Carruthers Creek Watershed Plan
Aquatic Impact Assessment

Prepared for the Region of Durham

September 2019

Toronto and Region Conservation Authority

Contents

List of Tables

List of Figures

Foreword

The Region of Durham recognizes watershed plans as an effective tool to inform the management of Durham's water resources, natural heritage, and natural hazards, such as flooding. In 2015, the Region retained the Toronto and Region Conservation Authority (TRCA) to update the watershed plan for Carruthers Creek.

This four-year study will build upon the goals, objectives, and management recommendations established in the 2003 *Watershed Plan for Duffins Creek and Carruthers Creek*.

The following report is one of a series of scenario analysis technical reports that follow the watershed characterization studies (completed in 2017). Information contained in these technical reports will examine potential impacts of future growth and land use changes in combination with other influences such as climate change. Additionally, these technical reports provide the knowledge base necessary to develop the plan's management recommendations. Any recommendations contained in the scenario analysis technical reports are consolidated in the Carruthers Creek Watershed Plan's management framework. The Watershed Plan is the final source for goals, objectives, indicators and management recommendations related to Carruthers Creek. Readers are encouraged to refer to the technical reports for more detailed implementation suggestions.

Executive Summary

Reviewing historical (1999), current (2015) and future scenarios for the Carruthers Creek Watershed (CCW), future scenario 2, which includes the official plan and enhanced Natural Heritage System (NHS), provides the best-case land use scenario to support a functioning and healthy aquatic ecosystem within CCW. However, under future scenario 2 there is still the expectation of continued declines in both aquatic habitat and biodiversity in CCW. Thus, an expanded NHS (proposed scenario in this AIA) that includes, future scenario 2 with habitat critical to supporting endangered species and features required for critical groundwater recharge function in CCW, would enhance the future outlook for the aquatic ecosystem in CCW. In order to achieve this outcome, this report outlines seven management recommendations, based on current (2015) conditions and expected futures outcomes that should be pursued to enhance the state of the watershed. The following actions will maintain and/or enhance overall quality of the aquatic ecosystem:

1. Seek further reductions in impervious cover.
2. Improve water quality and limit water quality impacts within headwaters.
3. Improve fish connectivity in good quality habitat areas (north of Taunton Road).
4. Maintain or enhance groundwater recharge and discharge function inside and contributing to the watershed.
5. Limit or reduce threats to Endangered Redside Dace habitat.
6. Enhance natural heritage system coverage and be proactive with its implementation.
7. Increase spatial coverage of long-term monitoring sites for habitat and biota.

These management actions stem from the general trend in the Greater Toronto Region and CCW, where urbanization continues to drive land conversion from natural cover and agriculture to various other land uses, such as impermeable built infrastructure. This has known negative impacts on ecosystems by altering key processes such as biogeochemical cycling, hydrology, and biodiversity (Grimm et al. 2008). The Carruthers Creek Watershed Plan (CCWP) is one initiative that supports Durham Region to comprehensively advance its sustainability and resiliency goals. It includes recommendations for watershed planning from the Province, natural heritage planning, and recommendations made in the 2016 Durham Community Climate Adaptation Plan. As such, the technical information provided in the CCWP will also inform the Region as it undertakes the provincially mandated municipal comprehensive review process.

This Aquatic Impact Assessment (AIA) technical report is a part of the broader Phase 2 analysis that follows the Phase 1 watershed characterization studies. It examines the aquatic ecosystem objectives and indicators from historical and baseline conditions as well as examines expected impacts of possible future land use change scenarios. These scenarios reflect historical conditions (1999), current conditions (2015), and three potential future conditions with changes in both built and natural areas. The three future scenarios represent changes based on Official Plans (+OP), changes based on OPs and enhancement to the natural heritage system (+NHS), and potential urbanization with the enhanced natural heritage system (+PotentialUrban). A comparative assessment of aquatic impacts under each of the scenarios were completed and the results were iteratively used to: (i) provide a better understanding of the implications of each land use scenario on aquatic ecosystems, and (ii) identify strategic actions on the ground, which will assist Durham Region ensure a resilient aquatic ecosystem as climate and landuse continues to change.

In the AIA, the aquatic ecosystem and the impacts are defined based on the foundations of the 2003 CCWP and the four key goals that are related to (i) hydrologic function, (ii) groundwater levels and baseflows, (iii) surface water quality, and (iv) aquatic habitat and species. In particular, the amount of impervious land cover and conditions of aquatic habitat are evaluated to assess the impact on the abundance and diversity of aquatic communities. This ensures that a holistic approach was taken that includes several aspects of what contributes to the functioning and health of the aquatic ecosystem.

Generally, impervious cover, aquatic habitat conditions and biodiversity within the current scenario (2015) are found to be worse in the urbanized southern portions of CCW (south of Taunton Road). Conversely, the upstream headwater catchments (north of Taunton Road) support better impervious cover, habitat conditions and biodiversity, indicating good quality catchment conditions. Additionally, impervious cover, habitat conditions and biodiversity appear to be declining or (at best) maintained from historical (1999) to current (2015) conditions in most metrics evaluated in this AIA. Out of the three future scenarios evaluated in the CCWP, scenario 2 (+OP+NHS) provides the best case for habitat conditions and biodiversity to be maintained within CCW. Both future scenario 1 (+OP) and scenario 3 (+OP+NHS+PotentialUrban) will be expected to have lower and higher declines, respectively, in habitat and biodiversity. In order to stem future declines and enhance the aquatic ecosystem, the management activities and recommendations (outlined above) should be implemented to maintain current conditions, and at best, enhance the condition of CCW. The future proposed scenario (includes scenario 2 (+OP+NHS) and natural cover for Redside Dace (*Clinostomus elongatus*) habitat and ecologically significant groundwater recharge areas) minimizes impacts due to development to achieve a potential enhancement in the function and health of the aquatic ecosystem in CCW.

Objectives & Overview

The overall objective of this report is to conduct an Aquatic Impact Assessment (AIA) that provides recommendations for land use and natural system planning for the Carruthers Creek Watershed Plan (CCWP). The specific objectives of this analysis were to determine the impact of three future watershed-scale land use scenarios on the:

1) amount of impervious land cover
2) condition of aquatic habitat
3) abundance and diversity of aquatic communities

This document also provides case studies of past land use impacts in the watershed and suggests measures to mitigate current impacts and prevent these in the future. There are several references within this document to work that assesses future conditions and these documents provide in-depth assessments of the potential changes in habitat under each of the future land use scenarios. While the AIA uses and interprets the results of these other technical documents to assess subsequent changes in aquatic habitat and communities, they were unique in their purpose and scope, and as such, remain separate technical documents. Brief summaries of the main findings of other assessments are presented in this document in the context of the aquatic ecosystem.

1.1 Study area: Carruthers Creek watershed

Carruthers Creek is a relatively small watershed with a drainage area of approximately 38km^2. The watershed drainage area ranges from 2 to 3 km in width, and only 18 km in length. It is the easternmost watershed in TRCA's jurisdiction and is located entirely in the Region of Durham. There is estimated to be approximately 72.8 km of stream channel length within the watershed. The watershed occurs within the south slope and glacial Lake Iroquois physiographic regions, south of the Oak Ridges Moraine. The headwaters of Carruthers Creek begin to the south of the Oak Ridges Moraine in the City of Pickering. Both the upstream east and west branches of the creek originate north of Concession 8. The confluence is immediately north of Taunton Road and the creek enters Lake Ontario in the Town of Ajax. Topographically, most of Carruthers Creek Watershed (CCW) is flat to slightly rolling except for the low hills associated with the Lake Iroquois Shoreline and the main valley feature of Carruthers Creek, which forms a distinct but shallow ravine from Taunton Road south to Highway 401. The watershed is mainly rural north of Highway 7 with most of these lands located within the Protected Countryside of the provincial Greenbelt. From Taunton Road south to the lakeshore, low to medium density suburban development is the predominant land use.

1.2 Land use scenarios

The analysis in this report compares the historical and current watershed landscapes to predicted watershed landscapes under three land use scenarios (Table 1, Figure 1). Further details are provided in Appendix 1 and the Terrestrial Impact Analysis.

Table 1. Descriptions of future land use scenarios for the Carruthers Creek watershed

Scenario	Land Use	Description
Historical	1999	Historical land use conditions from 1999 prior to 2003 Carruthers Creek Watershed Plan.
Current	2015	Existing land use conditions from 2015 based on aerial photo interpretation.
Scenario 1 (+OP)	Current+OP	Refines current by assuming all lands south of the Greenbelt are now developed as approved up to 2031 in the Official Plans. Only minor changes from 2015 have resulted as most of the urban area was already developed in 2015.
Scenario 2 (+NHS)	Current+OP+NHS	Future Scenario 1 by adding an enhanced Natural Heritage System as per the approved Official Plans and using updated information on terrestrial habitat connectivity, habitat configurations, and climate vulnerabilities.
Scenario 3 (+Potential Urban)	Current+OP+NHS+ Potential Urban	Illustrates prospective development post-2031 in the headwaters area outside of the enhanced Natural Heritage System identified in Scenario 2. There is no change in the existing urban area south of the Greenbelt.

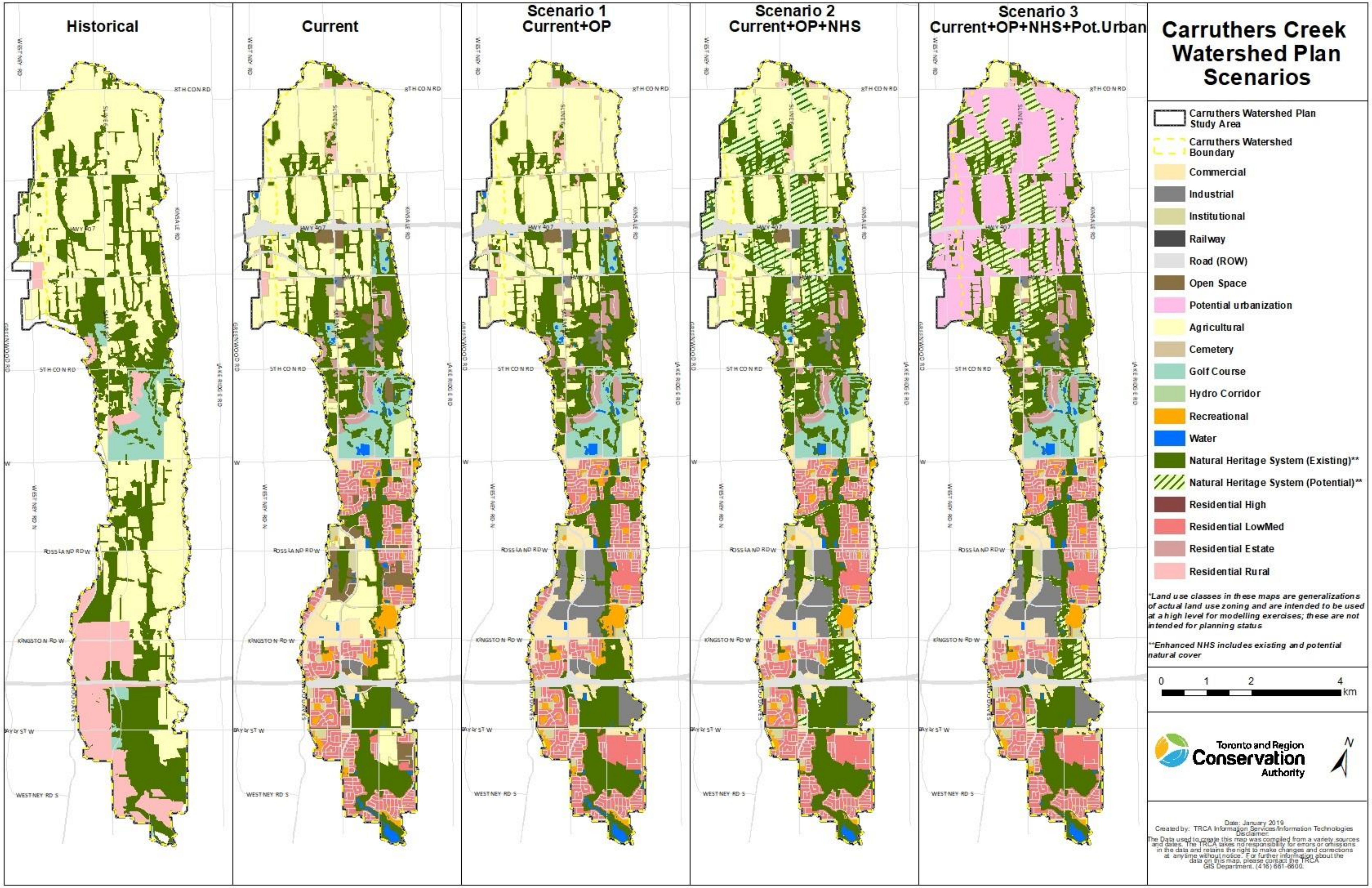

Figure 1. Five land use scenarios for the Carruthers Creek watershed depicting (i) Historical (1999), (ii) Current (2015), (iii) Current + Official Plan (Scenario 1), (iv) Current + Official Plan + enhanced Natural Heritage System (Scenario 2), and Current + Official Plan + enhanced Natural Heritage System + Potential Urbanization (Scenario 3). NB: the marsh by Lake Ontario is outside the geographic scope of this report.

1.3 Watershed objectives, indicators, metrics, and targets

The current CCWP is founded on the principles and goals set in the CCWP developed in 2003 (TRCA 2003). It outlined several goals, one of which is to protect aquatic habitat and species. This highlighted the need to:

1. Limit and minimize the impact of the expansion of impervious land cover
2. Protect, maintain, and enhance aquatic habitat conditions to help maintain the current abundance and distribution of aquatic species
3. Maintain and/or improve the current abundance and diversity of aquatic communities (e.g. fish, invertebrate, and mussel)

Table 2 summarizes each of these objectives along with the specific indicators and metrics that can be quantified to set measurable targets for each objective. Most of the metrics are based on TRCA-developed desktop and field collected data as well as modelled information such as stream thermal stability and stream water quality of the aquatic systems. The targets are being set based on the information from literature, expert opinion, potential opportunities and constraints from policy implementations and land use planning processes.

Land use scenario assessment evaluated the potential impact of each scenario on the aquatic ecosystem. This AIA builds on the data collected and reported on in several Phase 1 technical documents characterizing the current conditions of the watershed including the *Aquatic Habitat and Community Characterization* (TRCA 2017a) and the *Aquatic Crossing and Barrier Assessment Report* (TRCA 2017b). Impacts of future land use scenarios on aquatic biota and habitat were assessed using known thresholds from the literature, desktop analyses and modelling outputs. The results of the AIA are used to (i) provide a better understanding of the implications of each land use scenario on each objective and (ii) identify strategic actions on the ground that will assist Durham Region meet its sustainability goals. Detailed methods, results, and discussion on the AIA are provided in this report in the subsequent sections.

Table 2. Objectives, indicators and metrics used to conduct the aquatic impact assessment, and targets for the aquatic ecosystem of the Carruthers Creek watershed.

Goal	Objective	Indicator and metrics	Target
To protect aquatic habitat and species	Limit/minimize or improve impervious land cover	Percent impervious cover • Amount for the watershed and sub-watersheds	• Primary: Decrease from current • Secondary: <25% for watershed or subwatershed
	Protect, maintain and enhance aquatic habitat conditions to help maintain the current abundance and distributions of aquatic species	Riparian vegetation • Percent of total stream bank length with riparian natural cover	• Primary: >65% natural cover • Secondary: 65% natural cover
		Fish passage • Presence of in-stream barriers to fish movement	• Primary: >6 barriers removed • Secondary: remove 6 priority barriers
		Stream thermal stability • Water temperature	• Maintain cool/cold water habitat and thermal stability
		Hydrology/Water Quantity • Indicators of Hydrologic Alteration (IHA) - High pulse count; High pulse duration; Rise rate	• Maintain or improve IHA metrics
		Groundwater Recharge/discharge • Amount of potential change in recharge/discharge function	• Maintain groundwater recharge/discharge function
		Water Quality • Measures of instream conditions - Chloride; Phosphorous; Nitrogen; Turbidity; Heavy metals	• Maintain or improve water quality
	Maintain and/or improve the current abundance & diversity of aquatic communities	Fish community • Community health and function - Index of biotic integrity - Presence and abundance of indicator species - Presence of invasive species	• Maintain or improve IBI and indicator species abundance • Reduce/limit the number of invasive fish species
		Benthic Macroinvertebrates • Community health and function - Family biotic index (FBI) and Hillsenhof biotic index (HBI) - % EPT; % Tolerant species - Species richness - Presence of invasive species	• Maintain or improve FBI • Improve EPT and reduce tolerant species • Reduce/limit the number of invasive fish species

Background & Methods

2.1 Objective: Limit/minimize or improve impervious land cover

When precipitation falls on the land, it is naturally infiltrated into soils and runs towards streams, lakes and eventually to the ocean. When natural surfaces are replaced with impervious surfaces, water instead flows over these surfaces and directly into streams affecting natural flow, temperature and water quality regimes (Leopold 1968, Booth 1991, Schueler 1994; Table 3). These changes subsequently affect aquatic biota through changes in aquatic habitat quality (May et al. 1997, Wang and Kanehl 2003). Guidance is provided by Environment Canada related to the recommended percent cover of impervious surfaces within urbanizing quaternary watersheds based on a review of the scientific literature (EC 2013). Environment Canada recommends that urbanizing watersheds maintain less than 10% impervious land cover in order for the preservation of the abundance and biodiversity of aquatic species (Table 3; Figure 2). Significant impairment in stream water quality and quantity is highly likely above 10% impervious land cover and can often begin before this threshold is reached (Table 3; Figure 2). In urban systems that are already degraded, a second threshold is likely reached at the 25% level, where above this threshold the management of downstream pollutant loads can be achieved by reducing the amount of impervious cover (Table 3; Figure 2).

Table 3. The amount of impervious and stream condition related to channel stability, water quality, stream biodiversity and how it aligns with overall management objectives. Adapted from Schueler 1994 and EC 2013.

Urban Stream Classification	Sensitive (0-10% Imperv.)	Impacted (11-25% Imperv.)	Non-supporting (26-100% Imperv.)
Channel stability	Stable	Unstable	Highly Unstable
Water quality	Good	Fair	Fair-Poor
Stream biodiversity	Good-Excellent	Fair-Good	Poor
Management objective	Protect biodiversity	Maintain critical elements of stream quality	Minimize downstream pollutant loads

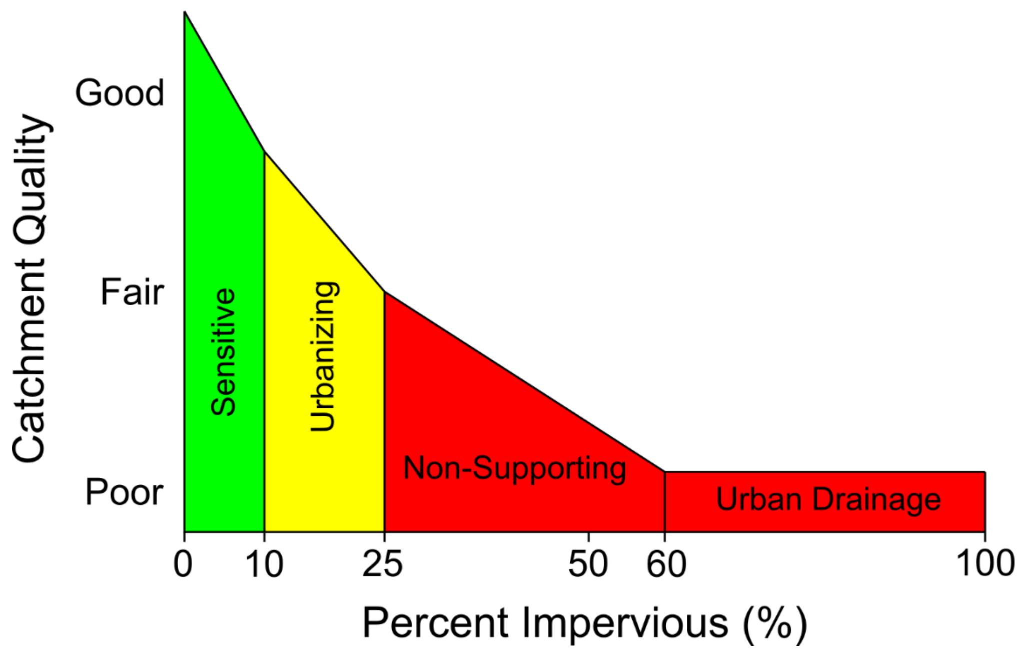

Figure 2. Overall stream quality as it relates to landscape imperviousness within the drainage area of a given stream. Adapted from Schueler 1994.

The percent cover of impervious surface in all scenarios was assessed using a desktop GIS analysis. To do so, land uses for scenarios were given an overall imperviousness value calculated by summarizing the area as a function of the runoff coefficient (here referred to as the Directly Connected Impervious Cover/Area), such that:

$$A_{IC} = A_{LU} * DCIA/100$$

Where, A_{LU} is the area of land use in hectares, *DCIA* is the runoff coefficient, and A_{IC} is the impervious area in hectares. Here the overall impervious cover (IC) percentage for a scenario is calculated by:

$$IC = (TA_{IC}/TA) * 100$$

Where, TA_{IC} is the total area of impervious cover in hectares, *TA* is the total area in the watershed and *IC* is the overall impervious cover percentage for the watershed. DCIA values used for this analysis are detailed in Table 4. For current and future scenarios, the DCIA percentages were applied to the land use categories. Using the *Tabulate Intersection* tool in ArcMap, each scenario was divided according to land use categories for each sub-watershed, watershed boundary and study area boundary. Once the DCIA percentages were applied, the areas for each category were calculated. Historic land use had general categories, so the DCIA values were averaged and simplified to fit the categories for all other scenarios. Briefly, the historical scenario land use from 1999 was only created with the categories: agriculture, golf course, natural cover and urban area (TRCA 2003). The urban area category from 1999 was expanded for this analysis using the current (2015) landuse categories, where the urban area from historical was intersected with urban landuse categories from the current scenario. The categories from current scenario were then attributed to the historical scenario to approximate the urban categories. This report summarizes changes in percent impervious cover under historical conditions, current conditions and under each future land use scenario. Lastly, for this analysis the amount of overall impervious cover and the impervious cover amounts by four different catchments in CCW are provided for each of the five scenarios (Figure 3).

Table 4. The Directly Connected Impervious Area values used for calculating imperviousness for each scenario.

Landuse	DCIA
Agricultural	5
Cemetery	3
Commercial	95
Estate Residential	25
Future Urban	85
Golf Course	3
Hydro Corridor	10
Industrial	95
Institutional	75
Natural Cover	0
Natural Cover (Potential)	5
Railway	40
Recreational	15
Residential High	80
Residential LowMed	50
Road (ROW)	90
Rural Residential	15
Water	0

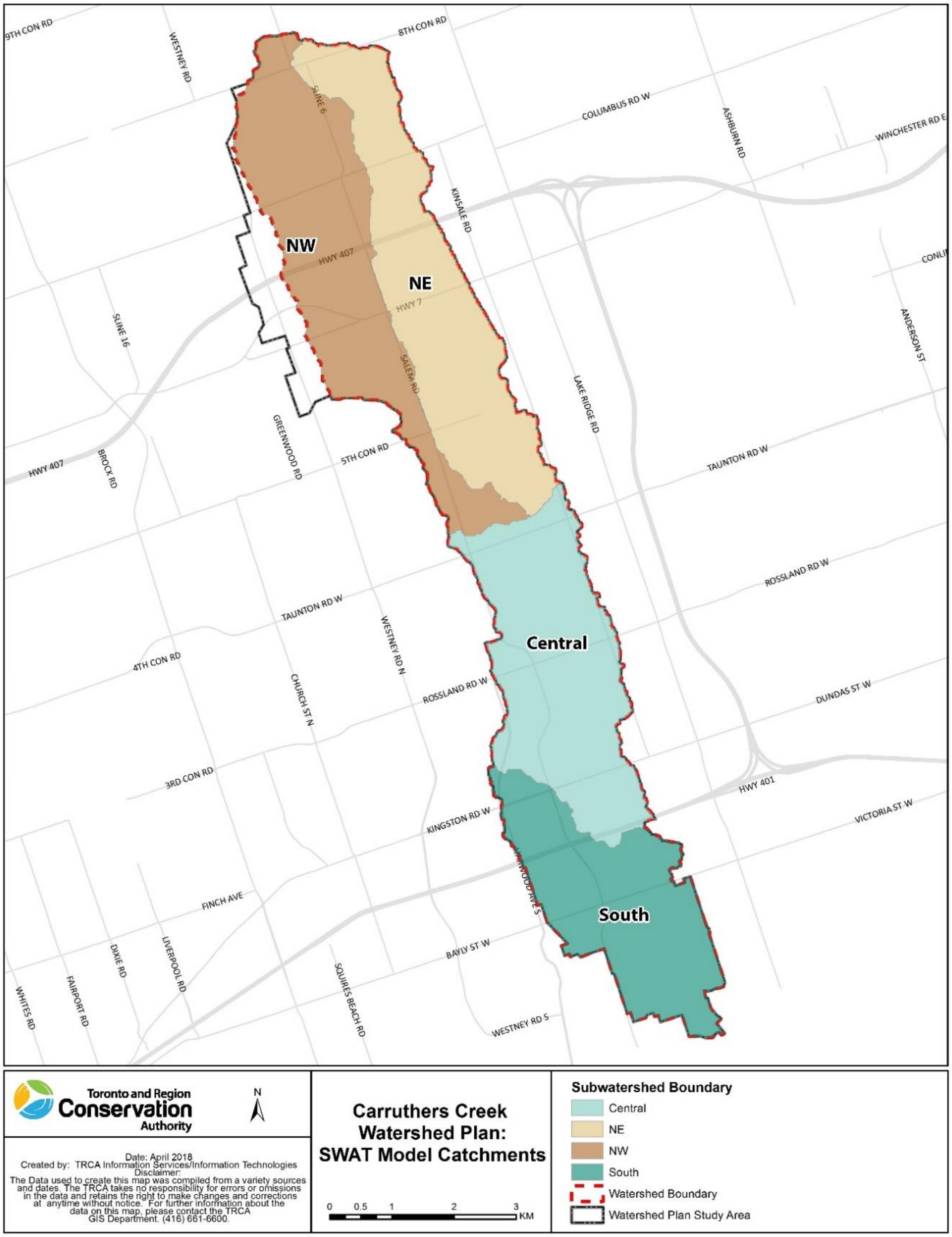

Figure 3. Map of the four catchments used in this analysis. The four sub-catchments used, include the Upper East (NE), Upper West (NW), Central and South.

2.2 Objective: Protect, maintain, and enhance aquatic habitat conditions to help maintain the current abundance and distribution of aquatic species

Aquatic biota is strongly affected by changes of in-stream habitat. Habitat requirements of aquatic biota vary but typically consist of: specific vegetation types and cover both in-stream and adjacent to streams (for protection, feeding or reproduction), physical streambed characteristics (sediment size), adequate movement opportunities (connectivity; absence of barriers), water flow rates, chemistry and thermal regime (for physiological functioning) (Ward and Stanford 1982, Statzner and Higler 1986, Eaton and Scheller 1996, Todd and Kaltenecker 2012, Cheek et al. 2015, Huttenun et al. 2017, Choy et al. 2018). Both landscape disturbance within the watershed (e.g. urbanization, industry, agriculture) or direct disturbance in the stream (stormwater inputs, channelization, sedimentation) can cause changes aquatic habitat suitability and subsequently impact the community structure of aquatic biota (Frissell et al. 1986, Riley et al. 2005, ECCC 2019). Aquatic habitat assessments in the CCW focussed on several general aspects of habitat: 1) headwater drainage features, 2) in-stream habitat, channel stability and form, 3) riparian vegetation, 4) barriers and connectivity, 5) thermal stability, 6) hydrology and water quantity, 7) groundwater recharge/discharge and 8) water quality. Aquatic habitat was assessed using a combination of literature reviews, existing TRCA data reported during the Phase I characterization, desktop analyses and modelling.

2.2.1 Headwater Drainage Features

Headwater drainage features are defined as zero-, first- or second- order streams (ephemeral or intermittent), swales or connected wetlands, are critical to the maintenance of watershed health, including: biodiversity, fisheries, ecosystem functions, natural resource-based economies, and human society and culture (CVC & TRCA 2014; Colvin et al. 2019). Despite these benefits, land use change due to development is a major contributor to headwater drainage feature loss (Ohio EPA 2003; Colvin et al. 2019). Thus, the proper strategic management of headwater drainage features, which provide these many benefits and values, can limit the loss and potential future economic costs related to water quantity and quality; the provisioning of habitat for fish, insects, and amphibians; sediment regulation; and the transport of organic material (Ohio EPA 2003; CVC & TRCA 2014).

For the CCWP, headwater drainage features were assessed in CCWP Phase I as part of the headwater drainage features characterization (TRCA 2017a) and that work is not duplicated in this aquatic impact assessment. Instead a short review to assess the potential impact of future scenarios on headwater drainage features is provided.

Headwater drainage features convey a range of functions, both ecological and hydrological, where hydrologically they are classified into four different categories: important (water year-round), valued (seasonal; surface dry in summer), contributing (spring freshet; storm events; surface dry in late spring) and limited (no surface flow but may provide recharge; CVC & TRCA 2014). Currently, almost all the headwater drainage features in the CCW are found in the northern half (upstream) of CCW (TRCA 2017a). Land use changes between historical (1999) to current (2015) scenarios were limited to the southern half of CCW (south of Taunton Road); however, there was still some land use change towards greater imperviousness (from ~4% to ~10%) upstream of Taunton Road between historical (1999) to current (2015) scenarios, highlighting that there was some potential for impacts to headwater drainage features.

Reviewing future scenarios, both scenario 1 and 2 do not have major development proposed within the northern half (upstream of Taunton Road) of the CCW and would likely have a more limited impact on headwater drainage features. Additionally, scenario 2 with the proposed enhanced NHS, would likely have a net benefit of improvement on headwater drainage features by first conserving features and providing opportunity to restore natural riparian and wetland areas, as will be explored through the restoration opportunities analysis in detail (TRCA 2018a). Lastly, scenario 3 (enhanced NHS and full build-out) would have the greatest potential impact on headwater drainage features and would require increased monitoring effort to better inform development decisions to prevent major impacts to headwater drainage features. With a higher potential for impact on headwater drainage features, it is likely that scenario 3 would convey the largest loss in function of headwater drainage features, which would be associated with the highest economic costs related to water quantity and quality; provisioning of habitat; sediment regulation; and the transport of organic material. In order to avoid this outcome, if urban development is contemplated, it needs to be strategically limited within the northern half (upstream of Taunton Road) of CCW to protect headwater drainage feature functions. Lastly, to better conserve headwater drainage feature function in CCW, a further expansion of the NHS system in future scenario 2 should be sought.

2.2.2 In-stream habitat

In-stream habitat is important for the biodiversity of organisms found within the aquatic ecosystem (Allan 2004). Specifically, understanding the amount and trend of habitat that is available to both fish and benthic macroinvertebrates is key to identifying a potential key driver of patterns of aquatic biodiversity and ecosystem health within CCW (Allan 2004; Hering et al. 2015). In-stream habitat for fish, insects, and amphibians includes bank morphology, sediment size and amount, downed woody debris, riparian vegetation, instream vegetation, pool-riffle sequences, depth of water, among many other aspects. A major driver of habitat condition within a watershed is related to the amount and type of land-use within the watershed, where the relationship can be defined by the amount of impervious cover within a watershed or sub-catchment (as summarized above; Schueler 1994, EC 2013).

As part of the CCWP, in-stream habitat (in-stream cover, sediment size, channel stability and form) was assessed using standardized Ontario Stream Assessment Protocol (OSAP) sampling (Stanfield 2017) for the CCWP Phase I technical work (TRCA 2017b). Additionally, current conditions of Fluvial Geomorphology are reported in detail in Matrix Solutions Inc. (2018). The OSAP stream assessments are conducted triennially in CCW, where data from 2003-2015 (with some additional sampling in 2015) can be found across three sites, accounting for approximately 120-240 m out of an approximate total of 72.8 km (for the entire CCW) sampled. Unfortunately, this provides a limited window (0.0016-0.0032%) of potential habitat available to fish and benthic macroinvertebrates throughout CCW. Moreover, many of the fish and benthic macroinvertebrate species have annual movement that is often greater than the standard ~40-80m OSAP sampling site length, which makes it difficult to link habitat conditions to fish and benthic macroinvertebrate communities (e.g., Rodtka et al. 2015). Thus, for the AIA we utilize results from the Fluvial Geomorphology report for CCW by Matrix Solutions (2018a) and literature to provide insight into the potential impacts of land-use change across the scenarios on in-stream cover, sediment size, and bank morphology.

Increases in the amount of impervious cover have a direct impact on the hydrological regime of watercourses, which subsequently impacts the instream cover, sediment size, and bank morphology (Schueler 1994, Walsh et al. 2005, EC 2013). Specifically, increases in the amount of impervious cover (or a rise in surface runoff) are expected under future scenarios for CCW (see impervious cover results below). While storm water management may be able to mitigate some of the associated impacts of potential increases in impervious cover, it can be difficult to fully mitigate the fundamental changes to the landscape (Matrix 2018). Given the expected land use changes in future scenarios for CCW (scenarios 1-3), bank morphology and stability for the watershed is likely to become more unstable, leading to the need for future restoration activities to improve degraded habitat (Allan 2004, Walsh et al. 2005). Expected changes of in-stream habitat would likely mirror changes in impervious cover (Wallace et al. 2013), where habitat conditions would be expected to be worse towards the mouth of CCW and increase in quality towards the headwaters of CCW under current conditions (see below for impervious analysis). Moreover, out of the three future scenarios, scenario 2, with the enhanced natural heritage system and no buildout, would be expected to provide the best instream habitat condition and subsequent ecological health and function within CCW. Conversely, scenario 3 would provide the least amount of good quality habitat and likely produce conditions representative of Urban Stream Syndrome, including reduced instream cover, finer sediment size (increased bedload), and unstable bank morphology (Walsh et al. 2005). Scenario 3 would likely provide poor habitat and negatively impact aquatic species. To seek an enhancement in instream habitat conditions, further expansion of the NHS to reduce impervious cover below 10% (which conveys good catchment quality) should be sought.

2.2.3 Riparian vegetation

Stream riparian areas, the interface between terrestrial and aquatic ecosystems, are important transitional zones (Gregory et al. 1991). These environments provide habitat, act as a buffer between aquatic and terrestrial ecosystems and contribute resources to streams, such as woody structure, nutrients and shade (EC 2013). Both the width of the riparian zone and the length of the stream that is vegetated are important considerations for continued aquatic ecosystem function (Beacon Environmental 2012). Generally, there is evidence that the riparian corridor can mitigate the impact of land use or stressors instream, including: water quantity, water quality, temperature, human disturbance, erosion hazards and provide habitat protection (Beacon Environmental 2012). A recent review of riparian corridors found that corridors with a buffer in the range of 30 to 50 m were considered to be beneficial to aquatic ecosystems and for reducing hazards (Beacon Environmental 2012). Generally, wider riparian corridors had increased benefits to the aquatic ecosystem.

Riparian vegetation was assessed for the historical, current and future land use scenarios through a desktop GIS analysis. The amount of natural cover within the riparian corridor was quantified within the riparian corridor under each scenario in order to assess land use scenarios related to riparian targets. The riparian corridor is calculated as the perpendicular distance from the centreline by:

$$RC = 0.5(Wb) + 30$$

Where, RC is the riparian corridor width in metres and Wb is the average bankfull width of the stream in metres. In order to account for riparian zones associated with lentic systems as in ponds and lakes, the following methodology was applied. Where open water data were available (e.g. areas identified as open water polygons in the updated Land use/Landcover layer), a 30 m buffer was applied around the open water polygon. In some instances, a waterbody was represented by a series of tributaries off the main creek branch in the watercourse layer. Where open waterbodies were connected to watercourses, a 30 m buffer was applied around the open water polygon instead of assigning riparian zones around the individual watercourse tributaries. Pond/lake riparian zone calculations were combined with the overall riparian zone calculations assessed for streams. Lastly, in order to scale up to the watershed the analyses on riparian natural cover was conducted by stream order (according to Strahler 1964), where RC was calculated for each stream order type.

The next step was to determine the amount of natural cover within the riparian corridor (RC). To calculate this amount, the following considerations were made:

1. Length of watercourse in kilometers.

2. Average stream width for each type of stream order in meters. Determine average width for streams through orthophotography interpretation. Where available, use Regional Watershed Monitoring Program (RWMP) data to determine average widths of third, fourth, fifth, and sixth order streams. Each RWMP station averages the widths from three sampling points. This number from a minimum of four stations was used to supplement orthophotography interpretation to determine the stream width for the stream order from which the data was collected.

3. Area within the riparian corridor (as defined above) with existing riparian cover in km^2. Here the riparian cover was defined as an area designated as forest, successional, meadow, wetland, or beach/bluff according to the 2013 GIS natural cover layer.

4. Area within the riparian corridor with potential riparian cover in km^2. Potential riparian cover was defined as land that is not currently classified as forest, successional, meadow, wetland, or beach/bluff, and is suitable for restoration (i.e. no existing or future urbanization). If updated land use/land cover mapping information was available and included urban and agricultural land use classes, this information was used in the assessment of potential natural cover. Existing urban land uses or other permanent impervious surfaces was not considered potential natural cover. As such all urban uses such as residential, commercial, industrial and institutional as well as all airports, roads, highways, transit corridors and railways were not included as potential natural cover. However, land uses that do not typically require hardened surfaces were included such as agricultural (both cultivated and pasture), utility corridors, open space, golf courses, cemeteries, parks/recreational uses.

5. Area in km^2 within the riparian corridor that does not constitute existing or potential riparian cover as defined above. These lands are either presently urbanized or committed to future urban land uses. If updated land use mapping was not available, the most recent available mapping was used in this assessment.

To calculate the amount of riparian cover, the most recent ortho-photography was used for all analyses and all data were calculated by stream order for the overall watershed and each sub-watershed separately.

2.2.4 Fish passage

In-stream barriers such as dams, weirs and road crossings pose a significant challenge for fish movement (Choy et al. 2018). If these barriers are impassible, they often exclude fish from spawning grounds, suitable habitat and limit dispersal (Choy et al. 2018). Connectivity was assessed in Carruthers Creek in 2016 by walking all streams in the watershed from the headwaters to Carruthers Marsh, but only in areas where landowner access was permitted. Current conditions of the stream barrier assessment are provided in TRCA (2017c) and are summarized here. Changes in fish passage under future scenarios was not assessed because the practices which resulted in many of the existing barriers are no longer permitted. Moreover, for the purposes of the watershed plan, future road networks are not included in the scenario-based assessment. A summary of priority barriers to remove is provided in the results section.

To assess fish species passage of barriers water levels were first corrected for the 2016 sampling of barriers in CCW which occurred during low flow conditions. Here the adjustment in water level was calculated as the difference in median water level from stream gauge HY013 (CCW mouth; Figure 4) from August 15 – September 15 in 2016 (during the sampling period) and from 2008 -2018. The difference in median water level was used to adjust the height of barriers and pools to evaluate barrier passage under median flow conditions, providing insight into what barriers impede fish movement for over half of the time relative to the period of 2008-2018. After the adjustments, fish species passage was reassessed using the procedure outlined in TRCA (2017c). The priority of barrier removals was then assessed for those that provide access to >1 km of stream habitat and depending on the type of infrastructure that the barriers support. Altogether, the priority for barrier removal is assessed considering the potential to conserve/improve the health of fish communities, the potential passage of the barrier (no species or jumping species only), the amount of habitat made available by removal, and the ease of barrier removal (e.g., type of structure).

2.2.5 Thermal classification

Water temperature can play a vital role in the maintenance of healthy and functioning aquatic ecosystems. As water temperature is directly linked to the metabolic rates of both benthic macroinvertebrate and fish species, it will influence the growth, survival, and distribution of these species. In particular, of importance to aquatic ecosystems is the thermal stability of stream reaches, which reflects how much stream temperature changes through time. As the stream temperature of a watercourse is governed by many different factors, including upper catchment forest cover, groundwater discharge, ambient air temperature, stream order, watershed slope and storm water management ponds (Chu et al. 2010; Hester & Bauman 2013), thermal stability will be dependent on these attributes. Generally, thermally stable stream reaches are often found in more groundwater dependent reaches with shading, whereas thermally unstable reaches tend to have minimal groundwater inputs with lower canopy cover (Chu et al. 2010).

Here thermal regimes were assessed based on July 1-21 maximum weekly average temperatures (MWAT) at three logger locations (CC001WM, CC002WM, CC003WM). Fish community classification was determined using three main temperature categories: cold (<19°C), cool (19 to 21°C), or warm (>21°C). Thermal stability was determined using three temperature fluctuation categories: stable (<5°C), moderate (5 to 9°C), or extreme (>9°C). Changes in thermal regime were assessed under current conditions (from sampling in 2015 and 2016) and each future land use scenario using known land use impacts on stream temperature found in the scientific literature. Lastly, we assess the spatial arrangement of thermal regimes using data collected from expanded monitoring across 14 sites in 2015, to provide insight into where particular thermal regimes may be present throughout CCW.

2.2.6 Hydrology

Hydrological impacts from urbanization and industrial development are well-established in the scientific literature (Foster 1990, Paul and Meyer 2001). Urbanization alters the hydrology of a watershed as natural areas are converted to impervious surfaces, streams are channelized, and water is diverted (Faulkner 2004, Grimm et al. 2008). The effects of these changes vary based on the type and stage of urban development but generally include decreased infiltration, increased runoff volume, higher peak flows, diminished baseflow, and a deterioration of stream water quality (Foster 1990, Faulkner 2004). Proper hydrologic function is essential for aquatic ecosystems in order to maintain the hydrologic cycle and the physical habitat characteristics required by aquatic biota (Richter et al. 1996). Disruptions to the hydrologic cycle of the watershed affect ecosystem processes and the supportive services they provide to humans, such as flood protection and clean water (Lam and Conway 2018). A surface water quantity characterization was conducted as part of Phase I of CCWP (TRCA 2018b) and we extend on this work to provide insight into how current conditions may impact aquatic biota and ecosystems.

Stream hydrology was assessed using data collected at three stream gauges in the CCW (HY013, HY089, and HY090; Figure 4) and values for the upper East Branch were calculated by simple subtraction of HY089 from HY090 (Figure 4). These data were used to calculate Indicators of Hydrologic Alteration (IHA; Richter et al. 1996). Thirty-two IHA values were created to represent changes in hydrology that are ecologically relevant and that influence aquatic, wetland and riparian ecosystems (Richter et al. 1996). Of the 32 IHA parameters, 3 parameters that reflect the flashiness of the system were chosen because they reflect the most ecologically relevant changes in hydrology that affect aquatic communities (Trudeau and Richardson 2015). These three parameters included high pulse count, high pulse duration, and rise rate. High pulse count is calculated as the median number of high pulses within each water year. High pulse duration is the median duration (days) of high pulses. Rise rate is the median of all positive differences between consecutive daily values. Parameters that may influence aquatic habitat and communities (The Nature Conservancy 2009), include:

- the frequency and magnitude of soil moisture and anaerobic stress for plants
- the variability of floodplain habitats for aquatic organisms
- nutrient and organic matter exchanges between river and floodplain
- soil mineral availability
- bedload transport, channel sediment textures, and duration of substrate disturbance
- entrapment of organisms on islands or floodplains

Changes in IHA parameters were assessed under current conditions and each future land use scenario was assessed using known land use impacts on IHA parameters found in the scientific literature. IHA parameters from the CCW (site HY013; 2008-215) were also compared to those calculated for a stream gauge in Mimico Creek (HY045) using data from 2004-2014. Mimico Creek is a heavily urbanized stream with a similar contributing drainage area to HY013, thus Mimico Creek can provide a benchmark for comparisons for the purposes of the AIA and a potential proxy for hydrology under future scenario 3.

Figure 4. The location of the three stream gauge sites in the Carruthers Creek Watershed.

2.2.7 Groundwater discharge/recharge

Groundwater provides many functions and services, such as water purification, habitat for rare/endemic species, buffering droughts and sustaining wetlands (Griebler and Avramov 2015). Groundwater also interacts with surface water that impacts surficial processes and aquatic habitat and species. Groundwater discharge/recharge was evaluated for the CCW using two main assessments: the identification of Ecologically Significant Groundwater Recharge Areas (ESGRAs) and identifying potential groundwater discharge areas using the TRCA Expanded Groundwater Flow Model (TEGWFM). TEGWFM is a steady-state numerical groundwater flow model, which was provided by the Oak Ridges Moraine Groundwater Program (ORMGP) and is used here to assess the potential impact of varying land use scenarios on the CCW (ORMGP 2018). Model results provide both the potential recharge points and discharge points of groundwater that were used to identify potential changes to both recharge and discharge of groundwater under the different land use scenarios, the ORMGP (2018) report is summarized here.

2.2.7.1 Ecologically significant groundwater recharge areas (Oak Ridges Moraine Groundwater Program)

Ecologically Significant Groundwater Recharge Areas (ESGRA) methodology was designed to be used with existing regional-scale groundwater models built for, amongst other things, Source Water Protection (Marchildon et. al., 2016). The methodology combines modelling outputs with GIS techniques to produce a map of areas on the landscape where groundwater recharge is interpreted to directly contribute to the hydrological function of pre-specified ecological features, such as wetlands and streams (Figure 5). The methodology makes use of groundwater particle tracks, tracked backward in time, originating from ecological features of interest. Track (or pathline) generation is a post-processing technique widely used in the groundwater modelling community to delineate zones of groundwater contributing areas. By tracking particles backward in time, ecological features (e.g. wetlands, headwater streams, etc.) that receive groundwater discharge as predicted by the model can be linked to areas on the land surface where the discharging water originates. Where pathlines, tracked backward in time, intersect the land surface, endpoints are created. While every endpoint is linked to an ecological feature, many of them may be found isolated, while others tend to converge in large clusters. These clusters are of main interest owing to the fact that the ESGRA methodology is premised on the principle that endpoint clusters are a surrogate for the likelihood that the area indeed supports the hydrological function of some identified ecological feature. A complete summary of ESGRA identification is beyond the scope of this report but an overview of the selection of thresholds and relationships chosen for TRCA and CCW can be found in (TRCA 2019a). This AIA report reviews potential impacts of current and future scenarios to ESGRAs that have been identified in CCW. To do so, the amount of ESGRAs that would be protected under the natural heritage system was assessed across scenarios.

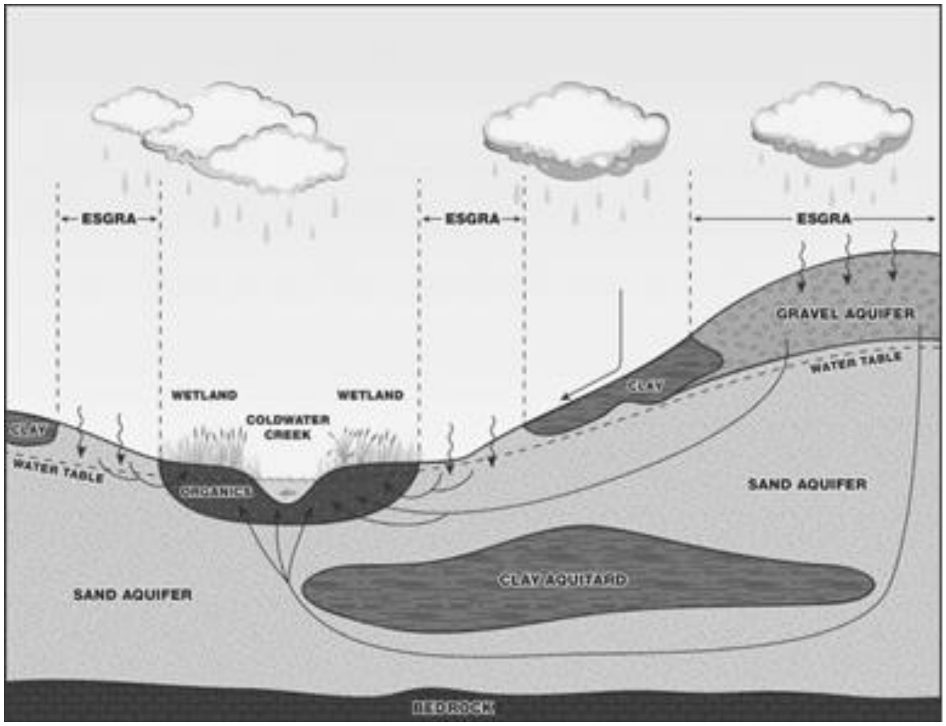

Figure 5. Conceptual drawing of Ecologically Significant Groundwater Recharge Areas in a landscape context.

2.2.7.2 Groundwater discharge (Oak Ridges Moraine Groundwater Program)

Using the methodology described above for identifying ESGRAs, when a particle is tracked backward in time, the pathline of particle is associated with a starting point that is a potential discharge point in the watershed associated with mapped features such as streams, wetlands, ponds. Using the potential discharge points for many particles produces a spatially explicit map of potential recharge points that can be used to identify where groundwater discharge in ponds, streams or wetlands throughout the watershed originates. Further, as the amount of expected groundwater discharge can also be assessed in relation to different land use scenarios which provides insight into potential development impacts on groundwater discharge within the watershed. An assessment of the land use scenarios on overall discharge potential and discharge potential within specific catchments (Figure 6) was conducted by ORMGP (2018) and this report was summarized here.

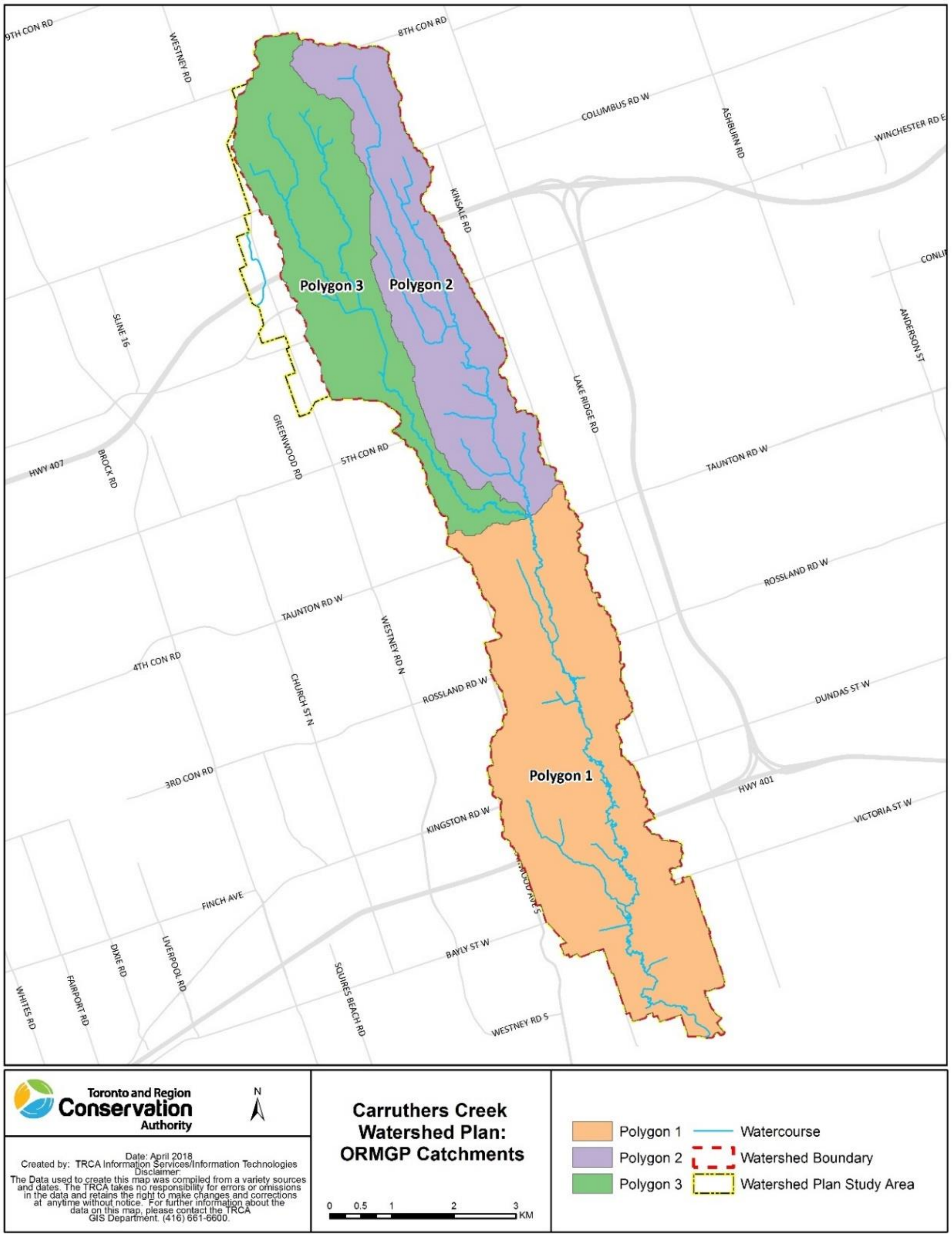

Figure 6. The location of the three sub-catchments used in the TEGWFM model where groundwater for both discharge and recharge were assessed for CCW.

2.2.8 Water quality

Stream water quality in urbanized watersheds is generally degraded by increased turbidity, nutrients, metals, *E. coli* and other contaminants due to more impervious surfaces and increased runoff (Paul and Meyer 2001).

These altered conditions lead to eutrophication, salinization, along with other changes in water chemistry, which subsequently affect aquatic communities and have been identified widely in the literature as stressors at multiple spatial scales (Wallace *et al.* 2013, Kaushal et al. 2018, Sarma *et al.* 2018).

Water quality was assessed for the current scenario (2015) of the CCWP in the Phase I report on the Surface Water Quality Characterization (TRCA 2017d). Using both historical and additional collection of data in 2015/2016 of several water quality parameters, such as ammonia, phosphorus, nitrogen compounds, suspended solids, chlorides, *E. coli*, and dissolved oxygen, both the current and long-term (30 years) conditions were assessed. The main findings included elevated levels of total phosphorus, phosphate, total ammonia, *E. coli*, TSS, turbidity, and some trace metals detected during runoff events in the headwaters (TRCA 2017d). Below the confluence of both Upper East and West branches of CCW, decreases were observed in many water quality parameters as groundwater inputs increased but increases in chloride concentrations were starting to be detected alongside increasing urbanization of the east branch (TRCA 2017d). Increases in levels of chloride concentrations were further observed towards the mouth of the CCW, which was found to exceed both Provincial and Federal Water Quality Guideline levels by 16-17 times as this was downstream of Ajax's urban area boundary (TRCA 2017d). Lastly, increases in phosphorus, *E. coli*, nitrate, TSS, and some trace metals were also detected downstream of the urban boundary of CCW during runoff flow/wet weather events (TRCA 2017d). This pattern reflects expected water quality changes in relation to land use patterns in CCW in 2015. With further land use changes expected in the future (scenarios 1-3), additional impacts to water quality would also be expected to occur. Of note, with the recent opening of the 407 in June 2016, it is expected that increases in chloride concentrations would likely now be detected within the headwaters of CCW and further buildout under scenario 3 would also increase the expected amount of pollutants within CCW.

The Soil and Water Assessment Tool (SWAT) was used to model changes in surface water quality and quantity under three future land use scenarios (Di Luzio et al. 2001, Arnold et al. 2012). This tool uses numerous model inputs/components (e.g. soils, weather, point sources) to simulate future changes in water quality and quantity; it has also been used in the past for various watersheds within and outside of the TRCA jurisdiction. Here, the predicted average of total suspended solids (turbidity), total nitrogen, total phosphorous and flow is provided for each scenario. For more details on the model please review (TRCA 2019b). For this report, we summarize the results of the SWAT model for the overall watershed to infer potential impacts of land-use change on water quality.

2.3 Objective: Maintain and/or improve the current abundance and diversity of aquatic communities (e.g. fish, invertebrates, and mussels)

Freshwater aquatic biota is an important part of stream ecosystems. They are critical to nutrient cycling, controlling water quality, providing food energy and streambed stabilization (Holmlund and Hammer 1999, Vaughn et al. 2008). However, a variety of stressors related to urbanization such as increases in impervious surfaces leading to degraded water quality, competition and predation by invasive species and changes in thermal regime and in-stream habitat, can impact aquatic biota (Riley et al. 2005, EC 2013, MNRF 2016). Due to these threats, several species have either been extirpated or have been listed as endangered or threatened under provincial and/or federal legislation. For example, Redside Dace (*Clinostomus elongatus*) are listed as Endangered under both *Ontario's Endangered Species Act* (Government of Ontario 2007) and the federal *Species-at-Risk Act* (COSEWIC 2017). The Eastern pondmussel (*Ligumia nasuta*) is listed as Endangered under the federal *Species-at-Risk Act* but has been re-assessed as of Special Concern due to increased sampling effort and the discovery of new sub-populations and a reduction in the rate of decline (COSEWIC 2017). Due to their sensitive nature, fish and benthic macroinvertebrates (including mussels) are good indicators of disturbance in the watershed.

2.3.1 Fish communities

Fish communities are surveyed in each watershed by the TRCA every three years with 2015 marking the fifth year of monitoring in the CCW. There are three stations surveyed in the CCW (CC001WM, CC002WM, CC003WM), with data from 2003, 2006, 2009, 2012 and 2015 (Figure 6). Sampling was also conducted in 2015, where a further 6 sites (CCWP-08, CCWP-09, CCWP-03, CCWP-10, CCWP-11 and CCWP-12) were also sampled across CCW (Figure 7). An additional two sites sampled in 2018, located south of Taunton Road and north of Rossland Road, were also included in this analysis (see section 3.3.1 for location and scores associated with these sites). Lastly, data available from 2000 from six stations (CC01, CC02, CC03, CC04, CC05, CC06; Figure 7) in CCW were also used in this report. This data provides insight into trends in fish communities between 1999 and 2015. Stations from 2000 and the 2015 period do not overlap exactly, but comparisons between the historical (1999) and current (2015) scenarios can be completed at three stations, CC001WM (CC06), CC003WM (CC02), and CCWP-11 (CC03; Figure 7).

Fish communities were sampled using single pass electrofishing methods documented in the Ontario Stream Assessment Protocol (OSAP; Stanfield 2017, TRCA 2017b). Fish were identified to species, where both the presence-absence of species and relative abundances were obtained. For a complete summary of fish survey methodology, please see Stanfield (2017) and TRCA (2017b). Fish community Index of Biotic Integrity (IBI) scores were calculated using the same methodology as in the 2003 CCWP (TRCA 2003). This IBI produces a score ranging from 10 (poor) to 50 (very good) using nine measures of fish community composition under four broad groups (Table 5). Two modifications of Steedman's work were made, similar to what was done for the previous Carruthers Creek watershed plan (TRCA 2003), including the exclusion of blackspot and brook trout presence/absence (as there is no concrete evidence of Brook Trout presence in CCW) and therefore the IBI score had a maximum value of 45 instead of 50.

Here, the overall trend (2001-2015) of fish community IBI values were assessed and a focus on the comparison between historical (2000) and current (2015) conditions at three sites within CCW was completed. Lastly, an additional 6 sites are included and assessed for spatial patterns in IBI for the current scenario (2015). Changes in fish communities were assessed under each future land use scenario using known land use impacts on fish communities found in the scientific literature. The fish IBI (Steedman 1987) was the primary metric used to assess future changes.

Table 5. Nine sub-indices used in fish index of biotic integrity calculations.

Group	Sub-index
Species richness	• Number of native species • Number of darter and/or sculpin species • Number of sunfish and/or trout species • Number of sucker and/or catfish species
Local indicator species	• Presence or absence of Brook Trout (only in coldwater streams) • Percent of sample as *Rhinichtys* species
Trophic composition	• Percent of sample as omnivorous species • Percent of sample as piscivorous species
Fish abundance	• Catch per minute of sampling

Figure 7. Distribution of sampling locations for sampling years 2000 (*n*=6) and 2015 (*n*=6) alongside the long-term monitoring plots (RWMP; 2003-2015; *n*=3).

2.3.2 Benthic macroinvertebrates

A well-balanced and functioning biological community is a good indicator of a healthy aquatic system. Benthic macroinvertebrates (BMI), bottom-dwelling organisms including aquatic insects, crustaceans, molluscs, and worms, provide an important ecological link between microorganisms and fish communities (Lindeman 1942). They are often used in studies to determine the quality of waters because of their abundance, relatively well-known pollution tolerances, limited mobility, and dependence on the surrounding environment of the stream they live in (Hilsenhoff 1987, 1988). They are useful indicators of aquatic habitat conditions and changes because their community composition is affected by both short-term and continuous pollution and stress (Hilsenhoff 1987, 1988). Community characteristics of BMI, such as abundance, richness, diversity, evenness, and community composition, are highly dependent on habitat conditions, thus can be monitored to determine how the quality of the habitats are changing over time. In particular, a high abundance of pollution sensitive taxa, such as Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), typically indicates a higher water quality; while a high abundance of Chironomidae (midges) and Oligochaeta (worms), considered pollution-tolerant, indicates an impaired habitat.

Benthic macroinvertebrate (BMI) surveys were conducted annually in the Carruthers Creek Watershed starting in 2002 until present (2017). Data were collected using TRCA-specific protocols from 2002 to 2012 and subsequently sampling method was changed to match the provincial standard, the Ontario Benthos Biomonitoring Network Protocol (OBBN; Jones et al. 2007), in 2013. Thus, for this report we use standardized BMI samples from three locations in the watershed (CC001WM, CC002WM, CC003WM; Figure 6) annually (2013-2017) as the benchmark condition for the current scenario. We reference historical conditions with data collected from 2002-2003, which corresponds closely to historical scenario (1999), and compare Family Biotic Index (FBI) values with current data from 2015-2016 (scenario 2 (2015)), to assess potential changes in the BMI community across two different scenarios.

Briefly, OBBN sampling involves collecting three samples in each reach: two riffles and one depositional area (pool). All BMI samples were preserved in the field and brought to the lab for processing. Approximately 300 organisms (composed of 100 organisms from each of riffle 1, riffle 2, and pool) were identified. In most years, the majority of taxa were identified to genus/species level, and some groups, including Chironomidae and Oligochaeta to family. For a complete summary of OBBN sampling methodology, please see Jones *et al.* (2007). For this report, data were summarized using several metrics including: Hilsenhoff's Biotic Index (HBI; Hilsenhoff 1987, 1988), Family Biotic Index (FBI), % EPT (Ephemeroptera, Plecoptera, Trichoptera), % tolerant (Chironomidae and Oligochaeta), taxonomic richness and Shannon's Diversity Index (Shannon 1948).

The Hilsenhoff Biotic Index (HBI) is based on organic pollution tolerance with higher scores indicating a more degraded site in terms of organic pollution, but not necessarily habitat degradation or other types of pollution. The FBI is similar to the HBI, but the FBI involves family-level identification compared to finer taxonomic level identification of HBI (genus/species-level). Here FBI values were also utilized to provide a comparison between historical (scenario 1) and current (scenario 2) conditions. FBI values were determined using tolerance (to organic pollution) values which range from 0 to 10 and increase as water quality decreases (Table 6). Low values are assigned to groups which are sensitive to organic pollution while high values suggest groups which are tolerant to organic pollution. Each tolerance value is used in a weighted average calculation with the relative abundance of each benthic group summed into a single value.

$$FBI = \sum \frac{x_i * t_i}{N}$$

where:

x_i = number of individuals within a taxon
t_i = tolerance value of a taxon
N = total number of organisms in the sample

For the BMI benchmark community for the CCWP (2013-2017) only riffle samples were used as the HBI and FBI metrics were metrics that were developed based on riffle communities (Hilsenhoff 1987, 1988). Generally, a high percentage of EPT taxa is an indicator of good water quality. On the contrary, the presence of high percentages of tolerant species usually indicate habitat degradation or pollution. Taxonomic richness is the count of all the different types of taxa collected within a site. The Shannon Diversity Index (H) quantifies diversity while accounting for how individuals were distributed among the taxa. Low diversity and unevenness are characteristics of a degraded aquatic environment.

Table 6. Hilsenhoff's Biotic Index (HBI) values, Family biotic index (FBI) values, the associated ratings of community health, and the interpreted degree of organic pollution (Hilsenhoff 1987, 1988).

HBI Value	FBI Value	Rating	Degree of Organic Pollution
0.00 - 3.50	0.00 - 3.75	Excellent	Organic pollution unlikely
3.51 - 4.50	3.76 - 4.25	Very good	Possible slight organic pollution
4.51 - 5.50	4.26 - 5.00	Good	Some organic pollution probable
5.51 - 6.50	5.01 - 5.75	Fair	Fairly substantial pollution likely
6.51 - 7.50	5.76 - 6.50	Fairly poor	Substantial pollution likely
7.51 - 8.50	6.51 - 7.25	Poor	Very substantial pollution likely
8.51 - 10.00	7.26 - 10.00	Very poor	Severe organic pollution likely

Assessing changes in BMI communities between historical and current conditions is challenging due to methodological differences between sampling periods 2002-2012 and 2013-2017. Here the FBI was used to assess changes in BMI communities between historical (2002/2003) and current (2015/2016) conditions. FBI was chosen as it was determined to best capture BMI changes compared to other indices given the noted methodological changes and the limited number of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) present in CCW (pers. comm. Jessica Fang *TRCA Biologist Environmental Monitoring and Data Management*). In order to compare similar FBI values between historical (2002/2003) and current (2015/2016) conditions, both pool and riffle samples were included as prior to 2013 no specific habitat was targeted. Changes between historical and current conditions should be interpreted cautiously because of methodological inconsistency. Changes in BMI communities were assessed between historical and current conditions using FBI data from 2002-2003 and 2015-2016, respectively. A benchmark for current conditions was calculated using data from 2013-2017 and impacts based on each future land use scenario was assessed using known land use impacts on BMI communities found in the scientific literature.

2.3.3 Indicator species

2.3.3.1 Redside Dace (Endangered Species-at-Risk)

Redside Dace (Clinostomus elongatus) are a small Cyprinid minnow species that have a limited distribution in Ontario, but have specific habitat needs, often associated with small tributaries (5-10 m wide) that have cool, clear water and are generally found in pools (11-100 cm in depth; COSEWIC 2017; DFO 2019). Activities such as residential/commercial development, agriculture, pollution, natural system modifications, and invasive species are thought to be the biggest threats to Redside Dace (DFO 2019). Redside Dace were used in this report as an indicator species because of their restricted range and sensitivity to urbanization (MNRF 2016). Urbanization is associated with more impervious surfaces and Redside Dace populations are negatively correlated to the percent cover of impervious surfaces; Poos et al. 2012). Additionally, the amount of impervious cover is related to Redside Dace habitat, including altered riparian habitats, flow regimes, streambed alteration, nutrient and stormwater inputs and the disruption of headwater features (COSEWIC 2017). As an Endangered species, Redside Dace habitat is regulated by the Ministry of the Environment, Conservation and Parks (MECP) and includes both occupied and recovery reaches. Occupied reaches are a stream reach in which Redside Dace has been sited/captured within the last 20 years and recovery reaches are historically occupied reaches that have a good chance of recolonization. Additionally, the MECP regulation extends to contributing habitat such as habitat elements near the occupied/recovery stream reaches and areas that are important for augmenting or maintaining baseflows, coarse sediment supply and surface water quality (COSEWIC 2017).

Changes in Redside Dace occurrence and distribution between historical and current conditions were not done due to a lack of historical data. The CCW does have Redside Dace occupied and recovery reaches and for the purposes of this assessment, contributing habitat was termed “potentially contributing” because mapping for the CCWP is only designed as a screening map. The province will provide the final assessment as to whether the habitat is or is not contributing to Redside Dace occupied/recovery habitat. At the site level, a project proponent will be responsible for site level due diligence.

Here, the meander belt width (MBW) delineation methodology completed by Matrix Solutions Inc. 2018b was reviewed with MECP and contributing habitat delineation followed methods from the West Humber (Matrix 2017), where the MBW, plus 30 m on either side of the stream is considered contributing habitat. Further, potentially contributing habitat included all flowing streams, permanent or intermittent headwater drainage features, groundwater discharge areas, or wetlands that augment or maintain the baseflow, coarse sediment supply, or surface water quality of a part of a stream or other watercourse along with forests and wetlands that intersected with the OMNRF occupied Redside Dace habitat. Tile drainage that was also continuously flowing was noted. For wetlands, the entire wetland complex was included as potentially contributing habitat. If TRCA and Ontario Ministry of Natural Resources and Forestry (OMNRF) wetland layers differed, professional judgment was used (e.g. if TRCA staff were sure of the wetland boundaries then they were included but a list of these areas was retained). For forest areas, Ecological Land Classification (ELC) codes were used and only forests were excluded if there was no hydrological connection to Redside Dace occupied habitat. If the TRCA watercourse layer was more up to date than OMNRF, the TRCA layer was used. If there were discrepancies between the OMNRF watercourse layer and the TRCA layer, the locations were recorded for further discussion if necessary. Redside Dace habitat was presented in this assessment, but no specific locations of Redside Dace occurrence are reported. TRCA has added text to maps and reports that say that our layer is for "screening purposes only". For the current scenario, we analyzed the amount of different types of natural cover (forest, wetland, successional and meadow) found within Redside Dace "potentially contributing" habitat. For the CCWP future land use scenario assessment, Redside Dace "potentially contributing" habitat was compared across future scenarios to identify habitat protected within the natural heritage system (natural cover) or whether it was proposed for future development.

2.3.3.2 Eastern Pondmussel (Special Concern Species-at-Risk)

Mussel surveys are not a component of the current long-term monitoring program at TRCA, and as such there is limited data on their distribution within Carruthers Creek watershed. However, critical habitat has been identified within the Carruthers Creek watershed by Fisheries and Oceans Canada in 2013 due to Eastern Pondmussel being listed federally as Endangered under the SARA. Further, an informal field survey for Eastern Pondmussel shells was completed in May 2018. While more abundant species were found (Giant Floater (*Pyganodon grandis*) and Creek Heelsplitter (*Lasmigona compressa*)), no Eastern Pondmussel shells were identified. For the purpose of this document and due to limited data, Eastern Pondmussel critical habitat is presented in the results section as a map from the federal recovery document and current/future threats are discussed.

2.3.4 Aquatic Invasive Species

2.3.4.1 Invasive fish species: Round Goby

There are numerous invasive fish species that have either been found in the CCW or adjacent waters, including several of note, such as Common Carp (*Cyprinus carpio*), Goldfish (*Carassius auratus*), Sea Lamprey (*Petromyzon marinus*) and Round Goby (*Neogobius melanostomus*). All these invasive species have a combination of direct and indirect impacts on native biota, which can reduce the overall health and function of aquatic ecosystems. Common Carp (https://www.ontario.ca/page/common-carp) and Goldfish (https://www.ontario.ca/page/goldfish) are established species in Lake Ontario and surrounding waters, where the impacts of these species have likely already taken hold throughout the TRCA jurisdiction and CCW, but refuges (where available) where these species are absent will be vital for some native biota. Additionally, Sea Lamprey are managed with inter-agency consultation (Fisheries and Oceans Canada, OMNRF, TRCA), where the main concern is its impact to larger fish species, which are generally absent in the CCW. Continued monitoring of this species is recommended, but it is not considered to be a huge threat to most native species within CCW.

The Round Goby is a relatively new invasive fish species within the great lake's basin, which was first found in the St. Clair River in 1990 (MNRF 2018). Round Goby has expanded its range rapidly and is considered a noxious invader as it can outcompete and prey on native species (e.g., mottled sculpin; *Cottus biardii*), consume eggs and young of many native fish, and it may also be a carrier of disease that can be transferred to other wildlife species (from zebra mussels to gobies to birds) (MNRF 2018). Here, we assess the occurrence of Round Goby in CCW to provide insight into whether this species may be problematic for aquatic communities in CCW in the future.

2.3.4.2 Invasive benthic macroinvertebrates: Rusty Crayfish & Chinese Mystery Snail

Similar to fish, there are numerous invasive benthic macroinvertebrate that may have negative impacts on aquatic ecosystems. Of importance to CCW is the Rusty Crayfish (*Orconectes rusticus*) and Chinese Mystery Snail (*Bellamya chinensis*).

The Rusty Crayfish is an invasive species that is capable of outcompeting and displacing native crayfish species, and it is expanding its range in southern Ontario. Therefore, native crayfish are not expected to buffer the range expansion in Ontario (Phillips et al. 2009). Originally from the Northeastern United States, the Rusty Crayfish is increasing its range presumably due to its use as fish bait (Phillips et al 2009). Once established, it can reduce the benthic macroinvertebrate community, macrophyte biomass, as well as alter aquatic habitats. Rusty Crayfish was first collected by TRCA staff in the mid-1980s in the Duffins Creek watershed, which is located immediately west of Carruthers Creek.

Mystery snails are an invasive species that were introduced to California in the late 1800s for the seafood market and likely released into the Niagara River in the 1930s (Minnesota Sea Grant 2012). These species have invasive tendencies including the formation of dense populations, outcompeting native species, predation on fish embryos and transmitting parasites that can affect native species (Minnesota Sea Grant 2012). Mystery Snails were first collected by TRCA staff in CCW in 2015.

Here, we assess the occurrence of Rusty Crayfish and Chinese Mystery Snails relative to CCW to provide insight into whether this species may be problematic for aquatic communities and ecosystem health in CCW in the future.

Results and Discussion

3.1 Land use and impervious cover

The area and amount of land use types across the five scenarios varies dramatically, which is expected to produce concordant changes in the impervious cover. For this AIA, the specific details about the area and amount of land use change across scenarios are not analyzed in detail as the similarities and differences between scenarios have been discussed at length in the CCWP Terrestrial Impact Assessment (TIA) and elsewhere. However, included here is some discussion about general land use patterns across scenarios, where the area and percent of each land use type is summarized in Appendix 1 for reference.

The overall percent impervious cover for each scenario follows a simple relationship, as the amount of impervious cover types increase, the overall percent imperviousness for CCW increases (Table 7). As the historical scenario (1999) has the lowest amount of impervious cover, this analysis indicates that CCW would be a ‘sensitive’ watershed and in relatively good overall condition (Figure 8). Correspondingly, CCW shows an overall increase in the percent impervious cover in current scenario (2015), where CCW is considered to be ‘urbanizing’ and in good-fair condition (Figure 8). Lastly, for the future scenarios 1, 2, and 3, the overall percent imperviousness is high enough that it would be expected that CCW would be ‘non-supporting’ and have a fair-poor overall condition (Figure 8). Of note, the enhanced natural heritage system associated with scenario 2, has a slightly better overall condition by increasing the natural cover from what is found in Scenario 1, which produces a slight reduction (~1%) of imperviousness in CCW.

Table 7. The percent impervious cover for each scenario is shown for the overall catchment and by four different SWAT catchments (West Branch, East Branch, Central and South) are summarized.

Catchment	Scenario				
	Historical	Current	1	2	3
East Branch	4	11	11	11	31
West Branch	4	10	10	9	39
Central	9	37	53	52	52
South	29	44	49	48	48
Overall	9	24	30	29	42

Breaking down the percent of impervious cover spatially by catchment can provide insight into where in the CCW one might expect there to be good, fair and poor stream conditions across the scenarios. For the historical scenario, 3 out of 4 catchments appear to confer a good level of catchment quality (<10% impervious cover; Table 7 and Figure 9). The historical scenario has a low percentage of impervious cover likely related to changes in the central catchment (Figure 9). For the upper headwater catchments (East and West Branch), both current and future scenarios (1-2) generally have a good-fair quality, with the exception of scenario 2 where the upper west branch has a low enough impervious cover that could support good quality conditions (Figure 9). This is consistent with overall CCW values shown in Table 7 and the notion that the enhanced natural heritage system coveys a net benefit to CCW. Lastly, Scenario 3 represents the full build out scenario with the highest impervious cover overall (Table 7), where every catchment is considered to have fair-poor conditions (Figure 9).

Of note, this analysis does not find that any of the catchments has a percentage of impervious cover (>60%) that produces a strict poor overall quality indicative of an 'urban drainage' (Table 7 and Figure 8).

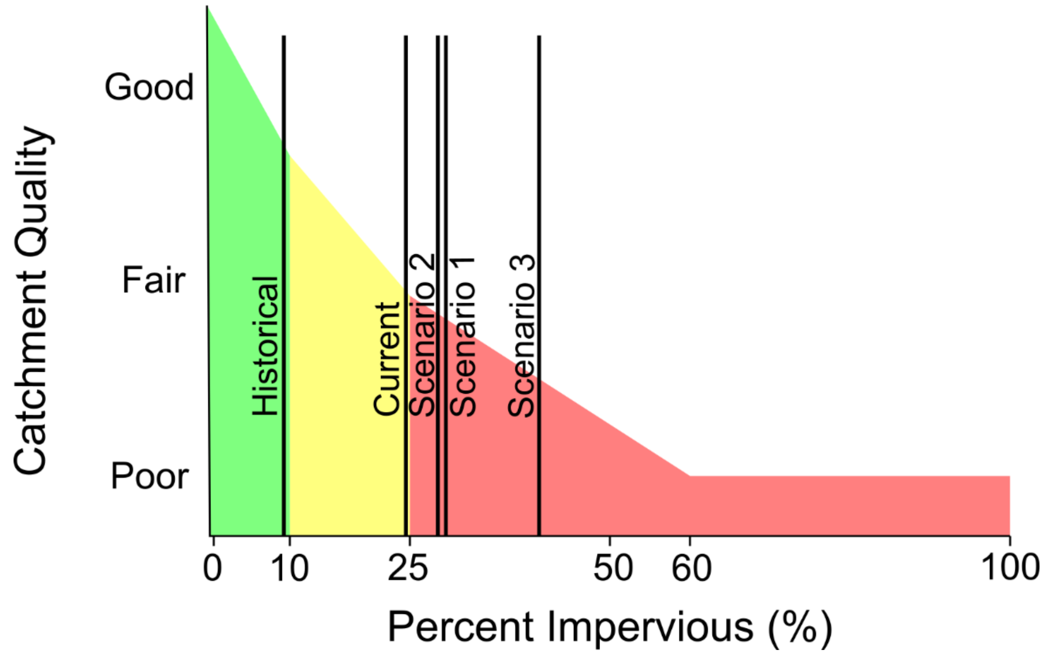

Figure 8. Overall watershed imperviousness for each scenario and the corresponding expected health of the watershed. The historical (1999), current (2015) and future scenarios (1-3) are shown here. Adapted from Schueler 1994.

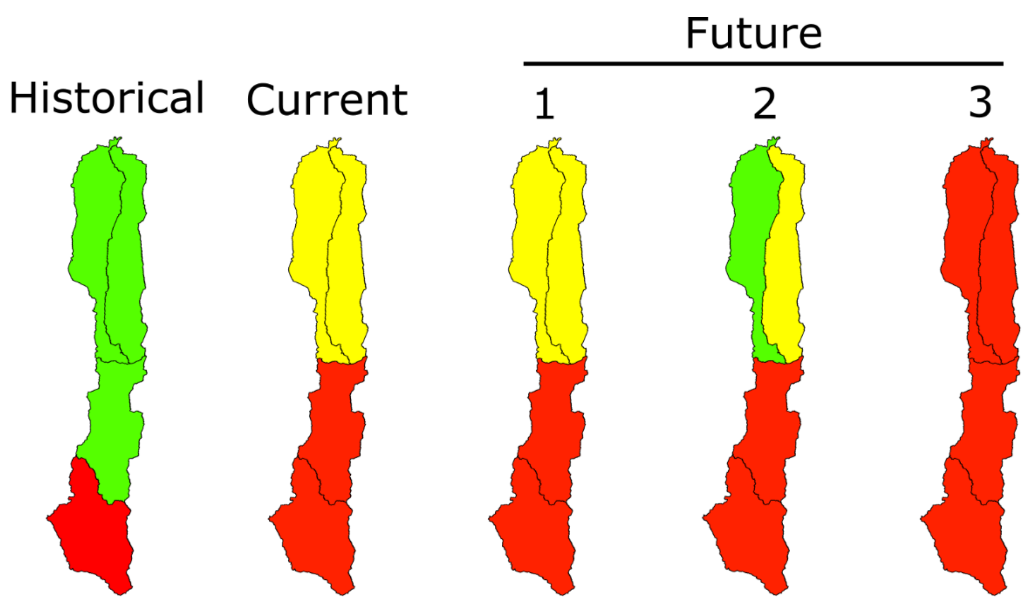

Figure 9. Catchment quality due to impervious cover by the four catchment zones for each scenario included in CCW. Here catchment quality is determined by the amount of impervious cover within each catchment and classified as good (green), good-fair (yellow) and fair-poor (red) shown in Figure 7. The historical (1999), current (2015) and future scenarios (1-3) are shown here.

The main land use types that are related to impervious cover patterns in the CCWP scenarios are chiefly urban cover, natural cover and agricultural lands (see Appendix 1 for details). The historical scenario had approximately 28% natural cover in 1999 (including water features) and 53% agricultural lands, which has been reduced substantially by the current scenario (2015). In the current (2015) land use scenario there is approximately 23% natural cover (a decrease of approximately 5%), 34% agricultural land (decrease of approximately 19%), and 29% urban (increase of approximately 17%) indicating that the natural and agricultural lands were likely converted to other urban land uses. Only minor differences exist between current and future scenario 1 with small decreases in agriculture and open space and small increases in residential, commercial and industrial land uses. This is not surprising given that most of the land use change within the urban boundary has already occurred within the watershed and is reflected in the current scenario. However, when compared to future scenario 2, there is a substantial increase in natural cover (from 23% to 36%), which is driven by the additional areas included in the enhanced NHS. When comparing the scenario 2 to 3, there was a 19% increase in urban land cover and a 15% decrease in agricultural cover. As a result, scenario 3 confers the worst quality conditions compared with other scenarios. These patterns of land use mirror the impervious values found for CCW (Table 7).

Given the amount of impervious cover in the future scenarios (all >25%; Figure 8), the overall stream quality of fair-poor would be expected for all, which will produce highly unstable stream banks, fair-poor water quality and lead to poor biodiversity outcomes (Schueler 1994; EC 2013). However, there is the potential that catchments within the headwaters may be able to obtain lower impervious cover values (<25%: Figure 9) that produce good to fair overall quality habitat that produces (at the very least) unstable bank stability, fair water quality and fair-good biodiversity in scenarios 1 and 2 (Schueler 1994; EC 2013). Of note, impervious values for the upper east and west branches are just above 10% threshold (Table 7; only the upper east in scenario 2, upper west is <10%), meaning that stream quality is close to a good condition such that it produces good bank stability, good water quality and good-excellent biodiversity. In particular, future scenario 2 produces the best outcome in the headwaters with the enhanced natural heritage system. However, in order to ensure all of the headwaters produce good quality habitat for aquatic species, at a very minimum at least 0.5% less impervious cover is required within the upper east branch in scenario 2.

Another consideration in order to better achieve a better water balance with new development is by reducing the impact of increasing imperviousness by including low impact design (LID), such as green infrastructure (GI), into future designs. The idea is that LID can mimic natural processes such as the infiltration, evapotranspiration or use of stormwater, to mitigate impacts to water quality and aquatic habitat (Copeland 2016). This includes features such as bioretention facilities, rain gardens, vegetated rooftops, rain barrels and permeable pavements (Copeland 2016). While this will certainly mitigate some of the impacts of increased imperviousness, there are also added benefits to ecology and society (Filazzola et al. 2019; Hamilton & Sawka 2019). However, to date there is no example from which water balance has been achieved with any amount or combination of these pieces of infrastructure. In particular, mimicking the surface water runoff of natural cover (for both small and large storm events) has not been shown to be possible. Thus, even an aggressive LID development approach in future scenario 3 will realize increased stressors and impacts to both habitat and species within CCW. However, any properly maintained LID in perpetuity would certainly lessen impacts to the aquatic ecosystem.

3.2 Aquatic habitat conditions

3.2.1 Riparian vegetation

Currently, approximately 49% of the riparian corridor in CCW is natural cover, followed by rural (42%) and urban (8%) land covers (Table 8). Within the riparian corridor natural cover (49%), forest represents the dominant type of natural cover (27%), followed by wetland (15%) and meadow (4%). Spatially, there are also large differences in the amount of land cover types within each of the four catchments. Within the southernmost catchments (central and southern) the major land cover within the riparian corridor is natural cover followed by urban cover (Table 9). Conversely, the upper headwater catchments (upper east and west) have rural land cover as the dominant land cover followed by natural cover (Table 9). Similarities across catchments include meadow having consistently low (≤10%) amounts throughout CCW, with the lowest amounts within the headwaters (~3%; Table 9). Whereas, the amount of forest and wetland can vary depending on the catchment (Table 9).

Comparing current and future scenarios, future scenario 1 (representing the official plan) has a comparable natural cover amount to the current scenario, but a slightly higher urban and lower rural cover within the riparian corridor (Table 8). Future scenario 2 has an increase in the amount of natural cover (by approximately 15%) within the riparian corridor with the addition of the enhanced natural heritage system (Table 8). This is achieved with a reduction in the amount of rural land cover. Lastly, future scenario 3 has the highest amount of urban land cover within the riparian corridor, yet it maintains high amounts of natural cover with the enhanced natural heritage system (Table 8).

The previous watershed plan for Carruthers Creek (2003) sought to have a target of 100% natural cover within the riparian corridor, where 75% of this cover would be woody vegetation. In reality, reaching 100% natural cover within the riparian corridor is likely not achievable given that built infrastructure, such as road crossings, would prevent this target from ever being realized. Moreover, improved knowledge since 2003 of the composition of riparian natural cover would suggest that a mix of forest, meadow and wetland cover types would support a more diverse, robust and healthy aquatic ecosystem, making the 75% woody vegetation target untenable (e.g., Jackrel & Wooten 2015). For example, the Endangered Redside Dace requires meadow within the riparian corridor as this is identified as their optimal habitat (COSEWIC 2018). Notably, only 4.4% of the riparian corridor is currently found to be meadow (Table 9). An enhancement of meadow within the riparian corridor would likely not only benefit Redside Dace, but other terrestrial species that require it (please see terrestrial impact analysis for CCW).

A recent review of riparian corridors found that 30 m buffers around all watercourses convey a net benefit to the aquatic system and could improve overall function and health of the ecosystem (Beacon Environmental 2012). Here, using a 30 m riparian corridor analysis, there is only natural cover within 49% of the current scenario and 65% of the best-case future scenario (Table 8). This is well below the amount needed to provide good quality habitat for aquatic communities and realize benefits for other water quality and/or fluvial geomorphology processes (see above for context). While scenario 2 is the best-case future scenario for the riparian corridor, the amount of natural cover should be further enhanced (>65%) to maximize the benefit of this feature and provide the added benefit of reducing higher impervious cover amounts within CCW catchments (see impervious cover section above).

Table 8. The overall percent natural, rural and urban cover within the riparian corridor for the current (2015) and each of the three future scenarios.

Scenarios	Natural	Rural	Urban
Current	49	42	8
1	50	41	9
2	65	27	8
3	65	15	20

Table 9. The percent natural, rural and urban cover within riparian areas by each of the four catchments in the Carruthers Creek Watershed (see Figure 3 for catchment areas) for the current scenario (2015). Also shown is the overall percent of each type of natural cover for forest, meadow and wetland.

Catchment	Natural Cover Type			Totals		
	Forest	Meadow	Wetland	Natural	Rural	Urban
Upper West	19	3	18	40	53	7
Upper East	29	3	9	41	52	7
Central	43	10	10	63	22	15
South	41	8	41	90	0	10

3.2.2 Fish passage

The barrier assessment conducted during Phase I of the CCWP revealed that there are 139 structures within CCW (TRCA 2017c). Only 39 of these barriers represent an impediment to fish species movement and 16 of 39 barriers are only a barrier to non-jumping fish species (TRCA 2017c). Additionally, 35 of these barriers would have a large impact on habitat availability by providing access to > 1km in stream length (Figure 10). If low flow conditions during sampling are corrected (water level is about 9cm below the median), this means that 29 barriers are still found to remain a potential impediment to fish movement (Table 10). Spatially, the 29 barriers are not evenly distributed as the highest number of barriers exist within the upper east branch (*n* = 16), followed by the southern portion (*n* = 7) and the upper west branch (*n* = 6) of CCW (Table 10 and Figure 10).

Table 10. The current number of barriers to fish species movement for the overall Carruthers Creek watershed, below the confluence (southern), and the West and East branch above the confluence. Classifications are based on barriers that provide access to >1 km of river length and barrier heights are adjusted to median flow conditions for 2008-2018.

Barrier Passage	Overall	Southern	West Branch	East Branch
No Species	17	5	3	9
Jumping Species Only	12	2	3	7
Total	29	7	6	16

Considering the benefit of barrier removal (access to habitat for fish species, rescue effects for populations), any barrier removal will undoubtedly provide a net improvement for fish species; however, some barrier removals will have a larger overall net benefit for fish connectivity by providing greater access to habitat and providing greater movement potential. Considering current fish connectivity, because the practices which resulted in many of the existing barriers are no longer permitted, the highest connectivity (measured as dendritic connectivity index) for fish species in CCW is found in the southern portion below the confluence of the east and west branch of Carruthers Creek (TRCA 2017c). Further, fish community analysis (see section 3.3 below) reveals that the region north of the confluence conversely has the healthiest fish communities in CCW (Figure 10) and lowest potential for habitat impairment via future impervious cover (Scenario 3 and 4; Figure 9). Thus, the highest potential benefit associated with barrier removal would be north of the confluence in the CCW. Because of this prioritization of barrier removal is focused within this area of CCW (Figure 10A).

The spatial distribution of barriers within the upper west and east branches differs (Figure 10A), where the east branch has more barriers in distinct spatial clusters and the west branch has fewer barriers that are fairly spread out from one another. Thus, based on this spatial distribution, the upper west branch of CCW achieves the largest net benefit with the removal of each single barrier by providing greater access to habitat with every barrier that is offline. Of these 6 barriers on the west branch, those that prevent passage to all species, but provide access to more potential habitat are prioritized (Table 11 and Figure 10A). Lastly, the structure and type are considered where the potential ease of removal is prioritized (easier to remove prioritized first). Thus, removing these identified barriers in the upper west branch would provide the largest net benefit first to resident species (barriers to all species), enhance a healthy fish community and will have the greatest potential to realize biodiversity conservation goals under future scenarios.

Table 11. A summary of the priority number for barrier removal, fish species passage, structure, description of type, and the approximate amount of habitat made available through the removal of the barrier (km).

Number	Passage	Structure	Type	Habitat*
1	No Species	Pedestrian	Metal Perched Culvert	6
2	No Species	Weir	Concrete/Wood Weir	2
3	No Species	Natural	Log Jam	0.75
4	Jumping Species	Weir	Step Weir	0.75
5	Jumping Species	Ramp	Rock/Metal Pipe	0.75
6	Jumping Species	Road Crossing	Perched Concrete Culvert	0.75

*Note: habitat refers to the approximate amount of habitat made available if all other structures are still in place.

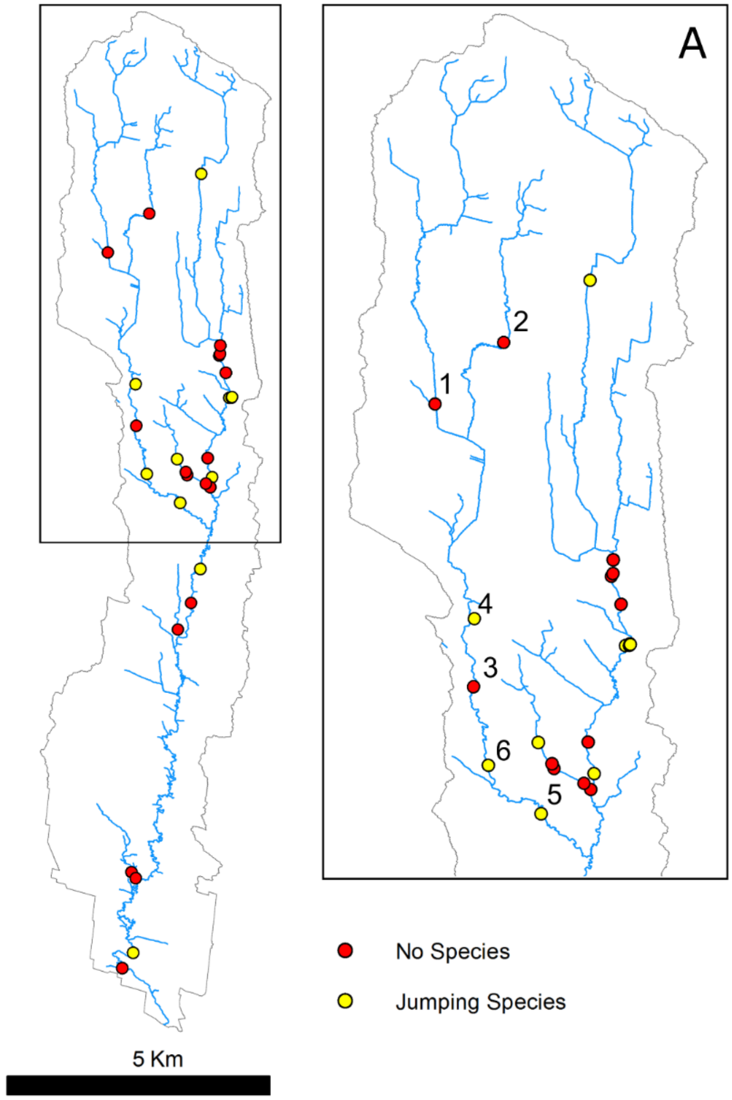

Figure 10. Aquatic passage of fish species for barriers during median flow conditions (2008-2018) in the Carruthers Creek Watershed and for (A) the area above the confluence. Shown are categories for barriers that allow no species and only jumping species to pass. Numbers refer to the priority of barrier removal on the west branch of CCW. Note: Barriers that provide access to < 1km of stream habitat have been omitted.

3.2.3 Thermal regime and classification

The thermal regimes at long-term monitoring locations (*n* = 3) have cool to warm water thermal regimes that are moderately stable under current conditions (2015/2016; Table 12). Additionally, the spatial distribution of thermal regimes for the current scenario (2015) shows a general pattern of warmer temperatures within the southern portion of the watershed, and cooler or colder temperatures in the upstream portion of the watershed (Figure 12). This indicates that the thermal regime in CCW could potentially support a diversity of cold, cool and warmwater fish and benthic communities. This pattern in thermal regime mirrors the amount of impervious cover throughout CCW (less upstream, more downstream; Figure 9) and potential sources of groundwater discharge (Figure 13). Under future scenarios (1 and 2), there will likely be minimal changes in the thermal regime and thermal stability as there are expected to be minimal changes in urban cover on the landscape. Additionally, the enhanced NHS in scenario 2 may provide further cooling and stability through added shading provided by increases in forest cover. One caveat to this is that future scenarios for CCWP do not consider the configuration and number of future roadways explicitly and instead implicitly assume that they are a part of a particular type of land cover. Of note, the addition of the 407-highway corridor and its associated stormwater management ponds may be a source of thermal effluent that could raise temperatures and produce less stable thermal regimes within the colder headwaters (Sabouri *et al.*, 2013; Hester & Bauman, 2013). Of note for this analysis, CCWP thermal regimes do not consider the 407 as part of the current scenario (2015). It is highly likely that this feature would contribute to higher instream temperatures. Additionally, expected increases in the ambient air temperatures due to climate change will also raise instream temperatures and contribute to less stable thermal regimes (Melles et al. 2015). Lastly, scenario 3 will provide increased instream temperature and increased thermal instability with the creation of stormwater management infrastructure needed with the development of buildout within the upper watershed.

Table 12. Thermal classification and stability at three long-term monitoring stations in the Carruthers Creek watershed under current conditions.

Thermal variable	Site and year					
	CC001WM		CC002WM		CC003WM	
	2015	2016	2015	2016	2015	2016
Average weekly temperature (°C) and thermal regime classification	20.6 (Cool)	21.7 (Warm)	20.5 (Cool)	21.4 (Warm)	21.3 (Warm)	20.4 (Cool)
Average weekly fluctuation (°C) and stability classification	6.2 (Moderately stable)	6.5 (Moderately stable)	7.6 (Moderately stable)	7.3 (Moderately stable)	6.8 (Moderately stable)	6.7 (Moderately stable)

Temperatures categories: cold (<19°C), cool (19 to 21°C), or warm (>21°C)

Temperature fluctuation categories: stable (<5°C), moderate (5 to 9°C), or extreme (>9°C)

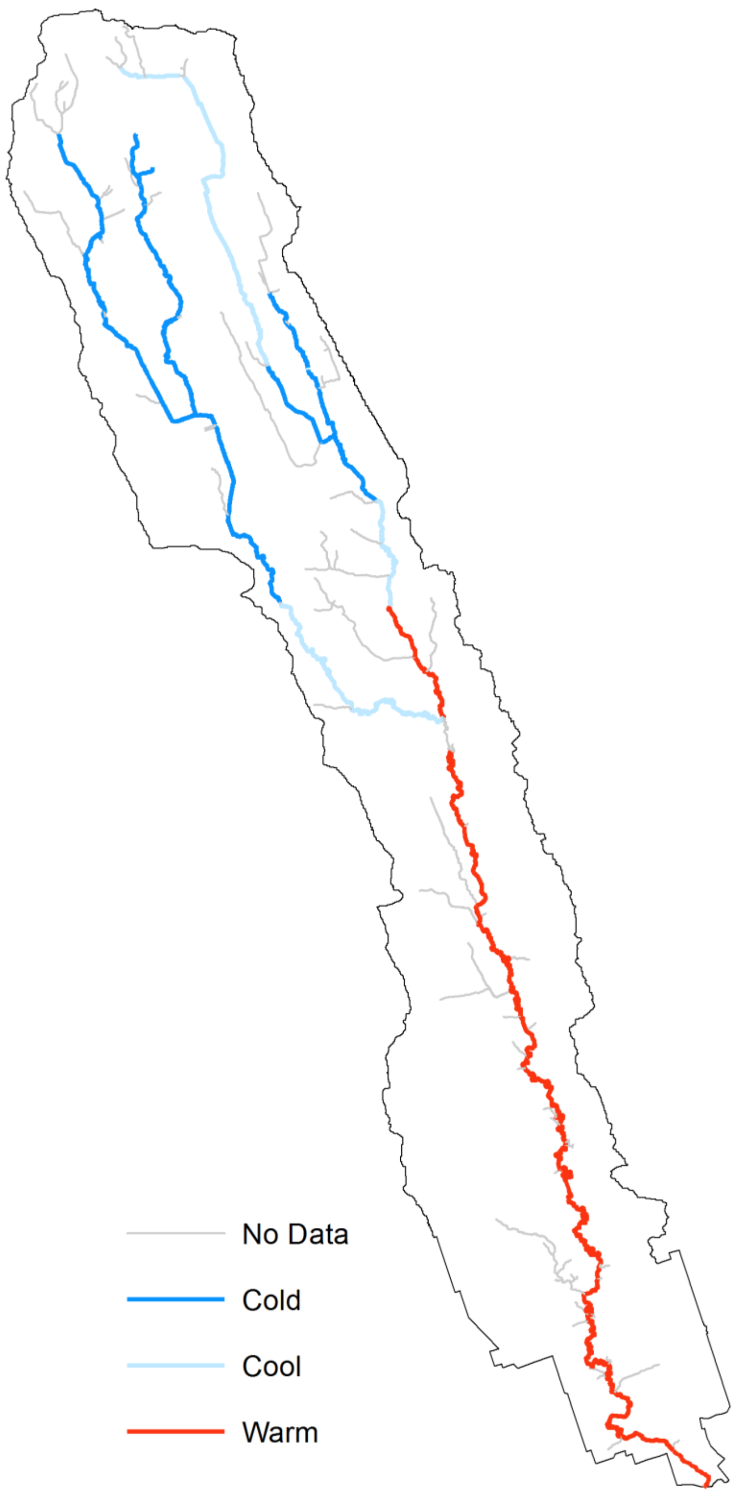

Figure 11. Spatial distribution of thermal regime classes within the Carruthers Creek watershed for the current scenario (2015).

3.2.4 Hydrology

From the Phase I report on the water quantity characterization (TRCA 2018b) the discharge amounts from 2015-2016 in the lower reaches (site HY013) were found to be broadly like the upper reaches (HY090; Figure 4). However, differences in hydrological responses were found in the summer and fall in relation to smaller (<20mm) precipitation events (TRCA 2018b). Generally, responses to smaller precipitation events were more muted in the upper watershed relative to the lower watershed. As the hydrological response is closely related to amount of impervious cover within the catchment, the higher proportion of impervious cover found in the lower watershed (Figure 9) produces faster runoff peaks and greater total runoff (Schueler 1994). In contrast, upper watershed responses are more similar to the lower watershed in the winter when the ground is frozen (or impervious), but the additional storage volume created by pervious soils and by the summer soil moisture deficit, leads to lower summer-fall runoff per unit area in the upper watershed relative to the more developed lower reaches (TRCA 2018b).

Using the IHA values from the same stream gauges there is a similar story, where the lower watershed has a higher median pulse count and a higher median rise rate compared to the upper watershed (Table 9). Thus, the median number of high pulses within each water year and the median of all positive differences between consecutive daily values is higher in the southern portion of CCW, suggesting that the urbanized section of CCW has an impact on the number and size of hydrological events within the aquatic system. On the other hand, the median duration (days) of high pulses is consistent throughout CCW, where all stations have values around 2-3 days.

Mimico Creek (HY045) is a highly urbanized system compared to CCW and here it is used as a proxy reference for future scenario 3 in CCWP. Mimico Creek is a system that has attributes of a flashier system with a higher number of events, bigger events, which occur within a shorter time frame (Table 13). CCW (HY013) by contrast shows quite different values for the current scenario (2015), where the hydrology appears to be in much better condition compared to Mimico Creek (Table 13). It would be expected that the current scenario (2015) would be relatively similar to scenario 1 and 2 (using the same precipitation events of 2015-2016), however, scenario 2 with the expanded NHS would likely provide a slight improvement given the lower impervious cover values (Table 13). It should be noted that while the system properties would be similar under scenario 1 and 2 to the current (2015) scenario, future climate change will bring larger and more frequent storm events that would contribute to the deterioration of the hydrological quality of CCW (EBNFLO 2010).

Table 13. IHA parameters calculated at four locations in Carruthers Creek (West Branch, East Branch, Confluence and Mouth) and one gauge in Mimico Creek (Mouth).

IHA parameter	Carruthers Creek				Mimico Creek
	West Branch	East Branch	Confluence	Mouth	Mouth
Median high pulse count	15.5	16	16.5	21	37
Median high pulse duration	3.5	2	2.75	3	2
Median rise rate	0.0096	0.0092	0.0171	0.0532	0.1951

3.2.5 Groundwater quantity impact assessment summary (Oak Ridges Moraine Groundwater Program)

3.2.5.1 Ecologically significant groundwater recharge areas (ESGRAs)

Using the TEGWFM to model potential groundwater recharge and discharge from a variety of land use conditions can provide a window into groundwater function under different planning scenarios to understand prospective impacts to aquatic ecosystems. TEGWFM model results demonstrate a consistent decrease in the long-term average amount of recharge in the CCW; resulting in decreases ranging from 8-14% (Table 14). Here scenarios are compared to the amount of recharge under historical conditions (1999). While all scenarios are expected to decrease the amount of recharge in the CCW, the model results suggest that an expanded Natural Heritage System (NHS) in scenario 2 may mitigate some of the expected recharge decreases (Table 14). Delineation of ESGRA features for CCW has also been conducted, and as expected the amount of ESGRA features that could potentially be protected by the enhanced NHS changes across scenarios in a similar pattern to overall recharge amount (Table 15). Lastly, it should be noted that TEGWFM identifies approximated 30% of groundwater discharging in the CCW originates from outside of its watershed boundary (ORMGP 2018). Thus, given the spatial extent of the CCWP scenario analysis, the results provided in this section assume that land use in neighbouring watersheds have not changed. Further, given that 30% of discharge originates from neighbouring watersheds the conservation of groundwater recharge potential for CCW will require cross-watershed planning to reduce impacts to ESGRAs in other watersheds that are contributing discharge within the CCW.

Specifically, there is a total area of approximately 2,357 hectares of ESGRA features associated with CCW (from both outside and inside CCW). Here only 28.8% (679.6 hectares) of the areal extent of ESGRAs are found within the CCWP boundary, but this accounts for about 70% of the recharge function of CCW (Figure 12). Of the ESGRA features within the CCWP boundary the amount of overlap with natural heritage, low impervious cover and high impervious cover across current and future scenarios is summarized in Table 15. Future scenario 2 has the highest amount of natural cover and low impervious cover types associated with ESGRAs within CWW (Table 15). By contrast, future scenario 3 has the highest amount of high impervious land cover type associated with ESGRA features (Table 15). Given that these groundwater recharge features are significant to the maintenance of ecological components of the CCW water resource system, future scenario 2 represents the best scenario for the continued presence of these ecological features and for maintaining suitable baseflow for ecological systems in CCW. However, further increases in the NHS coverage would provide more protection and maintain good quality groundwater recharge that is considered a critical water resource system feature.

Table 14. Summary of Carruthers Creek Watershed long-term average groundwater recharge from the TEGWFM model across scenarios (ORMGP 2018).

	Historical	Current	Future		
			1	2	3
Estimated recharge (mm/yr)	165	152	147	152	141
Percent change (%)		-8	-11	-8	-14

Table 15. Shown is the percent potential overlap of ecologically significant groundwater recharge areas with natural heritage, low impervious (DCIA≤5) and moderate-high impervious (DCIA ≥15) covers with current and future scenarios.

Land Use Type	Current	Future		
		1	2	3
Natural Heritage	18.63	18.64	36.19	36.19
Low Impervious	55.04	53.84	38.24	2.28
High Impervious	26.32	27.52	25.58	61.54

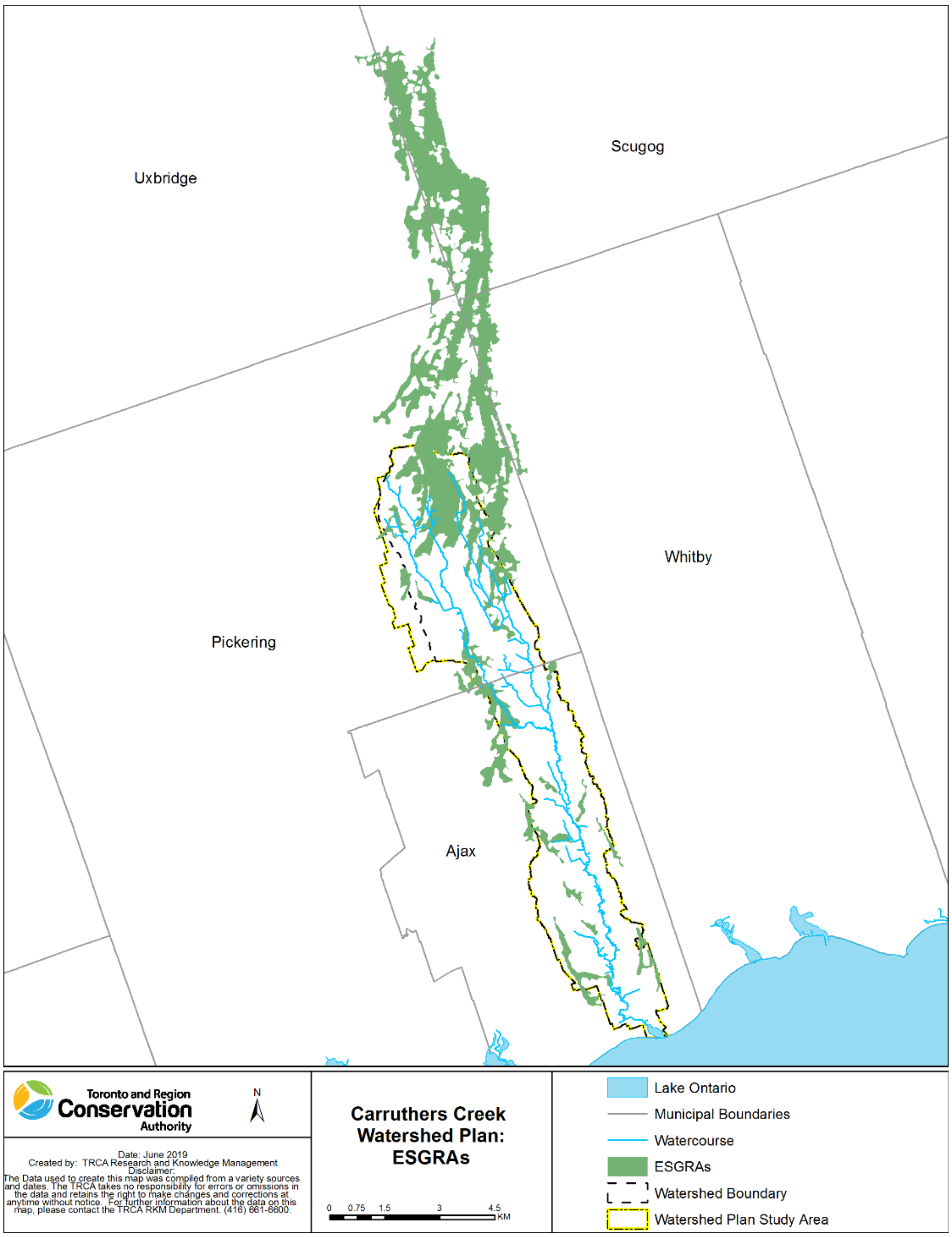

Figure 12. Ecologically significant groundwater recharge areas associated with the Carruthers Creek Watershed (ORMGP 2018). Shown is the distribution and size of the 2,357 hectares of ESGRAS.

3.2.5.2 Groundwater discharge potential

For discharge potential, the long-term average of groundwater discharge for current land use is highly spatially variable throughout CCW (Figure 13). Of note, the eastern branch of Carruthers Creek has almost double the amount of discharge potential than the western branch (Figure 13). Additionally, there is a potentially large recharge area within the lower portion of the western branch. With the scenario analysis, concomitant with changes in recharge predicted by the TEGWFM model are expected to cause changes in the long-term average groundwater discharge (Table 15). All scenarios show a decrease in discharge potential compared to the historical scenario. Of note, the expanded NHS in future scenario 2 may mitigate some of the expected discharge decrease. Lastly, future scenario 3 shows the largest decrease in discharge potential, which is associated with decreases in groundwater discharge potential in the western upper catchment and the main stem confluence (ORMGP 2018). Again, it is likely that further increases in the NHS coverage would provide more protection of groundwater discharge in CCW.

Table 16. Summary of Carruthers Creek Watershed long-term average groundwater discharge from the TEGWFM model across scenarios (ORMGP 2018).

			Future		
	Historical	Current	1	2	3
Net discharge (mm/yr)	212	201	197	201	194
Percent change (%)		-5	-7	-5	-8

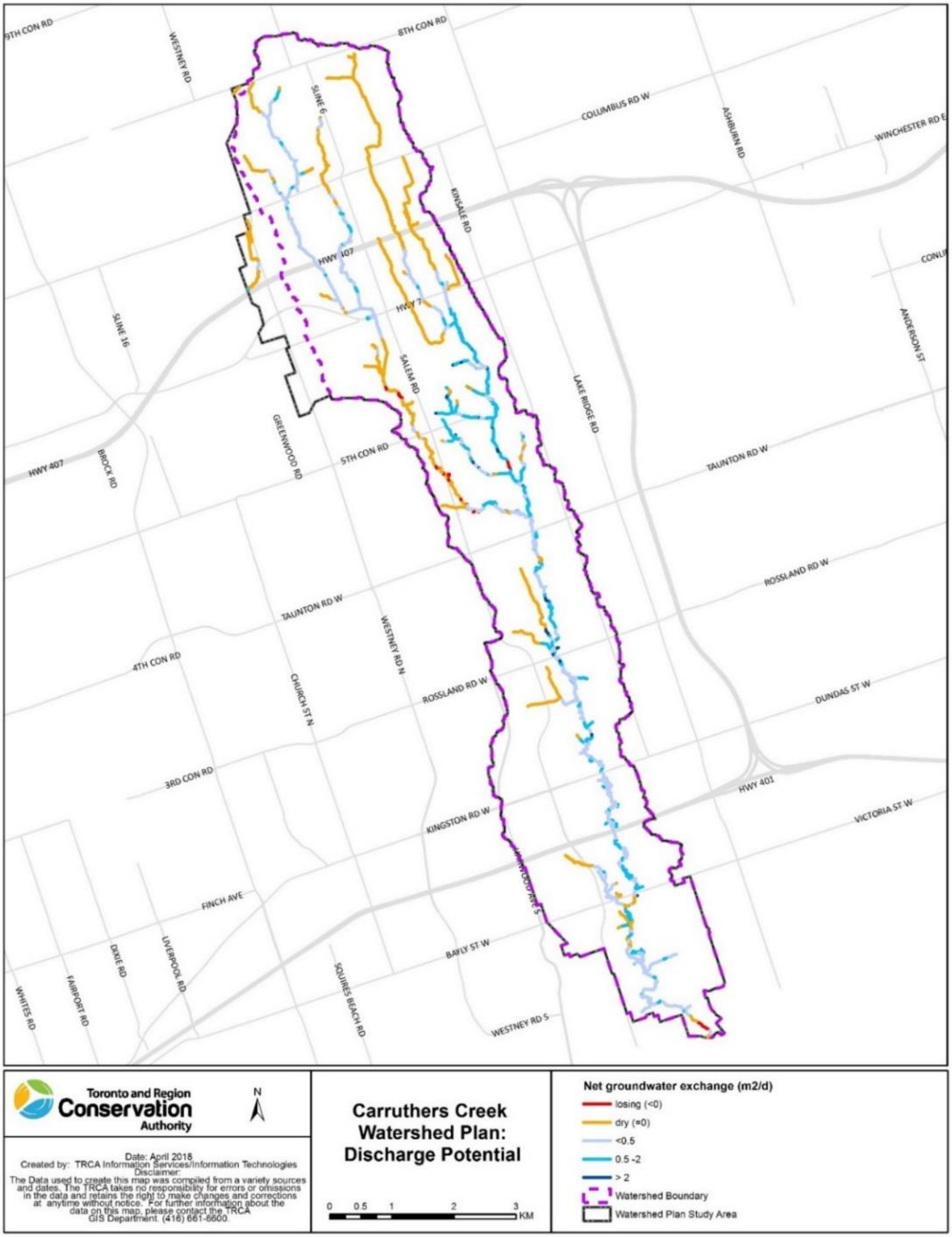

Figure 13. The average discharge potential for the Carruthers Creek Watershed. Losing reaches (<0) indicate potential groundwater recharge, dry reaches (=0) receive largely surface water inputs, where gaining reaches (>0) potentially receive groundwater.

3.2.6 Water quality impact assessment overview

The Soil and Water Assessment Tool (SWAT) was used to model changes in surface water quality and quantity under three future land use scenarios (Di Luzio et al. 2001, Arnold et al. 2012). Here the model was run using precipitation patterns from 2005-2015 under each of the five scenarios (TRCA 2019). Generally, more pronounced patterns were found under high precipitation years for the flow, total nitrogen, total phosphorous, and total suspended solids; however, on average these values did not differ much on average across scenarios (Figure 14). This result is expected as higher precipitation would contribute to higher surface flows within CCW. From a landcover perspective, the most pronounced difference was between historical (1999) land cover and all other scenarios, where slightly lower flow and total suspended solids are found alongside increases in total phosphorous and nitrogen (Figure 14). These differences follow the pattern that historical conditions had less impervious cover, yet higher levels of agricultural land cover compared to current and future scenarios. Despite this result, the observed variance in in model estimates (standard deviation across 2005-2015 estimates) suggest these patterns are not a certainty (Figure 14) and that average overall changes to landcover alone will not bring about significant changes in water quality. However, given the link between higher precipitation years and landcover there is the potential for an interactive negative impact on water quality within CCW (TRCA 2019). This also suggests that changes in precipitation linked to future climate change conditions (more intense and frequent storm events) could have an increased negative impact on water quality in the future.

One aspect of water quality not assessed as part of this modelling work is the influence of road salts that can impact aquatic communities (Wallace et al. 2013). Currently, there are detectable increases in the amount of chloride in the downstream portion of CCW (the urbanized portion of CCW), where levels exceed both Provincial and Federal Water Quality Guideline levels by 16-17 times. Of note, with the recent opening of the 407 in June 2016, it is expected that increases in chloride concentrations would likely now be detected in the headwaters of CCW and if there is further buildout within the upper headwaters (under a future scenario 3) this would also increase the expected overall amount of chloride and other urban associated pollutants in CCW. Freshwater aquatic organisms can tolerate a limited amount of increased chloride, but both acute and chronic increases in chloride instream can reduce the survival of most freshwater species (CCME 2011). CCME (2011) outlines that the Canadian guideline for the protection of aquatic life is 120 mg/L and 640 mg/L for chronic and acute exposure, respectively. These targets should be sought within the CCW.

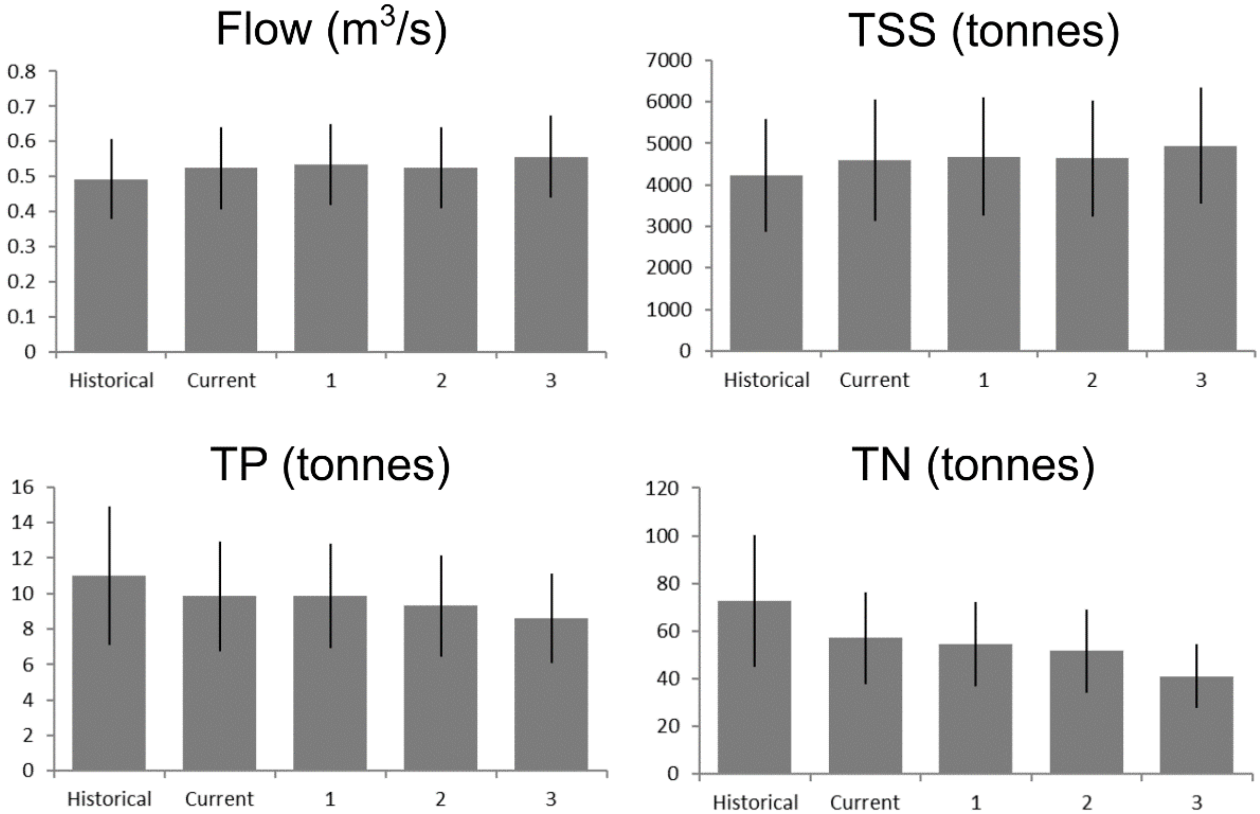

Figure 14. Overall mean (+/- standard deviation) of water quality parameters (flow, total nitrogen (TP), total phosphorous (TP), and total suspended solids (TSS)) by scenario. Values are produced by the SWAT model for Carruthers Creek watershed with precipitation records from 2005-2015.

3.3 Aquatic communities

3.3.1 Fish communities

Examining the long-term sampling stations independently over time shows that the southernmost site (CC001WM) has slightly negative change in the IBI score over time, which has largely been driven by a loss of sunfish and top-predators (Figure 15). However, the other stations (CC002WM and CC003WM) are static in IBI score over the course of the sampling period (2003-2015), with the northernmost sampling location (CC003WM) showing some marginal increases in IBI score towards a good score (Figure 15). One caveat is that some species have not been seen for years and others could be missed by the standardized sampling that is conducted triennially in the lower portion of the watershed. For instance, Redside Dace have high local abundances, but are consistently not detected in the three RWMP CCW sites. For Redside Dace, they have only recently been sampled due to a limited increase in effort in the headwaters in 2015 (Figure 16). Comparisons of IBI between historical (2000) and current (2015) scenarios demonstrate that scores increased slightly at two stations near Deer Creek Golf and Country Club but have decreased at station CC001WM near the mouth of Carruthers Creek (Figure 16). Further comparisons between years are difficult because surveys were not conducted at the exact same location.

To summarize, it appears that the overall trend from the fisheries sampling is that there are more fish and more diversity in the fish community as one travels north toward the headwaters of the watershed and out of the urbanized portion of the watershed (see 2015 in Figure 16). Scores do reduce as habitat becomes more limited for fish species within the upper headwaters with intermittent and ephemeral flows (Figure 16). The increase in diversity and abundance towards the upper portion of CCW is an inverse trend of how biodiversity and abundance should be developing in a natural river system (Vannotte et al. 1980). The likely outcome for the future scenarios (1-3) is that as urban expansion continues northward in the watershed there will be a corresponding decline in both fish abundance and diversity in the headwaters. Of note, the potential impact of highway 407 (associated water quality and habitat changes) have not been accounted for in this analysis and there would be expected declines in diversity and abundance for many fish species in the proceeding years. Future scenario 2 represents the best-case scenario given the benefit to many habitat variables discussed above; however, for many of these habitat conditions, further expansion of the NHS beyond that seen in future scenario 2 would be beneficial to achieve a desirable ecological outcome in the fish community. The ecological and environmental factors relating to these declines can be found in other sections of the AIA report including impervious cover, hydrology, instream temperature and water quality.

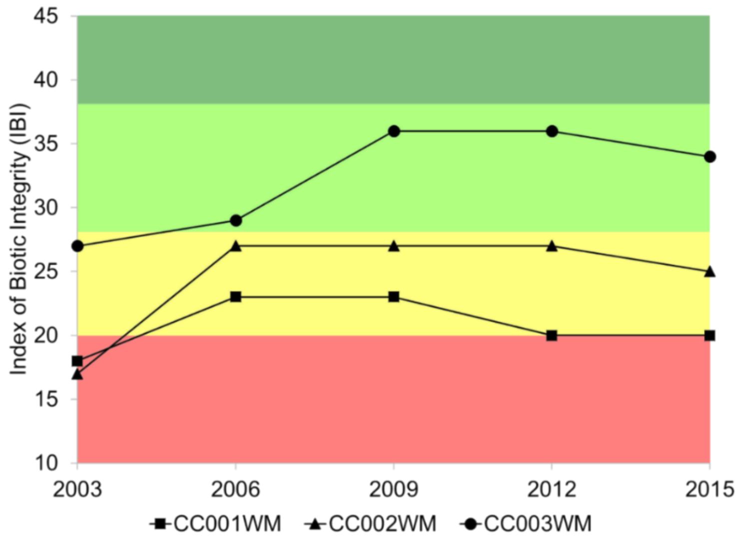

Figure 15. The Index of Biotic Integrity (IBI) values for long-term monitoring sites through time. Classification of fish communities has been overlaid with IBI scoring for poor (IBI ≤ 20; red), fair (IBI = 20-27.9; yellow), good (IBI = 28-37.9; green) and very good (IBI ≥ 38; dark green) IBI values.

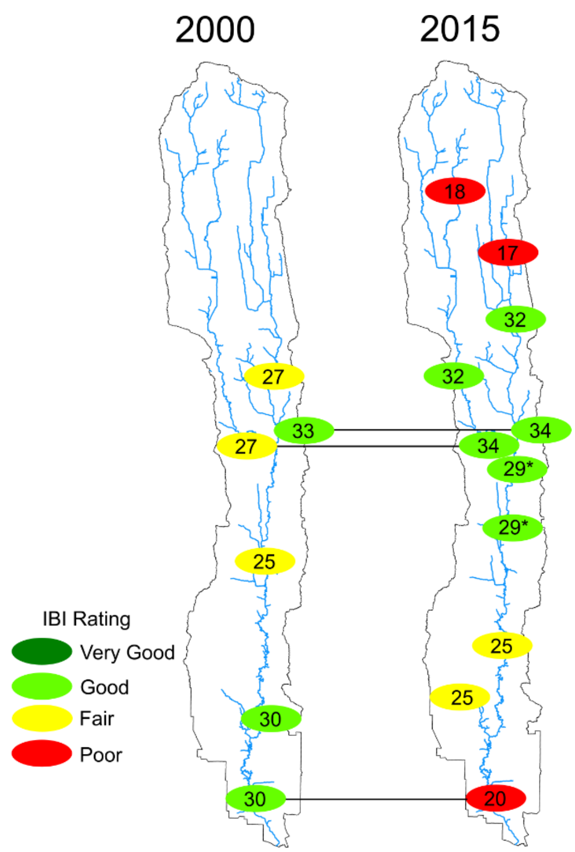

Figure 16. Fish Index of Biotic Integrity (IBI) scores for historical (2000) and current (2015) sampling in the Carruthers Creek watershed. Lines connect sites for similar locations in 2000 and 2015. Scores are coded as poor (IBI ≤ 20; red), fair (IBI = 20-27.9; yellow), good (IBI = 28-37.9; green) and very good (IBI ≥ 38; dark green). *Denotes sites sampled in 2018.

3.3.2 Benthic macroinvertebrates

All indices and metrics demonstrate similar patterns spatially across the sampling sites in CCW and the results also mirror fish community patterns related to aquatic health. Reviewing the benchmark values (2013-2017; Table 14) demonstrates that all sites have HBI values that have fair to fairly poor ratings, which indicate fairly substantial to substantial organic pollution is likely (Table 6 and Table 14). The FBI values are similar to HBI and have ratings of fairly poor to poor indicating that substantial to very substantial organic pollution is likely (Table 6 and Table 14). Spatially sites in CCW have a poorer HBI and FBI rating towards the southernmost site (CC001WM) and a small increase in rating is observed towards the most northernmost site (CC003WM; Figure 16 and Table 14). Additionally, a lower taxonomic richness is observed at the southernmost site (CC001WM), with similar Shannon diversity indices across all sites (Table 14). Generally, there is also a very low amount of EPT taxa in samples, representing approximately 1-2% of the BMI sample at each site, so it is difficult to use this metric for any meaningful comparison (Table 14). Lastly, the amount of tolerant species found at sites is ≥50% of the BMI sampled, with higher amounts at the southernmost site (~90%) compared to the other two sites (~50%; Table 14).

Table 17. Benchmark benthic macroinvertebrate index values for the Carruthers Creek watershed. Shown is the Hilsenhoff Biotic Index (HBI), Family Biotic Index (FBI), Taxa richness (Richness), Shannon diversity index (H), the percent Ephemeroptera, Plecoptera, and Trichoptera (% EPT), and the percent tolerant taxa (Chironomidae and Oligochaeta). Grey rows denote the mean values (± standard deviation) for the period of 2013-2017.

Site	Year	HBI	FBI	Richness	H	%EPT	%Tolerant
CC001WM	2013	6.75	6.71	12	0.92	0.3	94.2
	2014	6.46	6.47	14	1.57	2.9	81.8
	2015	6.30	6.27	9	1.39	0.6	91.5
	2016	6.72	6.72	16	1.25	0.0	89.8
	2017	6.77	6.78	16	1.74	0.0	86.7
		6.60 ± 0.21	6.59 ± 0.21	13.4 ± 2.97	1.38 ± 0.31	0.77 ± 1.24	88.81 ± 4.77
CC002WM	2013	5.83	6.25	18	1.68	2.2	66.0
	2014	6.37	6.33	17	0.83	1.0	59.0
	2015	6.43	6.41	12	1.40	0.8	66.8
	2016	6.03	5.99	19	1.34	2.1	21.8
	2017	5.98	5.95	18	1.10	4.4	16.1
		6.13 ± 0.26	6.19 ± 0.21	16.80 ± 2.77	1.27 ± 0.32	2.11 ± 1.44	45.95 ± 24.90
CC003WM	2013	5.62	6.18	16	1.68	0.0	65.9
	2014	6.05	6.01	18	1.69	2.4	39.6
	2015	6.02	6.08	12	1.18	1.9	64.4
	2016	6.02	6.04	14	1.35	0.6	44.2
	2017	6.05	6.05	17	2.16	0.9	46.8
		5.95 ± 0.19	6.07 ± 0.06	15.40 ± 2.41	1.61 ± 0.38	1.16 ± 0.98	52.19 ± 12.15

The comparison of FBI values from 2002/2003 to 2015/2016 at the three RWMP sampling sites shows minimal changes in FBI between the historical (1999) and current (2015) conditions. However, this comparison of FBI should be interpreted cautiously given the sampling methodology change in 2013. In 2015-2016 using OBBN methodologies, two riffles and one pool were targeted whereas in 2002-2003 using OSAP methods, samples were not targeted as riffles or pools so the relative contribution of these habitats could affect the results since different invertebrates prefer different habitat types. Regardless, we do not find major changes in the BMI community between historical and current scenarios.

While conditions appear to slightly improve from the southernmost to the northernmost sampling site, the amount of change shown in the HBI and FBI indices does not suggest there was a significant difference. Further, differences in values between 2002/2003 and 2015/2016 show numerical, but not significant improvement (Figure 17), suggesting that BMI communities are already heavily impacted by pollutants within the watershed, such as chloride, phosphorus, *E. coli*, nitrate, TSS, and some trace metals, seen within the water quality analysis (TRCA 2017c). Corroborating this are the consistently low values of EPT and higher values of tolerant species that typically indicating a lower water quality and impaired habitat. Altogether the BMI analysis demonstrates that CCW is an impacted watershed in the southern portion (confluence to mouth). Moreover, improvements in the water quality that result in positive benthic macroinvertebrate community changes have not been achieved through land use change between 2002/2003 and 2015/2016. It is possible that higher quality headwater reaches might exist in CCW, but with limited sampling within CCW it is difficult to comment on the BMI community within the headwater region. Finally, an examination of the BMI data indicates that there are currently no known aquatic invasive species (AIS) found within the sampling sites. As the watershed continues to urbanize this may change, there is an increasing likelihood that AIS will appear in the future, the result of which may change the BMI community and related watershed evaluative scoring.

Similar to the fish community, the likely outcome for the future scenarios (1-3) is that as urban expansion continues northward in the watershed there will be a corresponding decline in both abundance and diversity. Of note, potential impacts of highway 407 (and the associated water quality and habitat changes) have not been accounted for in this analysis and there would be expected declines in diversity and abundance for many species in the proceeding years. Future scenario 2 represents the best-case scenario given the benefit to many habitat variables discussed above. However, for many of these habitat conditions, further expansion of the NHS beyond that seen in future scenario 2 would be beneficial to achieve a desirable ecological outcome in the benthic and fish community. The ecological and environmental factors relating to these declines can be found in other sections of the AIA report including impervious cover, hydrology, instream temperature and water quality.

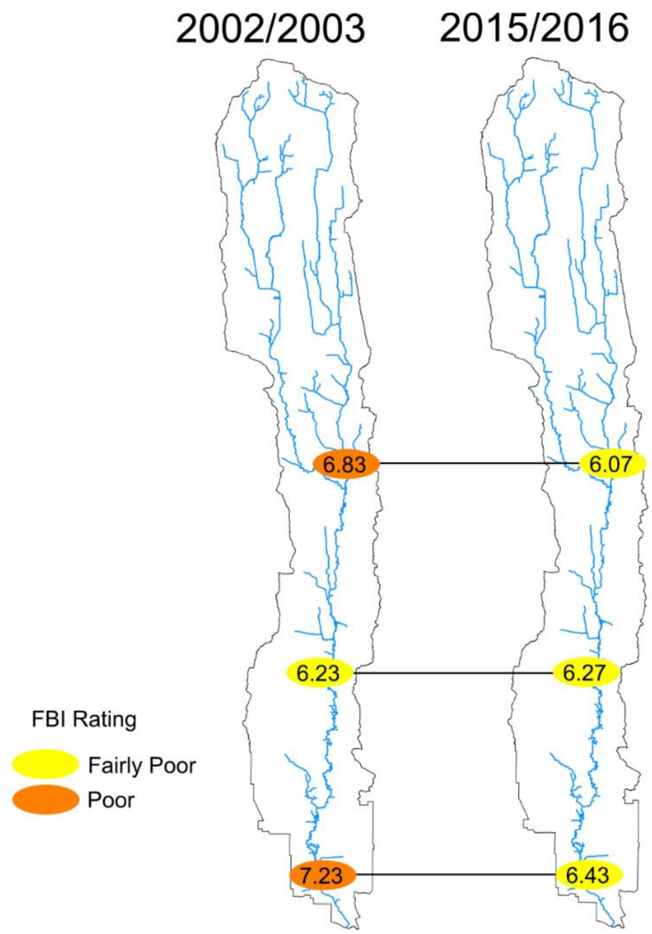

Figure 17. Benthic macroinvertebrate Family Biotic Index (FBI) scores in 2002/2003 (historical) and 2015/2016 (current) in the Carruthers Creek watershed. Lines connect comparable sampling locations.

3.3.3 Indicator species

3.3.3.1 Redside Dace

Under current conditions (2015), there is an estimated 525 hectares of potentially contributing habitat for Redside Dace within the CCW, which is all located north of Taunton Road (Figure 18). Within the current (2015) land use scenario, approximately 386 hectares (73.5%) of the 525 hectares of potentially contributing habitat is comprised of natural cover (Table 15). The natural cover is predominantly composed of forest (67.4%), followed by wetland (17.1%), meadow (12.4%), and successional forest (3.1%). The second most dominant land cover in the potentially contributing habitat is low impervious land use (20.9%; agricultural, cemetery, and golf course), which has a Directly Connected Impervious Area (DCIA; the runoff coefficient or amount of imperviousness) value of ≤ 5 (Table 15). Lastly, moderate-high impervious cover (DCIA ≥ 15) amounts to only 5.6% of land cover within the potentially contributing habitat for Redside Dace (Table 15).

Future scenarios show a wide range of values for land cover types within potentially contributing habitat for the Redside Dace (Table 15). The first scenario follows the same patterns as the current scenario as there is no expansion of either the natural heritage system or potential future buildout. For scenario 2, increases in the natural cover that would be gained through an enhanced system results in 86.8% of potentially contributing habitat for Redside Dace to be located within the NHS (Table 15). The gains in natural cover are achieved through a reduction of both low and moderate-high impervious cover under Scenario 2 (Table 15). Lastly, scenario 3 with the full buildout and enhanced natural heritage system, converts low impervious cover to moderate-high impervious cover within potentially contributing habitat for Redside Dace. Scenario 3 would be expected to have the largest negative impact on potentially contributing habitat for the Redside Dace due to the expected land use changes and impacts to imperviousness, hydrological changes, and resulting habitat conditions.

Currently, 73.5% of potentially contributing habitat for Redside Dace is natural cover. Meadow/shrub classes of riparian habitat (considered to be high quality contributing habitat for Redside Dace (COSEWIC 2017)) only represent 12.4% of this natural cover within the current scenario. This amounts to a very small portion of contributing habitat for Redside Dace. For future scenarios, scenario 2 represents the best outcome for protecting and potentially enhancing contributing habitat for Redside Dace. Here scenario 2 has approximately 60 hectares of natural cover added within the potentially contributing habitat for Redside Dace (within the enhanced NHS; Table 15) and given the current level meadow habitat (12.4%) within the natural cover of potentially contributing habitat, meadows should be prioritized with establishment of the enhanced NHS, especially within this 60 hectares proposed in the potentially contributing habitat areas. Lastly, only 86.8% of potentially contributing habitat is protected under future scenario 2, a further expansion of the NHS to include 100% of potentially contributing habitat should be sought to conserve this species over the long-term. Note that all these figures are not based on a finalized and approved layer and this analysis was for screening purposes only.

Table 18. The percent of potentially contributing habitat for the Endangered Redside Dace that overlaps with different land use types within current and future scenarios. The percent coverage within natural heritage, low impervious cover land use types (Directly Connected Impervious Area (DCIA) ≤ 5) and moderate-high impervious cover land use types (DCIA ≥ 15).

Land Use Type	Current	Future Scenarios		
		1	2	3
Natural Heritage	73.5	73.5	86.8	86.8
Low Impervious Cover	20.9	20.9	7.8	5.1
Moderate-High Impervious Cover	5.6	5.6	5.3	8.1

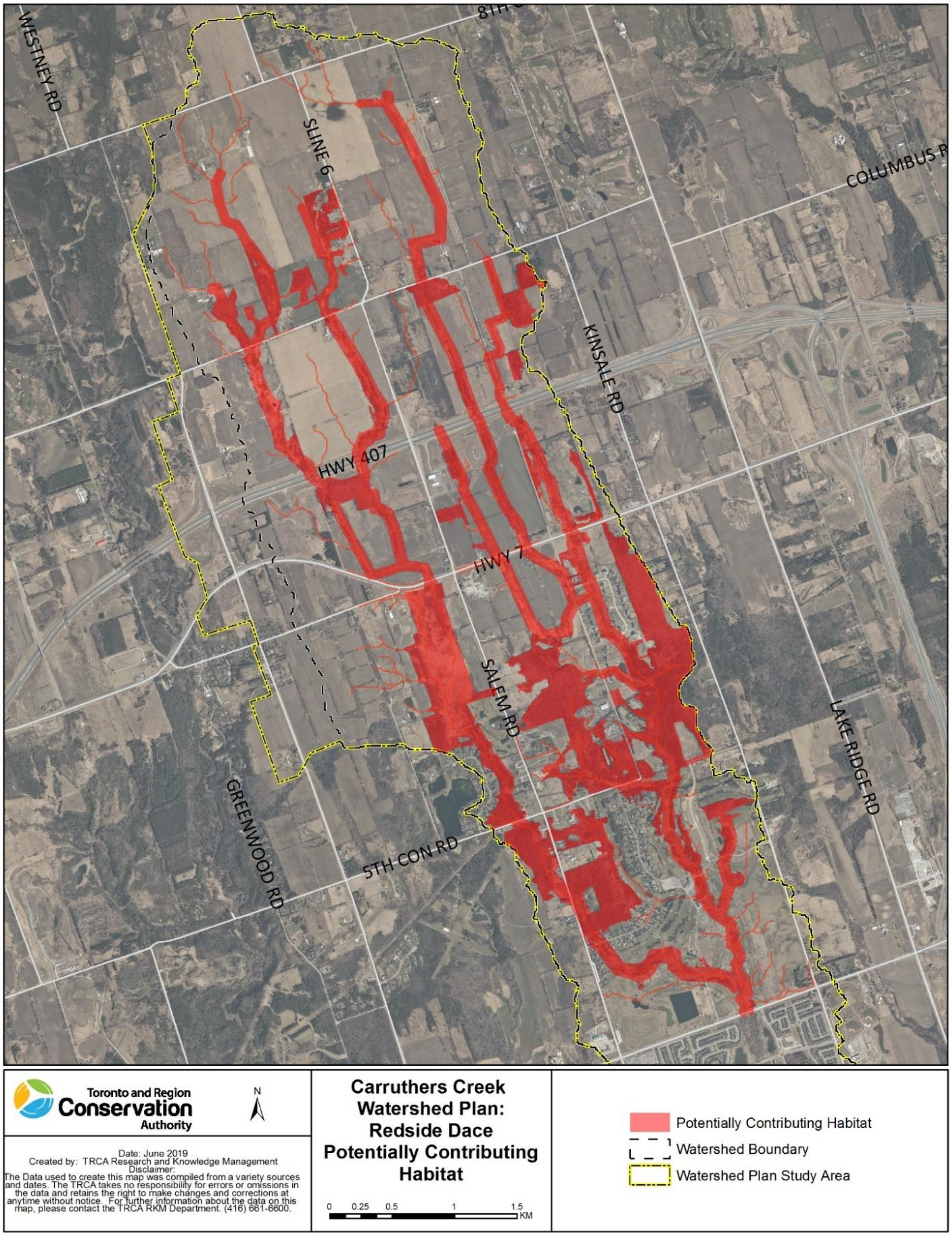

Figure 18. The potentially contributing habitat for the Endangered Redside Dace. This is not a finalized and approved layer and is only intended for screening purposes only. For specific details and official contributing habitat please contact MECP prior to any planned works.

3.3.3.2 Eastern Pondmussel

Critical habitat has been identified for Eastern Pondmussel in the Carruthers Creek estuary as all contiguous waters and wetlands (marsh and open water classes) up to the high-water mark elevation for Lake Ontario (75.32 m above sea level; International Great Lakes Datum 1985; McNichols et al. 2018). The critical habitat also includes all occasionally exposed lands lying between the high-water mark and the water's edge of the Carruthers Creek wetland which is variable based on fluctuating Lake Ontario water levels (McNichols et al. 2018). The high-water mark may extend to areas that are dry due to low water levels and may extend higher where coastal wetlands exist, and habitat function is connected to Lake Ontario (McNichols et al. 2018).

For CCW the critical habitat for Eastern Pondmussel has been mapped using data collected in 2013 by Fisheries and Oceans Canada (Figure 19). Given the observed declines of fish communities close to the river mouth (CC001WM; Figures 15), it is expected that the ecological and environmental factors relating to these declines (impervious cover, hydrology, instream temperature and water quality) would also impact Eastern Pondmussel. Due to the lack of recent and comprehensive data for mussel species presence and distribution in the CCW it is recommended that (i) any construction activity within the habitat for the species? may require a preliminary mussel survey in addition to standard aquatic surveys and that a (ii) formal survey for mussel presence and distribution be conducted across the watershed.

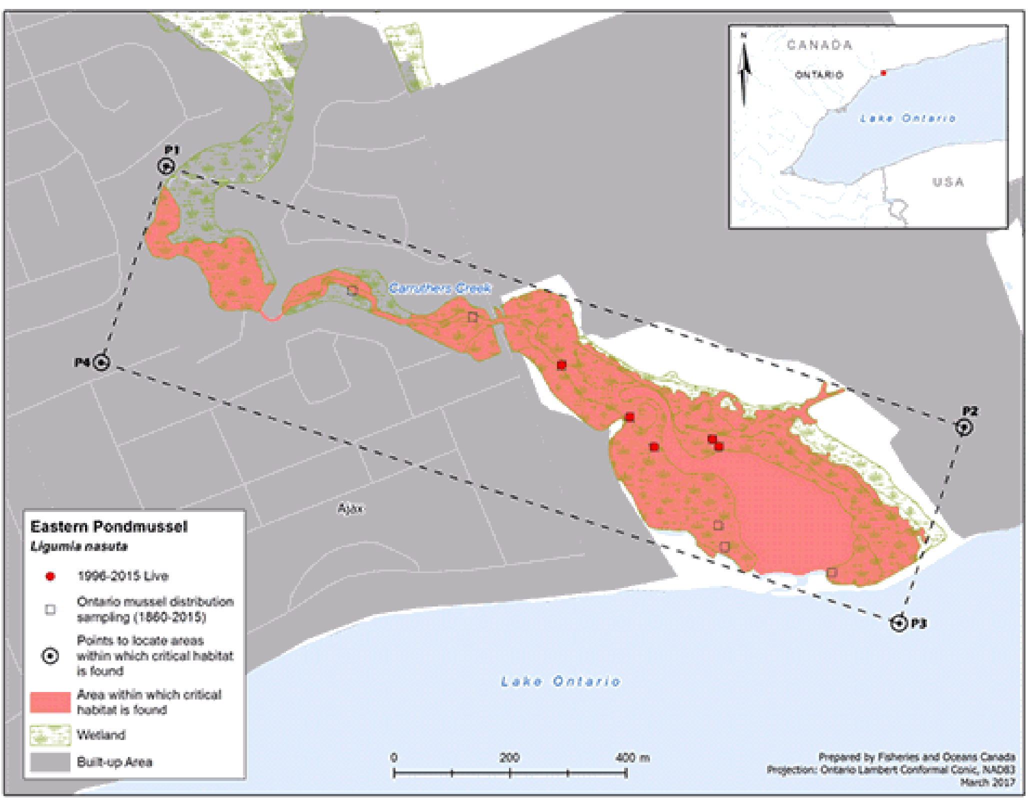

Figure 19. Critical habitat of the Eastern pondmussel in the Carruthers Creek near the mouth of the system (prepared by Fisheries and Oceans Canada in March 2017; projection – Ontario Lambert Conformal Conic, NAD 83).

3.3.4 Aquatic Invasive Species

3.3.4.1 Invasive fish species: Round Goby

Aquatic invasive species are capable of out-competing indigenous species for food or refuge resources and who therefore disrupt the balance of the native ecosystem. The spread of such species is considered to be one of the most serious threats to biodiversity and ecosystem health (EC 2004), in particular for freshwater ecosystems (Reid et al. 2019). Round Goby were first detected in CCW in 2012 (CC001WM) with a recurring presence in 2015 (CC001WM) and 2018 (CC001WM and CC002WM) during RWMP sampling. Given the consistent presence of Round Goby it is likely they are now established in CCW (with some evidence of range expansion) and they could be using CCW for spawning/reproduction (Blair et al. 2018). This outcome would suggest that that they would impact the presence and abundance of native fish and benthic macroinvertebrate species, perhaps contributing to lower fish community scores near the CCW mouth (Figure 15).

Further sampling of aquatic communities in CCW is recommended to provide a full assessment of Round Goby impacts on aquatic ecosystems. With aquatic invasive species there should be an emphasis on monitoring and preventing the spread of invasive and exotic fish species and disease, where possible. However, given the perceived establishment of Round Goby, preventing their spread might not be possible. Despite this, there would be some benefit to increasing the coordination of existing stewardship and outreach programs to prevent new introductions and any further spread of aquatic invasive species, particularly with Round Goby. Lastly, one desirable option may be to safeguard upstream habitat and species by installing a partition (or barrier) to prevent their establishment in good quality habitat areas (North of Taunton Road).

3.3.4.2 Invasive benthic macroinvertebrates: Rusty Crayfish & Chinese Mystery Snail

Similar to fish, invertebrate aquatic invasive species pose a threat to biodiversity. Two invertebrate invasive species have been found in Carruthers including the Rusty Crayfish (*Orconectes rusticus*) and more recently the Chinese Mystery Snail (*Bellamya chinensis*). Presently, Rusty Crayfish are located throughout the majority of the Duffins Creek watershed. However, to date there have been no confirmed sightings of Rusty Crayfish in the CCW. Given the proximity of Duffins Creek watershed, there is a high potential for rusty crayfish to expand their range within CCW. Within an abandoned gravel pit, now a natural pond, a confirmed sighting of a Chinese Mystery Snail was found (Figure 19; shell sample taken; Gavin Miller Sept 9, 2015 ELC surveys at Beechridge wetlands; south of C.P. rail line and east of Salem North). Given the potential negative impacts to ecosystem health and function of these two species of invasive benthic macroinvertebrates, it is recommended that monitoring for these invasive species through the RWMP should continue.

Figure 20. Photo of Chinese Mystery Snail found in the Carruthers Creek Watershed.

Conclusions and Next Steps

4.1 Overall trends and patterns for objectives

The rationale of the CCWP AIA was to assess the implications of different land use scenarios, including historical (1999), current (2015) and three potential future scenarios on aquatic system objectives in CCW as summarized below. A comparison of potential impacts of each scenario would (i) provide a better understanding of the implications of each land use scenario on each objective and (ii) identify strategic actions that will assist Durham Region in its objective to achieve greater sustainability and resiliency in the aquatic ecosystem. The specific objectives for the aquatic system that were examined are:

1. Limit/minimize and/or improve impervious land cover
2. Protect, maintain, and enhance aquatic habitat conditions to help maintain the current abundance and distribution of aquatic species
3. Maintain and/or improve the current abundance and diversity of aquatic communities (e.g. fish, invertebrate, and mussel)

The CCWP AIA was a comparative assessment between the historical and current scenarios where there is a substantial increase in the urban land use class at the expense of agricultural lands and, to a lesser extent, natural cover. Though the agricultural lands were converted in the northern parts of the watershed, in the southern portions the conversion included natural cover in some areas. This reflects that as urbanization continues, mostly permeable cover is converted to more impervious cover. The comparison between the current and three future land use scenarios allowed for an assessment of their impacts on the aquatic system objectives and thereby the trend towards or away from achieving the stated objective. Here we summarize both the trends and potential impacts of historical, current and future scenarios as it relates to the stated objectives.

Both the trends and patterns of scenarios were evaluated in relation to the impact of the expansion of impervious land cover. Between historical (1999) and current (2015) impervious cover in CCW has increased from a good quality catchment (9% impervious cover overall) to a good-fair quality catchment (24% impervious cover overall). All future scenarios were all rated to have fair-poor catchment quality (>25% impervious cover overall), with a majority of the increase in impervious cover occurring within the downstream half of CCW (Figure 7 and 8). This implies that all future scenarios will be expected to have overall conditions of highly unstable channels, fair-poor water quality, and poor stream biodiversity, where the achievable management outcome may be to minimize downstream pollutant loads (Schueler 1994, EC 2013). Despite this outcome, catchments in the upstream portion of CCW have the potential to provide either good, good-fair and fair-poor catchment quality depending on the scenario, whereas the downstream portion of CCW consistently has fair-poor catchment quality in all current and future scenarios (Figure 8). Specifically, both future scenarios 1 and 2 have approximately 10% impervious cover (the threshold between good and good-fair catchment quality) within the upstream catchments. Specifically, scenario 2 is the only future scenario to have impervious cover in one catchment <10% (West Branch) that may confer good catchment quality (Figure 8). This threshold of 10% is just surpassed for the Upper East branch in future scenario 2.

Protecting, restoring, and enhancing aquatic habitat conditions to help maintain the current abundance and distribution of aquatic species were also evaluated. Most of this work concerned current (2015) conditions (headwater drainage features, instream habitat, riparian vegetation, fish passage, thermal regimes and hydrology), with a few habitat conditions that were evaluated across scenarios in future scenarios (groundwater discharge/recharge and water quality). Currently, the downstream half of CCW (south of Taunton Road) displays signs of an aquatic ecosystem that is under stress, with high levels of impervious cover that contributes to poor water quality, warmer thermal regimes, lower natural cover within the riparian corridor, and altered hydrology. The downstream portion also has the highest levels of ecological connectivity due to a fewer number of barriers to fish movement, but the poorest habitat quality in CCW. Conversely, the upstream portion of CCW appears to have a better habitat condition with a greater number of barriers that restricts the movement of species. Across scenarios, the riparian vegetation, groundwater discharge/recharge and water quality display some differences and scenario 2 appears to be the best at supporting healthier habitat conditions for aquatic species in CCW. Notably, these average changes in habitat condition do not change dramatically across scenarios, but one habitat factor not considered at length in this AIA across scenarios, hydrology, is likely to have larger impacts across scenarios. Lastly, ecologically significant groundwater recharge areas, important to cold water thermal regimes and fish species, appear to be more intact under scenario 2, where 36.2% are conserved under natural heritage system development and another 38.2% are located within low impervious cover areas (Figure 11). A further expansion of the NHS in future scenario 2 may help to maintain and even enhance habitat conditions in CCW.

Trends and patterns in the current abundance and diversity of aquatic communities (e.g. fish, invertebrate, and mussel) were also evaluated across historical (1999) and current (2015) conditions for CCW. Notably, trends in the fish community suggest decreasing community health in the downstream portion of CCW, but a slight increase in community health near the confluence of the upper east and west catchments (Figure 15). Conversely, benthic macroinvertebrate communities show marginal increases in community health (in 2 out of 3 sites; Figure 16), but this is not considered to be a significant ecological change. These changes could be a response to changes in water quality and habitat that have occurred because of the conversion of agricultural lands to urban areas within the central region of CCW from historical (1999) to current (2015) land use scenarios or simply a sampling bias due to the different techniques used between time periods. Additionally, better quality benthic communities are found upstream compared to downstream sites. Despite these patterns, instream habitat near the mouth of CCW supports Endangered Eastern Pondmussel and the upper headwater catchments support habitat for the Endangered Redside Dace. For the Endangered Redside Dace terrestrial and aquatic systems that support or contribute to their persistence in CCW is best conserved through the natural heritage system, where scenario 2 provides the best coverage (86.8% of potentially contributing habitat is natural cover). Currently, only 12.4% of contributing habitat is of high quality for Redside Dace (meadow land cover) and opportunities for increasing this amount should be sought within existing and future natural cover and potential natural cover. This need is emphasized by the riparian corridor only having 49.4% of natural cover within CCW with only 4.4% meadow. Additionally, potential impacts of highway 407 (and the associated water quality and habitat changes) have not been accounted for in this analysis and there would be expected declines in diversity and abundance for many species in the proceeding years. Lastly, both invasive benthic macroinvertebrates and fish pose a threat to CCW communities. In particular, the recent establishment (2012) and range expansion of Round Goby within CCW will likely have subsequent negative impacts to aquatic communities that have not been fully realized due to time lags in the response of native species to invasives.

Altogether, impervious cover, habitat, and the aquatic communities tend to be trending towards a worse overall quality from historical (1999) to current (2015) scenarios. In particular, there is a consistent pattern of worse quality ecosystem health and function at the mouth of CCW with a gradual improvement in quality near the confluence of upper catchments. Additionally, future scenarios that reduce the potential stress to the aquatic system tend to have reduced urbanization in the upper catchments and an enhanced natural system feature. This points to reduced urbanization and increases in natural cover being required to protect, maintain, and enhance conditions for the aquatic ecosystem in CCW under future development scenarios.

4.2 Recommendations and future climate conditions

Currently, the downstream half of Carruthers Creek Watershed (CCW) displays signs of an aquatic ecosystem that is under stress, with high levels of impervious cover that contributes to poor water quality and an altered hydrologic regimes contributing to the presence of primarily urban tolerant aquatic communities (fish and benthic macroinvertebrates) and ecosystems. Conversely, the upstream portion of CCW, while impacted by agriculture and the construction of the 407 highway, currently has a relatively higher quality biota and ecosystem, while providing habitat to Endangered fish species, Redside Dace (*Clinostomus elongatus*). These spatial patterns are fairly consistent from historical to current land use scenarios for aquatic species and there is some support for the aquatic system becoming increasingly stressed in the southern portion of the watershed.

Of the future scenarios, scenario 2 (current land use, official plan, and enhanced natural heritage system) represents the best option for the conservation of aquatic ecosystems in CCW. However, to improve the likelihood of a desired ecological outcome in the future, this AIA suggests that further reductions in impervious cover (more than what is provided in scenario 2) in the upper headwaters of CCW should be sought. Here a target of impervious cover <10% should be sought within the upper east and west branches. Moreover, efforts to protect headwater drainage features, wetlands, reforestation, ESGRAs, thermal regimes, and barrier removal within the upper portion of CCW would help to improve the overall condition of the aquatic ecosystem within CCW.

Further supporting this need for reduced impervious cover in scenario 2 is the expected added impact of future climate change. With climate change, it is expected that shifting climatic conditions and more frequent, intense storm events will provide further stress to the water resource system and the aquatic ecosystems (Durham 2016; Tu et al. 2017). In particular, it would be expected that hydrology will be altered further under future climate conditions, which will impact thermal regimes, instream habitat, water quality, and groundwater discharge that support the aquatic ecosystem (Tu et al. 2017). Given the added impact of climate change, the best safeguard against dramatic impacts to aquatic ecosystems, people and property would require further reductions in impervious cover, stormwater mitigation measures and the need to support the aquatic ecosystem through restoration activities and NHS development. Additionally, all lines of evidence suggest that future scenarios will have a difficult time supporting the legal habitat requirements for the Endangered Redside Dace (*Clinostomus elongatus*) unless enhancements and further protections for potentially contributing habitat are sought. Under future climate change and the future development scenarios evaluated as part of this AIA, there is a high likelihood that this population will not persist.

Unfortunately, there is still much uncertainty in this statement as there is limited analysis that could be completed in this AIA, because of the insufficient monitoring effort within CCW through time. Increasing the scope and amount of aquatic ecosystem monitoring would help to reduce this uncertainty. To further characterize and monitor the state of the watershed it is recommended that there be further aquatic characterization work completed in the headwaters of CCW. Specifically, there is a great need for long-term monitoring sites in locations where future growth is anticipated to assess functional changes in the ecosystem, which includes species population estimates. Lastly, a characterization of mussel populations in the lower reaches of CCW should also be completed.

4.2.1 Future land use and the proposed future land use scenario

Based on the expected outcomes summarized above for future scenarios, a fourth future scenario is proposed that includes further conservation enhancements with the recommended future scenario. Here the goal is to adhere to the three core objectives:

1. Limit/minimize and/or improve impervious land cover
2. Protect, maintain, and enhance aquatic habitat conditions to help maintain the current abundance and distribution of aquatic species
3. Maintain and/or improve the current abundance and diversity of aquatic communities (e.g. fish, invertebrate, and mussel)

Future scenario 2 minimizes the amount of impervious cover and provides the least amount of impact to aquatic habitat and subsequently supports a healthier biota and ecosystem. However, there is a need for further reductions in impervious cover, which may be achieved through restoration activities (e.g., reforestation, wetland restoration) within the NHS and the further expansion of the NHS area within CCW. Here, areas that can increase pervious cover and provide multiple benefits for the water resource system are targeted, which includes areas that support Endangered species (Redside Dace potentially contributing habitat) and Ecologically Significant Groundwater Recharge Areas (ESGRAs) to maintain groundwater recharge and discharge. Enhancement of the NHS to protect these features will provide improved habitat conditions to support aquatic biodiversity, ecosystem function and ultimately improve and/or conserve the overall health of the aquatic system.

Under future scenario 2, the NHS overlaps with 86.8% of Redside Dace potentially contributing habitat and only 36.2% of ESGRAs within the CCW (Table 14 and 17). The proposed scenario presented here has a modest expansion of the NHS (by approximately 500 hectares) that will provide further conservation and protection for the aquatic ecosystem by enhancing the coverage of the NHS to include all Redside Dace potentially contributing habitat and ESGRAs in CCW (Figure 21). This will provide added benefits for headwater drainage feature conservation, improved water quality, improved hydrology, conservation of biodiversity, reduced stream bank erosion, among many other benefits discussed in this AIA. Notably, there are several areas located downstream of the confluence, which are within the proposed expanded NHS for this scenario due to the presence of ESGRAs; however, these areas have already been developed. These features could be targeted for low impact design infrastructure that increases the perviousness of this developed urbanized cover (Figure 21).

Lastly, under this proposed scenario the impervious cover amount within both upper catchments (East and West) would be <10%, realizing the many benefits associated with being below this threshold (bank stability, good water quality and good biodiversity). Overall, this proposed scenario would be expected to support good quality sub-watershed catchments within the headwaters that would also have a net positive impact on catchments downstream. Most importantly, there is a high likelihood with the implementation of this scenario that the three core objectives can be achieved.

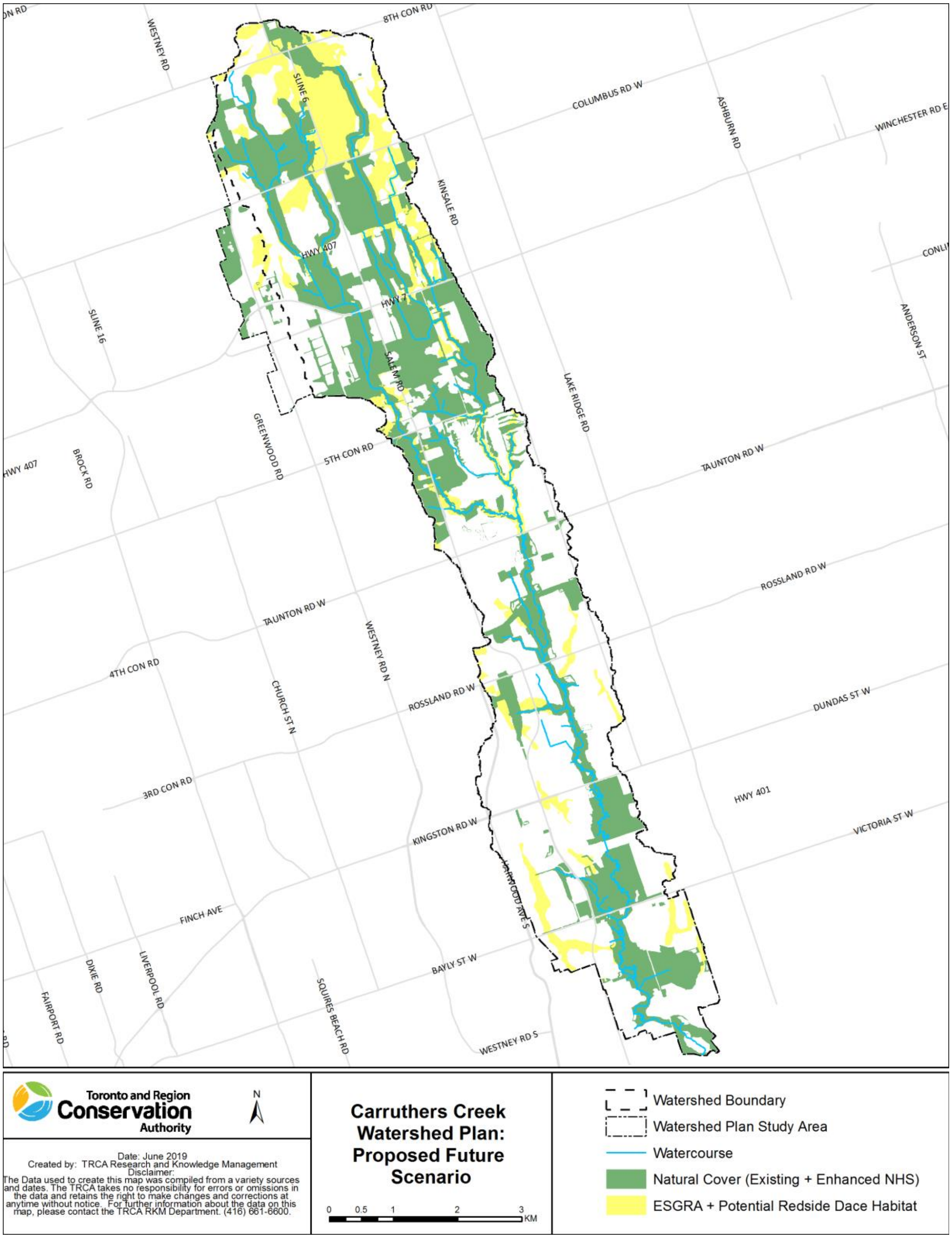

Figure 21. Shown is the proposed NHS expansion to conserve Ecologically Significant Groundwater Recharge Areas and Redside Dace potentially contributing habitat for the Carruthers Creek watershed under future scenario 2 (official plan and enhanced NHS).

4.2.2 Management recommendations and actions

Given the trends observed (historical to current) and expected changes under future conditions, in order to achieve the objective to maintain, protect and enhance the aquatic ecosystem, the following management recommendations are given. Broadly, following these recommendations and actions would increase the likelihood that the overall objective to protect aquatic habitat and species within CCW will be achieved.

1. Seek further reductions in impervious cover.

Current and potential future conditions are around the secondary goal of <25% impervious cover within the watershed, which supports a fair catchment quality (see section 3.1). However, spatially by sub-catchment area there is an opportunity to achieve good catchment quality (<10 % impervious cover) within the headwater catchments upstream of the confluence. One way to realize good catchment quality within the upper headwaters is through the expansion of the NHS, which is outlined in the proposed scenario (Figure 20). With the proposed scenario (expanded NHS), not only is there a better chance of habitat and biodiversity being conserved, but there are added benefits for endangered species (Redside Dace) and ESGRAs. Future scenario 2 represents a good secondary goal for impervious cover within CCW, however, there would be expected declines in both habitat and biodiversity.

2. Improve water quality and limit water quality impacts within headwaters.

As of 2015 the CCW generally shows a pattern whereby north of the confluence, agriculture related water quality impacts are observed and south of the confluence more urbanized impacts on water quality and subsequently biota are detected (see section 2.2.8). However, water quality north of the confluence supports the highest biodiversity within the CCW, suggesting that it is relatively better than below the confluence. Despite this result, the recent expansion of highway 407 (in 2016) has likely already further impacted water quality throughout CCW headwaters. To conserve habitat and support biodiversity these impacts need to be mitigated. Options for mitigating water quality impacts include specific design considerations such as minimizing road crossings, bioengineering instead of hard infrastructure, and improved stormwater controls. The expansion of the NHS would be one way to realize these design considerations and the proposed scenario (expanded NHS) would be the best option to achieve this goal. Future scenario 2 (with the enhanced NHS) would be a good secondary option to limit future declines in water quality, however, it is highly likely there would still be decreases in water quality under this scenario.

3. Improve fish connectivity in good quality habitat areas (North of Taunton Road).

The best quality habitat for fish in CCW is found upstream of the confluence in CCW, however, this area represents the least connected area of CCW due to instream infrastructure (e.g., culverts, weirs) that impedes the movement of fish species. While the removal of any barrier to fish movement would represent a net benefit, this benefit can be maximized by strategically targeting areas that support good habitat and high biodiversity but have higher numbers of barriers. As regulations and policies that supported the creation of these barriers has changed (and they are now not permitted), targeting the removal of barriers above the confluence on the west branch would provide the best net benefit to fish populations in CCW (see section 3.2.2).

4. Maintain or enhance groundwater recharge and discharge function inside and contributing to the watershed.

Approximately 30% of groundwater recharge comes from recharge features outside of the CCWP boundary yet depending on the future land use scenario there can be up to a 14% reduction in recharge function for CCWP (future scenario 3; full buildout). Groundwater recharge not only supports the aquatic ecosystem (and subsequently habitat and biodiversity), but the water resource system itself through supporting discharge function in CCW. This is critical to the conservation and mitigation of impacts to water resource system that it is proposed that ESGRA features are conserved under the proposed scenario by expanding the NHS (see section 4.2.1). The proposed scenario attempts to conserve as many ESGRA features as possible (as close to 100% as possible), but a good secondary goal would be future scenario 2 (enhanced NHS), which protects approximately 70% of ESGRAs as natural cover or low impervious cover (see section 3.2.5.1). Conserving as many ESGRA features is required to maintain a functioning and healthy aquatic ecosystem in CCW and is vital under future climate change, where hotter and drier summers will have a greater impact on the aquatic ecosystem, especially if ESGRA function is not maintained at current levels.

5. Limit or reduce impacts to Endangered Redside Dace habitat.

Redside Dace populations are increasingly coming under threat within CCW due to habitat related changes largely related to infrastructure development (e.g., riparian vegetation, hydrology, water quality, groundwater discharge) and mitigating impacts to their contributing habitat will be a vital first step to insuring their long-term persistence within the watershed. Under future scenarios, the proposed scenario strives to protect/mitigate impacts to potentially contributing habitat (as close to 100% as possible). A secondary option, scenario 2 (enhanced NHS) represents the next best-case for conserving their potentially contributing habitat (86.8% is protected under an enhanced NHS; see section 3.3.3.1). Moreover, the amount of high impervious cover is mitigated by comparison to scenario 3 (full buildout). However, the best quality habitat for Redside Dace, meadow, only represents 12.4% of the potentially contributing habitat area, improvements in this natural cover type should also be sought under future NHS development scenarios.

6. Enhance natural heritage system coverage and be proactive with its implementation.

The proposed future scenario 2 and 3 (enhanced NHS) provides the best areal coverage of natural heritage system throughout CCW, however, this falls short of many aquatic based targets. This includes impervious cover (see recommendation 1), habitat and aquatic species that maintain the function and health of the aquatic ecosystem. The natural heritage system should be expanded to include headwater features that provide habitat for aquatic biota and better water quality/quantity within watercourses in CCW (those included in potentially contributing habitat for Redside Dace; see section 3.3.3.1). The proposed scenario in this AIA provides better coverage in this regard and is likely to better achieve a better functioning and healthier aquatic ecosystem. The caveat to realizing these outcomes, is the requirement of the full restoration of natural cover within the NHS. Of note, the current riparian corridor has ~50% natural cover and it only improves to about 65% under the enhanced NHS (future scenarios 2 and 3; assuming the potential NHS natural cover is developed). This value should be much higher to protect vital habitats and watershed conditions; specifically, improvements in the amount of meadow habitat within the riparian corridor and the broader NHS should be sought with NHS development. Under the proposed scenario, 75.6% of the riparian corridor would be natural cover, which would maximize ecological and economic benefits to the water resource system. Given that it can take the biological ecosystem years to respond to enhancements, NHS expansion should occur as soon as possible and in advance of any development.

7. Increase spatial coverage of long-term monitoring sites for habitat and biota.

Much of the habitat data available is collected at too small of a spatial resolution and represents a very small proportion of available habitat to aquatic organisms in CCW. Coarse scale habitat metrics over a larger spatial extent, such as number of pools (depth), riffles and coarse sediment mapping, is required to investigate long-term trends. Indicator species (Redside Dace) also require population size estimates, so long-term population viability analysis can be completed to estimate survival potential. Currently, the sampling methods used and the amount of sampling in CCW does not provide this information. Long-term sampling sites should be added in the headwaters to provide population level information for indicator species and expand the spatial coverage of available data in potentially developable lands. Lastly, expanding monitoring data sources by using inventory-based methods (e.g., simply presence-absence) from multiple sources (TRCA, consulting, etc.) could also help to improve the ability to detect species, such as invasive species, throughout CCW.

References

Allan J.D. 2004. Landscapes and riverscapes: The influence of land use on stream ecosystems. Annual Review of Ecology Evolution and Systematics 35: 257-284.

Arnold, J., D. Moriasi, P. Gassman, K. Abbaspour, M. White, R. Srinivasan, C. Santhi, R. Harmel, A. van Griensven, M. Van Liew, N. Kannan, and M. Jha. 2012. SWAT: model use, calibration, and validation. American Society of Agricultural and Biological Engineers 55: 1491-1508.

Auld, H., H. Switzman, N. Comer, S. Eng, S. Hazen, and G. Milner. 2016. Climate trends and future projections in the Region of Peel. Ontario Climate Consortium: Toronto, ON: pp.103.

Beacon Environmental 2012. Ecological Buffer Guideline Review. Prepared for Credit Valley Conservation. Accessed on August 20, 2019. (Online: https://cvc.ca/wp-content/uploads/2013/08/Ecological-Buffer-Guideline-Review.pdf).

Blair, SG, May, C, Morrison, B, Fox, MG. 2019. Seasonal migration and fine-scale movement of invasive round goby (*Neogobius melanostomus*) in a Great Lakes tributary. Ecology of Freshwater Fish 28: 200-208.

Booth, D. 1991. Urbanization and the natural drainage system - impacts, solutions, and prognoses. Northwest Environmental Journal 7: 93-118.

Canadian Council of Ministers of the Environment (CCME). 2011. Canadian water quality guidelines for the protection of aquatic life: Chloride (online: http://ceqg-rcqe.ccme.ca/download/en/337?redir=1535032589).

Cheek, B., T. Grabowski, P. Bean, J. Groeschel, and S. Magnelia. 2015. Evaluating habitat associations of a fish assemblage at multiple spatial scales in a minimally disturbed stream using low-cost remote sensing. Aquatic Conservation: Marine and Freshwater Ecosystems 26: 20-34.

Choy, M., D. Lawrie, and C. Edge. 2018. Measuring 30 years of improvements to aquatic connectivity in the Greater Toronto Area. Aquatic Ecosystem Health & Management 21: 342-351.

Chu C, Jones NE, Allin L 2010. Linking the thermal regimes of streams in the Great Lakes Basin, Ontario, to landscape and climate variables. River Research Applications 26: 221–241.

Colvin, S. A., Sullivan, S. M., Shirey, P. D., Colvin, R. W., Winemiller, K. O., Hughes, R. M., Fausch, K. D., Infante, D. M., Olden, J. D., Bestgen, K. R., Danehy, R. J. and Eby, L. 2019. Headwater Streams and Wetlands are Critical for Sustaining Fish, Fisheries, and Ecosystem Services. Fisheries 44: 73-91.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2017. COSEWIC assessment and status report on the Eastern Pondmussel *Ligumia nasuta* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xii + 61 pp. (online: http://www.registrelep-sararegistry.gc.ca/default.asp?lang=en&n=24F7211B-1).

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2012. COSEWIC assessment and status report on the Wood Thrush *Hylocichla mustelina* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. ix + 46 pp. (online: www.registrelep-sararegistry.gc.ca/default_e.cfm)

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2017. COSEWIC assessment and status report on the Redside Dace *Clinostomus elongatus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xii + 63 pp. (online: www.registrelep-sararegistry.gc.ca/default.asp?lang=en&n=24F7211b-1)

Copeland, C. 2016. Green Infrastructure and Issues in Managing Urban Stormwater. Congressional Research Service, USA. Accessed August 21, 2019. (Online: https://fas.org/sgp/crs/misc/R43131.pdf).

Credit Valley Conservation (CVC) and Toronto and Region Conservation Authority (TRCA), 2014. *Evaluation, Classification and Management of Headwater Drainage Feature Guidelines.* Credit Valley Conservation Authority and Toronto and Region Conservation Authority. (online: http://www.trca.on.ca/dotAsset/180724.pdf)

DFO. 2019. Recovery Potential Assessment of Redside Dace (*Clinostomus elongatus*) in Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2019/012.

Dietz, M. and J. Clausen. 2008. Stormwater runoff and export changes with development in a traditional and low impact subdivision. Journal of Environmental Management 87: 560-566.

Di Luzio, M., Srinivasan, R., Arnold, J.G., 2001. ArcView Interface for SWAT2000 — User's Guide. Blackland Research Center, Texas Agricultural Experiment Station and Grassland, Soil and Water Research Laboratory, USDA Agricultural Research Service, Temple, Texas.

Durham Region. 2016. Towards Resilience: Durham community climate adaptation plan 2016.

Government of Ontario. 2007. Endangered Species Act, 2007. Toronto, Ontario.

Eaton, J. and R. Scheller. 1996. Effects of climate warming on fish thermal habitat in streams of the United States. Limnology and Oceanography 41: 1109-1115.

EBNFLO Environmental AquaResource Inc. 2010. Guide for Assessment of Hydrologic Effects of Climate Change in Ontario. The Ontario Ministry of Natural Resources and Ministry of the Environment.

Environment Canada. 2010. Recovery Strategy for the Butternut (*Juglans cinerea*) in Canada. *Species at Risk Act* Recovery Strategy Series. Environment Canada, Ottawa vii + 24 pp.

Environment Canada (EC). 2013. How much habitat is enough? Third edition. Environment Canada, Toronto, Ontario.

Environment and Climate Change Canada (ECCC). 2019. Canadian Environmental Sustainability Indicators: Water quality in Canadian rivers. Consulted on February 19, 2019. (Online: www.canada.ca/en/environment-climate-change/services/environmental-indicators/water-quality-canadian-rivers.html).

Falconer, M., K. Richardson, A. Heagy, D. Tozer, B. Stewart, J. McCracken, and R. Reid. 2016. Recovery Strategy for the Bank Swallow (*Riparia riparia*) in Ontario. Ontario Recovery Strategy Series. Prepared for the Ontario Ministry of Natural Resources and Forestry, Peterborough, Ontario. ix + 70 pp.

Faulkner, S. 2004. Urbanization impacts on the structure and function of forested wetlands. Urban Ecosystems 7:89-106.

Filazzola, A., Shrestha, N. McIvor, J.S. 2019. The contribution of constructed green infrastructure to urban biodiversity: A synthesis and meta-analysis. Journal of Applied Ecology (Early View). 13 pages.

Forman, R. 1995. Some general principles of landscape and regional ecology. Landscape Ecology 10: 2-9.

Foster, S. 1990. Impacts of urbanization on groundwater. Hydrological Processes and Water Management in Urban Areas (Proceedings of the Duisberg Symposium, April 1988). IAHS Publ. No. 198, 1990.

Frissell, C., W. Liss, C. Warren, and M. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10: 199-214.

Geschke, A., S. James, A. Bennett and D. Nimmo. 2018. Compact cities or sprawling suburbs? Optimising the distribution of people in cities to maximize species diversity. Journal of Applied Ecology 55: 2320-2331.

Gleeson, J., P. Gray, A. Douglas, C. Lemieux, and G. Nielsen. 2011. A practitioner’s guide to climate change adaptation in Ontario’s ecosystems. Ontario Centre for Climate Impacts and Adaptation Resources. Sudbury, Ontario. 74p.

Gregory, S., F. Swanson, W. McKee, and K. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience 41:540-551.

Griebler, C. and M. Avramov. 2015. Groundwater ecosystem services: a review. Freshwater Science 34: 355-367.

Griebler, C., F. Malard, and T. Lefeburez. 2014. Current developments in groundwater ecology – from biodiversity to ecosystem function and services. Current Opinion in Biotechnology 27: 159-167.

Grimm, N., S. Faeth, N. Golubiewski, C. Redman, J. Wu, X. Bai, and J. Briggs. 2008. Global change and the ecology of cities. Science 319: 756-760.

Hamilton, J. & Sawka, M. 2019. State of Large Parks in Ontario's Golden Horseshoe. Toronto and Region Conservation Authority. Accessed August 21, 2019. (Online: https://greeninfrastructureontario.org/app/uploads/2019/06/StateofParks_Report-Final.pdf).

Hanski, I. and O. Ovaskainen. 2000. The metapopulation capacity of a fragmented landscape. Nature 404:755-758.Haskell, D. G., A. M. Knupp, and M. C. Schneider. 2001. Nest predator abundance and urbanization. *In* Avian ecology and conservationin an urbanizing world (J. M. Marzluff, R. Bowman, and R. Donnelly, Eds.). Kluwar Academic Publishers, Norwell, Massachusetts, USA.

Heagy, A., D. Badzinski, D. Bradley, M. Falconer, J. McCracken, R.A. Reid and K. Richardson. 2014. Recovery Strategy for the Barn Swallow (*Hirundo rustica)* in Ontario. Ontario Recovery Strategy Series. Prepared for the Ontario Ministry of Natural Resources and Forestry, Peterborough, Ontario. vii + 64 pp.

Hester E.T. & Bauman K.S. 2013. Stream and Retention Pond Thermal Response to Heated Summer Runoff from Urban Impervious Surfaces. Journal of the American Water Resources Association 49: 328-342.

Hering D., Aroviita J., Baattrup-Pedersen A., Brabec K., Buijse T., Ecke F., Friberg N., Gielczewski M., Januschke K., Kohler J., Kupilas B., Lorenz A.W., Muhar S., Paillex A., Poppe M., Schmidt T., Schmutz S., Vermaat J., Verdonschot P.F.M., Verdonschot R.C.M., Wolter C. & Kail J. 2015. Contrasting the roles of section length and instream habitat enhancement for river restoration success: a field study of 20 European restoration projects. Journal of Applied Ecology 52: 1518-1527.

Hester E.T. & Bauman K.S. 2013. Stream and Retention Pond Thermal Response to Heated Summer Runoff from Urban Impervious Surfaces. Journal of the American Water Resources Association 49: 328-342.

Hilsenhoff, W.L. 1987. An Improved Biotic Index of Organic Stream Pollution. The Great Lakes Entomologist 20: 31-39.

Hilsenhoff, W.L. 1988. Rapid Field Assessment of Organic Pollution with a Family-Level Biotic Index. Journal of the North American Benthological Society 7: 65-68.

Holmlund, C. and M. Hammer. 1999. Ecosystem services generated by fish populations. Ecological Economics 29: 253-268.

Huttenun, K., H. Mykra, J. Oksanen, A. Astorga, R. Paavola and T. Muotka. 2017. Habitat connectivity and in-stream vegetation control temporal variability of benthic invertebrate communities. Scientific Reports 7: 1448.

International Panel on Climate Change (IPCC). 2014. Climate change 2014: impacts, adaptation, and vulnerability – summary for policymakers.

Jackrel SL, Wootton JT 2015. Diversity of Riparian Plants among and within Species Shapes River Communities. PLOS ONE 10(11): e0142362.

Jaeger, J., J. Bowman, J. Brennan, L. Fahrig, D. Bert, J. Bouchard, N. Charbonneau, K. Frank, B. Gruber and K. Tluk von Toschanowitz. 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. Ecological Modelling 185: 329-348.

Jones, C., K. Somers, B. Craig, and T. Reynoldson. 2007. Ontario Benthos Biomonitoring Network: Protocol Manual. Environmental Monitoring and Reporting Branch, Dorset Environmental Science Centre. Queen's Printer for Ontario.

Kaushal S.S., Likens G.E., Pace M.L., Utz R.M., Haq S., Gorman J. & Grese M. 2018. Freshwater salinization syndrome on a continental scale. Proceedings of the National Academy of Sciences 115: E574-E583.

Knutson, R.L., J.R. Kwilosz, R. Grundel. 1999. Movement patterns and population characteristics of the Karner blue butterfly (Lycaeides melissa samuelis) at Indiana Dunes National Lakeshore. Natural Areas Journal 19:109–120

Lam, S. and T. Conway. 2018. Ecosystem services in urban land use planning policies: a case study of Ontario municipalities. Land Use Policy 77:641-651.

Leopold, L. 1968. Hydrology for urban planning, a guidebook on the hydrologic effects of urban land use. U.S. Geological Survey Circular 554. Washington, DC: U.S. Department of the Interior.

Lindenmayer, D.B., J. F. Franklin. 2002. Conserving forest biodiversity: A comprehensive multiscaled approach. Island Press, Washington DC.

Lindeman, R.L. 1942. The Trophic-Dynamic Aspect of Ecology. Ecology 23: 399-417.

Marchildon, M., P.J. Thompson, S. Cuddy, E.J. Wexler, K. Howson, J.D.C. Kassenaar, 2016. A methodology for identifying ecologically significant groundwater recharge areas. Canadian Water Resources Journal (4): 515-527.

Matrix Solutions Inc. 2017. Draft overall benefit strategy for strategic planning of urban development projects within regulated Redside dace habitat. West Humber Watershed, Brampton, Ontario. Prepared for: The corporation of the City of Brampton. May 2017, Mississauga, Ontario.

Matrix Solutions Inc. 2018a. Carruthers Creek fluvial geomorphic assessment of regional watershed monitoring program data 2003-2016. Prepared for: Toronto and Region Conservation Authority. November 2018, Mississauga, Ontario.

Matrix Solutions Inc. 2018b. Meander belt width delineation for Carruthers creek watershed. Prepared for: Toronto and Region Conservation Authority. November 2018, Mississauga, Ontario.

May, C., R. Horner, J. Karr, B. Mar, and E. Welch. 1997. Effects of urbanization on small streams in the Puget Sound Ecoregion. Watershed Protection Techniques 2: 483-94.

McNichols, K., P. Diamond, A. Boyko, and S. Staton. 2018. Recovery strategy and action plan for the Eastern Pondmussel (*Ligumia nasuta*) in Canada. Retrieved on November 30, 2018. (Online: https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/recovery/eastern-pondmussel-recovery-strategy-action-plan.html#toc18).

Melles S.J., Chu C., Alofs K.M. & Jackson D.A. 2015. Potential spread of Great Lakes fishes given climate change and proposed dams: an approach using circuit theory to evaluate invasion risk. Landscape Ecology 30: 919-935.

Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC. Ministry of Environment and Energy (MOEE) and Ministry of Natural Resources (MNR). 1993. Water management on a watershed basis: implementing an ecosystem approach. Queen's Printer for Ontario, Toronto, Ontario.

Ministry of Municipal Affairs (MMA). 2017. Growth Plan for the Greater Golden Horseshoe. Queen's Printer for Ontario.

Ministry of Natural Resources and Forestry (MNRF). 2016. Guidance for development activities in Redside Dace protected habitat. Version 1.2. Ontario Ministry of Natural Resources and Forestry, Peterborough, Ontario. Iv+32 pp.

Ministry of Natural Resources and Forestry (MNRF) 2018. Invasive Species: Round Goby. Accessed April 3, 2019. (Online: https://www.ontario.ca/page/round-goby).

Minnesota Sea Grant. 2012. Mystery snails (Chinese, Japanese, Banded). Accessed February 20, 2019. (Online: http://www.seagrant.umn.edu/ais/mysterysnail).

Moudrak, N., B. Feltmake, H. Venema and H. Osman. 2018. Combating Canada's rising flood costs: natural infrastructure is an underutilized option. Prepared fro Insurance Bureau of Canada. Intact Centre on Climate Adaptation, University of Waterloo.

Oak Ridges Moraine Groundwater Program (ORMGP). 2018. Carruthers Creek Watershed Plan: Groundwater modelling memo. Monday 17th December 2018.

Ohio EPA. 2003. Fact Sheet: Economic reasons for sound management of primary headwater streams. Division of Surface Water. Columbus, Ohio.

Ontario Planning Act. 1990. R.S.O. Chapter. P.13. Accessed on July 30, 2018. (Online: https://www.ontario.ca/laws/statute/90p13).

Paul, M. and J. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics 32: 333-365.

Phillips I.D., Vinebrooke R.D. & Turner M.A. 2009. Ecosystem consequences of potential range expansions of Orconectes virilis and Orconectes rusticus crayfish in Canada — a review. Environmental Reviews 17: 235-248.

Reid, A. J., Carlson, A. K., Creed, I. F., Eliason, E. J., Gell, P. A., Johnson, P. T., Kidd, K. A., MacCormack, T. J., Olden, J. D., Ormerod, S. J., Smol, J. P., Taylor, W. W., Tockner, K. , Vermaire, J. C., Dudgeon, D. and Cooke, S. J. 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. Biological Reviews 94: 849-873.

Richter, B., J. Baumgartner, J. Powell and D. Braun. 1996. A method for assessing hydrologic alternation within ecosystems. Conservation Biology 10: 1163-1174.

Riley, S., G. Busteed, L. Kats, T. Vandergon, L. Lee, R. Dagit, J. Kerby, R. Fisher, and R. Sauvajot. 2005. Effects of urbanization on the distribution and abundance of amphibians and invasive species in southern California streams. Conservation Biology 19: 1894-1907.

Rodtka, M.C., Judd, C.S., Aku, P.K.M., and Fitzsimmons, K.M. 2015. Estimating occupancy and detection probability of juvenile bull trout using backpack electrofishing gear in a west-central Alberta watershed. Canadian Journal of Fisheries and Aquatic Sciences 72: 1-9.

Sabouri F., Gharabaghi B., Mahboubi A.A. & Mcbean E.A. 2013. Impervious surfaces and sewer pipe effects on stormwater runoff temperature. Journal of Hydrology 502: 10-17.

Sarma A.K., Singh V.P., Bhattacharjya R.K. & Kartha S.A. 2018. *Urban Ecology, Water Quality and Climate Change,* Springer International Publishing.

Schueler, T. 1994. The Importance of Imperviousness. Watershed Protection Techniques 2: 100-111.

Sekercioglu, C. 2006. Increasing awareness of avian ecological function. Trends in Ecology and Evolution 21: 464-471.

Shiklomanov, I. 1993. World freshwater resources in Peter H. Gleick (Ed), Water in Crisis: A Guide to the World's Fresh Water Resources. Oxford University Press, New York.

Shannon, C. E. (1948) A mathematical theory of communication. The Bell System Technical Journal 27: 379–423 and 623–656.

Stanfield, L. 2017. Ontario Stream Assessment Protocol. Ontario Ministry of Natural Resources.

Statzner, B. and B. Higler. 1986. Stream hydraulics as a major determinant of benthic invertebrate zonation patterns. Freshwater Biology 16: 127-139.

Steedman, R. J. 1987. Comparative analysis of stream degradation and rehabilitation in the Toronto area. Ph.D. thesis. University of Toronto. vii + 172pp.

Strahler, A. N., 1964. Quantitative geomorphology of drainage basins and channel networks. In Chow, V.T. (ed.) Handbook of Applied Hydrology, McGraw-Hill, New York. pp 439-476.

Summers, R., R. Plummer, and J. FitzGibbon. 2013. The influence of sub-watershed plans on the Ontario planning process. Canadian Water Resources Journal 28: 375-394.

The Nature Conservancy, 2009. Indicators of Hydrologic Alteration. Version 7.1 User's Manual.

Todd, A. and G. Kaltenecker. 2012. Warm season chloride concentrations in stream habitats of freshwater mussel species at risk. Environmental Pollution 171: 199-206.

Toronto and Region Conservation Authority (TRCA). 2003. A watershed plan for Duffins Creek and Carruthers Creek.

Toronto and Region Conservation Authority (TRCA). 2017a. Carruthers Creek watershed plan: headwater drainage features characterization.

Toronto and Region Conservation Authority (TRCA). 2017b. Carruthers Creek watershed plan: aquatic habitat and community characterization.

Toronto and Region Conservation Authority (TRCA). 2017c. Carruthers Creek watershed plan: aquatic crossing and barrier assessment report.

Toronto and Region Conservation Authority (TRCA). 2017d. Carruthers Creek watershed plan: surface water quality assessment.

Toronto and Region Conservation Authority (TRCA). 2018a. Restoration Opportunities Planning primer.

Toronto and Region Conservation Authority (TRCA). 2018b. Carruthers Creek Watershed Plan Water Quantity Characterization.

Toronto and Region Conservation Authority (TRCA). 2019a. Ecologically Significant Groundwater Recharge Areas in TRCA Jurisdiction: Updated Mapping.

Toronto and Region Conservation Authority (TRCA). 2019b. Soil-Water Assessment Tool as an evaluation of water quality changes in Carruthers Creek watershed.

Trudeau, M. and M. Richardson. 2015. Change in event-scale hydrologic response in two urbanizing watersheds of the Great Lakes St Lawrence Basin 1969-2010. Journal of Hydrology 527: 1174-1188.

Tu, C., G. Milner, D. Lawrie, N. Shrestha, and S. Hazen. 2017. Natural systems vulnerability to climate change in Peel Region. Toronto, Ontario: Toronto and Region Conservation Authority and Ontario Climate Consortium Secretariat.

Vannote R.L., Minshall G.W., Cummins K.W., Sedell J.R. & Cushing C.E. 1980. The River Continuum Concept. Canadian Journal of Fisheries and Aquatic Sciences 37: 130-137.

Vaughn, C., S. Nichols, and D. Spooner. 2008. Community and food web ecology of freshwater mussels. Journal of the North American Benthological Society 27: 409-423.

Villasenor, N., A. Tulloch, D. Driscoll, P. Gibbons and D. Lindenmayer. 2017. Compact development minimizes the impacts of urban growth on native mammals. Journal of Applied Ecology 54: 794-804.

Wallace A.M., Croft-White M.V. & Moryk J. 2013. Are Toronto's streams sick? A look at the fish and benthic invertebrate communities in the Toronto region in relation to the urban stream syndrome. Environmental Monitoring and Assessment 185: 7857-7875.

Walsh, C. J., Roy, A. H., Feminella, J. W., Cottingham, P. D., Groffman, P. M., & Morgan, R. P. 2005. The urban stream syndrome: current knowledge and search for a cure. Journal of the North American Benthological Society 24: 706-723.

Wang, L. and P. Kanehl. 2003. Influences of watershed urbanization and instream habitat on macroinvertebrates in cold water streams. Journal of the American Water Resources Association 39: 1181-96.

Ward, J. and J. Stanford. 1982. Thermal responses in the evolutionary ecology of aquatic insects. Annual Review of Entomology 27: 97-117.

Appendix

Appendix 1.: GIS notes on the five land use scenarios

Table. Summary of land use as percent cover under each land use scenario for the Carruthers Creek watershed.

Land use type	Scenario				
	Hist.	Curr.	1	2	3
Natural Cover	28	23	24	25	25
Natural Cover* (Potential)	-	0	0	11	11
Agricultural	53	34	29	19	4
Cemetery	-	<1	<1	<1	<1
Golf Course	6	4	4	4	4
Hydro Corridor	-	<1	<1	<1	<1
Recreational	-	2	2	2	2
Water**	-	1	1	1	1
Urban***	12	-	-	-	-
Future Urban	-	0	0	0	19
Residential High	-	<1	<1	<1	<1
Residential LowMed	-	10	12	12	12
Estate Residential	-	2	3	3	3
Rural Residential	-	1	1	<1	<1
Commercial	-	3	4	4	4
Industrial	-	1	5	5	5
Institutional	-	1	1	1	1
Open Space (Construction)	-	4	<1	<1	0
Railway	-	0	0	0	0
Road (ROW)	-	11	11	11	9

* Natural cover (potential) is delineated only in scenarios with updated enhancements to the NHS
** Water in the historical scenario is aggregated with natural cover; for rest of the scenarios it is a separate class
*** Urban in the historical scenario is aggregated; for the rest of the scenarios it is broken down by specific classes

Accompanying notes on GIS processing each scenario

Brief descriptions of the five different scenarios can be found below.

i. **Historical 1999 (Historical)**

The "Historical" land use scenario represents the approximate land use (1999 imagery) of the previous watershed plan (TRCA 2003). This scenario informs what the land use change trend has been over the past decade and a half between 1999 and 2015.

ii. **Current 2015 (Current)**

The "Current" land use scenario assumes maintenance of existing (2015 data) land use conditions and associated land cover characteristics (i.e. areas of imperviousness, vegetation, etc.). Current land uses and Natural Heritage Systems (NHS) were delineated based on a combination of data including orthophoto interpreted natural cover data, land use data, NHS data from municipalities, and Ecological Land Classification data. Agricultural lands were additionally updated using maps that were ground verified. Evaluation of this scenario related to watershed objectives provides a benchmark to describe current watershed conditions.

iii. **Scenario 1 (S1) – Official Plan (Current + OP)**

The "Official Plan" scenario utilizes updated information from local and regional municipalities Official Plans (OP) to supplement the "Current" scenario. Evaluation of this scenario in relation to watershed objectives provides insight into how the watershed conditions will likely change as OPs are implemented and whether there are key priorities for Carruthers Creek Watershed Plan objectives that emerge for management consideration. The most up-to-date OP data were downloaded from Ajax, Pickering, and Durham, which was refined with on-the-ground information for both land use and land cover categories as well as the currently delineated NHS in the OPs.

iv. **Scenario 2 (S2) - Enhanced Natural Heritage System (Current + OP + NHS)**

The "Enhanced Natural Heritage System" scenario was developed based on the "Official Plan" scenario that included existing conditions and OP information supplemented with new and updated information from natural heritage planning science locally and globally. In addition, all key natural heritage features, key hydrologic areas and other surface water features, including headwater drainage features, were delineated based on Growth Plan definitions (MMA 2017). Vegetation protection zones (30 m) were added to these features based on good state of practice (MMA 2017).

v. **Scenario 3 (S3) – Potential Urbanization (Current + OP + NHS + Potential Urban)**

The "Potential Urban" scenario is based on the land use designations identified in Growing Durham (Regional Official Plan Amendment No. 128). The build out area was added to scenario 3, which included the existing land use, OPs and the enhanced NHS. This illustrates prospective development post-2031 in the headwaters area outside of the enhanced Natural Heritage System.

Additional considerations for land-use scenarios

NHS enhancement additional considerations

The enhanced NHS for scenarios 2 and 3 was designed to achieve terrestrial biodiversity goals and has not considered or addressed other community goals or management considerations. This represents a first approximation of the required natural system for the Carruthers Creek watershed, where further refinement is recommended through the planning process to address other ecosystem services and community objectives. The design of the enhanced system is not beholden to the original 2003 watershed targets. The design of the enhanced system has attempted to capture all the natural features and areas identified for protection based on the natural heritage policies within municipal OPs. However, there may be additional areas required for protection that are not easily identified at the watershed scale or that must be protected to address other goals not addressed within this exercise. For example, specific federal and provincial species-at-risk requirements have not been considered in the design of this system.

Habitat types in potential areas of enhanced NHS

The specific habitat types planned for the enhanced natural heritage system were identified using TRCA's Restoration Opportunity Planning (ROP) tool (TRCA 2018a). Briefly, the ROP tool provides a strategic approach to identify where and what to restore within a watershed. Both terrestrial and aquatic ROP involves an initial desktop analysis followed by field surveys. For the purposes of this document only the terrestrial desktop portion was completed. The desktop analysis uses ArcGIS software to interpret orthophotography, digital elevation models and delineate drainage catchments. Once restoration opportunities are identified through desktop analysis, they can be targeted for field visits. Data collected during field visits include surrounding/existing land use, access for implementation, existing habitat features, drainage features, habitat opportunity type (riparian, wetland, forest, wet/dry meadow) and site dimensions, other indicators of site suitability (soils, topography), site quality, ease of implementation and invasive species (TRCA 2018a). The final product is a digital layer file of ROP polygons that can be overlaid with the enhanced NHS. For this analysis, any areas in the enhanced NHS that did not have a ROP overlaid were considered to be restored as forest.

Potential development areas

Areas for potential development for scenario 3 was identified based on the Greater Golden Horseshoe Growth Plan (MMA 2017) using minimum intensification and density targets. These targets were measured over the entire area excluding (a) natural heritage features and areas, natural heritage systems and floodplains, provided development is prohibited in these areas; (b) rights-of-way for electricity transmission lines; energy transmission pipelines; freeways, as defined by and mapped as part of the Ontario Road Network; and railways; (c) employment areas; and (d) cemeteries. The potential communities in these areas were assumed to be new complete communities and have a compact built form. The fine level detail on further restrictions on the extent of potential built and non-built areas within these areas is not represented (e.g. the headwaters are not designated greenfield areas, prime agricultural areas, no planning efforts are needed to minimize land consumption, natural heritage systems refined at site-level).