Next generation watershed and subwatershed planning to inform flood mitigation in the context of urbanization and climate change

Wilfred Ho, Melanie Randolph, Elizabeth Speller, Namrata Shrestha
Toronto and Region Conservation Authority, 5 Shoreham Drive, Toronto, ON, M3N 1S4, Canada
E-mail: Namrata.shrestha@trca.ca

ABSTRACT

Next-generation watershed and subwatershed planning in the Greater Toronto Area increasingly integrates comprehensive baseline data, historical environmental records, and advanced flood and predictive modelling. These approaches improve the integrated assessment of watershed-scale impacts and support the prioritization of mitigation measures, particularly for downstream communities most vulnerable to flooding.

This presentation outlines the techniques that leverage diversity of data sources including field monitoring networks, LiDAR, multi-spectral imagery, climate data, hydrologic modelling, and engagement with partners and the public to evaluate potential future management scenarios and their implications on flood risk management. The results help identify priority actions and areas that most effectively reduce off-site impacts to flood-prone areas and protect key eco-hydrological features and functions. These findings inform watershed and subwatershed scale policy and planning decisions and guide implementation of green and grey infrastructure enhancements aimed at strengthening community resilience to flooding and climate change.

Using examples from several watersheds within the jurisdiction of Toronto and Region Conservation Authority (TRCA) such as Carruthers Creek, Etobicoke Creek, and Humber River, this presentation will illustrate the importance of integrated watershed planning processes and partnerships to advance flood risk management. This will be done within the larger framework of building climate resilience, ecosystem enhancement, and effective engagement of the public, governments, and agencies on flood risk management.

KEYWORDS: Flood Management, Watershed planning, Collaborative, Modelling, Climate Resilience

1 INTRODUCTION

1.1 Watershed Context

A watershed is the land area that drains rainfall and snowmelt into a river system and its tributaries. Everything that happens within a watershed is interconnected through the movement of water above and below ground, meaning actions upstream directly influence conditions downstream.

Healthy watersheds deliver critical ecosystem services, including reducing flood and erosion risks, protecting water quality and supply, supporting biodiversity, and strengthening climate resilience. Because of their central role in community safety, environmental health, and economic stability, watersheds require coordinated, cross-sector collaboration to ensure their long-term sustainability and resilience including effective flood risk management.

Toronto and Region Conservation Authority (TRCA) watersheds encompass one of the most highly urbanized and fastest-growing regions in Canada, with substantial population and infrastructure growth projected over the coming decades. Managing this growth in a way that avoids, minimizes, and mitigates natural hazard risks - particularly flooding - while maximizing the benefits of nature-based solutions requires an integrated watershed approach.

Integrated Watershed Management (IWM) provides a systematic framework to accomplish this, especially in the face of climate change, as nature often provides the most effective and cost-efficient solutions for building resilience. Effective flood risk reduction and climate adaptation are closely linked to the protection and restoration of natural systems along with the human designed systems. Achieving these outcomes depends on a holistic understanding of the complex interactions among land use, hydrology, infrastructure, and ecosystems across the watershed (Figure 1).

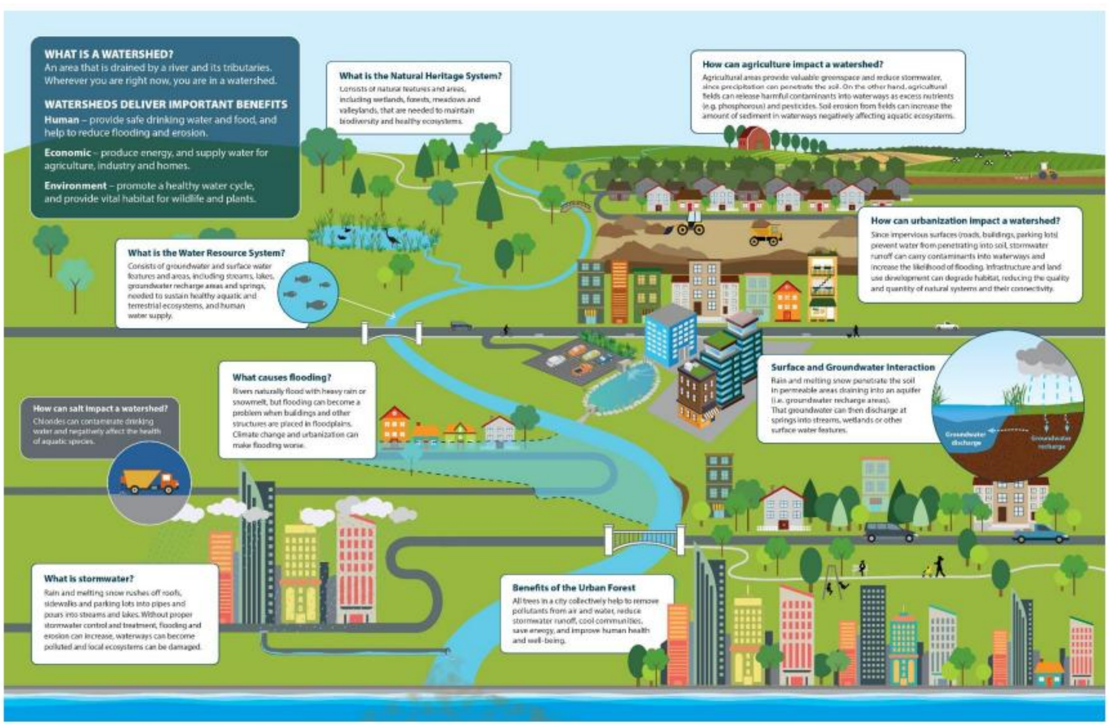

Figure 1: Integrated nature of watershed components, their inter-connections, and benefits

1.2 Watershed Planning

One of the main ways by which TRCA and partners comprehensively undertake IWM is by integrating the information from all our science-based programs and engagements through the development and periodic update of the watershed plans.

The watershed planning process provides a systematic and comprehensive framework to characterize current watershed conditions, assess future implications under potential future land use and climate conditions, and identify measures to protect, restore, and enhance the health of the watershed and build resiliency to land use and climate changes.

The development of watershed plans has been a collaborative effort between TRCA, local and regional municipalities, First Nations and Indigenous Communities, stakeholders, and public. Watershed plans do not make land use and infrastructure planning decisions. Rather, they are intended to help municipalities make informed decisions on where and how to grow in a way that minimizes and/or mitigates impacts to watershed health. Watershed plans also help inform other initiatives including ecosystem restoration and management, land management and acquisition, best practices for rural land uses, low impact development and green infrastructure implementation, and climate adaptation.

The watershed planning process at TRCA is initiated by scoping, building partnerships, and data gap filling. This is followed by watershed characterization to understand current conditions and trends in the watersheds, future management scenario analysis to help understand implications of potential future land use and climate conditions, and implementation planning to develop a management framework to identify priority measures and areas to strategically plan for mitigation and adaptation in the watershed (Figure 2). The final watershed plan provides a comprehensive blueprint for all participating organizations to endorse and implement identified actions.

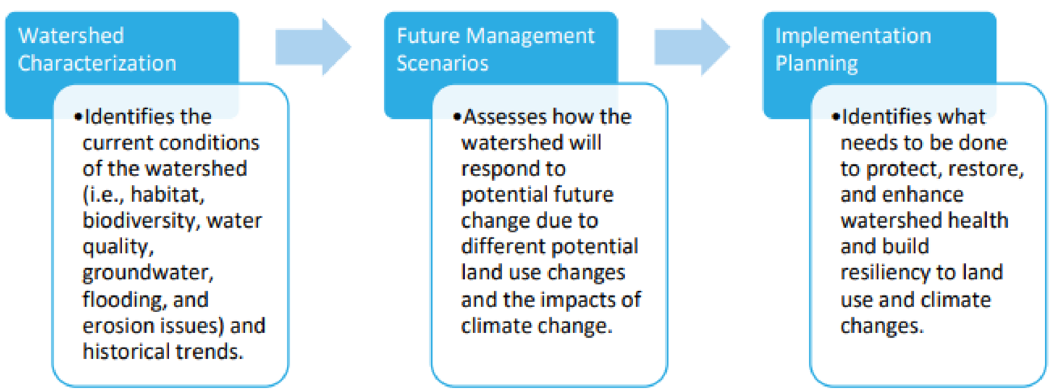

Figure 2: Overview of the watershed planning process

The watershed plans at TRCA focus on four broad thematic areas that are critical components for the health and safety of watersheds and their residents (Figure 3). These include Natural Hazards (i.e., flooding and erosion), Water Resources (i.e., surface water, groundwater, aquatic habitat, in-stream barriers), Water Quality (i.e., surface water quality), and Natural Heritage and Urban Forest (i.e., terrestrial habitat quantity, quality, and connectivity, tree canopy, and sensitive species). These four components are assessed within the broader context of land use and climate scenarios, and various policy and on-the-ground interventions such as restoration and other enhancements.

Figure 3: The four key components of the integrated watershed plans

1.3 Flood Risk Management and Key Concepts

At TRCA, a flood is defined as an overflow or inundation that comes from a river or other body of water and causes or threatens damage. Within a riverine system, floods are a natural process that occur as the result of relatively high flow of water overtopping the channel within a valley system. TRCA defines flood risk in its jurisdiction through extensive mapping of the flood plain.

1.3.1 Flood plain mapping

TRCA's flood plain maps identify the areas on normally dry land that may be covered by water during flood events. These maps can identify the specific risk of flooding to structures, people, and assets. The extent of the flood plain is determined through flood plain mapping studies. These are technical assessments prepared and approved for TRCA by qualified engineers, using standards and criteria established by the Ontario Ministry of Natural Resources.

Flood plain mapping studies use topographical information, surveys of infrastructure (e.g., bridges and culverts), land use and land cover information, weather, and stream flow data to create detailed hydraulic and hydrologic models of each watershed. A hydrology model simulates the effect of this amount of rainfall falling over each watershed, accounting for topography, soil type, land use, and other characteristics to determine how much water would be conveyed to rivers and streams. A hydraulic model then looks at where this water would go, and what areas would be inundated. The inundated area for the Regional storm is called the Regulatory Flood Plain.

Within TRCA's jurisdiction it is standard practice to complete comprehensive flood plain mapping updates on a 10-year cycle. This ensures that flood plain maps and associated hydrology and hydraulic modelling incorporate the latest land use and land cover information, and incorporate technological advancements in modelling software and techniques so that the resulting flood plain maps remain current and state of the art.

1.3.2 Flood Vulnerable Areas/Clusters

Through its flood plain mapping program, TRCA identified approximately 10,000 flood vulnerable roads and buildings in the Regulatory Flood Plain. These Flood Vulnerable Areas (FVAs) include Special Policy Areas, as well as historical flood damage centres. To help agencies allocate attention and resources, the FVAs have been grouped into 41 ranked Flood Vulnerable Clusters (FVCs), for each of which a single, comprehensive flood remediation approach may be viable. The FVCs represent urban areas that are at an elevated risk of flooding and are areas that have historically experienced riverine flooding under less extreme events than the Regional storm and may continue to do so without remediation. This work has also enabled TRCA to develop site specific plans for emergency response and digital handbooks with information and resources for residents living in FVCs.

1.3.3 Peak flow estimates

To support TRCA's Regulatory flood Plain mapping program, a hydrology study is conducted for each watershed, which includes watershed-scale hydrologic modelling. These hydrologic models use the Regional storm, as well as design storms typically at the 2-, 5-, 10-, 25-, 50-, and 100-year return periods as precipitation inputs. These models generate flow hydrographs at various points along the rivers within the watershed, and the peaks from these hydrographs are input to hydraulic models of the river systems, resulting in flood depth, velocity, and water surface elevations for regulatory and design purposes.

2 FLOOD RISK ASSESSMENT IN WATERSHED PLANNING

One of the main responsibilities of TRCA is to protect life and property from natural hazards including riverine flooding and erosion risks. Riverine flood risk is well understood within the watersheds through flood plain mapping and the underlying hydrology models described in Section 1.3. These are mostly updated every decade at the regional scale and further refinements are completed, as needed, to align with watershed and subwatershed needs.

Riverine flooding occurs when water levels rise, and the streams overtop their banks. Urban flooding, on the other hand, is caused by limited capacity of stormwater infrastructure or drainage systems. Historically, urbanization has generally increased flood risk by altering the volume, intensity, and timing of runoff to streams. This is especially true for areas that were built without stormwater management features in place (i.e., developments pre-1980s).

The flood plain mapping leads to development of the Regulatory Flood Plain, which is the approved standard used in a particular watershed to define the limit of the flood hazard for regulatory purposes. Within TRCA's jurisdiction, the Regulatory Flood Plain is based on the greater of the Regional storm (i.e., Hurricane Hazel) or the 100-year return period applied to the watershed developed to an approved future planning horizon (e.g., 2051) without controls.

Hypothetically, flood risk as defined by the Regulatory Flood Plain should not significantly change between the baseline and current periods because it is based on future development conditions; however, data-driven techniques such as model recalibration, validation, and general refinement (e.g., higher resolution topographic information), as well as policy-driven processes such as Official Plan Amendments, may result in a current Regulatory Flood Plain that is somewhat different than the previous versions used to regulate land use in years past. Looking at TRCA's identified FVCs can provide a nuanced understanding of how urbanization impacts flood risk during the baseline and current conditions, as these areas have historically experienced, or are likely to experience, flooding during less intense events than the Regional storm.

2.1 Case Example: Humber River Watershed Plan

At 90,258 hectares in size, the Humber River watershed is the largest watershed in TRCA's jurisdiction. The upper portions of the watershed are largely rural and the middle and lower parts are mostly urbanized. The watershed consists of five subwatersheds including Main Humber, East Humber, West Humber, Lower Humber, and Black Creek (Figure 4).

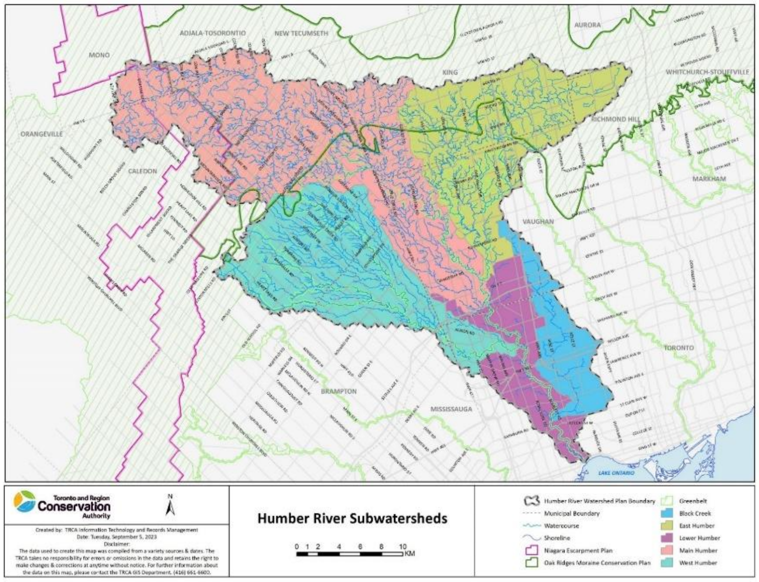

Figure 4: Humber River Watershed and Subwatersheds

2.1.1 Data and Methods

Land use changes between baseline and current periods alter watershed hydrologic response, which can influence flows to FVCs and associated flood risk. To quantify these impacts, baseline and current-conditions hydrologic models were developed using the 2015 Humber River Hydrology Update and 2017 addendum (Civica Infrastructure Inc.) as the base hydrologic model, built on the Visual OTTHYMO (VO) platform. This base model was rigorously calibrated and validated using streamflow gauges and flood frequency analysis to select appropriate return-period Atmospheric Environment Service (AES) design storms.

The model subdivides the watershed into 714 subcatchments (about 4–860 ha, avg. ~126 ha) using topography and sewershed data, and incorporates stormwater quantity control ponds. For the Humber River Watershed Plan (HRWP), the model was updated to represent 2002, 2012, and 2020 development conditions using land use mapping, historic orthophotography, and municipal/TRCA stormwater management (SWM) datasets.

Hydrologic response was parameterized using total imperviousness (TIMP) and effective imperviousness (XIMP), where subcatchments with ≥20% TIMP were treated as urban and modelled using the STANDHYD routine. TIMP and XIMP were calculated through ArcGIS preprocessing, intersecting land-use datasets with subcatchments, and further refined in Excel before being batch-assigned in VO.

Hydraulic features such as SWM ponds, dams, and reservoir-like structures were represented using the RouteReservoir command, which applies discharge–storage relationships. The model includes 79 SWM ponds, Claireville Dam, Lake Wilcox, and additional reservoir-type features—such as the Black Creek Dam, where two storage–discharge curves were used to reflect capacity changes between 2002 and 2020.

After model updates, simulated historical rainfall events were used to verify hydrologic parameters. The models were then run using 2-, 5-, 10-, 25-, 50-, and 100-year return-period AES design storms (6- or 12-hour). Because the baseline and current models share consistent structure, flows extracted at common nodes allow direct comparison of hydrologic changes over time. These flow results were then applied to assess effects on FVCs across the Humber River watershed to characterize the current conditions.

In addition to current conditions, three potential future land use scenarios reflecting the range of urbanization and enhancements in the watershed were assessed as part of the future management scenarios analysis. These scenarios were tested using a hydrology model for flood risk assessment.

- Scenario 1 looked at the full build out of the areas in the watershed that are yet to be developed, controlled peak flows using TRCA's SWM criteria, and minimal on-site retention targets and natural cover enhancement.
- Scenario 2 looked at urban expansion based on Official Plans (OPs), controlled peak flows using enhanced stormwater quantity control criteria, local on-site retention targets, and moderate natural cover enhancements.
- Scenario 3 also looked at OP urban expansion with the same enhanced quantity control as Scenario 2, but with broader on-site retention targets, and optimal natural cover enhancements.

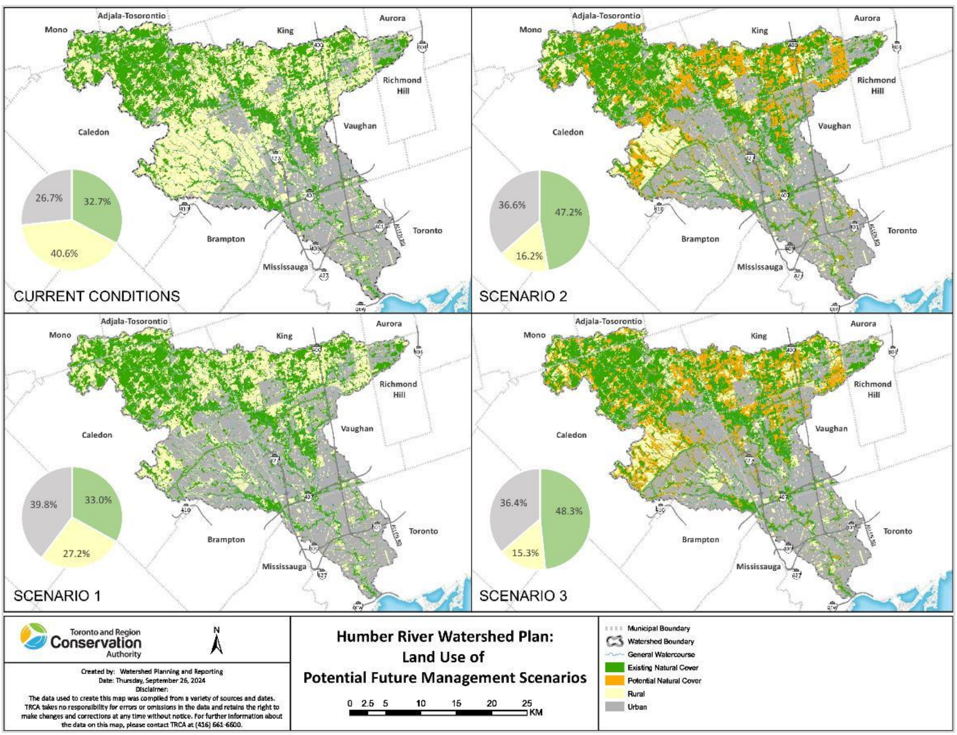

Figure 3: Current and three future land use scenarios for Humber River Watershed

Two illustrative climate scenarios were selected for future scenario analysis including the very high emissions (SSP5-8.5) and moderate emissions (SSP2-4.5) scenarios. The future climate data used in the scenario analysis was derived from downscaled global climate models (GCMs). Modelled historical and future climate data were retrieved through the Power Analytics and Visualization for Climate Science (PAVICS) portal for the two climate scenarios. PAVICS is part of a national suite of climate data portals that have been developed with support from the Canadian Centre for Climate Services. It offers future climate data at a resolution of approximately 10 km. Statistically downscaled daily data from 26 GCMs were used to derive almost all of the 52 climate variables for the HRWP scenario analysis, except the Humidex variables which were based on 19 GCMs.

As part of scenario analysis, hydrologic modelling was completed to examine how flood risk (i.e., peak flows) in the seven Humber FVCs and the broader watershed may change between current (2020 land use) conditions and the three potential future land use scenarios with varying degrees of watershed enhancements/management and without and with climate change. Climate change scenarios were tested by upscaling standard design storms and applying them to the future management scenario models. Each future management scenario was run without and with climate change.

Peak flow results for each of the seven FVCs and design storms from the 2 to 100-year return period and the Regional storm were obtained. The inflow locations to the seven FVCs were chosen as observation points for changes in flood risk because these areas experience riverine flood conditions under less extreme events than the Regional storm or the 100-year storm, and are therefore sensitive to upstream development and management interventions. Figure 4 shows the locations of the inflows to the 7 FVCs within the Humber River watershed.

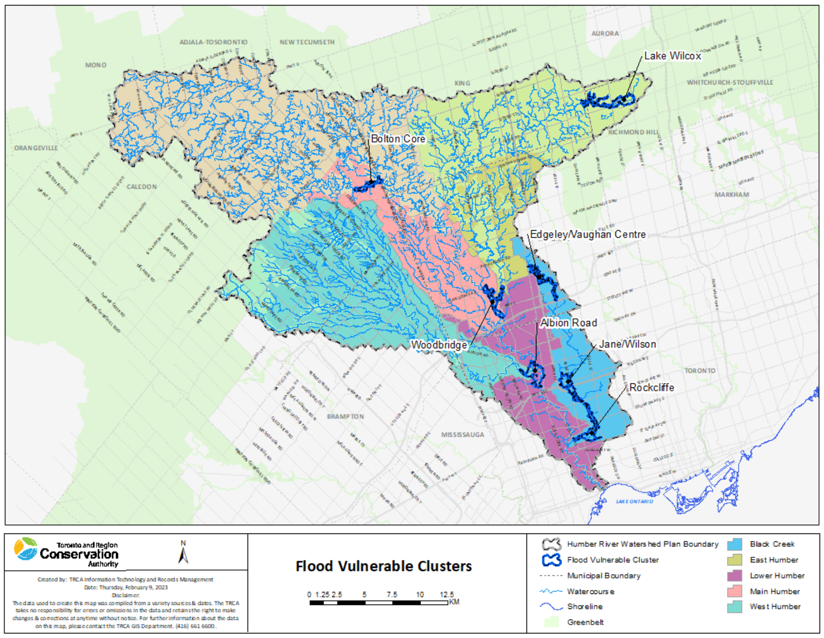

Figure 4: Humber River Watershed and Seven Flood Vulnerable Clusters

2.1.2 Results

Historically, flood risk has generally increased due to urbanization, which alters the volume, intensity, and timing of runoff to watercourses. This is especially true for areas that were built without SWM features in place, such as quantity control ponds.

Based on the results of a hydrologic modelling exercise, this technical report will examine how flood risk in the seven FVCs and the broader watershed may change between current (2020 land use) conditions and potential future urban expansion and climate change scenarios with varying degrees of management.

The key findings of the flood risk assessment indicated that where the standard or enhanced SWM criteria were able to maintain peak flows at the FVCs to current levels or lower, the on-site retention targets for each of the future management scenarios generally trimmed the event peaks further. Where standard SWM criteria were not sufficient to control peak flows to current levels or reduce them, both enhanced quantity control and greater on-site retention targets were needed to bring peak flows down to current levels at the FVCs. In areas where standard or enhanced SWM criteria are not widely distributed or not applied, downstream FVCs generally benefitted more from the Scenario 2 and 3 retention targets than the Scenario 1 targets. The natural cover enhancements generally did not have a significant impact on the volume of stormwater in urbanized areas. The climate change scenarios were tested by upscaling standard design storms and applying them to the future management models; the previously noted trends were magnified and consequently the 100-year peak flows were significantly higher than current levels at all FVCs regardless of the management strategy. An example of this is illustrated in Figure 5 below, which compares the peak flows at FVCs under current and future climate (high emission) scenarios for the 100-year return period storm in land use Scenario 1 (minimal enhancement) and Scenario 3 (optimal enhancement).

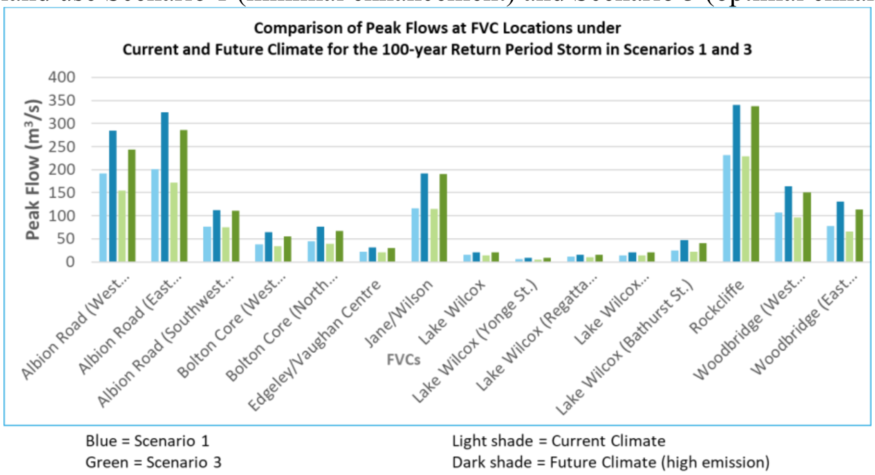

Figure 5: Humber River Watershed and Seven Flood Vulnerable Clusters

Regional storm peak flows from all three future management scenarios were near the current levels at the southwest tributary of the Albion Road FVC and the Black Creek FVCs likely because the contributing drainage areas were currently considered built out and were not expected to undergo significant future development. To an extent, this trend is also seen at the Oak Ridges and Bolton Core FVCs because the potential future land uses were mostly consistent with current conditions. Notably, the west tributary to the Bolton Core FVC saw significant decreases in peak flows for Scenarios 1 to 3. In contrast, inflows to the west tributary of the Albion Road FVC significantly increased for all three future management scenarios likely because of the expansive potential future development across the West Humber and Rainbow Creek subwatersheds. For similar reasons, but to a lesser extent, peak flow increases were also seen in the future management scenarios in the east tributary to the Woodbridge FVC, which was the entirety of the East Humber subwatershed.

The potential future development in the East Humber did not cut across the subwatershed to the extent that it did in the West Humber and Rainbow Creek. Rather, it was concentrated mostly in one tributary. In the case of development occurring across a subwatershed, the timing of peak flows from the various development areas coincided and compounded farther downstream. However, in the case of concentrated development, the timing of peak flows was staggered, with flows from relatively undeveloped areas tending to lag behind flows from the potential future development areas in reaching the main branch of the East Humber. At the confluence of the Woodbridge east and west tributaries, the flow increases from the East Humber seemed to be dampened by flows from the Upper Main Humber, which remained largely unchanged between current and future conditions. In addition, a lower increase in peak flows was seen on the downstream receiving end at the east tributary of the Albion Road FVC for Scenario 1 while Scenario 2 saw somewhat significant reductions and Scenario 3 was reasonably consistent with current levels.

For more information on the results refer to the TRCA's Humber Future Scenarios Analysis Report (2025).

3 CONCLUSION

The flood risk assessment in TRCA's watershed planning framework incorporated site level field information and integrated the hydrology and hydraulic modelling with watershed scale information on potential future land use change, climate change, various management interventions such as natural cover enhancements and implementation of low impact development and urban canopy enhancements to understand their potential implications on the peak flows at the FVCs in the watershed. This provides insights into other areas that may be affected in terms of flood risk across the watershed. The watershed planning framework and data allowed for the decision makers to identify potential measures and priority catchments to enhance flood risk management in a proactive way for watershed health and community resilience.