Costing for Infiltration Chambers (IC) is based on two alternative approaches used for design: (a) Based on a specified ratio of DA to the IC surface area (SA). The SA determines the number of chambers and total storage volume. (b) Based on R which determines required storage volume and SA. An OGS is added if there is road drainage.

ASSUMED DESIGN:

- Designed to receive drainage from roof and parking lot area.
- Options: (1) roof drainage only, no pre-treatment with an oil grit separator (OGS), (2) Roof and pavement drainage, pre-treatment with an OGS
- Rainfall capture target = 25 mm
- Length of the IC area (determines IC column length) = 15 m, width determined by required number of rows of chambers.
- Total depth of chambers and clear stone bedding = 1.1 m, Fill depth below asphalt = 0.39 m, Bedding depth below and above chambers (50 mm clear stone) = 0.1524 m,
- Chamber dimensions: height= 0.762, width = 1.295 m, length = 2.169 m, Void ratio = 0.40, Storage volume of a single chamber = 1.39 m3
- Storage zone void ratio = 0.40.
- Excludes land cost.

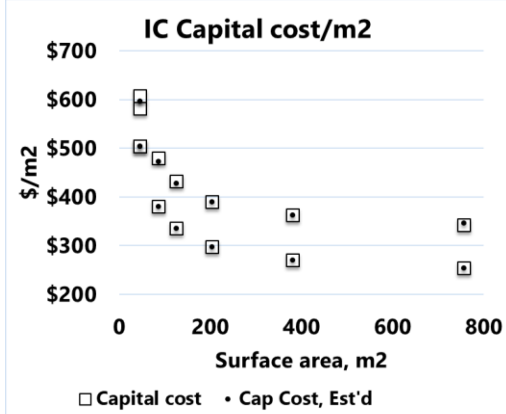
Storage volume = 0.67 m3 per m2 of surface area.

COST COEFFICIENTS (linear cost function based on facility surface area, m2: cost/m2 = a + b/SA)

CAPITAL

Unit costs, $/m2 (plotted to the left)	
No underdrain	238.06 + 12,141 * (1/area)
With underdrain	330.97 + 12,141 * (1/area)
Total costs ($s)	
No underdrain	12,141 + 238.06 * area
With underdrain	12,141 + 330.97 * area
Simplified total cost*	
No underdrain	262.34 * area
With underdrain	355.25 * area

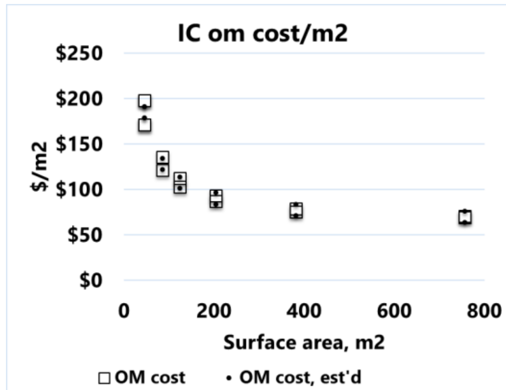
*area set to 500 m2 to determine coefficient value



OPERATING AND MAINTENANCE

Unit costs, $/m2 (plotted to the left)	
No underdrain	68.922 + 5,581.3 * (1/area)
With underdrain	56.331 + 5,581.3 * (1/area)
Total costs ($s)	
No underdrain	5,581.3 + 68.922 * area
With underdrain	5,581.3 + 56.331 * area
Simplified total cost*	
No underdrain	80.084 * area
With underdrain	67.493 * area

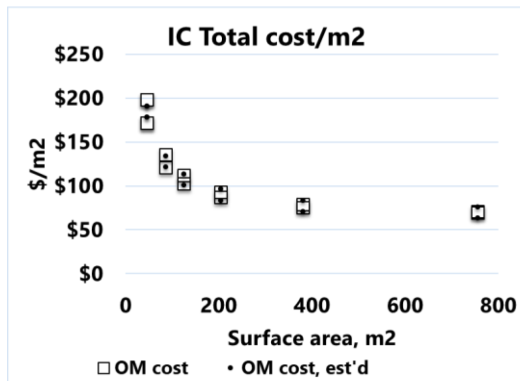
*area set to 500 m2 to determine coefficient value



TOTAL LIFE CYCLE COSTS

Unit costs, $/m2 (plotted to the left)	
No underdrain	306.98 + 17,722 * (1/area)
With underdrain	387.30 + 17,722 * (1/area)
Total costs ($s)	
No underdrain	17,722 + 306.98 * area
With underdrain	17,722 + 387.30 * area
Simplified total cost*	
No underdrain	342.43 * area
With underdrain	422.74 * area

*area set to 500 m2 to determine coefficient value



RAIN GARDEN

Rain Gardens (RG) design is based on DA and a maximum DA/SA ratio using the STEP costing tool LID feature called a vegetated filter strip.

ASSUMED DESIGN:

- Rectangular garden area, Length to width ratio = 5:1.
- Adjacent to road with added curbs and curb inlets. Outlet by culvert to storm sewer.
- Planted with an herbaceous native seed mix plus 50% coverage with trees and shrubs.
- Drainage area to surface area ratio = 10:1
- Compost amended native topsoil, no filter Media.
- Excludes land cost

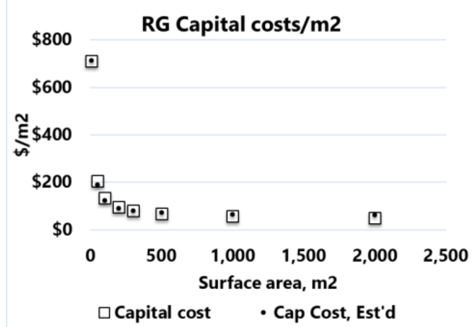
Add $100 to the total capital cost and NPV cost for residential applications to account for the cost of redirecting downspouts (see downspout redirect below).

COST COEFFICIENTS (linear cost function based on facility surface area, m2: cost/m2 = a + b/SA)

CAPITAL

Unit costs, $/m2
59.125 + 6,555.0 * (1/area)
Total costs ($s)
6,555.0 + 59.125 * area
Simplified total cost*
80.975 * area

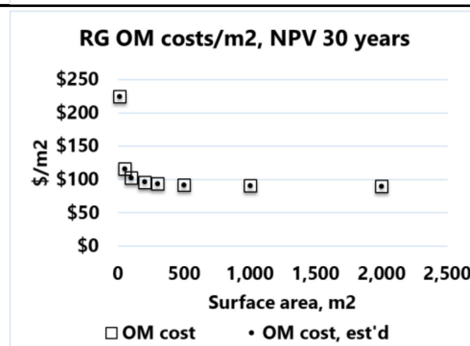
*area set to 300 m2 to determine coefficient value



OPERATING AND MAINTENANCE

Unit costs, $/m2
89.683 + 1,352.6 * (1/area)
Total costs ($s)
1,352.6 + 89.683 * area
Simplified total cost*
94.192 * area

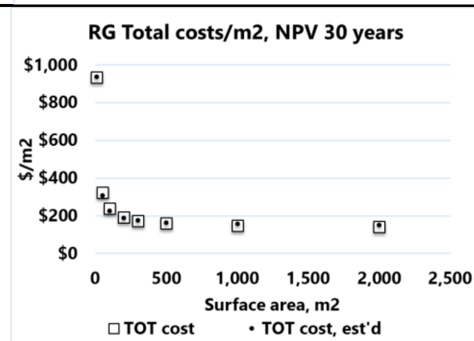
*area set to 300 m2 to determine coefficient value



TOTAL LIFE CYCLE COSTS

Unit costs, $/m2
148.81 + 7,907.6 * (1/area)
Total costs ($s)
7,907.6 + 148.81 * area
Simplified total cost*
175.17 * area

*area set to 300 m2 to determine coefficient value



GREEN ROOF

Green roofs **(GR) D**esign is based on roof area. Cost drivers include depth of bedding, planting material and building height.

ASSUMED DESIGN:

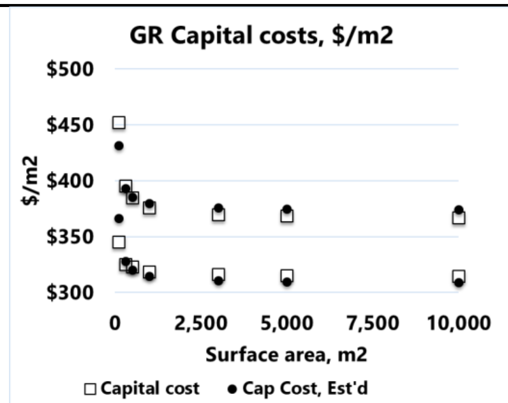
- Square roof, EPDM membrane.
- 6" inches of growth medium planted with sedum mats.
- Options: (1) Building height = 1 to 5 stories (system assumed not to use an irrigation system)' (2) Building height > 5 stories (system assumed to use an irrigation system)
- Roof slope <= 2%,
- Land cost not relevant.

COST COEFFICIENTS (linear cost function based on facility surface area, m2: cost/m2 = a + b/SA)

CAPITAL

Unit costs, $/m2 (plotted to the left)	
Bldg 1-5 stories	308.62 + 5,797.2 * (1/area)
Bldg > 5 stories	373.80 + 5,797.2 * (1/area)
Total costs ($s)	
Bldg 1-5 stories	5,797.2 + 308.62 * area
Bldg > 5 stories	5,797.2 + 373.80 * area
Simplified total cost*	
Bldg 1-5 stories	314.42 * area
Bldg > 5 stories	379.59 * area

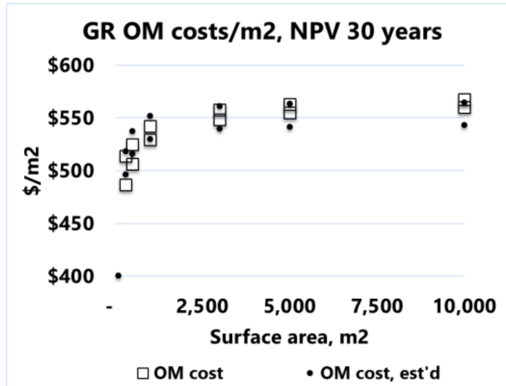
*area set to 1000 m2 to determine coefficient value



OPERATING AND MAINTENANCE

Unit costs, $/m2 (plotted to the left)	
Bldg 1-5 stories	566.16 -14,383 * (1/area)
Bldg > 5 stories	544.65 -14,383 * (1/area)
Total costs ($s)	
Bldg 1-5 stories	-14,383 + 566.16 * area
Bldg > 5 stories	-14,383 + 544.65 * area
Simplified total cost*	
Bldg 1-5 stories	551.78 * area
Bldg > 5 stories	530.27 * area

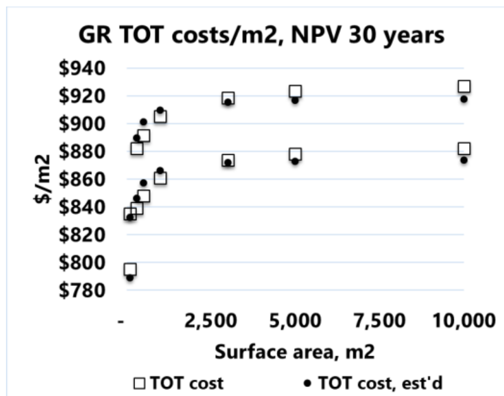
*area set to 1000 m2 to determine coefficient value



TOTAL LIFE CYCLE COSTS

Unit costs, $/m2 (plotted to the left)	
Bldg 1-5 stories	874.78 – 8586.0 * (1/area)
Bldg > 5 stories	918.45 – 8586.0 * (1/area)
Total costs ($s)	
Bldg 1-5 stories	-8586.0 + 874.78 * area
Bldg > 5 stories	-8586.0 + 918.45 * area
Simplified total cost*	
Bldg 1-5 stories	866.19 * area
Bldg > 5 stories	909.86 * area

*area set to 1000 m2 to determine coefficient value



CISTERN

Cisterns (CI) design is based on roof area and average daily water use. Cisterns are referred to as rainwater harvesting in the Step costing tool.

ASSUMED DESIGN:

- System assumes rainwater harvesting for non-potable reuse.
- Includes below-ground concrete storage tank, tank water level controls, a make up water system, filters and backflow preventers, and associated plumbing.
- Storage tank size is estimated based on water demand and can be related to roof area as follows:

  Tank size (m3) = 3,114.5 ln(roof area, m2) – 10,614
- Demand set at a maximum of 3,000 l/d and roof drainage area varied up to 3000 m2. This configuration maximizes tank size but does not optimize the system for water demand.
- Excludes land cost

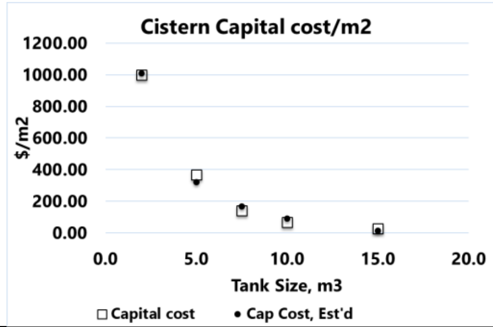
Available tank storage will depend on the period between rain events and rate of tank draw down (assumed to be 3.0 m^3/day).

COST COEFFICIENTS (linear cost function based on facility tank volume, m3: cost/m3 = a + b/V)

CAPITAL

Unit costs, $/m³
-137.37 + 2,289,600 * (1/m³)
Total costs ($s)
2,289,600 + -137.37 * m³
Simplified total cost*
228,820 * m³

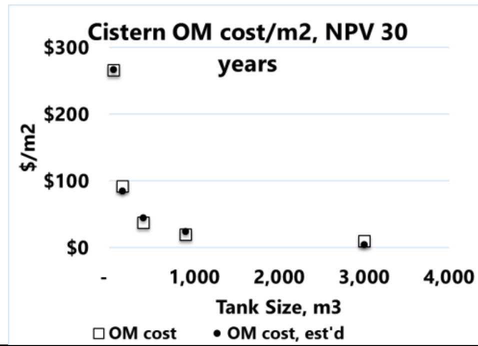
*area set to 10 m3 to determine coefficient value



OPERATING AND MAINTENANCE

Unit costs, $/m³
-35.822 + 606,280 * (1/ m³)
Total costs ($s)
606,280 -35.822 * m³
Simplified total cost*
60,592 * m³

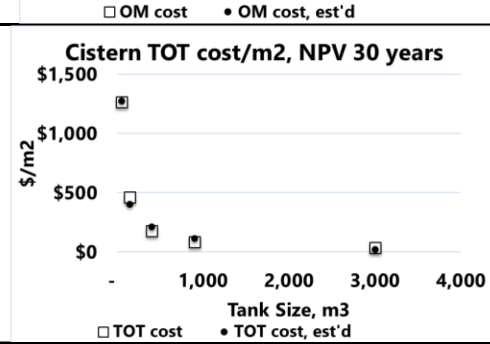
*area set to 500 m2 to determine coefficient value



TOTAL LIFE CYCLE COSTS

Unit costs, $/m³
-173.19 + 2,895,900 * (1/ m³)
Total costs ($s)
2,895,900 - 173.19 * m³
Simplified total cost*
289,410 * m³

*area set to 500 m2 to determine coefficient value



WET AND HYBRID SWM PONDS

Wet, hybrid SWM Ponds (WP) feature a forebay, permanent pool with an optional wetland area, and an active storage area. Design is based primarily on drainage area plus design standards for WQ storage and active storage for control of sediment from erosion and flood flows.

ASSUMED DESIGN:

- Pre-treatment with forebay. Rectangular pond with length to width ratios for the pond and forebay of 4:1. Side and end buffers of 10 m. Wet pond permanent pool depth = 1.5 m, Wetland depth = 0.2 m, Active storage depth = 1.5 m, Freeboard = 0.3 m. Side slopes for forebay, berm and permanent pool (width:depth) = 3:1.
- Impervious portion of drainage area = 30%.
- WQ Protection set at 'normal' (70% long-term S.S. removal).
- Water quality storage requirement determines the overall pond volume based on WQ protection targets and equals 71.5 m3/ha for the assumed WQ target and impervious area (see figure in text box 1 on following page).
- Extended detention storage requirement is assumed to be 40 m3/ha. Permanent pool volume equals WQ storage requirement less detention storage.

- Pre-treatment forebay is 20% of the permanent pool volume. Riprap berm separates the forebay from the permanent pool.
- A shallow wetland area occupies 25% of the permanent pool area.
- No clay liner. Land cost excluded.

Modelling analysis should assure that estimated water storage requirements can be accommodated within the available parcel of land. Equations below enable estimation of pond dimensions based on WQ storage requirements (SR, m3) and the drainage area size (DA, ha):

$$SR = 71.5 \text{ m3/ha} * DA$$
$$SA = 1680.7 + 0.93664 * SR$$
$$TA = 2080.1 + 1.6964 * SA$$

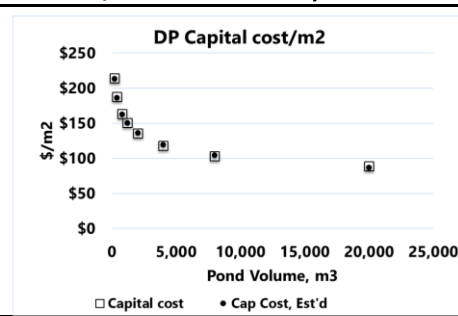
Where:
SA = Surface area of the pond's extended detention storage (m2)
TA = total facility area (m2)
Note:

- SA is determined by design standards. It cannot be estimated directly from SR and average depth since the average depth varies with overall size of the pond.
- TA is based on assumed buffers to the edge of the SA. This is flexible as it does not represent regulated design standards.

COST COEFFICIENTS (exponential cost function based on total pond volume, m3: cost = a*V^b)

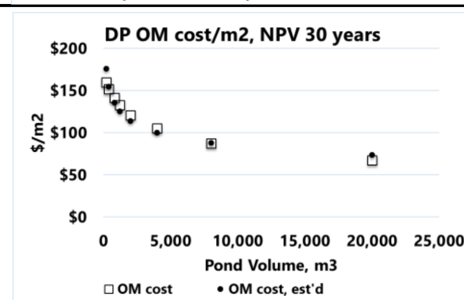
CAPITAL

Unit costs, $/m2
$597.67 * (m^3)^{-0.19438}$
Total costs ($s)
$597.67 * (m^3)^{0.80562}$
Simplified total cost
n.a.



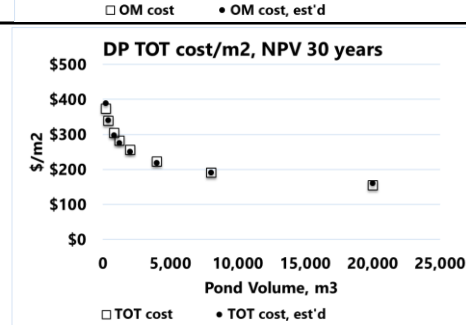
OPERATING AND MAINTENANCE

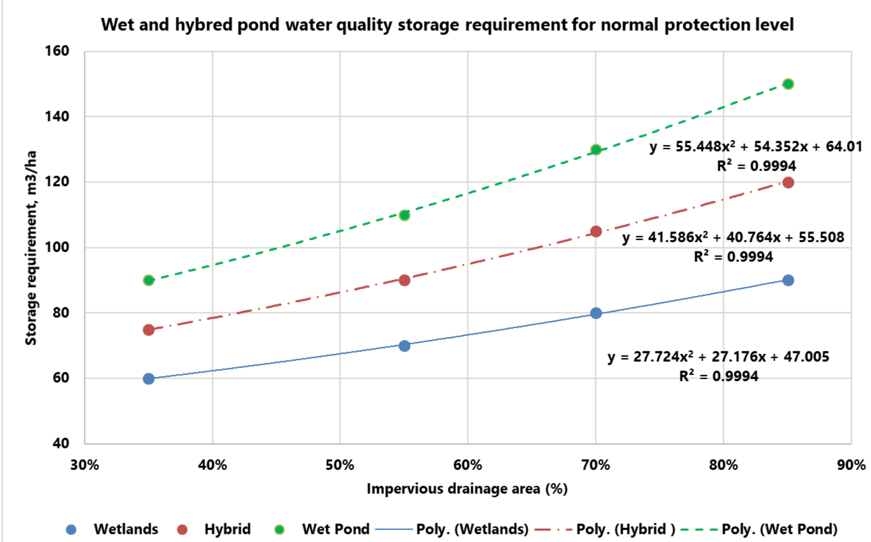
Unit costs, $/m2
$477.16 * (m^3)^{-0.18825}$
Total costs ($s)
$477.16 * (m^3)^{0.81175}$
Simplified total cost
n.a.



TOTAL LIFE CYCLE COSTS

Unit costs, $/m2
$1075.5 * (m^3)^{-0.19164}$
Total costs ($s)
$1075.5 * (m^3)^{0.80836}$
Simplified total cost
n.a.





Text box 1

Water quality storage requirements based on: MOE SW Management Planning & Design Manual, 2003 (Table 3.2 Water Quality Storage Requirements based on Receiving Waters).

Curves shown in the figure are estimated from data in Table 3.2.

DRY SWM PONDS

Dry SWM Ponds (DP) feature a forebay or OGS pre-treatment and an active storage area. Design is based primarily on drainage area plus design standards for flood flows and for active storage for control of sediment from erosion.

ASSUMED DESIGN:

- Pre-treatment with forebay. Rectangular pond with length to width ratios for the pond and forebay of 4:1. Side and end buffers of 10 m. Dry pond depth = 2.0 m, Freeboard above forebay = 0.3 m. Side slopes for forebay, berm and dry pond (width:depth) = 4:1.
- Impervious portion of drainage area = 30%.
- WQ Protection set at ‘basic’ (60% long-term S.S. removal).
- Water quality storage requirement determines the overall pond volume based on WQ protection targets and equals 57.3 m3/ha for the assumed WQ target and impervious area (see figure in text box 2 on following page).
- Extended detention storage requirement is assumed to be 40 m3/ha.
- Pre-treatment forebay is 20% of the permanent pool volume. Earthen berm separates the forebay from the permanent pool.
- No clay liner. Land cost excluded.

Modelling analysis should assure that estimated water storage requirements can be accommodated within the available parcel of land. Equations below enable estimation of pond dimensions based on WQ storage requirements (SR, m3) and the drainage area size (DA, ha):

$$SR = 57.3 \text{ m3/ha} * DA$$
$$SA = 508.64 + 0.57288 * SR$$
$$TA = 2333.5 + 2.2379 * SA$$

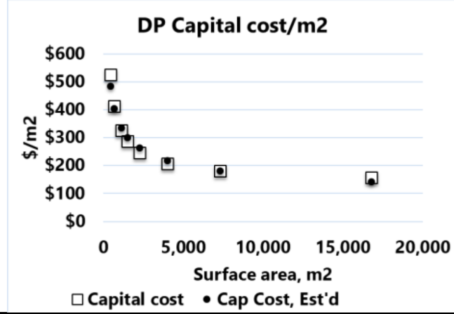
Where:
SA = Surface area of the pond’s storage requirement (m2)
TA = total facility area (m2)
Note:

- SA is determined by design standards. It cannot be estimated directly from SR and average depth since the average depth varies with overall size of the pond.
- TA is based on assumed buffers to the edge of the SA. This is flexible as it does not represent regulated design standards.

COST COEFFICIENTS (log functions on total pond volume, m3: cost = a*V^b)

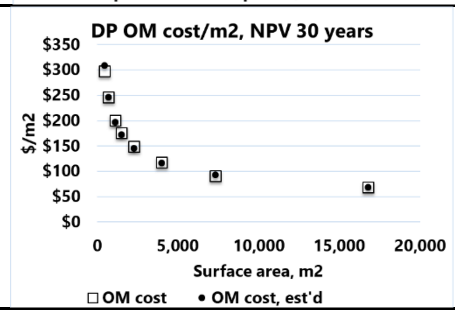
CAPITAL

Unit costs, $/m2
2182.8 * $(m^3)^{-0.26592}$
Total costs ($s)
2182.8 * $(m^3)^{0.73408}$
Simplified total cost
n.a.



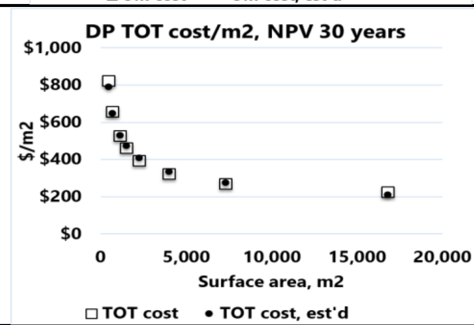
OPERATING AND MAINTENANCE

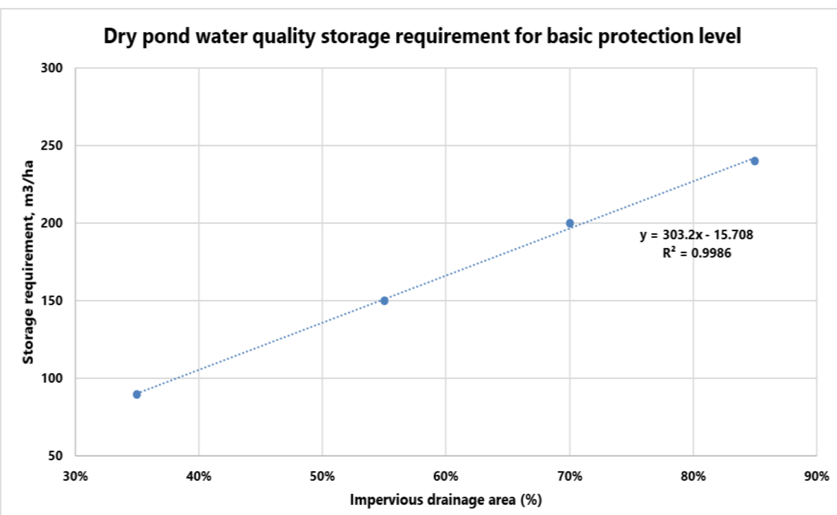
Unit costs, $/m2
1940.05 * $(m^3)^{-0.32479}$
Total costs ($s)
1940.05 * $(m^3)^{0.67521}$
Simplified total cost
n.a.



TOTAL LIFE CYCLE COSTS

Unit costs, $/m2
3992.9 * $(m^3)^{-0.28603}$
Total costs ($s)
3992.9 * $(m^3)^{0.71397}$
Simplified total cost
n.a.





Text box 2

Water quality storage requirements based on: MOE SW Management Planning & Design Manual, 2003 (Table 3.2 Water Quality Storage Requirements based on Receiving Waters).

Curve shown in the figure are estimated from data in Table 3.2.

COSTING FOR MEASURES NOT INCLUDED IN THE STEP COSTING TOOL

BOULEVARD TREE PITS

Assumes boulevard trees are planted below surface finishes using SILVA CELLS filled with amended native soil.

ASSUMED DESIGN:

Assume 30 m3 of soil volume per trees. Tree and grate costs not included as these costs are incurred even without SILVA CELLS.

Costing based on all-in costs cited in identified references.

Design assumptions:

- SILVA CELL dimensions are 24” wide x 48” long X 16” deep, 3 stacked SILVA CELLS provide 0.9 m3 of soil volume. Installation assumes 48” depth (3 cells deep).
- 30 m3 of soil required per tree or 16 m3 per tree if soil volume is shared by multiple trees. Costing here assumes multiple trees. Each installation requires 13.2 m2 per tree.
- Cells filled with a bioretention soil or native soil amended to perform in a comparable manner. Soil has a void ratio of 0.25
- A portion of the SILVA CELL installation, assumed to be 25%, is excavated and replaced every 20 years in conjunction with infrastructure maintenance work. Cells and soil are reused.
- Excludes land cost

Storage volume = 0.22 m3 /m2 surface area (48” depth, 25% void ratio)

COST CALCULATION

SOURCE	Capital cost ($2018)	Annual OM/ha
Adam Barkovitz, Program Manager Urban Forestry Renewal, Natural Heritage and Forestry, Environmental Services, York Region. Email September 18, 2019 4:45 PM	$378/Cell → $20,200/tree (no details provided on costing assumptions)	$76/Cell to remove and replace → $4,000/tree
An urban canopy to nurture a city's growth, Globe and Mail, Wendy Stueck, Published December 29, 2011updated May 8, 2018	$11,000 per tree (trees and grates not included)	na
Creating and Utilizing Mature Trees for On-Site Stormwater Management in Ultra Urban Sites, Deeproot (no date)	Lincoln Center Bosque, New York City - $11,500 (12.7 m3/tree) Sundance Square, Fort Worth, TX - $17,000 (22.5 m3/tree) Sugar Beach Toronto, ON - $20,800 (35 m3/tree)	na
Development Services Department, Engineering Services, City of Kitchener, 2018. *Design Brief, Ahrens Street West* and related tender documents. Facility includes perforated pipe drain and stone storage gallery below the SILVA cells.	Facility includes 17 trees in a 276 m2 bioretention facility designed using SILVA cells. Total cost $18,200/tree or $1120/m2	na

Cost Summary

Cost/ tree = $15,900, Cost/m2 = $1,200

OM cost / tree = $40.0, Cost/m2 = $3.0

Cost Coefficients

CAPITAL COST / m2	Annual OM / m2 /year		NPV OM cost / m2	LCC / m2
$1,200	$3		$70	$1,270

PERFORATED PIPE WITH BOULEVARD TREE PITS

This option combines the Perforated pipe (infiltration trench) with Boulevard trees in SILVA cells. The measures are assumed to be adjacent to each other and each measure occupies 50% of the total surface area.

CAPITAL

Unit costs, $/m2
760.33 + 5,687.0 * (1/area)
Total costs ($s)
5,687.0 + 760.33 * area
Simplified total cost*
771.70 * area

*area set to 500 m2 to determine coefficient value

OPERATING AND MAINTENANCE

Unit costs, $/m2
113.03 + 7,365.5 * (1/area)
Total costs ($s)
7,365.5 + 113.03 * area
Simplified total cost*
127.76 * area

*area set to 500 m2 to determine coefficient value

TOTAL LIFE CYCLE COSTS

Unit costs, $/m2
873.36 + 13,053 * (1/area)
Total costs ($s)
13,053 + 873.36 * area
Simplified total cost*
899.47 * area

*area set to 500 m2 to determine coefficient value

PUMPING STATION

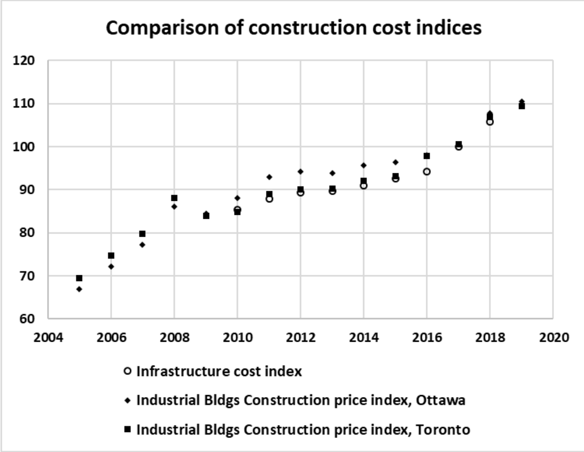
Pumping Stations are assumed to be installed as a separate facility linked to a storm water pond.

ASSUMED DESIGN:

Costing of pumping stations relies on cost curves for wastewater lift stations published in R.J. Burnside Associates Ltd, 2005. Water and Wastewater Asset cost Study, M0 03 5326 Ministry of Infrastructure Renewal. The original Burnside cost curve covered costs for pumps, building or manhole structures, a wetwell, valves, and electrical controls. It was based on curves fitted to actual project cost data using regression analysis. Two cost curves were provided, one for lift stations with capacity less than 500 L/second and a second for larger lift stations. The curves shown below combine results from these two curves for a range of pump capacities and update the estimated costs for inflation. New cost curves are estimated using regression analysis once again.

Burnside provides OM and rehabilitation costs as a percentage of capital costs as follows: OM = 4% of capital every year, Rehabilitation = 10% of capital every 10 years. These same values are used here.

Costs are updated to 2019 using the Statistics Canada industrial construction price index for Toronto. This choice of index was based on its close match to an infrastructure cost index for the available period of record. The infrastructure index itself did not cover the required period of time so could not be used.

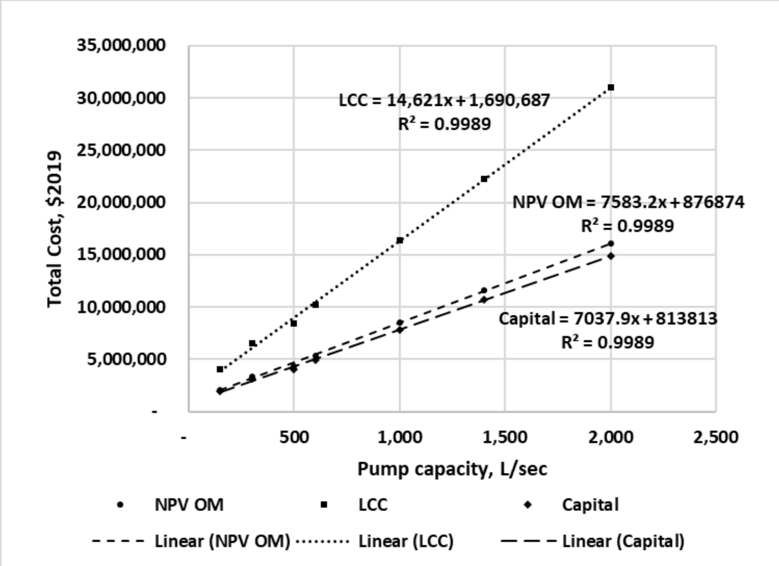


Total Cost curves: Curves are shown in the figure below.

Total capital costs ($s)
813,813 + 7,037.9 * L/sec

Total OM costs ($s)
876,874 + 7583.2 * L/sec

Total LCC costs ($s)
1,690,687 + 14,621 * L/sec



OIL-GRIT SEPARATOR

Oil-grit separator - OGS are included in the STEP tool for the design of infiltration chambers and infiltration trenches that receive road/parking lot runoff. This approach can be used for costing of OGS as a stand alone SWM measure.

Costing is based on OGS installation bids provided to area municipalities and the peak flow rate stipulated in product design specs. Four seta of cost data were compared: costs based on bids for EF, CDS and Vortec equipment as well as costs provided in the 2018 RSMeans heavy construction cost book. CDS bids were mid-range in this set of data and the costing here is based on CDS bids.

Annual OGS cleanout costs were based on cleanout service costs provided in the STEP LID costing tool.

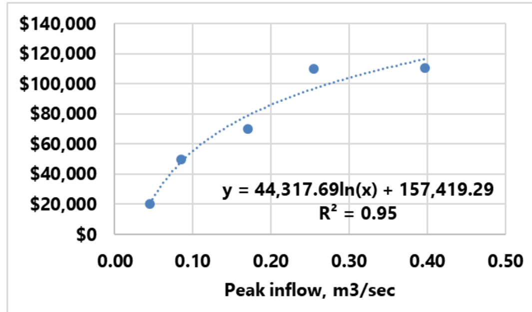
ASSUMED DESIGN:

Installation assumptions based on dimensions of CDS OGS models CDS2025-5, CDS3030-6, CDS4040-8, CDS5640-10 and CDS5653-10. Bid amounts were cited for equipment and installation and are assumed to include excavation, bedding, pipes, labour and other costs.

OGS sizing based on inflows, measured as m3/sec, and water quality targets (see Wash. State Dept of Ecology, April 2013, General Use Level Designation for Pre-treatment (Tss) And Pilot Use Level Designation for Oil Control for CONTECH Engineered Solutions CDS® System.)
Excludes land cost.

CAPITAL COSTS (based on a logarithmic functional form: C = A + B * ln(Q) WHERE Q = peak flow into OGS, m3/sec)

Total costs ($s)
157,419 + 444,318 * LN(m3/sec)

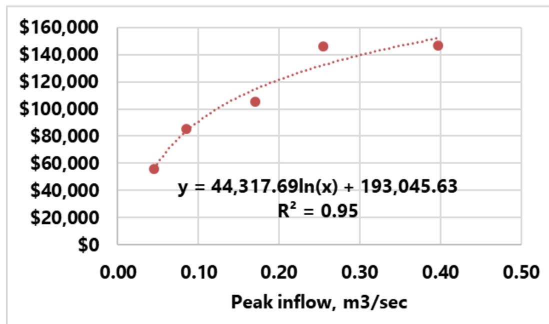


OM COSTS (fixed)

Annual OM	NPV OM cost
$1,578	$35,600

TOTAL LCC (based on a logarithmic functional form: C = A + B * ln(Q) WHERE Q = peak flow into OGS, m3/sec)

Total costs ($s)
193,046 + 444,318 * LN(m3/sec)



DOWNSPOUT REDIRECT

Downspout Redirect – Costing based on cost data for pilot projects.

ASSUMED DESIGN:
Easy – existing downspout turned towards grass or extended to direct the water to a good location for infiltration. This cost is added to ‘perforated pipes’ and ‘rain gardens’ in low to high density residential applications.
Excludes land cost.
(reference: Residential SWM pilot Project Downspout Redirection Project 2017, LRSCA)

COST CALCULATION

	Avg cost per disconnect	Storage provided, m3	Program admin. Cost, %	Total cost/m3
Difficult	$932.25	0.347	23%	$3,291
Easy	$100.00	0.380	0%	$263
Average	$516.13	0.364	11%	$1,777

Cost Coefficients (fixed)

CAPITAL COST	Annual OM*	NPV OM cost	LCC
$1,777	$18	$200	$2,177

* Assumed to be 0.5% of capital

LAND RETIREMENT

Land Retirement - This is assumed to be a long-term retirement (=> 5 years). Costing based on the rental value of land.

ASSUMED DESIGN: Land is assumed to be crop land that is rented on a long-term basis. The landowner is assumed to provide cleared land so that there is no initial capital investment for removal of structures or other improvements.

COST CALCULATION

Rental cost data (2019 prices):

SOURCE	Annual OM/ha	COMMENT
ALUS Canada	$500	Norfolk County
Brady Deaton Jr., March 2018. 2017 Farmland Value and Rental Value Survey Summary of Findings.	$260	York region
Brady Deaton Jr., March 2018. 2017 Farmland Value and Rental Value Survey Summary of Findings.	$230	Average of Peel, Simcoe and Durham
Estimated Rental Rate per acre, Province, CAR, CD, 1991-2016, 1991-2016, Census of Agriculture, Statistics Canada	$430	York region

The Deaton data provides median values for average quality farmland. These values, reported for 30 Counties, indicate that rental rates are higher away from large urban centres. This explains the differential between Norfolk and the municipalities just north of the GTA area.

The Census figure is a mean reflecting the value of more productive lands.

The median values are most representative of costs for land set-asides.

Cost Summary:

Assumed cost for project analysis: $250/ha/year

Cost Coefficients

CAPITAL COST	Annual OM / m2	NPV OM cost / m2	LCC / m2
n.a.	$0.025	$0.60	$0.60

CONSTRUCTED WETLAND

Constructed Wetlands - Costing based on the opportunity cost of land (i.e. net value for crop production or pasture), any initial capital expenditures (e.g. fencing, land forming, removal of invasives, planting …) and ongoing OM (monitor for invasives, water control during establishment, replacement planting …)

ASSUMED DESIGN:

Rural wetland projects – land clearing to remove unwanted vegetation, fences and other structures; minimal land forming; located on previously humic lands with an existing seedbank of wetland vegetation so planting is not required. If planting is required, plants are acquired from proximate wetlands.

Urban wetland projects – Typically a component of a stormwater pond involving detailed design, land forming and planting.

COST CALCULATION

Wetland project cost data (2019 prices):

SOURCE	CAPITAL COST PER HA*	Annual OM/ha**
RURAL		
Ducks Unlimited, email communication, Michael Williams, DU, 2019-07-08, 1:32 p.m.	$32,100-37,100/acre $12,300-$14,800/acre added for planting	na
ALUS Canada	$33,200	$500
Tyndall & Bowman, 2016, 2016 Cost Sheet for Constructed Wetlands.pdf	$35,000	na
Pattison, Yang, Liu and Gabor, 2011, duc_blackwater_case.pdf	$31,900	na
URBAN		
Paattison, Gabor, Scott 2013, *A Business Case for Wetland Conservation and Restoration in the Settled Areas of Alberta Vermilion River Subwatershed Case Study* https://www.ducks.ca/assets/2012/06/DUC-AB-Business-Case_Final.pdf	$68,800	$860
Ducks Unlimited, email communication, Michael Williams, DU, 2019-07-08, 1:32 p.m.	$168,000	na
* Does not include cost of land ** Includes annual cost for land lease		

Cost Summary:

AREA	CAPITAL COST PER HA*	Annual OM/ha/year
Rural	$32,000	$500**
Urban	$69,000	$900*
* Does not include cost of land or land lease ** Includes annual cost for land lease		

Cost Coefficients

	CAPITAL COST/ m2	Annual OM / m2	NPV OM cost / m2	LCC / m2
Rural	$3.20	$0.050	$1.130	$4.330
Urban	$6.90	$0.090	$2.030	$8.930

RURAL AFFORESTATION

Rural afforestation costing is based on the value of land (i.e. net value for crop production or pasture), initial capital expenditures (e.g. fencing, land forming, removal of invasives, tree planting …)

ASSUMED DESIGN: Mix of species with planting density of about 2000/ha.

COST CALCULATION

Costing data:

SOURCE	CAPITAL COST PER HA, $2019	COMMENT
D. N. Bird and Eric Boysen, 2007. The Carbon Sequestration Potential from Afforestation in Ontario, RESEARCH INFORMATION NOTE #5, Applied Research and Development Branch, Ontario MNR	$2900	Separate planting schemes for 6 zones in Ont. using hard- and softwoods and hybrid poplar, planting densities from 800 to 2700/ha
N.Gale, J.Trant, T.Schiks, J.L'Ecuyer, C. Jackson, N.Thevasathan, A.Gordon, 2013. An economic analysis of afforestation as a carbon sequestration strategy in southwestern Ontario, Canada. Studies by Undergraduate Researchers at Guelph, Volume 6 • Issue 2 • Winter 2013 School of Env. Sciences, Ontario Agricultural College, University of Guelph, Guelph, ON Canada	$4500	Three planting schemes for Wellington Co. using a mix of species at 2000 plants/ha.
Elaine Anselmi, 2019. How millions of Ontario trees escaped Doug Ford's cuts. TVO, June 6, 2019	$4600	no design details provided
A.Corlett, P.Gagnon, T.Clark and M.Penner, 2012. Alternative Approaches to Afforestation, Discussion Paper. TREES ONTARIO	$3500 to $4000	5 conventional and rehabilitation design scenarios, planting of seeds and seedlings, 988 to 2200 trees/ha, rehabilitation design includes herbaceous plants and land forming to restore hydrologic function
LRSCA forest services, 26 July 2019, teleconference Costs include: planning, site assessment (soil survey, ground water …), funding procedures, administration, purchase and delivery of stock, cold storage for stock, site labor, use and maintenance of vehicles and other equipment, occasionally follow up monitoring. Urban projects can cost 10 times more per tree than rural projects	$5600 to $6900/ha. $4600-$5000/ha	Hand planted Tractor mounted planter
Alus	$3700	Norfolk Co. No planting details.

Cost Summary (average):

CAPITAL COST PER HA	Annual OM/ha/year*
$4300	$500
* Based on wetland OM cost, includes land rental	

Cost Coefficients

CAPITAL COST/m2	Annual OM / m2	NPV OM cost / m2	LCC / m2
$0.43	$0.050	$1.130	$1.560

Appendix 6

WATERSHED-WIDE SCM IMPLEMENTATION RECIPE: Achieving 40% phosphorus reduction at East Holland Landing

- Aurora
- East Gwillimbury
- King
- Newmarket
- Whitchurch-Stouffville

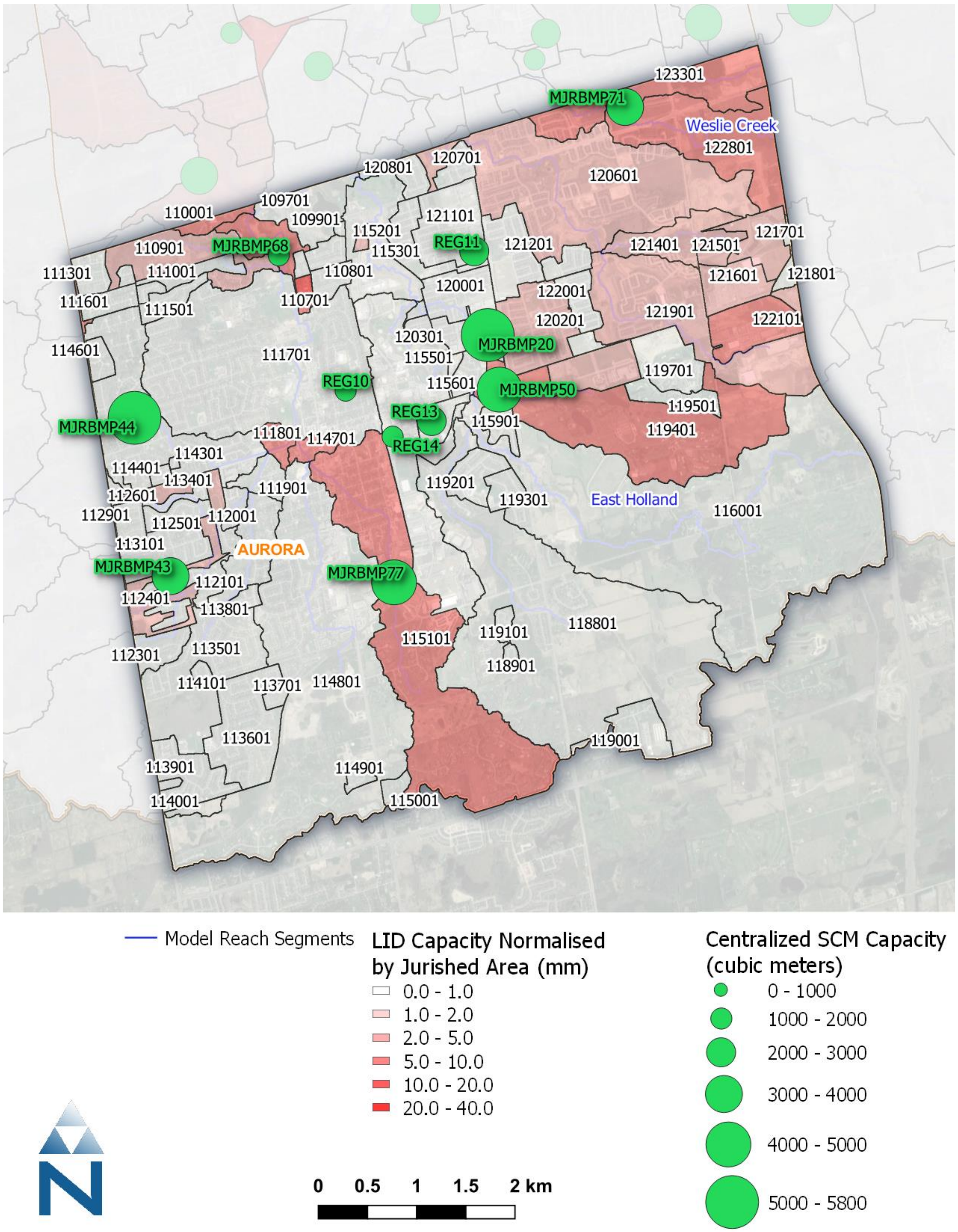


Figure 1. Heat map of SCM implementation for Aurora to achieve basinwide 40% phosphorous reduction at Holland Landing.

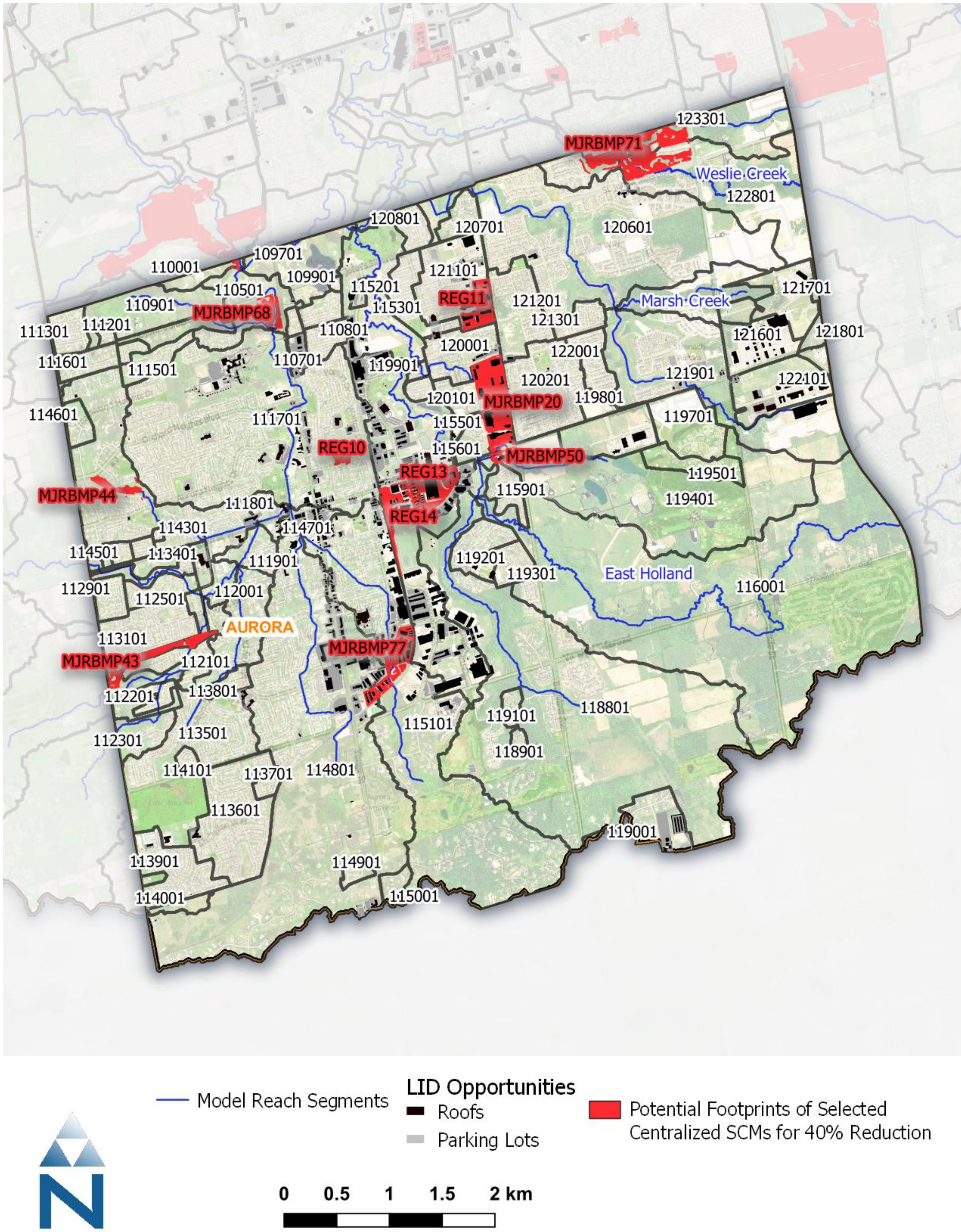


Figure 2. SCM footprint locations in <u>Aurora</u> to achieve basinwide 40% TP reduction at Holland Landing.

Table 1. SCM Implementation Recipe for Aurora to Achieve Basinwide 40% TP Reduction at Holland Landing

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Green Street (Boulevard Tree Pits with Infiltration Trench)	Future Growth (Bioretention)	Offline Facility (Hybrid Pond)	Inline Facility (Hybrid Pond)
109601	AURORA	Capacity	0	0	0	0	0	0
109601	AURORA	Footprint	0	0	0	0	0	0
109601	AURORA	Cost	0	0	0	0	0	0
109701	AURORA	Capacity	146	5	2	93	47	0
109701	AURORA	Footprint	289	10	2	202	75	0
109701	AURORA	Cost	8,306	237	40	8,029	0	0
109801	AURORA	Capacity	0	0	0	0	0	0
109801	AURORA	Footprint	0	0	0	0	0	0
109801	AURORA	Cost	0	0	0	0	0	0
109901	AURORA	Capacity	0	0	0	0	0	0
109901	AURORA	Footprint	0	0	0	0	0	0
109901	AURORA	Cost	0	0	0	0	0	0
110001	AURORA	Capacity	369	0	0	0	369	0
110001	AURORA	Footprint	598	0	0	0	598	0
110001	AURORA	Cost	0	0	0	0	0	0
110501	AURORA	Capacity	853	10	164	347	273	0
110501	AURORA	Footprint	1,495	22	216	755	471	0
110501	AURORA	Cost	36,785	525	4,050	30,084	0	0
110601	AURORA	Capacity	13	0	0	0	1	0
110601	AURORA	Footprint	8	0	0	0	1	0
110601	AURORA	Cost	470	0	0	0	0	0
110701	AURORA	Capacity	368	18	318	0	0	0
110701	AURORA	Footprint	477	40	420	0	0	0
110701	AURORA	Cost	9,963	942	7,866	0	0	0
110801	AURORA	Capacity	4	1	2	0	0	0
110801	AURORA	Footprint	6	3	3	0	0	0
110801	AURORA	Cost	118	61	57	0	0	0
110901	AURORA	Capacity	1,013	0	61	150	721	0
110901	AURORA	Footprint	1,676	0	83	325	1,225	0
110901	AURORA	Cost	17,200	0	1,253	12,963	0	0
111001	AURORA	Capacity	130	0	6	80	26	0
111001	AURORA	Footprint	238	0	8	175	46	0
111001	AURORA	Cost	7,734	0	122	6,968	0	0
111101	AURORA	Capacity	10	0	0	0	0	0
111101	AURORA	Footprint	5	0	0	0	0	0
111101	AURORA	Cost	372	0	0	0	0	0
111201	AURORA	Capacity	22	0	0	12	0	0
111201	AURORA	Footprint	31	0	0	25	0	0
111201	AURORA	Cost	1,391	0	0	1,009	0	0
111301	AURORA	Capacity	84	2	0	38	0	0
111301	AURORA	Footprint	110	5	0	82	0	0
111301	AURORA	Cost	4,993	116	0	3,272	0	0

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Green Street (Boulevard Tree Pits with Infiltration Trench)	Future Growth (Bioretention)	Offline Facility (Hybrid Pond)	Inline Facility (Hybrid Pond)
111401	AURORA	Capacity	71	0	0	61	0	0
111401	AURORA	Footprint	138	0	0	132	0	0
111401	AURORA	Cost	5,644	0	0	5,271	0	0
111501	AURORA	Capacity	38	0	0	0	2	0
111501	AURORA	Footprint	23	0	0	0	4	0
111501	AURORA	Cost	1,332	0	0	0	0	0
111601	AURORA	Capacity	26	0	0	0	0	0
111601	AURORA	Footprint	14	0	0	0	0	0
111601	AURORA	Cost	965	0	0	0	0	0
111701	AURORA	Capacity	2,361	20	129	10	272	1,930
111701	AURORA	Footprint	1,706	43	170	22	466	1,005
111701	AURORA	Cost	76,033	1,014	3,185	892	0	70,941
111801	AURORA	Capacity	316	10	253	27	0	0
111801	AURORA	Footprint	435	21	343	58	0	0
111801	AURORA	Cost	9,087	489	5,305	2,305	0	0
111901	AURORA	Capacity	56	0	21	0	1	0
111901	AURORA	Footprint	48	0	29	0	2	0
111901	AURORA	Cost	1,668	6	437	0	0	0
112001	AURORA	Capacity	23	0	5	0	2	0
112001	AURORA	Footprint	19	0	7	0	4	0
112001	AURORA	Cost	696	0	130	0	0	0
112101	AURORA	Capacity	1,464	0	0	0	1	0
112101	AURORA	Footprint	764	0	0	0	2	0
112101	AURORA	Cost	53,800	0	0	0	0	0
112201	AURORA	Capacity	507	0	0	0	3	0
112201	AURORA	Footprint	268	0	0	0	5	0
112201	AURORA	Cost	18,550	0	0	0	0	0
112301	AURORA	Capacity	644	0	0	0	4	0
112301	AURORA	Footprint	340	0	0	0	7	0
112301	AURORA	Cost	23,539	0	0	0	0	0
112401	AURORA	Capacity	750	0	252	62	12	0
112401	AURORA	Footprint	710	0	333	135	22	0
112401	AURORA	Cost	27,159	0	6,241	5,367	0	0
112501	AURORA	Capacity	53	0	12	0	1	0
112501	AURORA	Footprint	38	0	16	0	2	0
112501	AURORA	Cost	1,765	0	295	0	0	0
112601	AURORA	Capacity	130	0	0	104	1	0
112601	AURORA	Footprint	241	0	0	227	2	0
112601	AURORA	Cost	9,919	0	0	9,041	0	0
112901	AURORA	Capacity	33	0	0	0	0	0
112901	AURORA	Footprint	17	0	0	0	0	0
112901	AURORA	Cost	1,213	0	0	0	0	0
113101	AURORA	Capacity	123	0	0	0	1	0
113101	AURORA	Footprint	65	0	0	0	2	0
113101	AURORA	Cost	4,484	0	0	0	0	0

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Green Street (Boulevard Tree Pits with Infiltration Trench)	Future Growth (Bioretention)	Offline Facility (Hybrid Pond)	Inline Facility (Hybrid Pond)
113301	AURORA	Capacity	287	0	0	196	0	0
113301	AURORA	Footprint	473	0	0	426	0	0
113301	AURORA	Cost	20,313	0	0	16,974	0	0
113401	AURORA	Capacity	319	23	73	177	4	0
113401	AURORA	Footprint	559	49	96	386	6	0
113401	AURORA	Cost	19,865	1,160	1,797	15,364	0	0
113501	AURORA	Capacity	463	9	115	39	20	0
113501	AURORA	Footprint	440	20	155	85	34	0
113501	AURORA	Cost	16,681	465	2,535	3,403	0	0
113601	AURORA	Capacity	284	6	59	0	8	0
113601	AURORA	Footprint	218	13	80	0	16	0
113601	AURORA	Cost	9,338	314	1,291	0	0	0
113701	AURORA	Capacity	18	0	0	0	1	0
113701	AURORA	Footprint	10	0	0	0	1	0
113701	AURORA	Cost	629	0	0	0	0	0
113801	AURORA	Capacity	29	0	6	0	4	0
113801	AURORA	Footprint	24	0	8	0	7	0
113801	AURORA	Cost	856	0	138	0	0	0
113901	AURORA	Capacity	112	0	0	0	1	0
113901	AURORA	Footprint	59	0	0	0	1	0
113901	AURORA	Cost	4,112	0	0	0	0	0
114001	AURORA	Capacity	3	0	2	0	0	0
114001	AURORA	Footprint	4	1	3	0	0	0
114001	AURORA	Cost	73	21	47	0	0	0
114101	AURORA	Capacity	14	0	0	0	0	0
114101	AURORA	Footprint	7	0	0	0	0	0
114101	AURORA	Cost	528	0	0	0	0	0
114201	AURORA	Capacity	5,664	21	400	506	46	0
114201	AURORA	Footprint	4,210	47	541	1,100	81	0
114201	AURORA	Cost	225,804	1,092	8,444	43,802	0	0
114301	AURORA	Capacity	3	0	0	0	0	0
114301	AURORA	Footprint	2	0	0	0	0	0
114301	AURORA	Cost	124	0	0	0	0	0
114401	AURORA	Capacity	15	0	0	0	0	0
114401	AURORA	Footprint	8	0	0	0	0	0
114401	AURORA	Cost	560	0	0	0	0	0
114501	AURORA	Capacity	16	0	0	0	1	0
114501	AURORA	Footprint	9	0	0	0	1	0
114501	AURORA	Cost	558	0	0	0	0	0
114601	AURORA	Capacity	249	0	0	0	2	0
114601	AURORA	Footprint	133	0	0	0	4	0
114601	AURORA	Cost	9,100	0	0	0	0	0
114701	AURORA	Capacity	365	43	238	31	3	0
114701	AURORA	Footprint	506	94	315	67	5	0
114701	AURORA	Cost	12,584	2,198	5,890	2,668	0	0

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	**Parking Lot Capture** (Infiltration Gallery)	**Green Street** (Boulevard Tree Pits with Infiltration Trench)	**Future Growth** (Bioretention)	**Offline Facility** (Hybrid Pond)	**Inline Facility** (Hybrid Pond)
114801	AURORA	Capacity	4,431	364	2,733	262	321	0
114801	AURORA	Footprint	5,988	791	3,649	569	588	0
114801	AURORA	Cost	131,933	18,536	63,158	22,656	0	0
114901	AURORA	Capacity	14	0	0	0	0	0
114901	AURORA	Footprint	7	0	0	0	0	0
114901	AURORA	Cost	504	0	0	0	0	0
115001	AURORA	Capacity	21	1	0	7	7	0
115001	AURORA	Footprint	32	2	0	14	12	0
115001	AURORA	Cost	871	41	0	576	0	0
115101	AURORA	Capacity	10,251	866	6,896	0	90	0
115101	AURORA	Footprint	12,403	1,883	9,108	0	163	0
115101	AURORA	Cost	302,818	44,108	170,531	0	0	0
115201	AURORA	Capacity	430	47	214	85	84	0
115201	AURORA	Footprint	706	101	283	186	135	0
115201	AURORA	Cost	15,072	2,370	5,302	7,399	0	0
115301	AURORA	Capacity	70	14	54	0	3	0
115301	AURORA	Footprint	106	30	71	0	4	0
115301	AURORA	Cost	2,042	705	1,337	0	0	0
115401	AURORA	Capacity	6,304	0	0	0	168	3,537
115401	AURORA	Footprint	3,467	0	0	0	272	1,842
115401	AURORA	Cost	225,578	0	0	0	0	130,041
115501	AURORA	Capacity	9	4	3	0	2	0
115501	AURORA	Footprint	15	8	4	0	4	0
115501	AURORA	Cost	256	186	70	0	0	0
115601	AURORA	Capacity	71	14	0	46	11	0
115601	AURORA	Footprint	150	30	0	100	21	0
115601	AURORA	Cost	4,670	694	0	3,976	0	0
115701	AURORA	Capacity	102	23	78	0	1	0
115701	AURORA	Footprint	155	50	105	0	1	0
115701	AURORA	Cost	2,944	1,165	1,779	0	0	0
115801	AURORA	Capacity	33	4	28	0	1	0
115801	AURORA	Footprint	49	10	38	0	2	0
115801	AURORA	Cost	800	225	576	0	0	0
115901	AURORA	Capacity	0	0	0	0	0	0
115901	AURORA	Footprint	1	1	0	0	0	0
115901	AURORA	Cost	16	16	0	0	0	0
116001	AURORA	Capacity	2,379	5	423	65	1,886	0
116001	AURORA	Footprint	4,285	10	574	142	3,558	0
116001	AURORA	Cost	14,619	241	8,708	5,670	0	0
118701	AURORA	Capacity	0	0	0	0	0	0
118701	AURORA	Footprint	0	0	0	0	0	0
118701	AURORA	Cost	0	0	0	0	0	0
118801	AURORA	Capacity	614	60	124	209	222	0
118801	AURORA	Footprint	1,167	130	167	454	415	0
118801	AURORA	Cost	23,710	3,050	2,576	18,084	0	0

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Green Street (Boulevard Tree Pits with Infiltration Trench)	Future Growth (Bioretention)	Offline Facility (Hybrid Pond)	Inline Facility (Hybrid Pond)
118901	AURORA	Capacity	23	0	0	0	23	0
118901	AURORA	Footprint	44	0	0	0	44	0
118901	AURORA	Cost	0	0	0	0	0	0
119001	AURORA	Capacity	275	7	268	0	0	0
119001	AURORA	Footprint	379	16	363	0	0	0
119001	AURORA	Cost	5,885	380	5,505	0	0	0
119101	AURORA	Capacity	6	0	0	0	6	0
119101	AURORA	Footprint	11	0	0	0	11	0
119101	AURORA	Cost	0	0	0	0	0	0
119201	AURORA	Capacity	2	2	0	0	1	0
119201	AURORA	Footprint	5	4	0	0	1	0
119201	AURORA	Cost	94	94	0	0	0	0
119301	AURORA	Capacity	5	1	0	0	4	0
119301	AURORA	Footprint	10	2	0	0	7	0
119301	AURORA	Cost	53	53	0	0	0	0
119401	AURORA	Capacity	6,466	24	1,285	924	2,097	0
119401	AURORA	Footprint	8,765	51	1,743	2,009	3,849	0
119401	AURORA	Cost	186,236	1,204	26,433	80,023	0	0
119501	AURORA	Capacity	314	0	0	0	9	0
119501	AURORA	Footprint	174	0	0	0	16	0
119501	AURORA	Cost	11,182	0	0	0	0	0
119601	AURORA	Capacity	1,753	66	6	140	324	0
119601	AURORA	Footprint	1,615	144	8	304	526	0
119601	AURORA	Cost	60,362	3,367	142	12,103	0	0
119701	AURORA	Capacity	2,404	0	0	23	28	1,930
119701	AURORA	Footprint	1,321	0	0	50	45	1,005
119701	AURORA	Cost	88,498	0	0	1,999	0	70,941
119801	AURORA	Capacity	60	0	0	60	0	0
119801	AURORA	Footprint	130	0	0	130	0	0
119801	AURORA	Cost	5,173	0	0	5,173	0	0
119901	AURORA	Capacity	0	0	0	0	0	0
119901	AURORA	Footprint	0	0	0	0	0	0
119901	AURORA	Cost	0	0	0	0	0	0
120001	AURORA	Capacity	28	8	15	0	5	0
120001	AURORA	Footprint	45	16	20	0	9	0
120001	AURORA	Cost	764	387	378	0	0	0
120101	AURORA	Capacity	837	62	88	0	24	663
120101	AURORA	Footprint	635	135	116	0	39	345
120101	AURORA	Cost	29,713	3,170	2,169	0	0	24,373
120201	AURORA	Capacity	1,880	19	117	507	0	1,236
120201	AURORA	Footprint	1,942	42	155	1,102	0	644
120201	AURORA	Cost	93,220	984	2,902	43,888	0	45,446
120301	AURORA	Capacity	0	0	0	0	0	0
120301	AURORA	Footprint	0	0	0	0	0	0
120301	AURORA	Cost	0	0	0	0	0	0

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Green Street (Boulevard Tree Pits with Infiltration Trench)	Future Growth (Bioretention)	Offline Facility (Hybrid Pond)	Inline Facility (Hybrid Pond)
120401	AURORA	Capacity	35	3	31	0	1	0
120401	AURORA	Footprint	48	6	41	0	1	0
120401	AURORA	Cost	906	131	775	0	0	0
120601	AURORA	Capacity	4,403	15	252	792	3,344	0
120601	AURORA	Footprint	8,205	33	340	1,722	6,110	0
120601	AURORA	Cost	74,676	769	5,300	68,606	0	0
120701	AURORA	Capacity	107	0	12	86	8	0
120701	AURORA	Footprint	218	1	16	188	13	0
120701	AURORA	Cost	7,800	25	305	7,471	0	0
120801	AURORA	Capacity	35	0	8	23	4	0
120801	AURORA	Footprint	68	0	10	51	7	0
120801	AURORA	Cost	2,186	0	156	2,030	0	0
121101	AURORA	Capacity	85	48	19	7	11	0
121101	AURORA	Footprint	162	105	25	14	18	0
121101	AURORA	Cost	3,502	2,462	466	573	0	0
121201	AURORA	Capacity	2,642	0	0	0	44	2,597
121201	AURORA	Footprint	1,424	0	0	0	71	1,353
121201	AURORA	Cost	95,498	0	0	0	0	95,498
121301	AURORA	Capacity	1	0	0	0	1	0
121301	AURORA	Footprint	1	0	0	0	1	0
121301	AURORA	Cost	0	0	0	0	0	0
121401	AURORA	Capacity	655	0	0	132	523	0
121401	AURORA	Footprint	1,215	0	0	286	928	0
121401	AURORA	Cost	11,413	0	0	11,413	0	0
121501	AURORA	Capacity	83	1	0	0	82	0
121501	AURORA	Footprint	134	2	0	0	132	0
121501	AURORA	Cost	48	48	0	0	0	0
121601	AURORA	Capacity	301	75	17	142	67	0
121601	AURORA	Footprint	602	163	22	309	108	0
121601	AURORA	Cost	16,534	3,813	412	12,310	0	0
121701	AURORA	Capacity	304	75	0	0	230	0
121701	AURORA	Footprint	596	162	0	0	434	0
121701	AURORA	Cost	3,797	3,797	0	0	0	0
121801	AURORA	Capacity	29	0	0	17	12	0
121801	AURORA	Footprint	60	0	0	38	23	0
121801	AURORA	Cost	1,501	0	0	1,501	0	0
121901	AURORA	Capacity	1,867	402	198	206	1,062	0
121901	AURORA	Footprint	3,331	873	262	447	1,749	0
121901	AURORA	Cost	43,166	20,447	4,902	17,817	0	0
122001	AURORA	Capacity	364	0	0	0	0	364
122001	AURORA	Footprint	190	0	0	0	0	190
122001	AURORA	Cost	13,400	0	0	0	0	13,400
122101	AURORA	Capacity	924	88	137	0	699	0
122101	AURORA	Footprint	1,519	190	181	0	1,148	0
122101	AURORA	Cost	7,841	4,455	3,386	0	0	0

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Green Street (Boulevard Tree Pits with Infiltration Trench)	Future Growth (Bioretention)	Offline Facility (Hybrid Pond)	Inline Facility (Hybrid Pond)
122501	AURORA	Capacity	836	0	0	0	599	0
122501	AURORA	Footprint	1,092	0	0	0	969	0
122501	AURORA	Cost	8,716	0	0	0	0	0
122801	AURORA	Capacity	4,088	5	528	287	2,275	0
122801	AURORA	Footprint	5,859	12	698	624	4,009	0
122801	AURORA	Cost	74,669	270	13,068	24,857	0	0
123301	AURORA	Capacity	1,840	0	30	279	1,037	0
123301	AURORA	Footprint	2,582	0	40	606	1,679	0
123301	AURORA	Cost	43,068	0	747	24,139	0	0

East Gwillimbury:

Basinwide SCM Implementation Recipe to Achieve 40% Phosphorus Reduction at East Holland Landing

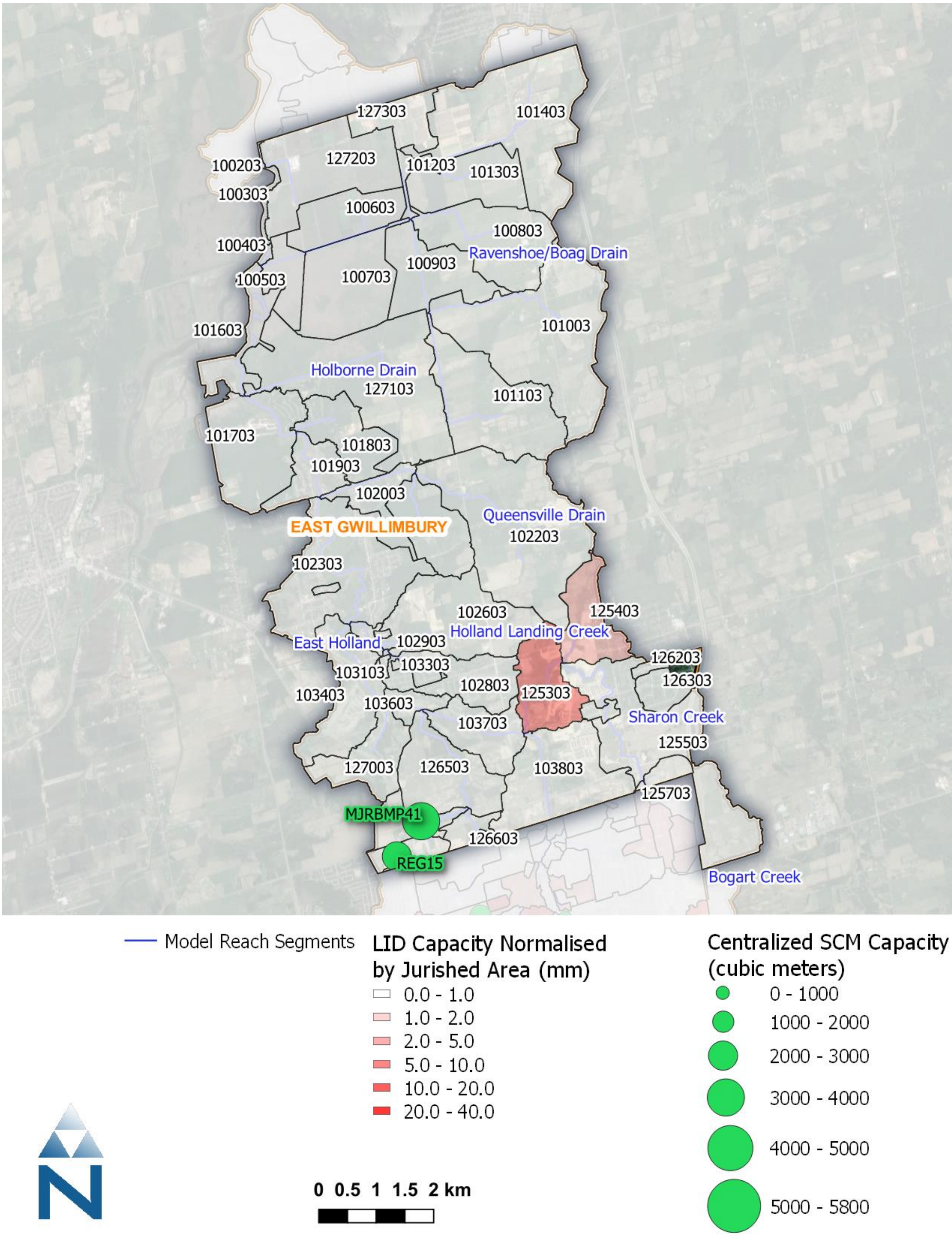


Figure 3. Heat map of SCM implementation for East Gwillimbury to achieve basinwide 40% phosphorous reduction at Holland Landing.

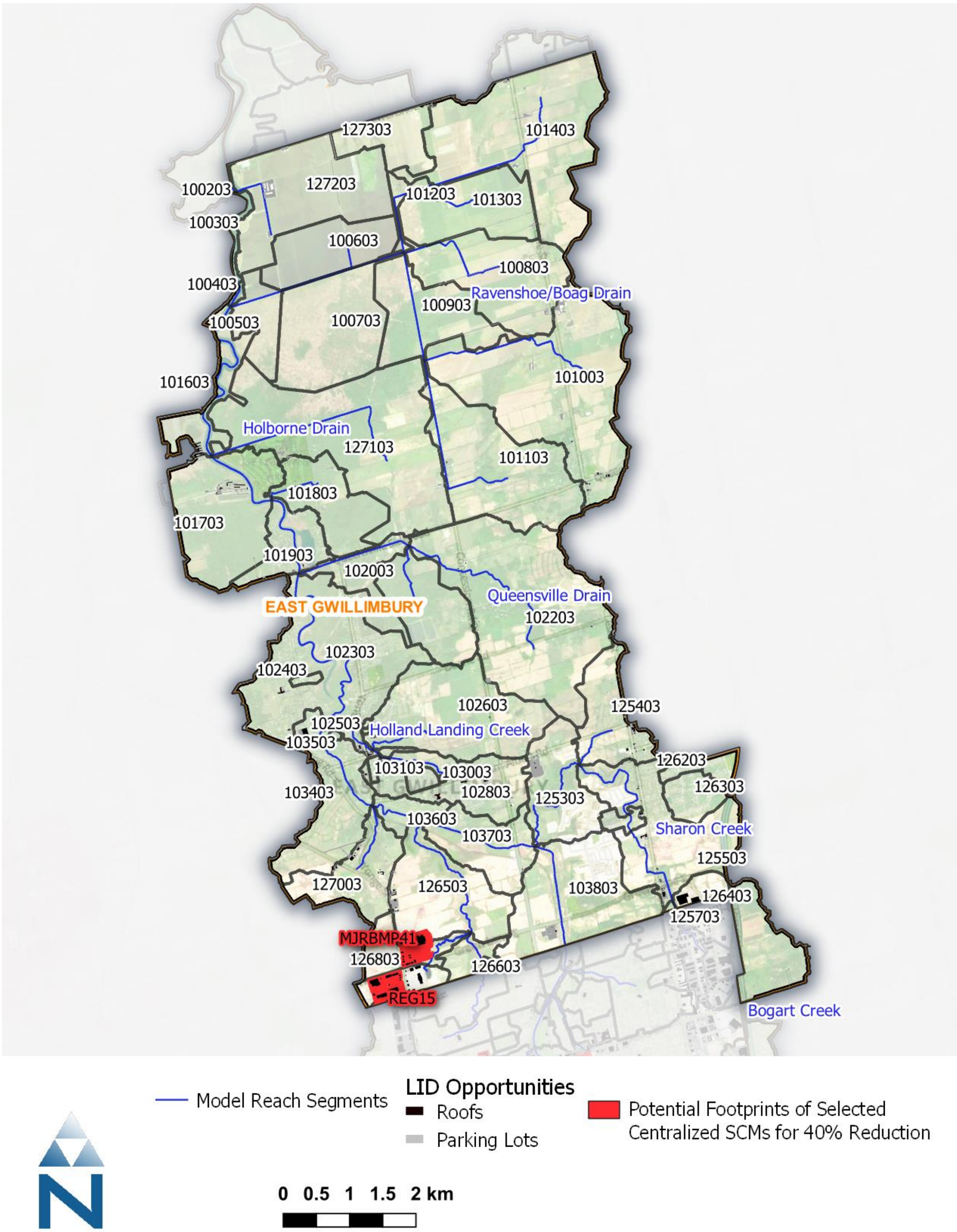


Figure 4. SCM footprint locations in East Gwillimbury to achieve basinwide 40% TP reduction at Holland Landing.

Table 2. SCM Implementation Recipe for East Gwillimbury to Achieve Basinwide 40% TP Reduction at Holland Landing

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Green Street (Boulevard Tree Pits with Infiltration Trench)	Future Growth (Bioretention)	Offline Facility (Hybrid Pond)	Inline Facility (Hybrid Pond)
103603	EAST GWILLIMBURY	Capacity	0	0	27	0	0	0
103603	EAST GWILLIMBURY	Footprint	0	0	59	0	0	0
103603	EAST GWILLIMBURY	Cost	0	0	2,348	0	0	0
103703	EAST GWILLIMBURY	Capacity	1	2	75	60	0	0
103703	EAST GWILLIMBURY	Footprint	2	3	164	97	0	0
103703	EAST GWILLIMBURY	Cost	47	50	6,530	0	0	0
103803	EAST GWILLIMBURY	Capacity	9	367	394	1,900	0	0
103803	EAST GWILLIMBURY	Footprint	19	485	856	3,075	0	0
103803	EAST GWILLIMBURY	Cost	447	9,076	34,100	0	0	0
105103	EAST GWILLIMBURY	Capacity	0	0	0	0	0	0
105103	EAST GWILLIMBURY	Footprint	0	0	0	0	0	0
105103	EAST GWILLIMBURY	Cost	0	0	0	0	0	0
125303	EAST GWILLIMBURY	Capacity	4	2,439	151	1,914	0	0
125303	EAST GWILLIMBURY	Footprint	10	3,310	327	3,207	0	0
125303	EAST GWILLIMBURY	Cost	226	50,198	13,045	0	0	0
125403	EAST GWILLIMBURY	Capacity	20	268	201	1,647	0	0
125403	EAST GWILLIMBURY	Footprint	43	360	436	2,727	0	0
125403	EAST GWILLIMBURY	Cost	1,017	6,001	17,361	0	0	0
125503	EAST GWILLIMBURY	Capacity	23	1,490	310	2,035	0	0
125503	EAST GWILLIMBURY	Footprint	51	2,013	673	3,463	0	0
125503	EAST GWILLIMBURY	Cost	1,186	31,598	26,831	0	0	0
125603	EAST GWILLIMBURY	Capacity	0	14	0	88	0	0
125603	EAST GWILLIMBURY	Footprint	1	19	0	166	0	0
125603	EAST GWILLIMBURY	Cost	21	288	0	0	0	0
125703	EAST GWILLIMBURY	Capacity	0	0	0	0	0	0
125703	EAST GWILLIMBURY	Footprint	0	0	0	0	0	0
125703	EAST GWILLIMBURY	Cost	0	0	0	0	0	0

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Green Street (Boulevard Tree Pits with Infiltration Trench)	Future Growth (Bioretention)	Offline Facility (Hybrid Pond)	Inline Facility (Hybrid Pond)
126203	EAST GWILLIMBURY	Capacity	0	0	0	1	0	0
126203	EAST GWILLIMBURY	Footprint	0	0	0	3	0	0
126203	EAST GWILLIMBURY	Cost	0	0	0	0	0	0
126303	EAST GWILLIMBURY	Capacity	0	0	0	0	0	0
126303	EAST GWILLIMBURY	Footprint	0	0	0	1	0	0
126303	EAST GWILLIMBURY	Cost	0	0	0	0	0	0
126403	EAST GWILLIMBURY	Capacity	0	1	0	0	0	0
126403	EAST GWILLIMBURY	Footprint	0	1	0	0	0	0
126403	EAST GWILLIMBURY	Cost	0	14	0	0	0	0
126503	EAST GWILLIMBURY	Capacity	45	169	47	1	0	0
126503	EAST GWILLIMBURY	Footprint	97	223	103	2	0	0
126503	EAST GWILLIMBURY	Cost	2,274	4,185	4,111	0	0	0
126603	EAST GWILLIMBURY	Capacity	0	0	130	4	0	0
126603	EAST GWILLIMBURY	Footprint	0	0	283	6	0	0
126603	EAST GWILLIMBURY	Cost	0	0	11,294	0	0	0
126703	EAST GWILLIMBURY	Capacity	0	0	0	2	0	0
126703	EAST GWILLIMBURY	Footprint	0	0	0	3	0	0
126703	EAST GWILLIMBURY	Cost	0	0	0	0	0	0
126803	EAST GWILLIMBURY	Capacity	21	83	188	8	1,930	0
126803	EAST GWILLIMBURY	Footprint	45	110	409	12	1,005	0
126803	EAST GWILLIMBURY	Cost	1,049	2,052	16,286	0	70,941	0
126903	EAST GWILLIMBURY	Capacity	0	0	0	3	2,078	0
126903	EAST GWILLIMBURY	Footprint	0	0	0	4	1,082	0
126903	EAST GWILLIMBURY	Cost	0	0	0	0	76,398	0

King:

Basinwide SCM Implementation Recipe to Achieve 40% Phosphorus Reduction at East Holland Landing

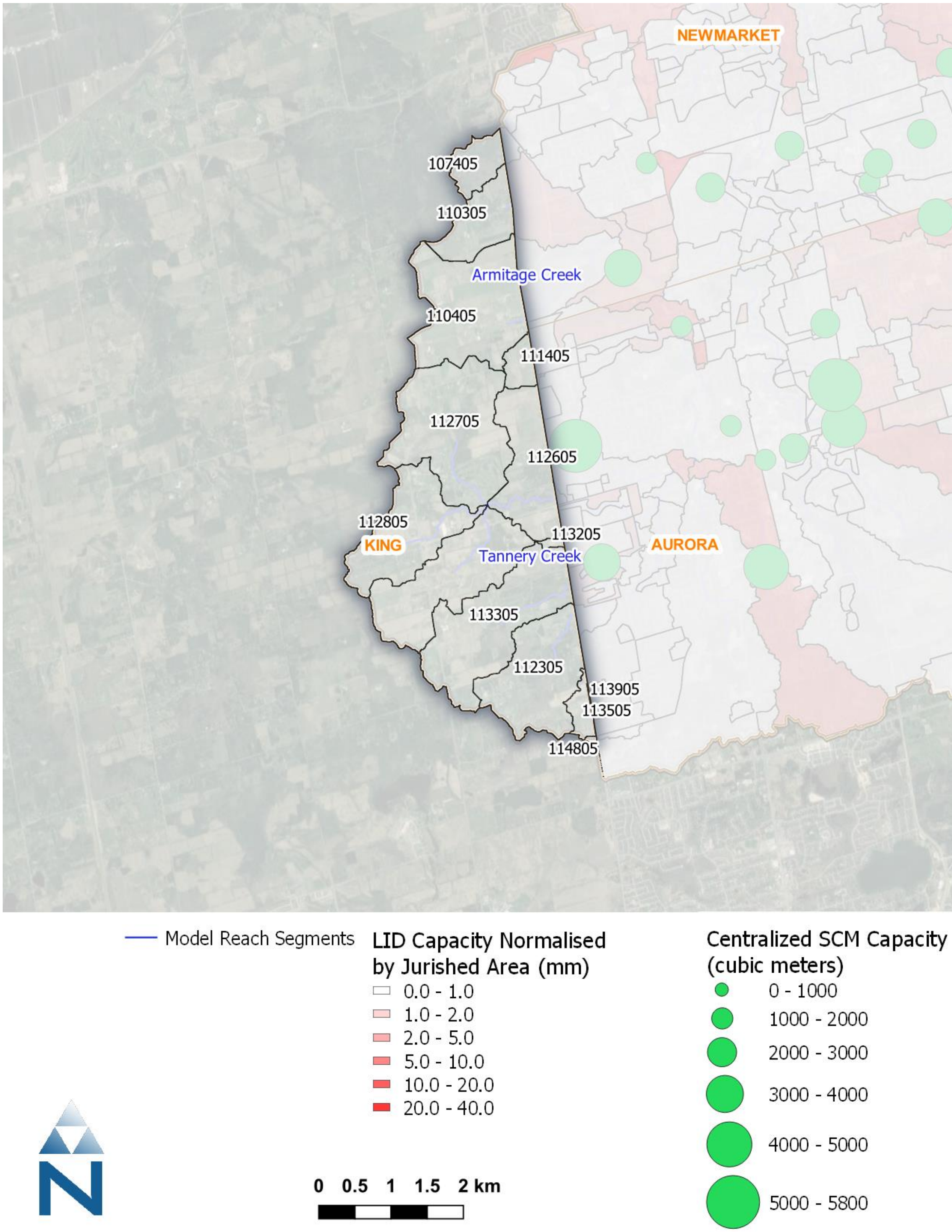


Figure 5. Heat map of SCM implementation for King to achieve basinwide 40% phosphorous reduction at Holland Landing.

Figure 6. SCM footprint locations in <u>King</u> to achieve basinwide 40% TP reduction at Holland Landing.

Table 3. SCM Implementation Recipe for King to Achieve Basinwide 40% TP Reduction at Holland Landing

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Green Street (Boulevard Tree Pits with Infiltration Trench)	Future Growth (Bioretention)	Offline Facility (Hybrid Pond)	Inline Facility (Hybrid Pond)
107405	KING	Capacity	0	0	0	0	0	0
107405	KING	Footprint	0	0	0	0	0	0
107405	KING	Cost	0	0	0	0	0	0
110305	KING	Capacity	0	0	0	0	0	195
110305	KING	Footprint	0	0	0	0	0	102
110305	KING	Cost	0	0	0	0	0	7,168
110405	KING	Capacity	0	175	236	0	0	446
110405	KING	Footprint	0	237	513	0	0	232
110405	KING	Cost	0	3,594	20,418	0	0	16,408
111405	KING	Capacity	0	0	30	0	0	8
111405	KING	Footprint	0	0	64	0	0	4
111405	KING	Cost	0	0	2,566	0	0	286
112305	KING	Capacity	4	0	329	0	0	1,519
112305	KING	Footprint	9	0	714	0	0	791
112305	KING	Cost	202	0	28,444	0	0	55,862
112605	KING	Capacity	0	0	178	0	0	39
112605	KING	Footprint	0	0	387	0	0	20
112605	KING	Cost	0	0	15,401	0	0	1,436
112705	KING	Capacity	0	352	86	0	0	79
112705	KING	Footprint	0	478	186	0	0	41
112705	KING	Cost	0	7,251	7,404	0	0	2,898
112805	KING	Capacity	8	713	90	0	0	121
112805	KING	Footprint	18	968	195	0	0	63
112805	KING	Cost	412	14,701	7,753	0	0	4,455
113005	KING	Capacity	0	58	87	0	0	69
113005	KING	Footprint	0	79	188	0	0	36
113005	KING	Cost	0	1,192	7,493	0	0	2,526
113205	KING	Capacity	0	0	0	0	0	2
113205	KING	Footprint	0	0	0	0	0	1
113205	KING	Cost	0	0	0	0	0	76
113305	KING	Capacity	0	94	1,010	0	0	1,384
113305	KING	Footprint	0	127	2,195	0	0	721
113305	KING	Cost	0	1,929	87,441	0	0	50,877
113505	KING	Capacity	0	14	49	0	0	13
113505	KING	Footprint	0	18	106	0	0	7
113505	KING	Cost	0	279	4,213	0	0	472
113905	KING	Capacity	0	0	0	0	0	2
113905	KING	Footprint	0	0	0	0	0	1
113905	KING	Cost	0	0	0	0	0	57
114805	KING	Capacity	0	5	0	0	0	2
114805	KING	Footprint	0	7	0	0	0	1
114805	KING	Cost	0	105	0	0	0	58

Newmarket:

Basinwide SCM Implementation Recipe to Achieve 40% Phosphorus Reduction at East Holland Landing

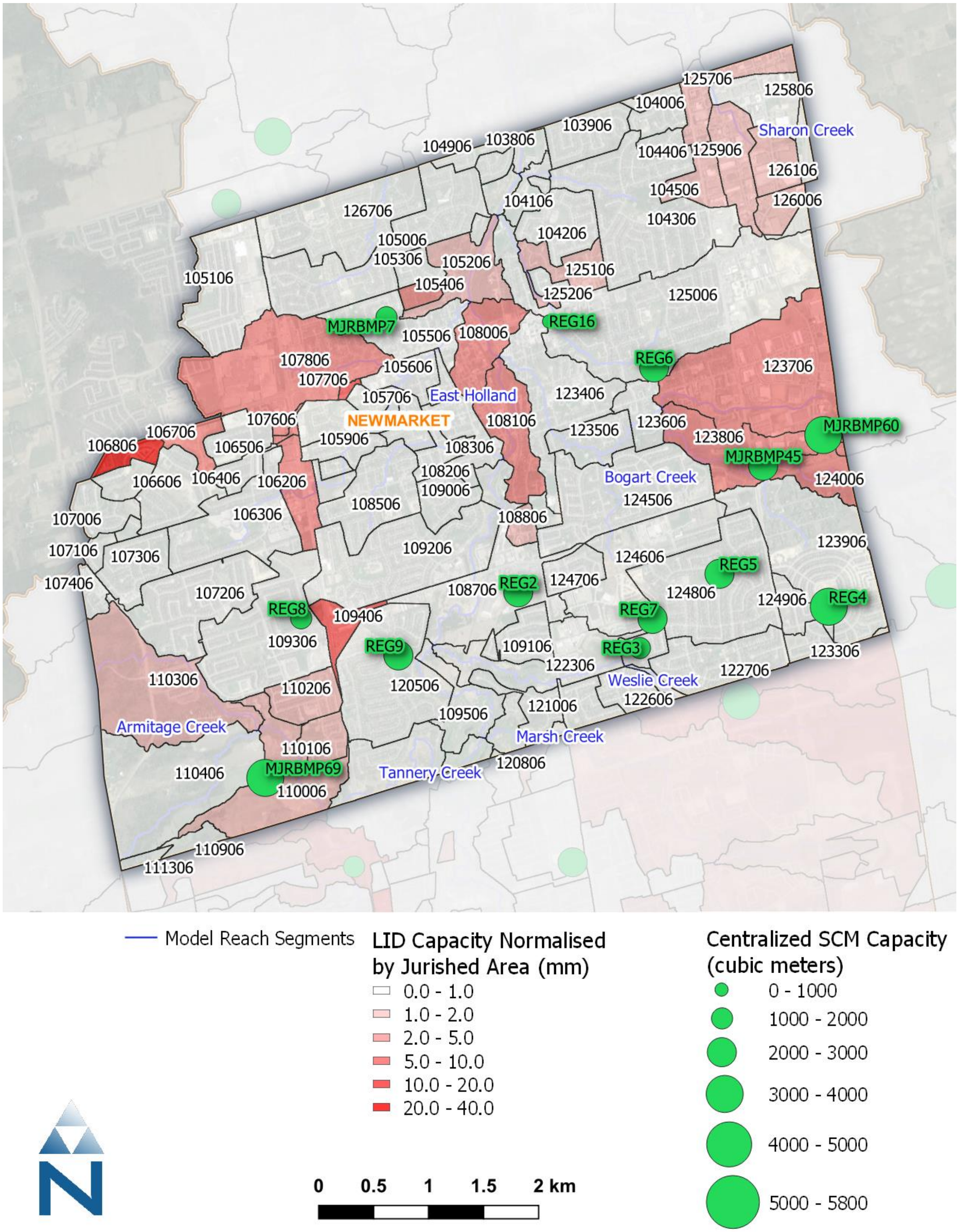


Figure 7. Heat map of SCM implementation for Newmarket to achieve basinwide 40% phosphorous reduction at Holland Landing.

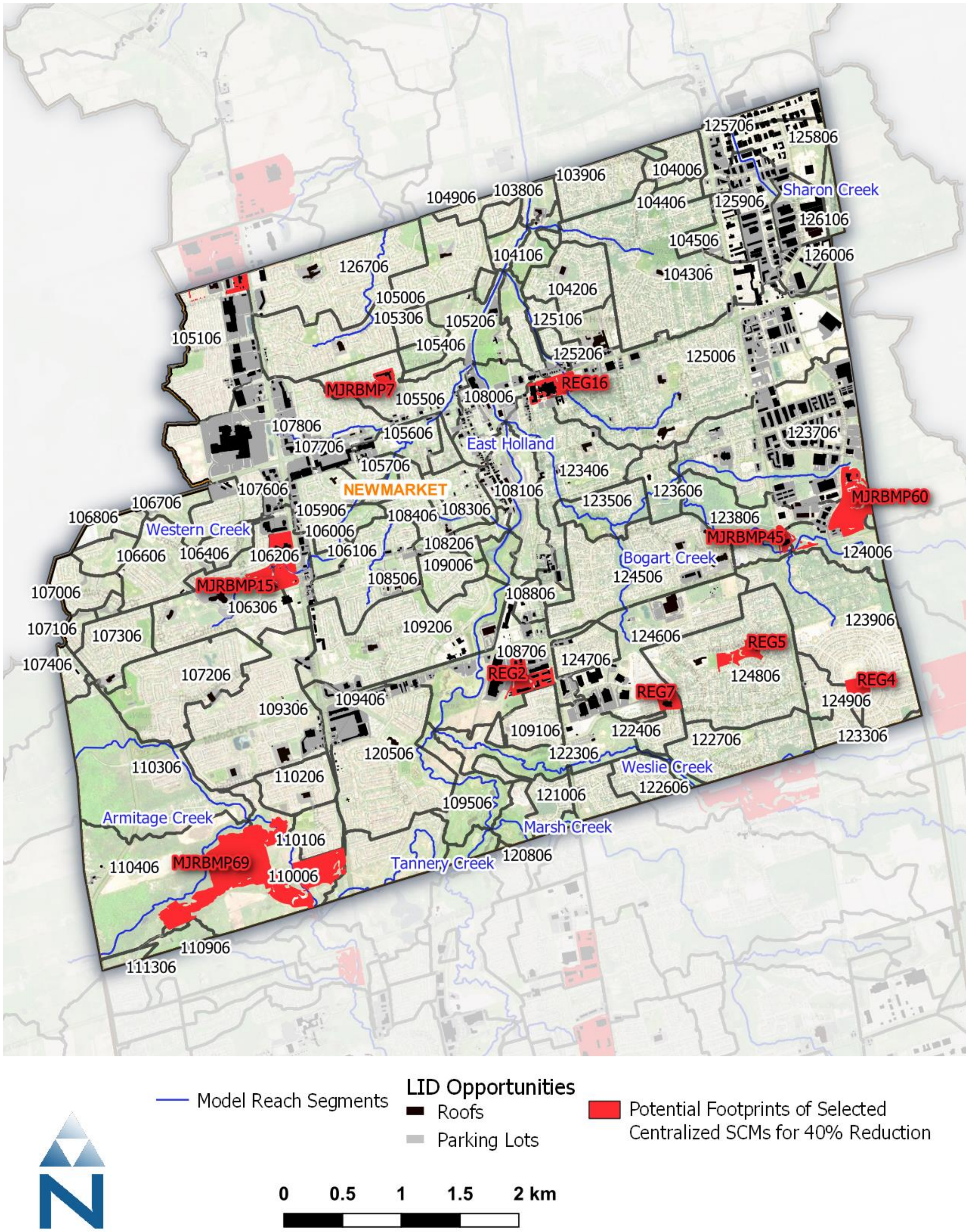


Figure 8. SCM footprint locations in Newmarket to achieve basinwide 40% TP reduction at Holland Landing.

Table 4. SCM Implementation Recipe for Newmarket to Achieve Basinwide 40% TP Reduction at Holland Landing

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Green Street (Boulevard Tree Pits with Infiltration Trench)	Future Growth (Bioretention)	Offline Facility (Hybrid Pond)	Inline Facility (Hybrid Pond)
103806	NEWMARKET	Capacity	57	5	49	0	3	0
103806	NEWMARKET	Footprint	80	10	65	0	5	0
103806	NEWMARKET	Cost	1,454	246	1,208	0	0	0
103906	NEWMARKET	Capacity	4	0	0	0	4	0
103906	NEWMARKET	Footprint	6	0	0	0	6	0
103906	NEWMARKET	Cost	0	0	0	0	0	0
104006	NEWMARKET	Capacity	56	7	45	0	4	0
104006	NEWMARKET	Footprint	81	14	59	0	7	0
104006	NEWMARKET	Cost	1,448	336	1,112	0	0	0
104106	NEWMARKET	Capacity	19	2	17	0	0	0
104106	NEWMARKET	Footprint	27	5	22	0	0	0
104106	NEWMARKET	Cost	525	115	410	0	0	0
104206	NEWMARKET	Capacity	61	8	52	0	1	0
104206	NEWMARKET	Footprint	87	17	69	0	1	0
104206	NEWMARKET	Cost	1,689	401	1,289	0	0	0
104306	NEWMARKET	Capacity	484	43	374	44	23	0
104306	NEWMARKET	Footprint	735	94	507	95	38	0
104306	NEWMARKET	Cost	13,687	2,206	7,689	3,793	0	0
104406	NEWMARKET	Capacity	0	0	0	0	0	0
104406	NEWMARKET	Footprint	1	0	0	0	1	0
104406	NEWMARKET	Cost	0	0	0	0	0	0
104506	NEWMARKET	Capacity	311	51	184	68	8	0
104506	NEWMARKET	Footprint	523	111	249	147	15	0
104506	NEWMARKET	Cost	12,245	2,605	3,784	5,856	0	0
104606	NEWMARKET	Capacity	0	0	0	0	0	0
104606	NEWMARKET	Footprint	0	0	0	0	0	0
104606	NEWMARKET	Cost	0	0	0	0	0	0
104706	NEWMARKET	Capacity	16	0	16	0	0	0
104706	NEWMARKET	Footprint	21	0	21	0	0	0
104706	NEWMARKET	Cost	393	0	393	0	0	0
104806	NEWMARKET	Capacity	0	0	0	0	0	0
104806	NEWMARKET	Footprint	0	0	0	0	0	0
104806	NEWMARKET	Cost	0	0	0	0	0	0
104906	NEWMARKET	Capacity	3	0	0	0	3	0
104906	NEWMARKET	Footprint	5	0	0	0	5	0
104906	NEWMARKET	Cost	0	0	0	0	0	0
105006	NEWMARKET	Capacity	89	6	58	3	21	0
105006	NEWMARKET	Footprint	131	14	77	6	34	0
105006	NEWMARKET	Cost	2,014	317	1,442	255	0	0
105106	NEWMARKET	Capacity	20	0	16	0	4	0
105106	NEWMARKET	Footprint	28	0	21	0	6	0
105106	NEWMARKET	Cost	404	11	393	0	0	0

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Green Street (Boulevard Tree Pits with Infiltration Trench)	Future Growth (Bioretention)	Offline Facility (Hybrid Pond)	Inline Facility (Hybrid Pond)
105206	NEWMARKET	Capacity	443	9	300	0	134	0
105206	NEWMARKET	Footprint	640	20	404	0	217	0
105206	NEWMARKET	Cost	7,060	466	6,594	0	0	0
105306	NEWMARKET	Capacity	22	0	0	0	22	0
105306	NEWMARKET	Footprint	35	0	0	0	35	0
105306	NEWMARKET	Cost	0	0	0	0	0	0
105406	NEWMARKET	Capacity	265	0	0	0	265	0
105406	NEWMARKET	Footprint	428	0	0	0	428	0
105406	NEWMARKET	Cost	0	0	0	0	0	0
105506	NEWMARKET	Capacity	373	24	266	71	11	0
105506	NEWMARKET	Footprint	580	53	354	155	18	0
105506	NEWMARKET	Cost	13,742	1,245	6,313	6,183	0	0
105606	NEWMARKET	Capacity	138	14	119	0	6	0
105606	NEWMARKET	Footprint	199	30	160	0	9	0
105606	NEWMARKET	Cost	3,378	705	2,673	0	0	0
105706	NEWMARKET	Capacity	63	8	52	0	3	0
105706	NEWMARKET	Footprint	92	18	68	0	6	0
105706	NEWMARKET	Cost	1,690	412	1,278	0	0	0
105806	NEWMARKET	Capacity	192	36	155	0	1	0
105806	NEWMARKET	Footprint	285	78	204	0	2	0
105806	NEWMARKET	Cost	5,657	1,830	3,827	0	0	0
105906	NEWMARKET	Capacity	54	3	49	0	2	0
105906	NEWMARKET	Footprint	75	7	65	0	3	0
105906	NEWMARKET	Cost	1,371	162	1,210	0	0	0
106006	NEWMARKET	Capacity	0	0	0	0	0	0
106006	NEWMARKET	Footprint	1	0	0	0	1	0
106006	NEWMARKET	Cost	0	0	0	0	0	0
106106	NEWMARKET	Capacity	34	1	28	0	5	0
106106	NEWMARKET	Footprint	48	2	37	0	8	0
106106	NEWMARKET	Cost	755	59	697	0	0	0
106206	NEWMARKET	Capacity	753	92	499	112	49	0
106206	NEWMARKET	Footprint	1,185	201	660	244	81	0
106206	NEWMARKET	Cost	26,739	4,700	12,322	9,716	0	0
106306	NEWMARKET	Capacity	483	59	342	0	83	0
106306	NEWMARKET	Footprint	713	127	451	0	134	0
106306	NEWMARKET	Cost	11,434	2,986	8,448	0	0	0
106406	NEWMARKET	Capacity	48	0	0	0	48	0
106406	NEWMARKET	Footprint	77	0	0	0	77	0
106406	NEWMARKET	Cost	0	0	0	0	0	0
106506	NEWMARKET	Capacity	2	0	0	0	2	0
106506	NEWMARKET	Footprint	4	0	0	0	4	0
106506	NEWMARKET	Cost	5	5	0	0	0	0
106606	NEWMARKET	Capacity	192	0	0	0	192	0
106606	NEWMARKET	Footprint	311	0	0	0	311	0
106606	NEWMARKET	Cost	0	0	0	0	0	0

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Green Street (Boulevard Tree Pits with Infiltration Trench)	Future Growth (Bioretention)	Offline Facility (Hybrid Pond)	Inline Facility (Hybrid Pond)
106706	NEWMARKET	Capacity	223	0	43	0	180	0
106706	NEWMARKET	Footprint	348	0	57	0	292	0
106706	NEWMARKET	Cost	1,061	0	1,061	0	0	0
106806	NEWMARKET	Capacity	0	0	0	0	0	0
106806	NEWMARKET	Footprint	1	0	0	0	1	0
106806	NEWMARKET	Cost	0	0	0	0	0	0
107006	NEWMARKET	Capacity	1	0	0	0	1	0
107006	NEWMARKET	Footprint	1	0	0	0	1	0
107006	NEWMARKET	Cost	0	0	0	0	0	0
107106	NEWMARKET	Capacity	0	0	0	0	0	0
107106	NEWMARKET	Footprint	0	0	0	0	0	0
107106	NEWMARKET	Cost	0	0	0	0	0	0
107206	NEWMARKET	Capacity	42	0	29	13	0	0
107206	NEWMARKET	Footprint	68	1	38	29	0	0
107206	NEWMARKET	Cost	1,801	15	624	1,162	0	0
107306	NEWMARKET	Capacity	64	1	63	0	0	0
107306	NEWMARKET	Footprint	88	2	86	0	0	0
107306	NEWMARKET	Cost	1,345	44	1,302	0	0	0
107406	NEWMARKET	Capacity	0	0	0	0	0	0
107406	NEWMARKET	Footprint	1	0	0	1	0	0
107406	NEWMARKET	Cost	42	0	0	42	0	0
107506	NEWMARKET	Capacity	0	0	0	0	0	0
107506	NEWMARKET	Footprint	0	0	0	0	0	0
107506	NEWMARKET	Cost	0	0	0	0	0	0
107606	NEWMARKET	Capacity	82	9	55	18	0	0
107606	NEWMARKET	Footprint	132	20	73	39	0	0
107606	NEWMARKET	Cost	3,378	467	1,365	1,546	0	0
107706	NEWMARKET	Capacity	98	15	83	0	0	0
107706	NEWMARKET	Footprint	143	33	110	0	0	0
107706	NEWMARKET	Cost	2,827	768	2,058	0	0	0
107806	NEWMARKET	Capacity	4,611	252	3,720	265	373	0
107806	NEWMARKET	Footprint	6,641	547	4,913	577	604	0
107806	NEWMARKET	Cost	127,789	12,825	91,983	22,981	0	0
107906	NEWMARKET	Capacity	8	0	8	0	0	0
107906	NEWMARKET	Footprint	11	0	11	0	0	0
107906	NEWMARKET	Cost	202	0	202	0	0	0
108006	NEWMARKET	Capacity	1,397	55	1,247	69	26	0
108006	NEWMARKET	Footprint	1,993	120	1,679	149	44	0
108006	NEWMARKET	Cost	35,871	2,823	27,095	5,954	0	0
108106	NEWMARKET	Capacity	1,036	71	767	110	87	0
108106	NEWMARKET	Footprint	1,567	155	1,030	239	144	0
108106	NEWMARKET	Cost	30,256	3,629	17,114	9,513	0	0
108206	NEWMARKET	Capacity	88	2	57	0	29	0
108206	NEWMARKET	Footprint	134	4	77	0	53	0
108206	NEWMARKET	Cost	1,403	101	1,303	0	0	0

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Green Street (Boulevard Tree Pits with Infiltration Trench)	Future Growth (Bioretention)	Offline Facility (Hybrid Pond)	Inline Facility (Hybrid Pond)
108306	NEWMARKET	Capacity	80	11	61	0	8	0
108306	NEWMARKET	Footprint	117	23	80	0	13	0
108306	NEWMARKET	Cost	2,049	543	1,505	0	0	0
108406	NEWMARKET	Capacity	0	0	0	0	0	0
108406	NEWMARKET	Footprint	1	0	0	0	1	0
108406	NEWMARKET	Cost	0	0	0	0	0	0
108506	NEWMARKET	Capacity	283	33	242	0	9	0
108506	NEWMARKET	Footprint	405	72	319	0	14	0
108506	NEWMARKET	Cost	7,658	1,677	5,981	0	0	0
108606	NEWMARKET	Capacity	68	5	55	0	7	0
108606	NEWMARKET	Footprint	96	12	73	0	11	0
108606	NEWMARKET	Cost	1,649	278	1,371	0	0	0
108706	NEWMARKET	Capacity	2,156	0	0	0	78	2,078
108706	NEWMARKET	Footprint	1,213	0	0	0	131	1,082
108706	NEWMARKET	Cost	76,398	0	0	0	0	76,398
108806	NEWMARKET	Capacity	41	5	31	1	5	0
108806	NEWMARKET	Footprint	60	10	40	1	8	0
108806	NEWMARKET	Cost	1,045	241	758	45	0	0
108906	NEWMARKET	Capacity	0	0	0	0	0	0
108906	NEWMARKET	Footprint	0	0	0	0	0	0
108906	NEWMARKET	Cost	0	0	0	0	0	0
109006	NEWMARKET	Capacity	10	3	1	0	5	0
109006	NEWMARKET	Footprint	17	7	1	0	8	0
109006	NEWMARKET	Cost	202	176	27	0	0	0
109106	NEWMARKET	Capacity	69	0	54	13	2	0
109106	NEWMARKET	Footprint	102	0	72	28	3	0
109106	NEWMARKET	Cost	2,441	0	1,343	1,098	0	0
109206	NEWMARKET	Capacity	517	75	330	26	85	0
109206	NEWMARKET	Footprint	801	164	436	57	144	0
109206	NEWMARKET	Cost	14,285	3,843	8,158	2,284	0	0
109306	NEWMARKET	Capacity	2,064	0	0	0	135	1,930
109306	NEWMARKET	Footprint	1,223	0	0	0	218	1,005
109306	NEWMARKET	Cost	70,941	0	0	0	0	70,941
109406	NEWMARKET	Capacity	854	40	577	233	4	0
109406	NEWMARKET	Footprint	1,362	87	762	507	7	0
109406	NEWMARKET	Cost	36,489	2,035	14,268	20,186	0	0
109506	NEWMARKET	Capacity	3	0	0	0	3	0
109506	NEWMARKET	Footprint	5	0	0	0	5	0
109506	NEWMARKET	Cost	0	0	0	0	0	0
109606	NEWMARKET	Capacity	0	0	0	0	0	0
109606	NEWMARKET	Footprint	1	0	0	0	1	0
109606	NEWMARKET	Cost	0	0	0	0	0	0
109706	NEWMARKET	Capacity	63	0	0	46	17	0
109706	NEWMARKET	Footprint	128	0	0	101	27	0
109706	NEWMARKET	Cost	4,017	0	0	4,017	0	0

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Green Street (Boulevard Tree Pits with Infiltration Trench)	Future Growth (Bioretention)	Offline Facility (Hybrid Pond)	Inline Facility (Hybrid Pond)
110006	NEWMARKET	Capacity	1,695	0	6	80	891	0
110006	NEWMARKET	Footprint	2,004	0	8	173	1,449	0
110006	NEWMARKET	Cost	33,462	0	118	6,905	0	0
110106	NEWMARKET	Capacity	706	0	6	194	8	0
110106	NEWMARKET	Footprint	702	0	8	421	13	0
110106	NEWMARKET	Cost	35,225	0	157	16,780	0	0
110206	NEWMARKET	Capacity	1,324	11	123	277	12	0
110206	NEWMARKET	Footprint	1,277	25	162	602	19	0
110206	NEWMARKET	Cost	60,744	584	3,043	23,979	0	0
110306	NEWMARKET	Capacity	1,985	3	0	1,268	0	0
110306	NEWMARKET	Footprint	3,135	7	0	2,756	0	0
110306	NEWMARKET	Cost	136,210	164	0	109,790	0	0
110406	NEWMARKET	Capacity	764	2	67	309	0	0
110406	NEWMARKET	Footprint	965	4	89	670	0	0
110406	NEWMARKET	Cost	42,662	101	1,665	26,711	0	0
110906	NEWMARKET	Capacity	24	0	23	0	0	0
110906	NEWMARKET	Footprint	32	0	31	0	0	0
110906	NEWMARKET	Cost	502	0	478	0	0	0
111306	NEWMARKET	Capacity	25	0	22	0	0	0
111306	NEWMARKET	Footprint	31	0	30	0	0	0
111306	NEWMARKET	Cost	565	0	449	0	0	0
120506	NEWMARKET	Capacity	2,630	0	0	0	32	2,597
120506	NEWMARKET	Footprint	1,405	0	0	0	52	1,353
120506	NEWMARKET	Cost	95,498	0	0	0	0	95,498
120606	NEWMARKET	Capacity	2	0	0	0	2	0
120606	NEWMARKET	Footprint	4	0	0	0	4	0
120606	NEWMARKET	Cost	0	0	0	0	0	0
120806	NEWMARKET	Capacity	0	0	0	0	0	0
120806	NEWMARKET	Footprint	0	0	0	0	0	0
120806	NEWMARKET	Cost	0	0	0	0	0	0
120906	NEWMARKET	Capacity	162	5	70	83	4	0
120906	NEWMARKET	Footprint	290	11	92	181	6	0
120906	NEWMARKET	Cost	9,180	253	1,723	7,204	0	0
121006	NEWMARKET	Capacity	7	0	0	0	7	0
121006	NEWMARKET	Footprint	11	0	0	0	11	0
121006	NEWMARKET	Cost	0	0	0	0	0	0
122206	NEWMARKET	Capacity	0	0	0	0	0	0
122206	NEWMARKET	Footprint	0	0	0	0	0	0
122206	NEWMARKET	Cost	3	3	0	0	0	0
122306	NEWMARKET	Capacity	356	34	216	98	8	0
122306	NEWMARKET	Footprint	586	74	285	214	13	0
122306	NEWMARKET	Cost	15,582	1,734	5,341	8,507	0	0
122406	NEWMARKET	Capacity	1,944	0	0	0	1	1,943
122406	NEWMARKET	Footprint	1,013	0	0	0	2	1,012
122406	NEWMARKET	Cost	71,433	0	0	0	0	71,433

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Green Street (Boulevard Tree Pits with Infiltration Trench)	Future Growth (Bioretention)	Offline Facility (Hybrid Pond)	Inline Facility (Hybrid Pond)
122506	NEWMARKET	Capacity	0	0	0	0	0	0
122506	NEWMARKET	Footprint	0	0	0	0	0	0
122506	NEWMARKET	Cost	0	0	0	0	0	0
122606	NEWMARKET	Capacity	1	0	0	0	1	0
122606	NEWMARKET	Footprint	2	0	0	0	2	0
122606	NEWMARKET	Cost	0	0	0	0	0	0
122706	NEWMARKET	Capacity	123	1	91	26	5	0
122706	NEWMARKET	Footprint	187	1	120	56	9	0
122706	NEWMARKET	Cost	4,518	32	2,253	2,233	0	0
123306	NEWMARKET	Capacity	45	0	0	0	1	0
123306	NEWMARKET	Footprint	24	0	0	0	2	0
123306	NEWMARKET	Cost	1,611	0	0	0	0	0
123406	NEWMARKET	Capacity	463	80	250	54	80	0
123406	NEWMARKET	Footprint	755	174	330	117	134	0
123406	NEWMARKET	Cost	14,900	4,074	6,171	4,655	0	0
123506	NEWMARKET	Capacity	36	3	13	0	20	0
123506	NEWMARKET	Footprint	56	6	18	0	32	0
123506	NEWMARKET	Cost	410	138	272	0	0	0
123606	NEWMARKET	Capacity	6	4	0	0	3	0
123606	NEWMARKET	Footprint	12	8	0	0	4	0
123606	NEWMARKET	Cost	181	181	0	0	0	0
123706	NEWMARKET	Capacity	3,075	357	2,274	76	369	0
123706	NEWMARKET	Footprint	4,678	775	3,051	164	687	0
123706	NEWMARKET	Cost	75,467	18,161	50,763	6,543	0	0
123806	NEWMARKET	Capacity	1,363	31	1,171	41	120	0
123806	NEWMARKET	Footprint	1,971	67	1,589	89	226	0
123806	NEWMARKET	Cost	29,216	1,579	24,093	3,544	0	0
123906	NEWMARKET	Capacity	3,742	0	0	212	0	3,006
123906	NEWMARKET	Footprint	2,298	0	0	460	0	1,565
123906	NEWMARKET	Cost	148,110	0	0	18,312	0	110,505
124006	NEWMARKET	Capacity	863	7	459	191	36	0
124006	NEWMARKET	Footprint	1,210	15	623	415	68	0
124006	NEWMARKET	Cost	32,596	363	9,447	16,550	0	0
124506	NEWMARKET	Capacity	887	38	721	108	19	0
124506	NEWMARKET	Footprint	1,326	83	973	236	35	0
124506	NEWMARKET	Cost	26,794	1,942	15,462	9,390	0	0
124606	NEWMARKET	Capacity	2,092	0	0	0	14	2,078
124606	NEWMARKET	Footprint	1,105	0	0	0	23	1,082
124606	NEWMARKET	Cost	76,398	0	0	0	0	76,398
124706	NEWMARKET	Capacity	56	5	50	0	1	0
124706	NEWMARKET	Footprint	78	11	66	0	1	0
124706	NEWMARKET	Cost	1,486	249	1,236	0	0	0
124806	NEWMARKET	Capacity	2,379	0	0	0	5	2,375
124806	NEWMARKET	Footprint	1,245	0	0	0	8	1,237
124806	NEWMARKET	Cost	87,312	0	0	0	0	87,312

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Green Street (Boulevard Tree Pits with Infiltration Trench)	Future Growth (Bioretention)	Offline Facility (Hybrid Pond)	Inline Facility (Hybrid Pond)
124906	NEWMARKET	Capacity	0	0	0	0	0	0
124906	NEWMARKET	Footprint	0	0	0	0	0	0
124906	NEWMARKET	Cost	0	0	0	0	0	0
125006	NEWMARKET	Capacity	2,847	23	64	0	157	2,603
125006	NEWMARKET	Footprint	1,782	51	86	0	289	1,355
125006	NEWMARKET	Cost	98,188	1,189	1,309	0	0	95,689
125106	NEWMARKET	Capacity	332	35	284	0	13	0
125106	NEWMARKET	Footprint	472	76	375	0	22	0
125106	NEWMARKET	Cost	8,791	1,776	7,015	0	0	0
125206	NEWMARKET	Capacity	27	5	21	0	0	0
125206	NEWMARKET	Footprint	40	12	28	0	0	0
125206	NEWMARKET	Cost	806	279	527	0	0	0
125506	NEWMARKET	Capacity	65	2	23	36	4	0
125506	NEWMARKET	Footprint	119	4	31	78	7	0
125506	NEWMARKET	Cost	3,781	84	577	3,119	0	0
125706	NEWMARKET	Capacity	401	99	255	48	0	0
125706	NEWMARKET	Footprint	664	214	346	104	0	0
125706	NEWMARKET	Cost	14,402	5,015	5,244	4,143	0	0
125806	NEWMARKET	Capacity	101	48	51	0	2	0
125806	NEWMARKET	Footprint	177	104	70	0	3	0
125806	NEWMARKET	Cost	3,496	2,441	1,055	0	0	0
125906	NEWMARKET	Capacity	406	140	265	0	0	0
125906	NEWMARKET	Footprint	665	305	360	0	0	0
125906	NEWMARKET	Cost	12,603	7,144	5,459	0	0	0
126006	NEWMARKET	Capacity	233	54	180	0	0	0
126006	NEWMARKET	Footprint	356	116	239	0	0	0
126006	NEWMARKET	Cost	6,918	2,725	4,193	0	0	0
126106	NEWMARKET	Capacity	233	58	170	0	5	0
126106	NEWMARKET	Footprint	367	127	230	0	10	0
126106	NEWMARKET	Cost	6,457	2,965	3,492	0	0	0
126706	NEWMARKET	Capacity	323	31	238	46	8	0
126706	NEWMARKET	Footprint	494	67	315	99	13	0
126706	NEWMARKET	Cost	11,430	1,577	5,897	3,957	0	0

Whitchurch-Stouffville:

Basinwide SCM Implementation Recipe to Achieve 40% Phosphorus Reduction at East Holland Landing

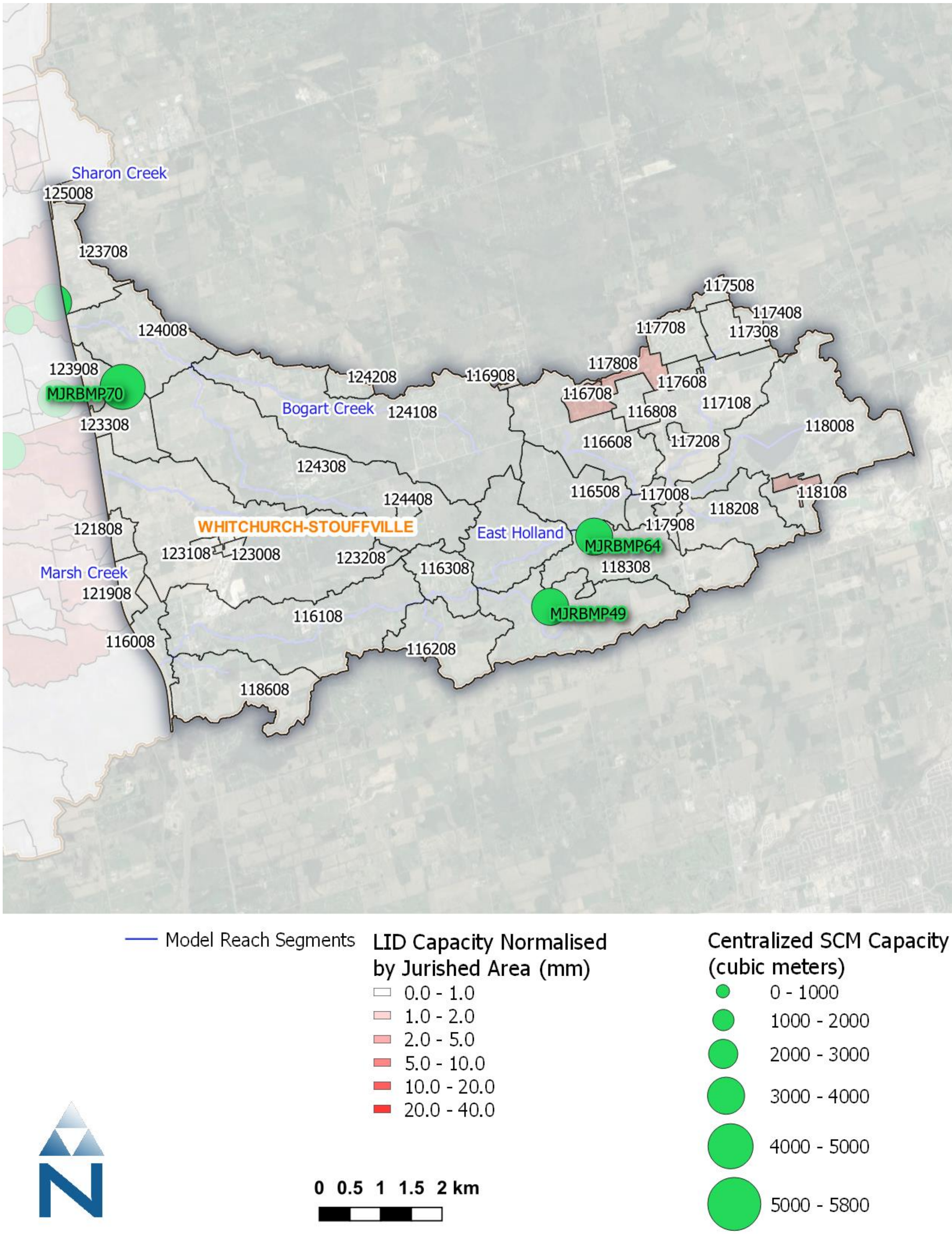


Figure 9. Heat map of SCM implementation for Whitchurch-Stouffville to achieve basinwide 40% phosphorous reduction at Holland Landing.

Figure 10. SCM footprint locations in Whitchurch-Stouffville to achieve basinwide 40% TP reduction at Holland Landing.

Table 5. SCM Implementation Recipe for Whitchurch-Stouffville to Achieve Basinwide 40% TP Reduction at Holland Landing

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration	Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)
116008	WHITCHURCH STOUFFVILLE	Capacity	0	0	0	0	0	0
116008	WHITCHURCH STOUFFVILLE	Footprint	0	0	0	0	0	0
116008	WHITCHURCH STOUFFVILLE	Cost	0	0	0	0	0	0
116108	WHITCHURCH STOUFFVILLE	Capacity	30	1,323	107	0	0	0
116108	WHITCHURCH STOUFFVILLE	Footprint	65	1,795	232	0	0	0
116108	WHITCHURCH STOUFFVILLE	Cost	1,534	27,231	9,260	0	0	0
116208	WHITCHURCH STOUFFVILLE	Capacity	0	11	76	0	0	0
116208	WHITCHURCH STOUFFVILLE	Footprint	0	16	165	0	0	0
116208	WHITCHURCH STOUFFVILLE	Cost	0	236	6,588	0	0	0
116308	WHITCHURCH STOUFFVILLE	Capacity	0	72	20	0	0	0
116308	WHITCHURCH STOUFFVILLE	Footprint	0	98	44	0	0	0
116308	WHITCHURCH STOUFFVILLE	Cost	0	1,479	1,769	0	0	0
116408	WHITCHURCH STOUFFVILLE	Capacity	0	15	0	0	0	0
116408	WHITCHURCH STOUFFVILLE	Footprint	0	20	0	0	0	0
116408	WHITCHURCH STOUFFVILLE	Cost	0	301	0	0	0	0
116508	WHITCHURCH STOUFFVILLE	Capacity	0	12	0	0	0	213
116508	WHITCHURCH STOUFFVILLE	Footprint	0	16	0	0	0	111
116508	WHITCHURCH STOUFFVILLE	Cost	0	243	0	0	0	7,817
116608	WHITCHURCH STOUFFVILLE	Capacity	3	28	476	0	0	325
116608	WHITCHURCH STOUFFVILLE	Footprint	7	38	1,034	0	0	169
116608	WHITCHURCH STOUFFVILLE	Cost	155	572	41,202	0	0	11,934
116708	WHITCHURCH STOUFFVILLE	Capacity	0	0	390	0	0	125
116708	WHITCHURCH STOUFFVILLE	Footprint	0	0	847	0	0	65
116708	WHITCHURCH STOUFFVILLE	Cost	0	0	33,729	0	0	4,592
116808	WHITCHURCH STOUFFVILLE	Capacity	41	112	197	0	0	185
116808	WHITCHURCH STOUFFVILLE	Footprint	90	152	429	0	0	97
116808	WHITCHURCH STOUFFVILLE	Cost	2,108	2,313	17,090	0	0	6,814
116908	WHITCHURCH STOUFFVILLE	Capacity	0	0	0	0	0	14
116908	WHITCHURCH STOUFFVILLE	Footprint	0	0	0	0	0	7
116908	WHITCHURCH STOUFFVILLE	Cost	0	0	0	0	0	519
117008	WHITCHURCH STOUFFVILLE	Capacity	0	15	0	0	0	37
117008	WHITCHURCH STOUFFVILLE	Footprint	0	20	0	0	0	19

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration	Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)
117008	WHITCHURCH STOUFFVILLE	Cost	0	307	0	0	0	1,370
117108	WHITCHURCH STOUFFVILLE	Capacity	298	653	1,344	0	0	386
117108	WHITCHURCH STOUFFVILLE	Footprint	647	885	2,922	0	0	201
117108	WHITCHURCH STOUFFVILLE	Cost	15,149	13,429	116,395	0	0	14,206
117208	WHITCHURCH STOUFFVILLE	Capacity	0	0	0	0	0	34
117208	WHITCHURCH STOUFFVILLE	Footprint	0	0	0	0	0	18
117208	WHITCHURCH STOUFFVILLE	Cost	0	0	0	0	0	1,239
117308	WHITCHURCH STOUFFVILLE	Capacity	112	241	0	0	0	511
117308	WHITCHURCH STOUFFVILLE	Footprint	243	327	0	0	0	266
117308	WHITCHURCH STOUFFVILLE	Cost	5,700	4,955	0	0	0	18,770
117408	WHITCHURCH STOUFFVILLE	Capacity	0	0	0	0	0	24
117408	WHITCHURCH STOUFFVILLE	Footprint	0	0	0	0	0	13
117408	WHITCHURCH STOUFFVILLE	Cost	0	0	0	0	0	887
117508	WHITCHURCH STOUFFVILLE	Capacity	0	0	0	0	0	12
117508	WHITCHURCH STOUFFVILLE	Footprint	0	0	0	0	0	6
117508	WHITCHURCH STOUFFVILLE	Cost	0	0	0	0	0	446
117608	WHITCHURCH STOUFFVILLE	Capacity	0	0	0	0	0	130
117608	WHITCHURCH STOUFFVILLE	Footprint	0	0	0	0	0	68
117608	WHITCHURCH STOUFFVILLE	Cost	0	0	0	0	0	4,781
117708	WHITCHURCH STOUFFVILLE	Capacity	0	177	0	0	0	551
117708	WHITCHURCH STOUFFVILLE	Footprint	0	240	0	0	0	287
117708	WHITCHURCH STOUFFVILLE	Cost	0	3,647	0	0	0	20,252
117808	WHITCHURCH STOUFFVILLE	Capacity	218	172	0	0	0	142
117808	WHITCHURCH STOUFFVILLE	Footprint	473	233	0	0	0	74
117808	WHITCHURCH STOUFFVILLE	Cost	11,083	3,536	0	0	0	5,233
117908	WHITCHURCH STOUFFVILLE	Capacity	0	0	0	0	0	57
117908	WHITCHURCH STOUFFVILLE	Footprint	0	0	0	0	0	30
117908	WHITCHURCH STOUFFVILLE	Cost	0	0	0	0	0	2,095
118008	WHITCHURCH STOUFFVILLE	Capacity	0	93	1,796	0	0	651
118008	WHITCHURCH STOUFFVILLE	Footprint	0	127	3,903	0	0	339
118008	WHITCHURCH STOUFFVILLE	Cost	0	1,921	155,499	0	0	23,930
118108	WHITCHURCH STOUFFVILLE	Capacity	0	3	268	0	0	72
118108	WHITCHURCH STOUFFVILLE	Footprint	0	3	583	0	0	37
118108	WHITCHURCH STOUFFVILLE	Cost	0	53	23,239	0	0	2,630

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration	Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)
118208	WHITCHURCH STOUFFVILLE	Capacity	0	0	0	0	0	55
118208	WHITCHURCH STOUFFVILLE	Footprint	0	0	0	0	0	29
118208	WHITCHURCH STOUFFVILLE	Cost	0	0	0	0	0	2,014
118308	WHITCHURCH STOUFFVILLE	Capacity	0	207	0	0	0	336
118308	WHITCHURCH STOUFFVILLE	Footprint	0	280	0	0	0	175
118308	WHITCHURCH STOUFFVILLE	Cost	0	4,250	0	0	0	12,353
118408	WHITCHURCH STOUFFVILLE	Capacity	0	72	0	0	0	3,400
118408	WHITCHURCH STOUFFVILLE	Footprint	0	98	0	0	0	1,771
118408	WHITCHURCH STOUFFVILLE	Cost	0	1,489	0	0	0	125,009
118508	WHITCHURCH STOUFFVILLE	Capacity	0	0	0	0	0	311
118508	WHITCHURCH STOUFFVILLE	Footprint	0	0	0	0	0	162
118508	WHITCHURCH STOUFFVILLE	Cost	0	0	0	0	0	11,416
118608	WHITCHURCH STOUFFVILLE	Capacity	0	55	64	0	0	0
118608	WHITCHURCH STOUFFVILLE	Footprint	0	74	139	0	0	0
118608	WHITCHURCH STOUFFVILLE	Cost	0	1,122	5,519	0	0	0
121808	WHITCHURCH STOUFFVILLE	Capacity	0	0	45	1	0	0
121808	WHITCHURCH STOUFFVILLE	Footprint	0	0	98	1	0	0
121808	WHITCHURCH STOUFFVILLE	Cost	0	0	3,904	0	0	0
121908	WHITCHURCH STOUFFVILLE	Capacity	0	0	28	0	0	0
121908	WHITCHURCH STOUFFVILLE	Footprint	0	0	62	0	0	0
121908	WHITCHURCH STOUFFVILLE	Cost	0	0	2,451	0	0	0
122808	WHITCHURCH STOUFFVILLE	Capacity	116	2,447	281	1	0	3,084
122808	WHITCHURCH STOUFFVILLE	Footprint	251	3,320	611	2	0	1,606
122808	WHITCHURCH STOUFFVILLE	Cost	5,884	50,355	24,350	0	0	113,404
122908	WHITCHURCH STOUFFVILLE	Capacity	4	12	0	0	0	188
122908	WHITCHURCH STOUFFVILLE	Footprint	8	16	0	0	0	98
122908	WHITCHURCH STOUFFVILLE	Cost	194	242	0	0	0	6,915
123008	WHITCHURCH STOUFFVILLE	Capacity	9	14	0	0	0	293
123008	WHITCHURCH STOUFFVILLE	Footprint	19	19	0	0	0	153
123008	WHITCHURCH STOUFFVILLE	Cost	456	287	0	0	0	10,780
123108	WHITCHURCH STOUFFVILLE	Capacity	11	53	0	0	0	102
123108	WHITCHURCH STOUFFVILLE	Footprint	24	72	0	0	0	53
123108	WHITCHURCH STOUFFVILLE	Cost	552	1,096	0	0	0	3,748
123208	WHITCHURCH STOUFFVILLE	Capacity	0	0	0	0	0	68

Jurished ID	Jurisdiction	SCM Detail: Capacity (m^3) Footprint (m^2) Annual LC Cost ($CAD)	LID SCMs				Centralised SCMs	
			Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)	Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration	Rooftop Capture (Infiltration Trench)	Parking Lot Capture (Infiltration Gallery)
123208	WHITCHURCH STOUFFVILLE	Footprint	0	0	0	0	0	35
123208	WHITCHURCH STOUFFVILLE	Cost	0	0	0	0	0	2,488
123308	WHITCHURCH STOUFFVILLE	Capacity	11	660	126	0	0	4,145
123308	WHITCHURCH STOUFFVILLE	Footprint	24	896	273	1	0	2,158
123308	WHITCHURCH STOUFFVILLE	Cost	556	13,584	10,879	0	0	152,389
123708	WHITCHURCH STOUFFVILLE	Capacity	0	25	842	0	0	3,859
123708	WHITCHURCH STOUFFVILLE	Footprint	0	33	1,830	1	0	2,010
123708	WHITCHURCH STOUFFVILLE	Cost	0	601	72,903	0	0	141,882
123908	WHITCHURCH STOUFFVILLE	Capacity	0	0	0	0	0	345
123908	WHITCHURCH STOUFFVILLE	Footprint	0	0	0	0	0	180
123908	WHITCHURCH STOUFFVILLE	Cost	0	0	0	0	0	12,682
124008	WHITCHURCH STOUFFVILLE	Capacity	10	227	547	0	0	455
124008	WHITCHURCH STOUFFVILLE	Footprint	22	308	1,190	0	0	237
124008	WHITCHURCH STOUFFVILLE	Cost	523	4,677	47,391	0	0	16,736
124108	WHITCHURCH STOUFFVILLE	Capacity	6	664	1,347	0	0	1,094
124108	WHITCHURCH STOUFFVILLE	Footprint	12	901	2,928	0	0	570
124108	WHITCHURCH STOUFFVILLE	Cost	282	13,662	116,634	0	0	40,231
124208	WHITCHURCH STOUFFVILLE	Capacity	0	0	0	0	0	108
124208	WHITCHURCH STOUFFVILLE	Footprint	0	0	0	0	0	56
124208	WHITCHURCH STOUFFVILLE	Cost	0	0	0	0	0	3,972
124308	WHITCHURCH STOUFFVILLE	Capacity	524	637	533	0	0	896
124308	WHITCHURCH STOUFFVILLE	Footprint	1,140	864	1,158	0	0	467
124308	WHITCHURCH STOUFFVILLE	Cost	26,702	13,102	46,122	0	0	32,954
124408	WHITCHURCH STOUFFVILLE	Capacity	0	0	0	0	0	80
124408	WHITCHURCH STOUFFVILLE	Footprint	0	0	0	0	0	42
124408	WHITCHURCH STOUFFVILLE	Cost	0	0	0	0	0	2,956
125008	WHITCHURCH STOUFFVILLE	Capacity	0	0	0	0	0	0
125008	WHITCHURCH STOUFFVILLE	Footprint	0	0	0	0	0	0
125008	WHITCHURCH STOUFFVILLE	Cost	0	0	0	0	0	0