Carruthers Creek Watershed Plan: Aquatic Habitat and Community Characterization

Toronto and Region Conservation for The Living City®

Prepared for:

Region of Durham

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Foreword

The Region of Durham recognises 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*, thereby ensuring a continuum of management efforts to achieve the desired ecological and sustainability objectives for the watershed.

The following report is one of a series of technical reports that were prepared at the end of the first phase of the watershed plan development process to characterize the existing conditions of the watershed. Information contained in these reports will provide the knowledge base necessary to develop management recommendations during Phase 2. The reports were subject to an independent peer review process. The final integrated watershed plan will be completed by the end of Phase 2.

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1. Introduction

1.1 Carruthers Creek Watershed Plan Study Area

Carruthers Creek is a relatively small watershed with a drainage area of approximately 3,748 hectares (9,261 acres), ranging from two to three kilometres in width, and only 18 kilometres in length (Figure 1). It is the easternmost watershed in TRCA's jurisdiction and is located entirely in the Region of Durham. At the request of the Region of Durham, a small section of lands in East Duffins Creek subwatershed, which are immediately adjacent to Carruthers Creek watershed and outside of the provincial Greenbelt, were included in the study area.

The watershed occurs within the South Slope and Glacial Lake Iroquois physiographic regions, south of the Oak Ridges Moraine. Topographically, most of Carruthers Creek watershed is flat to slightly rolling. The exceptions are low hills associated with the Lake Iroquois Shoreline, notably the Kinsale Raised Shoreline immediately west of Audley Road and south of Highway 7, and the main valley feature of Carruthers Creek which forms a distinct but shallow ravine from Taunton Road south to Highway 401.

Carruthers Creek's headwaters form to the south of the Oak Ridges Moraine in the City of Pickering. Both the 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. Carruthers Creek contains a total of 61 kilometres of stream channels. Historically, portions of the watershed would have supported cold water fish populations including Brook trout, Atlantic salmon, Slimy sculpin, and Mottled sculpin. Instream barriers to fish movement in the watershed adversely impact the aquatic system by limiting access to feeding and spawning areas, increasing water temperature, and affecting sediment transport. In addition, some instream structures increase water velocities to the point where fish passage is prevented. Instream structures that act as barriers to fish passage include dams, weirs, road and rail crossings, and some culverts.

Carruthers Creek watershed lies in the Great Lakes-St. Lawrence floristic region, which is comprised of mixed coniferous-deciduous forest. There are two provincial Areas of Natural and Scientific Interest (ANSI), as designated by the Ontario Ministry of Natural Resources and Forestry, in the watershed: the Kinsale Raised Shoreline Earth Science ANSI, designated for its distinct geological character as a well preserved part of the ancient Lake Iroquois Shoreline; and Shoal Point Marsh Life Science ANSI, which is included in the coastal Carruthers Creek Wetland Complex Provincially Significant Wetland. Two smaller wetlands are evaluated as Locally Significant: the Rossland Road Wetland Complex and the Salem Road Wetland Complex. The Carruthers Creek Wetland Complex is divided into two Environmentally Significant Areas: the coastal Carruthers Marsh and the Carruthers Creek Forest, a few hundred metres inland.

Long-term precipitation and air temperature patterns in the watershed are summarised from data collected by Environment and Climate Change Canada at the nearby Oshawa Water Pollution Control Plant station. In 2015, precipitation volumes of 985 mm exceeded the 30 year (1981-2010) normal of 892 mm, however the 2016 volumes were significantly lower at approximately 614 mm. For three of the last nine years, the total volume of precipitation exceeded the 30 year normal. Lower than normal precipitation volumes were reported in the years 2013, 2015, and 2016.

Stream flow records for the watershed are related to climate patterns. Preliminary water quantity data suggest that 2015 was a wet year in terms of stream flow and 2016 was significantly drier. Although stream flow has only been measured in the watershed for a relatively short period of record, a wide range of climatic conditions has been observed.

Carruthers Creek watershed is mainly rural north of Highway 7. From Highway 7 south to Taunton Road, the majority of lands are in the Protected Countryside of the provincial Greenbelt, however there is a noticeable loss of the integrity of the natural heritage system due to clearing of vegetation and filling. Low to medium density suburban development predominates from Taunton Road south to the lakeshore. Lands currently mapped as rural in the urban areas of Ajax are expected to be developed as employment lands to meet future demands. The older parts of the built urban area have little to no stormwater controls, while the newer parts include standard stormwater quality and quantity ponds accompanied by low impact development (LID) technologies. There is also a flood vulnerable area in the Pickering Beach neighbourhood of Ajax.

As expected, there are differences in agricultural land use in the upper reaches versus mid-reaches of the watershed which may be attributed to land tenure, drainage and soil properties, or a combination of factors. Horticulture dominates the east branch, whereas the west branch is predominantly cash crops and at least one livestock operation, although horticulture is also present. In the urban areas of Ajax, some lands slated for development are still cultivated with cash crops as an interim use.

Overall, the land use in this small watershed is in transition, therefore the characterization provided by the field work in Phase 1 of the watershed plan is an excellent benchmark for future study and decision-making. Regular monitoring during and following this watershed planning process continuously improves our understanding and will help to guide ongoing decision-making to protect, restore, and enhance Carruthers Creek watershed.

Aquatic ecosystems that support a diverse biological community are considered to be healthier and more resilient to both natural and anthropogenic stressors such as chemical spills, floods, invasive species, and climate change. Measuring and reporting on the state of aquatic habitats and the communities they support in our rivers and streams is an important step towards effective decision making and planning for these essential resources.

The aquatic ecology of Carruthers Creek watershed was previously characterised in the *Carruthers Creek State of the Watershed Report* (TRCA, 2002) and the *Fisheries Management Plan for Duffins Creek and Carruthers Creek*

(TRCA, 2004). The data in the previous reports were limited in scope and are now 10 to 15 years old. This report will characterise the aquatic ecology of Carruthers Creek riverine habitat and serve as a background document for subsequent watershed planning exercises. Stream dwelling fish, stream dwelling benthic macroinvertebrates (BMI), and stream habitat were considered as part of this report. Data from TRCA's Regional Watershed Monitoring Program (RWMP), historical data from various sources, and specific field work were considered in the preparation of this report.

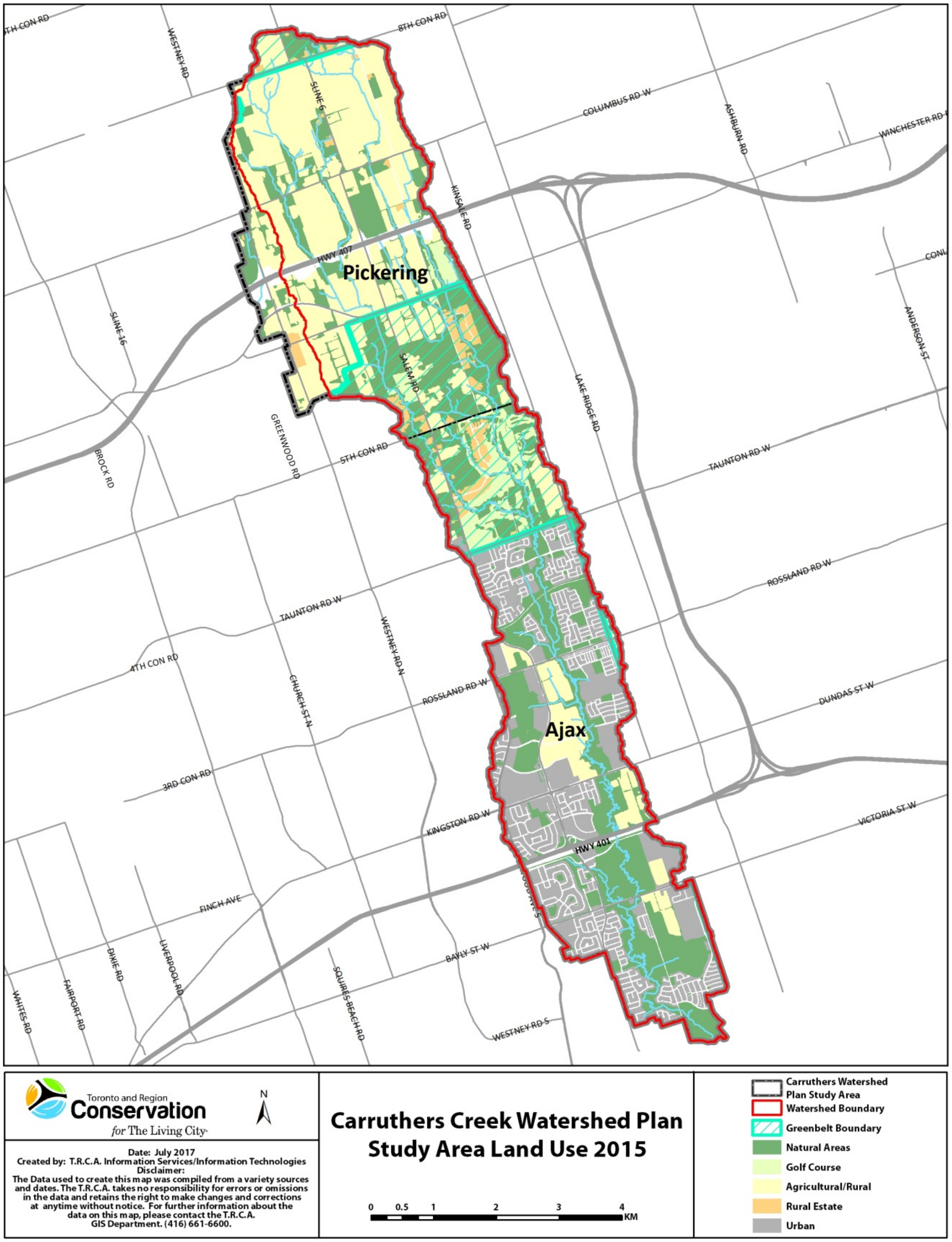


Figure 1: Carruthers Creek Watershed Plan Study Area as of 2015

2. Methods

Characterization of the current aquatic habitats and communities in Carruthers Creek watershed was achieved through the review of historical datasets and reports, the compilation and analysis of relevant datasets from recent monitoring projects, and additional data collection in 2015 specifically conducted to support this study.

Fish and benthic macroinvertebrates (BMI) were chosen as indicator organisms to help characterise the health of the riverine habitat in the watershed. The presence or absence of an indicator species or indicator community usually reflects environmental conditions. Fish are good indicators of long-term effects (over several years) and habitat conditions. They represent a variety of trophic levels (e.g., herbivores, carnivores) and their environmental requirements and life history information are relatively well known for most species (Plafkin *et al*., 1989). Benthic assemblages are perhaps the most widely studied aspects of urban stream ecosystems (Walsh *et al*., 2005), and BMI biomonitoring can be used as a tool to examine changes in biological health and water quality of water bodies over time.

Instream habitat was also characterised using water temperature and thermal stability, as well as sediment type and size, as these variables influence the ecology of the BMI and fish aquatic communities and the type of aquatic vegetation found in lotic systems (Wehrly *et al*., 1998; Robert, 2003).

The background information and data reviewed, along with a description of the additional monitoring sites and methods used, are as follows:

2.1 Background Information and Site Selection

Several TRCA documents including the *Carruthers Creek State of the Watershed Report* (TRCA, 2002) and the *Fisheries Management Plan for Duffins Creek and Carruthers Creek* (TRCA & OMNR, 2004) were reviewed as part of this study. The fisheries management plan (FMP) included fish and benthics monitoring data collected in 2000, along with any historical fish records and calculated metrics or indices (e.g., the Index of Biotic Integrity or IBI) used. Data summarised in the 2004 FMP were used to evaluate how fish species presence and the quality of the aquatic community (*i.e.*, IBI scores) in the watershed have changed throughout time (1976 to 2016).

Data from TRCA's Regional Watershed Monitoring Program (RWMP) were obtained for Carruthers Creek and synthesized for this report. The RWMP is a science based, long-term monitoring initiative developed by TRCA to collect aquatic and terrestrial ecosystem data at the watershed and sub-watershed scale, and across the region as a whole. Fish community and habitat data (including stream temperature) are collected on a three-year cycle, Carruthers Creek watershed was sampled in 2003, 2006, 2009, 2012, and most recently in 2015. Benthic invertebrates were sampled on an annual basis through this program from 2003 through 2015. Regional monitoring sites in Carruthers Creek watershed were selected to represent the lower end of the creek, upstream of the coastal marsh, the mid-reaches draining the urbanising portion of the watershed, and the east branch upstream of Taunton Road draining agricultural lands. These sites are identified as "RWMP" in Figure 2 and Table 1.

Monitoring and sampling records from other sources (e.g., private consultants, non-government organizations) maintained by the Ontario Ministry of Natural Resources and Forestry (OMNRF) Aurora District Office were included in the analysis where possible. These "fish dot" records provided by OMNRF were used to compare the presence of fish species in the watershed from 1976 to the most recent 2015 and 2016 data. The OMNRF historical data set could not be used to calculate indices since the sampling methodologies were not consistent through time or between sites, nor was there adequate information regarding the conditions of the site or effort dedicated to various sampling techniques. These sites are identified as MNRF Fish Dots in Figure 2.

Aquatic data collected during pre- and post-restoration monitoring (2015 and 2016) for project sites associated with Deer Creek Golf Course were used to supplement the data available for this study. Fish, habitat, and benthics data were available for six sites, however stream temperature data were not. These sites are identified as DCrest in Figure 1 and Table 1.

All sampling locations, with the exception of CCWP-06, CCWP-08, and CCWP-12, were located on the main stems of the Carruthers Watercourse. The three mentioned sites were located on tributaries flowing into the main Carruthers Creek channel.

2.1.1 Additional Field Collections 2015

To aid in the updated aquatic Characterization, additional aquatic community and habitat data were collected in 2015 and included a number of sites (13) originally sampled in 2000 in support of the FMP. These sites are identified as CCWP in Figure 2 and Table 1 and include fish and benthic community, instream habitat, and stream temperature collection where possible. Note that all aquatic data were not collected at each of these sites. Gaps in this dataset (Table 1) reflect "unsampleable" sites due to dry conditions or sampling restrictions (*i.e.*, no landowner permission or scientific collection permit granted). In addition, labour intensive sampling activities such as fish collections and benthic invertebrate surveys were only carried out at selected sites in order to represent headwater, mid-reach, and lower watershed conditions.

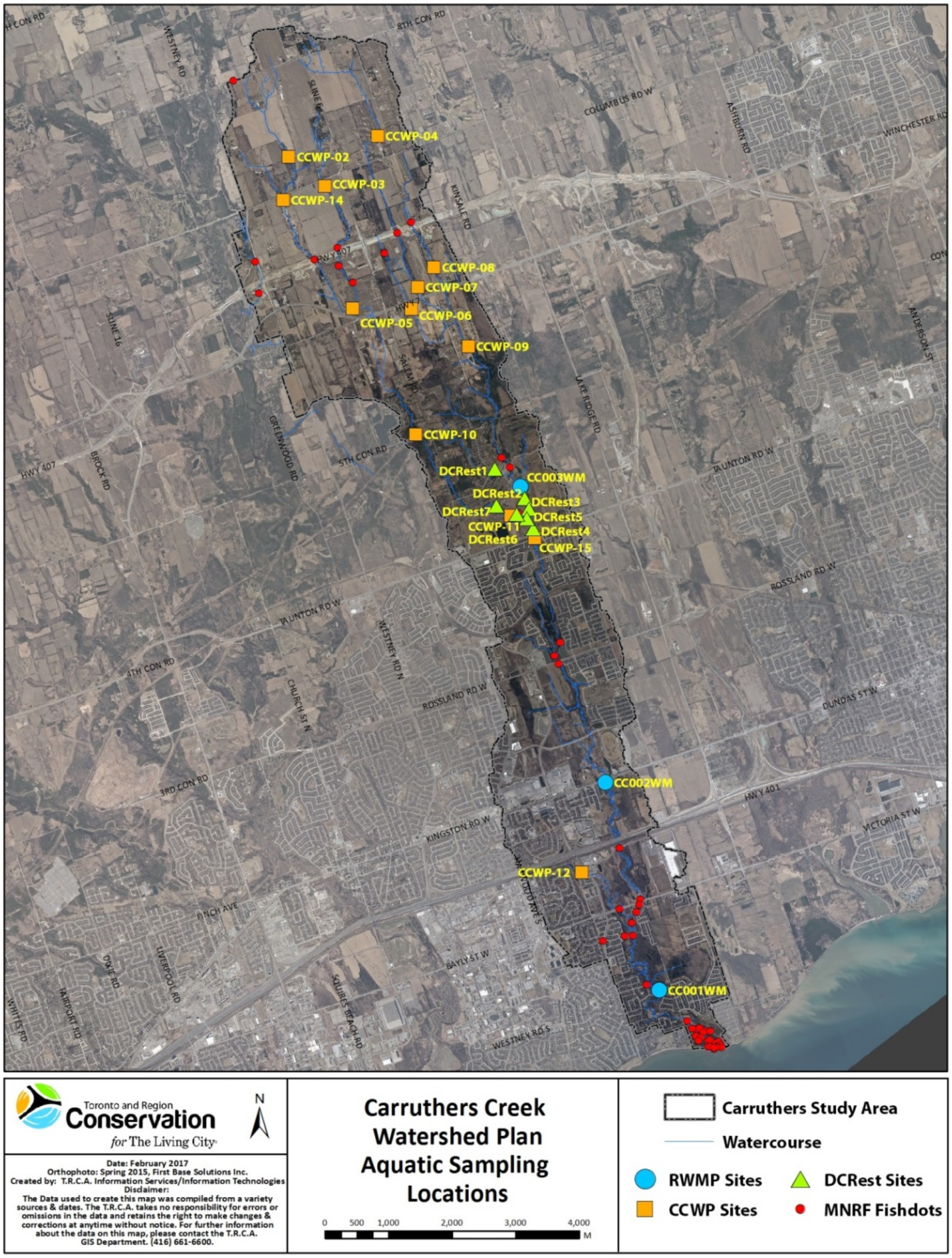


Figure 2: Carruthers Creek watershed boundary and aquatic sample/data locations

Table 1 - Carruthers Creek sample sites and data availability

Fish Site Name	Site Type	Years Sampled	Temperature	Fish	Habitat	Benthics
CC001WM	RWMP	2003, 2006,2009, 2012, 2015	yes	yes	yes	yes
CC002WM	RWMP	2003, 2006,2009, 2012, 2015	yes	yes	yes	yes
CC003WM	RWMP	2003, 2006,2009, 2012, 2015	yes	yes	yes	yes
CCWP-03	CCWP	2000, 2015	yes	yes	no	no
CCWP-04	CCWP	2000, 2015	yes	yes	no	no
CCWP-05	CCWP	2000, 2015	yes	yes	no	no
CCWP-06+	CCWP	2000, 2015	yes	no	no	no
CCWP-07	CCWP	2000, 2015	yes	no	no	no
CCWP-08+	CCWP	2000, 2015	yes	yes	yes	no
CCWP-09	CCWP	2000, 2015	yes	yes	yes	yes
CCWP-10	CCWP	2000, 2015	yes	yes	no	yes
CCWP-11	CCWP	2000, 2015	yes	yes	no	yes
CCWP-12+	CCWP	2000, 2015	yes	yes	no	yes
CCWP-14	CCWP	2000, 2015	yes	no	no	no
CCWP-15	CCWP	2000, 2015	yes	no	no	yes
DCRest2	DCrest	2000, 2015	no**	yes	yes	yes
DCRest3	DCrest	2000, 2015	no**	yes	yes	yes
DCRest4	DCrest	2000, 2015	no**	no	yes	yes
DCRest5	DCrest	2000, 2015	no**	yes	yes	yes
DCRest6	DCrest	2000, 2015	no**	yes	yes	yes
DCRest7	DCrest	2015, 2016	no**	yes	yes	yes
Total # of Sites			**15**	**16**	**11**	**14**

+ Site located in tributary. **data not available in the dataset used.

2.2 Aquatic Habitat

Instream physical habitat data have been regularly collected since 2003 (once every three years) at three sites in Carruthers Creek watershed under the RWMP (Figure 2 and Table 1). In addition, aquatic habitat assessments occurred at two CCWP sites and six DCrest sites.

Instream habitat was assessed using methods from the Ontario Stream Assessment Protocol (OSAP, Stanfield, 2013), that uses a series of standardised measurements from which habitat metrics were derived. Through the OSAP, sample sites were standardised to a geomorphic unit of 2 cross-overs (riffle/pool/run sequences) or a minimum of 40 m in length. Data were collected through a point-count/transect survey approach and metrics were based on a minimum of 60 points per site.

Metrics include: per cent habitat type (riffles, runs, and pools), per cent cover type (embedded, unembedded, and no cover), per cent instream vegetation type (filamentous and non-filamentous algae, grass, moss, macrophytes, watercress, terrestrial plants), and sediment type and size. For further information on these metrics, please refer to **Appendix A**. Similar to the fish community data, the aquatic habitat data were assessed for temporal trends. The indices were summarised on a watershed scale (data for each metric summarised across all sites combined) and compared through time (2003 to 2016). In addition, the most recent 2015/16 data were summarised by site. The individual 2015/16 site data were compared to the watershed values for the same time period using the described indices.

2.3 Stream Temperature and Thermal Stability

Stream temperature data were available from a number of sites (**Table 1**). Data loggers were deployed which continuously recorded temperature data once every 15 or 30 minutes (variation dependent upon data source and study design). Generally the data were logged continuously throughout three seasons (spring, summer, fall). Where possible, stream temperatures were obtained at the same sites as fish and benthic data, with the exception of the DCrest sites (stream temperature was not an indicator used to assess the performance of the restoration activities at these sites).

Data were summarised per site (mean, maximum, and minimum), per month, and per year. To observe spatial patterns, the 2015/16 site data are presented in a downstream to upstream order. Temperature data were also used to calculate thermal stability (stable < 5°C; moderate 5 to 9°C; and unstable > 9°C) and to classify the stream into temperature categories (cold <19°C; cool 19 to 21°C; and warm > 21°C) based on Wehrly *et al*. (1998). Thermal classification data were compared to the fish thermal guild data to observe whether the thermal classification (based on water temperature) matched the fish community present at the site.

Air temperature and precipitation data from Environment Canada were used to evaluate if the year was normal, abnormally hot or cold, and abnormally wet or dry. A criteria of five percent + or – applied to a ten year average was used to determine if the data was outside the 10 year normal. The Environment Canada data was used to evaluate observed trends in the water temperature data.

2.4 Fish Community

Fish community samples have been regularly collected (once every three years since 2003) at three sites in Carruthers Creek watershed under the RWMP. Additional samples were collected through pre- and post-restoration activity monitoring at the Deer Creek Golf Course in 2015 and 2016, and through sampling in support of this watershed Characterization in 2015.

Figure 3 indicates the period of record for the various fisheries datasets that were available for this study. This included the period for which various OMNRF fish dot records (combination of sources and techniques) were available.

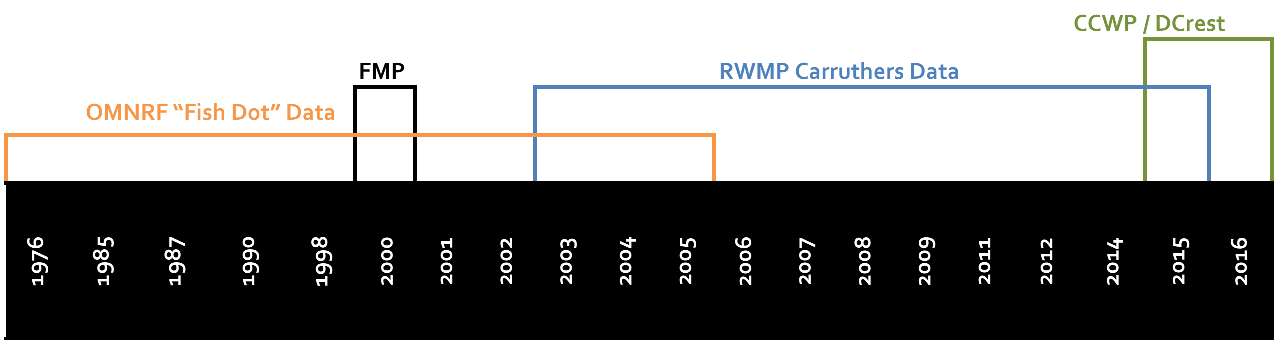


Figure 3: Data sources used for historical fish species presence comparison

Techniques used to sample fish communities through these various studies (with the exception of the OMNRF fish dots) have been consistent and have followed single pass electrofishing methods documented in the OSAP. Each fish was identified to species (where possible), measured, weighed, and released back into the stream. Sample sites were standardised to a geomorphic unit of 2 cross-overs (riffle/pool/run sequences) or a minimum of 40 m in length. A minimum effort of 7-12 seconds per square meter was used to collect the sample and ensure that all habitats within the site were sampled.

In addition to the presence of indicator fish species, several indices were calculated and compared where possible, including: species richness, per cent cold/cool/warm water species, per cent native/invasive/stocked fish and catch-per-unit-effort (CPUE). A modified version of the index of biotic integrity (IBI) was also calculated using the fish data (Steedman, 1988).

Classification of fish species into origin categories was undertaken and based on Mandrak and Crossman (1992), and designation by thermal guild was based on the Ontario Freshwater Fishes database (Eakins, 2002). Fish community data were converted to CPUE, where possible, which is an indirect measure of the abundance of fish. It is calculated as the abundance of fish per unit of area per time needed to sample that area (CPUE = Abundance / (Area / Time)). Since CPUE is standardised, it allows for comparisons of fish abundance both spatially and temporally. Definitions of these indices and how they were calculated are found in **Appendix B**.

Indices were summarised on a watershed scale (*i.e.*, data for each metric summarised across all sites combined) and compared through time (2003 to 2016). In addition, the most recent 2015/16 fish data were summarised annually by site and also compared to the watershed value for the same time period using the described indices. This was done to evaluate the performance and health of the riverine aquatic community at the individual sites against the overall health and performance of the watershed, to help contrast areas of aquatic health concern versus those areas which have a relatively healthy aquatic community.

Data for sites are presented in a downstream to upstream order to examine any spatial variation in the stream system. This contrast will assist in the identification of potential environmental restoration/enhancement opportunities in the watershed and aid in identifying and mitigating drivers which negatively contribute to the health of the aquatic community at individual sites, as well as downstream of those areas.

2.5 Benthic Macroinvertebrates

BMI samples are collected annually at three RWMP sites in Carruthers Creek watershed (Table 1) using kick and sweep methods outlined in the OSAP. These records were combined with data from six DCrest restoration monitoring sites and five additional CCWP sites to characterise the benthic community in the watershed (Table 1).

BMI data were summarised using a series of metrics and indices that encompass various ecological attributes, and biodiversity measures (Table 2). Definitions of these metrics are found in **Appendix B.** The data for each metric are summarised through time (2003-2016), and assessed for spatial variation between the sites.

Spatial trends were assessed using data collected from all stations in 2015 and 2016. Similar to the fish data, sites are presented in a downstream to upstream order to examine any spatial patterns.

Data from the three RWMP sampling stations (CC001WM, CC002WM, CC003WM) were used to assess temporal trends in Carruthers Creek, as long-term data were lacking in the other stations. Rarefaction curves were constructed using the statistical analysis program Paleontological Statistics (PAST) (Hammer *et al.*, 2001) to allow unbiased comparison of taxa richness within this 15 year period.

Table 2 - Metrics selected and their response to decreasing water quality

Metric	Category	Response to decreasing water quality
Taxa Richness	Diversity	↓
Shannon's Diversity Index (H')	Diversity	↓
Evenness (E)	Diversity	↓
% EPT	Composition	↓
% Chironomidae	Composition	↑
% Oligochaeta	Composition	↑
Hilsenhoff Biotic Index (HBI)	Tolerance	↑
Coastal marsh BMI IBI	Composition and Diversity	↓

The first three metrics evaluate diversity. Taxa richness is the count of all taxa collected within a site. Richness tends to decrease as water quality declines. Shannon Diversity Index **(H')** and Evenness **(E)** are based on Shannon (1948). Shannon Diversity Index quantifies diversity while accounting for how individuals were distributed among the taxa. Evenness is a measure of how similar the abundances of different taxa are. Low diversity and unevenness are typical characteristics of a degraded aquatic environment.

Community composition was evaluated by calculating percentages of groups of organisms present. A high percentage of Ephemeroptera, Plecoptera, and Trichoptera taxa (% EPT) is an indication of good water quality. On the contrary, high percentages of Chironomidae and Oligochaeta usually indicate habitat degradation or pollution.

The Hilsenhoff Biotic Index (HBI) is based on organic pollution tolerance. HBI scores were determined according to the methods described by Hilsenhoff (1987, 1988). A higher HBI score indicates a more degraded site in terms of organic pollution, but not necessarily habitat degradation or other types of disturbance.

3. Results and Discussion

The following sections characterise the current state of the aquatic community and supporting habitat in Carruthers Creek watershed and present the results using indices derived from the sampling of fish, BMI, and aquatic habitat parameters such as sediment type and size, aquatic vegetation, and water temperature.

3.1 Aquatic Habitat

Aquatic habitat, including its abundance and quality, plays an integral role in determining the type and health of the aquatic community present. Aquatic habitat provides feeding, breeding, and rearing areas for resident and migratory fish and BMI species. Understanding the changes in aquatic habitat such as thermal fluctuations, changing water quality parameters, changes in sediment transport processes, and the type of habitat available is useful in understanding the type of aquatic community present and gauging its health.

Instream habitat was measured at 11 sites in Carruthers Creek and included data collected through the RWMP (3 sites), the Deer Creek Golf Course restoration monitoring project (6 sites), and 2 additional sites sampled in 2015 (Table 1).

The following sections summarise the aquatic habitat based on the following metrics: per cent composition of pools, riffles and glides; per cent cover quality; sediment type and size; and per cent composition of vegetation type.

3.1.1 Composition of Pools, Riffles and Glides

A balanced combination of pool, riffle, and glide habitat is thought to be able to support a greater diversity of aquatic species. However, it is important to note that biodiversity is not strictly a function of the composition of these habitat features. Other abiotic factors such as water temperature, substrate type, water quality (e.g., dissolved oxygen), and the magnitude and frequency of flow all influence aquatic species richness and the composition of the benthic and fish communities present.

The proportion of each habitat type (e.g., pool, riffle, glide) was evaluated throughout the 40 metre (approximate) stretch of each site. From 2002 to 2016 pools were the most dominant habitat type for the sites sampled, followed by glides, and then riffles. Pool habitat ranged from approximately 40 to 95% by site, glide habitat ranged from approximately 9 to 30%, and riffle habitat ranged from 0.5 to 10% (Figure 4**).** Most streams have naturally repeating sequences of channel features and those that do not have often been artificially altered. It is unclear if the high proportion of pools compared to riffles or glides is a result of anthropogenic influence. This warrants future monitoring and further analysis and interpretation in order to better understand the natural channel morphology of the system.

Some features are greatly valued for specific life history requirements of different aquatic organisms. For example pool habitat is critical in terms of providing thermal refuge in summer, during drought conditions or during thermally unstable conditions. Deeper pools are important for over-wintering and under ice refuge for a variety of fish species. Glides or riffles are often used by fish as places of forage or reproduction specifically if there are groundwater upwelling's within these features.

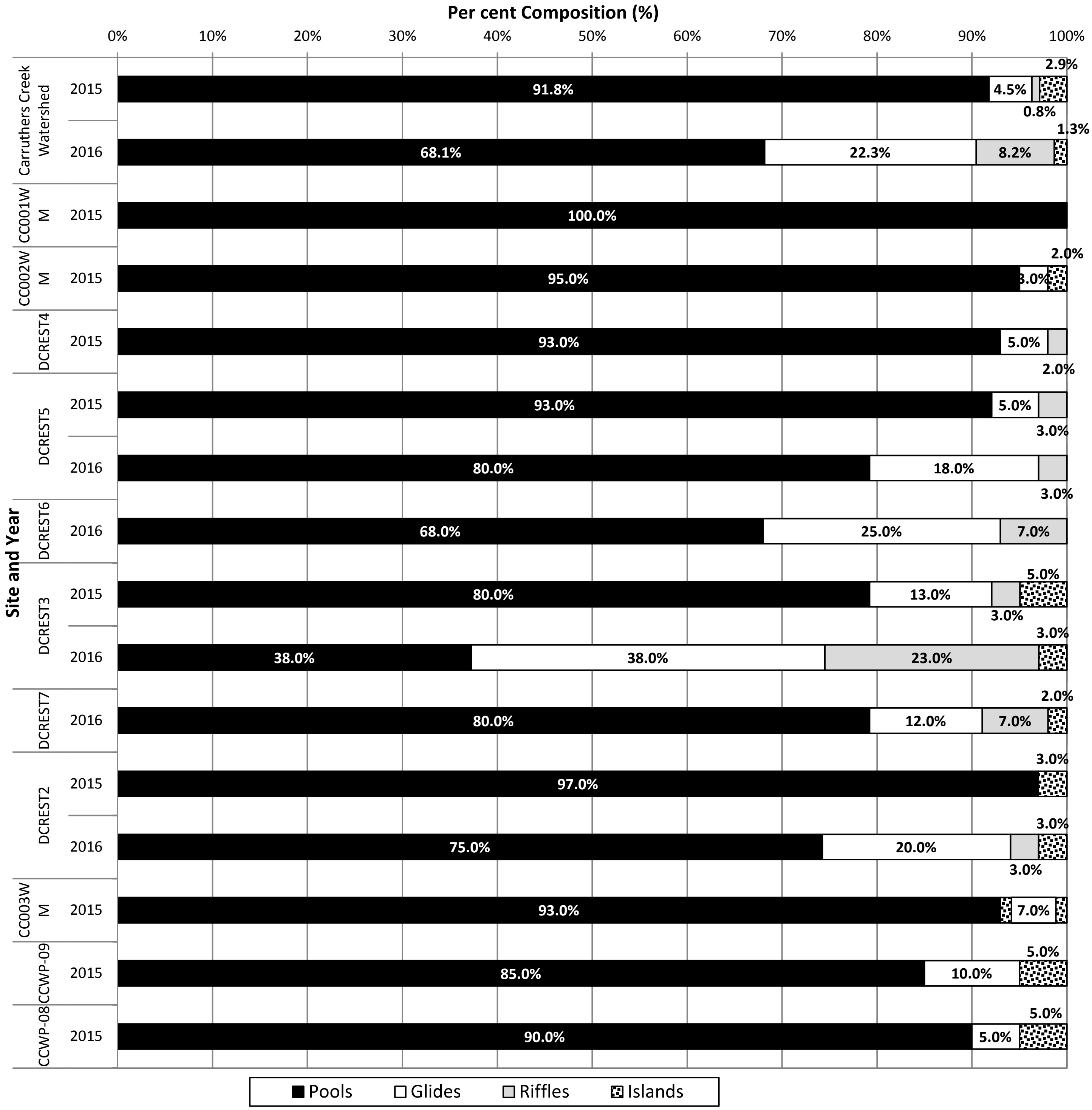


Figure 4: Site specific composition of habitat attributed to pool, riffle, glide (2015 and 2016)

3.1.2 Instream Cover and Quality

This metric speaks to the amount and quality of hiding spaces which aquatic organisms such as fish and benthos can utilise for refuge and for spawning/breeding. The cover quality is determined with respect to embeddedness; unembedded cover provides overhead and velocity protection for small fish whereas embedded cover provides only a velocity refuge as the interstitial spaces around the cover object are filled with material (OSAP; Stanfield 2013). The proportion of unembedded and embedded cover was evaluated throughout the 40 metre stretch of each site based on a point-transect survey.

Overall, the proportion of instream cover remained fairly consistent throughout sampling years 2003 to 2012. The percentage of unembedded cover ranged from 7 to approximately 70% by site, while the proportion of embedded cover ranged from approximately 2 to 13%. Sites which contained no cover (*i.e.*, no embedded or unembedded cover) ranged from approximately 20 to 90% (Figure 5). Differences in both the proportion of cover type and quality were apparent between sites and, as expected, were influenced by the type and size of substrate present. The DCrest sites generally had a higher percentage of cover compared to either RWMP sites or CCWP sites (Figure 5). Since embedded or unembedded cover is influenced by sediment size and type, it is also expected that the DCrest sites have a different sediment composition compared to the other sites. This is also consistent with the change in stream gradient and surficial geology associated with the sample sites.

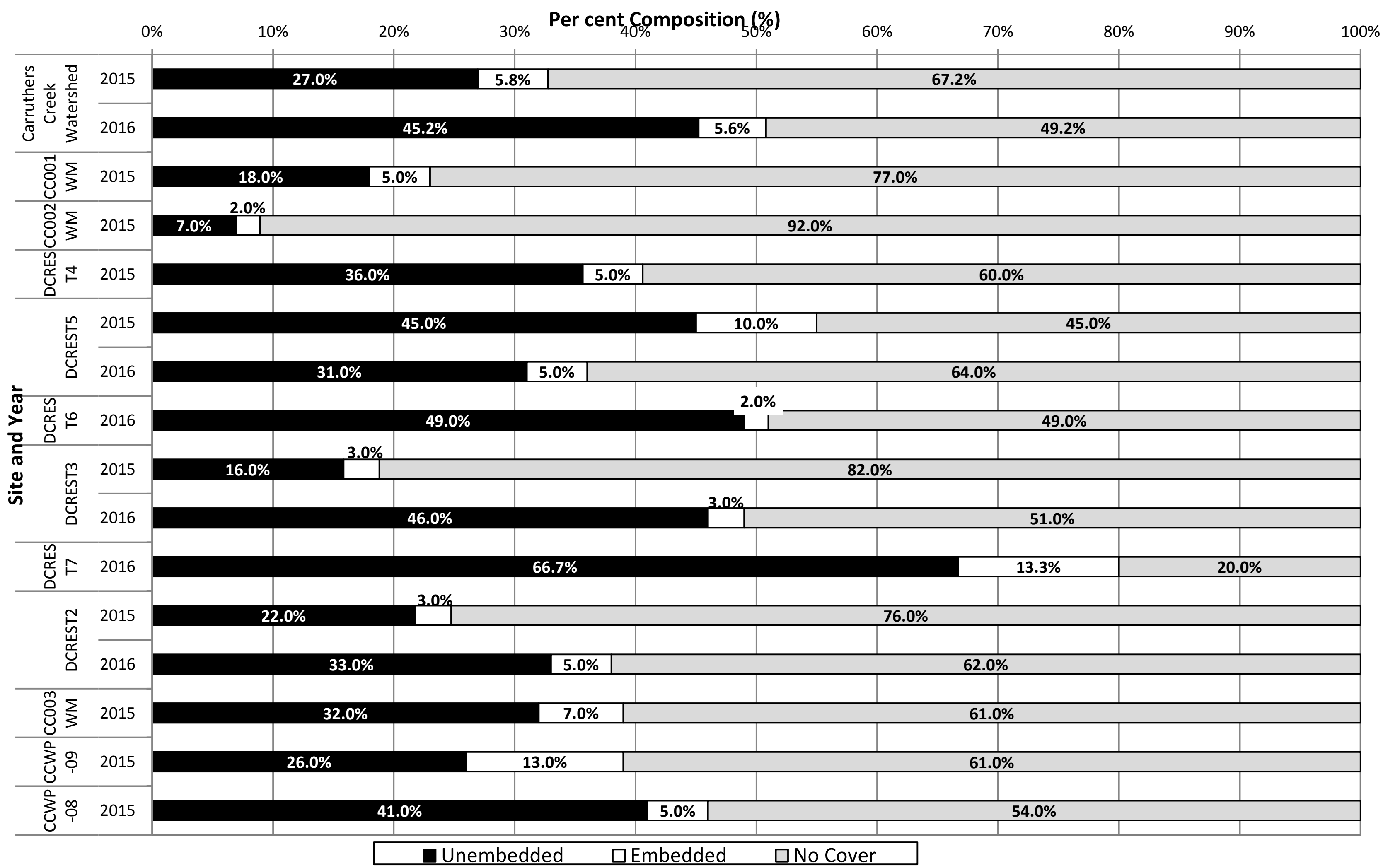


Figure 5: Proportion of cover type and quality by site (2015 and 2016)

3.1.3 Sediment Type and Particle Size

Stream systems and the aquatic communities they support are affected by, and adjust to, fluctuations in flow and sedimentary processes (Klingeman and MacArthur, 1990). Sediment type and the range of sediment sizes play a significant role in controlling the density and type of fish and benthic communities present in the aquatic system. Andre Robert (2003) provides an extensive summary of sedimentary process and their influence on the aquatic community.

Sediment size or "particle size" was measured at each site. Particle size was measured as the width of the particle along its median axis. The size of each particle was used to classify it into several categories as described inTable 3.

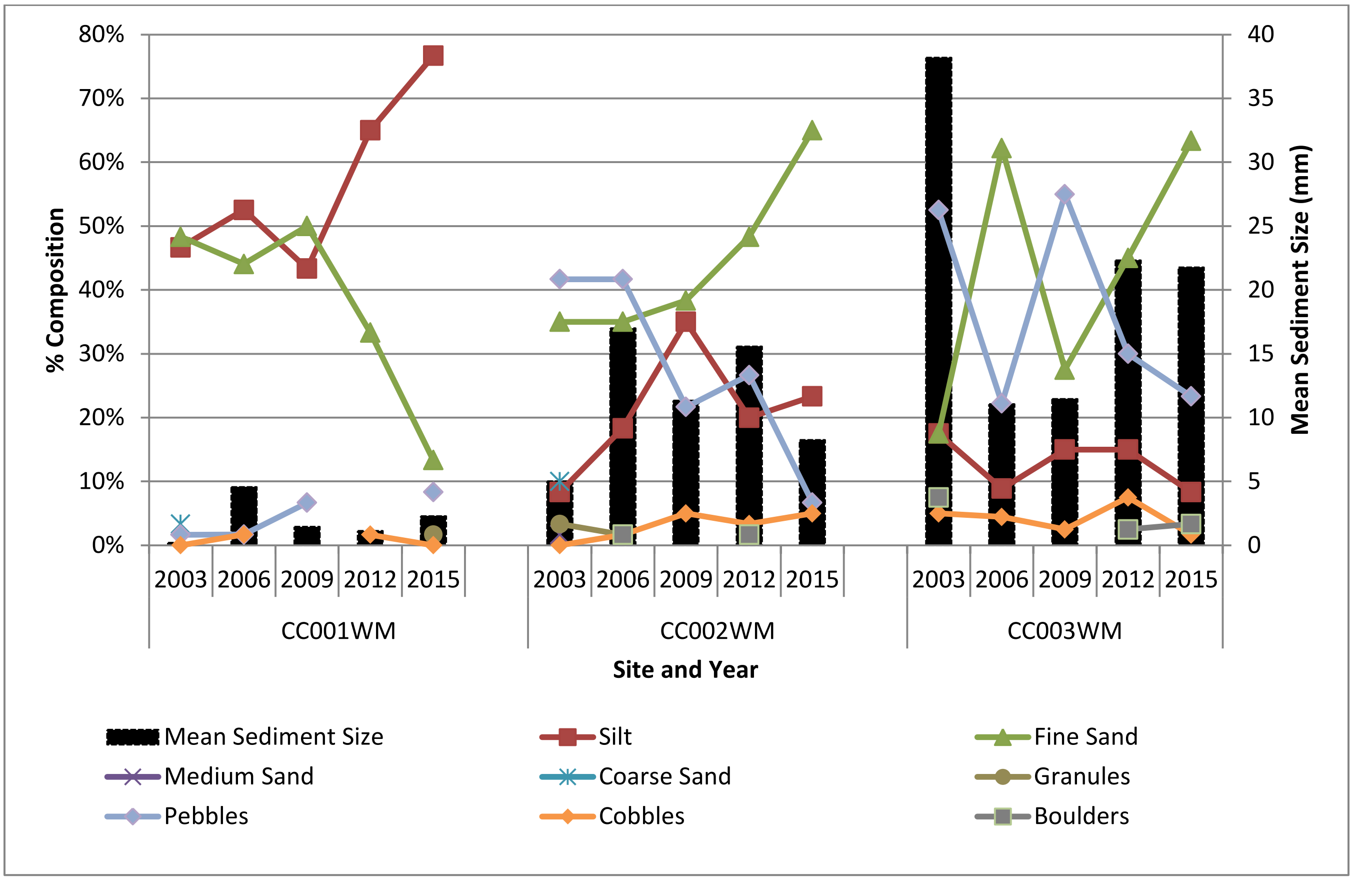
Table 3 - Particle size classes (from Andre Robert, 2003)

Class	Size (mm)
Clay	0.002-0.004
Silt	0.004-0.062
Fine Sand	0.062-0.25
Medium Sand	0.25-1
Coarse Sand	1-2
Granules	2-4
Pebbles	4-64
Cobbles	64-256
Boulders	>256

Sediment size and type fluctuate throughout a stream system as one travels from the headwaters to the mouth of the stream. The analysis of particle size was done on a site specific basis and not averaged throughout the years of sampling. Average sediment size has fluctuated temporally and spatially in Carruthers Creek (Figure 6 and Figure 7). On a temporal scale the RWMP sites showed fluctuation in mean sediment size per year. However regardless of the year, a general pattern of increasing particle size exists as one moved upstream. Site CC003WM had the greatest mean particle size of the three RWMP sites. Site CC001WM, located just upstream of the coastal marsh, showed the smallest mean sediment size. Site CC001WM was dominated by silt, whereas site CC003WM was dominated by fine sand and pebbles (Figure 6).

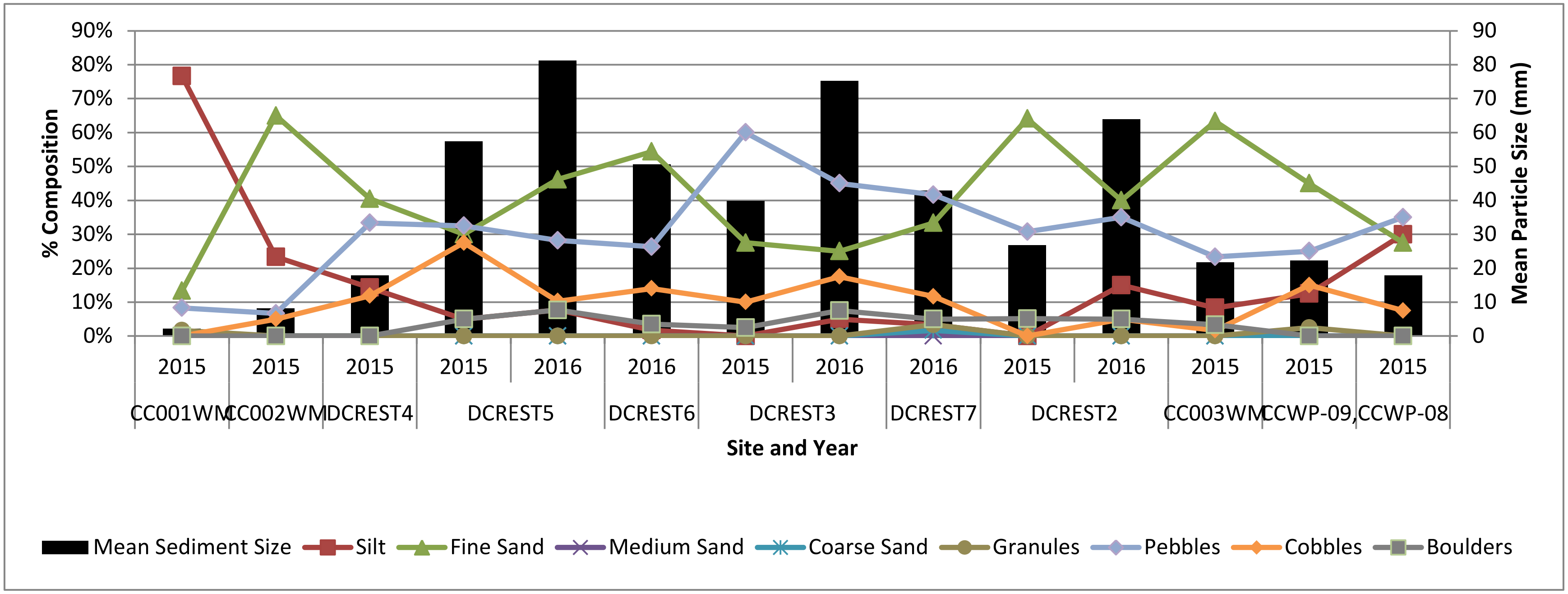
Data from 2015 and 2016 show the same spatial pattern of increasing particle size in sites as one moves upstream. Per cent composition of silt decreased in the upstream direction, with the exception of sites CCWP-08 and CCWP-09. The highest mean particle size was found at the DCrest sites, which were dominated by pebbles and fine sand. These sites also had a higher proportion of cobbles compared to any of the other sites sampled (Figure 7). This was a result of the stream restoration and habitat enhancement that occurred at the DCrest sites. The cobble and pebble material were specifically placed in this location of Carruthers Creek.

The spatial pattern observed in cover quality can be partially explained by the composition of sediment at each site. For example, the DCrest sites show a greater percentage of unembedded cover compared to any of the other sites. This can be attributed to the increased amount of interstitial spaces due to the increased percentage of pebbles and cobbles.



***Bars correspond to second X axis.**

Figure 6: Mean particle size and % composition in the riverine habitat (2003-2015)



*Bars correspond to second X axis.

Figure 7: Particle size and composition of sediments by site (2015 and 2016)

3.1.4 Instream Barriers

Instream barriers to fish passage were not assessed in this study, however a survey of natural and anthropogenic barriers was undertaken in 2016 in the watershed. Detailed results of this assessment can be found in TRCA's *Carruthers Creek Watershed Plan: Aquatic Crossing and Barrier Assessment Report*, 2017. The key findings of the assessment were as follows:

- A number of structures and crossings throughout Carruthers Creek watershed were identified during 2016; however the majority did not present a physical barrier to fish passage. The exceptionally dry year during which the survey was undertaken meant that data were collected during the "worst case scenario", when even minor barriers may be viewed to restrict fish passage.

- The highest proportion of barriers found to physically impede fish passage were "natural" barriers – debris jams or beaver dams. The higher concentrations of such structures were in the lower reaches of Carruthers Creek, south of Highway 401 and in the mid-reaches, south of Taunton Road.

The 2016 assessment identified a total of 77 major anthropogenic barriers (e.g., those associated with major capital infrastructure) which included road and railway crossings. Seven were determined to be barriers to fish species, however this number is expected to be lower during normal seasonal and baseflow conditions. A total of seven barriers (combination of road and pedestrian crossings) were found to be associated with Deer Creek Golf Course, located between Taunton Road and 5th Concession Road. This section of Carruthers Creek contained the highest frequency of crossings and barriers identified through the 2016 survey.

Results from the Dendritic Connectivity Index (DCI) assessment undertaken based on the barriers data suggest that less than 10% of the watershed segments are structurally connected and that the entire watershed has less than 20% connectivity between stream segments. These data should be treated with caution since one of the variables used to calculate the DCI is baseflow and, as stated previously, 2016 was a very dry season which would have affected the "permeability" values assigned to each barrier. It is suggested that the DCI assessment be used to examine the relative connectivity between parts of the watershed.

3.1.5 Instream Vegetation

Many stream systems support aquatic communities that can include a wide diversity of macrophytes, mosses, and algae. The type, abundance, and community composition of aquatic vegetation is highly dependent on various physical and chemical factors including instream sediments, nutrient availability, light penetration, and stream flows. Instream vegetation was assessed based on seven categories: filamentous algae, non-filamentous algae, grass, moss, macrophytes, watercress, and terrestrial plants. The proportion of each vegetation type was determined for each site.

Vegetation diversity varied between the years sampled and also spatially between sites. During the 2003 to 2006 period, the dominant aquatic vegetation type was moss. By 2009 moss made up only 7.1% of vegetation within the sites sampled throughout the watershed. Algae became the dominant vegetation type in 2009 and this trend continued through 2016 (Figure 8). It is not clear from the data if this shift was an actual change in the community dominance, or was a result of misidentification of the vegetation type (e.g., moss *versus* algae).

Algae continue to be the dominate vegetation type at all sites, irrespective of site location, with the exception of DCrest 7, which was predominantly moss and macrophytes. Several of the DCrest sites (DCrest 2, 5, 6, 7) showed the presence of watercress which is indicative of groundwater upwelling. DCrest sites were found to have a higher proportion of aquatic macrophytes compared to the other sites, and in general had a higher proportion of all seven types of vegetation types compared to other sites sampled in the watershed (Figure 9).

Sites located in the lower portion of the watershed, between Kingston Road and the coastal marsh (CC001WM, CC002WM) had little to no aquatic vegetation present during the 2015 sample. This is not unexpected and is substantially due to the sediments present at these sites (comprised of primarily silts and sands) and the depth and flow regimes in these locations.

The type of aquatic vegetation is a function of several abiotic variables, one being sediment composition. Sites such as CC001WW or CC002WM which are dominated by fine sediment such as silt or fine sand (Figure 7) have an almost nonexistent vegetation community as the sediment poses difficulty for rooted vegetation to establish. The surface area of fine sediment also limits the establishment of moss or algae, furthermore its size contributes to its lack of weight which allows it to be dislodged and entrenched in flow, thus increasing turbidity. Turbid waters typically have less vegetation as turbidity decreases light penetration and thus prevents macrophytes from photosynthesising (Wetzel, 2001). The DCrest sites have an increased proportion of cobbles compared to the other riverine sites (Figure 7). Cobbles provide a surface area on which algae and moss can establish, they are also heavy enough to withstand certain flow velocities, thus allowing rooted vegetation to be established and not become dislodged downstream during periods of increased flow.

Another variable which affects aquatic vegetation is water quality, specifically the input of nutrients like phosphorus and nitrogen (Hutchinson, 1973; Schindler, 1974). Common sources of phosphorus and nitrogen are fertiliser and sewage. The DCrest sites have an increased proportion of all seven types of vegetation compared to the other sites. Increased aquatic vegetation at these sites can partially be explained by their sediment composition, but may also be due to increased nutrient loading resulting from golf course fertilisation practices.

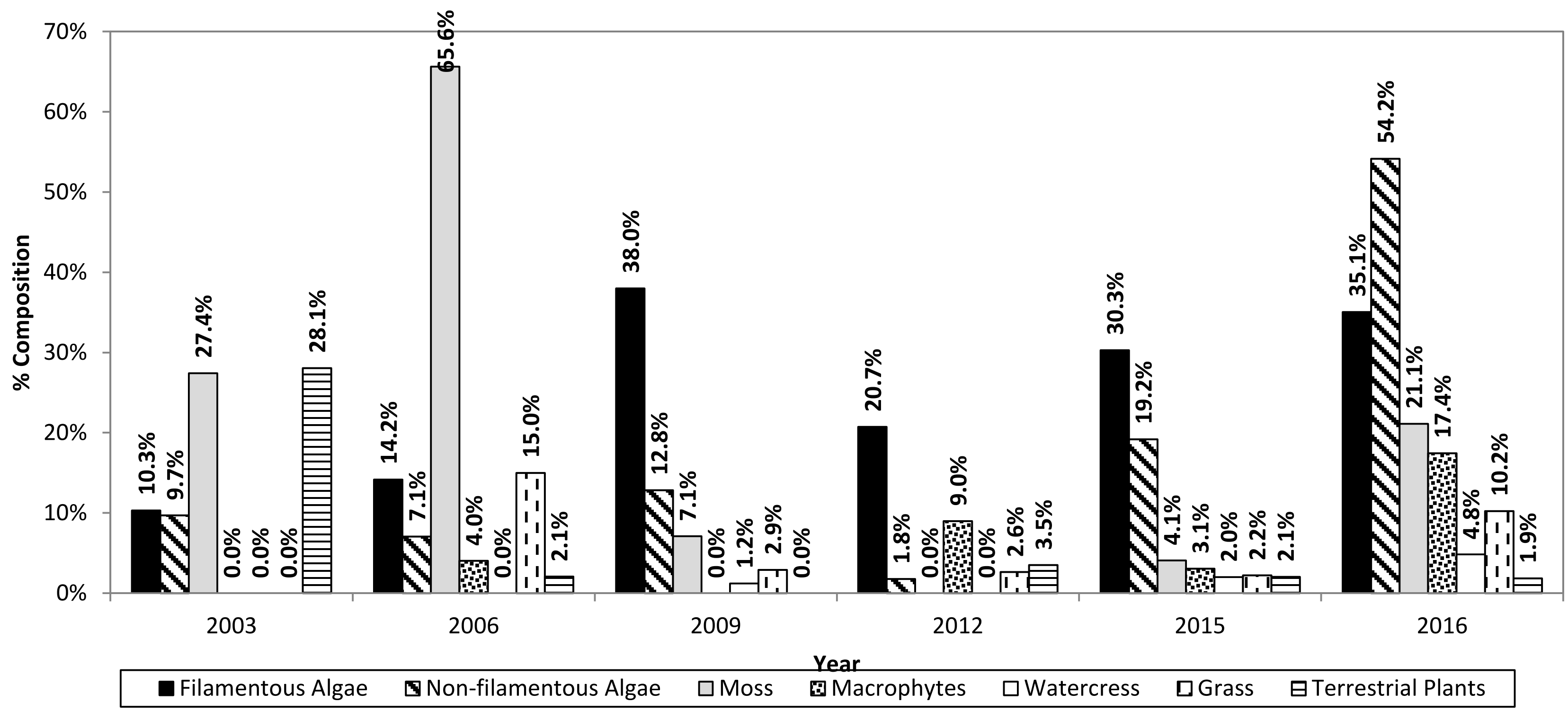


Figure 8: Composition (%) of vegetation type found in Carruthers Creek sites (2003-2016)

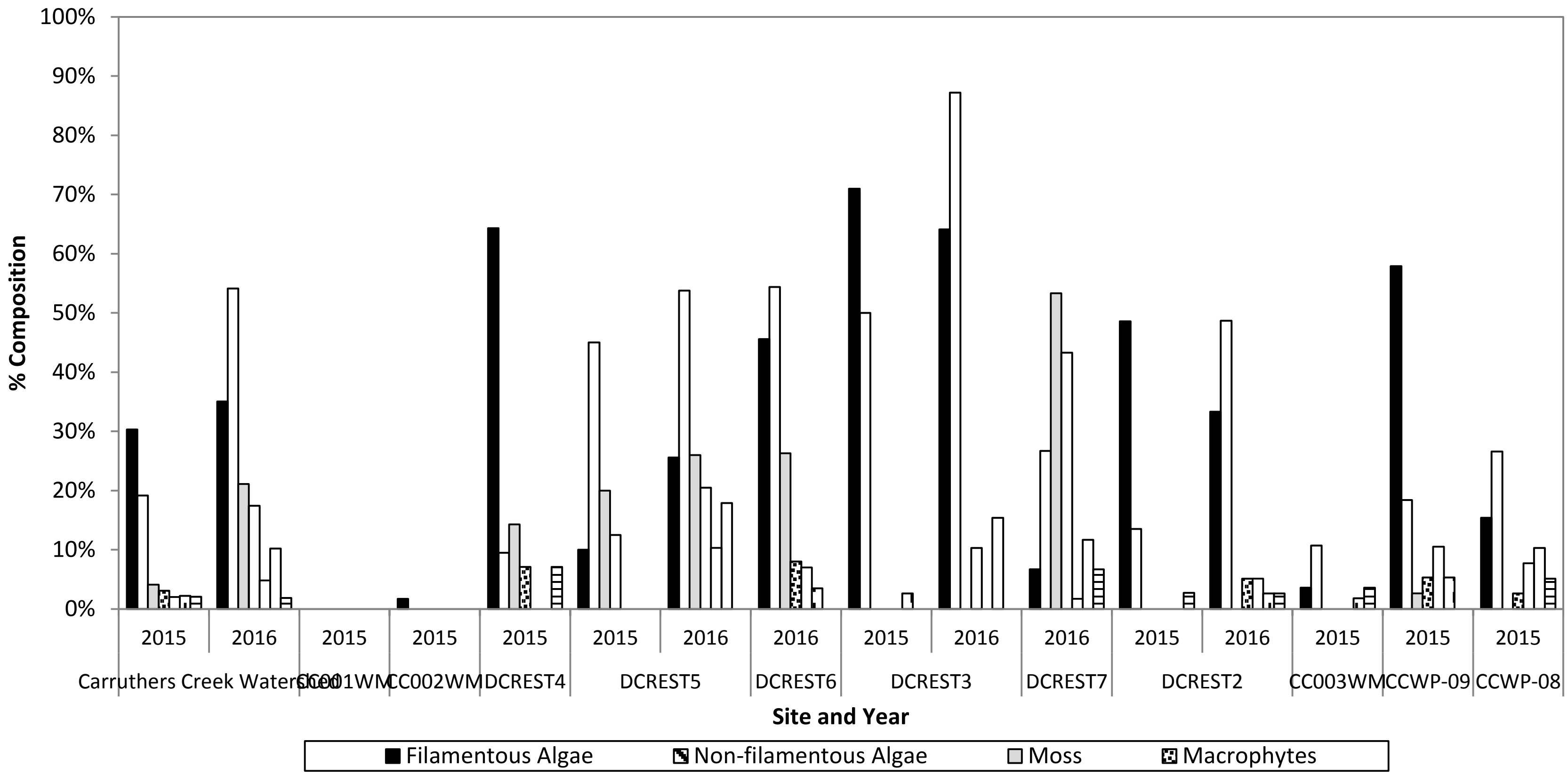


Figure 9: Composition of vegetation type by site (2015 and 2016)

3.2 Stream Temperature and Thermal Stability

Many aquatic organisms are highly dependent on the temperature of the water they inhabit, as a result the diversity and abundance of species found in a stream system can be associated with the thermal range and stability of their aquatic habitat. Monitoring water temperatures can also highlight the influences of groundwater or runoff in the form of stormwater and help determine their effect on the aquatic communities present.

Stream temperature was monitored at 15 sites in Carruthers Creek watershed, and includes data collected through the RWMP (3 sites), and 12 additional sites sampled in 2000 in support of the FMP, and again in 2015 specifically for this watershed Characterization report (Table 1).

3.2.1 Temporal Trends

Stream temperature fluctuates seasonally and between years and is directly influenced by climate (air temperature and precipitation) and groundwater inputs. Comparison of Environment Canada air temperature and precipitation data to a 10 year average revealed that certain years can be considered abnormal in terms of air temperature and total precipitation (Table 4). The data revealed that most years following a winter with low amounts of snow fall (2002, 2005, 2007, 2011 and 2013) result in air temperatures within the 10 year average. This pattern of low snowfall with the following year having normal air temperatures appears to repeat on a two to three year cycle. More so, abnormally warm years (2001, 2006, 2010, 2012, and 2016) are usually preceded by abnormally high amounts of precipitation the year before with the exception of 2006 and 2016 (**Table 4**).

Based on the datasets used in this study, the warmest mean stream temperatures in Carruthers Creek were experienced during 2006, 2013, and 2016 (Table 5) while the coolest water temperatures on record were observed in 2012. With the exception of 2013, air temperatures in 2006, 2012 and 2016 were above the 10 year average. Total precipitation in 2006 and 2013 was also above normal (Table 4). The greatest range of water temperature fluctuation (maximum and minimum temperatures) was experienced during 2016, which was a warm drought year.

For all years of sampling the warmest stream temperatures are experienced through the months of June, July, and August, where maximum air temperatures ranged from 25°C to 31°C. These are also the months that typically experience the warmest air temperatures and lowest precipitation levels. During the same time period, minimum water temperatures have ranged from 8.94°C to 17.58°C, while mean water temperatures ranged from 16.63°C to 22.38°C (Table 5). A summary of the monthly average, minimum, and maximum water temperatures is found in **Appendix C**.

Table 4 - Yearly mean air temperature and total yearly precipitation

Year	Mean Temperature (°C)	Total Rain (mm)	Total Snow (cm)	Total Precipitation (mm)
2000	7.2	798.6	184.8	975.1
2001	8.8	648.5	104.7	744.8
2002	8.7	610.7	145.1	760.4
2003	7.2	755.1	156.7	914.3
2004	7.5	621.7	129.0	742.3
2005	8.3	609.0	179.4	775.4
2006	9.1	886.9	68.4	944.0
2007	8.2	472.4	162.2	621.0
2008	7.7	760.9	292.0	1009.8
2009	7.4	845.4	154.7	975.5
2010	9.0	808.2	80.6	858.1
2011	8.6	865.9	154.7	982.0
2012	9.9	809.0	86.7	878.7
2013	7.9	875.3	180.4	1026.7
2014	6.9	817.1	175.9	962.8
2015	8.1	660.0	88.3	729.2
2016	9.3	550.9	162.7	688.3
10-Year Average (2006-2015)	**8.3**	**780.1**	**144.4**	**898.8**

Green shading represents below 10 year average. Red shading represents above 10 year average.

Table 5 - Mean, minimum, and maximum water temperature summarised by year and month

Month	Statistics	2003	2006	2009	2012	2013	2014	2015	2016
January	**Mean**					**4.44**			**4.31**
	Min					4.01			4.10
	Max					4.74			4.93
February	**Mean**								**4.92**
	Min								4.01
	Max								7.68
March	**Mean**					**4.03**		**4.39**	**5.40**
	Min					4.01		4.10	4.00
	Max					4.09		4.73	10.55
April	**Mean**		**11.87**		**8.05**	**8.22**	**7.59**	**7.59**	**8.29**
	Min		8.67		4.10	4.01	4.01	4.01	4.00
	Max		15.44		17.48	13.93	11.32	14.80	16.25
May	**Mean**		**14.63**	**14.34**	**14.41**	**16.67**	**14.12**	**14.66**	**14.16**
	Min		8.52	9.37	4.83	10.86	6.91	4.04	4.69
	Max		26.74	20.14	24.93	22.15	23.21	24.55	27.96
June	**Mean**	**18.75**	**19.99**	**18.13**	**17.52**	**18.99**	**19.11**	**16.63**	**17.66**
	Min	14.34	13.21	11.72	10.75	15.03	15.76	8.94	9.87
	Max	23.91	26.13	25.42	27.67	23.21	24.97	24.63	29.75
July	**Mean**	**19.69**	**22.38**	**19.41**	**20.31**	**22.04**	**20.24**	**19.17**	**20.37**
	Min	16.22	17.30	15.57	13.94	17.58	16.39	11.78	13.40
	Max	25.24	28.25	23.10	28.56	27.06	25.99	28.76	30.92
August	**Mean**	**20.13**	**21.00**	**21.19**	**18.71**	**20.42**	**19.74**	**18.81**	**21.27**
	Min	14.47	15.51	14.71	11.24	16.37	16.14	11.59	14.63
	Max	24.63	29.54	26.49	27.96	24.17	23.38	27.02	31.76
September	**Mean**	**16.78**	**16.88**	**17.49**	**15.06**	**17.30**	**17.11**	**17.43**	**17.24**
	Min	13.77	10.98	11.33	8.68	13.11	12.01	10.17	9.28
	Max	18.91	21.80	22.62	25.42	23.42	22.75	27.83	29.18
October	**Mean**		**10.42**	**9.49**	**10.48**	**12.74**	**12.06**	**10.48**	**13.80**
	Min		5.10	4.21	4.31	5.80	8.44	4.01	6.27
	Max		16.96	13.65	18.14	18.01	17.44	17.86	20.62
November	**Mean**		**5.37**	**7.26**	**6.60**	**6.23**	**6.35**	**7.47**	
	Min		4.01	4.10	4.10	4.01	4.01	4.00	
	Max		7.32	10.36	11.43	9.78	8.98	14.23	
December	**Mean**						**4.37**	**5.50**	
	Min						4.10	4.00	
	Max						4.93	10.06	

3.2.2 Spatial Trends

Spatial patterns in water temperature also exist, the data revealed a decrease in water temperature from the lower reaches of the watershed towards the headwaters (Figure 10). This pattern is most evident in the months of May to August as the water temperature warms relative to the ambient air temperature and when the effect of any groundwater influence or thermal buffering becomes most apparent. Not surprisingly, during the months of October to December water temperature appears to be relatively uniform throughout all sites.

The warmest water temperatures were recorded at site CC001WM, just upstream of the coastal marsh, and the coldest water temperature was recorded at site CCWP-14 which is located upstream of 7th Concession Road on the west branch of the creek. However, statistical differences in water temperatures do not exist between all the sites, for example, the sites situated between CC001WM and CC003WM have similar mean water temperatures. All sites upstream of CC003WM have colder mean water temperatures compared to those downstream (Figure 10). These patterns were observed for all years of data, although graphs were only generated using the 2015 and 2016 datasets. The 2016 graphs can be viewed in **Appendix C**.

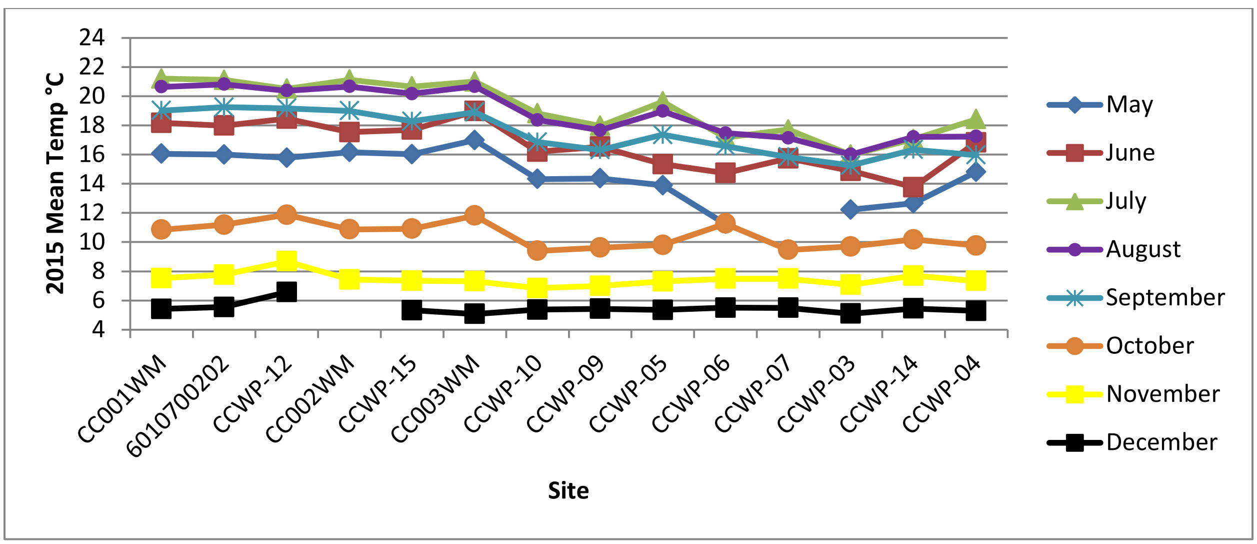


Figure 10: Monthly average water temperature summarised by site (May – December 2015)

3.2.3 Thermal Regime and Stability

Throughout all years of sampling, the majority of sites were thermally classified as cool (Table 6). However, the 2015 data show an almost even split between sites thermally classified as cool (42.86%) or cold (57.14%). 2015 air temperatures fall within the 10 year average, however 2015 similar to 2016 was a drought year (Table 4). The 2016 data show that a number of sites classified as cool in 2015 switched to the thermal classification of warm in 2016 (Figure 11). This can be explained by abnormally warm air temperatures and lack of precipitation during 2016 (Table 4). The sites which shifted from thermally cool to warm are located downstream, including site CC003WM. These are the same sites with significantly warmer mean water temperatures compared to sites upstream of site CC003WM. The thermal classification also shows a similar spatial pattern to that of the water temperature data: moving upstream, the thermal classification changes from warm, to cool, to cold, with the most abrupt change occurring upstream of site CC003WM (Figure 11).

Throughout all years of sampling, the majority of sites were classified as "moderately stable" (Table 6), with the exception of 2014 where there was a split between sites classified as "moderately stable" or "stable". Air temperatures during 2014 were below the 10 year average and precipitation was above the 10 year average. In all years of sampling, thermally unstable sites comprised a maximum of 10% of all sites Table 6). The thermal stability data does not show any apparent spatial trends, although the only two sites classified as "stable" are upstream sites (CCWP-08 and CCWP-03) (Figure 12). These sites are also thermally classified as "cold". In summary, the vast majority of sites in the riverine habitat are classified as "moderately stable" "cool" water sites. Depending on air temperature and amount of precipitation, these sites appear to shift to "moderately stable" "warm" water sites. "Cool" sites which are "moderately unstable" or "unstable" shift to a "warm" thermal regime during abnormally warm and dry climatic conditions. The reverse can also potentially occur if climatic conditions are abnormally cold and wet, however this has not been observed in the dataset. It appears that once a site has a thermal regime of "warm" it does not shift back to being "cool" even if the site is considered "unstable". Hence if the objective is to have cold or cool water habitat it appears that the best way to achieve that is to prevent sites from reaching a thermal classification of warm. However, based on recent climate change and climate warming scenarios this may be difficult to do especially since urbanization also acts to increase water temperatures (Wallace et al., 2013). One way that this can potentially be achieved is by bank vegetation initiative (Mees and Driessen, 2011) which would create shade similar to the type of bank restoration that the DCrest sites experienced. However, this approach neglects to deal with upstream sources of warm water such as storm pond outlets that are heavily associated with modern urbanization and flood mitigation. A full summary of the thermal classification (regime) and stability of each site by year is in **Appendix D**.

Table 6 - Thermal stability and thermal regime of sites (percentage by year)

% Thermal Regime	2003	2006	2009	2012	2013	2014	2015	2016
% Cold	0.00%	0.00%	33.33%	30.00%	0.00%	0.00%	42.86%	25.00%
% Cool	100.00%	0.00%	66.67%	40.00%	0.00%	100.00%	57.14%	66.67%
% Warm	0.00%	100.00%	0.00%	30.00%	100.00%	0.00%	0.00%	8.33%
% Thermal Stability	**2003**	**2006**	**2009**	**2012**	**2013**	**2014**	**2015**	**2016**
% Stable	0.00%	0.00%	33.33%	10.00%	100.00%	50.00%	14.29%	25.00%
% Moderately Stable	100.00%	100.00%	66.67%	80.00%	0.00%	50.00%	85.71%	66.67%
% Unstable	0.00%	0.00%	0.00%	10.00%	0.00%	0.00%	0.00%	8.33%

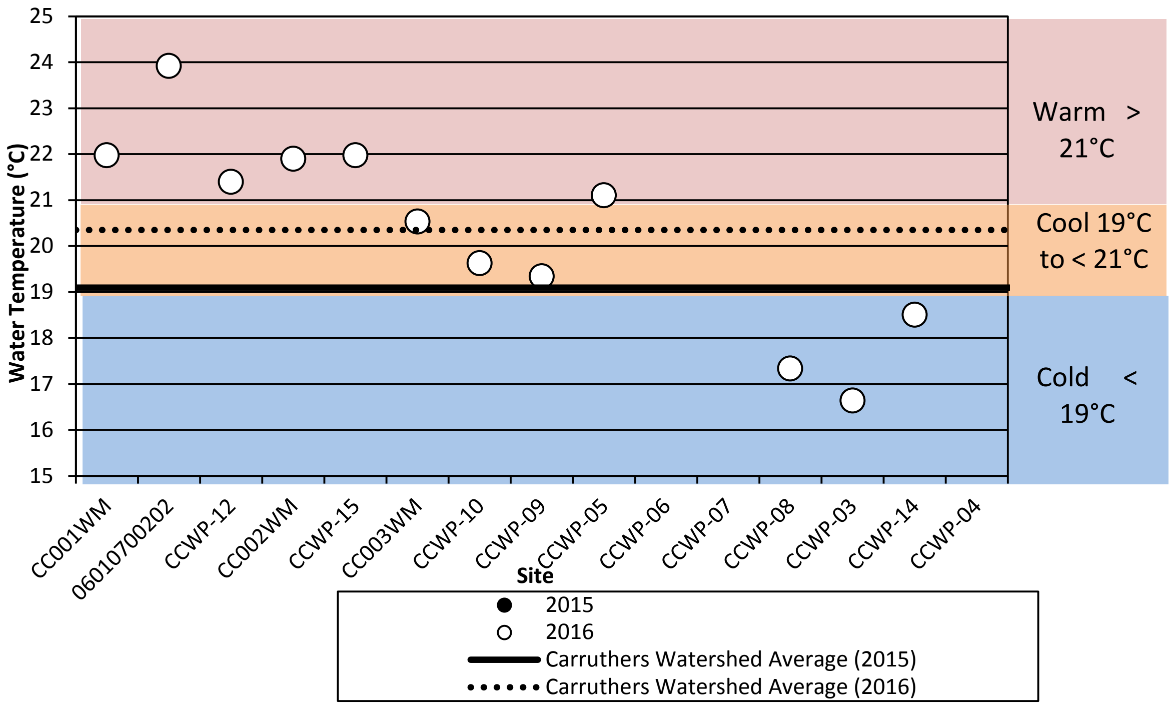


Figure 11: Thermal classification of riverine habitat (2015 and 2016)

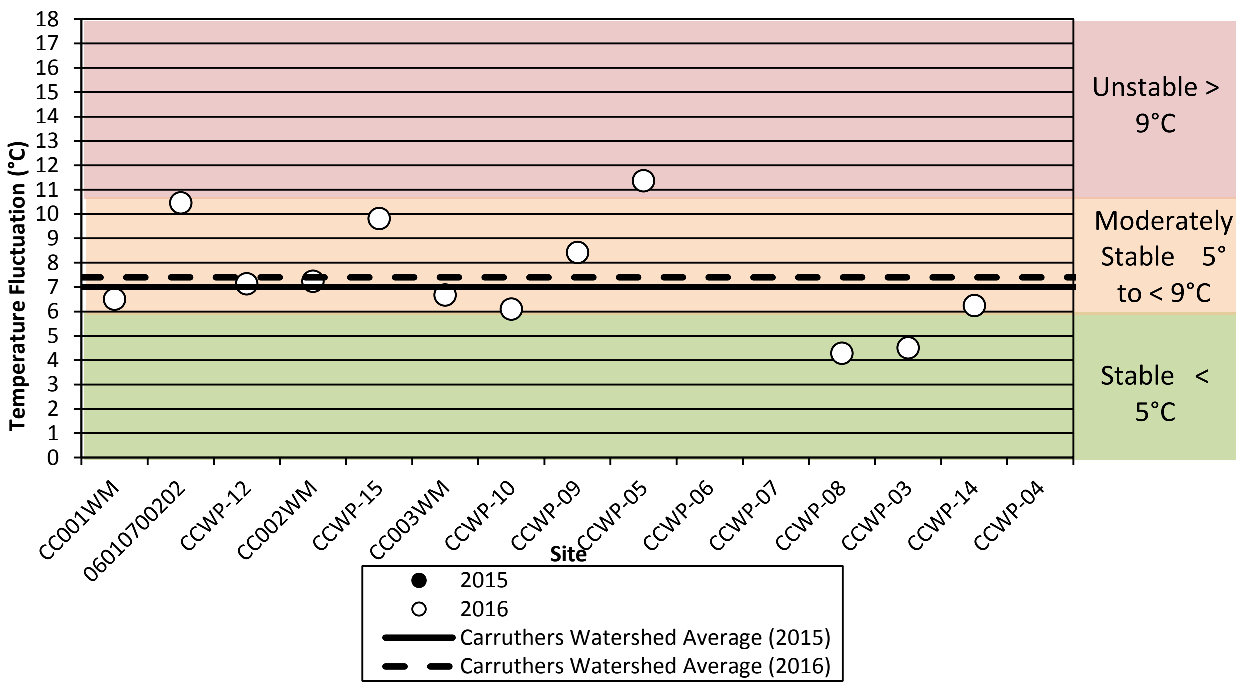


Figure 12: Thermal stability classification of riverine habitat (2015 and 2016)

3.3 Fish Community

Fish community was assessed through 16 sites in Carruthers Creek watershed and included data collected through the RWMP (3 sites), the Deer Creek Golf Course restoration project monitoring (5 sites), plus 8 additional sites originally sampled in 2000 in support of the FMP, and again in 2015 specifically for this watershed Characterization report (Table 1). Data were also included from the Durham Coastal Wetland Monitoring Program, to update the species recently recorded in Carruthers Creek Marsh (CLOCA 2004, 2016)

3.3.1 Fish Species Richness

Species richness is a common measure of biodiversity typically represented as the number of different species in a given unit of area, intended to provide a general assessment of the fish community. Generally, higher species richness occurs in healthier stream systems, however smaller streams including headwater systems tend to have lower species richness.

Based on current data (2015/16), a total of 21 fish species were recorded in Carruthers Creek watershed including 17 species found at riverine monitoring locations and 13 species in the coastal marsh (Table 7). This total across both habitat types is 3 more species than reported in the FMP (based on 2000-2002 data), but is less than half of the species richness compared to other historic data records. Of the 21 species currently identified, 13 belong to the cool water thermal guild and 8 to the warm water thermal guild.

The most common and abundant fish present in the riverine habitat include Blacknose Dace, Creek Chub, Johnny Darter, and White Sucker. Three of these species (Blacknose Dace, Creek Chub, White Sucker) are also among the most common species found across TRCA jurisdiction and appear to be relatively well-adapted to surviving in a variety of habitat conditions including varied thermal, water quality, and flow regimes (Wallace *et al.*, 2013). TRCA sampling conducted between 2003 and 2014 indicates that these are among the most abundant species present in Carruthers Creek and throughout TRCA's nine watersheds (TRCA, 2011).

No cold water species were captured during sampling in 2015-2016. It should be noted that the majority of TRCA sampling activities represent monitoring efforts which are typically undertaken in the summer months during predominantly baseflow conditions. As a result, datasets may not capture migrating fish which enter the system during the spring or summer months. It is typical however, to capture young-of-the-year cold water fish species (e.g., salmonids) if they are present or reproducing in the tributary.

Historically (1976-2014), a total of 49 fish species were reported to be present in the riverine and coastal marsh habitats. The majority of these fish were native cool water species (26 cool water, 16 warm water, 7 cold water). Fifteen species identified in the FMP including American Brook Lamprey, Banded Killifish, Blacknose Shiner, Brook Trout, Central Mudminnow, Longnose Sucker, Rainbow Darter, Rock Bass, Rosyface Shiner, Sand Shiner, Stonecat, Threespine Stickleback, Walleye, White Bass, and White Perch have not been captured since 1999 (Table 7).

The majority of the fish captured (historically and presently) were native species, one of which is listed as endangered and is protected under the Endangered Species Act (Redside Dace). This native cool water fish species continues to be sparsely captured in the watershed's riverine habitat.

Currently (2015-2016), two invasive fish species (Common Carp and Round Goby) were captured in the watershed. However, it is unclear if actually three invasive fish species (Common Carp, Goldfish, Round Goby) exist in the watershed, as Goldfish was last captured in 2003 in the coastal marsh. Historically, the one invasive species present was Common Carp. The earliest record of Round Goby dates back to 2012, as it was captured in the riverine habitat. Fish presence data summarised by year is available in **Appendix C.**

Table 7 - Fish species found in Carruthers Creek watershed (current and historic)

Thermal Guild	Fish Species Common Name	Riverine Habitat		Coastal Marsh		Total Species	
		Historic* 1976-2012	2015-2016	Historic 1976-2014	2015-2016	Historic 1976-2014	2015-2016
	Lamprey Family						
Cold	American Brook Lamprey	x				x	
	Bowfin Family						
Warm	Bowfin			x		x	
	Herring Family						
Cold	Alewife			x		x	
Cool	Gizzard Shad			x	x	x	x
	Salmon Family						
Cold	Rainbow Trout	x				x	
Cold	Brook Trout	x				x	
	Smelt Family						
Cold	Rainbow Smelt			x		x	
	Mudminnow Family						
Cool	Central Mudminnow	x		x		x	
	Pike Family						
Cool	Northern Pike	x		x	x	x	x
	Sucker Family						
Cool	White Sucker	x	x	x	x	x	x
Cold	Longnose Sucker			x		x	
	Minnow Family						
Warm	Sand Shiner	x				x	
Cool	Redside Dace	x	x			x	x
Warm	Rosyface Shiner	x				x	

Thermal Guild	Fish Species Common Name	Riverine Habitat		Coastal Marsh		Total Species	
		Historic* 1976-2012	2015-2016	Historic 1976-2014	2015-2016	Historic 1976-2014	2015-2016
Warm	Spotfin Shiner	x		x		x	
Cool	Spottail Shiner			x		x	
Cool	Northern Redbelly Dace	x	x	x		x	x
Cool	Longnose Dace	x	x			x	x
Warm	Common Carp	x		x	x	x	x
Cool	Common Shiner	x	x	x		x	x
Cool	Creek Chub	x	x	x		x	x
Cool	Emerald Shiner	x		x		x	
Warm	Fathead Minnow	x	x	x	x	x	x
Cool	Finescale Dace	x					
Cool	Golden Shiner	x		x	x	x	x
Warm	Goldfish			x			
Cool	Brassy Minnow	x				x	
Warm	Bluntnose Minnow	x	x	x	x	x	x
Cool	Blacknose Dace	x	x	x		x	x
Cool	Blacknose Shiner			x		x	
	Catfish Family						
Warm	Stonecat	x				x	
Warm	Brown Bullhead	x	x	x	x	x	x
	Freshwater Eel Family						
	Killifish Family						
Cool	Banded Killifish	x		x		x	
	Stickleback Family						
Cool	Threespine Stickleback	x				x	
Cool	Brook Stickleback	x	x			x	x
	Temperate Bass Family						
Warm	White Perch	x		x		x	
Warm	White Bass	x		x		x	
	Sunfish Family						
Warm	Smallmouth Bass	x		x		x	
Warm	Pumpkinseed	x	x	x	x	x	x
Cool	Rock Bass	x		x		x	
Warm	Largemouth Bass	x	x	x	x	x	x

Thermal Guild	Fish Species Common Name	Riverine Habitat		Coastal Marsh		Total Species	
		Historic* 1976-2012	2015-2016	Historic 1976-2014	2015-2016	Historic 1976-2014	2015-2016
Warm	Bluegill			x		x	
Cool	Black Crappie	x		x		x	
	Perch Family						
Cool	Walleye	x				x	
Cool	Tessellated Darter	x	x			x	
Cool	Rainbow Darter	x				x	
Cool	Yellow Perch	x	x	x	x	x	x
Warm	Logperch	x		x	x	x	x
Cool	Johnny Darter	x	x	x		x	x
	Sculpin Family						
Cold	Mottled Sculpin	x				x	
	Goby Family						
Warm	Round Goby	x	x	x	x	x	x
Species Richness		**42**	**17**	**35**	**13**	**49**	**21**

During 2015 and 2016, the riverine habitat had an average of 5.3 and 7.4 species present per site respectively. Sites associated with Deer Creek Golf Course (DCrest) had approximately 1 to 2 more species present compared to other sites (Figure 13). The DCrest sites generally have more cover and more aquatic vegetation than the other sites. Sediment sizes are also larger at the DCrest sites compared to others with higher proportions of cobbles (Figure 7).

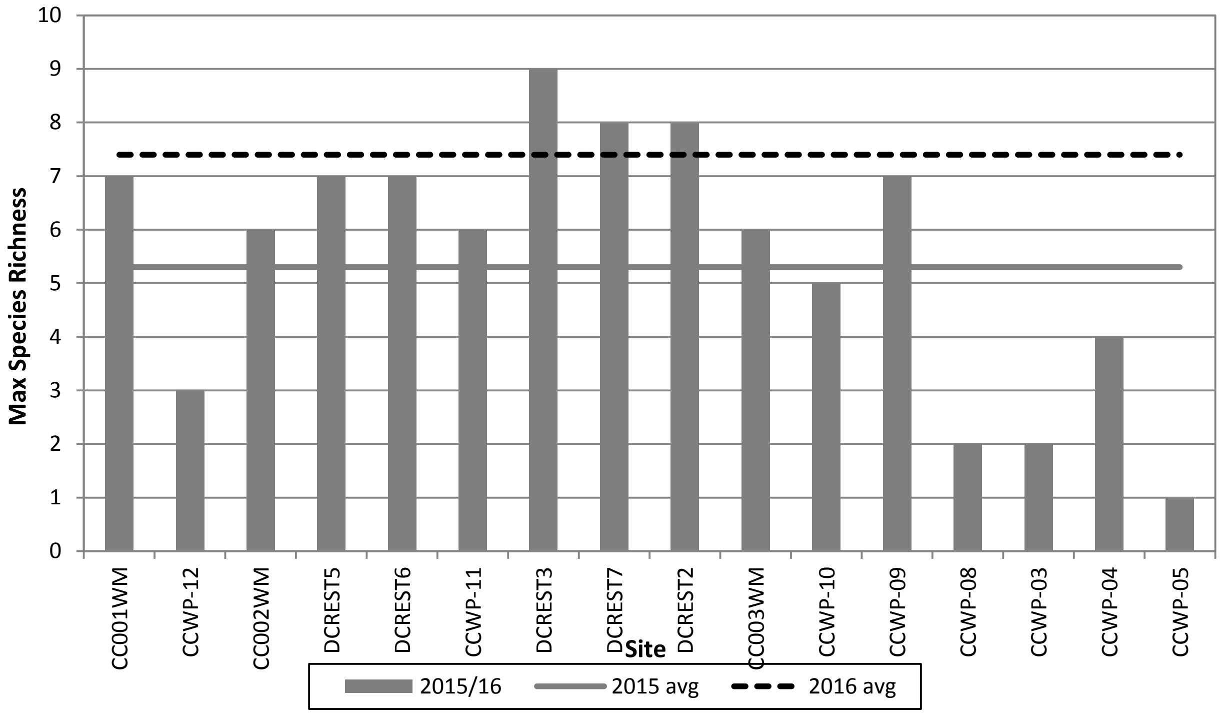


Figure 13: Maximum species richness by site sampled (2015 and 2016)

Lowest fish species richness occurred at sites CCWP-05, CCWP-08, and CCWP-03, where only one to three species were captured in 2015 (Figure 13). All are sites with small catchments which drain agricultural lands. These sites were generally shallow and it is expected that they may have been dry at one point during the year, hence the low species richness. Typically, sites with smaller drainage areas, shallower depth, and more homogenous habitat are expected to have lower species biodiversity (Steedman, 1988).

One additional site in the lower portion of the watershed (CCWP-12) is located in a park and appears to have high anthropogenic disturbance based on the amounts of trash present at the site. The drainage area directly upstream of this site is mainly urban residential and commercial/industrial. The aquatic habitat and community associated with sites draining urban land are typically associated with lower species diversity, increased number of tolerant species, poorer water quality, increased stream temperatures, and a flashier hydrograph (Wallace *et al.*, 2013).

3.3.2 Temporal Changes in Fish Community

Fish diversity in Carruthers Creek followed a bimodal trend of decreasing then increasing biodiversity in the watershed. Diversity in the watershed decreased from 2000 to 2005. However, from 2006 through to 2016, fish biodiversity increased to the point where species richness in 2016 was almost as high as in 1987 (Figure 14).

Historically (1976-1999), as reported in the FMP, fish species richness in the riverine habitat was 36 compared to 17 in 2015-2016 (Table 3). It is unclear whether this was a real phenomenon or if the higher riverine species richness values are simply due to higher effort related to sampling and a broader and more diverse spatial distribution of sampling sites and sampling techniques historically employed. Sampling effort and methodology have been consistent since the inception of the RWMP through the use of single pass electrofishing following the OSAP methodology, and therefore the increase in riverine fish species richness between 2005 and 2016 is a good news story (Figure 14).

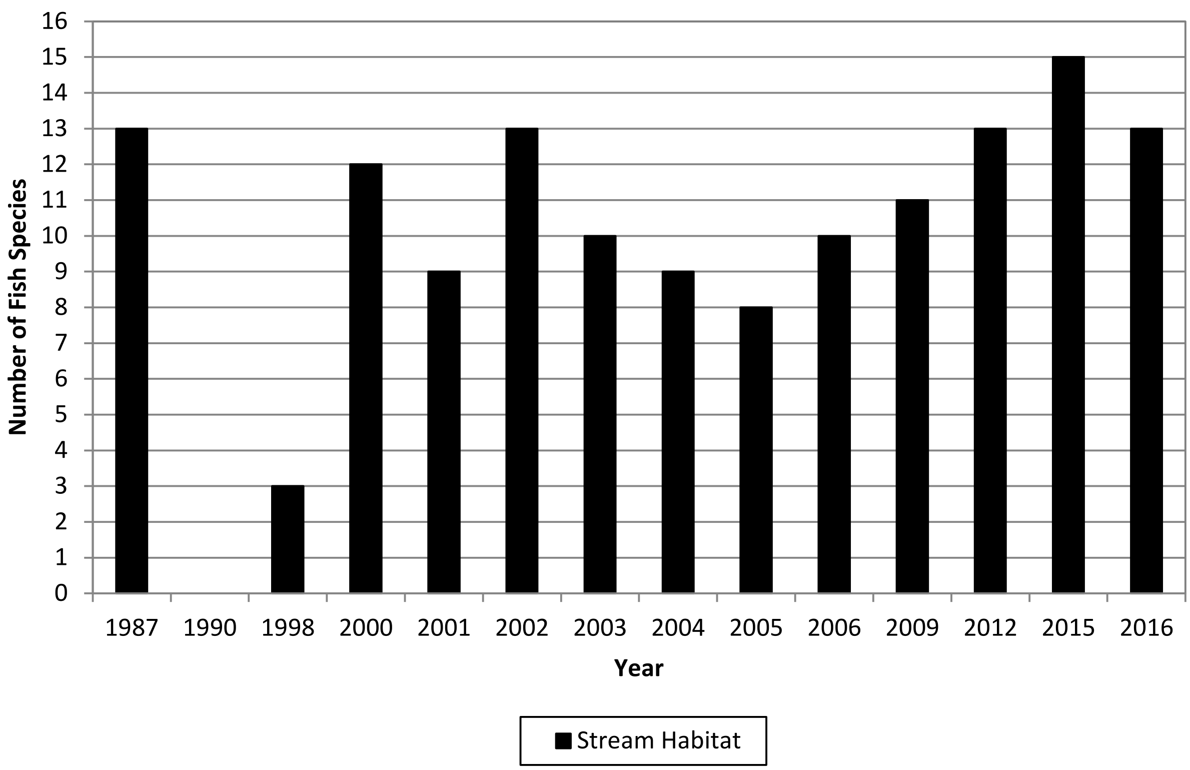


Figure 14: Fish species richness in the Carruthers Creek Watershed by year since 1987

3.3.3 Fish Species Origin

Classification of fish species into origin categories was undertaken based on Mandrak and Crossman (1992) which identifies species a being native, non-native, invasive, or stocked (*i.e.*, introduced).

More than 95% of all fish captured in the riverine habitat of Carruthers Creek were native species. In 2012 and 2015, very small proportions of invasive fish species were found. This is attributed to the presence of Round Goby captured at CC001WM, which is the RWMP site closest to Lake Ontario. Rainbow Trout, a stocked species, was captured in 2012 (Figure 15).

The following sections relating to fish species origin and fish thermal guilds are based on data collected from RWMP, CCWP, and DCrest sites which were used for the riverine habitat analysis. In order to standardise the data, analysis was based on catch-per-unit-effort (CPUE) results. As a result, the OMNRF historical data could not be used for this analysis due to inconsistency in sampling methods and effort.

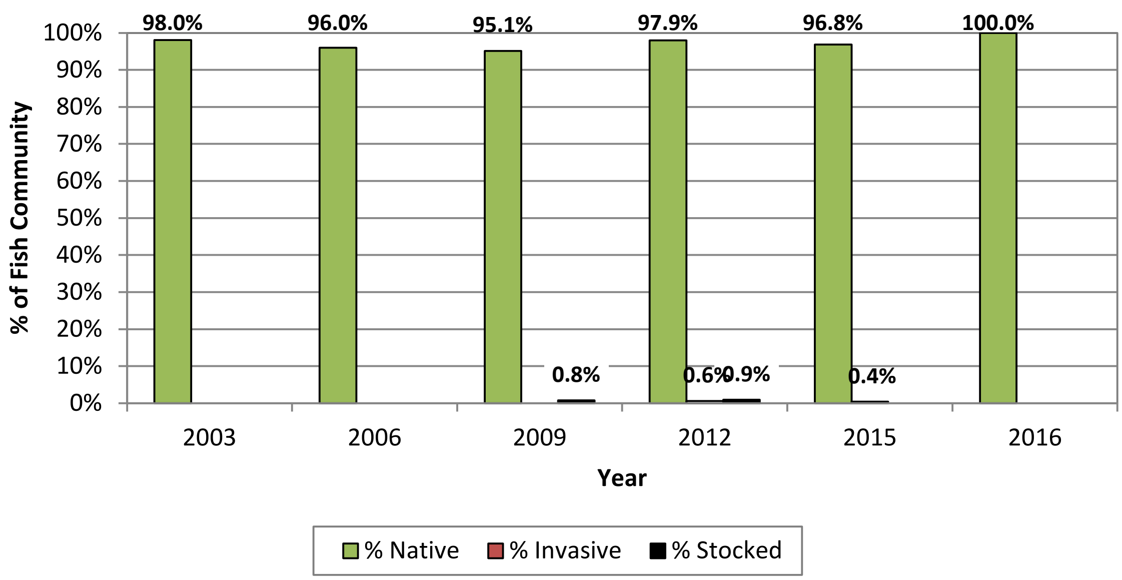


Figure 15: Proportion (%) of community attributed to species origin (based on CPUE)

3.3.4 Fish Thermal Guilds

Thermal guilds represent an association or assemblage of fish species based on their preference and tolerance for specific thermal conditions. These conditions usually reflect important temperature ranges for spawning, rearing, foraging, and other aspects of their life cycle. Although many species can survive or tolerate temperatures outside of their thermal guild for periods of time, this designation associates fish species to their preferred known temperature regime and is important for planning and regulatory purposes. Designation of fish species by thermal guild was based on the Ontario Freshwater Fishes Database (Eakins, 2002) and included cold, cool, and warm water designations.

The most abundant fish found in all datasets were cool water species (*i.e.*, belonging to the cool water thermal guild). This is not surprising since the majority of species recorded through the RWMP in all nine TRCA watersheds have been cool water species (TRCA 2011).

Since 2003 the percentage of fish attributed to the cool water guild has increased, while the percentage of warm water fish has decreased. Rainbow Trout, a stocked salmonid, was captured in 2009 and 2012 and is responsible for the slight proportion of cold water species recorded (Figure 16) in Carruthers Creek. No other cold water species were captured in the riverine habitat during recent sampling.

Spatially, there was a decrease in warm water species moving upstream from the coastal marsh where the fish community is increasingly dominated by warm water species (Figure 17).

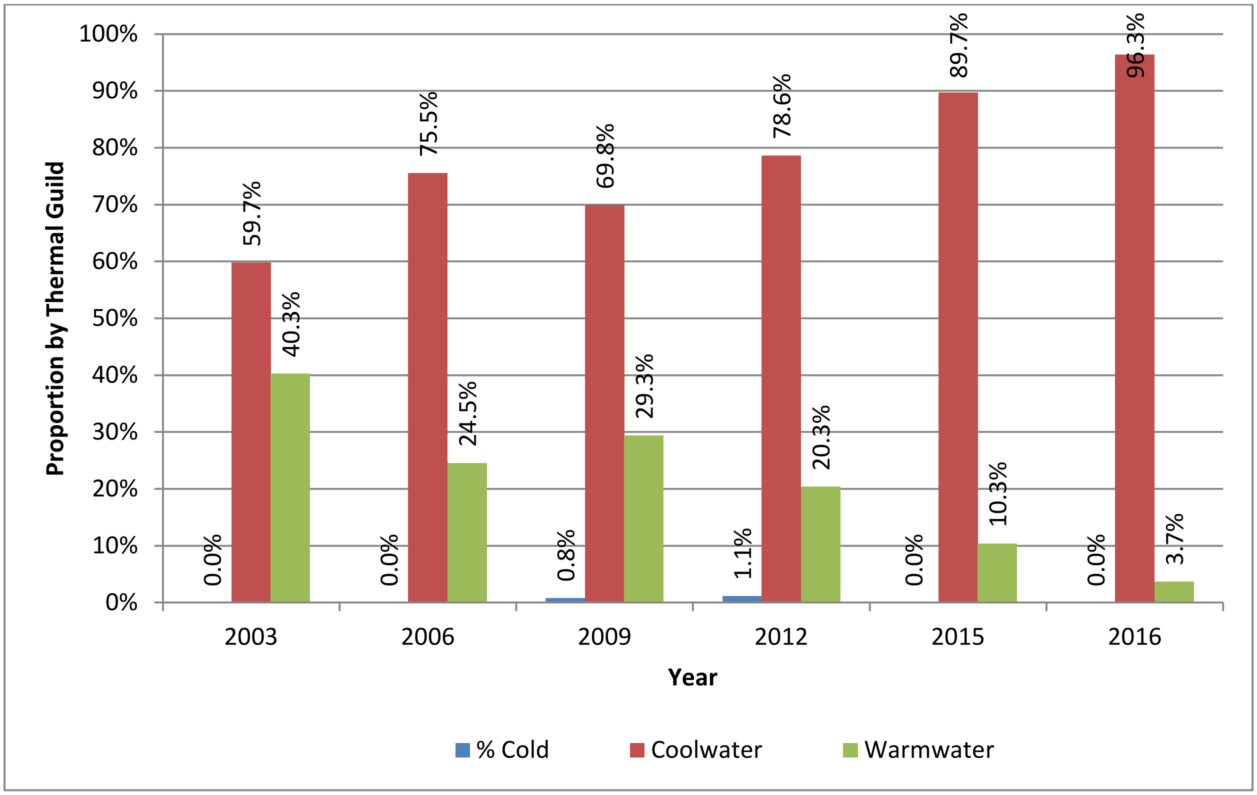
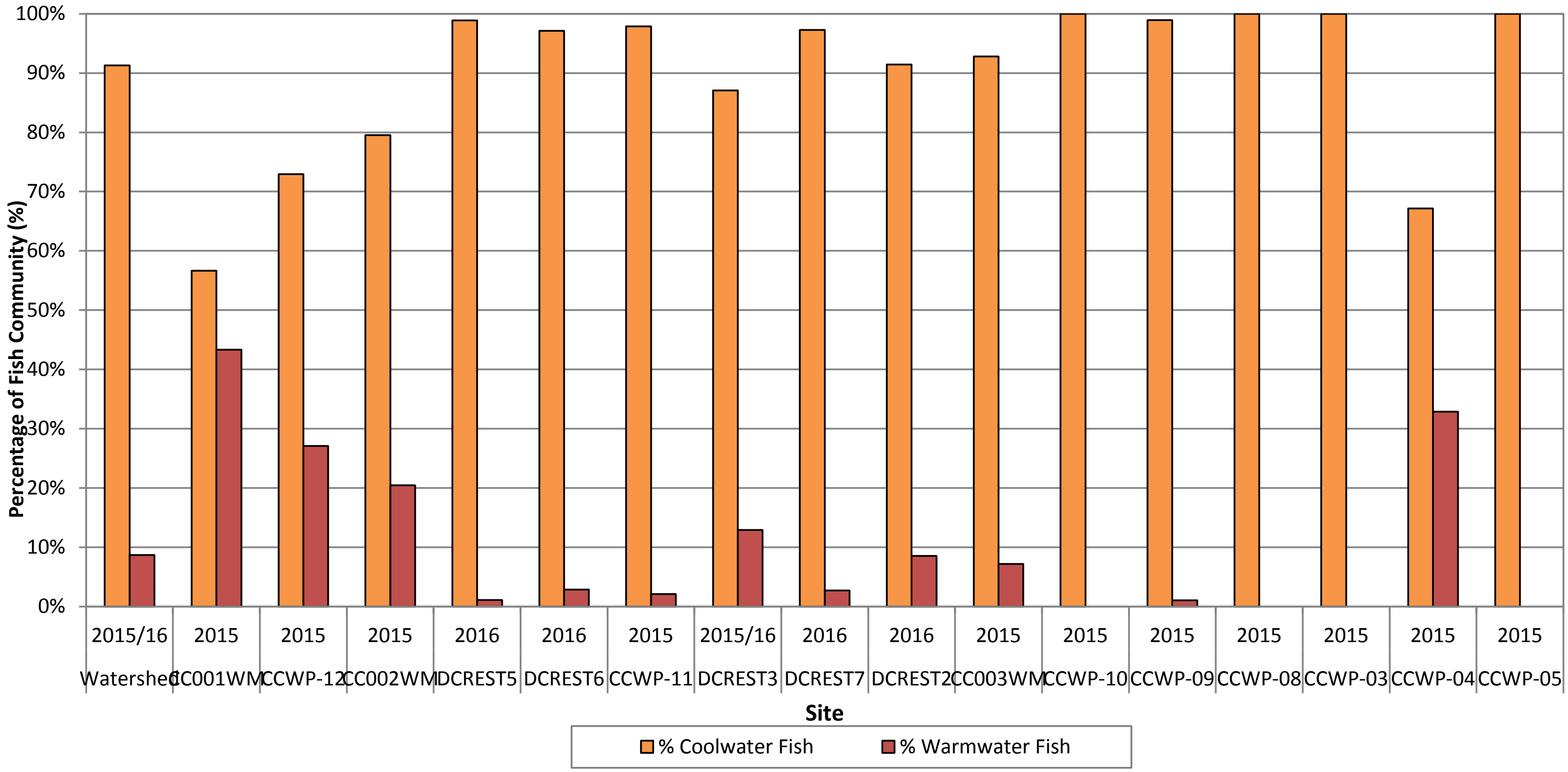


Figure 16: Proportion (%) of fish community attributed to each thermal guild (2003-2016) based on CPUE



*Sites displayed in order from downstream to upstream. Data based on fish CPUE

Figure 17: Proportion (%) by site of fish community attributed to each thermal guild (2015-2016). Data based on fish CPUE.

3.3.5 Community Composition

Catch-per-unit-effort (CPUE) is a metric used to estimate the abundance of fish per unit of area per time needed to sample that area (CPUE = Abundance / (Area / Time)). Large values of CPUE indicate large population size since many fish are captured per unit of area and time. CPUE was also assessed among three thermal guilds (cold water, cool water, warm water), and four origin categories (native, invasive, non-native, stocked).

CPUE increased in 2015-2016 compared to 2003-2014 (Table 8), however this was found to be non-significant (based on t-test). As mentioned above, the majority of species captured in the riverine habitat are native cool water species. During 2015 and 2016, the most abundant fish present include Blacknose Dace, Creek Chub, Johnny Darter, and White Sucker. All four of these species are native cool water species. Blacknose Dace and White Sucker have doubled their CPUE based on most recent data compared to 2003-2014, whereas, Creek Chub quadrupled its CPUE during the same time period. Of the fish species captured between 2003 and 2014, three species (Black Crappie, Northern Pike, Rainbow Trout) were not captured during 2015 and 2016 sampling. However, Brown Bullhead, Largemouth Bass, and Redside Dace were captured during 2015/16 but not during 2003 to 2014 (Table 8).

Table 8 - Total catch and CPUE of Carruthers Creek riverine fish species

Origin	Thermal Guild	Species Common Name	Species Scientific Name	Trophic Guild	Parameter	2003 2014	2015 2016
Native	**Cool water**	Black Crappie	*Pomoxis nigromaculatus*	Invertivore/ Carnivore	**Total Catch**	1	0
					CPUE	0.11	
		Blacknose Dace	*Rhinichthys atratulus*	Invertivore	**Total Catch**	151	518
					CPUE	14.61	39.53
		Brook Stickleback	*Culaea inconstans*	Planktivore / Invertivore	**Total Catch**	6	72
					CPUE	0.82	3.38
		Common Shiner	*Luxilus cornutus*	Invertivore	**Total Catch**	19	1
					CPUE	1.81	0.07
		Creek Chub	*Semotilus atromaculatus*	Invertivore/ Carnivore	**Total Catch**	144	775
					CPUE	15.40	63.82
		Johnny Darter	*Etheostoma nigrum*	Invertivore	**Total Catch**	323	384
					CPUE	36.61	31.18
		Johnny/Tessellated Darter	*E. nigrum/E. olmstedi*	Invertivore	**Total Catch**	0	20
					CPUE	0.00	2.67
		Longnose Dace	*Rhinichthys cataractae*	Invertivore	**Total Catch**	13	9
					CPUE	1.71	0.99
		Northern Pike	*Esox lucius*	Carnivore	**Total Catch**	1	0
					CPUE	0.14	
		Northern Redbelly Dace	*Chrosomus eos*	Invertivore/ Planktivore	**Total Catch**	2	17
					CPUE	0.25	0.52
		Redside Dace	*Clinostomus elongatus*	Invertivore	**Total Catch**	0	48
					CPUE	0.00	0.75
		White Sucker	*Catostomus commersonii*	Invertivore / Detritivore	**Total Catch**	32	69
					CPUE	3.69	6.66
		Yellow Perch	*Perca flavescens*	Carnivore	**Total Catch**	2	1
					CPUE	0.24	0.15
	Warm water	Bluntnose Minnow	*Pimephales notatus*	Detritivore	**Total Catch**	92	6
					CPUE	9.79	0.64
		Brown Bullhead	*Ameiurus nebulosus*	Invertivore / Herbivore/ Carnivore	**Total Catch**	0	2
					CPUE	0.00	0.24
		Fathead Minnow	*Pimephales promelas*	Detritivore /Invertivore	**Total Catch**	87	85
					CPUE	9.79	1.53
		Largemouth Bass	*Micropterus salmoides*	Invertivore/ Carnivore	**Total Catch**	0	8
					CPUE	0.00	1.01
		Pumpkinseed	*Lepomis gibbosus*	Invertivore/ Carnivore	**Total Catch**	77	79
					CPUE	8.28	7.16
Stocked	**Cold water**	Rainbow Trout	*Oncorhynchus mykiss*	Invertivore/ Carnivore	**Total Catch**	4	0
					CPUE	0.44	
Invasive	**Cool water**	Round Goby	*Neogobius melanostomus*	Benthic Invertivore	**Total Catch**	1	3
					CPUE	0.13	0.40
Sum					**Total Catch**	**995**	**2097**
					CPUE	**130.83**	**160.73**

3.3.6 Index of Biotic Integrity

The Index of Biotic Integrity (IBI) score is a multivariate measure of stream quality which uses fish fauna as a biological indicator. Nine measures, or metrics, of fish community composition grouped into four categories (species richness, local indicator species, trophic composition, fish abundance) are used to derive the IBI score. The IBI score is used to rate the overall health of the stream (site) on a scale of 9 (poor) to 45 (very good). For more information on this metric please refer to Steedman, 1988.

The Carruthers Creek riverine habitat received an average IBI score of 26 which is considered “fair”. Scores have remained in the fair category based on data collected throughout 2003 to 2015 time period (Figure 18). The 2016 data showed an IBI score of 31 (good category), however this due to the fact that only DCrest sites were sampled during that year.

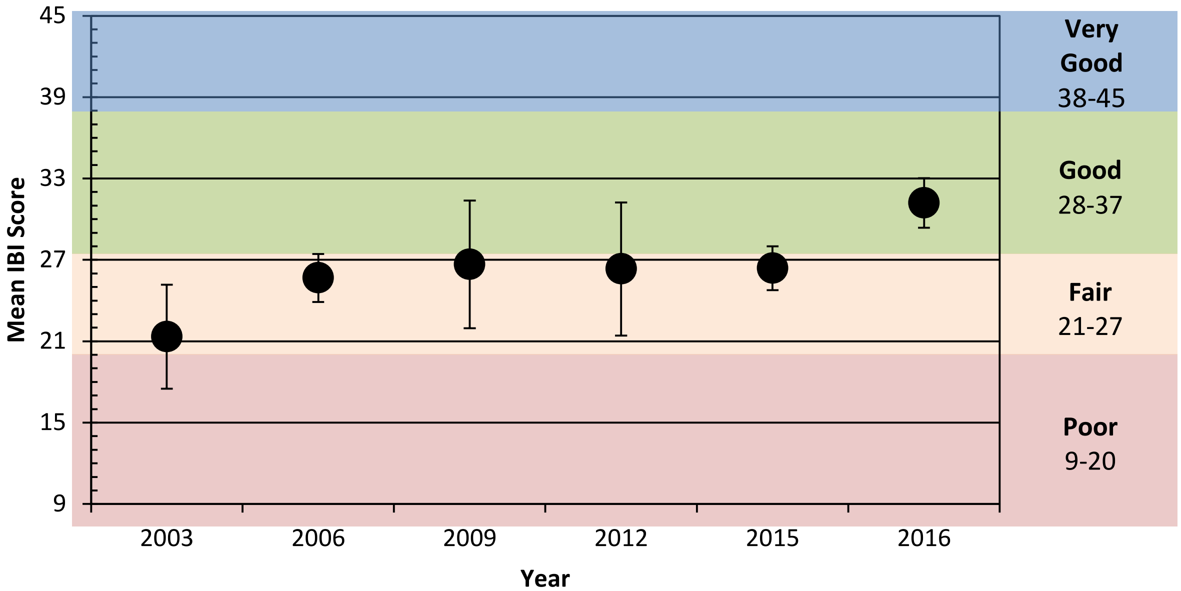


Figure 18: Carruthers Creek IBI Score by year (2003-2016)

Spatially, IBI scores increased farther upstream into the DCrest sites, with the exception of the two sites farthest upstream (CCWP-08 and CCWP-03) which showed a lower IBI score. Upstream sites and sites downstream of Kingston Road (CC001WM, CCWP-12, CC002WM), which are closer to the coastal marsh, had IBI scores below the watershed mean IBI scores calculated using the 2015 and 2016 datasets (Figure 19).

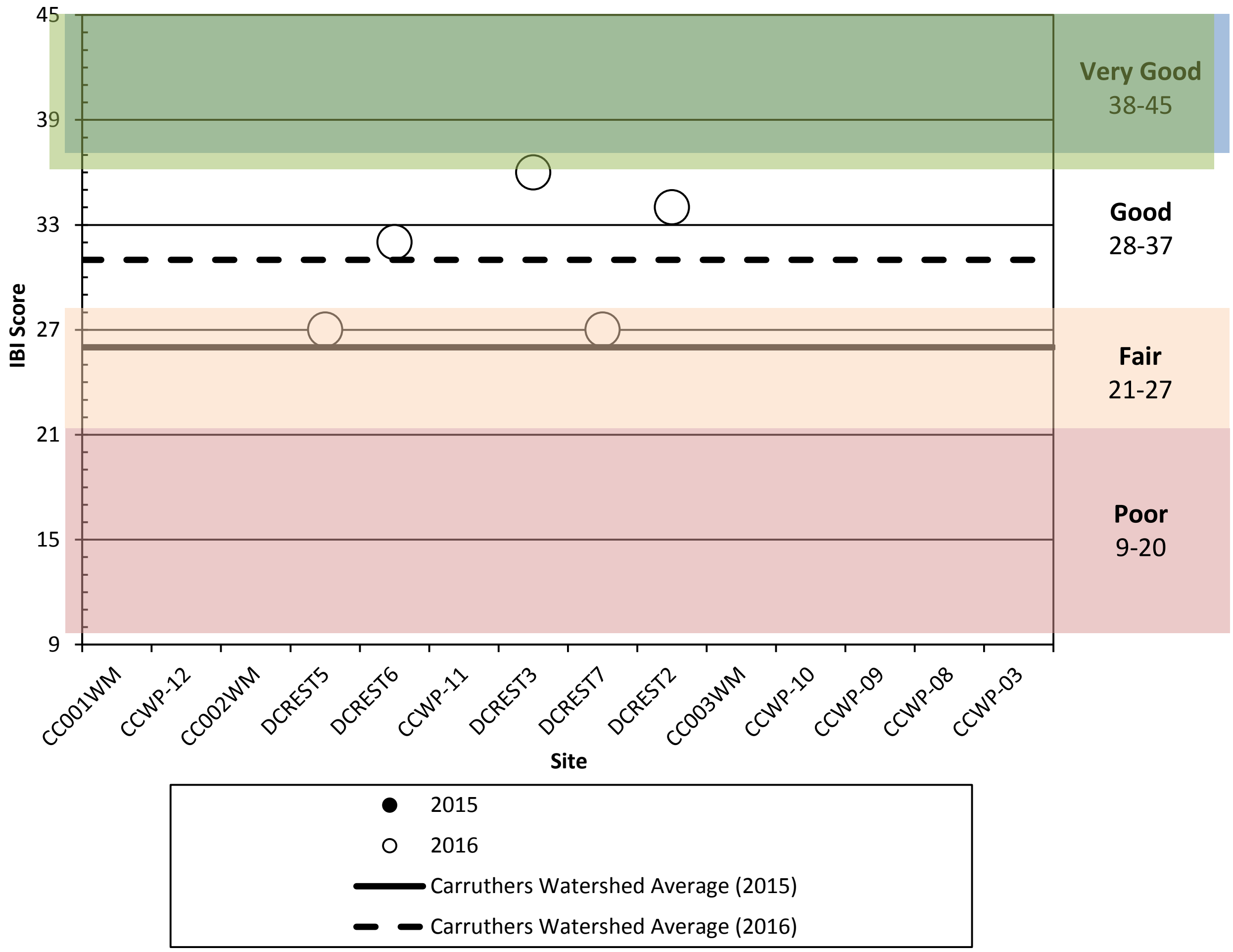


Figure 19: Carruthers Creek IBI Score by site (2015 and 2016)

Decreased drainage area and channel widths/depths moving upstream act to decrease species richness which in turn affects the IBI score (Steedman 1988). The site's drainage area also became dominated by agricultural land. In addition, cold water habitats typically have lower species richness compared to warm water habitats of equal drainage area (Dodds and Whiles 2010), hence the IBI score is often inflated for warm water lotic systems compared to their cold water counterparts.

It is recommended that when using the IBI, one compares sites of similar drainage area and thermal category in order to evaluate their health. Sites CCWP-08 and CCWP-03 both have a drainage area of less than 5 km^2 and are both dominated by a cool water fish community (Figure 19), which is also generally true for all other riverine sites sampled in the Carruthers Creek watershed (2003-2016). Both of these sites received a poor IBI score due to their low species richness (two species, Figure 13). Species richness contributes more to the overall IBI score at sites with a small drainage area, as the expected number of species is also low. Inclusion or exclusion of one species at such sites can mean the difference between a poor or good rating, as opposed to sites where expected species richness is high.

3.3.7 Species at Risk

Currently, Redside Dace is the only species at risk (SAR) found in Carruthers Creek watershed, federally designated by the Canadian Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

Redside Dace have been observed and sampled historically in Carruthers Creek as part of the 2004 FMP, and were captured during the 2015-2016 surveys. Creeks and rivers in the Greater Toronto Area house a large proportion of Redside Dace populations in Ontario, the species is often restricted to the headwaters (OMNRF, 2016). Threats to their population include loss of suitable habitat which is compounded by increased erosion, and sedimentation associated with urban regions and construction sites. To see their prey, Redside Dace require clear water, making them highly sensitive to suspended particles. Based on the capture records, several sections of Carruthers Creek have been designated as critical habitat, and/or occupied reaches, by Fisheries and Oceans Canada in the Recovery Strategy for this species.

3.4 Benthic Macroinvertebrates (BMI)

A well-balanced and functioning biological community is a good indicator of a healthy aquatic system. BMI are bottom-dwelling organisms including aquatic insects, crustaceans, molluscs, and worms that provide an important ecological link between micro-organisms and fish. They are often used in studies to determine water quality because of their abundance, known environmental tolerances, limited mobility, and dependence on the surrounding environment of the stream they live in. 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.

Community characteristics of BMI such as abundance, richness, diversity, evenness, and community composition, are highly dependent on habitat conditions, and in some circumstances, varied climatic conditions between years (temperatures, floods, droughts). BMI can be monitored to determine how habitat quality changes over time. A high abundance of sensitive taxa, such as Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) typically indicates higher water quality, while a high abundance of Chironomidae (midges) and Oligochaeta (worms), considered pollution-tolerant, indicates impaired habitat.

From 2002 to 2016, approximately 18,000 macroinvertebrate organisms representing more than 81 taxa were identified in Carruthers Creek. The family Chironomidae was the most abundant group (24.3%) and was the only taxa group collected at every site (14 stations) sampled since 2002.

3.4.1 Taxa Richness and Community Composition

Taxa richness varied considerably among the years. In 2002, 2005, 2011, 2013, and 2014, taxa richness was above average (n=21). There is no clear temporal trend in taxa richness changes in Carruthers Creek. The fluctuation of BMI taxa richness may be correlated to patterns of seasonal variation or climate conditions (Figure 20). Shannon's Diversity Index and Evenness values indicated that overall richness has also fluctuated but not significantly changed over the years (Table 9).

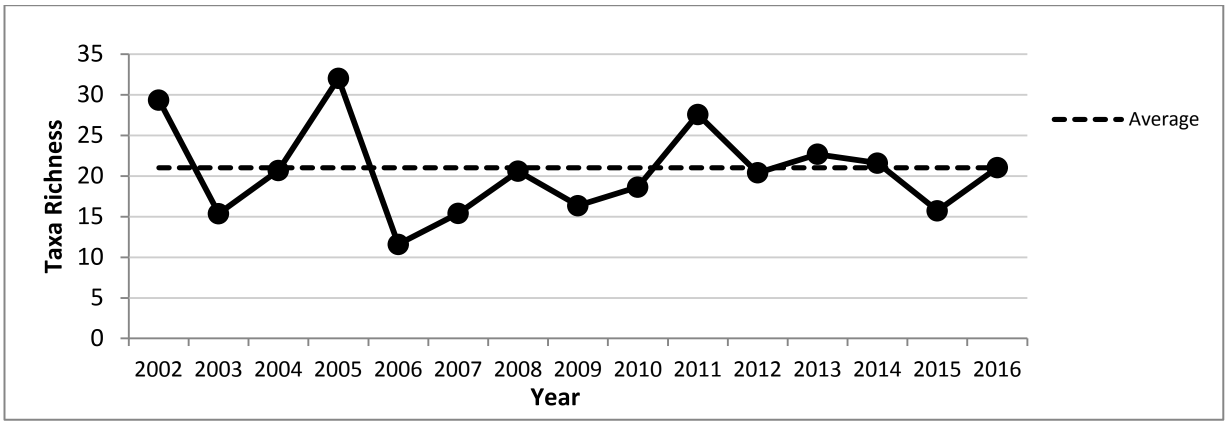


Figure 20: BMI Taxa Richness of RWMP stations in Carruthers Creek (2002 – 2016)

Table 9 - Benthic macroinvertebrate metrics in Carruthers Creek (2002-2016)

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Taxa Richness (modified)	29	15	21	32	12	15	21	16	19	28	21	23	22	16	21
Shannon (H')	2.15	1.54	2.16	2.05	1.52	1.44	1.84	1.55	1.74	2.08	1.83	1.36	1.58	1.29	1.6
Evenness (E)	0.18	0.18	0.36	0.24	0.38	0.25	0.31	0.26	0.29	0.28	0.31	0.13	0.17	0.19	0.17
% EPT	2	<1	10	3	2	<1	3	3	3	1	3	<1	2	1	<1
% OLIGO	8	2	3	13	3	<1	2	4	14	4	2	16	14	13	7
% CHIRON	33	44	35	48	50	55	48	51	50	43	47	64	55	62	54
HBI	6.79	6.65	5.79	6.5	5.69	5.42	5.59	6.15	6.37	5.48	5.29	6.46	6.18	6.55	5.94

= Highest Scores

Overall, the RWMP stations did not support a wide range of EPT taxa, with the highest percentage of EPT (in actuality Ephemeroptera and Trichoptera, since no Plecoptera were found) in 2004 at only 10%. No Plecoptera were found in any of the samples. The complete absence of Plecoptera is not necessarily a cause for concern, as winter stoneflies (Taeniopterygidae and Capniidae) are often absent from BMI collections done in the summer due to the timing of their emergence or hatch (Stark *et al.*, 1998).

Percentages of Chironomidae have significantly (P=0.0016) increased over time, suggesting the enrichment of nutrients, such as phosphorus and nitrogen continues to occur. Relatively low percentages of Oligochaeta are present in Carruthers Creek, the trend also shows that it is on the rise, but not significantly (Figure 21).

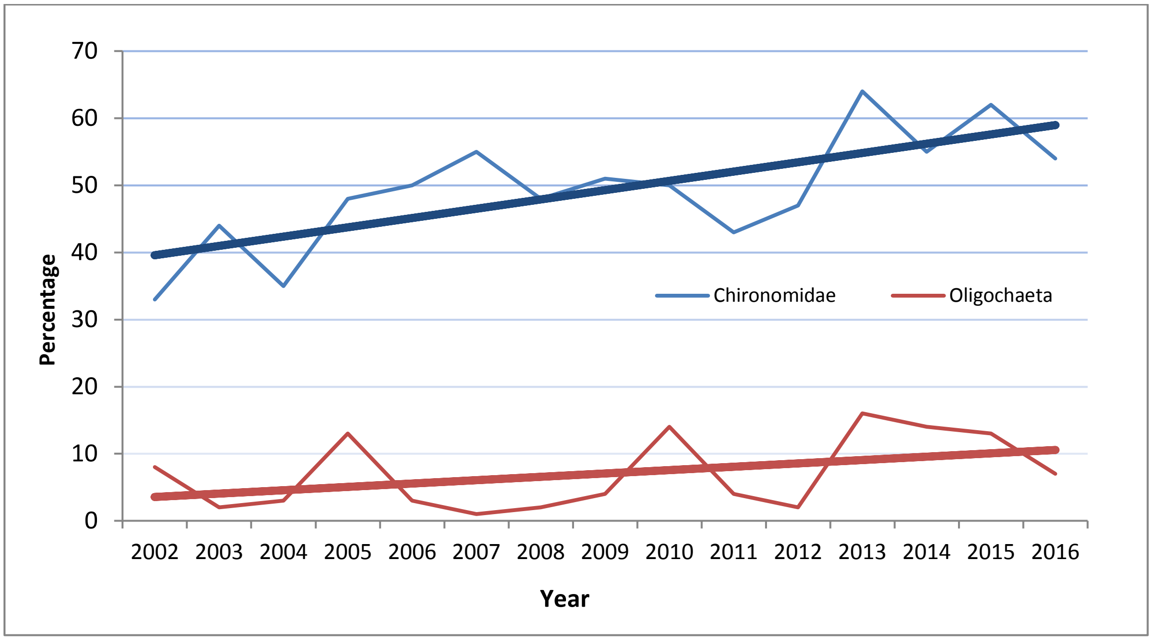


Figure 21: Trends in Percentages of Chironomidae and Oligochaeta in Carruthers Creek (2002-2016)

Taxa richness and per cent EPT data from 2015-2016 indicate a bell curve distribution when graphed by site in order from downstream to upstream (Figure 22). The farthest downstream sites (CC001WM, CCWP-12, CC002WM) and farthest upstream sites (CC003WM, CCWP-10, CCWP-09) had the lowest per cent of EPT amongst all sites and were also below the 2015-2016 per cent EPT mean of 9.89. Downstream sites also had the lowest taxa richness values compared to all other sites.

Additional sampling efforts in 2015 and 2016 resulted in several taxa recorded for the first time. EPT richness had increased as a number of more sensitive taxa (*Chimarra* sp., *Neophylax* sp., stoneflies) were recorded in either the agricultural stations or the golf course stations (DCrest). The DCrest sites showed both the highest per cent of EPT and taxa richness (Figure 22) of the sites sampled. The drainage area of the DCrest sites do not have a large urban contribution and have also been the subject of bank habitat enhancement (live staking) and stream channel restoration (bank protection: log bank protection, live brush layering, and vegetative buttress, hydrolic stone sizing). TRCA restoration efforts and the lack of urban influence have resulted in the DCrest sites having generally 1 or 2 more fish species and higher benthic taxa richness compared to the other sites. This increase in biodiversity in the fish and BMI community can be attributed to a number of factors related to habitat. The DCrest sites generally have more cover and more aquatic vegetation compared to the other sites. The sediment size is also larger at the DCrest sites compared to other sites as there are a greater amount of cobbles as a result of the restoration. This difference in sediment type is also responsible for the DCrest sites having the highest percentage of EPT. This can be attributed to an increased amount of groundwater and interstitial spaces present at the DCrest sites as indicated by an increased percentage of watercress presence.

The increased amount of unembedded cover and interstitial spaces provides more forage and shelter type habitat for EPT and other benthic taxa (Robert, 2003). As BMI are often prey for fish, the increased amount of BMI taxa at the DCrest sites probably also contributes to the increased fish species richness as there is more forage available.

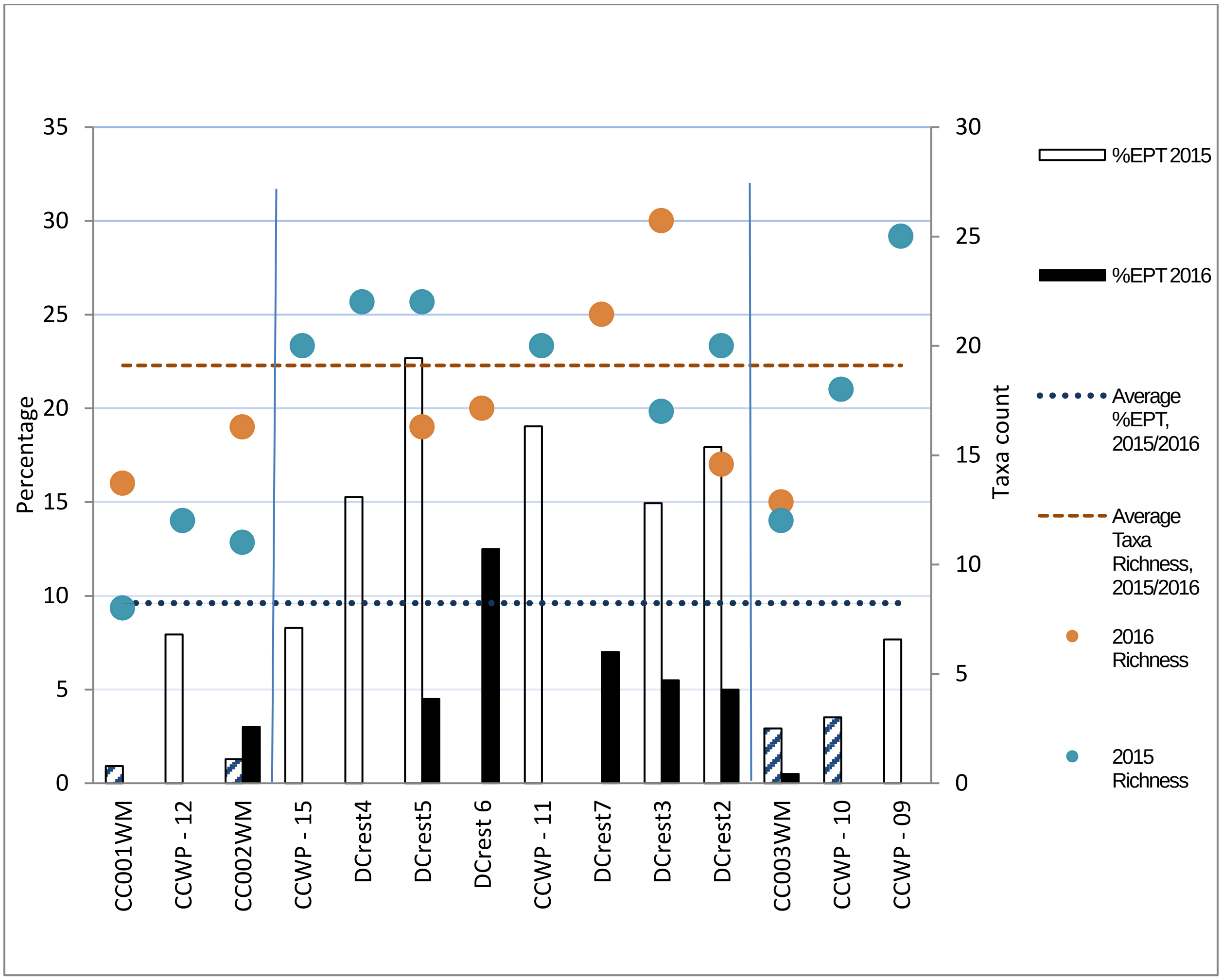


Figure 22: Taxa Richness and EPT Percentage in Carruthers Creek by site (2015 and 2016)

3.4.2 Hilsenhoff Biotic Index (HBI)

Hilsenhoff Biotic Index is calculated based on all taxa collected, and their tolerance values, therefore it is less affected by the population of individual taxon. While a BMI group may be temporarily absent during the time of the year when samples were collected, other taxa with similar tolerance values should still be present. Biotic

Index values ranged from 4.68 (2004) at the mid-stream site (CC002WM) to 7.60 (2002) at the downstream site (CC001WM) (Figure 23). The mean HBI for all Carruthers Creek sites was 6.05, indicating that water quality is fairly poor. The highest HBI values were recorded in 2002 and the lowest in 2012. Generally, all sites experienced a decrease in HBI score, indicating an improvement in water quality conditions, during 2002 to 2007, and then again during 2010 to 2012. From 2007 to 2010, and again from 2012 to 2015, there was an increase in the HBI score, indicating degrading water quality conditions. From 2015 to 2016, sites CC002WM and CC003WM showed a decrease in HBI score. In the same time period, site CC001WM showed an increase in HBI score. In all years of sampling, site CC001WM always scored above the HBI mean and had higher HBI values compared to sites CC002WM and CC003WM (Figure 23). These results are consistent with moderate organic enrichment, which may be attributable to the agricultural land use and urbanization in the watershed.

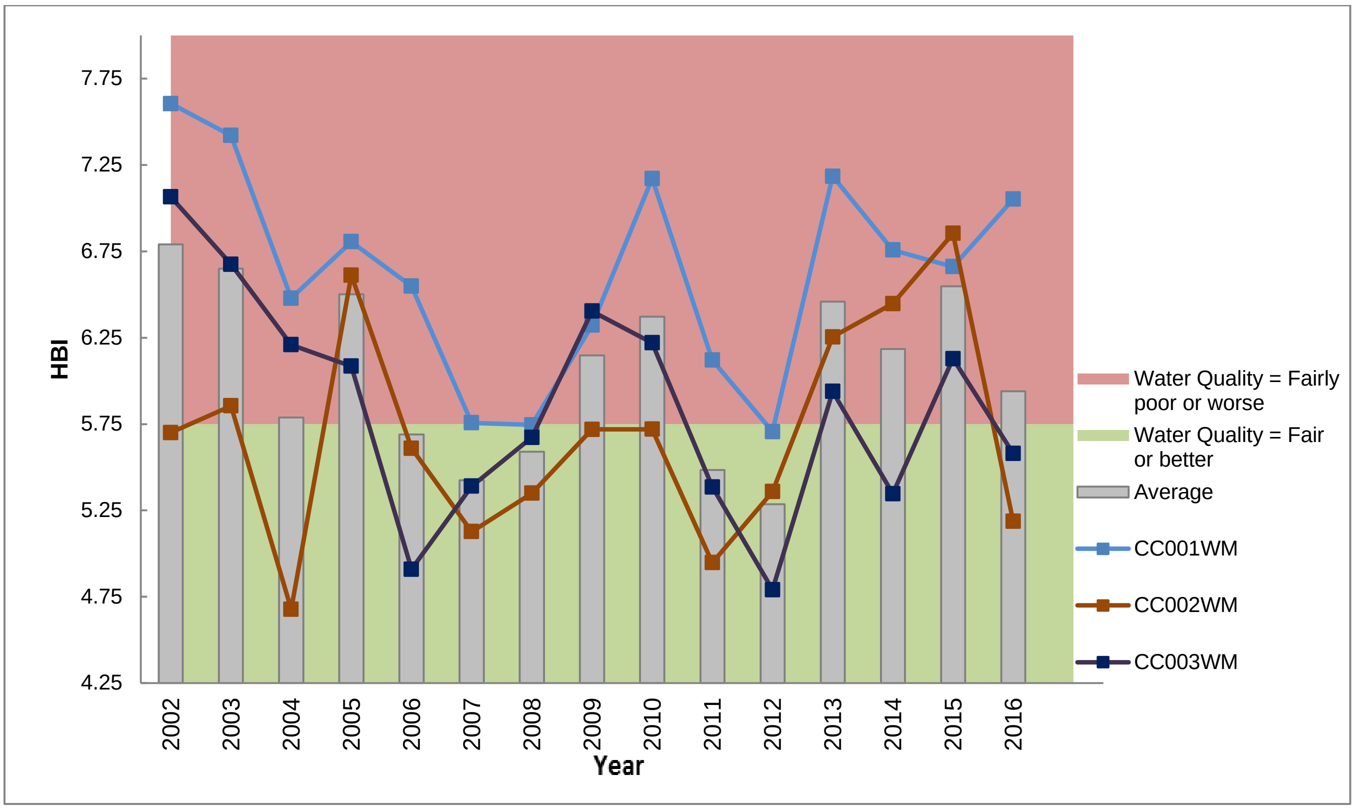


Figure 23: Hilsenhoff Biotic Index (HBI) in Carruthers Creek (2002-2016)

Overall the 2015-2016 HBI score decreased (improved) as one moved upstream. The three sites farthest downstream (CC001WM, CCWP-12, CC002WM) had the highest HBI scores, indicating fairly severe organic pollution conditions. While the lowest HBI scores were attributed to the majority of the DCrest sites (DCrest 5, 6, 7, 3, 2), as well as site CCWP-11 which is located near DCrest sites 6 and 7 (Figure 24).

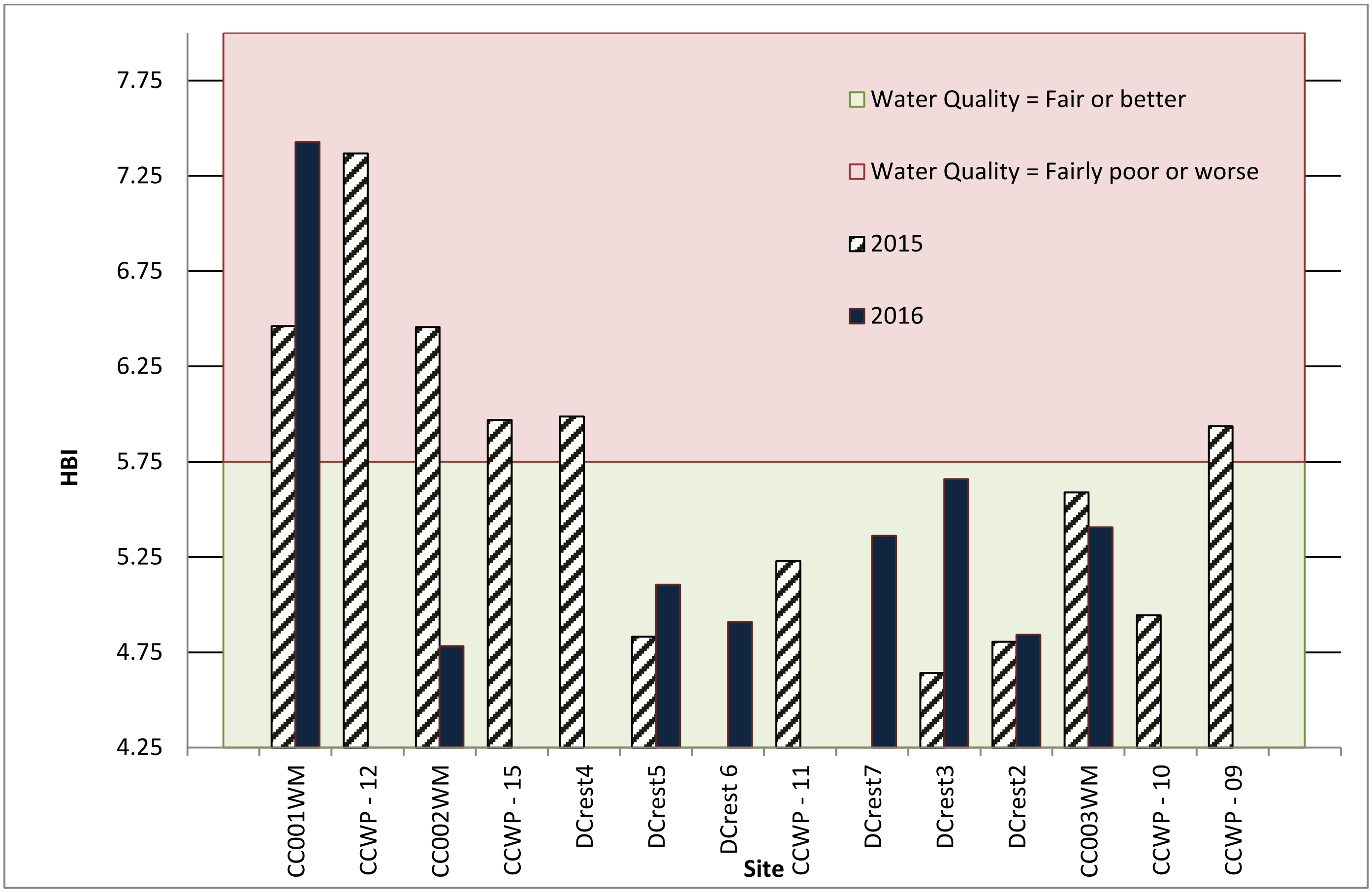


Figure 24: Hilsenhoff Biotic Index in Carruthers Creek by site (2015 and 2016)

3.5 Management Targets

A number of management targets for Carruthers Creek watershed were identified in the 2004 *Fisheries Management Plan*. These targets focused on a variety of physical parameters such as baseflow, water extraction, water quality, instream barriers, riparian vegetation, altered watercourses, and wetlands in the watershed. Specific targets related to the fish community were also identified. The following sections present information that speaks to the status of the fish community targets based on the updated data collected and analysed for this study, including the IBI, and target fish species.

3.5.1 Water Temperature and Fish Thermal Guild

The 2004 FMP identified reaches of the stream habitat as belonging either to a cold or warm water regime and considered to be either thermally stable or fluctuating. This classification was compared to the thermal regime and stability results from the 2015 and 2016 datasets (Table 10). Most sites did not have similar thermal classifications based on the FMP and 2015-2016 data, however sites CCWP-12 and CC003WM, classified by the FMP as warm water with a fluctuating thermal regime, matched the results from 2015-16. Site CCWP-08 was the only site classified as cold water and thermally stable in both the FMP and recent data.

The target for most reaches in Carruthers Creek was previously classified as warm water with fluctuating thermal stability, indicating that the reaches may alternate between warm water or cool/cold water. Most sites were also previously classified as moderately stable. However, recent results indicate that the majority of sites are classified as belonging to the cool water thermal regime. The most evident contrast occurs at sites CC002WM, CCWP-15, and CCWP-04, where the FMP classifies these reaches as cold water and thermally stable whereas the 2015/16 data shows them as cool or warm water and moderately stable or unstable (Table 10).

Fish species and the thermal regimes of their sites were compared in order to observe whether the thermal regime classification based on water temperature matches the present fish community. Most of the fish community belonged to the cool water thermal guild (per Section 3.2). Despite several sites being thermally classified as cold (CCWP-10, CCWP-09, CCWP-03), the fish community at these sites was dominated by species belonging to the cool water thermal guild (Table 10). Sites that were thermally classified as cool and moderately stable (CCWP-12, CC002WM, CC003WM) based on the 2015/16 water temperature data supported both a cool and warm water fish community. It was noted that based on 2015-2016, sites changed in thermal classification towards a warmer category (e.g., cold water toward cool water, or from cool water toward warm water). This is expected to be in response to lower water levels and flow as a result of drought conditions in 2016.

3.5.2 Presence of Target Fish Species and IBI Score

Previously identified fish species management targets for the creek included the presence of target species such as Brook Trout, Redside Dace, Rainbow Trout, and Darter species (Table 10). Redside Dace and one darter species (Johnny Darter) were present in the 2015-2016 data set, however, no cold water target species such as Brook Trout or Rainbow Trout, or other cold water species in general such as the Mottled Sculpin, were captured in 2015/16. A total of two adult Rainbow Trout were captured close to the mouth of the creek in 2012 and the last record of Mottled Sculpin dates back to 2000. Although there is a pattern of decreasing water temperature moving upstream (Figure 10), along with the presence of sites which are thermally classified as cold, the fish community lacks the presence of cold water species at any site sampled with recent data.

Northern Pike and Largemouth Bass were both identified as target species in the coastal marsh habitat and site CC001WM, which is located directly upstream of the marsh. Both species of fish were captured during 2015 and 2016 in the coastal marsh, but in low abundances (e.g., one per year). None of these fish species or salmonid fish species was captured during 2015-2016 at site CC001WM.

The IBI target for the overall Carruthers Creek watershed (riverine habitat) is "Good" (Table 10). In 2004, the FMP reported that the IBI in the riverine habitat ranged from poor to good. Recent data document a mean IBI for the riverine habitat of 26, putting it in the fair category of 21-27. Individual site fish IBI scores ranged from poor to good, similar to what was reported in the 2004 FMP. Despite the mean fish IBI being below the target IBI, several riverine sites had an IBI score in the good category range (28-37) (Table 10). It should also be noted that when considering only the 2016 data (which only include the DCrest sites), the mean riverine habitat fish IBI score rises to 31, with sites ranging from fair to good.

However, the interpretation of sites meeting the FMP IBI targets is only based on 2015 data. The 2015 IBI is more representative of the current conditions of the riverine system as the 2015 dataset is comprised of a greater variety of sites, expanding a greater spatial range within the Carruthers lotic system as opposed to just the DCrest sites. Therefore the riverine habitat fish IBI score FMP target was not reached as the average 2015 IBI score was only 26 which places it two points lower than the good category.

Table 10 - FMP management targets and 2015-2016 related data

Site	FMP Thermal Regime / Stability Target	2015 2016 Thermal Regime / Stability	2015 2016 Fish Thermal Regime	FMP Fish Management Targets	2015 2016 Presence of FMP Fish Management Targets	FMP IBI Target	2015 2016 IBI score
CC001WM	Warm / Fluctuates	Cool / Moderate	Cool / Warm	No trout present, salmonid migratory corridor, managed for Northern Pike and Largemouth Bass	None and no salmonids	Good (28-37)	Poor (20)
CCWP-12	Warm / Fluctuates	Cool or Warm / Moderate	Cool / Warm	Redside Dace and Darter Sp.	None	Good (28-37)	Fair (23)
CC002WM	Cold / Stable	Cool or Warm / Moderate	Cool / Warm	Salmonid migratory corridor	No salmonids	Good (28-37)	Fair (23)
CCWP-15	Cold / Stable	Cool / Moderate or Unstable		Rainbow Trout and Redside Dace		Good (28-37)	
DCREST4	Warm / Fluctuates			Rainbow Trout and Redside Dace		Good (28-37)	
DCREST5	Warm / Fluctuates		Cool / Warm	Redside Dace and Darter Sp.	Johnny Darter and RSD	Good (28-37)	Good (27)
DCREST6	Warm / Fluctuates		Cool / Warm	Redside Dace and Darter Sp.	Johnny Darter	Good (28-37)	Good (32)
CCWP-11	Warm / Fluctuates		Cool / Warm	Redside Dace and Darter Sp.	Johnny Darter	Good (28-37)	Good (29)
DCREST3	Warm / Fluctuates		Cool / Warm	Redside Dace and Darter Sp.	Johnny Darter	Good (28-37)	Good (34)
DCREST7	Warm / Fluctuates		Cool / Warm	Redside Dace and Darter Sp.	None	Good (28-37)	
DCREST2	Warm / Fluctuates		Cool / Warm	Redside Dace and Darter Sp.	Johnny Darter	Good (28-37)	
CC003WM	Warm / Fluctuates	Cool or Warm / Moderate	Cool / Warm	Redside Dace and Darter Sp.	Johnny Darter	Good (28-37)	Good (34)
CCWP-10	Warm / Fluctuates	Cold or Cool / Moderate	Cool / Warm	Redside Dace and Darter Sp.	Johnny Darter and RSD	Good (28-37)	Good (32)
CCWP-09	Warm / Fluctuates	Cold or Cool / Moderate	Cool / Warm	Redside Dace and Darter Sp.	Johnny Darter and RSD	Good (28-37)	Good (28)

Site	FMP Thermal Regime / Stability Target	2015 2016 Thermal Regime / Stability	2015 2016 Fish Thermal Regime	FMP Fish Management Targets	2015 2016 Presence of FMP Fish Management Targets	FMP IBI Target	2015 2016 IBI score
CCWP-06	Cold / Stable	Cold / Unstable		Brook Trout		Good (28-37)	
CCWP-05	Warm / Fluctuates			Redside Dace and Darter Sp.		Good (28-37)	
CCWP-07	Cold / Stable	Cold / Unstable		Brook Trout		Good (28-37)	
CCWP-08	Cold / Stable	Cold / Stable	Cool / Warm	Brook Trout		Good (28-37)	Poor (17)
CCWP-03	Warm / Fluctuates	Cold / Stable	Cool / Warm	Redside Dace and Darter Sp.	None	Good (28-37)	Poor (18)
CCWP-14	Warm / Fluctuates	Cold / Moderate		Redside Dace and Darter Sp.		Good (28-37)	
CCWP-01	Warm / Fluctuates			Redside Dace and Darter Sp.		Good (28-37)	
CCWP-02	Warm / Fluctuates			Redside Dace and Darter Sp.		Good (28-37)	
CCWP-04	Cold / Stable	Cool / Moderate		Brook Trout		Good (28-37)	

Green Box represents instances where FMP target matches the 2015-2016 data.
Yellow Box represents instances where target partially meets 2015-2016 data
Blanks represent lack of data due to the site not being monitored.

4. Summary

4.1 Overall Summary of Results

Results for each of the indicators selected to characterise the aquatic community and habitat in the Carruthers Creek watershed are presented below.

Instream Habitat

The riverine habitat can be summarised as comprised mainly of pools. Algae were the predominant vegetation type documented at most sites sampled regularly since 2003, and the proportion of this vegetation class has increased over time. The only sites with lower proportions of algae appeared to be those with finer bed substrates (silts and sands) which would restrict the attachment and proliferation or filamentous algae. Watercress was present at some sites, particularly those associated with Deer Creek Golf Course, which is attributed to higher groundwater contributions in this part of the watershed.

Instream cover (type and proportion) remained fairly consistent throughout 2003 to 2012. However, during 2015 and 2016 there was an increase in the proportion of both unembedded and embedded cover; with the highest percentage of cover attributed to the DCrest sites.

Sediment size increases and water temperature decreases farther upstream from the coastal marsh, towards the upper reaches and headwaters.

Stream Temperature

Stream temperatures were found to vary spatially within the watershed, with a trend towards cooler temperatures upstream. Cooler water temperatures were identified in the mid-watershed sites associated with Deer Creek Golf Course, where increased baseflow contributions are known to occur. The majority of the sites are thermally classified as cool and moderately stable.

In general, the riverine habitat can be thermally classified as cool switching to cold moving upstream, with the majority of sites considered moderately stable in terms of temperature fluctuations. Limited cold water habitat exists in the upper west branch of the watershed (TRCA and OMNR 2004). Sites in this part of Carruthers Creek continue to represent the coldest thermal regimes documented in the watershed.

Fish community

Based on the data assessed, the fish community has changed through time in Carruthers Creek watershed. Data included in this Characterization document an initial decline in species richness between 2000 and 2005, however between 2006 through to 2015 fish biodiversity increased to the point where species richness in recent samples (2015 and 2016) was as high as the peak richness observed in the last 3 decades. Highest species richness was observed in the mid-reaches of the watershed at sites associated with Deer Creek Golf Course, where cooler water temperatures and more diverse habitat conditions exist.

Fish communities in the watershed are dominated by native species primarily belonging to the cool water thermal guild. The thermal classification data also show a similar spatial pattern to that of the stream temperature data, a tendency from warm toward cool and cold thermal regimes farther upstream, with the most abrupt switch occurring upstream of site CC003WM (where a known change of stream gradient exists due to the Lake Iroquois south slope). The fish community data however, do not reflect this pattern since regardless of the location the majority of the fish community in Carruthers Creek is comprised of cool water species. Although some cold water habitat is present, no cold water fish species were documented at any of the recently sampled sites.

The majority of fish captured historically and currently were native fish species, one of which is listed as endangered (Redside Dace) and protected under the Endangered Species Act. Round Goby is the one invasive species present in the riverine habitat. Of the fish species captured between 2003 and 2014, three species: Black Crappie, Northern Pike, and Rainbow Trout, were not captured during 2015 and 2016 sampling. Brown bullhead, Largemouth Bass, and Redside Dace were captured during 2015-2016 but not during the 2003 to 2014 sampling in Carruthers Creek.

Overall, the riverine habitat in Carruthers Creek received a fish IBI score of "fair" (score of 26 based on 2015 data). The IBI score category of fair has not changed throughout the years from 2003 to 2015, and is just shy of the management target of "Good" that was identified for the watershed in the 2004 FMP.

Benthic Macroinvertebrates

Sites closest to the mouth (CC001WM, CCWP-12, C002WM) all show low IBI scores (below the mean IBI calculated for the watershed), and high HBI scores with a decrease in overall BMI biodiversity and per cent EPT (taxa associated with well oxygenated water, good water quality, and considered more sensitive and pollution intolerant).

Similar to the fish community, the DCrest sites also have higher benthic taxa richness compared to the other sites. This increase in biodiversity in the fish and BMI community can be attributed to a number of factors related to habitat, particularly sediments. The difference in sediment type is also responsible for the DCrest sites having the highest percentage of EPT.

Management Targets

Comparison of the data collected through this study to the management targets identified in the Fisheries Management Plan identified that some targets are being met, however there is room for improvement in terms of thermal classification, target fish species/communities and overall biotic health.

The majority of the sites assessed did not have similar thermal classifications based on the FMP and only one of the monitoring sites assessed (CCWP-08) was classified as cold water and thermally stable in both the FMP and recent data. The target for most reaches in Carruthers Creek was previously classified as warm water with fluctuating thermal stability, indicating that the reaches may alternate between warm water or cool/cold water. Most sites were also previously classified as moderately stable. However, recent results indicate that the majority of sites are classified as belonging to the cool water thermal regime.

Previously identified fish targets for the creek included the presence of species such as Brook Trout, Redside Dace, Rainbow Trout, and Darter species. Redside Dace and one darter species (Johnny Darter) were present in the 2015-2016 data set, however, no cold water target species such as Brook Trout or Rainbow Trout, or other cold water species in general such as the Mottled Sculpin, were captured in 2015/16. Although there is a pattern of decreasing water temperature moving upstream (Figure 9), along with the presence of sites which are thermally classified as cold, the fish community lacks the presence of cold water species at any site sampled with recent data.

The overall IBI target for the Carruthers Creek is "Good", however the recent data document a mean IBI for the riverine habitat of 26, putting it in the fair category of 21-27. Despite the mean fish IBI being below the target IBI, several riverine sites had an IBI score in the good category range (28-37).

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Appendix A: OSAP Derived Habitat Metrics

% Pools, % Riffles, % Glides: Pools have a low hydraulic head as they are characterised by slow moving water, whereas riffles have a greater hydraulic head as they are characteristic of greater flow velocities. Hydraulic head increases from pool, to glide, to riffle. The percentage of riffles (areas of relatively fast, turbulent flow; typically occur at cross-over locations; poorly defined thalweg), pools (deepest locations of the reach; often located at the outside of meander bends) and glides (located immediately downstream of pools, deeper area without surface turbulence, uniform channel bottom). Habitat types were classified based on the measure of hydraulic head which is an indicator of flow velocity.

% of cover type (embedded, unembedded, and no cover): This metric speaks to the amount of hiding spaces an aquatic organism such as a fish can use. Cover presence is determined and classified by its quality and type. A cover particle is any object that touches the water in the sample area, is at least 100 mm wide along the median axis, and of sufficient density to block >75 % of sunlight from reaching the stream bottom. A cover particle can consist of a mat of materials such as twigs, macrophytes, or the bank. The mat must still meet the median diameter size and light penetration restrictions. The percentage of cover type refers to particle sizes greater than 100 mm with an overhang of greater than 4 cm (OSAP; Stanfield 2013).

The cover quality is determined with respect to embeddedness. Unembedded cover provides overhead and velocity protection for small fish and has at least a 4 cm overhang. Embedded cover provides only a velocity refuge and has less than a 4 cm overhang (e.g., the interstitial spaces around the cover object are filled with material) (OSAP; Stanfield 2013).

Sediment size and Type: This metric speaks to the mean sediment or particle size. Sediment size or particle size was measured at each point along the transect for each transect in in a site (please refer to Section 4, module 2, page 4, table 1, of the OSAP manual for methods related to determining the number of transects, and points along the transect). Particle size was measured as the width of the particle along its median axis. Size of the particle was used to classify the particle into several particle categories as described in **Table 3** (from Andre Robert, 2003)**.**

% instream vegetation type: This metric speaks to the per cent of vegetation present in a site. Vegetation is categorized into seven categories: filamentous algae, non-filamentous algae, grass, moss, macrophytes, watercress, and terrestrial plants.

Appendix B: Fish and BMI Biotic Indices

Taxa Richness: Richness measures reflect the diversity of the aquatic assemblage (Resh *et al*., 1995). Increasing diversity correlates with increasing health of the assemblage and suggests that niche space, habitat, and food source are adequate to support survival and propagation of many taxa. The number of taxa (*i.e.*, number of genera) is a measure of community composition. Sites with more taxa are generally considered to be in better condition. A high number of taxa present at a site suggest that habitat and water quality conditions are adequate to support the variable life requirements of benthic invertebrates. Caution should be taken when interpreting this index as the number of taxa can increase with moderate nutrient enrichment, but usually decreases with excessive levels of nutrients, toxic conditions, or physical disturbance of habitat.

Number of Ephemeroptera, Plecoptera, and Trichoptera (#EPT) Genera: EPT is a short form for Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). These taxa are generally considered to be sensitive to pollution, and a high abundance of these organisms can indicate good environmental conditions. Loss of taxa in these groups is an indication of perturbation (Wallace *et al*., 1996).

% EPT - All three groups (Ephemeroptera, Plecoptera, Trichoptera; EPT) require gravel stream bottoms with good concentrations of dissolved oxygen and are typical of high quality stream environments. The presence of these three groups indicates both good water and habitat quality status. For example, stream environments impacted by suspended solids will be expected to have a lower % EPT because interstitial spaces in substrate will be filled, thereby reducing suitable habitat for the EPT groups. If there is a high % EPT, it is likely that conditions at the site are better than those sites with a low % EPT.

% Chironomidae: Chironomidae (midges) account for most of the invertebrates in many freshwater environments. In streams, they are found in nearly every type of habitat from small substrates, such as silt/sand, to large substrates such as cobble. Therefore, their complete absence from a site would be unexpected and provides a clue to potential stream impacts. By comparison, a predominance of midges at a site generally indicates poor water quality. However, it is important to note that there is a wide tolerance range for changes in water quality within the midge family. Nonetheless, a high percentage of midges at a site suggest that stream conditions do not support a "healthy" benthic invertebrate community.

% Oligochaeta: Aquatic worms are commonly found in soft sediments rich in organic matter and sites that receive organic pollution. Oligochaeta are considered generally tolerant organisms (e.g., some can tolerate anoxic conditions). Therefore, worms are often found in relatively higher numbers at sites receiving excessive organic inputs than more oxygen sensitive groups (e.g., stoneflies). A high percentage of Oligochaeta suggests that the site is affected by high organic inputs and as a consequence, low oxygen levels.

Simpson's Diversity - Diversity indices provide more information about community composition than simply taxa richness; they also take the relative abundances of different taxa into account. Diversity indices provide important information about community structure (e.g. rarity and commonness of species in a community).

The Simpson's Diversity Index is related to the proportion of total organisms contributed by each taxon. Diversity is low when the benthic community is dominated by a few taxa, and higher when the number of organisms is more evenly distributed across numerous taxa. High diversity indicates better environmental conditions, while low values can indicate stresses on the system. The index ranges from "0" which represents no diversity to "1" which represents infinite diversity.

$$Simpson's Diversity = 1 - D$$

$$D = \sum (n/N)^2$$

where:

n = Total number of organisms of a particular taxa (e.g. family)

N = Total number of organisms

Hilsenhoff Biotic Index (HBI): The Hilsenhoff Biotic Index (1987) was originally designed to reflect the nutrient status of streams using benthic macroinvertebrate data (the index has been revised/modified by others such as Bode *et al*., 1991, 2002). Although originally developed to assess low dissolved oxygen caused by organic loading, a purpose for which it works best, the index may also be sensitive to the effects of impoundment, thermal pollution, and some types of chemical pollution (Hilsenhoff 1998, Hooper 1993). HBI values are determined using tolerance (to organic pollution) values which range from 1 to 10, and increase as water quality decreases. Low values suggest 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 (see table below).

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

where:

x_i = number of individuals within a taxon

t_i = tolerance value of a taxon

N = total number of organisms in the sample

HBI Value	Rating	Degree of Organic Pollution
0.00 - 3.75	Excellent	Organic pollution unlikely
3.76 - 4.25	Very good	Possible slight organic pollution
4.26 - 5.00	Good	Some organic pollution probable
5.01 - 5.75	Fair	Fairly substantial pollution likely
5.76 - 6.50	Fairly poor	Substantial pollution likely
6.51 - 7.25	Poor	Very substantial pollution likely
7.26 - 10.00	Very poor	Severe organic pollution likely

Riverine Index of Biotic Integrity (fish): The IBI score is a multivariate measure of stream quality that uses fish fauna as a biological indicator. Nine measures, or metrics, of fish community composition grouped into four categories (species richness, local indicator species, trophic composition, fish abundance) are used to derive the IBI score. The IBI score is used to rate the overall health of the stream (site) on a scale of 9 (poor) to 45 (very good). For more information on this metric please refer to Steedman, 1988.

Rating	IBI Score
Poor	9-20
Fair	21-27
Good	28-37
Very Good	38-45

Catch per Unit Effort: CPUE is a metric is used to estimate the abundance of fish per unit of area per time needed to sample that area (CPUE = Abundance / (Area / Time)). Large values of CPUE indicate large population size since many fish are captured per unit of area and time.

% Thermal Guild: Generally fish can be broken down into 3 thermal guilds (cold, cool, and warm) as per Eakins, 2002. Per cent cold was calculated as the total catch of fish belonging to the cold thermal guild divided by the total number of fish captured. The same was done for the other two thermal guilds.

% Origin: Origin refers to whether the fish species is considered to be native, invasive, stocked, or non-native but not invasive. Native fish generally contribute positively to biodiversity whereas invasive fish species generally have a negative impact on biodiversity. This classification was based on the work of Mandrak and Crossman, 1992.

Appendix C: Water Temperature Data

Table E1 - Mean monthly temperature per site per year

Site Code	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CC001WM	2003						18.20	19.37	20.28	16.59			
CC002WM	2003						18.38	19.43	20.10	16.96			
CC003WM	2003						19.68	20.26	20.01	16.71			
CC001WM	2006				12.04	14.77	19.50	22.09	20.54	16.34	10.16	5.49	
CC002WM	2006				12.09	14.74	20.13	22.76	21.16	16.59	10.15	5.34	
CC003WM	2006				11.47	14.38	20.35	22.29	21.29	17.69	10.95	5.28	
CC001WM	2009					14.62	18.29	19.77	21.36	17.23	9.56	7.27	
CC002WM	2009					13.74	17.54	18.74	20.63	16.80	9.12	6.70	
CC003WM	2009					14.65	18.55	19.88	21.58	18.45	9.80	7.81	
CC001WM	2012				9.16	16.77	19.64	22.66	21.05	16.85	10.99	6.37	
CCWP-12	2012				9.52	16.66	20.14	22.94	21.91	18.45	12.58	8.32	
CC002WM	2012				8.83	16.51	19.58	22.97	21.13	16.94	10.85	6.32	
CCWP-11	2012				7.82	13.39	17.26	20.94	19.13	15.03	11.01	6.26	
CCWP-10	2012				7.16	14.24	16.99	19.59	18.28	14.09	9.27	5.81	
CCWP-09	2012				7.62	14.51	17.51	19.90	18.12	14.41	9.65	6.11	
CCWP-05	2012								17.98	15.08	10.08	6.25	
CCWP-07	2012				7.90	14.01	16.03	18.43	16.55	13.80	9.89	5.97	
CCWP-08	2012								15.96	14.22	11.11	7.83	
CCWP-03	2012				6.98	12.30	15.32	17.01	16.21	13.39	9.46	5.67	
CCWP-14	2012				7.39	12.24	14.99	18.72	17.43	14.43	10.59	7.31	
CCWP-04	2012				7.63	12.91	17.71	19.65	17.54	13.79	10.22	6.22	
CC003WM	2013	4.44		4.03	8.22	16.67	18.99	22.04	20.42	17.30	12.74	6.23	
CC001WM	2014				7.35	12.94	17.37	19.20	19.33	16.80	12.09	6.69	4.34
CC003WM	2014				7.84	15.30	20.86	21.27	20.14	17.42	12.03	5.99	
CCWP-10	2014												4.37
CCWP-05	2014												4.43
CC001WM	2015			4.39	7.81	16.05	18.17	21.20	20.64	19.01	10.85	7.53	5.42
107002	2015					16.00	17.99	21.11	20.81	19.25	11.19	7.76	5.55
CCWP-12	2015					15.78	18.45	20.50	20.37	19.17	11.87	8.67	6.57
CC002WM	2015					16.16	17.53	21.12	20.66	18.99	10.88	7.43	
CCWP-15	2015					16.02	17.70	20.66	20.17	18.28	10.91	7.34	5.34
CC003WM	2015				8.05	16.98	18.97	21.00	20.67	18.91	11.82	7.31	5.07
CCWP-10	2015				7.91	14.32	16.20	18.82	18.37	16.85	9.40	6.85	5.38
CCWP-09	2015					14.36	16.54	17.96	17.66	16.32	9.62	6.99	5.43
CCWP-05	2015				6.33	13.89	15.33	19.63	18.97	17.36	9.81	7.31	5.36

Site Code	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CCWP-06	2015					11.25	14.74	17.16	17.47	16.58	11.27	7.49	5.51
CCWP-07	2015						15.74	17.71	17.14	15.83	9.47	7.49	5.50
CCWP-03	2015					12.22	14.88	15.99	16.01	15.25	9.70	7.08	5.10
CCWP-14	2015					12.66	13.75	17.05	17.20	16.34	10.18	7.70	5.45
CCWP-04	2015					14.81	16.83	18.42	17.24	15.97	9.76	7.34	5.29
CC001WM	2016			4.84	8.32	15.35	19.26	22.16	22.94	18.46	14.49		
107002	2016		4.34	5.08	8.89	17.69	20.37	23.05	24.01	19.48	15.38		
CCWP-12	2016	4.37	4.98	6.78	9.02	15.14	18.74	21.63	22.46	18.63	15.05		
CC002WM	2016					16.99	19.25	21.96	23.03	18.63	14.54		
CCWP-15	2016			4.97	9.11	17.66	19.37	21.85	22.78	17.76	14.46		
CC003WM	2016			4.83	9.55	16.33	18.47	21.38	22.84	18.09	14.45		
CCWP-10	2016			5.01	8.46	15.79	17.49	19.82	20.46	16.99	13.71		
CCWP-09	2016			5.35	8.13	13.10	16.54	19.09	19.93	15.95	12.45		
CCWP-05	2016			4.72	7.78	14.12	18.58	20.95	21.66	16.83	12.71		
CCWP-06	2016	4.14		5.71	7.16	9.73							
CCWP-07	2016			5.29	8.02	13.03	16.12						
CCWP-08	2016					13.10	14.69	17.35	18.24	15.37	12.78		
CCWP-03	2016			4.58	6.80	10.93	14.36	16.52	17.29	14.85	12.59		
CCWP-14	2016		4.07	5.26	7.72	12.63	16.14	18.70	19.59	15.81	12.98		
CCWP-04	2016			5.37	8.57	13.93	17.30						

Table E2 - Minimum monthly temperature per site per year

Site Code	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CC001WM	2003						14.47	16.22	14.47	13.77			
CC002WM	2003						14.34	16.51	16.08	15.84			
CC003WM	2003						16.81	16.65	16.49	15.69			
CC001WM	2006				9.46	9.56	14.29	17.75	16.37	11.61	6.18	4.01	
CC002WM	2006				8.67	8.52	13.21	17.82	16.11	10.98	5.10	4.01	
CC003WM	2006				10.39	10.59	16.70	17.30	15.51	13.98	5.92	4.19	
CC001WM	2009					10.46	12.21	17.00	15.76	12.21	4.73	4.93	
CC002WM	2009					9.37	11.72	15.57	14.71	11.33	4.21	4.10	
CC003WM	2009					10.46	13.08	17.19	17.28	13.56	5.96	5.96	
CC001WM	2012				4.62	8.18	13.56	19.47	16.43	11.63	6.57	4.10	
CCWP-12	2012				5.04	8.48	14.04	19.38	16.81	12.88	8.18	5.14	
CC002WM	2012				4.21	7.58	13.65	17.76	14.90	10.75	5.14	4.10	
CCWP-11	2012				4.10	6.78	12.11	15.86	13.56	11.04	8.28	4.10	

Site Code	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CCWP-10	2012				4.10	5.86	12.11	15.76	14.33	8.88	4.93	4.10	
CCWP-09	2012				4.10	7.18	12.21	15.47	12.88	8.98	4.31	4.10	
CCWP-05	2012								15.19	9.77	4.42	4.10	
CCWP-07	2012				4.10	6.47	11.82	15.57	12.88	9.47	5.76	4.10	
CCWP-08	2012								13.37	9.97	7.98	5.96	
CCWP-03	2012				4.10	4.83	10.75	13.94	12.21	8.68	5.14	4.10	
CCWP-14	2012				4.10	5.55	11.33	15.09	13.17	10.16	6.06	5.24	
CCWP-04	2012				4.10	6.27	11.82	14.04	11.24	9.67	5.35	4.10	
CC003WM	2013	4.01		4.01	4.01	10.86	15.03	17.58	16.37	13.11	5.80	4.01	
CC001WM	2014				4.10	7.28	15.76	17.86	16.14	12.01	8.88	4.10	4.10
CC003WM	2014				4.01	6.91	16.08	16.39	16.34	13.55	8.44	4.01	
CCWP-10	2014												4.10
CCWP-05	2014												4.10
CC001WM	2015			4.10	4.10	10.94	13.56	16.52	16.14	14.23	5.24	4.10	4.10
107002	2015					9.57	13.38	16.61	15.49	14.16	5.06	4.02	4.01
CCWP-12	2015					9.97	13.17	14.90	15.57	14.42	5.96	4.10	4.10
CC002WM	2015					10.26	14.52	16.33	15.57	14.23	4.93	4.10	
CCWP-15	2015					7.99	12.29	15.89	14.57	13.42	4.80	4.00	4.00
CC003WM	2015				4.01	7.49	13.98	15.22	12.82	12.85	7.78	4.10	4.10
CCWP-10	2015				4.10	8.14	10.18	13.53	14.26	12.65	4.05	4.01	4.01
CCWP-09	2015					6.98	11.14	14.33	13.27	11.82	4.10	4.10	4.10
CCWP-05	2015				4.10	9.08	11.72	13.27	13.85	12.21	4.10	4.10	4.10
CCWP-06	2015					7.58	10.75	14.04	13.85	13.56	6.67	4.93	4.10
CCWP-07	2015						10.55	13.17	13.46	11.53	4.10	4.10	4.10
CCWP-03	2015					7.52	10.64	13.43	13.59	12.70	4.45	4.01	4.01
CCWP-14	2015					5.41	8.94	11.78	12.99	11.66	4.01	4.01	4.01
CCWP-04	2015					4.04	10.61	12.78	11.59	10.17	4.69	4.01	4.01
CC001WM	2016			4.10	4.10	8.18	13.08	17.00	18.05	13.27	9.08		
107002	2016		4.06	4.01	4.01	9.12	14.20	16.43	18.31	13.01	8.93		
CCWP-12	2016	4.10	4.10	4.10	4.10	7.68	12.40	16.52	17.67	12.59	9.37		
CC002WM	2016					8.58	13.46	16.71	17.28	12.98	8.78		
CCWP-15	2016			4.00	4.00	8.50	12.13	14.96	16.79	12.15	8.47		
CC003WM	2016			4.10	4.10	9.57	12.59	14.90	18.05	13.08	9.87		
CCWP-10	2016			4.02	4.01	6.31	11.93	14.56	16.78	12.53	8.68		
CCWP-09	2016			4.10	4.10	6.98	10.55	13.65	14.90	10.65	7.08		
CCWP-05	2016			4.10	4.10	4.93	9.87	13.94	15.28	9.28	6.27		
CCWP-06	2016	4.10		4.10	4.10	6.17							
CCWP-07	2016			4.10	4.10	5.24	9.87						
CCWP-08	2016					6.37	10.85	13.94	15.76	12.01	9.28		

Site Code	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CCWP-03	2016			4.01	4.01	5.85	10.93	13.40	14.63	11.95	9.34		
CCWP-14	2016		4.01	4.01	4.01	5.49	10.83	14.15	14.79	10.88	8.17		
CCWP-04	2016			4.01	4.01	4.69	10.69						

Table E3- Maximum monthly temperature per site per year.

Site Code	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CC001WM	2003						23.56	24.63	24.63	18.67			
CC002WM	2003						23.91	24.32	23.81	18.91			
CC003WM	2003						23.69	25.24	23.18	18.41			
CC001WM	2006				14.34	24.41	24.05	26.60	26.30	20.46	15.46	7.32	
CC002WM	2006				15.44	26.74	26.13	28.25	26.99	21.70	16.96	7.19	
CC003WM	2006				12.65	20.34	25.19	26.23	29.54	21.80	16.68	6.74	
CC001WM	2009					19.95	24.84	23.10	26.20	22.62	12.69	10.36	
CC002WM	2009					19.85	25.42	22.72	26.49	21.66	12.21	9.87	
CC003WM	2009					20.14	24.35	22.91	25.51	21.86	13.65	9.87	
CC001WM	2012				15.95	22.91	25.71	26.59	26.10	22.53	16.81	9.08	
CCWP-12	2012				16.05	21.95	27.37	27.67	27.57	25.42	18.05	11.43	
CC002WM	2012				16.43	24.93	27.67	28.56	27.96	24.06	18.14	8.88	
CCWP-11	2012				14.04	18.33	24.55	27.76	26.59	22.72	14.90	9.18	
CCWP-10	2012				14.42	19.95	22.24	23.48	22.33	20.52	14.61	8.68	
CCWP-09	2012				14.71	21.66	23.77	25.71	24.16	21.00	15.19	8.88	
CCWP-05	2012								21.09	20.71	16.05	9.67	
CCWP-07	2012				16.71	20.81	22.14	21.86	19.66	17.86	14.42	9.28	
CCWP-08	2012								18.52	20.14	16.33	10.06	
CCWP-03	2012				14.04	19.95	21.19	21.57	20.23	19.76	14.13	8.88	
CCWP-14	2012				15.19	18.81	19.85	23.39	22.24	19.19	15.00	10.16	
CCWP-04	2012				17.48	20.62	24.74	27.96	23.68	18.71	15.66	9.77	
CC003WM	2013	4.74		4.09	13.93	22.15	23.21	27.06	24.17	23.42	18.01	9.78	
CC001WM	2014				9.47	17.28	20.71	21.38	22.72	22.53	17.19	8.98	4.62
CC003WM	2014				11.32	23.21	24.97	25.99	23.38	22.75	17.44	8.39	
CCWP-10	2014												4.62
CCWP-05	2014												4.93
CC001WM	2015			4.73	14.23	21.76	22.62	26.00	25.22	25.03	15.66	12.21	7.68
107002	2015					23.96	22.68	28.76	26.49	27.83	15.94	12.57	8.20
CCWP-12	2015					23.00	24.16	26.10	25.81	26.78	17.86	14.23	10.06
CC002WM	2015					22.43	21.95	26.88	25.71	25.61	15.76	12.40	
CCWP-15	2015					24.55	24.30	27.07	27.02	23.74	15.86	12.67	7.69
CC003WM	2015				14.22	23.09	24.63	25.60	25.67	24.70	16.63	11.33	6.37

Site Code	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CCWP-10	2015				14.80	20.51	21.89	24.46	23.02	22.31	13.53	11.94	8.00
CCWP-09	2015					21.38	21.00	22.91	23.00	22.14	13.56	11.92	7.98
CCWP-05	2015				11.63	19.95	20.23	26.49	24.93	23.97	14.52	13.08	8.08
CCWP-06	2015					20.42	21.57	23.00	20.71	20.81	14.42	11.33	7.48
CCWP-07	2015						20.81	23.29	20.81	22.53	13.75	12.88	8.48
CCWP-03	2015					17.65	18.39	19.06	18.39	18.41	13.57	11.22	7.09
CCWP-14	2015					21.20	19.48	21.89	21.34	21.80	14.72	12.90	8.05
CCWP-04	2015					23.11	21.18	24.58	23.18	23.18	14.86	12.36	8.05
CC001WM	2016			6.78	12.88	24.06	25.03	26.10	26.29	24.93	17.57		
107002	2016		4.59	7.78	15.45	26.95	29.75	30.92	31.76	29.18	20.62		
CCWP-12	2016	4.93	7.68	10.55	15.76	23.58	25.71	27.37	26.68	26.49	19.57		
CC002WM	2016					24.45	24.93	27.08	28.36	25.81	18.81		
CCWP-15	2016			7.27	16.25	27.44	26.59	28.35	27.73	24.69	18.50		
CC003WM	2016			7.48	15.66	24.45	24.26	28.26	26.68	23.20	17.38		
CCWP-10	2016			6.45	14.60	23.11	22.62	22.98	23.34	21.97	16.29		
CCWP-09	2016			7.78	13.37	23.48	23.48	24.93	24.26	21.86	15.86		
CCWP-05	2016			7.28	13.27	27.96	27.76	28.26	27.96	24.64	16.43		
CCWP-06	2016	4.21		10.16	12.01	15.66							
CCWP-07	2016			8.28	15.66	22.24	23.39						
CCWP-08	2016					18.43	17.48	20.81	21.66	19.85	14.71		
CCWP-03	2016			6.84	10.93	18.18	18.53	19.65	20.10	18.41	14.12		
CCWP-14	2016		4.12	8.79	14.31	20.25	21.34	22.39	24.53	21.63	15.92		
CCWP-04	2016			9.04	15.58	25.60	26.11						

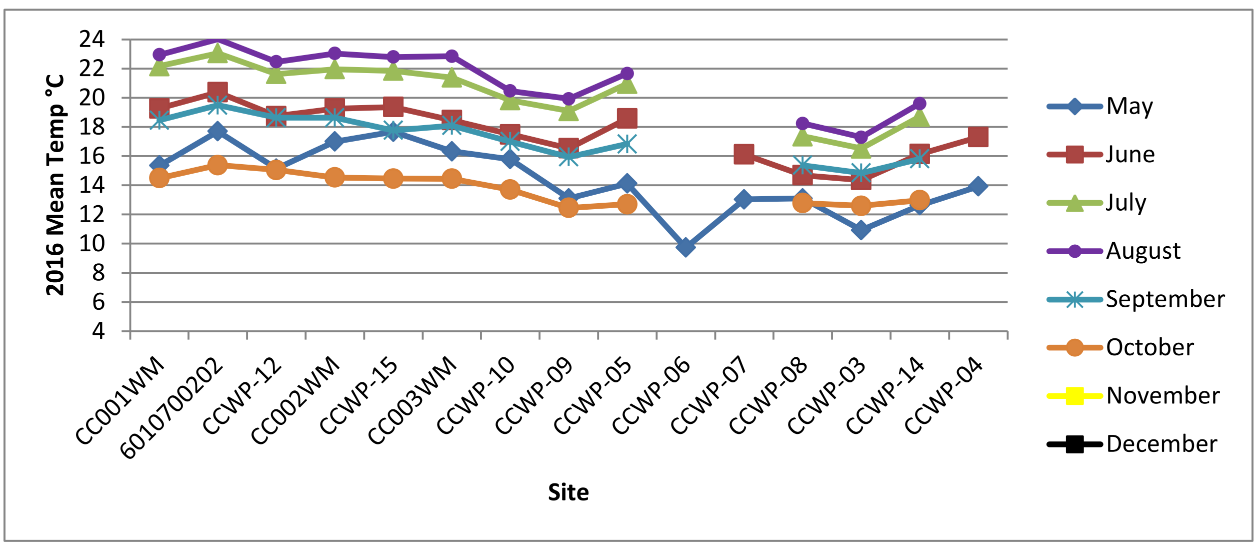

Figure E1: 2016 monthly average water temperature summarised per site

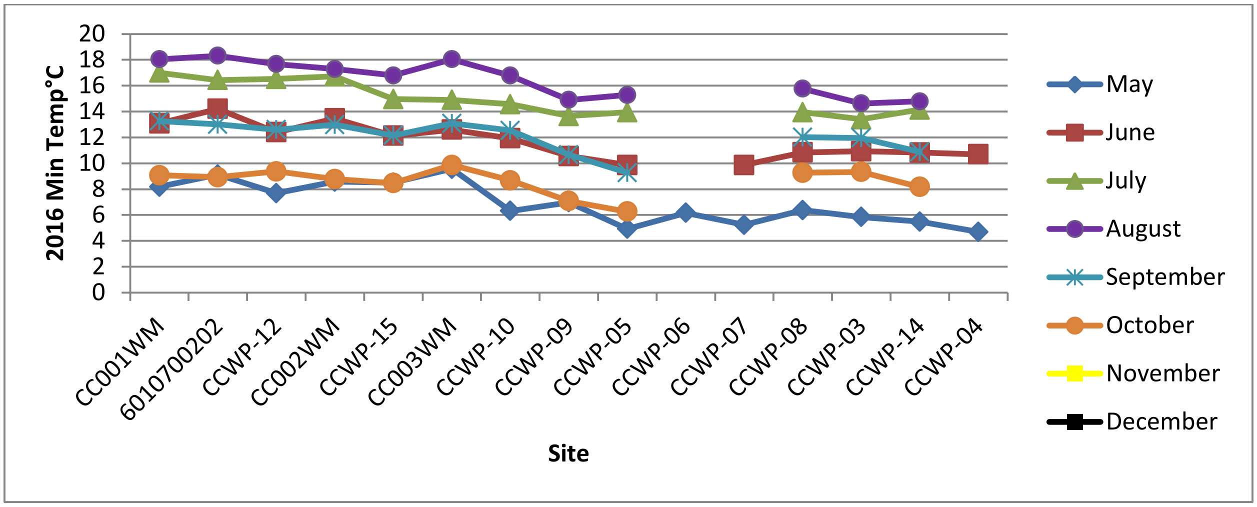

Figure E2: 2016 monthly minimum water temperature summarised per site

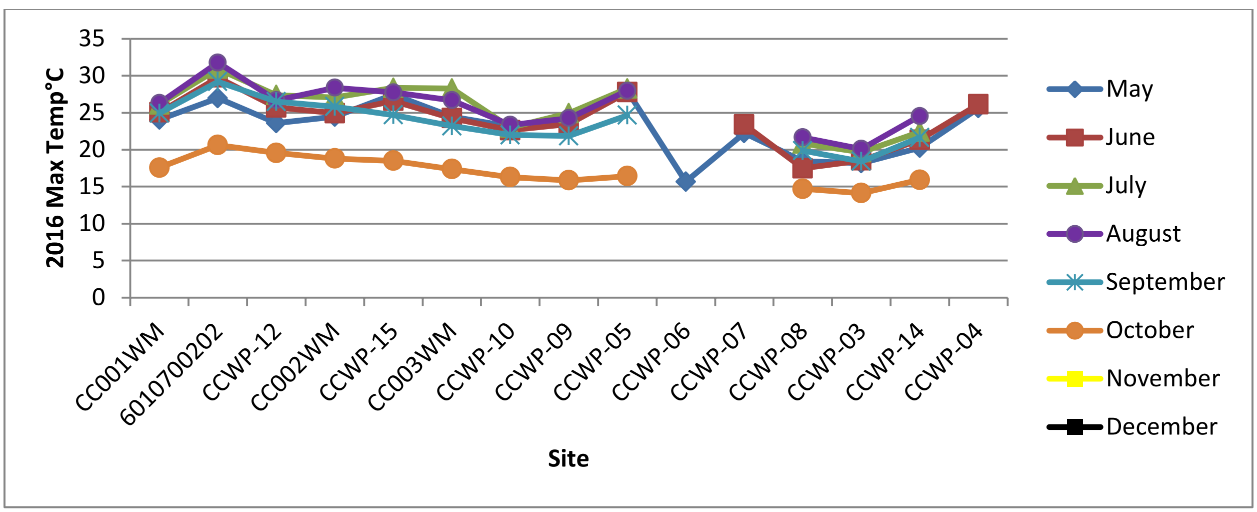

Figure E3: 2016 monthly maximum water temperature summarised per site

Appendix D: Thermal stability and thermal classification.

Temperature Logger Code	Corresponding Fish Site	Variable	2003	2006	2009	2012	2013	2014	2015	2016
CC001WM	CC001WM	Mean Weekly Temp (°C)	19.84	22.24	18.97	22.79		19.27	20.61	21.97
		Thermal Regime Classification	Cool	Warm	Cold	Warm		Cool	Cool	Cool
		Average Weekly Fluctuation (°C)	6.30	6.20	2.41	5.25		1.87	6.21	6.51
		Stability Classification	Moderate	Moderate	Stable	Moderate		Stable	Moderate	Moderate
CC002WM	CC002WM	Mean Weekly Temp (°C)	19.85	23.21	19.00	23.45			20.97	21.89
		Thermal Regime Classification	Cool	Warm	Cool	Warm			Cool	Cool
		Average Weekly Fluctuation (°C)	5.94	7.96	6.16	9.61			7.55	7.25
		Stability Classification	Moderate	Moderate	Moderate	Unstable			Moderate	Moderate
CC003WM	CC003WM	Mean Weekly Temp (°C)	20.80	22.58	20.02		22.88	21.02	21.17	20.53
		Thermal Regime Classification	Cool	Warm	Cool		Warm	Cool	Cool	Cool
		Average Weekly Fluctuation (°C)	5.19	6.05	5.21		4.47	7.20	6.77	6.68
		Stability Classification	Moderate	Moderate	Moderate		Stable	Moderate	Moderate	Moderate
CC004	CCWP-12	Mean Weekly Temp (°C)				22.86			20.23	21.39
		Thermal Regime Classification				Warm			Cool	Cool
		Average Weekly Fluctuation (°C)				6.28			8.50	7.14
		Stability Classification				Moderate			Moderate	Moderate
CC005	CCWP-11	Mean Weekly Temp (°C)				21.38				
		Thermal Regime Classification				Cool				
		Average Weekly Fluctuation (°C)				9.64				
		Stability Classification				Unstable				
CC006	CCWP-10	Mean Weekly Temp (°C)				19.60			18.43	19.62
		Thermal Regime Classification				Cool			Cold	Cool
		Average Weekly Fluctuation (°C)				5.97			6.26	6.11
		Stability Classification				Moderate			Moderate	Moderate
CC007	CCWP-09	Mean Weekly Temp (°C)				20.46			18.03	19.34
		Thermal Regime Classification				Cool			Cold	Cool
		Average Weekly Fluctuation (°C)				9.08			6.38	8.43
		Stability Classification				Unsta			Moder	Moder

Temperature Logger Code	Corresponding Fish Site	Variable	2003	2006	2009	2012	2013	2014	2015	2016
						ble			ate	ate
CC008	CCWP-08	Mean Weekly Temp (°C)								17.33
		Thermal Regime Classification								Cold
		Average Weekly Fluctuation (°C)								4.29
		Stability Classification								Stable
CC009	CCWP-07	Mean Weekly Temp (°C)				18.22			17.50	
		Thermal Regime Classification				Cold			Cold	
		Average Weekly Fluctuation (°C)				4.54			6.74	
		Stability Classification				Stable			Moderate	
CC010	CCWP-06	Mean Weekly Temp (°C)							16.98	
		Thermal Regime Classification							Cold	
		Average Weekly Fluctuation (°C)							4.54	
		Stability Classification							Stable	
CC011	CCWP-05	Mean Weekly Temp (°C)							19.68	21.10
		Thermal Regime Classification							Cool	Cool
		Average Weekly Fluctuation (°C)							9.81	11.38
		Stability Classification							Unstable	Unstable
CC012	CCWP-04	Mean Weekly Temp (°C)				21.00			19.15	
		Thermal Regime Classification				Cool			Cool	
		Average Weekly Fluctuation (°C)				13.92			8.39	
		Stability Classification				Unstable			Moderate	
CC013	CCWP-03	Mean Weekly Temp (°C)				17.52			15.84	16.63
		Thermal Regime Classification				Cold			Cold	Cold
		Average Weekly Fluctuation (°C)				6.58			3.46	4.51
		Stability Classification				Moderate			Stable	Stable
CC014	CCWP-14	Mean Weekly Temp (°C)				18.68			16.88	18.50
		Thermal Regime Classification				Cold			Cold	Cold
		Average Weekly Fluctuation (°C)				6.29			7.80	6.26
		Stability Classification				Moderate			Moderate	Moderate
CC015	CCWP-15	Mean Weekly Temp (°C)							21.03	21.97

Temperature Logger Code	Corresponding Fish Site	Variable	2003	2006	2009	2012	2013	2014	2015	2016
		Thermal Regime Classification							Cool	Cool
		Average Weekly Fluctuation (°C) Stability Classification							8.81 Moderate	9.82 Unstable
06010700202	06010700202	Mean Weekly Temp (°C) Thermal Regime Classification							20.86 Cool	23.91 Warm
		Average Weekly Fluctuation (°C) Stability Classification							6.77 Moderate	10.47 Unstable

Appendix E: Riverine Habitat Fish Species Richness

OMNRF Fish Data (1976–2005); TRCA FMP (2000); TRCA RWMP Data (2003–2015); CCWP / Restoration (2015–2016)

Fish Species	FMP Historic	1976	1985	1987	1990	1998	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2011	2012	2014	2015	2016
American Brook Lamprey	x																				
Banded Killifish	x			x																	
Black Crappie	x																	x			
Blacknose Dace	x			x			x	x	x	x	x	x	x			x		x		x	x
Bluntnose Minnow	x			x					x				x			x		x		x	x
Brassy Minnow	x			x					x												
Brook Stickleback	x							x	x		x					x		x		x	x
Brook Trout	x																				
Brown Bullhead	x			x			x		x	x										x	x
Central Mudminnow	x																				
Common Carp	x																				
Common Shiner	x	NS	NS	x	NS			x					x	NS	NS	x	NS	x	NS	x	
Creek Chub	x			x			x	x	x	x	x	x	x			x		x		x	x
Emerald Shiner	x																				
Fathead Minnow	x			x			x	x	x	x			x			x		x		x	
Finescale Dace											x	x									
Golden Shiner	x									x											
Johnny Darter	x			x			x	x	x	x	x	x	x			x		x		x	x
Largemouth Bass	x						x													x	x
Logperch	x						x		x	x											
Longnose Dace	x						x			x	x	x	x					x		x	x
Mottled Sculpin	x						x														
Northern Pike	x															x					
Northern Redbelly Dace	x						x	x	x	x	x	x								x	x
Pumpkinseed	x			x		x	x		x	x	x	x	x			x		x		x	x

CCWP / Restoration

TRCA FMP

TRCA RWMP Data

OMNRF Fish Data

Fish Species	FMP Historic	1976	1985	1987	1990	1998	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2011	2012	2014	2015	2016
Rainbow Darter	x																				
Rainbow Trout	x						x									x		x			
Redside Dace	x							x												x	x
Rock Bass	x			x																	
Rosyface Shiner	x																				
Round Goby																		x		x	
Sand Shiner	x																				
Smallmouth Bass	x								x												
Spotfin Shiner	x																				
Spottail Shiner	x																				
Stonecat	x																				
Tessellated Darter						x	x														
Threespine stickleback	x																				
Walleye	x																				
White Bass	x																				
White Perch	X																				
White Sucker	x			x		x	x	x	x		x	x	x			x		x		x	x
Yellow Perch	x			x									x								x
Riverine Species Richness				13		3	14	9	13	10	9	8	10			11		13		15	13
Carruthers Watershed Species Richness		10	13	13	16	3	25	8	21	14	9	8	14	8	2	14	9	13	12	18	19