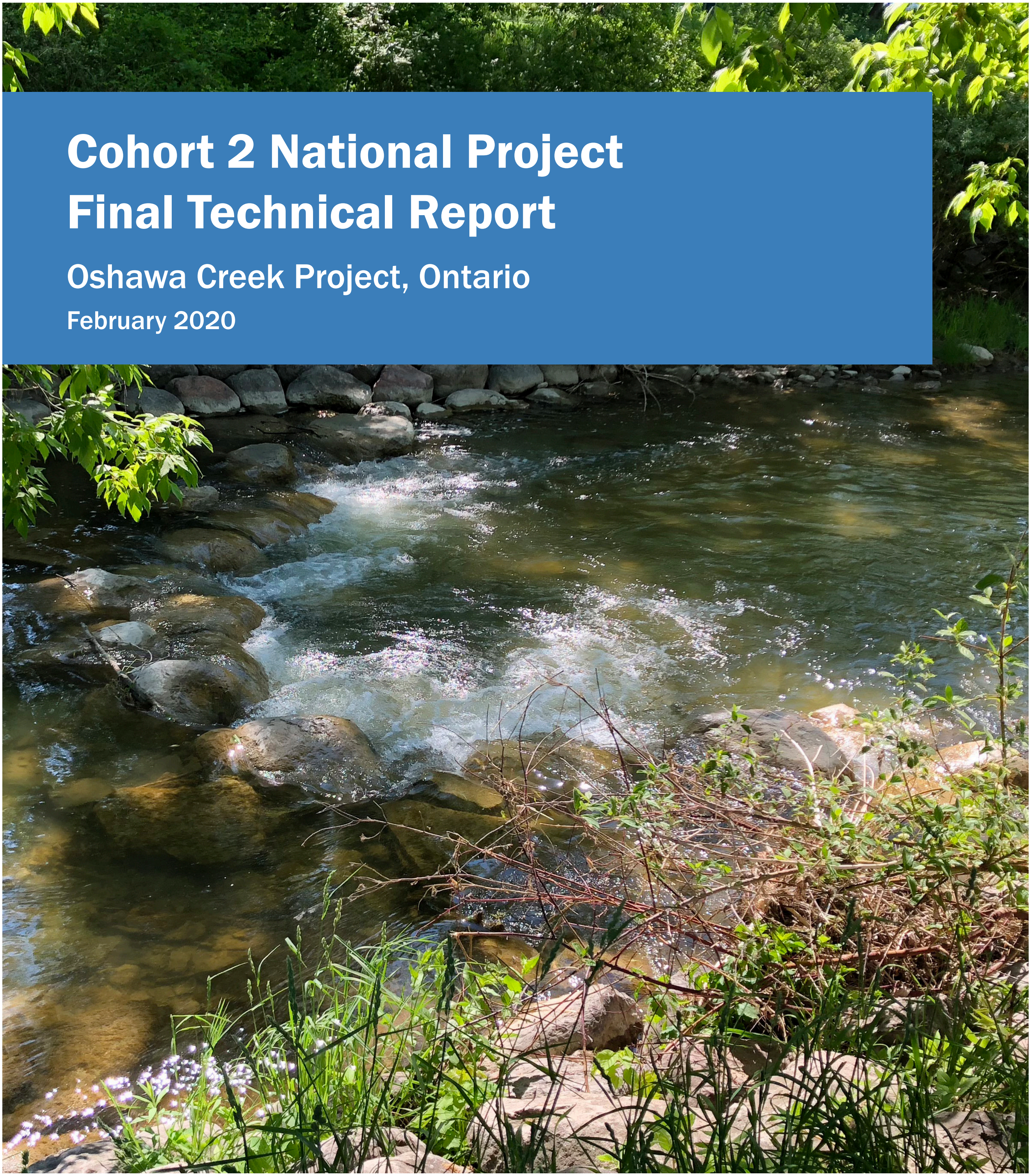
Cohort 2 National Project Final Technical Report

Oshawa Creek Project, Ontario

February 2020



Municipal Natural Assets Initiative

Making Nature Count

INVEST IN NATURE

The Municipal Natural Assets Initiative (MNAI) is changing the way municipalities deliver everyday services, increasing the quality and resilience of infrastructure at lower costs and reduced risk. The MNAI team provides scientific, economic and municipal expertise to support and guide local governments in identifying, valuing and accounting for natural assets in their financial planning and asset management programs and developing leading-edge, sustainable and climate resilient infrastructure.

Acknowledgements

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Summary

The Province of Ontario implemented the Asset Management Planning for Municipal Infrastructure Regulation, O. Reg. 588/17 to help municipalities plan for their infrastructure.

The regulation requires all Ontario municipalities to prepare an asset management plan for core infrastructure assets by July 1, 2021, and in respect of all other municipal infrastructure assets by July 1, 2023. The definition of core municipal infrastructure found in the regulation includes water, wastewater, and stormwater management assets, including green infrastructure assets, as well as roads, bridges, and culverts. The regulation defines green infrastructure as infrastructure assets consisting of natural or human-made elements that provide ecological and hydrological functions and processes.

Consistent with this new regulatory requirement, the City of Oshawa worked with the Municipal Natural Asset Initiative (MNAI) to better understand the condition, function and value of the riparian area and stream banks along the Oshawa Creek south of Oshawa's downtown core.

The project focus was on the current role of these natural assets in reducing erosion and maintaining water quantity and quality, and to identify opportunities to improve both through natural asset management and low impact development practices.

The inventory, assessments and modelling indicate that the 7 km project area in the Oshawa Creek, excluding the floodplain, has a current value of $18.9 million in terms of current stormwater conveyance services. Operations and maintenance data was not available and therefore lifecycle costs comparisons were not possible. The total value of Oshawa Creek watershed *including* both the creek and surrounding floodplain, ranges between $392 million and $414 million.

This value relates only to stormwater management and does not include many co-benefits provided by the natural assets in the corridor including the following:

- Reduced flood risk by storing flood waters
- Habitat for aquatic and terrestrial organisms
- Improving aesthetics of creek corridors
- Improved human health and well-being through recreational opportunities, air quality/cooling/shade; and, connecting priority neighbourhoods

Importantly, some of the co-benefits can create particular value for areas identified as Priority Health Neighbourhoods.

Under the current watershed management program, the City of Oshawa provides funding to restore erosion sites along the creek, but work is largely remedial and reactive. Therefore, through this project, additional preventative measures to protect against erosion have been identified and modelled in City-owned riparian lands to improve the function of natural assets. These included the development of infiltration trenches, although the analysis suggests that these would need to be developed upstream of the project area for maximum effectiveness.

1. Introduction

The term “municipal natural assets” refers to the stock of natural resources or ecosystems that is relied upon, managed, or could be managed by a municipality, regional district, or other form of local government for the sustainable provision of one or more local government services (MNAI, 2017). Conceptualizing nature as an asset, makes it possible to codify, measure, and monitor the ways in which communities depend on and impact the environment. Business and economic activity depends on natural assets to provide important inputs into production such as clean water, minerals, and timber. Natural assets are also important to human physical and social well-being. Benefits in terms of better air quality, water quality and climate stability as well as protection from flood and erosion impacts of extreme weather events are well established. Urban greenspaces, parks, wetlands and protected areas provide important recreation spaces and buffer the effect of extreme heat in urban settings reducing the prevalence of respiratory infections and heat related illnesses. If natural assets are not managed responsibly, their value depreciates and their ability to provide services from which humans benefit will diminish. Indeed, like any asset, natural assets need to be carefully managed to ensure a sustainable supply of services.

Communities like Oshawa, ON recognize that it is as important to understand, measure, manage and account for natural assets as it is for engineered ones. The MNAI Oshawa Creek project (the project) was initiated by Oshawa to increase their understanding of how proper management of the natural assets within the community do, or could, contribute to stormwater services. This report summarizes the technical results of the project and is organized as follows:

- This **Introduction** chapter describes the project area, the project objectives and provides a brief overview of the relevant natural assets.
- The **Approach** chapter describes the overall MNAI framework, as well as the modelling approach.
- The **Natural Assets Assessment** chapter describes the quantity and condition of natural assets in the project area.
- The **Planning for Natural Assets** chapter provides modelling results for current and future conditions, as well as an analysis of erosion mitigation options.
- The **Implementation of Natural Assets Plan** chapter describes the challenges that may limit the implementation of the natural asset plan as well as strategies for overcoming those challenges.
- The **Conclusion** chapter summarizes the key findings and outcomes of the project and articulates next steps and key priorities for the City of Oshawa.
- **Appendices** contain additional information of relevance to the project.

Project Context

The City of Oshawa is located on the Lake Ontario shoreline approximately 60 kilometers east of downtown Toronto. It is the largest municipality in the Regional Municipality of Durham and lies in the eastern portion of the Greater Toronto Area and the Golden Horseshoe, housing a population of 172,434 (City of Oshawa, 2019). The city has a diversified economy in the manufacturing, knowledge, health and technology-based sectors, with strong growth projections for the coming years. (City of Oshawa, 2015). The City of Oshawa is responsible for a diverse array of capital assets essential to the delivery of services to residents, businesses and visitors.

The Province of Ontario implemented the Asset Management Planning for Municipal Infrastructure Regulation, O. Reg. 588/17, effective January 1, 2018. The goal of this regulation is to help improve the way municipalities plan for their infrastructure.

The regulation requires all Ontario municipalities to prepare an asset management plan for core infrastructure assets by July 1, 2021, and in respect of all other municipal infrastructure assets by July 1, 2023. The definition of core municipal infrastructure found in the regulation includes water, wastewater, and stormwater management assets, including green infrastructure assets, as well as roads, bridges, and culverts. The regulation defines green infrastructure as infrastructure assets consisting of natural or human-made elements that provide ecological and hydrological functions and processes (MNAI, forthcoming).

Definitions

The Province of Ontario defines a Green infrastructure asset as an infrastructure asset consisting of natural or human-made elements that provide ecological and hydrological functions and processes and includes natural heritage features and systems, parklands, stormwater management systems, street trees, urban forests, natural channels, permeable surfaces and green roofs.

MNAI defines natural assets as ecosystem features that are nature-based and provide services that would otherwise require the equivalent of engineered infrastructure. For local governments, natural assets can include forests that convey stormwater and recharge aquifers, wetlands that reduce flooding risk, and coastal areas that protect against storm surges and sea level rise, among others. By identifying natural assets at the community level and prioritizing those in municipal asset management portfolios, local governments can secure important budget savings while also delivering vital municipal services. They will also be better prepared to deal with the local effects of climate change (MNAI 2018).

The Municipal Natural Assets Initiative (MNAI) is changing the way municipalities deliver everyday services, increasing the quality and resilience of infrastructure at lower costs and reduced risk. The MNAI team provides scientific, economic and municipal expertise to support and guide local governments in identifying, valuing and accounting for natural assets in their financial planning and asset management programs and developing leading-edge, sustainable and climate resilient infrastructure.

The City has an Asset Management Plan (AMP) that supports the City’s corporate strategic direction. It includes reports on the state of the City’s assets, how the City manages those assets to satisfy desired service levels, and how the City plans to invest in those assets. The AMP is intended to inform the current budget year and the nine-year capital forecast. As per O. Reg. 588/17, the City is working to achieve phase-in for municipalities to have approved asset management plans for all municipal infrastructure assets, including green infrastructure assets, by 2024.

As part of the City’s commitment to asset management, the City is committed to understanding the role of natural assets and the services they provide. Oshawa’s Strategic Plan identifies the need to manage and fund present and future assets, including parks and open spaces in order to ensure safe and reliable infrastructure. By working with MNAI, the City hopes to apply similar attention to natural assets as is applied to typical engineered assets, consistent with the new regulatory requirement.

The City also recognizes that river and creek corridors, wetlands, urban forests and greenspaces provide valuable habitat for wildlife and fish, improve water quality and provide flood attenuation and erosion control. The latter are understood to increase the City’s resilience to climate change, and in highly urbanized areas, such natural assets can be an important part of a sustainable infrastructure strategy. Although the capacity of natural systems to supply infrastructure-related services is compromised by urban impacts, they can still play an important role in minimizing costs and supply important co-benefits to the population.

Natural Asset Focus

The Oshawa Creek and its tributaries drain an area of approximately 119-square-kilometer watershed from its headwaters in the Oak Ridges Moraine (OMR) south through the Lake Iroquois Beach and into Lake Ontario. he Oak Ridges Moraine and the major Oshawa Creek valley lands are recognized as part of the Greenbelt Area.

Oshawa Creek is a prime conveyance of stormwater to Lake Ontario and as such provides a necessary service to the City as part of the City's stormwater management process.

The entire length of Oshawa Creek is approximately 50 km. Of this, the southernmost 7 km segment, located within the Oshawa Main Subwatershed of the Oshawa Creek Watershed (see Figure 1), was identified as the area of focus for the project This segment is between Adelaide Avenue West and Oshawa Harbour, covers 7% of the watershed and contains 41 outfalls that drain roughly 450 hectares of urban residential and commercial land (City of Oshawa, 2018). Thus, the creek itself and the riparian area and floodplain immediately surrounding it are the natural assets of principle interest.

The subwatershed within which the 7 km segment resides is typical of a highly urbanized creek area, with numerous impervious areas and landscape extensively influenced by residential and commercial developments.

More specifically, the southern portion of the subwatershed is dominated by urban land uses. This portion of the Creek and its surrounding floodplain is located in a highly urbanized area and lacks the stormwater controls typically seen in new developments. Within the creek corridor is a floodplain, the majority of which is managed by the City as parks and naturalized areas. This space may provide opportunity to manage stormwater and increased creek flow which is expected as development continues upstream.

The northern half of the subwatershed is agricultural, with a large area currently under development. Developments upstream of the project area will have, as a condition of construction, new engineered storm water management ponds to manage both the quantity and quality of stormwater prior to entering the Oshawa Creek. The required stormwater ponds constructed upstream will be sized to manage effectively both the quality and quantity of water, as consideration of downstream impacts are essential to minimizing downstream erosion, flooding, water quality degradation and habitat loss, and maintaining natural flows.

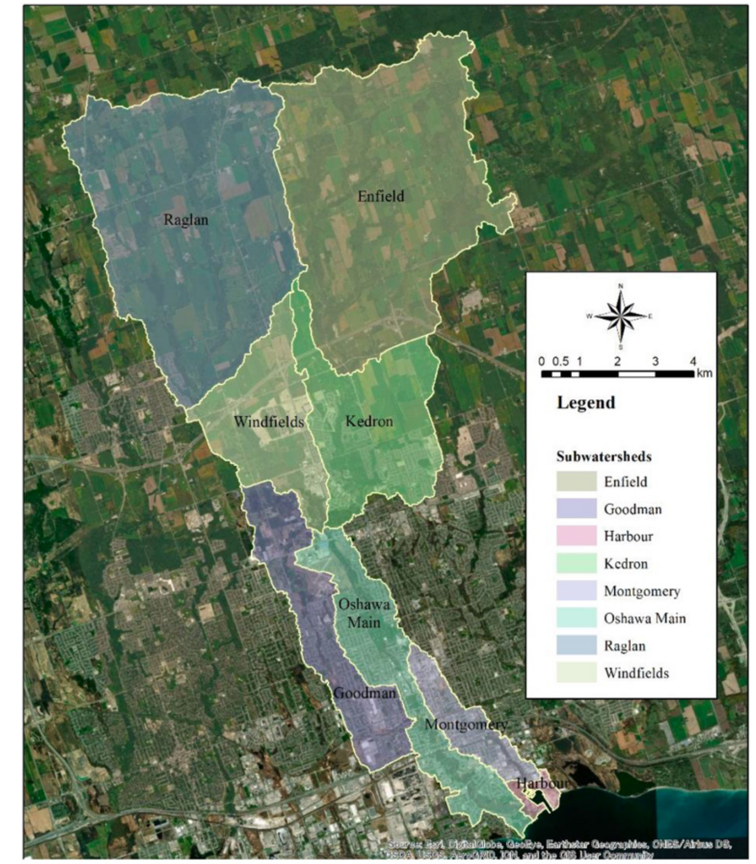


Figure 1. The Oshawa Creek Watershed. Source: CLOCA

Project Goal and Objectives

The City of Oshawa wants to increase their understanding of how proper management of the natural assets within the community do, or could, contribute to stormwater services.

The goal of the Oshawa MNAI project is to increase the quality and resilience of the riparian area and stream banks along a 7km segment of Oshawa Creek south of Oshawa's downtown core to minimize erosion from more frequent storm events. A key aspect of the project is to look for natural asset-based opportunities within this area to manage stormwater quantity and quality, potentially including low impact development (LID) practices.

Objectives in support of this goal were to:

- Inventory natural assets in the creek areas of focus;
- Determine the potential of inventoried natural assets for protection and restoration activities to manage stormwater from smaller, more frequent (1-5 year) storm events;
- Determine erosion minimisation benefits from potential protection and restoration activities;
- Determine how these erosion minimization benefits could offset engineered erosion control measures (e.g. armor stones or Gabion walls) and associated costs;
- Based on the foregoing, prioritize projects and/or operations and maintenance (O&M) activities to minimise erosion and maximise cost savings to the City

2. Project approach

This section of the document describes the approach employed in the Oshawa project. An overview of the MNAI approach is provided along with a more detailed description of the modelling work that was completed.

MNAI Approach

MNAI's natural asset methodology is rooted in modern, structured asset management processes. The methodology generally follows the standard asset management assess, plan and implement steps, highlighting novel considerations required for local natural assets and associated services.

MNAI has a range of tools, including templates and guidelines,that are configured for use according to local government needs. The methodology and tools are delivered through ongoing support from the MNAI technical team over the project life. The levels and details of this support are described in a Memorandum of Understanding that MNAI signs with local government partners.

Asset management require a multi-disciplinary, team-based approach. MNAI's process begins with an initial engagement session with local government representatives from numerous disciplines. This includes, for example, Parks, Public Works, Geographic Information Systems (GIS), Engineering, Planning, Water and Wastewater, and Finance. During the initial engagement session, plans and priorities of the community are discussed, key natural assets within the jurisdictional boundaries of the community are identified along with the important services those assets provide. Site visits to areas containing important natural assets may be undertaken and key geospatial features observed and documented. The objectives of this initial engagement session are to identify:

- natural asset(s) that will be the focus of the natural asset assessment
- geographic boundary/ies of the focus assets
- skillsets and expertise of relevance to the natural asset assessment
- local government personnel that will engage in the assessment process
- data needs of the assessment and the sources for the relevant data

The initial community engagement session for the project took place on May 29, 2018. It was attended by representatives from departments including Operation Services such as parks and public works, Engineering Services including staff responsible for infrastructure asset management and water resources, representatives from the Central Lake Ontario Conservation Authority (CLOCA), the TeachingCity Initiative[1] and local universities. Appendix A contains the agenda for the session and a list of participants.

1 https://www.oshawa.ca/business-and-investment/teaching-city.asp

Following the initial community engagement session, the MNAI team works with local government partners to complete, as a first step, *a natural asset assessment*. This involves:

1. Defining the scope of natural assets to be considered
2. Inventorying and conducting a condition assessment of the assets
3. Quantifying existing service levels from the assets, as well as co-benefits
4. Quantifying the financial value of the natural assets if the services they provide had to be delivered by an engineered alternative
5. Developing scenarios to explore alternative management plans and future implications for existing service levels
6. Quantifying services levels under alternative scenarios
7. Developing operation and management (O&M) plans based on existing conditions, risks, and desired service level trajectories

These steps were completed for Oshawa with a focus on understanding stormwater conveyance services provided by the identified creek segment. O&M plans were not completed due to time and capacity restrictions. Modelling was completed by a graduate student of the University of Toronto's Department of Civil Engineering.

Modelling natural assets

The City of Oshawa engaged the TeachingCity Initiative for modelling assistance. TeachingCity is a collaborative partnership which brings together the City of Oshawa and its education and research partners to address urban issues. Through the TeachingCity, a graduate student from the University of Toronto's Department of Civil Engineering completed modelling for the project under the guidance of a professor. The modelling was completed in two phases using hydrology and hydraulics model from the Central Lake Ontario Conservation Authority (CLOCA; see Appendix B for Oshawa Creek Hydrologic and Hydraulic Modeling Briefs), as described below (Monri & Karney, 2019).

Phase 1: Understanding the services provided by the Oshawa Creek and their value

The objective of the first phase of the project was to understand current services provided by the identified area of the Oshawa Creek, and the value of these services if they had to be delivered by engineered alternatives. This was achieved using estimates of creek restoration projects.

Steps for this phase were:

1. **Determine the stormwater management functions that are provided by the creek and its surrounding floodplain system**. These functions can include conveyance capacity, flood mitigation to surrounding properties, peak flow attenuation, and water quality treatment. The basis for this included:
    a. the Oshawa Creek Watershed Plan;
    b. the Oshawa Creek Hydrologic and Hydraulic Modelling brief; and,
    c. existing hydrologic and hydraulic models.
2. **Model land-use and climate change scenarios that increase stressors to the system**. This establishes the extent to which the creek system can adapt to changing conditions without compromising its health and integrity. The scenarios considered were:
    a. **Scenario 1: Existing land use conditions under current climatic conditions.** This models the creek system under existing land use and current climatic conditions, as described within the Oshawa Creek Watershed Plan and Oshawa Creek Hydrologic and Hydraulic Modelling reports.
    a. **Scenario 2: Future land use conditions under current climatic conditions.** This models the creek system under full Official Plan build-out conditions and current climatic conditions, as described within the Oshawa Creek Watershed Plan and Oshawa Creek Hydrologic and Hydraulic Modelling reports.
    a. **Scenario 3: Future land use conditions under future climatic conditions.** This models the creek system under full Official Plan build-out as with Scenario 2, and considers rainfall conditions that incorporate climate change projections.
3. Determine the value of the creek's functions. This is achieved by determining the cost and scale of engineered assets required to provide comparable service as the natural assets; and by considering any limits to how much the natural assets can adapt, as identified in Step 2, above. Functions that cannot be replaced by engineered infrastructure are also identified.

Phase 2: Improvement Strategies

Phase 2 focused on identifying options for improving the health of the creek system to increase stormwater management functions, particularly in areas without engineered capacity. This phase evaluated the effectiveness of implementing preventative measures along the sewer outfalls to the creek to prevent erosion and improve stream stability. Through this project, existing erosion control measures were studied and critiqued, an erosion control performance index was identified, and the influence of implementation was explored through a sensitivity analysis.

3. Natural Asset Condition Assessment

The condition of natural assets influences their provision of services and resilience to threats. A condition *assessment* examines how well assets function in relation to their ability to provide such services and can be used to model changes in service provision that may result from interventions to improve asset condition, or impacts that diminish asset conditions.

Condition assessments considered natural and built assets within the Oshawa Creek Corridor from Adelaide Avenue west to Oshawa Harbor that increase water storage and reduce total and peak water flows during rainfall events to prevent flooding and stream bank erosion.

The condition assessment was to be completed following modelling results, originally scheduled for May 31st, 2019. Delays in the modelling prevented the MNAI technical team from completing a standard natural asset inventory and condition assessment as originally scoped. As such, the condition assessment of the broader watershed, compiled by the modeller for Phase 1 is provided below and summarized in Table 1.

Current Watershed Conditions

The Oshawa Creek Watershed Plan (CLOCA, 2013b) is the primary source of information on the current condition of the creek and its upstream watershed. While the Oshawa Creek Watershed Plan speaks to the conditions of the entire watershed, sections that are relevant to the present project are summarized in the following sections.

- **Water Quality:** The creek exhibits evidence of historical water quality degradation caused by untreated sewer discharge, contaminated stormwater, and nutrient enrichment from agricultural practices. In addition, copper, phosphorous, and nitrates concentration exceedances, as well as high chloride content can be observed in the lower reaches downstream of highly urbanized land uses. As of 2013, dissolved oxygen levels were not critical, but previous lows had reached critical levels.
- **Fish habitat and water temperature:** Oshawa Creek is home to approximately 35 fish species, including some invasive species. The creek has cold water habitats in the upper and middle reaches where the land consists primarily of natural cover. The lower areas closer to the urban core show evidence of temperature degradation and are considered a cool water habitat.
- **Land use:** The overall imperviousness of the watershed is estimated at 13%, with Oshawa Main being the third-most impervious subwatershed at 39% (see Figure 1). It is anticipated that any future development within this subwatershed will be infill or intensification due to its current highly urbanized condition. As such, the imperviousness should not increase significantly. The watershed also consists of about 15% forest cover and 17% natural cover. Most of these are located within the ORM and the Greenbelt, which are provincially protected natural features at the upper reaches of the watershed.

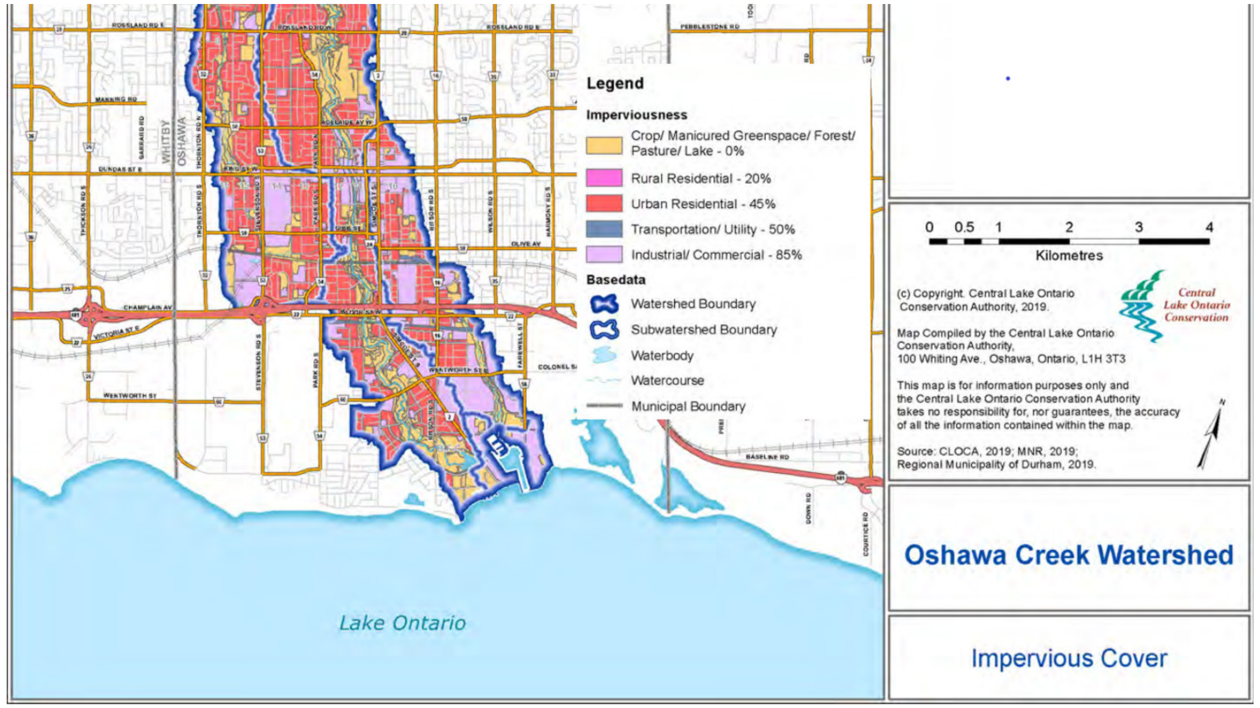


Figure 2: Oshawa Creek Watershed Impervious Cover. Source: CLOCA

- **Flood management:** Regulatory floodplains are established by taking the greater of the water surface elevation anticipated as a result of the 100-year design storm and the regional storm. The floodplain delineation has also identified Flood Damage Centers, which are locations identified to be flood-prone.

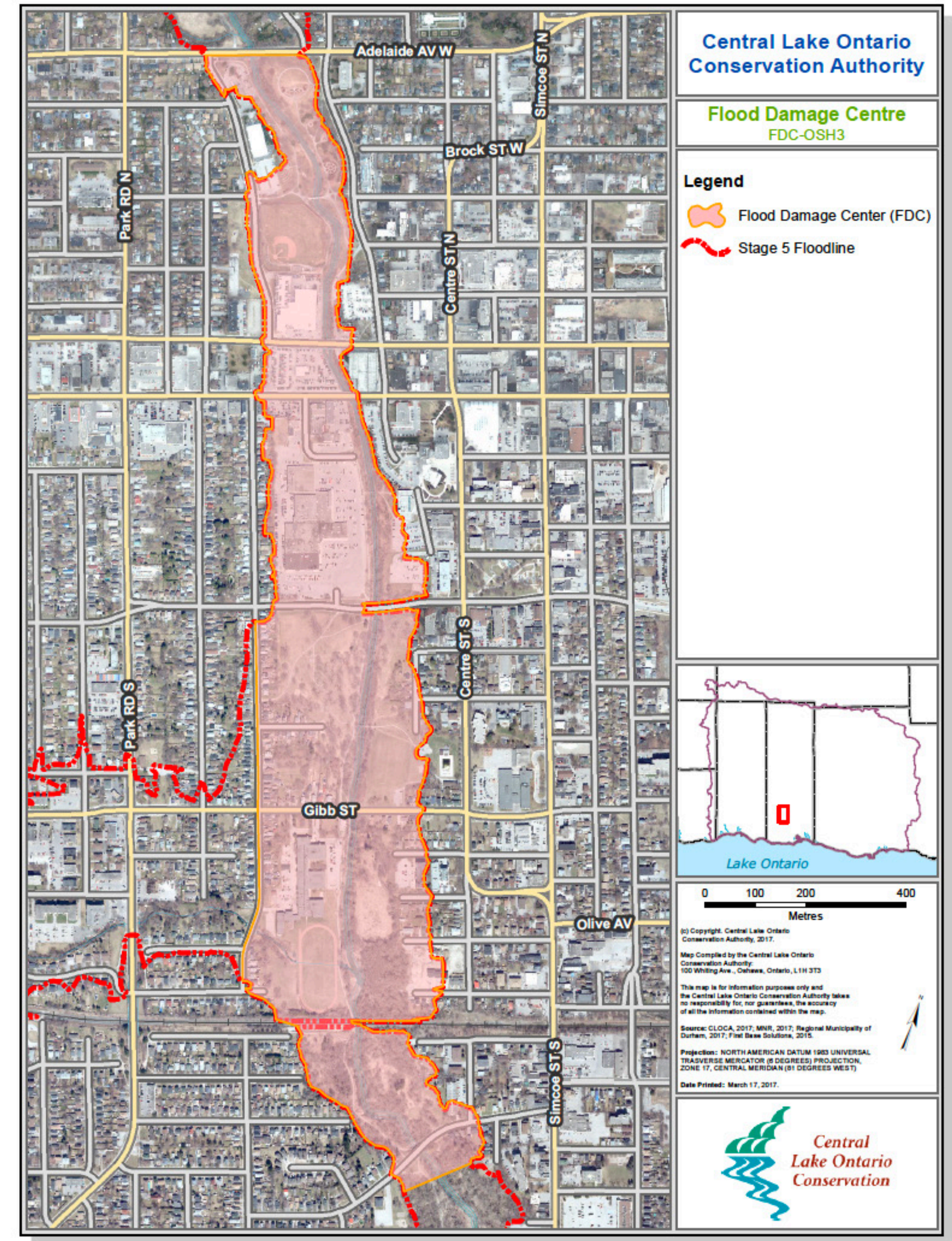


Figure 3: Flood damage centres. Source: CLOCA, Draft Watershed Plan

Watershed Targets

Oshawa Creek targets in the CLOCA watershed plan are based on recommendations from Environment and Climate Change Canada and the provincial government and balanced with the local context (CLOCA, 2013b). Notable recommendations are as follows:

- **Target for 30% natural cover:** While the recommendation is to have 30% forest cover, given the current forest cover of 15%, doubling the forest cover would likely prove to be impractical. Aiming to increase natural cover to 30% is more realistic and could potentially lead to a higher percentage of forest cover in the future;
- **Target for 10% wetland cover:** As the current wetland cover is at 7%, the recommended amount of wetland cover was determined to be achievable;

- **Target for less than 10% imperviousness on ORM and Greenbelt:** Environment and Climate Change Canada's recommendation is to have no more than 10% imperviousness over the watershed. While the current imperviousness of the watershed is 13%, the lower reaches are highly urbanized. This is planned to be offset by maintaining a low rate of imperviousness in the upstream reaches;
- **Target for sufficient riparian cover:** 75% of the creek's stream length should have sufficient riparian cover, consisting of a 30-meter buffer on both sides of the stream. While only 30% of the stream length has the full 30-m buffer, riparian cover enhances the hydrologic function of the creek system, and as such, this target has remained unamended. Current land uses within this 30 m zone consists of urban, recreational, agricultural, and natural land uses, among others;
- **Stormwater management targets**
  - Enhanced (Level 1) protection is required for water quality. Generally, locations that do not currently have on-site water quality treatment are those built prior to the implementation of the control targets;
  - In all tributaries other than Oshawa Main, quantity control for the 2- through 100-year return period events are required.

TABLE 1 – OSHAWA CREEK WATERSHED CONDITION ASSESSMENT		
Indicator	**Target**	**Assessment**
Water quality	Under development	Creek exhibits evidence of historical water quality degradation caused by untreated sewer discharge, contaminated stormwater, and nutrient enrichment from agricultural practices.
Fish habitat & water temperature	Under development	Creek is home to approximately 35 fish species, as well as invasive species. The creek has coldwater habitats in the upper and middle reaches where the upstream land use consists primarily of natural cover. The lower reaches closer to the urban core shows evidence of temperature degradation.
Land use	10% imperviousness over the watershed	Oshawa Main subwatershed has 39% impervious surfaces.
Forest cover	30% forest cover	Current forest cover of 15%
Wetland cover	10% wetland cover	Current wetland cover of 7%
Riparian cover	75% of creek's stream length should have a 30-meter buffer on both sides of the stream	30% of the stream length has the full 30-m buffer

Implementation Actions

The following implementation actions have been identified within the watershed plan for CLOCA and relevant municipalities (CLOCA, 2013b):

- CLOCA is to ensure that special watershed health objectives can be achieved, such as the Urban Land Use and Low Impact Development Retrofits Plan, Imperviousness Report Card, and the Stormwater Management Performance Monitoring and Maintenance Plan.
- Oshawa is to ensure that any pertinent recommendations from the Watershed Plan are incorporated into the city's Official Plan.

CLOCA is currently updating the Watershed Plan for Oshawa Creek. This was released in Draft for comment on November 18, 2018 (https://www.cloca.com/watershed-plan-updates-splash-page).

Assessment of Natural Asset Conveyance Services

This section examines the extent of stormwater management functions that are provided by the creek and its surrounding floodplain system including conveyance capacity, flood mitigation to surrounding properties, peak flow attenuation, and water quality treatment. The regulatory event is determined to be the greater of the 100-year design storm or the "regional storm," which is understood to mean a major event, specifically the 1954 Hurricane Hazel.

Table 2 below provides peak flow and time to peak rates using Visual OTTHYMO's event-based model. Table 3 provides change in velocity and water surface elevation using Hydrologic Engineering Center's River Analysis System (HEC-RAS) modelling.

TABLE 2 - PEAK FLOW CHARACTERISTICS FOR EXISTING CHANNEL				
Description	**Peak Flow Rates [m³/s]**		**Time to Peak [hours]**	
	2-Year	**Regulatory**	**2-Year**	**Regulatory**
OM4 (36)	38.7	637	10.5	12.5
OM3-DS of Goodman (38)	42.5	674	10.5	12.5
OM2 (39)	39.1	672	11.0	12.5
OM1 (40)	39.0	672	11.3	12.5

TABLE 3 - VELOCITY AND WATER SURFACE ELEVATION				
Location	**Velocity [m/s]**		**Water Surface Elevation [m]**	
	2-Year	**Regulatory**	**2-Year**	**Regulatory**
Adelaide	0.37	2.91	101.77	107.45
King	0.39	3.08	98.53	100.86
CPR	0.89	5.84	94.09	100.06
Highway 401	1.16	4.04	90.69	98.13
CNR	0.91	5.92	89.97	95.87
Wentworth	1.08	4.94	81.69	89.28
Simcoe St.	0.55	1.36	76.01	78.23

Value of Oshawa Creek's current stormwater conveyance services

Replicating the assessed services of the Oshawa Creek is best approximated by a concrete-lined channel with naturalized embankments and buffer zones. Whereas the typical MNAI approach to valuation involves sizing an engineered alternative to provide an equal level of service, the modeller chose to follow a different approach that completed the valuation based on a range of high-level cost estimates for creek reconstruction based on reference projects. It is important to note that this approach is separate from the modelling results. The following results were reported in *Phase 1: Valuation of Oshawa Creek Report* (Monri & Karney, 2019b)

Capital valuation of infrastructure alternatives

Determining the value of services provided by natural assets in the Oshawa Creek corridor requires consideration of both the value of Oshawa Creek and the floodplain surrounding it.

Totalling these values provides a service value estimate for the project area.

Importantly, this estimated value only accounts for the potential construction cost of engineered assets. It does not account for the value of features such as access to green and recreational space for residents, hydraulic detention, and water quality functions, consideration of which would increase the recorded value.

Valuation of Oshawa Creek for flow conveyance

A survey of creek rehabilitation and restoration projects was conducted to gather data on the cost of constructing open channels, ensuring that the creek had a comparable flow rate to Oshawa Creek (see Appendix C for data extracted from sample projects). Many projects initially identified as possible references were discounted as their flow rates were too small to provide a comparison for Oshawa Creek. As a guideline, projects included in the data collection met the following criteria:

- Documentation on the project's description, flow rates, width of channel, and length of construction were publicly available;
- Flow rates were generally within one-third to one-half of Oshawa Creek's 2-year and regional storm flows; and
- Proposed works included channel realignment works.

A regression analysis was then completed to approximate a model between common parameters used to characterize a creek, and the cost of constructing the channel.[2] The final regression model to estimate the cost of the creek was determined to be as follows, with full details of the regression analysis provided within Appendix C:

Project Cost [$] = −1,697,000 + 2,400 [Channel Length (m)] + 149,000 [Channel Width (m)]

Based on this model, which has an $R2$ value of 95.9% indicating a high degree of explanation for the overall variability, the estimated value of the project area (7 km) of Oshawa Creek [excluding the floodplain] is $18.9 million.

Resulting values were then compared to "rule-of-thumb" costs used by practitioners in southern Ontario. Three sources of generalized linear-meter cost estimates for the construction of natural channels were obtained and are presented in Table 4.

TABLE 4 - RULE OF THUMB COST ESTIMATES

Source	Cost per linear meter	Project Value of Oshawa Creek Stormwater Services
Wilket Creek Geomorphic Systems Master Plan, Appendix G: General Cost Estimates	$2,500 to $3,500	$21 million
Interview with natural channel design consultant	$3,000 to $5,000	$28 million
Interview with a contractor specializing in natural channel construction – for channels around 6 m wide with armour stone channel banks	Approximately $3,750	$26.2 million
Average Values	$3,580	$25.1 million

Compared to the rule-of-thumb estimate of $25.1 million, the value of Oshawa Creek estimated through linear regression is between 10% and 30% lower. "Rule-of-thumb" estimates are difficult to prove from the standpoint of a rigorous scientific analysis but should not be considered less accurate for the purposes of this project, as these estimates are the result of the professional judgement of engineers in the field.

2 All studies used Canadian dollars unadjusted to 2019 dollars

Comparison with Vaughan Metropolitan Centre Black Creek Renewal Class EA

A third step to arrive at the value of stormwater services was completed. The Vaughan Metropolitan Center Black Creek Renewal Class EA (hereafter referred to as VMC Black Creek Renewal) was eliminated from the regression analysis due to the overall project cost being an outlier. Nonetheless, this project is still valuable for comparative purposes, as it is the only project that considered full channel realignment. As such, this project will incorporate cost items that would not have been considered for creek rehabilitation and restoration projects. The following cost items were extracted from the capital cost estimate for VMC Black Creek Renewal, and extrapolated for the length of Oshawa Creek, to provide an estimated value of Oshawa Creek assuming greenfield conditions:

- **Land Value**
  - A per-hectare cost of $2.7 million has been used to capture the value of the land upon which the creek and the surrounding system is built (TMIG, 2018). As an asset to the city, the value of the floodplain land should be an important cost to consider. While land values in Oshawa and Vaughan are likely different, applying this value to the floodplain of Oshawa Creek would add $248 million to the value of the creek. This was calculated based on the 7-kilometer creek length, an average floodplain top width of 190 meters during the Regional storm and the percent of land requiring purchase by the City. These values were also added to the Creek Rehabilitation and Rule-of-Thumb estimates in table 3 below.
- **Cost of Greenfield Channel Works**
  - While similar to the costs presented in Table 3 below, an estimate of $5,000 per linear meter is used for the realignment, earthworks, and restoration of a channel with naturalized embankments assuming greenfield conditions. Projecting this cost to Oshawa Creek would be $35 million.
- **Cost of Naturalized and Urban Buffers**
  - The projects used in the regression analysis were mostly creek rehabilitation projects, and as such, they did not incorporate the cost of buffer zones surrounding the creek system and the surrounding properties. The land surrounding Oshawa Creek is mostly parkland with urban land uses surrounding the northern edge of area of interest. Assuming that 15% of the creek's length would require an urban buffer while the remainder is naturalized, the estimated value of this item would be $9.7 million. These values were also added to the Creek Rehabilitation and Rule-of-Thumb estimates in table 3 below.
- **Contingency**
  - A contingency of 30% to the subtotal thus far of $403.7 million is $121.1 million. A 30% contingency was also added to the Creek Rehabilitation and Rule-of-Thumb estimates to cover the monetary impacts of project risks or uncertainties. Valuation estimates are presented in Table 5 below.

TABLE 5 - VALUATION ESTIMATES

Natural Asset	Cost	Creek rehabilitation or restoration projects with Regression Analysis	Comparison with Rule of Thumb Estimates	Comparison with Vaughan Metropolitan Center Black Creek Renewal Class EA
Oshawa Creek:	Flow conveyance	$18.9 million	$25.1 million	$35 million
Floodplain	Land purchase	$248 million	$248 million	$248 million
Channel	Cost of naturalized & urban buffers	$9.7 million	$9.7 million	$9.7 million
	Contingency (30%)	$116.3 million	$118.1 million	$121.1 million
Total		$392.9 million	$400.9 million	$413.8 million

Based on the above three items and the contingency amount, *the total value of Oshawa Creek watershed, including both the creek and surrounding floodplain, ranges between roughly $393 million and $414 million*. This figure assumes greenfield construction. While this is an extrapolation of costs based on numbers used for a single project in an area with different land use planning goals, it highlights the importance of considering the value of the land on which the creek resides, as opposed to solely the construction costs.

Valuation Limitations:

The estimated value of the creek presented within this section is an "order of magnitude" estimate for the construction of a naturalized channel and the following limitations are noted:

- Whereas the MNAI approach typically involves sizing an engineered alternative to provide an equal level of service, the Oshawa project identified an engineered alternative, and then assessed how the level of service would compare to that of the existing natural asset.
- An estimate for a concrete-lined channel for a creek of this size could not be obtained, as the construction of such structures have fallen out of practice. The costs are estimated by analysing cost estimates found in Appendix C, and comparing this estimate to "rule-of-thumb" estimates received from consultants specializing in this field in Southern Ontario, provided in Table 5 above.
- The flow rates for the studies listed in Appendix C were generally within one-third to one-half of Oshawa Creek's 2-year and regional storm flows, implying additional measures would be required to meet regulatory storm event.
- All studies referenced are in Canadian dollars, but they were not adjusted to 2019 dollars. To improve the accuracy of estimates, values should be provided in 2019 dollars.
- Project costs listed in Appendix C were derived from preliminary estimates, most commonly derived as part of an Environmental Assessment. As such, this linear regression model is a second layer on the initial estimate. The high $R2$ value is likely due to the fact that the data points used within the linear regression were calculated from a standard per-meter cost with a few additional factors to account for any special elements. As such, the high degree of explanation is likely to be higher than if other costs, such as tendered costs or actual construction costs had been used.
- This model was derived using projects where the constructed length varied between 50 meters and 940 meters, and the average channel width varied between 12 meters to 16 meters. As the area of interest for Oshawa Creek has a length of 7 kilometers and a channel width of 35 meters, this is a significant extrapolation from the range of values used for its derivation.

Natural Asset Co-benefits

In the process of incorporating the targeted services into an asset management plan, care must be taken to also recognize the co-benefits of natural assets. Economic and policy decisions that focus narrowly on comparisons between conventional infrastructure and natural assets may overlook other benefits, to the detriment of the community.

The Oshawa Creek corridor provides co-benefits, including:

1. Reduced flood risk by storing flood waters
2. Habitat for aquatic and terrestrial organisms
3. Improving aesthetics of creek corridors
4. Improved human health and well-being:
    - Recreational opportunities (active and passive)
    - Air quality/cooling/shade,
    - Social: connecting priority neighbourhoods with services the floodplain
    - Nature appreciation

Each co-benefit is expanded upon below. Importantly, additional values could be calculated using accepted methodologies to develop a more comprehensive assessment of the value of the Oshawa Creek corridor's natural assets.

1. Reduced flood risk by storing flood waters

Flooding can occur due to heavy spring rains and snowmelt, significant localized rainfall events and ice jams. Creek flooding occurs when the flow rate exceeds the size of a creek causing overtopping of the creek banks. Affected lands are located in a natural floodplain and/or along a creek. Flooding is a natural part of healthy river system however they can have significant impacts to property, economy and human health including long-term social and emotional stress. Managing the risk associated with flooding and erosion is one of the primary roles of Conservation Authorities under the Conservation Authorities Act of which floodplain mapping is a critical component.

Regulated floodplains have been established as part of proper land use planning which restrict development within flood prone areas. However older developments and infrastructure established prior to regulations are still at risk from flooding. CLOCA is the governing agency within the Oshawa Creek Watershed which maintains floodplain maps and the identification of flood-prone areas.

Within the Oshawa Creek Watershed CLOCA has identified 14 Flood Damage Centres (see Figure 4 below) which are areas where buildings are located within the regulated floodplain system. Two are considered high risk, one moderate and the remaining 11 are considered low risk. These areas were identified in the August 2017 Flood Damage Centre Upgrading (CLOCA, 2017).

The two high-risk FDC's are within the project area:

- Between King Street West and McMillan Drive: includes part of downtown Oshawa, a number of businesses and commercial properties including the downtown and 2 shopping plazas, a school and a number of residences
- Between Gibb Street and Park Road South: includes a number of residences which have been built in the 100 year or regulatory floodplain.

These FDC's are heavily influenced by the Canadian Pacific Railway embankment which increases the flood elevations more than 2 metres than downstream of the railway.

CLOCA maintains a database with floodplain mapping data and information about the structures within the Flood Damage Centres, which is shared with municipal emergency staff for use during flooding events.

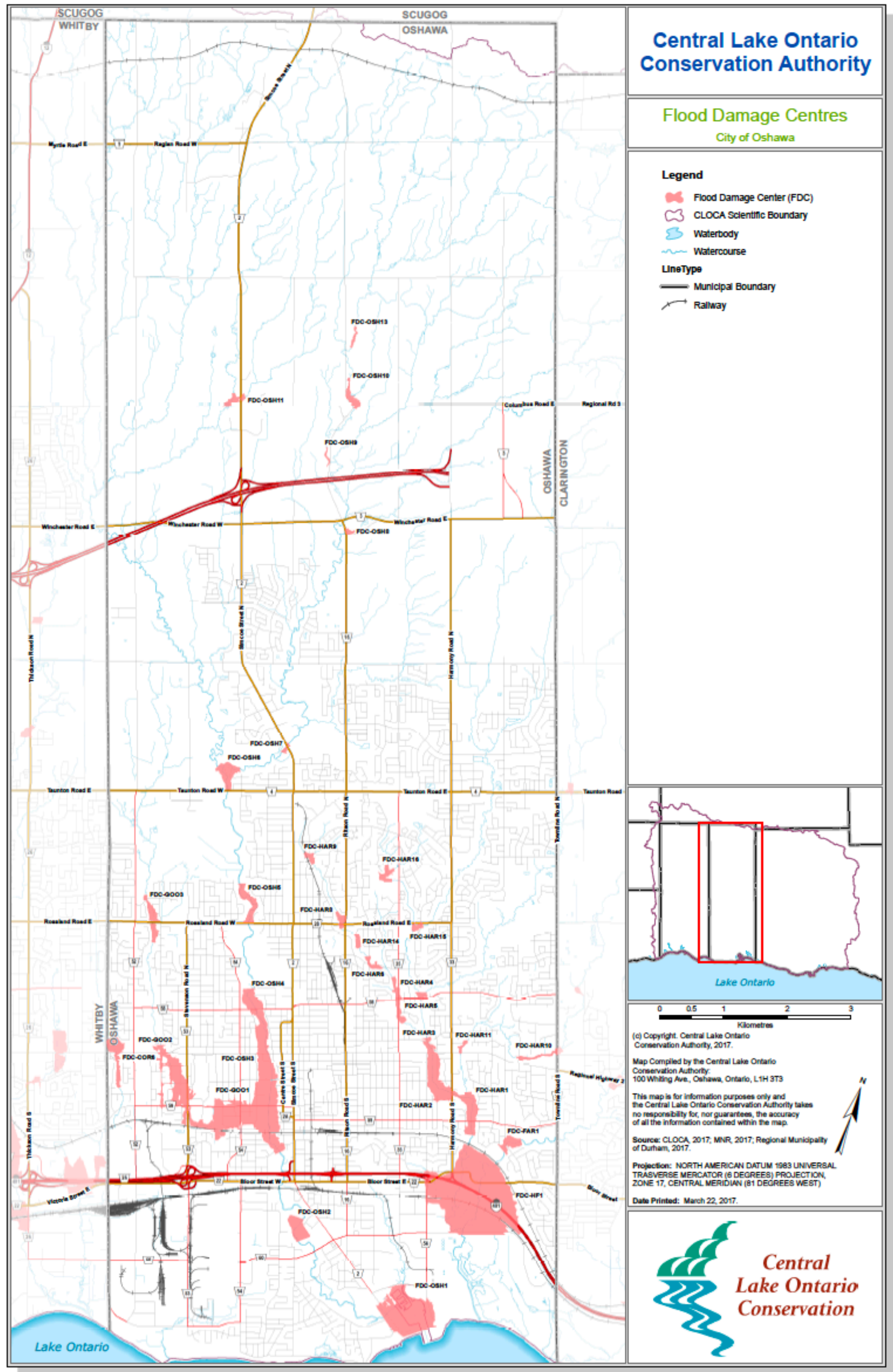


Figure 4: Oshawa Creek Regulated Areas and Flood Damage Centres

2. Maintaining habitat for aquatic and terrestrial organisms

Development in Southern Ontario have put pressure on aquatic and terrestrial habitats in the basin and lead to the loss of about 70% of historic wetlands, degraded habitat within tributaries and lakes themselves, and drastic alteration of coastal areas (Ontario Ministry of Environment, 2010).

Protecting and restoring habitat is vital for Ontario's Great Lakes region. Natural habitats play a critical role in maintaining ecosystem health and function as well as contributing to the social and economic vitality of the province. Habitats supply numerous fish and bird species that provide recreational activities for society and act as reservoirs of biodiversity, hosting many of Ontario's species at risk. In addition, habitat ecosystems provide important complementary services to society such as flood control, water filtration and nitrogen fixation (ibid).

The Oshawa Creek watershed has a total natural vegetated cover of approximately 23%, or about 27 km^2. The natural cover is well distributed across the northern and central portions of the watershed, but is confined to valley lands in the southern portion due to the urbanization. Approximately 40% of the natural cover of the watershed is forests; 22% is forested wetlands; 5% is non-forested wetlands, and 9.8% are cultural savannah's, cultural hedgerows, thicket swamps, open water, shallow, submerged and meadow marshes, as well as shrub bluffs and beach bars (CLOCA, 2013). These intact, natural areas benefit aquatic and terrestrial organisms, as well as the local population that values biodiversity.

Aquatic organisms:

Currently, there are 35 fish species, representing 14 families, known to occur within the watershed including those found only within the Oshawa Coastal Wetland or Oshawa Harbour. Healthy fisheries include: Chinook Salmon, Brook Trout, Brown Trout and Rainbow Trout populations, in addition to sensitive non-game species like Slimy or Mottled Sculpin. There are no fish species at risk known to currently exist within the Oshawa Creek Watershed. However, there are invasive species present including Goldfish, Common Carp and Round Goby. Environmental stressors, including impacts from adjacent land uses, are negatively affecting the fishery resources and aquatic habitat in this watershed (CLOCA, 2013, p. 14).

The Central Lake Ontario Conservation Authority has implemented an Integrated Watershed Monitoring Program for the Watershed comprising five indicators, including Fish Community, Invertebrate Community, Water Quality, Water Flow, and Water Temperature. Monitoring began in 2017 with the first two of five indicators. These are discussed below:

Fish Community: Fish community monitoring collects data on: the proportion of fish that are tolerant or sensitive to changes in habitat, changes in temperature, and the amount of trophic structure at a site. The overall score for the sub-watershed is very poor, based on the number of monitoring stations and the average fish community size.

Invertebrate Community: The invertebrate community is sensitive to changes in water quality, temperature, and habitat, providing an indicator of overall stream health based on species presence and absence. The overall score for invertebrate community is fair, based on the number of monitoring stations and the average invertebrate community size.

Terrestrial organisms:

CLOCA has undertaken bird monitoring as a component of watershed terrestrial health within each of their conservation areas. Due to resource constraints, annual monitoring is not completed in each location on an annual basis. The Oshawa Creek watershed was surveyed in 2007 and 2012.

Within the watershed's conservation areas[3], a number of sensitive species and species at risk in Ontario (SARO) were recorded. Within the broader Oshawa Creek Watershed, generalist species were recorded including the Song Sparrow, American Robin, and Red-winged Blackbird. Significant habitats for amphibian breeding - particularly for Wood Frog and Spring Peeper - were also recorded. One owl - an Eastern Screech-owl – was recorded during the Nocturnal Owl Surveys. For all regions, the trend was increased species sightings within conservation areas and more naturalized areas, and fewer sightings in more urbanized areas. With urbanization moving northward due to population growth and the future extension of Highway 407 East, it is anticipated that the number of bird sightings will decline over time.

3 Conservation Authorities own and protect conservation areas, which are areas of natural and scientific interest, recreational lands, natural heritage and cultural sites, as well as, land of flood and erosion control.

3. Improving the aesthetic value of creek corridors

Economists have established that public water bodies provide external benefits that are reflected in the value of nearby residential real estate (Kulshreshtha and Gillies, 1993; Streiner and Loomis, 1995; Loomis and Fledman, 2003). For instance, Streiner and Loomis found that property prices in areas with restored streams were found to increase by 3 to 13% of the mean property price in the study located within 335 meters of the creek. This benefits both property owners along the creek corridor and the city through increases in property taxes).

Improving the aesthetic quality of a place increases land and property prices which indirectly benefit local economies. An economic fact sheet compiled by Landscape Ontario (2019) notes:

- Employment opportunities are associated with the creation and long-term maintenance of urban open space, as well as tourism dollars of visitors from parks, gardens and civic areas (Woolley 2003).
- Increases retail activity. Studies have proven that greenery and flowers attract shoppers and residents to urban areas, spurring economic growth (Hauer, Jeanne. n.d).
- Business growth. Small businesses choosing a new business location rank the amount of open space and proximity to parks and recreation as the number-one priority in site selection (The Trust for Public Land. n.d).

4. Improved Health and Well Being

Social: connecting priority neighbourhoods with services the floodplain

Oshawa Creek and the ravine around it represent a predominately unfragmented "green" corridor encompassing parks, opens spaces, and woodlands. The space provides opportunities for recreation including a well-used trail network that connects communities along the corridor to the downtown core. Parks and greenspaces in cities also contribute to a sense of community, vibrancy and improved health and well-being of users (Cheesbrough et al., 2019).

In addition to the psychological outcomes associated with spending time in greenspaces and the physical outcomes from recreation, there is an impact of green space on air quality and urban temperatures, discussed in more detail below.

Much research has been done to indicate that vulnerable groups such as children, seniors and people with low income often gain the most from increased access to green spaces potentially offering opportunities for reducing health inequalities. Direct beneficiaries of the Oshawa Creek corridor include residents living adjacent to the greenspace surrounding the creek corridor including those residents living in Priority Neighborhoods of Gibb West, Downtown Oshawa and Lakeview (Durham Regional Health Department, 2015).

These Priority Health Neighbourhoods have the lowest income levels in the area and have been identified as communities that require focus to build health and well-being. Indirect beneficiaries of the corridor include all residents of Oshawa.

The Oshawa Creek corridor is also important in connecting neighbourhoods and providing alternative transportation routes. The City has the opportunity to invest and prioritize greenspaces along the Creek corridor and within the surrounding areas recognizing the benefits to human health and well-being of the surrounding neighbourhoods.

TABLE 6 - SUMMARY OF DEMOGRAPHICS - PRIORITY HEALTH NEIGHBOURHOODS IN OSHAWA

Oshawa -Priority Neighbourhood	Seniors (65+)	Youth (15-24)	Children (0-14)	Residents (2011)	Community Assets
Downtown	2000	1400	1500	10,900	12 Parks
Gibb West	1600	1600	1700	11,700	11 Parks
Lakeview	1700	2700	3300	17,800	23 Parks

Although the Health Communities' Map Viewer includes Regional Trails, Parkland and Conservation Areas, as points of interest, proximity to green/blue space is not represented in the indicators. Though people may not realize it, the watershed they live in is a vital contributor to their health. As the foundation of many health-related services - such as water purification, water storage, flood protection, recreational opportunities, income opportunities and cultural values – watershed management improves and supports both the environmental and social determinants of health.

As such, it is recommended that the Durham Region consider growing the list of Health Neighbourhood indicators to incorporate environmental health. Common indicators of environmental health include:

- Park Accessibility and Proximity – defined as park distribution by neighbourhood OR park facilities provision OR total parks within 0.5 miles, 1 mile, and 0.5 to 1 mile
- Neighbourhood/community parks within 0.5 miles, 1 mile, and 0.5 to 1 mile
- Percentage of residents with ½ mile of park

Air quality/cooling/shade:

The Oshawa Creek Corridor and floodplain represent a significant amount of the City's urban tree canopy within the project area. Urban heat island (UHI) refers to the phenomena of higher temperatures in urban areas compared to rural areas, caused by land use practices and human activities that are typical to urban growth and development. Specific contributing factors to UHI include: removal of vegetation; dark surface materials; urban form; and waste heat (Durham Region, 2018).

UHI impacts include:

- **Health** – UHI intensifies the effects of extreme heat and humidity. Heat-related impacts can include skin rashes, cramps, dehydration, fainting, exhaustion, heat stroke, and death (Health Canada, n.d.)
- **Social** – Vulnerable community members include the elderly; young children; individuals with pre-existing chronic lung, heart, and kidney conditions; those who are socially isolated, homeless or low income, and new immigrants (Toronto Medical Officer of Health, 2013).
- **Economic** – UHI are correlated with increased demand and costs for cooling via air conditioners and refrigeration. In extreme events they can overload the electricity grid, leading to blackouts and large economic costs.
- **Environmental** – Increased energy use associated with UHI results in increased greenhouse gases and air pollution. Warmer runoff, resulting from water running over dark-covered materials, increases water temperatures in creeks and rivers which negatively impacts aquatic life that are adapted to particular temperature ranges (EPA, 2008).

The Durham Region has a growing and aging population. Projections indicate that the population with double to 1.19 million by 2041 (Government of Ontario, 2017) with 24% of the population 65 years or older by 2036 (Public Health Ontario, 2015). It also has higher asthma and lung disease than the Ontario average (Durham Region, 2017). Climate change is expected to exacerbate these impacts. In the Durham Region, the number of extreme heat days per year (where the temperature is above 30C) is expected to increase from 18 to 23 days. Humidex levels are also projected to rise.

There are actions municipalities can take to mitigate the impacts of UHI on vulnerable populations. These include planting trees and urban greening, 'cool' or 'green' roofs, reflective surfaces, energy efficiency and heat alert and protection planning. The Oshawa Creek is an important green space that can act as a refuge area during periods of extreme heat. As Figure 5 demonstrates below, the creek corridor experiences cooler temperatures than the surrounding urbanized area.

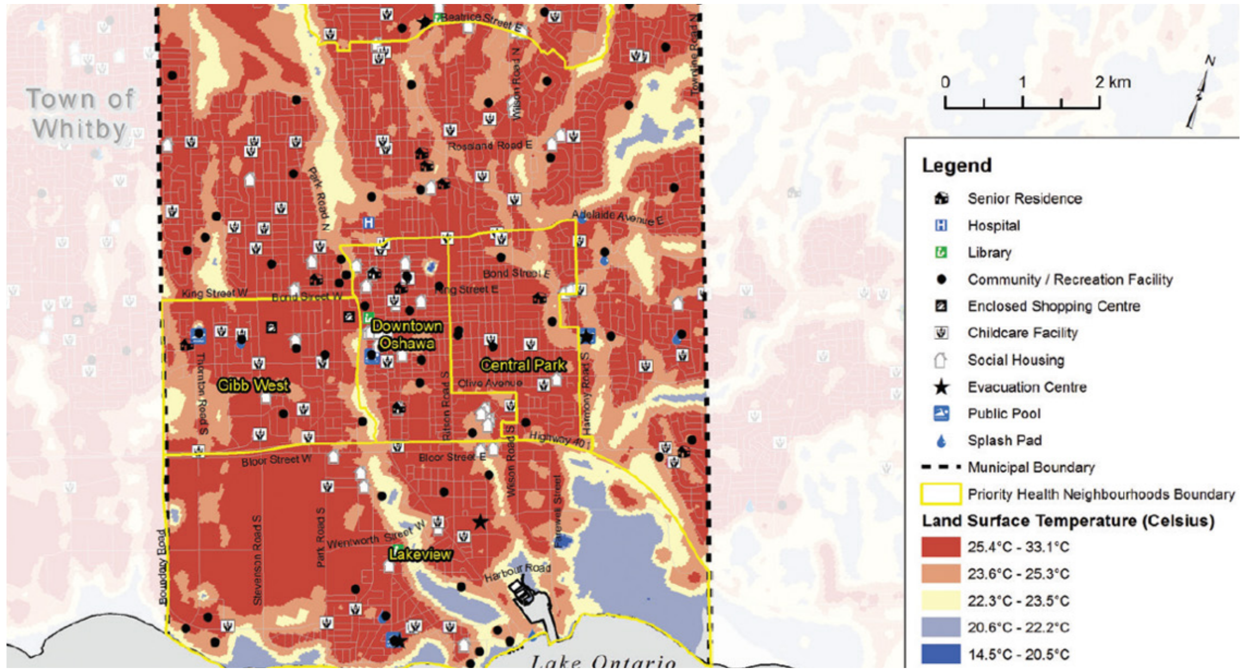


Figure 5: City of Oshawa Land Surface Temperature, September 2017 (Durham Region, 2018)

Recreational opportunities

The project area contains many sites of aesthetic and recreational value such as ball diamonds, soccer fields, playgrounds, basketball courts and an outdoor swimming pool. The Active Transportation Master Plan sets out the means for improving and expanding Oshawa's active transportation network, which benefits users of active transportation within City of Oshawa, drivers facing reduced congestion, and businesses in proximity to active transportation network. The network is predicated on the following vision (City of Oshawa, 2015):

> *There are many actions that can be taken to enhance the quality of life for residents and employees in the City by providing a connected, attractive and convenient active transportation system that offers a high degree of comfort and safety, expands recreation options, encourages sustainable modes of transportation, respects the natural scenic character, and supports economic development.*

Benefits of active transportation include:

- *Health* – an opportunity to be physically active on a regular basis;
- *Social* – high accessibility for residents and employees of all ages, lifestyles and cultural and socio-economic groups, and increases social interactions;
- *Transportation* – reduced road congestion;
- *Environmental* – reduced greenhouse gas emissions; and
- *Economic* – savings on gas, parking, insurance, vehicle maintenance and other costs.

Figure 6 depicts the current pedestrian network for the southern portion of the City. The Oshawa Creek project area's extensive network of trails, bridges and crossings is clearly visible as one of the most connected recreational networks at this time.

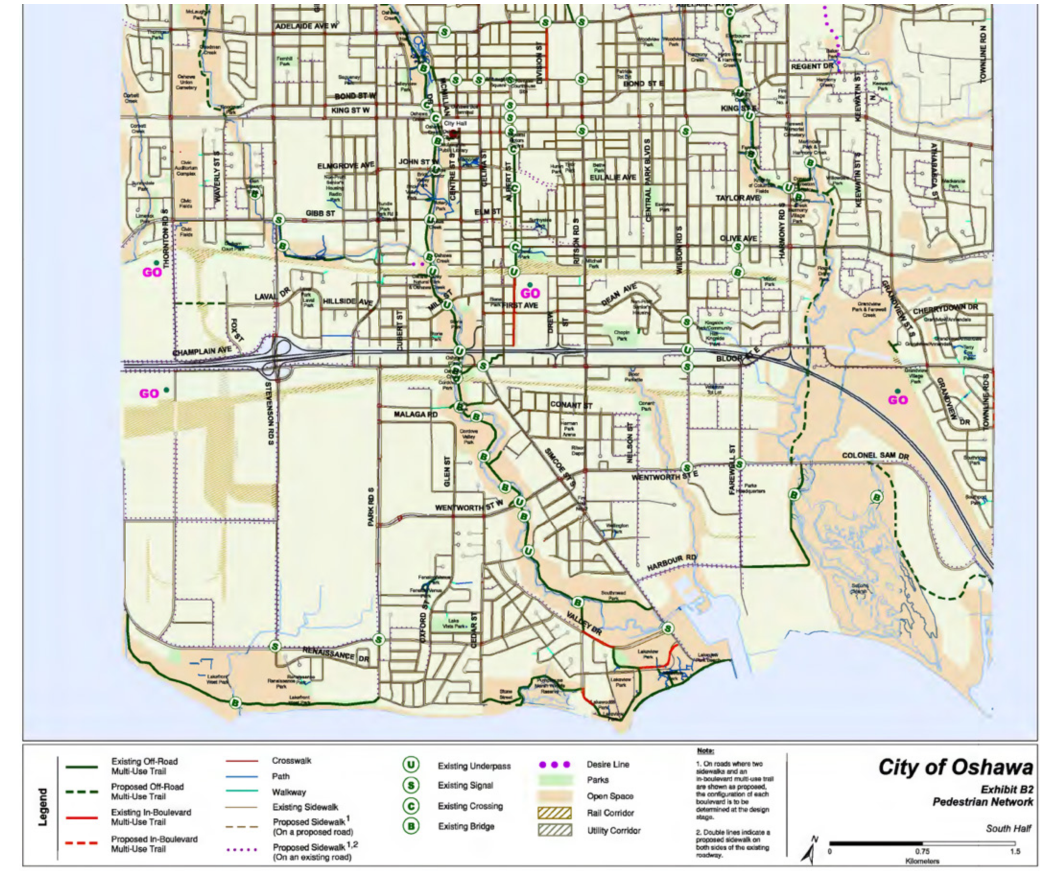


Figure 6: Current Pedestrian Network. Source: City of Oshawa, 2015

The City is undertaking efforts to expand their network of pedestrian and cycling facilities to link communities and major destinations, providing opportunities for cross-city recreation and day-to-day trips (see Figure 6). Once completed, the recommended network will comprise approximately 310 km of active transportation trails.

Figure 7 below depicts the proposed trails within the southern portion of the City, which include a number of bicycle routes and trails connecting the more urban neighbourhoods surrounding the project area to the Oshawa Creek trails. This should, effectively, expand and amplify the benefits of active transportation.

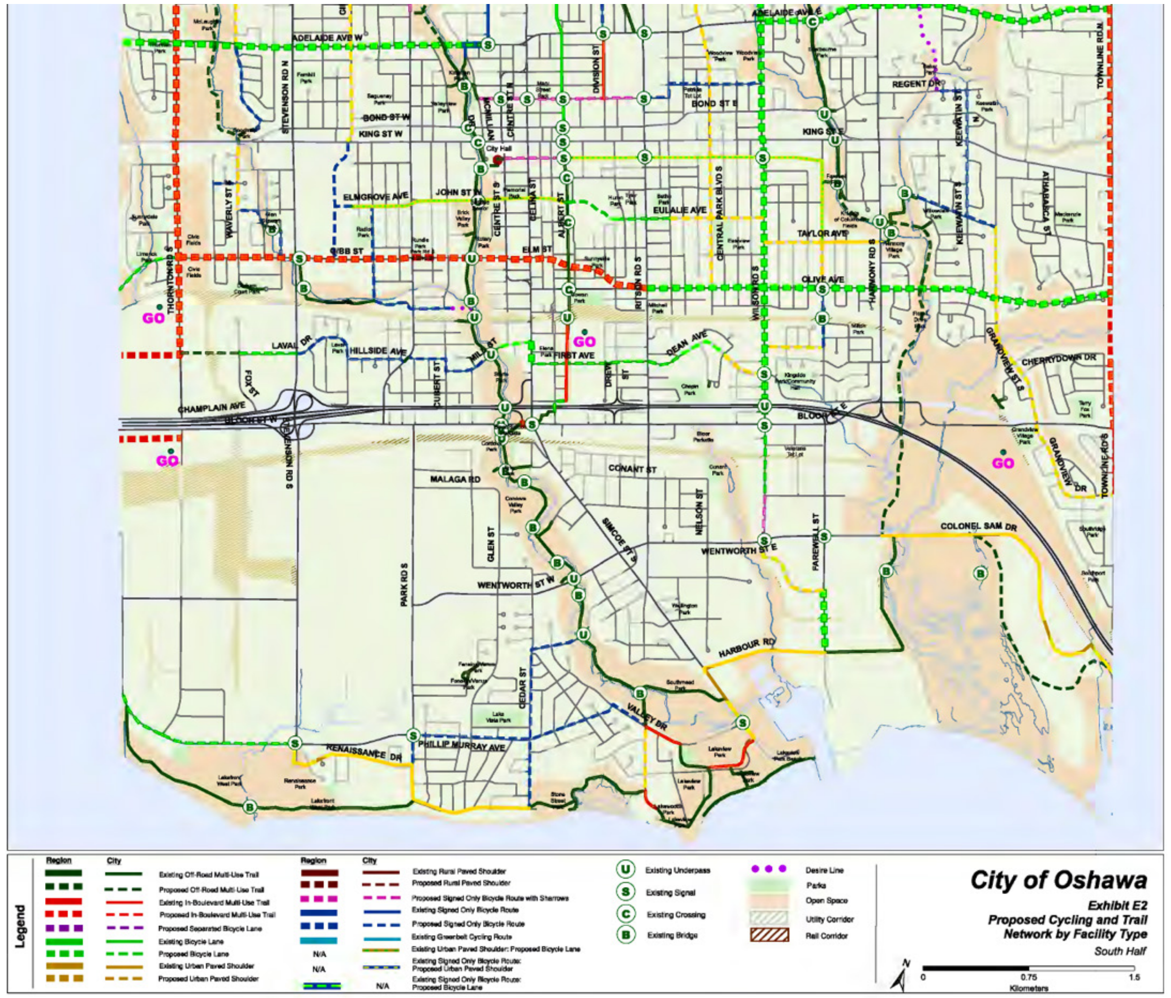


Figure 7: Proposed Cycling and Trail Network (City of Oshawa, 2015)

4. Comparison of Natural Asset and Engineered Asset Stormwater Conveyance Services

In this section, the analysis of stormwater management functions provided by the creek and its surrounding floodplain system are expanded to evaluate it against the engineered alternative discussed above (Scenario 1). Specifically, the existing channel and the alternative are evaluated under a full build out (Scenarios 2), as well as under projected climate change (Scenario 3). The results of the modelling of these scenarios are provided here.

The analysis is reported by comparing flow characteristics between the existing natural creek and the hypothetical concrete-lined channel, as defined in the Approach section. It is important to note that the entire length of Oshawa Creek (i.e. 50 km) was modelled as concrete-lined for the engineered alternative, and not just the 7 km stretch within the project area. For each scenario, the changes are reported for the 2-year design storm and the regulatory event. These return periods were chosen for the following reasons:

- Bankfull[4] flow within a floodplain is the flow rate that defines the channel of a watercourse, and generally corresponds to the 2-year return period event at most (Terraprobe Ltd. & Aqua Solutions, 2002). As such, this was taken as the bare minimum amount of infrastructure that would be required for a potential creek replacement
- The regulatory event is the highest level of projection that is required for stormwater drainage systems and is the basis of most flood prevention design criteria.

For all scenarios, the regulatory event is determined to be the greater of the 100-year design storm or the regional storm. For Scenario 3, the 100-year climate change hyetograph is compared against the unaltered Hurricane Hazel distribution to determine the regulatory event condition.

Areas of Interest and Land Cover Information

The land use information received from CLOCA was used without modification. Therefore, the existing condition is derived from the 2010 aerial imagery and digital elevation model (DEM) as outlined in the Oshawa Creek Hydrologic and Hydraulic Modeling Brief (CLOCA, 2013a, 2014, 2018). The subcatchments of interest are Oshawa Main 1 (OM1 through OM4), as shown in Figure 6. While the area of interest is between Adelaide Avenue West and Oshawa Harbour, the entirely of subcatchment OM4 has been included, as this is treated as one area within the hydrologic model.

External areas of the watershed are grouped as follows:

- Watershed areas upstream of Adelaide Avenue West, i.e., the Raglan, Enfield, Windfields, and Kedron subwatersheds (subcatchment OM5 and the portion of subcatchment OM4 north of Adelaide Avenue West from the Oshawa Main subwatershed);
- The entirety of the Goodman Creek subwatershed; and
- The Montgomery and Harbour subwatersheds.

4 The term **bankfull** refers to the water level stage that just begins to spill out of the channel into the floodplain.

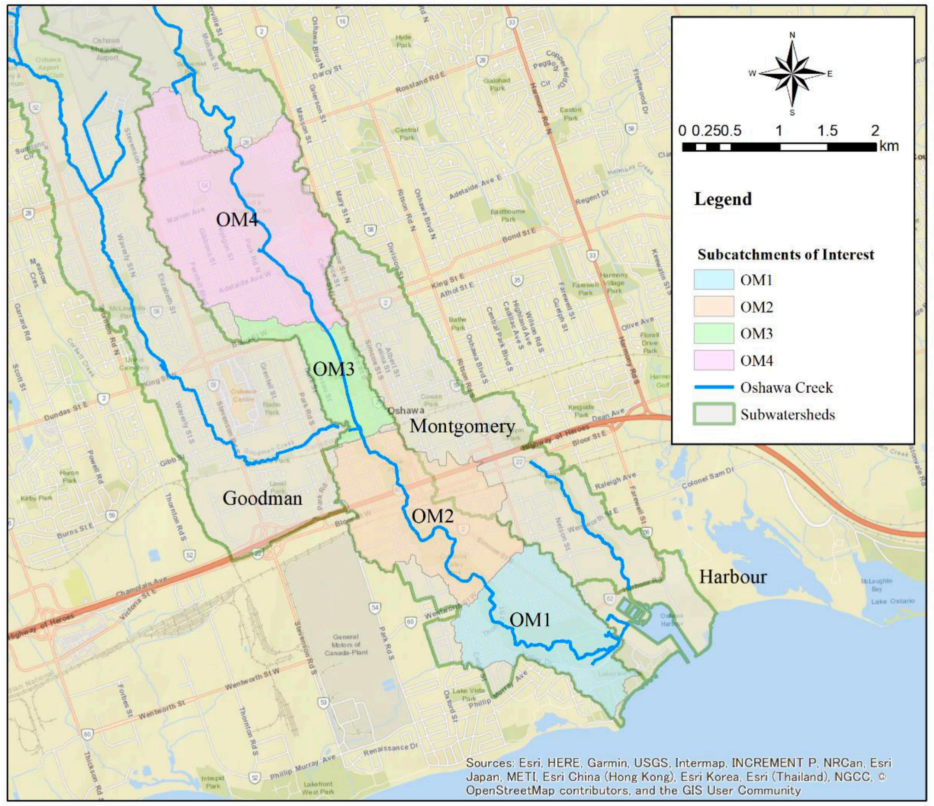


Figure 8: Areas of Interest

Table 7 provides aggregated hydrologic parameters for the subcatchments of interest as well as external areas under existing land use conditions, while Table 8 describes the future land use conditions based on the current Official Plan.[5] The "Average C" values correspond to the runoff coefficient value used in the Rational Method. These values have been derived by regrouping parameters as presented within the Oshawa Creek Hydrologic and Hydraulic Modeling Brief (CLOCA, 2014).

TABLE 7 - EXISTING LAND COVER CHARACTERISTICS FOR OSHAWA CREEK

Location	Area [km²]	Proportion of Watershed	Average C	% Impervious
Areas upstream of Adelaide Avenue West	96.9	81%	0.36	6%
OM4 (Area of interest)	3.3	1%	0.40	32%
OM3 (Area of interest)	0.8	2%	0.50	42%
OM2 (Area of interest)	2.1	1%	0.49	45%
OM1 (Area of interest)	1.6	3%	0.42	36%
Goodman Subwatershed	9.6	8%	0.39	35%
Montgomery and Harbour Subwatersheds	5.0	4%	0.55	54%
Total	119.3	100%	0.38	13%

5 Two future ponds in the Kedron subwatershed are included in the future land use and 2-year return period scenario, per the existing hydrology model.

TABLE 8 - FUTURE LAND COVER CHARACTERISTICS FOR OSHAWA CREEK

Location	Area [km²]	Proportion of Watershed	Average C	% Impervious
Areas upstream of Adelaide Avenue West	96.9	81%	0.40	19%
OM4 (Area of interest)	3.3	3%	0.40	31%
OM3 (Area of interest)	0.8	1%	0.52	45%
OM2 (Area of interest)	2.1	2%	0.50	45%
OM1 (Area of interest)	1.6	1%	0.45	39%
Goodman Subwatershed	9.6	8%	0.49	49%
Montgomery and Harbour Subwatersheds	5.0	4%	0.58	58%
Total	119.3	100%	0.42	24%

These tables show that 84% of the watershed area outlets to Oshawa Creek upstream of the 7 km section of interest, while an additional 4% from the Montgomery and Harbour subwatersheds drain into Oshawa Harbour directly. Because these two inflow areas combined make up roughly 85% of the entire watershed area, all treatment methods considered within Phase 2 of this project must consider the proportion of the total inflow area that can be treated, especially if downstream measures located at the outfall to the creek are to be considered.

Scenario 1: Comparison of Existing Channel and Engineered Channel under Current Conditions

Peak Flow Rate and Time to Peak

The estimated peak flow rate at the downstream end of each subcatchment is summarized in Table 9, below, while the time to peak is summarized in Table 10. Each of these comparisons hold the land use and climactic conditions constant. Therefore, all differences can be attributed to changing the creek from its existing natural condition to a grey infrastructure system.

TABLE 9 - CHANGE IN PEAK FLOW RATES [M³/S] FOR SCENARIO 1

Location (NHYD)	Existing/Natural		Concrete-Lined		% Change	
	2-Year	Regulatory	2-Year	Regulatory	2-Year	Regulatory
OM4 (36)	38.7	637	39.4	641	2%	1%
OM3-DS of Goodman (38)	42.5	674	46.0	684	8%	2%
OM2 (39)	39.1	672	42.0	690	7%	3%
OM1 (40)	39.0	672	42.1	694	8%	3%

TABLE 10 - CHANGE IN TIME TO PEAK [HOURS] FOR SCENARIO 1						
Location (NHYD)	Existing/Natural		Concrete-Lined		% Change	
	2-Year	Regulatory	2-Year	Regulatory	2-Year	Regulatory
OM4 (36)	10.5	12.5	10.3	12.3	-2%	-1%
OM3-DS of Goodman (38)	10.5	12.5	6.2	12.2	-41%	-3%
OM2 (39)	11.0	12.5	10.7	12.2	-3%	-3%
OM1 (40)	11.3	12.5	10.8	12.2	-4%	-3%

For the 2-year runoff hydrographs for Scenario 1, there are two distinct peaks. The first peak occurs around 7 hours and the second peak around 11 to 12 hours, generally corresponding to drainage arriving from downstream urban and upstream rural areas of the watershed, respectively. This bimodal shape is most likely attributed to the distribution of land uses within the watershed, where rural land uses that generate runoff more slowly constitute roughly 80% of the watershed and are located in the upstream reaches, whereas urban land uses make up the remaining 20% and are primarily located downstream around the area of interest. While the second peak is greater for all subcatchments in the existing natural creek in Scenario 1, the flow rates at the two peaks are similar, especially at OM3 where the first peak is 38.5 m^3/s and the second peak is 42.5 m^3/s. When the engineered alternatives' channel's lining is assumed to be concrete within Scenario 1, the peaks are not attenuated as much, and as a result, the flow rate at the first peak becomes greater than the second peak, as illustrated in Figure 9 and the hydrographs in Appendix E.

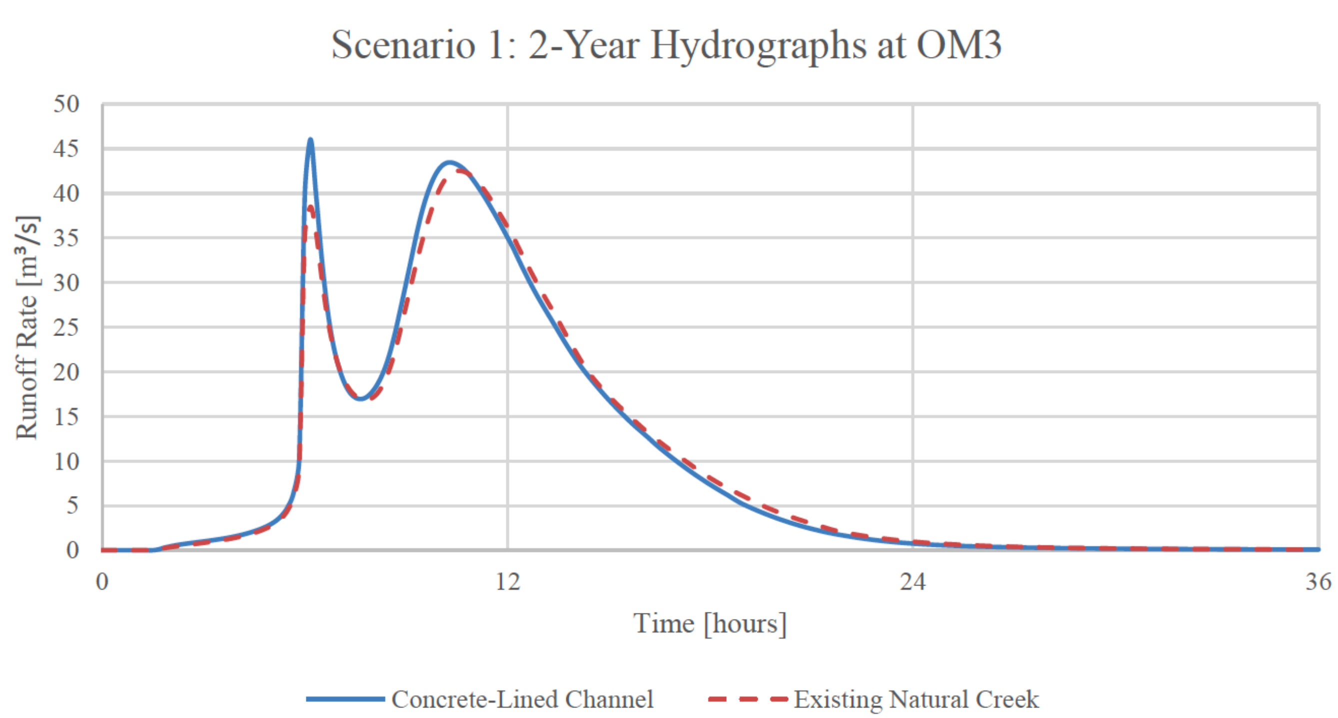


Figure 9: 2-Year Hydrographs at OM3 for Scenario 1

Flow Depth & Changes to Velocity

The flow depths have been modelled using HEC-RAS, as these are a function of the hydraulics of the channel. The changes to the velocity are discussed qualitatively, as the HEC-RAS model was originally developed for floodplain delineation using only subcritical flow regimes, and as such, will not accurately reflect the magnitude of the change.

TABLE 11 - CHANGE IN FLOW DEPTH [M] FOR SCENARIO 1						
Location	Existing/Natural		Concrete-Lined		% Change	
	2-Year	Regulatory	2-Year	Regulatory	2-Year	Regulatory
Adelaide	2.39	7.15	2.14	7.07	-10%	-1%
John	2.42	6.68	1.52	6.63	-37%	-1%
CPR	2.21	7.63	1.56	7.6	-29%	0%
Highway 401	1.93	8.77	1.78	8.47	-8%	-3%
CNR	2.75	8.03	1.99	7.92	-28%	-1%
Wentworth	2.01	9.03	1.78	6.27	-11%	-31%
Simcoe St	2.41	4.34	2.21	3.95	-8%	-9%

While it may seem beneficial that the flow depth, and consequently the size of the floodplain decreases throughout the channel's length when using a concrete-lined channel, this comes at the cost of significantly increased velocity. Manning's equation, which governs open channel flow, describes an inverse relationship between velocity and the friction factor of the flow surface (Chin, 2013). Therefore, by replacing the natural channel with a concrete-lined channel, the smoother contact surface of concrete to the water reduces the friction that is induced and allowing the creek to flow relatively unhindered (Chin, 2013).

High velocities can carry a larger sediment load and prevent sediment deposition, leading to a higher concentration of suspended materials (Brooker, 1985). This results in visibility issues, especially for predatory fish. Many fish species are also sensitive to the flow velocities and require a specific range for a watercourse to be inhabitable (Brooker, 1985). As such, fish species that currently reside within Oshawa Creek may lose their habitat.

Faster velocities also inhibit nutrient cycling as plants and aquatic species require time to absorb and decompose them (Brooker, 1985; Brookes & Gregory, 1983). Finally, the high flow rates and velocities adversely impact humans as well, especially during high return period events where the watercourse would pose a safety risk due to the possibility of being swept away by the current.

Scenario 2: Existing Channel Geometry with Full Build Out

The City of Oshawa's Official Plan sets out the land use policy directions for long-term growth and development (City of Oshawa, 2019b). The current plan was developed in 1987 and last updated in 2019. The Official Plan uses population, housing and employment forecasts to manage growth and guide land use decision-making to 2031. Table 12 below is from the city's Official Plan. Given the current population of 172,434, the City is anticipating an additional 23,000 people over the coming decade.

TABLE 12 - POPULATION, HOUSEHOLDS AND EMPLOYMENT PROJECTIONS					
Forecasts	2011	2016	2021	2026	2031
Urban Population	152,565	164,355	173,650	183,405	195,935
Rural Population	1,020	1,035	1,045	1,055	1,065
Total Population	153,585	165,390	174,695	184,460	197,000
Households	59,100	64,535	70,415	75,655	82,590
Employment	68,270	75,305	84,660	86,835	90,790

Notes:
(1) The population figures identified above exclude post-secondary students who reside temporarily in the City.
(2) Totals may not add precisely due to rounding.
(3) Population includes undercount.
(4) The rural population forecast represents an allocation of *development* potential in the City's rural area, not a target to be achieved.

CLOCA completed a scenario analysis of given planned and anticipated developments in Oshawa, as well as other communities within the Oshawa Creek Watershed, in order to predict future impacts to the watershed's natural resources (CLOCA, 2013). The full build-out scenario was used in this project to understand changes to the Oshawa Main subwatershed under current climate conditions.

Peak Flow Rate and Time to Peak

The estimated peak flow rate at the downstream end of each subcatchment is summarized in Table 13, below, while the time to peak is summarized in Table 14 for full-build out conditions.

TABLE 13 - CHANGE IN PEAK FLOW RATES [M³/S] FOR SCENARIO 2 CONDITIONS						
Location (NHYD)	Existing/Natural		Concrete-Lined		% Change	
	2-Year	Regulatory	2-Year	Regulatory	2-Year	Regulatory
OM4 (36)	61.0	673	65.9	680	8%	1%
OM3–DS of Goodman (38)	69.2	768	75.3	778	9%	1%
OM2 (39)	57.2	770	68.8	794	20%	3%
OM1 (40)	56.9	779	70.1	807	23%	4%

TABLE 14 - CHANGE IN TIME TO PEAK [HOURS] FOR SCENARIO 2						
Location (NHYD)	Existing/Natural		Concrete-Lined		% Change	
	2-Year	Regulatory	2-Year	Regulatory	2-yr	Regulatory
OM4 (36)	7.0	11.3	6.8	11.2	-2%	-1%
OM3–DS of Goodman (38)	7.2	11.2	6.8	11.2	-5%	0%
OM2 (39)	7.5	11.3	7.2	11.2	-4%	-1%
OM1 (40)	7.7	11.3	7.2	11.2	-7%	-1%

When considering the future land use conditions in Scenario 2, a greater proportion of the upstream areas will be developed, which adds volume to the earlier peak flow rate while simultaneously reducing the second peak, thereby resulting in the overall shift in the time to peak towards the 7-hour mark for the 2-year event. For the regulatory event where the regional storm is the dominant condition, the antecedent moisture condition largely drowns out the bimodal peaks created by the rural versus urban land use.

Comparing the existing channel to the engineered channel results, the existing channel shows lower peak flow rates and higher time to peak flow. The difference is more pronounced for the 2-year event.

Flow Depth & Changes to Velocity

TABLE 15 - CHANGE IN FLOW DEPTH [M] FOR SCENARIO 2						
Location	Existing/Natural		Concrete-Lined		% Change	
	2-Year	Regulatory	2-Year	Regulatory	2-Year	Regulatory
Adelaide	2.67	7.02	2.51	7.13	-6%	-1%
King	2.75	7.93	2.12	7.49	-23%	-6%
CPR	2.62	8.15	2.02	8.08	-23%	-1%
Highway 401	2.60	9.15	2.56	8.78	-2%	-4%
CNR	3.21	8.50	2.10	8.38	-35%	-1%
Wentworth	2.40	9.77	2.26	6.81	-6%	-30%
Simcoe St	2.55	4.40	2.34	4.02	-8%	-9%

With the reduced flow detention within the channel as discussed above, the flow depth will also decrease throughout the creek's length. As the with peak flow rates, the difference is most notable for the 2-year design storm. However, the change in flow depth is not as uniform as the peak flow rates as it is significantly affected by localized creek configurations such as the cross-section and the slope of the channel bottom. During the 2-year design storm event, the flow depth does not cause any bridges to submerge, whereas in the Regional event, many of the bridges become partially or fully submerged, and act as dams and weirs to the overall flow, which further impacts the uneven change. The reduction in flow depth results in a lower water surface elevation, which will reduce the floodplain area.

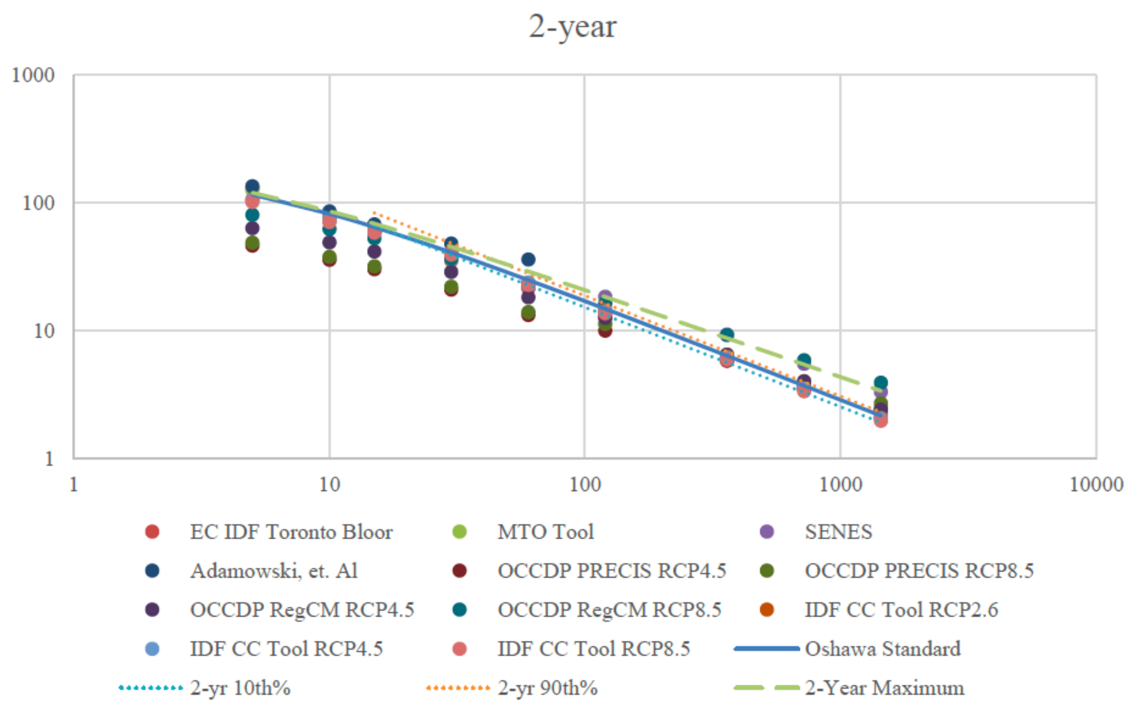
Scenario 3: Existing Channel Geometry with Full Build Out and Climate Change

A series of projected IDF curves were developed from a number of existing studies that can be applied to Oshawa Creek's hydrology model, which have been summarized in Figure 10 below. An extrapolation using the results of trend analysis helped define a set of possible scenarios to consider. Three studies were identified that include a trend analysis of IDF curves for meteorological stations in Ontario or the Oshawa area: one single station analysis and two regional analyses. See Appendix D for further information on the studies used.

For the purposes of this project, a three-parameter IDF relationship for the 2-year and 100-year return periods under climate change scenarios were derived from the maximum rainfall intensity for each time interval by the studies reviewed. The parameters of the IDF curve were found using the Climate Library within Visual OTTHYMO, and were determined to be as follows, where rainfall intensity (i) is given in millimeters per hour and storm duration (t), in minutes:

- 2-Year Return Period: $i = 550(t + 3.003)^{-0.687}$
- 100-Year Return Period: $i = 1474(t + 4.694)^{-0.679}$

To maintain comparability between the existing model simulations and Scenario 3, a 12-hour Chicago storm was derived based on this IDF curve, using a shape factor of 0.5. The shape factor was selected to match the original Chicago storms used by the City of Oshawa and CLOCA.



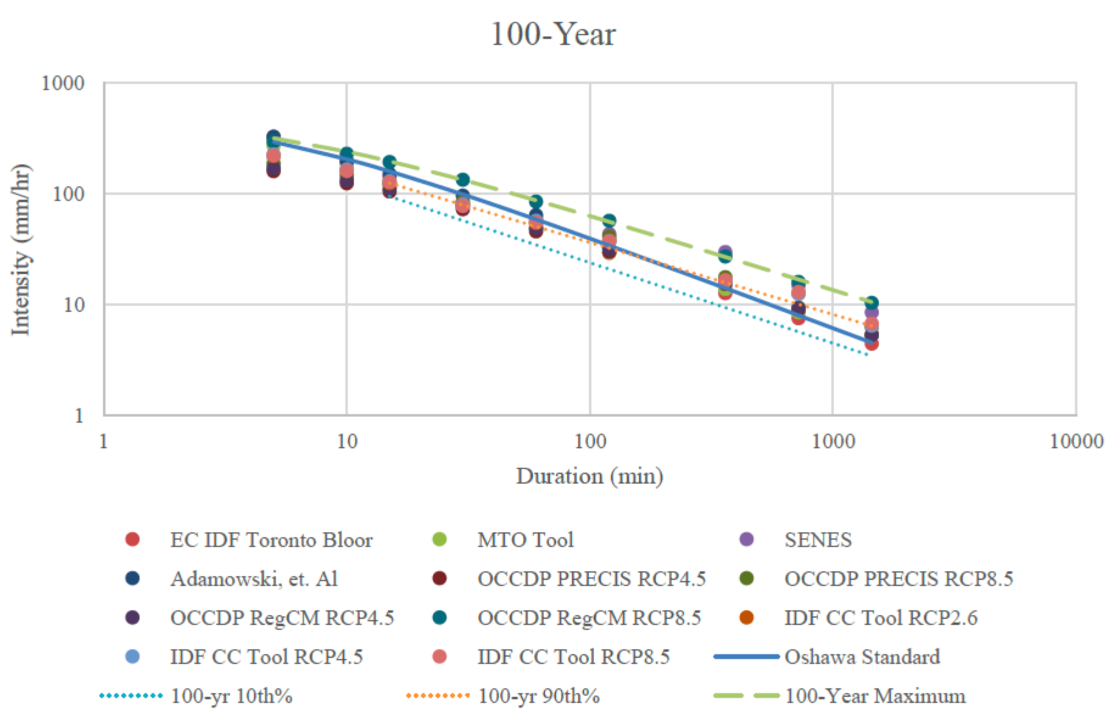


Figure 10: IDF Relationship for the 2-Year (top) and 100-Year (bottom) Return Periods

Peak Flow Rate and Time to Peak

The estimated peak flow rate at the downstream end of each subcatchment is summarized in Table 16, below, while the time to peak is summarized in Table 17 for full-build out conditions, as well as climate projections.

TABLE 16 - CHANGE IN PEAK FLOW RATES [M^3/S] FOR SCENARIO 3

Location (NHYD)	Existing/Natural		Concrete-Lined		% Change	
	2-Year	Regulatory	2-Year	Regulatory	2-Year	Regulatory
OM4 (36)	114.2	673	121.1	697	6%	4%
OM3 – DS of Goodman (38)	127.2	768	137.3	781	8%	2%
OM2 (39)	114.0	770	130.4	794	14%	3%
OM1 (40)	114.6	779	132.5	807	16%	4%

TABLE 17 - CHANGE IN TIME TO PEAK [HOURS] FOR SCENARIO 3

Location (NHYD)	Existing/Natural		Concrete-Lined		% Change	
	2-Year	Regulatory	2-Year	Regulatory	2-Year	Regulatory
OM4 (36)	6.8	11.3	6.7	6.3	-2%	-44%
OM3 – DS of Goodman (38)	7.0	11.2	6.7	6.5	-5%	-42%
OM2 (39)	7.5	11.3	6.8	6.5	-9%	-43%
OM1 (40)	7.7	11.3	7.0	6.5	-9%	-43%

The climate change hyetograph exhibits higher rainfall intensities throughout the design event, especially in the time period leading up to, and after the peak intensity. Therefore, while there is little difference in the peak rainfall intensity, the resultant rainfall volume overall is significantly greater.

For the 2-year climate change hyetograph results there is a significant increase in the peak runoff rates due to the higher total rainfall volume. In the concrete channel case, when the 100-year climate change hyetograph dominates, the effects of the land use differences are still visible through the pointed shape of the peak occurring at approximately 7 hours.

Overall, replacing a natural creek with a concrete-lined channel improves the hydraulic conveyance efficiency by reducing the friction between the flow and channel walls (Chin, 2013). As a result, detention effects are effectively eliminated within the channel, as the concrete walls do not provide localized storage along the floodplain (Chin, 2013). Both phenomena are evident in the increasing rate of change of flow rates as presented within the results tables. This effect is more pronounced for the 2-year return period for all scenarios, as a larger proportion of the flow area is in contact with the channel banks. In other words, replacing the natural asset with an engineered asset reduces water retention, effectively increasing flooding potential.

TABLE 18 - CHANGE IN FLOW DEPTH [M] FOR SCENARIO 3						
Location	Existing/Natural		Concrete-Lined		% Change	
	2-Year	Regulatory	2-Year	Regulatory	2-Year	Regulatory
Adelaide	3.20	7.20	2.75	7.16	-14%	-1%
King	3.19	7.93	3.04	7.51	-5%	-5%
CPR	3.27	8.15	2.87	8.09	-12%	-1%
Highway 401	3.93	9.15	4.02	8.80	2%	-4%
CNR	4.02	8.50	2.96	8.42	-26%	-1%
Wentworth	3.43	9.77	3.14	6.81	-8%	-30%
Simcoe St	2.86	4.40	2.41	4.02	-16%	-9%

Environmental Impacts of Engineered Alternative

The hypothetical concrete channel eliminates many features of a natural channel that support terrestrial and aquatic habitat. The uniformity and rigidity of the channel cross-section and the longitudinal slope does not provide natural pool-riffle sequences or meandering, which leads to a decrease in habitat diversity (Brooker, 1985). Aside from aquatic conditions, a concrete channel does not support terrestrial habitat to thrive along its banks. This leads to a number of negative impacts such as increases to the instream temperature due to a lack of natural cover, reducing nutrient sources from composting leaves, and preventing nutrient uptake by plants (Brooker, 1985). The reduction in terrestrial habitat also negatively affects any mammals and bird species that consider the banks of Oshawa Creek its home. Furthermore, natural systems are constantly evolving to attain a state of dynamic equilibrium, whereas a grey infrastructure system will only degrade throughout its lifecycle and ultimately need renewal. As a result, a concrete-lined channel will likely require significantly more ongoing investment to maintain its level of service compared to a natural creek system.

Construction of a concrete-lined channel will also cause degradation of the surrounding terrestrial and aquatic habitat due to the scale of work that would be required and access for the machinery required for construction (Brookes & Gregory, 1983; Rasid et al., 1985). In addition, the required increase in depth would have to be accommodated with a deepening of the creek as the existing sewer outfalls would have to remain at the same or similar relative elevation to the design flood line (a specific design requirement for the City of Oshawa could not be found at this time). Most hardened channels have also been found to be aesthetically displeasing (Rasid et al., 1985) and would detract from the enjoyment of the adjacent recreational land uses, particularly at the southern-most segment of the creek within the various parks. Finally, and while it was outside the scope of this particular project, it is important to note that any new engineered channel will necessarily result in additional greenhouse gas emissions, whereas natural assets can sequester carbon and thus contribute to climate change mitigation.

Lifecycle Cost Comparison:

The MNAI Approach considers upfront, as well as on-going costs (i.e. monitoring, operations and maintenance costs, disposal costs) for the natural asset as well as the engineered alternative. While this was identified as an objective for the project, we were unable to obtain O&M baseline data from the City. MNAI strongly recommends that the City complete lifecycle analysis once capacity allows them to do so.

5. Improvement Strategies

Under the current watershed management program, the City of Oshawa provides funding to restore erosion sites along the creek, but the work is largely remedial and reactive (City of Oshawa, 2018a).

The City is interested in identifying preventative measures to protect against erosion and has identified the portion of Oshawa Creek between Adelaide Avenue West and Oshawa Harbour as a project area. The City owns a large portion of the riparian lands in this area which makes it a prime candidate for applying preventative measures under City initiatives.

This section identifies potential strategies to mitigate the negative impacts of urbanization, specifically to improve the quality of natural assets such that additional engineered are not required.

As context, Oshawa Creek exhibits many of the symptoms associated with urbanization within its watershed, known as the “urban stream syndrome” (Meyer, Paul, & Taulbee, 2005; Vietz, Walsh, & Fletcher, 2015; Walsh et al., 2005). Symptoms include a consistently “flashier” hydrograph, which exhibits sharper ascending and descending limbs, increased peak flow rates from the predevelopment condition, increased contaminants entering the stream flow, reduced biodiversity with tolerant species dominating the ecosystem, and morphological changes such as channel deepening, instability, and a simplification of the stream structure (Meyer et al., 2005; Vietz et al., 2015; Walsh et al., 2005).

Existing literature suggests that these symptoms appear in watersheds where the imperviousness exceeds 10 to 20 percent (Bledsoe & Watson, 2001). To protect against these symptoms, regulatory agencies require the implementation of stormwater best management practices (BMPs) that generally address these issues in two ways (Vietz et al., 2015):

- Restoring and improving the watercourse structure such that it can withstand the increased stressors of its upstream watershed; or
- Applying restorative measures within the upstream urban watershed such that the runoff hydrograph mimics predevelopment conditions (commonly referred to as Low Impact Development).

Urbanization within the watershed has increased the overall imperviousness to 13%, with the highest subwatershed imperviousness being 58%. The stream banks show signs of erosion, while channel widening and loss of vegetation is evident, especially in the downstream reaches.

To identify potential strategies to mitigate the negative impacts of urbanization, existing erosion control measures are studied and critiqued, an erosion control performance index is identified, and the influence of implementation is explored through a sensitivity analysis.

Based on the foregoing, preventative measures similar to an *infiltration trench* are proposed. These are natural features in which runoff is captured and slowly infiltrated to the underlying soil. Based on these mechanics, the infiltration facility provides both retention and detention of the runoff generated. During rainfall events exceeding the capture volume, the storage capacity may be exceeded, in which case the runoff will discharge to the creek as overflow.

Figure 11: Creative Commons Infiltration Trench by SuSanA Secretariat is licensed under CC BY 2.0

Management Considerations

Erosion control in stormwater management is governed through the Ministry of Environment, Communities and Parks (MECP), the City of Oshawa, and CLOCA. The MECP's stormwater management guidelines are outlined in the 2003 Stormwater Management Planning and Design Manual which recommends a design methodology for instream erosion protection that "recognize[s] the importance of frequent flow events, the heterogeneity of boundary materials, as well as channel stability", while acknowledging that the necessary field data for such analyses is not always available. In such cases, the recommendation is to detain runoff from a 25 mm 4 hour Chicago distribution for 24 to 48 hours when controlled by a wet pond, in lieu of a detailed geomorphic assessment (MOE, 2003). This requirement is referenced by the City and CLOCA as their erosion control requirement for land development projects taking place within the Oshawa Creek watershed (CLOCA, 2010). CLOCA stipulates an additional requirement that the quantity control volume must be provided on top of the extended detention volume and cannot be overlapped (CLOCA, 2010).

Modelling the Infiltration Facility

As described above, infiltration facilities will provide runoff retention and detention by having both infiltration and overflow as outflow pathways. For the purposes of this analysis, these infiltration measures have been assumed to be a rectangular infiltration pit, where the footprint and depth is sized to ensure that the drawdown time is within 48 hours. A constant infiltration rate of 15 mm/hour was assumed, based on the minimum recommended rate by the MECP (MOE, 2003). The storage volume is assumed to be an empty chamber (i.e. a void ratio of 1) for simplicity. While such a structure may not be realistic, the infiltration rates and storage volumes can be sized to achieve an equivalent volume and infiltration rate at a later stage.

While storage facilities modelled in Visual OTTHYMO are generally simulated using the RouteReservoir command, this (by itself) is not suitable for this analysis as it does not allow the basin to have two pathways for outflows. In addition, the program is limited by only allowing a linear sequence of commands. As such, the proposed infiltration units are modelled by using the RouteReservoir command followed by and the DuHyd commands to account for volume reduction.

The RouteReservoir command is defined by a storage-discharge curve, which must be derived outside of VO. For the infiltration basin, the discharge rate on the storage-discharge curve represents the sum of the infiltration rate and the overflow rate. This combined runoff hydrograph is then routed to a DuHyd command which can subtract a constant flow rate from the incoming hydrograph. The constant flow rate is set at the infiltration rate of the proposed facility. A schematic of the storage discharge curve is below.

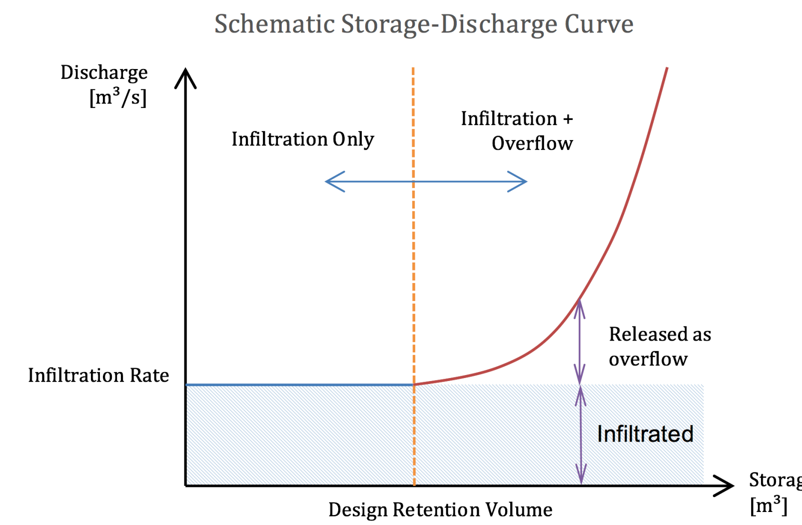


Figure 12: Schematic Storage-Discharge Curve

The following parameters are required to define the infiltration rate and the storage-discharge curves:

- The target rainfall depth to be infiltrated;
- The drawdown time of the infiltration unit, which was assumed to be 48 hours;
- Void ratio of the storage space, if applicable – for the current analysis, this was assumed to be 1 (i.e. an open basin);
- Infiltration rate of the underlying soils – a constant infiltration rate of 15 mm per hour was assumed, based on the minimum recommended infiltration rate by the MECP. In reality, this is a variable rate based on factors such as the hydraulic conductivity, the head differential, and the soil moisture; and
- The mechanism through which the overflow will discharge from the system – this is assumed to be weir flow.

More information model development is available in Appendix F.

Simulation Scenarios

The simulation scenarios were developed to address the objective of quantifying the improvement to instream erosion potential by implementing infiltration facilities as the storm sewer outfalls to Oshawa Creek. Each scenario tests a different level of runoff capture by varying the depth of rainfall over the watershed (i.e. the runoff volume) and spatial distribution. The results of each implementation scenario will be compared against a base case, which represents the current land use and runoff generation capacity of the watershed without the use of infiltration measures.[6] It is based on the existing land use condition for return period analysis, as defined in CLOCA's original hydrology model, but differs in that the subcatchment boundaries have been adjusted. A sensitivity analysis was performed on the depth of runoff capture and the spatial variation of implementation (See Appendix G). Table 18 below describes the simulation scenarios.

6 Given that potential stormwater management controls associated with future land-use conditions are not included in the current hydrology model, the existing land use was used as a proxy as stormwater management targets require the control of post-development runoff to pre-development conditions.

TABLE 18 - DESCRIPTION OF SIMULATION SCENARIOS			
No.	**Scenario Name**	**Captured Runoff Depth**	**Description of Area Coverage**
1	Base	None	Not Applicable
2	5 mm Capture	5 mm	Capturing runoff from 100% of storm sewer outfalls in all subcatchments
3	15 mm Capture	15 mm	Capturing runoff from 100% of storm sewer outfalls in all subcatchments
4	25 mm Capture	25 mm	Capturing runoff from 100% of storm sewer outfalls in all subcatchments
5	Upstream Capture	15 mm	Capturing runoff from 100% of storm sewer outfalls in subcatchments in OM4 and OM3 only
6	Downstream Capture	15 mm	Capturing runoff from 100% of storm sewer outfalls in subcatch-ments in OM2 and OM1 only
7	Uniform 50% Capture	15 mm	Capturing runoff from approximately half of sewer catchment ar-eas, divided to maintain similar hydrologic parameters between the two areas
8	Uneven 50% Capture	15 mm	Capturing runoff from approximately half of sewer catchment areas, divided to maintain similar spatial coverage but maximize the difference in hydrologic parameters

For Scenarios 7 and 8, the 48 outfall catchments were divided into two groups: one group was simulated to received infiltration treatments while the other group was left untreated. In Scenario 7, the catchments were divided to maintain similar total catchment areas and hydrologic parameters, whereas in Scenario 8, the difference in average total imperviousness between the two groups was maximized to the greatest extent possible, while maintaining similar total catchment areas.

While assumptions for the required drawdown time, infiltration rate and void ratio were required to construct the storage-discard graph for the infiltration measure, these variables were not included in the sensitivity analysis as these only affect the design dimensions of the infiltration measure, which will be referred back to the runoff capture depth.

Discussion and Interpretation of Results

Base Case

The runoff hydrograph for these reaches of Oshawa Creek exhibits a bimodal form, as presented in Figure 13. By tracing the runoff hydrographs from the upstream reaches, it is evident that the first peak corresponds to runoff generated from the urbanized downstream areas, generally within the Oshawa Main and Goodman subwatersheds, whereas the second peak corresponds to the relatively rural upstream subwatersheds. Implementing infiltration measures between Adelaide Avenue West and Oshawa Harbour will only impact the magnitude of the first peak and will have no impact on the magnitude of the second peak. Therefore, while limiting the placement of the outfall treatment measures to the current project area will likely not provide the necessary improvements to maintain a stable channel, the analysis can be used as a basis for considering the implementation of similar erosion control measures in upstream reaches of the watershed.

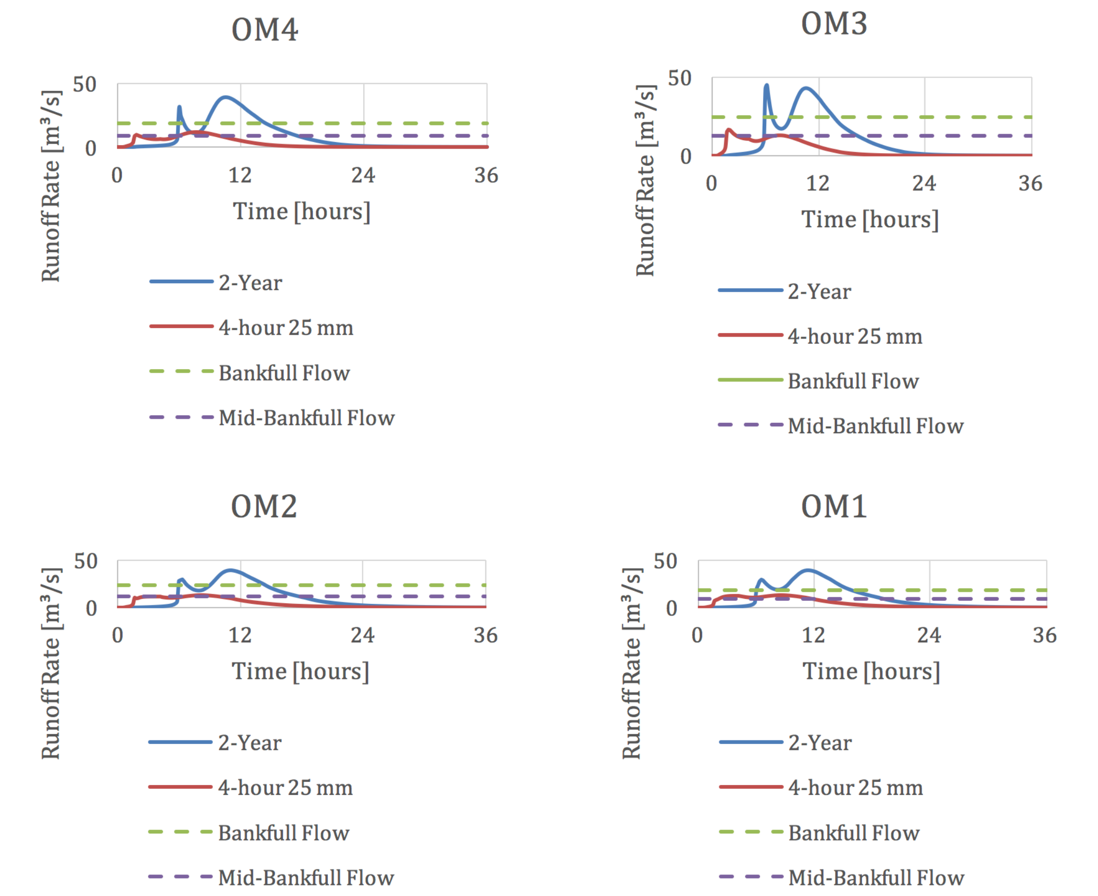


Figure 13: Runoff Hydrographs for Scenario 1 – Base Case

TABLE 19: EROSION INDICES (IN 1,000S) FOR SCENARIO 1 – BASE CASE				
Design Storm	**2-Year**		**4-hour 25 mm**	
Threshold				
OM4	250	540	0	26
OM3	230	590	0	17
OM2	220	610	0	5.0
OM1	350	720	0	56
Total	1,050	2,460	0	104

Table 19 presents the erosion indices in 1,000s using both the full bankfull flow (Q_{BF}**)** and the mid-bankfull flow ($0.5Q_{BF}$) as the threshold value. The only scenario where there is no theoretical potential for erosion is the case comparing the 4-hour 25 mm Chicago distribution against the full bankfull flow, which combines the smaller rainfall volume and the higher allowable critical flow, and as such, is the most lenient of the evaluation combinations. As any level of implementation will only reduce the runoff volume, the erosion index calculated using ($Q_{BF)}$ and runoff generated from the 4-hour 25 mm Chicago distribution will be omitted from the results tables for all remaining scenarios.

TABLE 20: EROSION INDICES (IN 1,000S) FOR SCENARIO 3 – 15 MM CAPTURE						
Design Storm	2-Year				4-hour 25 mm	
Threshold	Avg.Q_{BF}		50%Q_{BF}		50%Q_{BF}	
	E [m³]	% Change	E [m³]	% Change	E [m³]	% Change
OM4	240	-4%	520	-4%	26	0%
OM3	210	-9%	560	-5%	4.4	-74%
OM2	200	-9%	560	-8%	3.9	-22%
OM1	300	-14%	650	-10%	33	-41%
Total	950	-10%	2,290	-7%	67	-35%

TABLE 21: EROSION INDICES (IN 1,000S) FOR SCENARIO 4 – 25 MM CAPTURE						
Design Storm	2-Year				4-hour 25 mm	
Threshold	Avg.Q_{BF}		50%Q_{BF}		50%Q_{BF}	
	E [m³]	% Change	E [m³]	% Change	E [m³]	% Change
OM4	240	-4%	520	-4%	26	0%
OM3	200	-13%	550	-7%	4.4	-74%
OM2	190	-14%	530	-13%	3.8	-24%
OM1	290	-17%	630	-13%	33	-41%
Total	920	-12%	2,230	-9%	67	-35%

As expected, the erosion index decreases by reducing the runoff volume. The relative reduction in the erosion index is greatest when using 0.5 Q_{BF} as the threshold and the 4-hour 25 mm Chicago design storm as the input hydrograph, as the capture volume accounts for a larger proportion of the total runoff and the overall erosional hours. The plateau in reduction seen in the 4-hour 25 mm event indicates that all of the erosional flows from the first peak has been retained by capturing between 15 mm and 25 mm. For all subcatchments, capturing 25 mm of runoff will reduce the peak runoff rate to below both the bankfull and mid-bankfull flows. To achieve further reduction in the erosion potential will require similar flow retention measures in the upstream reaches.

For all subcatchments, there is a trend of diminishing returns on the improvement to the erosion potential as a result of capturing larger runoff volumes. While further refinement of the model is required, preliminary results indicate that implementing successively larger capture volumes may not be the most cost- or space-effective solution, and may cause unintended negative consequences during low-flow conditions.

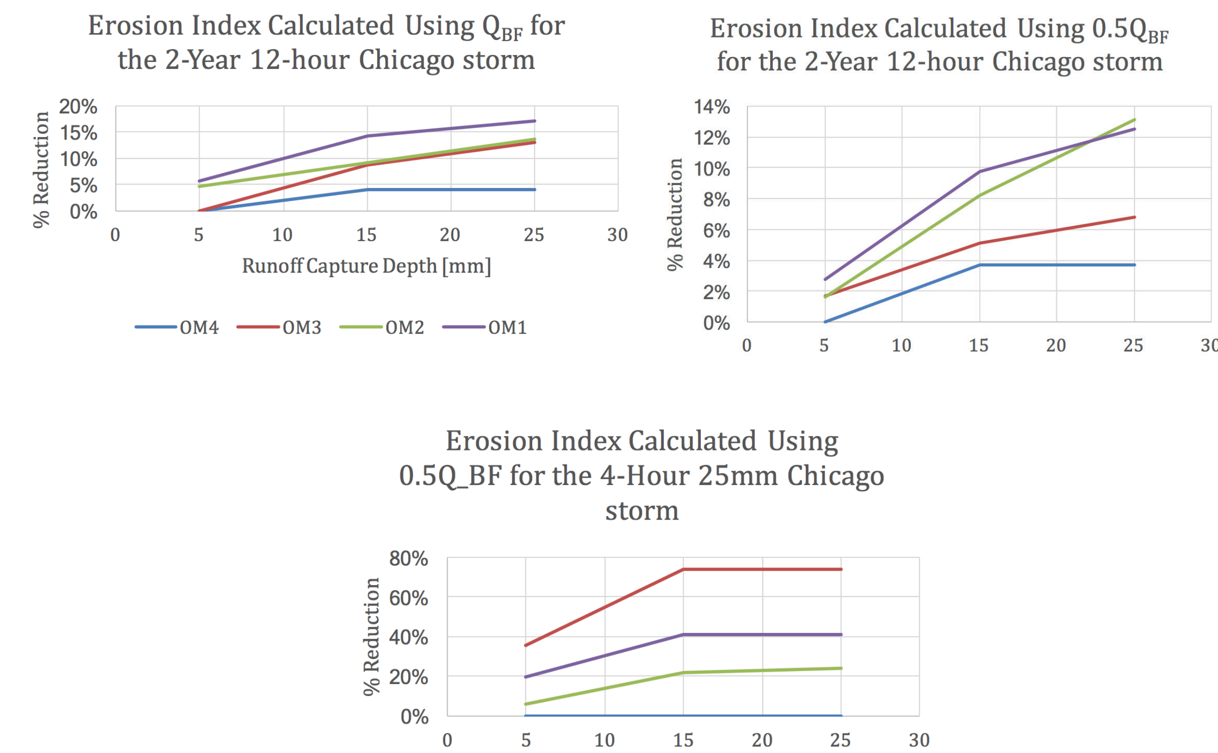


Figure 14: Change in Erosion Index based on Changing the Runoff Capture Volume

Findings

The results of the analysis indicate that a large proportion of the erosional hours is a consequence of runoff generated from reaches upstream of Adelaide Avenue West. As such, limiting the implementation of the improvement measures to the current project area will not adequately reduce the erosion potential. Capturing larger runoff depths will reduce the erosion index, but there is a trend of diminishing returns, where the incremental reduction in erosion potential decreases beyond a certain capture depth approximately between 15 mm and 25 mm.

In terms of spatial distribution, capturing runoff from subcatchments OM4 and OM3, which are the upstream two subcatchments within the project area, has a greater impact over the entire subject area than capturing from subcatchments OM2 and OM1 only, as the reduction in runoff volume is conveyed to downstream catchments, whereas there is no effect on reducing runoff volumes in OM2 and OM1 on upstream areas. In addition, if OM4 and OM3 are receiving treatment, then capturing OM2 does not contribute further erosion control improvements to the reach in OM2. There is no significant difference in the erosion index when attempting to target the implementation of the sewer outfall treatments to catchments with high total imperviousness, as catchments with high total imperviousness does not necessarily coincide with high CN values and low initial abstraction, which introduces a number of confounding variables.

Limitations of the Analysis and Model Appraisal

While improvements can be expected from implementing volume reduction measures, there are limitations to the current methodology, as follows:

- As the model used to perform the simulations in this analysis was not calibrated to field data, results of should be taken solely as a comparative study on the improvement to erosion potential.
- While the degree of improvement was quantified by calculating a percent reduction in the erosion index, this value does not indicate that an improvement of said magnitude will be realized by implementing the treatment measures. In particular, the threshold flow rate for erosion to occur requires field verification, as it is currently based on an estimated bankfull flow rate derived solely through a visual review of cross-sections extracted from a DEM without the necessary vertical accuracy for this application.
- The use of an event-based analysis adds another layer of simplification from the real system. A Chicago storm, while considered an industry standard for stormwater management simulations, is not a realistic hyetograph and does not consider any antecedent conditions, which can greatly affect the soil stability and erosion potential.
- This analysis assumes that a large rainfall event is the primary concern for runoff events capable of causing instream instability. However, a review of historical hydrometric data collected by the Water Survey of Canada for Oshawa Creek at Taunton Road generally experiences an increase in its monthly average flow rate during March and April, suggesting that snowmelt runoff could contribute to the increased erosion observed in the creek.
- This analysis does not take into consideration the physical feasibility of implementing the infiltration measures at each sewer outfall. While the City owns much of the riparian lands in this area, many outfalls are located near instream structures or are on steep banks where the placement of infiltration measures may not be possible. In addition, the space to accommodate the infiltration measures may not be available as the proposed footprint to accommodate the required capture volumes at each outfall is quite large.
- This analysis is based solely on the objective of reducing erosion potential within the creek and does not consider additional factors such as the maintenance of fish habitat and the riparian ecology.

6. Implementation of Natural Asset Plan

By assessing a 7km stretch of the Oshawa Creek and assigning a value, as well as identifying preventative measures, the City has pre-liminary evidence-based actions to manage the project site and can explore how to expand the work to other areas if desired.

Following are steps to build on this work and ultimately complete a natural asset management plan that can be refined and elaborated to translate the results into core management and financial processes, and support full compliance with the Asset Management Planning for Municipal Infrastructure Regulation, O. Reg. 588/17.

1. **Use the Oshawa Creek analysis as the first major step in a holistic asset management approach**

As described in this document, the Oshawa Creek provides valuable, quantifiable stormwater conveyance benefits to the City. This is information that can be leveraged in a variety of core City processes to, at a minimum, acknowledge the value of the services provided by the natural assets and the risk should they degrade and justify ongoing monitoring of the area.

More specifically, the MNAI team also recommends the following to more deliberately manage this important asset:

- Continue to implement Preferred Stormwater Strategy and LID techniques into capital road reconstruction and park redevelopment as either replacement or alternative to traditional storm sewer outfall, especially within the project area which is located in an established neighbourhood where there are direct discharges to City owned land or outfalls. This should be considered as part of the Stormwater Master Plan.
- Work with CLOCA to meet objectives specified within the Watershed Management Plan
- Work towards a better understanding of service levels and data gaps associated with the various natural assets in order to possibly incorporate natural assets into the City's Asset Management Plan.
- Consider a review of salt management practices along trails and parking lots within City facilities that drain directly into creek.
- Consider improved restoration and planting initiatives to increase vegetation within the natural area surrounding the creek and the watershed as part of future urban forestry management plan
- Establish targets for private tree preservation if possible.
- Continue to work with TeachingCity to investigate the requirements for stacking in stormwater ponds located upstream in order to determine if there are measures that can be taken down stream to reduce the requirements. It is thought that by incorporating infiltration measures along the creek corridor the City could eliminate or reduce the stormwater management pond requirements and thereby allow for more developable land upstream while increasing the value and services provided by the creek and its corresponding corridor.

2. **Implementation of additional preventative measures**

Section 5 provides analysis on measures that can be taken to enhance the services provided by the Oshawa Creek segment that was reviewed. The MNAI team recommends expanding on this analysis to determine specific projects that could be undertaken. In support of this, the following action items are recommended:

- Section 5 analysis should be preformed using continuous simulation as opposed to an event-based model to account for seasonable changes, the impact of small events, and to account for erosion caused by snowmelt conditions;
- Perform a geomorphic assessment to identify the critical shear strength of the channel bed and banks and the allowable exceedance to maintain healthy instream and riparian conditions. This should be tied to an ecological study to ensure that any improvements implemented within the creek corridor considers a holistic view of the surrounding environment.
- The hydrologic parameters of each subcatchment should be calibrated to field data to ensure that the model is representative of the Oshawa Creek watershed and contribute to improving the reliability of the results obtained in this project.

- The erosion potential in a creek can be reduced in a number of ways. While this analysis only considered implementing an infiltration storage unit at the sewer outfall, alternative methods such as source and conveyance controls (otherwise known as low impact development measures) should be considered and evaluated as part of site plan submissions for redevelopment with a goal to decrease imperviousness, increase infiltration and retain rainfall event volumes onsite.

3. **Consider developing a natural asset policy**

The Oshawa Creek is only one natural asset that provides services to the City.

A natural asset-management policy can formalize commitments to integrating nature into asset management at the strategic level in local governments, and could thus be a useful step to create momentum towards a holistic natural asset management approach.

An asset-management policy sets out *what* the local government will do in terms of asset management and is generally Council-endorsed.

The policy describes principles that the local government will follow when implementing asset-management practices to meet its strategic objectives; who will be responsible for ensuring the policy will be implemented; and the scope of assets and services covered by the policy.

An example of principles included in a good practice asset-management policy from the Federation of Canadian Municipalities Leadership in Asset Management Program include:

- **Service delivery to customers,** which centres decision-making on delivering defined levels of service that reflect customer expectations while balancing risk and affordability.
- **Long-term sustainability and resilience,** which requires that services and infrastructure assets be socio-culturally, environmentally and economically sustainable over the long term. This involves long-term planning that manages risks, incorporates triple bottom line (socio-cultural, environmental, economic) considerations, climate change awareness and development of resilience.
- **Holistic and integrated approach,** where decisions are made collaboratively across departments and disciplines.
- **Fiscal responsibility,** which requires robust asset-management decision-making processes to make the best use of available funds to deliver services to communities.
- **Innovation and continual improvement,** which recognizes that asset management is an ongoing process and that a culture of continual improvement will enable the local government to deliver services to the community and stakeholders more effectively and efficiently.

Natural assets can be included in the scope of the asset-management policy. Consideration of natural asset ownership is critical at this stage, as in some cases management and monitoring of the asset is possible without ownership (such as the management of Gibsons' aquifer), whereas in other cases negotiation with senior government is required to identify roles and responsibilities (such as watershed management). In situations where regulations are required for protection of an asset, the presence of conflicting needs may make management for local services difficult or impossible (such as the use of a provincial forest for local stormwater conveyance when the forest has an active harvesting licence). In these latter cases, a local government may wish to build a business case for further discussions with senior government officials.

A good-practice asset management policy usually starts with the policy's intent, describes how the policy will help support the achievement of the local government's strategic objectives, and lists strategic documents that it is aligned with. Strategic documents related to conservation, protection or management of natural assets such as a climate adaptation strategy, urban forest management plans, and/or source water protection plans can be included.

Example:

The City of Edmonton, AB adopted an asset management policy in 2018 that includes natural assets in its definition of infrastructure assets covered by the policy:

"Infrastructure Asset - The physical assets that support social, cultural and economic outcomes and deliverables (services), and also includes Natural Assets and software, but not data and information. Infrastructure assets are intended to be maintained indefinitely at a particular level of service potential by the continuing replacement and rehabilitation of their components." (City of Edmonton Asset Management Strategy)

Natural asset policy template:

The City/Town of ______ recognizes the importance of natural assets in providing vital services to the community and will include these in its inventories and asset-management practices. Examples include water bodies, wetlands and wildlife corridors.

4. **Develop a natural asset management road map**

An asset management road map is a plan to help guide local governments in implementing their strategy. It includes a path for implementing the range of improvement initiatives identified in their strategy or as a result of doing a maturity assessment. Local governments may have more than one road map. For example, one might focus on defining further engagement with stakeholders while another focuses on improving risk management decision-making.

Asset Management British Columbia developed a generic Asset Management Roadmap[7] to support local governments in developing basic asset-management practices. The road map is organized around a number of modules that break out the core components of asset management into tasks or activities that can be individually actioned. Local governments can use the road map to get started and make progress over time.

5. **Enhance co-benefits**

The project area provides numerous co-benefits, all of which can be analyzed in greater detail and enhanced. Of particular note given the proximity of the project area to priority communities, Oshawa may wish to encourage Durham Region Health Department to further consider the value of greenspaces, parks and nature in their review of Healthy Neighbourhoods

7 https://www.assetmanagementbc.ca/wp-content/uploads/Guide_for_using_the_Roadmap20-AMBC-Sept_23_2011.pdf

Appendix A: Launch workshop agenda

Municipal Natural Assets Initiative (MNAI) – Cohort 1 Launch Workshop

For Oshawa

May 29 2018 - 0800-1700

Location: Operations Depot (199 Wentworth St E Oshawa)

Draft Annotated Agenda

Meeting purpose

Launch MNAI project.

Objectives

1. Ensure common understanding of: MNAI method, process & milestones; project details; roles, responsibilities and expectations
2. Develop detailed roadmap towards Milestone 1, including understanding of roles and responsibilities

Anticipated outputs

1. Final project document (although some details may continue to evolve)
2. Roadmap towards Milestone 1* including specific dates and times for regular check-ins and product deadlines.
3. Description of next steps

Meeting documents (available at https://tinyurl.com/y8ynjjvu)

- Signed MOU
- Project document
- MNAI introductory presentation
- MNAI presentation on data needs and collection
- Enlarged maps of site (provided by local government)
- Workplan template (to fill out at end of meeting)
- MNAI guidance document
- MNAI Communications plan
- ***Note on Milestone 1**
- Milestone 1 needs to be reached by Week 1 of September 2018.
- The Milestone is: Creating foundation: biophysical characteristics and condition of municipal natural assets are understood and documented, all data is gathered.
- Milestone 1 webinar will occur in first 2 weeks of September with objective of extracting and sharing key lessons or findings from data gathering (e.g. are there particular challenges or opportunities in terms of finding good data, and lessons that can be shared.
- MNAI team will provide help desk support between launch workshop and Milestone 1 webinar to make sure Milestone is reached.

AGENDA			
Time	**Item**	**Lead**	**Outcome & Comments**
Part 1: Creating a common understanding			
0800-0815	Welcome and introductions	Local government	
0815-0900	Overview of MNAI process: how we got here and what to expect	Roy	Objective: ensure participants understand have shared understanding of MNAI and what to expect
0900-1030	Overview of project document: goals, objectives, outputs of project	Local government with Michelle and Jeff	Objective: ensure common understanding of project
1030-1230	Visit site	Local government	Objective: gather additional information/ context on site
1230-1330	Working Lunch	All	Discussion: did the site visit change anyone's understanding of the project? Lunch provided by local government
Part 2: Roles, responsibilities and actions			
1330-1430	Introduction to goals, objectives and activities towards Milestone 1	Michelle & Jeff	Objective: ensure common understanding of what is required for effective data gathering to meet project goals
1430-1530	Discussion on roles and responsibilities towards Milestone 1	Michelle & Jeff with support from Roy	
15h30-16h30	Conclusions, next steps	Roy, Michelle, Jeff	[This part can be shortened or used to cover additional issues raised during the day]

List of Participants:

Michelle Whitbread – Coordinator, Parks and Environmental Services, City of Oshawa

Patrick Lee – Director, Engineering Services, City of Oshawa

Harshad Patel – Water Resources Engineer, City of Oshawa

Adam Brooks – Senior Infrastructure Business Analyst, City of Oshawa

Heather Brooks – Director, Watershed Planning and Natural Heritage, Central Lake Ontario Conservation Authority

Julie MacIsaac - Director of strategic and business services, City of Oshawa; Chair of steering committee for TeachingCities.

Jennifer Bull – Program/Placement Coordinator, Trent University

Dr. Shaun Watmough – Professor & Director, School of the Environment, Trent University

Roy Brooke – Executive Director, MNAI

Michelle Molnar – Technical Director, MNAI

Jeff Wilson – Technical Support, MNAI

Josh Thiessen – Technical Support, MNAI

Appendix B: Oshawa Creek Hydrologic and Hydraulic Modeling Briefs

There are two Oshawa Creek Hydrologic and Hydraulic Modeling Briefs that, taken together, document the development of the current hydrologic and hydraulic models used by CLOCA (CLOCA, 2013a, 2014). The 2013 Modeling Brief assesses the implications of a future land-use scenario that goes beyond the current Official Plan, while the 2014 Modeling Brief describes the development of the hydrology and hydraulics models of Oshawa Creek, including further justification to the methodology and details updates made to the regulatory floodplain.

The motivation for developing the watershed models was to create a comprehensive model that is not segmented by municipal boundaries, is updated to reflect current land use conditions, and addresses future growth as designated within the 2010 City of Oshawa Official Plan. The existing land use information was derived from a 2010 aerial photography and digital elevation model (DEM) data set. Two future scenarios were included in the analysis: the first scenario (named Future Conditions 2a) reflects the projected growth as per the current Official Plan, while the Future Conditions 3a investigates the impacts of expanding development beyond the current Official Plan. The 2014 incorporated an update to Future Conditions 2a to include proposed amendments to the Northwood's Industrial Park.

The hydrology model is an uncalibrated, event-based model created in Visual OTTHYMO (VO) 2 using the same subwatershed delineations as the Oshawa Creek Watershed Plan. These subwatersheds are further subdivided into 63 catchments. The 12-hour Chicago storm is used for the 2- through 100-year return period events, using intensity-duration-frequency (IDF) curves generated from observations made at the Toronto Bloor Street rain gauge. For the regulatory events, the greater of the 12-hour 100-year Chicago design storm and the 12-hour Hurricane Hazel hyetograph is used. For the Hurricane Hazel event only, the CN values have been updated to antecedent moisture condition (AMC) III, to reflect fully saturated soils at the start of the design event. The regulatory events do not include any water quantity control within the drainage network.

The hydraulic model was created using HEC-RAS and the HEC-GeoRAS extension to extract the creek's geometry from existing spatial data. This was supplemented by field visits to road crossings to characterise the structures at these locations. The model used the peak runoff rate generated by the 100-year uncontrolled and regulatory storm to simulate the water maximum water level and delineate the regulatory floodplain. The simulations were performed using steady-state conditions and assuming a subcritical flow regime throughout, as this would generally lead to more conservative results. The results of the hydraulic model were also used to identify areas that would be flood-prone during high return period events.

Appendix C: Referenced Projects for Cost Information

Project Name & Reference	Description	Flow Rates [m³/s]	Channel Dimensions	Project Cost
Amberlea Creek from Bayly Street to Frenchman's Bay, Reach 3 (TRCA, 2013)	Comprehensive channel and valley wall remediation works for the entire length of Reach 3, including slope stabilization, floodplain activation, and creation of a natural channel morphology	2-Year: 8.1 100-Year: 47.8	Restored length: 240 m Channel width: 14 m	$1,200,000
Wilket Creek – Reach 1, Site 3 (Parish Aquatic Services, 2015)	Construct a grade-control riffle to protect the underlying sanitary sewer and stabilize the channel bed and banks to prevent erosion	2-Year: 20.6 100-Year: 137.3	Restored length: 220 m Channel width: 12.7 m	$650,000
Wilket Creek – Reach 2, Site 5 (Parish Aquatic Services, 2015)	Realign channel to avoid undercutting the valley wall. Stabilize channel bank and protect maintenance hole on the left bank.	2-Year: 20.6 100-Year: 137.3	Restored length: 180 m Channel width: 13.7 m	$600,000
Wilket Creek – Reach 3, Site 8 (Parish Aquatic Services, 2015)	Realign channel to avoid undercutting the valley wall, and add grade control structures to protect the underlying sewer crossing.	2-Year: 19.4 100-Year: 127.1	Restored length: 370 m Channel width: 13.7 m	$1,100,000
Tuck Creek, Between the Hydro ROW north of New Street (0+1460) to Regal Road (0+750) (Aquafor Beech, 2016)	Channel lowering and widening and creation of a low-flow channel to reduce the floodplain extent while preserving and enhancing aquatic habitat. Costs extracted for channel works only.	2-Year: 23.5 100-Year: 125.4	Restored length: 710 m Channel width: 16 m	$2,700,000
Black Creek, between Rockcliffe Blvd and Alliance Ave (AMEC, 2014)	Floodplain grading and low-flow channel widening to provide additional flood storage and increase the channel capacity to convey the 10-year storm.	2-Year: 82 100-Year: 563.8	Restored length: 620 m Channel width: 12 m	$1,600,000
Black Creek Renewal, between Highway 7 and Highway 407 (TMIG, 2018)	Establish a new alignment to convey the regional storm within the channel while improving the natural heritage system and water quality and mitigate current flooding and erosion hazards. New alignment includes a low flow channel, naturalized embankments, and buffer zones.	2-Year: 8.7 100-Year: 91.7	Restored length: 790 m Channel width: 15 m	$11,845,000
Roseland Creek at Lakeshore Road (Aquafor Beech, 2018)	Channel widening upstream of road crossing to prevent flood waters from overtopping roadways and address erosion concerns. Costs extracted for channel works only.	2-Year: 31.4 100-Year: 92.1	Restored length: 50 m Channel width: 12 m	$348,000
Cooksville Creek, between Rathburn Road E to Mississauga Valley Blvd (Aquafor Beech, 2012; R&M Construction, 2019)	Construction of armour stone structures such as cades, retaining walls, weirs, and channel lining to reduce flooding and erosion hazards as well as improving water quality conditions	2-Year: N/A 100-Year: 180	Restored length: 750 m Channel width: 25 m	$3,462,000

Regression Analysis of Project Costs

Details of the regression analysis performed to determine the construction cost of Oshawa Creek is presented within this Appendix. Based on the projects reviewed within Section 2.4, the following independent variables were tested as an explanatory variable for project cost [$] for significance using a forward regression analysis, where independent variables are systematically added:

- Channel length (m)
- Channel (low flow) width (m)
- 2-year flow rate (m^3/s)
- 100-year flow rate (m^3/s)
- Log(2-year) flow rate
- Log(100-year) flow rate

Prior to performing the regression analysis for each variable, the outliers were removed from the data set. The following table summarizes the results of the forward regression analysis:

Run	Independent Variables	Number of Data Points	Coefficients	F-Test Result	R^2
1	Channel Length	8	Intercept: $67,500 Regional Flow: 3,390	Significant	0.86
2	Channel Width	7	Intercept: $-5,088,000 Channel Width: 469,000	Significant	0.54
3	2-year flow	6	Intercept: $1,436,000	Reject	0.012
4	Regional flow	6	Intercept: $966,000 Regional Flow: 1,650	Reject	0.004
5	Log(2-year flow)	6	Intercept: $333,000 Log(2-year flow): 609,000	Reject	0.022
6	Log(Regional flow)	5	Intercept: $-5,487,000 Log(Regional flow): 3,173,000	Reject	0.045
7	Channel Length Channel Width	7	Intercept: $-1,697,000 Length (m): 2,400 (Average) Width: 149,000	Significant	0.96

As a result, the model derived from Run 7 was selected.

Appendix D: Projected Changes to IDF Curves Based on Climate Models

Future IDF Characteristics Based on Trend Analysis

Aside from studies that use results of climate change models, a number of studies have also studied the shift in precipitation amounts based on historical records. Strictly speaking, the identified trends are only applicable to the period from which the data originated, as there is no guarantee that the future will progress in the same way as the past. However, extrapolation using the results of trend analysis will help define a set of possible scenarios to consider. Three studies have been identified that include a trend analysis of IDF curves for meteorological stations in Ontario or the Oshawa area, consisting of one single station analysis and two regional analyses, as described below.

Environment and Climate Change Canada – Engineering Data Sets IDF Curve Update

As part of its Engineering Climate Data Sets, Environment and Climate Change Canada published IDF relationships at select meteorological stations across the country. This analysis uses precipitation data between 1965 and 2005 from individual weather stations to create an updated version of Environment and Climate Change Canada's published IDF curves at each station. Nationally, there were few stations with statistically significant trends in IDF relationships. Of the stations that had a statistically significant trend to report, shorter duration events tended to have decreasing trends while longer duration events tended to have increasing trends. At the Oshawa WCPC meteorological station, statistically significant increasing trends were detected for the 6-hour and 24-hour duration events only, while statistically significant decreasing trends were detected for the Toronto City station for the 6-, 12-, and 24-hour events. Overall, in southern Ontario, there is a lack of evidence to suggest that between there is a statistically significant trend in IDF relationships between 1965 and 2005.

Regional Trend Analysis for Ontario

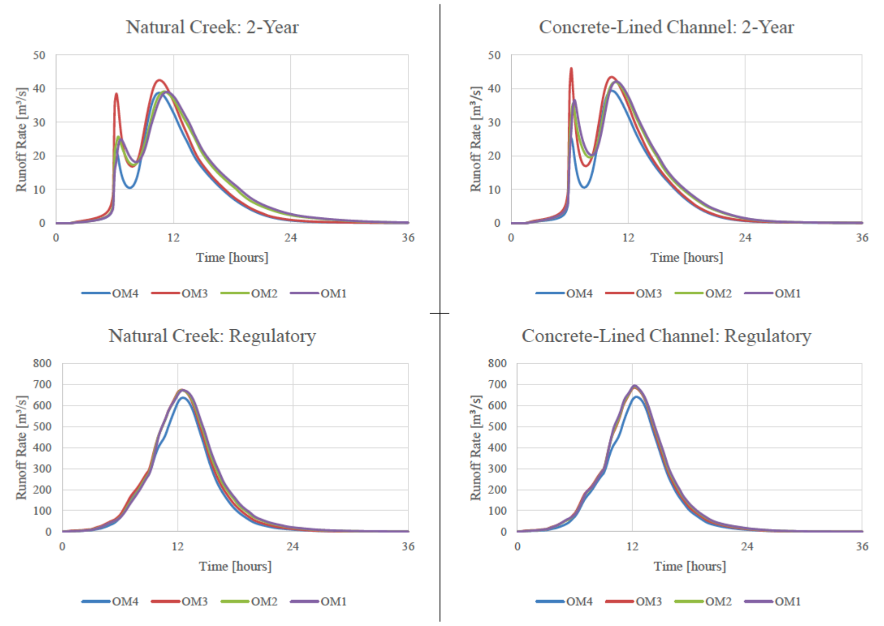
The Ministry of Transportation of Ontario uses the IDF relationships published by Environment and Climate Change Canada when designing infrastructure in their jurisdiction (Soulis, Sarhadi, Tinel, & Suthar, 2016). While the density of meteorological stations in Southern Ontario is sufficiently high, this is not the case in Northern Ontario, where stations are sparse. To improve the availability of IDF information, the MTO commissioned a study to interpolate IDF relationships from stations in the vicinity of a selected location. During this study, time-varying trends in the meteorological data were observed, and a follow-up study was commissioned to quantify this trend (Soulis et al., 2016).

An expression for the annual rate of change in rainfall intensity was developed though a linear regression analysis which aims to minimize the residuals of all stations considered. The rate of change is a function of the event duration and uses 2010 as the reference year. Two key assumption are that this rate of change is assumed to be uniform over the province, and that the standard deviation is stationary. The results of this study are available to the public as a web-based GIS data set as the Ministry of Transportation's IDF Lookup Tool (Soulis et al., 2016).

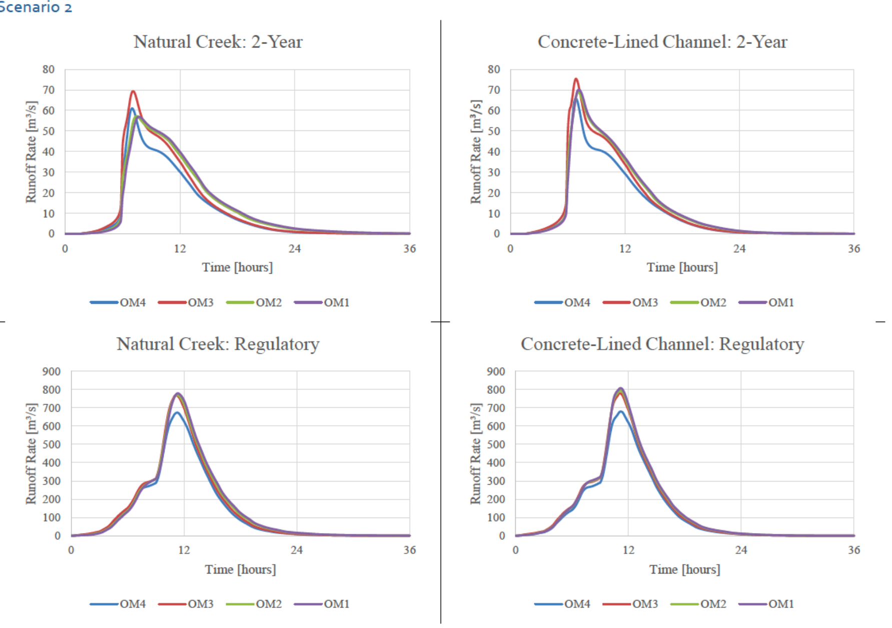
Appendix E: Runoff Hydrographs

The figures presented within this section are the estimated runoff hydrographs for each subcatchment of interest. All hydrographs have been truncated to 36 hours for ease of visibility. For Scenario 3, "+CC" denotes the application of climate change projections in the rainfall hyetograph.

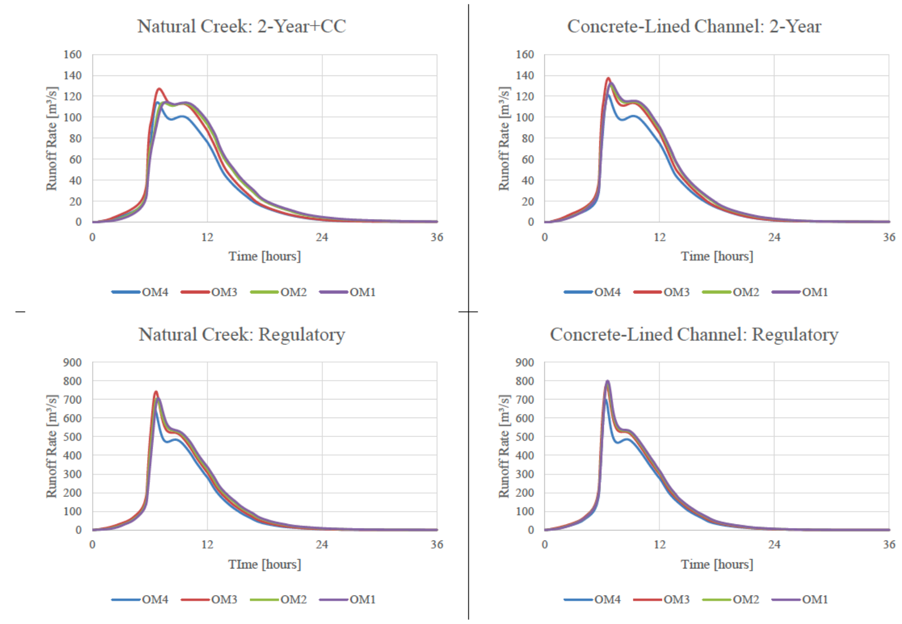
Scenario 1



Scenario 2



Scenario 3



Appendix F: Summary of Model Set Up and Assumptions

Hydrologic Model Development

The erosion index analysis was performed using the current hydrologic model of the Oshawa Creek watershed developed by CLOCA using the Visual OTTHYMO (VO) software package as the basis (CLOCA, 2013a, 2014). In this model, the Oshawa Creek watershed is subdivided into eight subwatersheds, which are then further subdivided into 63 subcatchment areas based on their hydrologic parameters (CLOCA, 2013a, 2014). The base land use and stormwater management scenario within CLOCA's model considers the existing land use condition for the 2- through 100-year return period, which includes all of the existing stormwater management ponds. The rainfall inputs were based on CLOCA's standard design storms and does not take potential changes due to climate change into account. In relation to the Phase 1 report, these conditions relate to Scenario 1: Existing land use conditions under current climatic conditions.

The existing hydrologic model is an event-based model and has not been calibrated against hydrometric field data. Standard practice for the City of Oshawa and CLOCA is to use the Chicago storm distributions for hydrologic analysis (City of Oshawa, 2017; CLOCA, 2010). As such, the 2-year 12-hour Chicago distribution and the 4-hour 25 mm Chicago distribution were used. The 2-year return period event was chosen as it corresponds to the high estimate of the bankfull flow event, whereas the 4-hour 25 mm event is the recommended hyetograph in the Stormwater Management Planning and Design Manual (MOE, 2003) for performing erosion control analysis.

Separation of Storm Sewer Outfall Catchments

To quantify the anticipated runoff reduction resulting from implementing infiltration measures at storm sewer outfalls, subcatchments OM4 through OM1 from the original hydrologic model from CLOCA were discretized into sewer catchment areas. Based on geographic information outlining the sewer catchments received from the City of Oshawa, there are 48 outfalls between Adelaide Avenue West and Oshawa Harbour, as seen in Figure F-1. To represent each area independently within the hydrologic model, a standard runoff generation node (known as a StandHyd in VO) was created for each sewer catchment. The parameters that define the StandHyd command are the area, curve number (CN), runoff coefficient (C), total impervious area (TIMP), directly connected impervious area (XIMP), initial abstraction (Ia), and the impervious flow length (LGI). For all other values, the default option was used in accordance with the original CLOCA model.

To calculate the parameters for each sewer catchment, the sewer catchment delineation from Oshawa was combined with the hydrologic soil group and land use data developed by CLOCA as part of the initial model development. The subcatchment areas in the original model were realigned to eliminate instances where the sewer catchment boundaries straddled subcatchment boundaries. Based on the realigned catchments, the hydrologic soil group and land use data from CLOCA was regrouped into the sewer catchments, and each hydrologic parameter was calculated using a weighted average by area. The impervious flow length was measured by approximating the longest branch of sewers in the catchment. Hydrologic parameters were also updated for catchments where the boundaries were adjusted.

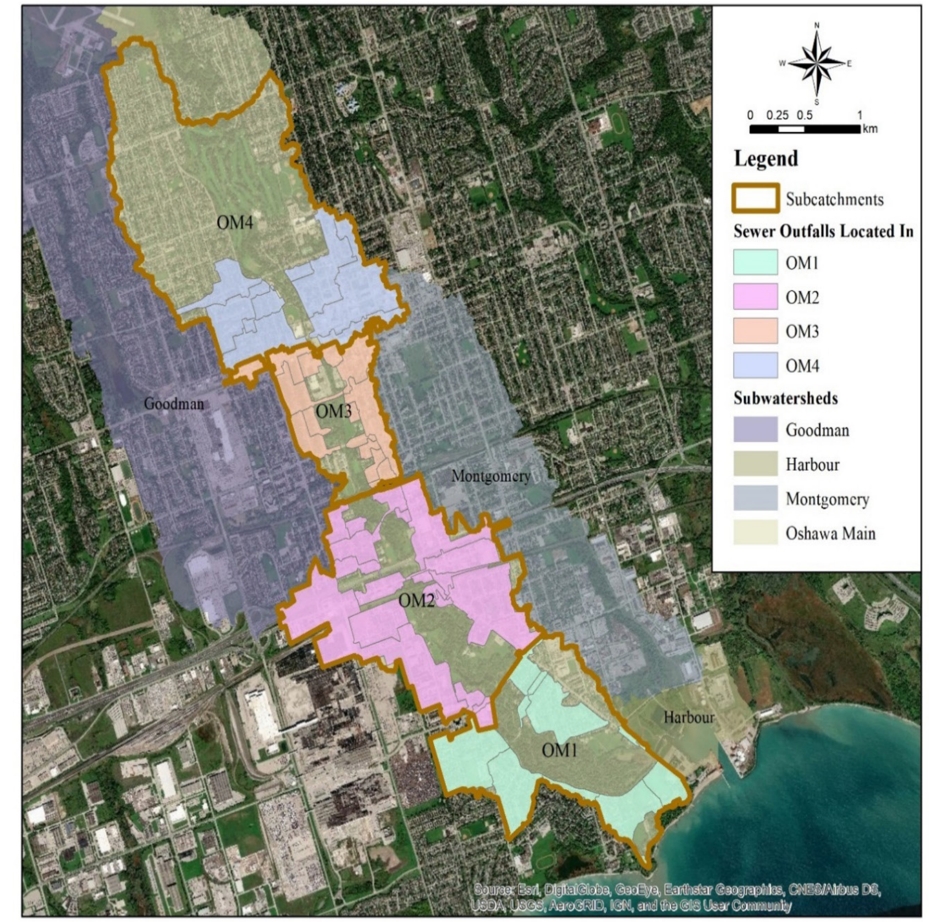


Figure F-1: Sewer Catchments Located within the Study Area

Appendix G: Sensitivity Analysis

Sensitivity to Depth of Runoff Capture

The sensitivity of the erosion index to the captured runoff volume was tested by sizing the total runoff capture volume to 5 mm, 15 mm, and 25 mm over the catchment areas. These simulations were conducted as Scenarios 2, 3, and 4, respectively. While the available capture volume of the infiltration measures would be equivalent to the target runoff capture volume, the actual infiltrated volume is greater as it is simultaneously infiltrating water and capturing runoff over the duration of the runoff hydrograph. The range between 5 mm and 25 mm was chosen as 5 mm of runoff capture is the standard onsite retention required for small sites and 25 mm would capture the entire volume of a 4-hour 25 mm Chicago distribution. The tables below present the results of these scenarios.

TABLE G-2: EROSION INDICES (IN 1,000S) FOR SCENARIO 2 – 5 MM CAPTURE

Design Storm	2-Year		4-hour 25 mm
Threshold	Q_{BF}	$0.5Q_{BF}$	$0.5Q_{BF}$
OM4	250 (0%)	540 (0%)	26 (-2%)
OM3	230 (0%)	580 (-2%)	11 (-33%)
OM2	210 (-5%)	600 (-2%)	4.7 (-6%)
OM1	330 (-6%)	700 (-3%)	45 (-19%)
Total	1,020 (-3%)	2,420 (-2%)	86.7 (-16%)

TABLE G-3: EROSION INDICES (IN 1,000S) FOR SCENARIO 3 – 15 MM CAPTURE

Design Storm	2-Year		4-hour 25 mm
Threshold	Q_{BF}	$0.5Q_{BF}$	$0.5Q_{BF}$
OM4	240 (-4%)	520 (-4%)	26 (-2%)
OM3	210 (-9%)	560 (-5%)	4.4 (-73%)
OM2	200 (-9%)	560 (-8%)	3.9 (-22%)
OM1	300 (-14%)	650 (-10%)	33 (-41%)
Total	950 (-10%)	2,290 (-7%)	67.3 (-35%)

TABLE G-4: EROSION INDICES (IN 1,000S) FOR SCENARIO 4 – 25 MM CAPTURE

Design Storm	2-Year		4-hour 25 mm
Threshold	Q_{BF}	$0.5Q_{BF}$	$0.5Q_{BF}$
OM4	240 (-4%)	520 (-4%)	26 (-2%)
OM3	200 (-13%)	550 (-7%)	4.4 (-73%)
OM2	190 (-14%)	530 (-13%)	3.8 (-24%)
OM1	290 (-17%)	630 (-13%)	33 (-41%)
Total	920 (-12%)	2,230 (-9%)	67.2 (-35%)

As expected, the erosion index decreases throughout the scenarios as a result of runoff volume reduction measures. The relative reduction in the erosion index is greatest when using 0.5QBF and the 4-hour 25 mm hydrograph, as the capture volume accounts for a larger proportion of the total runoff and the overall erosional hours. The plateau in reduction seen in the 4-hour 25 mm event indicates that all erosional flows from the first peak have been retained by capturing between 15 mm and 25 mm. For all subcatchments, capturing 25 mm of runoff will reduce the peak runoff rate to below both the bankfull and mid-bankfull flows. To achieve further reduction in the erosion potential will require similar flow retention measures in the upstream reaches.

For all subcatchments, there is likely a trend of diminishing returns for implementation, as shown in Figure G-2. While the goal is to reduce the erosion indices to zero in all subcatchments, implementing successively larger capture volumes may not be the most cost- or space-effective solution. In addition, this may lead negative impacts during low flow conditions.

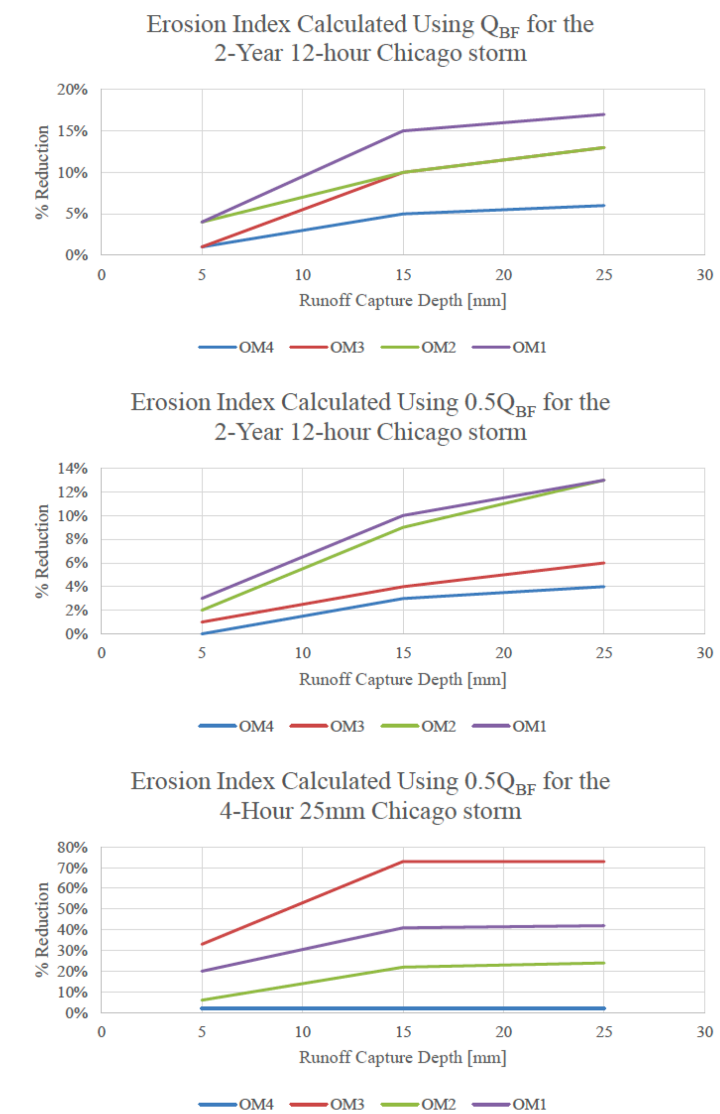


Figure G-2: Changes in Erosion Index based in Changing the Runoff Capture Volume

Sensitivity to Spatial Coverage

Upstream Catchments versus Downstream Catchments

It was assumed that all storm sewer outfalls would receive treatment with the infiltration measures, and the captured runoff volume is varied through the size of the facilities. In this analysis, the impact of only capturing runoff from certain subcatchments was investigated. In Scenario 5, only the storm sewer outfalls in subcatchments OM4 and OM3 were treated, whereas in Scenario 6, only those in catchments OM2 and OM1 were treated. The results are presented in Table G-5 and Table G-6 below.

TABLE G-5: EROSION INDICES (IN 1,000S) FOR SCENARIO 5 – UPSTREAM CAPTURE

Design Storm	2-Year		4-hour 25 mm
Threshold	Q_{BF}	$0.5Q_{BF}$	$0.5Q_{BF}$
OM4	240 (-4%)	520 (-4%)	26 (-2%)
OM3	210 (-9%)	560 (-5%)	4.4 (-73%)
OM2	200 (-9%)	580 (-5%)	3.9 (-22%)
OM1	320 (-9%)	690 (-4%)	36 (-35%)
Total	970 (-8%)	2,350 (-4%)	70.3 (-32%)

TABLE G-5: EROSION INDICES (IN 1,000S) FOR SCENARIO 6 – DOWNSTREAM CAPTURE

Design Storm	2-Year		4-hour 25 mm
Threshold	Q_{BF}	$0.5Q_{BF}$	$0.5Q_{BF}$
OM4	250 (0%)	540 (0%)	26 (-2%)
OM3	230 (0%)	590 (0%)	16.5 (0%)
OM2	210 (-5%)	580 (-5%)	5 (0%)
OM1	320 (-9%)	680 (-6%)	42 (-25%)
Total	1,010 (-4%)	2,390 (-3%)	89.5 (-14%)

Based on the results, retaining runoff from only upstream catchments improves the erosion potential along the entire study area better than capturing only downstream areas, as the reduction in runoff volume would be transmitted downstream, whereas the latter would have no effect on the upstream catchments.

For the erosion index in OM2 calculated using 0.5QBF as the erosive threshold, runoff generated from the 4-hour 25 mm Chicago hyetograph, and the implementation conditions of Scenario 6, there is no further improvement in erosion potential by capturing runoff from OM2.

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