10 Year Assessment of Stream Health at the *rare* Charitable Research Reserve 2006-2016

Prepared by:
Allie Abram
Christine Head
Jenna Quinn

February, 2018

Acknowledgements

Many thanks to Natural Resources Canada Science and Technology Internship Programs, RBC Bluewater Project, Region of Waterloo, John and Pat McCutcheon Charitable Foundation and Maxxam Analytics (in-kind support) for providing funding for the ***rare*** Aquatic Monitoring program.

Thank you to the many volunteers who assisted with field data collection and lab work throughout the years and to Mark Pomeroy and Joe Keene for their support and assistance with field work, invertebrate identification, and especially with compilation of this report, your knowledge and input has been invaluable.

Table of Contents

1.0 Introduction 8
1.1 Monitoring Objective and Purpose 8
1.2 Past monitoring at ***rare*** 9
1.2.1 Water Quality 9
1.2.2 Benthic Macroinvertebrates 9
1.2.3 Fisheries Monitoring 9
2.0 Methods 9
2.1 Sampling Locations and Site Selection 9
2.1.1 Water Quality and Benthic Macroinvertebrates 11
2.1.2 Electrofishing 11
2.2 Sampling Location and Site Descriptions 11
2.2.1 Bauman Creek 11
2.2.2 Cruickston Creek 12
2.2.3 Newman Creek 14
2.2.4 Blair Flats Wetland 15
2.2.5 Preston Flats Wetland 16
2.3 Field Sampling and Processing 16
2.3.1 Water Quality 16
2.3.2 Benthic Macroinvertebrates 17
2.3.3 Fisheries 18
2.4 Data Analysis 19
3.0 Results and Discussion 22
3.1 Water Quality Results 22
3.1.1 Bauman Creek 22
3.1.2 Cruickston Creek 24
3.1.3 Newman Creek 26
3.1.4 Wetlands 28
3.2 Water Quality Discussion 29
3.2.1 Inorganic Concentrations 29
3.2.2 Metal Concentrations 30
3.2.3 Nutrient Concentrations 33
3.2.4 Physicochemical Properties 33
3.3 Benthic Macroinvertebrates Results 33
3.3.1 Bauman Creek 33
3.3.2 Cruickston Creek 38
3.3.3 Newman Creek 41
3.3.4 Wetlands 41
3.4 Benthic Macroinvertebrates Discussion 42
3.4.1 Metrics and Taxa Richness 43
3.4.2 Seasonal Differences in Creek Health 43
3.4.3 Bauman Creek 43

3.4.4 Cruickston Creek 44
3.4.5 Newman Creek 45
3.4.6 Wetlands 45
3.5 Fisheries Results and Discussion 46
4.0 Summary and Conclusions 49
4.1 Creeks 49
4.2 Wetlands 49
5.0 Recommendations 50
5.1 Water Quality 50
5.2 Benthic Macroinvertebrates 50
5.3 Fisheries 51
6.0 References 52
7.0 Appendix 59
7.1 Field Sampling and Lab Processing 59
7.2 Data Analysis 69
7.3 Raw Data and Metrics 70
7.4 Reference Data 98

List of Figures

Figure 1: Property boundary highlighting main aquatic monitoring locations at ***rare***. 10

Figure 2: Newman Creek and Grand River watershed limits (City of Cambridge 2014). 10

Figure 3: Water quality, Benthic macroinvertebrate (all sites) and fisheries (B3A, B4, B5) monitoring sites on Bauman Creek. 12

Figure 4: Water quality, benthic macroinvertebrate (all sites) and fisheries monitoring sites (C1, C2, C4, C5, C7). 14

Figure 5: Water quality and benthic macroinvertebrate monitoring sites on Newman Creek. 15

Figure 6: Water quality and benthic macroinvertebrate monitoring sites at Preston Flats Wetland and Blair Flats wetlands. 16

Figure 7: Formulas used for calculating Hilsenhoff Biotic Index, Shannon-Wiener Diversity Index, Simpson Complement Index and Shannon's Equitability Index. 21

Figure 8: Dissolved Chloride concentrations at Bauman Creek, 2016. 22

Figure 9: Dissolved Chloride at Newman Creek in 2016. Dashed line indicates CCME chronic chloride threshold level. 27

Figure 10: Dissolved Chloride concentrations at the wetlands in 2016. Dashed line indicates CCME chronic chloride threshold level. 28

Figure 11: Per cent EPT at Bauman Creek from spring sampling in 2006 to 2015. EPT is the combined per cent Trichoptera, Plecoptera and Ephemeroptera. Per cent EPT below the lower dashed line (<5) indicates that the sites are impaired, between the lines (5-10) potentially impaired and above the upper line unimpaired. 36

Figure 12: Per cent EPT at Bauman Creek from fall sampling in 2006 to 2015. EPT is the combined per cent Trichoptera, Plecoptera and Ephemeroptera. Per cent EPT below the lower dashed line (<5) indicates that the sites are impaired, between the lines (5-10) potentially impaired and above the upper line unimpaired. 37

Figure 13: Per cent Oligochaeta at Bauman Creek in spring and fall 2006 to 2015. Per cent Oligochaeta above the upper dashed line (>30) indicate that the site is impaired, between the lines (10-30) potentially impaired, and below the bottom line (<10) unimpaired. 38

Figure 14: Taxa Richness at sites C3 and C4 at Cruickston Creek before and after culvert removal. Dashed line indicates impaired (below) and unimpaired (above). 40

Figure 15: Density at sites C3 and C4 before and after culvert removal. Density is the number of individuals per square foot. 40

Figure 16: Per cent composition of species caught at sites B5, B3a, and B3 in Bauman Creek in 2016. 47

Figure 17: Per cent Brook Trout population caught in major length classes in Bauman Creek in 2009 and 2016. 48

Figure 18: Comparison of Brook Trout age classes in Bauman Creek in 2009 and 2016 48

List of Tables

Table 1: Metals that exceeded threshold values at Bauman Creek. 23

Table 2: Total phosphorus (TP;µg/L) concentrations at Bauman Creek sampled in the Fall and Spring of 2015 24

Table 3: Total Nitrate Nitrogen concentrations (mg/L) at Bauman Creek in the Spring and Fall of 2015 24

Table 4: Metals that exceeded threshold values at Cruickston Creek. 25

Table 5: Total phosphorus (TP;µg/L) concentrations at Cruickston Creek sampled in the Fall and Spring of 2015 25

Table 6: Total Nitrate Nitrogen concentrations (mg/L) at Cruickston Creek in the Spring and Fall of 2015 26

Table 7: Metals that exceeded threshold values at Newman Creek. 27

Table 8: Metals that exceeded threshold values at Blair Flats and Preston Flats Wetlands. 29

Table 9: Sites designations at Bauman Creek in spring 2006 to 2015. 34

Table 10: Sites designations at Bauman Creek in Fall 2006 to 2015. 34

Table 11: Sites designations at Cruickston Creek in spring 2006 to 2015. 39

Table 12: Sites designations at Cruickston Creek in Fall 2006 to 2015. 39

Table 13: Sites designations at Newman Creek in Spring 2016. 41

Table 14: Sites designations at Blair Flats and Preston Flats Wetlands in Spring 2009 to 2015. 42

Table 15: Sites designations at Blair Flats and Preston Flats Wetlands in Fall 2009 to 2015. 42

List of Acronyms and Abbreviations

Acronym	Description
BMI	Benthic Macroinvertebrate
CABIN	Canadian Aquatic Biomonitoring Network
CCME	Canadian Council of Ministers of the Environment
DFO	Fisheries and Oceans Canada
DO	Dissolved Oxygen
EPT	Ephemeroptera, Plecoptera, Trichoptera
N.D.	No date (associated with reference)
OBBN	Ontario Benthos Biomonitoring Network
OSAP	The Ontario Stream Assessment Protocol
PWQO	Provincial Water Quality Objectives
H	Shannon- Weiner Diversity Index
Simpson	Simpson Complement Index

List of Terms

Anthropogenic: of, relating to, or resulting from the influence of human beings on nature.

Benthic Macroinvertebrates: animals without backbones that live on the bottom substrate of a watercourse or waterbody and are visible to the naked eye.

Physicochemical Properties: tested parameters including dissolved oxygen, pH, conductivity, and temperature.

Ecological Health: the ability of an ecosystem to resist and recover from a range of disturbances, while maintaining its functions and processes.

Ecological Threshold (threshold): "the point at which there is an abrupt change in an ecosystem quality, property or phenomenon, or where small changes in an environmental driver produce large responses in the ecosystem" (Groffman et al. 2006).

D-Net: a D-shaped net made of canvas used for kick-and-sweep sampling of benthic macroinvertebrates.

Freshet: melting of snow and ice in watercourse from spring thaw

Mining: aggregate mining practices that are occurring in close proximity to ***rare*** property. Hydrological conditions may be affected by nearby aggregate operations, including impacts on the quality and quantity of water.

Pollutant: a substance that pollutes something, especially water or the atmosphere.

Runoff: The part of the precipitation, snow melt, or irrigation water that drains into streams, rivers, drains or sewers.

Sampling Location: a creek or wetland that contains sites where sampling occurs.

Site: the particular location within a sampling location that is being sampled.

Surber Sampler: a mesh net of a given size used for surber sampling of benthic macroinvertebrates.

Surber Sampling: a quantitative method for sampling benthic macroinvertebrates using a surber sampler.

Thalweg: the line where maximum depth and velocity occurs in a stream.

Travelling-Kick-and-Sweep Method: a qualitative sampling method for sampling benthic macroinvertebrates using a D-net.

Water Quality Testing: testing water physicochemical and biological properties.

1.0 Introduction

Aquatic systems are vital for all natural and human processes to occur. They provide countless ecological, social, and economic functions including agriculture, recreation, industry, and increasing biodiversity (Carpenter et al. 1998; Gleick 1996; Gleick 2000; Walsh et al. 2005).

These systems can; however, become deteriorated over time as a result of human influence and land use practices (Walsh et al. 2005; Carpenter et al. 1998). In order to detect and mediate these changes, regular monitoring and appropriate management is necessary (Walsh et al. 2005). Aquatic monitoring consists of water quality, benthic macroinvertebrate and fisheries surveys to document and track aquatic health (Kilgour and Barton 1999).

Water quality parameters are used to determine a waterbody's ability to support life. The quality of water in a system is based on the natural and anthropocentric processes in the region (Regional Aquatics Monitoring Program N.D).

Benthic macroinvertebrates are commonly used to document stream condition for a variety of reasons:

(1) they are ubiquitous in most aquatic systems and are likely to be affected by a range of perturbations occurring in a range of different habitats,
(2) their taxonomic diversity means they exhibit a variety of responses to a variety of different perturbations,
(3) their sedentary nature allows researchers to locate the spatial extent of perturbations, and
(4) they are critical components of their food webs such that changes affecting them are likely to cascade to other trophic levels (Merritt and Cummins 1996; Richardson and Jackson 2002; Kilgour and Barton 1999; Suozzo 2005).

Fisheries surveys are used to identify changes in aquatic ecosystem health. As members of a high trophic level, fish reflect the overall condition of the environment in which they reside (Munkittrick and Dixon 1989).

1.1 Monitoring Objective and Purpose

The aquatic monitoring program at ***rare*** was implemented to examine the ecological health of the creeks and wetlands on the property. The capacity of individual ecosystems to remain ecologically healthy is dependent on unique characteristics of each ecosystem. Therefore, although we monitor similar indicators for all waterbodies at ***rare***, consideration is given to the individual characteristics of each waterbody when evaluating ecological health as variables that might indicate poor health for one watercourse may not for another.

Water quality, benthic macroinvertebrate and fisheries surveys are used as indicators of stream health and the collected data are the basis for a long-term monitoring program. The goal of this program is to collect long-term data to inform management plans, restoration activities, and future research projects. The following questions form the basis of this program, initially proposed in 2006 and revised in 2009:

1. What is the current state of ***rare's*** aquatic ecosystems and how do they compare to one another?
2. What are the long-term trends taking place within the aquatic ecosystems at ***rare***?
3. Is the ecosystem integrity of these aquatic ecosystems being maintained or improved under ***rare*** management?
4. What is the quality of the aquatic and riparian habitat of the aquatic ecosystems at ***rare***, and how do they compare with one another?

5. Is either the ecological health or integrity of ***rare's*** aquatic ecosystems being affected by on-site changes in agriculture and/or restoration efforts being implemented by ***rare***?

As defined by the above questions, the purpose of this report is to (1) identify trends and changes in the creeks and wetlands using long-term water quality and benthic data; (2) document changes in benthic macroinvertebrate taxa within creeks over time; (3) identify common nutrient concentrations and potential sources; and (4) investigate distribution and composition of fish populations.

1.2 Past monitoring at *rare*

1.2.1 Water Quality

Water quality samples were collected from eight sites along Bauman Creek in 2002 (Barfoot 2003). Several water parameters were measured at each site, including chloride, nitrate, total suspended solids, turbidity, phosphate, pH and conductivity.

1.2.2 Benthic Macroinvertebrates

A benthic macroinvertebrate monitoring program was piloted at ***rare*** in 2006, and is now repeated every three years. In 2006, two sites were sampled on Cruickston Creek (C1B and C2; Figure 4), and four sites were sampled along Bauman Creek (B1, B2, B3 and B4; Figure 3).

In 2009, the monitoring program was expanded to include three additional sites along Cruickston Creek (C3, C4 and C5, Figure 4) and two wetland locations, Blair Flats and Preston Flats (Figure 8). In 2012, site B5 was added to the Bauman Creek monitoring program (Figure 3) in response to inconsistent water flow at existing sites.

In both years, sites were selected using a random stratified sampling technique based on habitat type in accordance with the Ontario Benthos Biomonitoring Network (OBBN) protocol.

1.2.3 Fisheries Monitoring

Prior to ***rare*** taking ownership of the land, a fish population survey was completed by CH2M Gore & Storrie Ltd (1997) in 1994 along Bauman Creek. The survey found three species of fish residing in Bauman Creek: Brook Trout (*Salvelinus fontinalis*), Brook Stickleback (*Culaea inconstans*), and Creek Chub (*Semotilus atromaculatus*).

2.0 Methods

2.1 Sampling Locations and Site Selection

Aquatic monitoring occurred at ***rare's*** three creeks and two wetlands in 2016: Bauman Creek, Cruickston Creek, Newman Creek, Blair Flats Wetland, and Preston Flats Wetland (Figure 1) located within the Grand River watershed (Figure 2). See Appendix 7.1.1 for specific site coordinates.

Figure 1: Property boundary highlighting main aquatic monitoring locations at ***rare***.

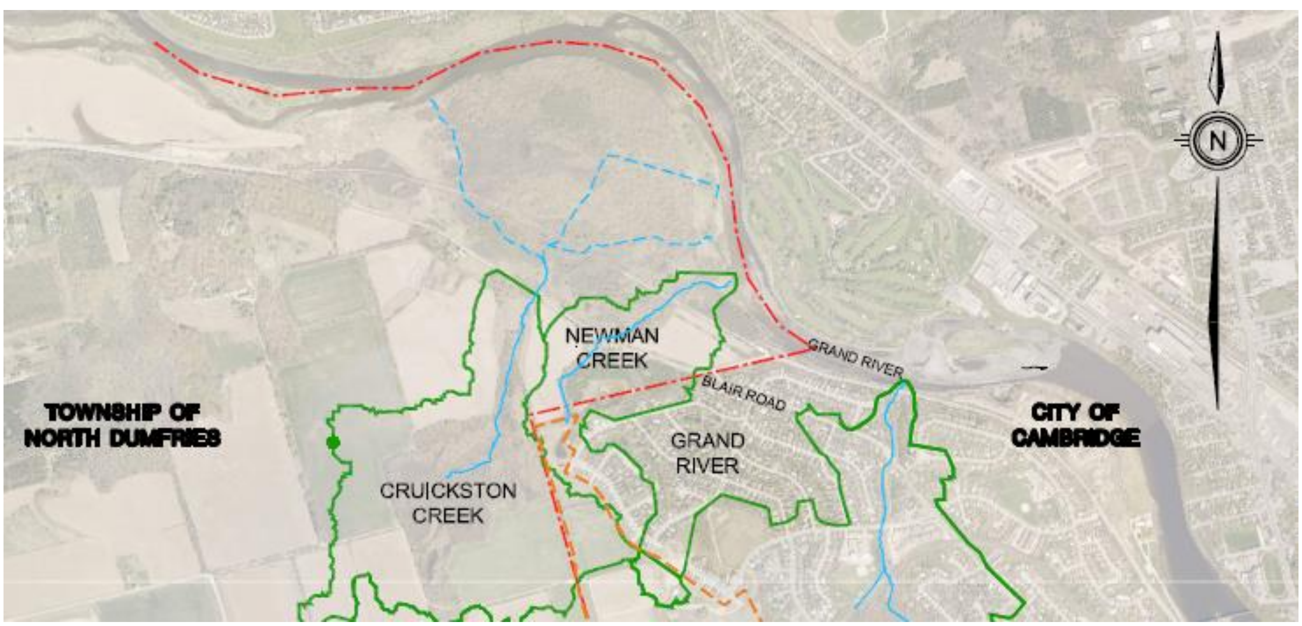


Figure 2: Newman Creek and Grand River watershed limits (City of Cambridge 2014).

2.1.1 Water Quality and Benthic Macroinvertebrates

Sites added at Newman Creek in 2016 were chosen to accommodate all aquatic monitoring. Habitat assessment of the creek was conducted in late May/ early June to map the macrohabitat and surrounding land use disturbances. In accordance with the Canadian Aquatic Biomonitoring Network (CABIN 2012) protocol, sampling sites were selected as representative areas of different habitat and disturbance levels. When possible, sites were a minimum of 40 m in length and separated by 40 m (Stanfield 2013). As Newman Creek has discontinuous flow and multiple channels, sites were placed in closer proximity and have shortened lengths to accommodate more sampling locations. Each site began and ended at a cross-over, where the thalweg crosses over the middle of the stream channel. If cross-overs were difficult to distinguish, they were considered areas with uniform bank height and water depth (Stanfield 2013). Within each sampling reach there were at least two riffles and one pool. When a riffle pool sequence could not be found, a "functionally defined riffle and pool" was used; riffle area of shallow, fast moving water, pool area of deep and slow moving water (Stanfield 2013).

Monitoring sites were numbered, beginning at the most downstream site and increasing upstream to avoid disturbance of sites prior to sampling (Jones et al. 2007).

2.1.2 Electrofishing

Electrofishing sites were selected to gain an understanding of the fish communities present at ***rare*** and within each creek system. Specific to Bauman Creek, sites were chosen to track changes in the resident Brook Trout population, determine Brook Trout distribution and expansion, and identify the presence of any additional fish species. As past electrofishing records show no present fish populations in Cruickston Creek, sites were selected to determine fish presence or absence throughout the entirety of the creek.

The Ontario Stream Assessment Protocol (OSAP) site selection guidelines and Fisheries and Oceans Canada (DFO) fish species at risk protocol were used to select appropriate sampling sites. Where possible, sites were approximately 40 m in length, placed a minimum of 40 m apart, beginning and ending at a cross-over (Stanfield 2013). Fish sampling sites were proposed to ensure adequate sampling coverage along the creeks and within varying habitats.

In 2009, six sites were sampled in total: one on Bauman Creek and five on Cruickston Creek (Figures 3 and 4). A total of eight electrofishing sites were sampled in 2016. Sites were selected along Newman Creek but were not able to be sampled due to low flow.

2.2 Sampling Location and Site Descriptions

2.2.1 Bauman Creek

Bauman Creek is a first order cold-water tributary of the Grand River (***rare*** Environmental Management Plan 2014). This creek is less than two kilometres in total length and drains an area of approximately 211 ha (Holton 2006; Hunter and Associates 2016). South of Blair Road, the river flows through Indian Woods, a remnant old-growth forest that makes up a portion of the 148 acres of continual mature and maturing forest. Bauman Creek contributed to the Blair Flats wetland and is included in the Barrie's Lake-Bauman Creek Provincially Significant Wetland Complex (***rare*** Environmental Management Plan 2014).

There are five benthic macroinvertebrate and water quality sampling sites on Bauman Creek. Three sites are located north of Blair Road: B1, B2 and B5 (Figure 3). Site B1 is the farthest north and most downstream site and is located in riparian grassland. Due to limited water, this site has not been sampled since fall 2009. Site B2 is located at the confluence of the new and old stream channels. Site B5 is located closest to Blair Road at the northern culvert exit, and has uniform gravel substrate with frequent bank undercuts. Riffle and pool sections were infrequent and only occurred as a result of instream debris build-up. Two sites are located south of Blair Road; B3 and B4. Site B3 is located downstream of the creek impoundment within a deciduous forest with full canopy cover and numerous groundwater seeps. The substrate is dominated by a mixture of gravel and cobble with frequent instream cover objects and undercuts, and riffle and pool sequences were evident throughout the sampling reach. Site B4 is the farthest upstream site located in a swamp region, just downstream of Bauman Creek headwaters. The stream is much slower moving at this site and thick with organic matter.

Three fish sampling sites are located on Bauman Creek: B3, B3A, and B5 (Figure 3). All sites are located downstream of the impoundment due to limited flow near Bauman Creek headwaters. Site B3 and B5 mimic the above described benthic macroinvertebrate and water quality sites. Site B3A was added in 2016 and is located approximately 30 m upstream from the Blair Road south side culvert. This site is fully shaded by deciduous forest canopy cover. The substrate was a mixture of cobbles and gravel with in-stream cover objects, riffles, and pools.

Figure 3: Water quality, Benthic macroinvertebrate (all sites) and fisheries (B3A, B4, B5) monitoring sites on Bauman Creek.

2.2.2 Cruickston Creek

Cruickston Creek is a first order cool-water tributary of the Grand River. It is two kilometres in length and drains an area of approximately 90.23 ha (Holton 2006; Hunter and Associates 2016). The headwaters of the creek lie within the Hogsback forest in the southeast corner of ***rare's*** property (Figure 1). The Hogsback forest is a 57 acre (42 of which lie within ***rare's*** boundary) deciduous forest and swamp area. Historically, this area was largely isolated from human development, with a subdivision located outside ***rare's*** eastern property line. An additional subdivision is planned for development just south of the Hogsback's southern edge (***rare*** Environmental Management Plan 2014).

South of Blair Road the creek flows through closed canopy forested areas intermixed with grassland regions. Immediately north of Blair Road, the creek flows through an open meadow. The channel loses definition as it flows into a Silver Maple swamp and re-channelizes north of the Grand Trunk Trail (***rare*** Environmental Management Plan 2014). Historically, the fields east and west of the creek along the south side of Blair Road were in agricultural production. The fields have since been removed from production and have undergone restoration efforts and naturalization since 2003.

There are six benthic macroinvertebrate and water quality sampling sites on Cruickston Creek (Figure 4). All sites are located south of Blair Road, with the exception of C7. Sites C3 and C4 are located on the south and north sides of the Springbank Lane footbridge, formerly a perched culvert that has since been removed. The area has undergone restoration efforts, and sites C3 and C4 were included to monitor the health of the creek before and after the perched culvert removal in 2015. Site C1 (later divided into two separate sites: C1A and C1B) is located within a forested area where the channel widens. An additional quantitative sample was included at C1A to allow for more direct year to year comparisons in response to the aforementioned planned housing development. Site C1 is located in a region with a mixture of full sun and full shade. The substrate is a mixture of gravel, cobbles, and boulders with infrequent riffle and pool sequences. Site C2 is located in a small forest clearing, west of an active agricultural field. It is shaded by partial canopy cover and has minimal instream cover objects and undercuts. This site is dominated by silt substrate and organic material. The most southern site, C5, is located in the centre of the Hogsback forest, under full forest canopy and surrounded by swamp. It is dominated by silt substrate and organic matter. Instream cover objects, downed logs, and undercuts were common in this reach. Water flow was slow and stream morphology was dominated by pools. C5 was added to better monitor changes occurring near the headwaters of the creek based on its proximity to a housing development. C7 was added in 2016 to document water quality parameters south of Blair Road. This site is the farthest downstream location and is within a purple-aster dominated meadow, approximately three metres downstream of the Blair Road culvert outfall. It is partially shaded by overhanging riparian vegetation and is dominated by gravel and silt substrate. Riffle and pool morphologies were limited to the upstream end of the sampling site.

Five sites were chosen along Cruickston Creek for fisheries sampling (C7, C4, C1, C2 and C5) (Figure 4). Cruickston Creek fishing sites are located at benthic macroinvertebrate and water quality sampling sites. Site C4 was moved farther upstream from the benthic macroinvertebrate and water quality site to accommodate the 40 m distance between sites. The new site location lies within a grassland/meadow dominated habitat with a small area providing partial canopy cover. The substrate consists mainly of gravel, interspersed with boulders.

Figure 4: Water quality, benthic macroinvertebrate (all sites) and fisheries monitoring sites (C1, C2, C4, C5, C7).

2.2.3 Newman Creek

Newman Creek is an ephemeral stream located on the eastern edge of the ***rare*** property line and drains an area of approximately 20.46 ha (Hunter and Associates 2016) (Figure 1). Newman Creek is part of the Grand River watershed, and historically drained into the Grand River (Figure 2). Due to the housing development located near the creek, water within the Grand River watershed now by-passes Newman Creek and flows directly into the Grand River via storm water ponds. The water diversion has resulted in diminished flows for Newman Creek (Hunter and Associates 2016). This creek is surrounded by several established land use practices including an active agricultural field, housing development and major roads. Furthermore, an additional housing development is proposed along the southern region of Newman Creek.

Newman Creek originates from two storm water retention ponds and flows north through a forest/grassland transitional zone to a grassland clearing. The creek splits into multiple channels through a coniferous mixed forest and re-converges into a single channel which exits into a marshland. The creek continues north under Blair Road, towards the Grand Trunk Trail and onwards to the Grand River. It is currently unclear if surface water from Newman Creek reaches the Grand River.

Five sites were proposed on Newman Creek in 2016 to accommodate benthic macroinvertebrate and water quality sampling. Due to lack of flow, site NM2 was removed from sampling (Figure 5).

NM1, NM3, NM4 and NM5 were sampled as water quality sites and NM3 and NM4 were benthic macroinvertebrate sites. NM1 is located north of Blair Road at the culvert exit. There is no defined stream channel, and the water pools in a wetland environment. NM3, NM4 and NM5 are located south of Blair Road. The most upstream water quality site, NM5 is located within the second storm water retention pond. The sample was taken at the pond edge within a thicket of cattails as the pond was not accessible. Site NM4 is located ten metres downstream of where water exits the storm water retention pond. The site is at the beginning edge of a forest/grassland transitional area with partial to full canopy cover. It is neighboured by a farm field directly west and a suburban housing development to the east. NM3 is situated within open grassland with sparse trees providing partial canopy cover.

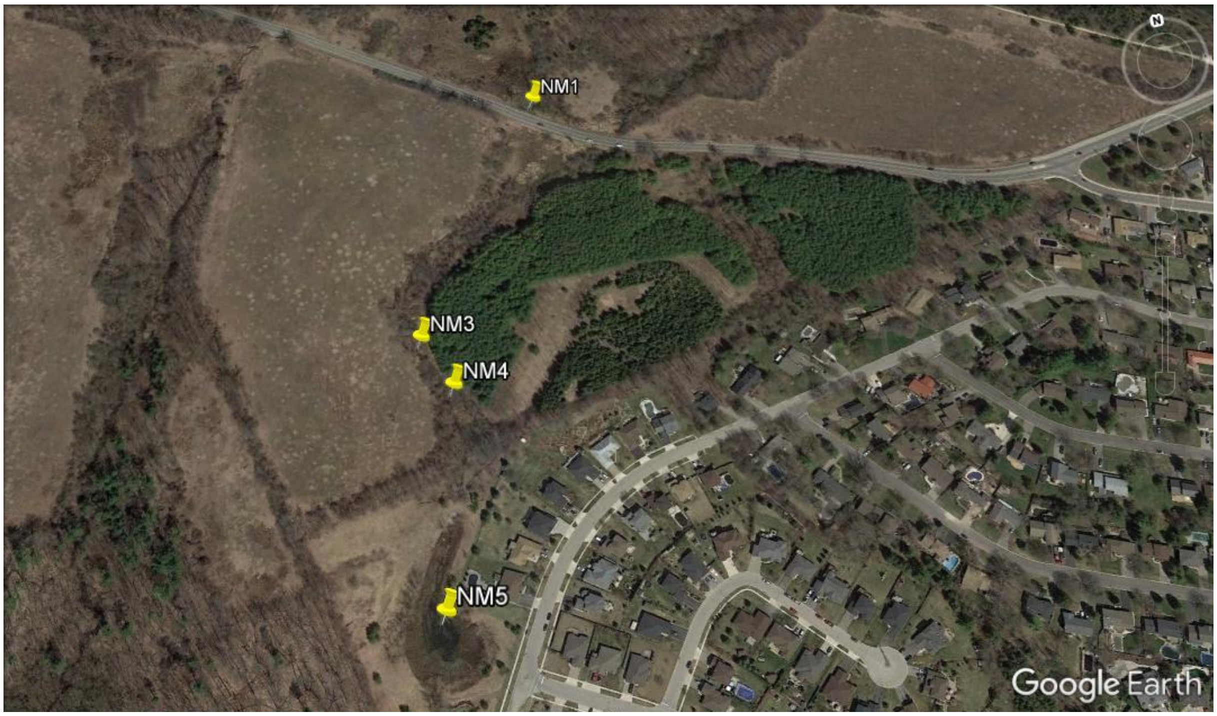


Figure 5: Water quality and benthic macroinvertebrate monitoring sites on Newman Creek.

2.2.4 Blair Flats Wetland

Blair Flats Wetland is located on the north side of Blair Road and is approximately 30 m wide and 200 m long, covering 0.60 ha (Hunter and Associates 2016; GRCA personal communication) (Figure 1). Blair Flats Wetland is a part of the Barrie's Lake-Bauman Creek Provincially Significant Wetland Complex, classified by the Ministry of Natural Resources and Forestry. It has also been given the designation of Environmentally Sensitive Policy Area #38, which is a locally significant biological area for wildlife. It supports large flocks of migrant waterfowl and overwintering birds, and in 2009 resident muskrat (*Ondatra zibethicus*). The land surrounding Blair Flats Wetland was conventionally farmed for over 100 years, resulting in a redirection of water to facilitate production. In 2005 and again in 2008, specific sections were removed from agriculture and left to naturalize. Additionally, a long-term project by the University of Guelph restored approximately 40 acres to tall grass prairie (***rare*** Environmental Management Action Plan 2015). This sampling location was initially added to monitor the changes as the flats underwent restoration from conventional agriculture to naturalized grasslands. The Blair Flats sampling site is located on the southwestern edge of the wetland and is predominately vegetated by cattails. This sampling region is surrounded by tall grass prairie (Figure 6).

2.2.5 Preston Flats Wetland

Preston Flats is located east of Fountain Street at the northern limit of the ***rare*** property (Figure 1). The wetland is approximately 25 m wide and 75 m long, covering 0.19 ha (Hunter and Associates 2016; GRCA personal communication). Preston Flats was farmed for over 40 years, rotating corn and soybean crops. Two areas were taken out of production in 2008: a 100 m wide strip of land along the Grand River to create a buffer between the farmed field and the rivers, and a small strip of land along the northern edge of the flats to establish a wildlife corridor. New projects set to impact Preston Flats include widening Fountain Street which began in December 2016, and changing the agriculture production to less-intensive hay crop.

The Preston Flats sampling site is located along the northern edge of the wetland in a dense thicket of cattails. Surrounding habitat is dominated by grassland vegetation, with an agricultural field to the south (Figure 6).

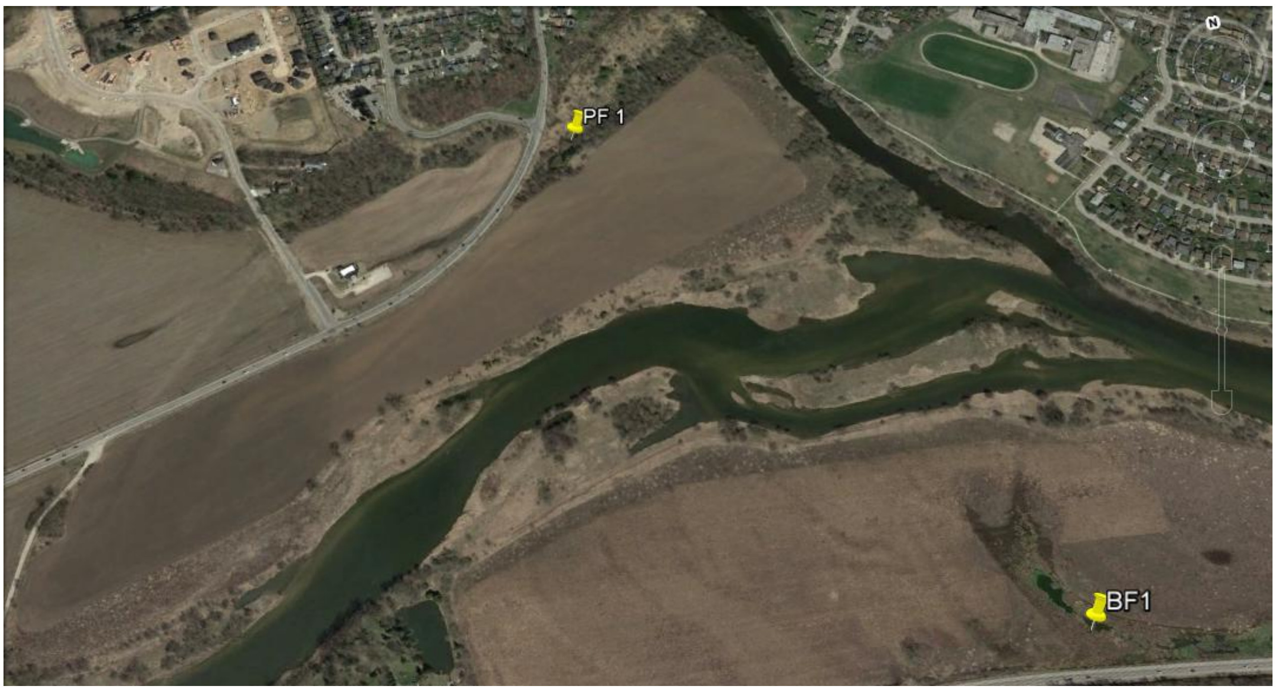


Figure 6: Water quality and benthic macroinvertebrate monitoring sites at Preston Flats Wetland and Blair Flats Wetland.

2.3 Field Sampling and Processing

2.3.1 Water Quality

Water samples were collected in June and September 2016 from water quality sites in ***rare*** waterbodies. Due to limited water during the fall sampling period, only one site (NM5) was sampled along Newman Creek. Additionally, water samples were collected in 2015 from Cruickston (sites C1 and C4) and Bauman Creeks (sites B3 and B5) and were tested for total phosphorus and total nitrate nitrogen in partnership with Dr. Pat Chow-Fraser and students from McMaster University. Site location coordinates can be found in Appendix 7.1.1.

Field Sampling and Laboratory Testing

Field sampling protocols were adapted from the CABIN protocol (2012) to accommodate wetland sampling, stagnant flow and low water depth.

A combination of physicochemical properties, organic, and inorganic elements were tested at the ***rare*** watercourses in 2016. Parameters tested included total suspended solids, chloride and twenty-one metals.

Water samples were collected by ***rare*** staff and analyzed by Maxxam Analytics. Prior to collecting water samples, site sample bottles were labelled with site name, organization name, date and time of sampling. Samples were collected in the middle of the stream in flowing water. In wetland habitats, samples were collected as close to the centre of the wetland as possible. To prevent the collection of surface particles, the sample bottles were fully submerged into the water source. Careful precaution was used to not touch the bottle mouth or inside of bottle lid while collecting a sample. Once the collection bottle was filled, the lid was secured to the bottle and placed in a re-sealable plastic bag for transport and separation from other sites.

At each sampling site, parameters including DO, pH, water temperature and conductivity were measured using a Hydrolab Quanta Multi-Probe Meter. Stream name, site number, sampling time, site coordinates, and site descriptions were documented on field sheets.

After daily sampling was complete, samples were stored at 4˚C, in a dark area to prevent bacteria and organism growth (CABIN 2012) and were subsequently delivered to the Maxxam Analytics office for analysis.

2.3.2 Benthic Macroinvertebrates

Newman Creek was the only site where benthic sampling occurred in 2016. Due to limited flow, only two sites (NM3 and NM4) were sampled in the spring out of the proposed four. No samples were collected in the fall months. A complete list of equipment needed for sample collection and processing is included Appendix 7.1.2

Field Sampling

In previous years, both spring/early summer (June – July) and fall (September – October) samples were collected at each site. In 2016 all sampling occurred in June. All sampling followed the OBBN recommended protocol for streams (Jones et al. 2007; Holton 2006; McCarter 2009).

Three replicate transects were sampled at each site within the creek: 1) downstream riffle, 2) pool and 3) upstream riffle. Sites were sampled in sequence downstream to upstream to minimize downstream site disturbance and sample contamination. In Blair Flats and Preston Flats, three sampling sites in each wetland were treated as replicates. Each transect was sampled using the travelling-kick-and-sweep technique (Jones et al. 2007). To sample, a 500µm-mesh D-net was placed on the stream bottom immediately downstream of the riffle or pool being sampled. The sampler slowly moved upstream in a zig-zag motion from bank to bank vigorously kicking the substrate and disturbing it to a depth of approximately 5 cm. While kicking the substrate, the sampler concurrently swept the D-net back and forth throughout the water column (Stanfield 2013). Macroinvertebrates residing in the benthic layer were swept downstream by the current and trapped in the D-net. Sampling continued for approximately three minutes.

After a sample was collected, the full contents of the D-net were rinsed with water from the creek and carefully scooped with a plastic ladle into a large labelled wide-mouth plastic jar. Large sticks and rocks were removed from the sample, thoroughly rinsed over the net and replaced in the creek. The three replicate samples collected from each site were stored in separate wide-mouthed jars and labelled.

Once sampling was complete, the sampling duration, distance sampled, and other variables were recorded on field data sheet (Appendix 7.1.3). Variables measured at each site included air temperature, water velocity and stream depth and width. Water velocity was recorded using the timed-float technique, in which a float (ping pong ball) was dropped into the stream and timed for a distance of one metre. This was repeated three times to determine average stream velocity in metres per second (m/s). Dissolved oxygen (DO), pH, water temperature and conductivity were also measured using a Hydrolab Quanta Multi-Probe Meter. Visually, macrophyte and algae abundance was recorded in addition to substrate description and water clarity/color. No pH values were recorded at Bauman Creek in 2009 due to equipment malfunction.

Prior to sorting, samples were preserved in 37 per cent formalin, adding formalin to make up approximately 10 per cent of the sample volume. Preserved jars were labelled in triplicate on the jar base, lid, and with a waterproof label inside the jar. Preserved jars were stored in the lab until sorting. This sampling technique was repeated for all replicates within the site.

In previous years, wetland samples and supplemental surber samples have been taken. For sampling methodology please refer to the McCarter (2009) or the OBBN Protocol Manual (Jones et al. 2007).

Lab Analysis

Prior to sorting, each preserved samples was poured through a 500 μm sieve and thoroughly rinsed to remove excess sediment and formalin. The cleaned sample was poured into a bucket which was filled to 3.5 L with tap water. The bucket's contents were stirred vigorously before a subsample was ladled into a measuring cup. For kick-and-sweep samples, a minimum of 100 individuals were collected for each sample. To calculate the per cent picked for "100-count", the volume of the removed subsample was recorded. This method of sampling is called the 'bucket sub-sampling method'. It ensures each subsample was randomly taken from the larger sample, helping to decrease potential bias (Jones et al. 2007). Using a dissecting microscope, all organisms found were identified to the OBBN 27 coarse-level benthic groups. Once sorted, individuals were placed in 70 per cent ethanol solution. Subsequent subsamples were taken from the bucket until the 100-count was met. All data, including per cent sorted and number of individuals found within each group, were recorded on the data sheet provided by OBBN (Jones et al. 2007). Completed sample data sheets can be found in Appendix 7.1.4.

2.3.3 Fisheries

Fisheries sampling was conducted in late September to accommodate the Brook Trout spawning season and low creek flows. Field sheets, equipment requirements, and site location coordinates can be found in Appendix 7.1.

Field Sampling

Fish sampling methods were adapted from the multiple pass using block nets method presented in OSAP (Stanfield 2013) and the DFO fish species at risk sampling protocol (Portt et al. 2008). Prior to field sampling, ***rare*** requested and was issued a "License to collect fish for scientific purposes" from the Ontario Ministry of Natural Resources and Forestry (OMNRF). For a complete list of sampling equipment, refer to Appendix 7.1.8.

At each sampling location, block nets were placed at the upstream and downstream limits of the sample site to facilitate a multiple pass-survey. DO, pH, water temperature, and conductivity were measured at the downstream end of the sampling reach using a Hydrolab Quanta Multi-Probe Meter prior to sampling. Stream flow was measured using a Global Flow Metre and a visual assessment of water color/clarity was documented.

Sites were sampled with a crew of two to four ***rare*** personnel. In narrow creeks (mainly sampling sites north of Blair Road) two crew members surveyed the reach. In wider sampling areas, an additional netter was used to ensure full coverage of the sites. Based on site size and quantities of fish, it was recommended that a minimum of three personnel form the crew for Bauman Creek, and two personnel for Cruickston Creek.

Crew members entered the stream approximately five metres downstream from the start location, to test and adjust the electrofishing settings. Settings proposed from the ‘quick start’ application were used during sampling; the least amount of current was used to immobilize fish. Crew members then moved to the downstream location, reset the shocker seconds on the electrofishing backpack and began sampling. Sampling began at the downstream end and continued upstream, ensuring all habitats and regions within the creek were sampled. Focus was placed on areas of key habitats such as instream cover objects, large pools, and undercuts to optimize catch results. All fish caught were netted and retained in a bucket for later processing. Each site was sampled three consecutive times. Electrofishing seconds were recorded and reset after the end of each pass. Adequate time was allotted between each pass to let any creek disturbance (e.g., sediment mobilized by walking in the creek) settle out before another pass began. For complete electrofishing stream survey techniques see OSAP manual section S3.M1 page 7-8 (Stanfield 2013).

Fish processing was completed at the end of each pass. Captured fish were placed in a shaded area and had regular water changes to reduce fish stress and mortality. Furthermore, captured fish were placed in multiple buckets to avoid overcrowding during processing. All captured fish were measured for total length, fork length and weight. Brook Trout were weighed individually whereas Brook Stickleback were batch weighed. Once processing was complete for one pass, all fish were released back into the creek outside the sampling area. The remainder of the field data sheet was completed once sampling was finished (Appendix 7.1.9). Creek depths and wetted widths were recorded at the downstream, middle and upstream locations. Finally, block nets were cleaned and removed from the stream.

2.4 Data Analysis

Benthic Community Metrics

Data were analyzed using Microsoft Excel™ 2010. The number of taxonomic groups present was used in place of the number of species in metric calculations.

Six community metrics were calculated for all sites; Hilsenhoff Biotic Index (HBI), Shannon-Wiener Diversity Index (H), Simpson Complement Index (Simpson), Shannon’s Equitability Index (Figure 7), per cent taxa (per cent EPT and per cent Oligochaeta) and Taxa Richness. These metrics were compared to reference values (Appendix 7.2.2), and classified as impaired, potentially impaired, or unimpaired. Reference values were not available for Simpson Complement Index and Shannon’s Equitability Index; however, metrics are presented in Appendix 7.3 for reference.

The dominant results amongst metrics determined if a site was impaired, potentially impaired, or unimpaired (i.e. 3 out of 5 were considered impaired that site would be considered impaired) (Conservation Halton, 2017). When a majority didn’t exist (i.e. 2 references indicated impaired, 2 unimpaired, and one potentially impaired) the site was classified as potentially impaired.

HBI determines stream nutrient status using macroinvertebrate sensitivity to organic pollutants. Scores are determined using a weighted calculation of tolerance values and macroinvertebrate relative abundances. The associated nutrient tolerance value of each benthic macroinvertebrate taxon can be found in Appendix 7.2.1. Scores range from 0-10; low values indicate low nutrient pollution while high values indicate excessive nutrient pollution. Scores were interpreted as unimpaired when < 6, potentially impaired when between 6 and 7, and impaired when >7 (Borisko et al. 2007; Kilgour 1998; Hilsenhoff 1988).

The Shannon-Wiener Diversity Index and Simpson Complement Index are used to measure population diversity. The Shannon-Wiener Diversity Index uses evenness and the total number of taxa to produce a score from 0-4. Zero (0) indicates very low diversity, while 4 is very high diversity; real world values typically fall between 1.5 and 3.5 (Magurran 2004). Simpson Complement Index uses the number of taxa present and their relative abundance to produce a score from 0-1. Zero (0) indicates all organisms belong to the same taxon, while one (1) indicates that the organisms are distributed evenly across all taxa found. Shannon's Equitability Index is used to determine the uniformity of taxa abundance. Values range from 0-1 where zero (0) indicates no evenness; the number of individuals in different taxa groups were extremely variable and were not the same. One (1) indicates that the number of individuals in different taxa groups were very similar and show no variation (Magurran 2004).

Relative abundance was calculated for four taxa groups; Oligochaeta, Ephemeroptera, Plecoptera, and Trichoptera. These groups were chosen because they are indicators for key stream conditions and nutrient loads. Per cent taxa were calculated as the number of individuals in taxon group *i* divided by the total number of organisms found at the site replicate locations. Per cent EPT is a summation of per cent Ephemeroptera, Plecoptera and Trichoptera. High numbers of these groups is considered an indicator of good water quality (Barbour et al. 1999) and per cent EPT is used by many groups in Benthic Macroinvertebrate (BMI) analyses. However, EPT metrics may not be sensitive to all ecological stressors (Herman and Nejadhashemi 2015; Thorne and Williams 1997); therefore these scores should be interpreted with caution. Relatively high per cent Oligochaeta can be an indicator of poorer water quality (lower DO and higher organic pollution) because Oligochaeta are generally more tolerant of, and commonly found in, poor water conditions (Barbour et al. 1996; Borisko 2007).

Mean taxa richness and pooled taxa richness were calculated for all sites. Mean taxa richness is the average number of taxa per replicate. Pooled taxa richness is the total number of distinct groups at each site. Pooled taxa richness values were used to determine the level of impairment at each site.

Sites C1A, C3 and C4 were not included in the analyses above because sites were sampled quantitatively for temporal analysis relating to site-specific questions. Taxa richness and density were calculated for sites C3 and C4, and a more in-depth analysis is planned once more years of data have been collected post restoration. Similarly, changes in C1B will be included in data analysis once several years of data post development have been collected.

$$HBI = \sum \frac{n_i t_i}{N}$$

Hilsenhoff Biotic Index: Where n_i is the number of individuals in group *i*, t_i is the tolerance value of group *i* and N is the total number of individuals

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

Shannon-Weiner Diversity Index: Where p_i is the proportion of individuals belonging to the i^{th} taxon and S is the number of taxa.

$$D = \left(\sum_{i=1}^{S} \frac{n_{i\,(n_i-1)}}{n(n-1)}\right)$$

$$Simpson\ Complement\ Index = 1 - D$$

Simpson Complement Index: Where n_i is the total number of organisms of a particular species, n is the total number of organisms of all species and S is the number of taxa.

$$\boldsymbol{E_H} = \frac{\boldsymbol{H}}{\ln(\boldsymbol{s})}$$

Shannon's Equitability Index: Where H is the Shannon-Wiener Diversity Index and S is the number of taxa.

Figure 7: Formulas used for calculating Hilsenhoff Biotic Index, Shannon-Wiener Diversity Index, Simpson Complement Index and Shannon's Equitability Index.

Water Quality Analysis

Physicochemical properties and concentrations of metals, nutrients and inorganic elements were compared to threshold limits identified by the Provincial Water Quality Objectives (PWQO) (Government of Ontario 1994), Canadian Water Quality Guidelines or the Canadian Council of Ministers of the Environment (CCME) Water Quality Guidelines for Protection of Aquatic Life (Appendix 7.4.2) as well as target values identified in the 2014 ***rare*** Environmental Management Plan (Appendix 7.4.1). Regional values from City of Kitchener Storm Water Management Monitoring Program report (AECOM 2015) were included for additional reference (Appendix 7.4.2).

Only metals that exceeded or approached threshold values were reported. For a complete list of tested parameters and associated values, refer to Appendix 7.3.

Fisheries Analysis

Fisheries data were entered into Microsoft Excel™ 2010 for ease of analysis. Analyses completed included per cent species composition, Brook Trout total length, and age class distribution. Per cent composition used 2016 data compared across all sampling sites. A comparison between Brook Trout length and age in 2009 and 2016 was completed by pooling all data collected from the stream in each year.

Per cent species composition was calculated as the number of species divided by the total number of individuals caught. The Brook Trout total length histogram uses standard length bin sizes from *Freshwater Fishes of Canada* (Scott and Crossman 1998). The Brook Trout age class distribution uses total length measurements to derive fish age in years (Scott and Crossman 1998).

3.0 Results and Discussion

3.1 Water Quality Results

3.1.1 Bauman Creek

For a complete list of tested parameters and the associated values for Bauman Creek, refer to Appendix 7.3.

Inorganic Concentrations

The Canadian Council of Ministers of the Environment (CCME) Water Quality Guidelines for Protection of Aquatic Life guidelines outlines chloride exposure thresholds of 120 mg/L (chronic) and 640 mg/L (acute). No sites exceeded this threshold, and the lowest concentration measured was at B4 (Figure 8).

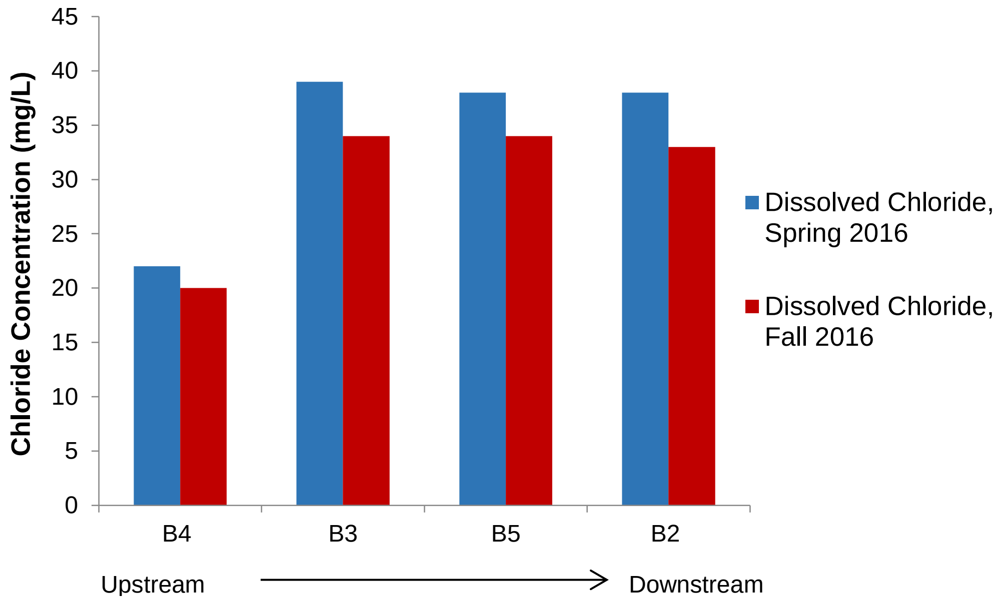


Figure 8: Dissolved Chloride concentrations at Bauman Creek, 2016.

Metal Concentrations

Site B2 and B4 consistently had the highest metal concentrations over all of the assessed sites. The threshold levels for aluminum, iron and lead were exceeded during spring sampling at site B2 (Table 1).

Table 1: Metals that exceeded threshold values at Bauman Creek. Note that only metals that exceeded threshold values at minimum one site were included.

Site	**Total Aluminum**		**Total Iron**		**Total Lead**	
	Spring	Fall	Spring	Fall	Spring	Fall
B2	180**	13	300**	ND	1.1**	ND
B5	45	21	ND	ND	ND	ND
B3	33	17	ND	ND	ND	ND
B4	29	70*	ND	130	ND	0.63

ND indicates that no traces were detected
**Indicates that the threshold was exceeded
*Indicates that the level is more than 90 per cent of the threshold level

Nutrient Concentrations

No exceedances in total phosphorus and total nitrate nitrogen thresholds (30 µg/L and 13 mg/L respectively) were observed at any sampled site on Bauman Creek (Table 2, Table 3).

Table 2: Total phosphorus (µg/L) concentrations at Bauman Creek sampled in the spring and fall of 2015 (Chow-Fraser & Fraser, 2016).

Stream	Site	Season	Concentration (µg/L)	Mean (µg/L)
Bauman	B3	Fall	12.72	12.72
	B3	Fall	12.72	
	B3	Spring	7.88	8.69
	B3	Spring	9.49	
	B5	Fall	9.49	9.49
	B5	Fall	9.49	
	B5	Spring	6.27	7.07
	B5	Spring	7.88	

Table 3: Total nitrate nitrogen concentrations (mg/L) at Bauman Creek in the spring and fall of 2015 (Chow-Fraser & Fraser, 2016).

Stream	Site	Season	Concentration (mg/L)	Mean (mg/L)
Bauman	B3	Fall	3.04	3.013
	B3	Fall	3.6	
	B3	Fall	2.4	
	B3	Spring	2.6	3.267
	B3	Spring	3.76	
	B3	Spring	3.44	
	B5	Fall	3.04	3.013
	B6	Fall	3.6	
	B7	Fall	2.4	
	B8	Spring	1.6	1.467
	B9	Spring	1.24	
	B10	Spring	1.56	

Physicochemical Properties

Generally, the physicochemical properties of Bauman Creek fell below guidelines for Ontario watercourses (Government of Ontario 1994), and fell within acceptable ranges of the 2014 ***rare*** Environmental Management Plan. The pH ranged between 7 and 8 for all sampling sites. Conductivity values ranged from 0.5-0.7 ms/cm which is within the normal range for southern Ontario streams (Government of Ontario 2016). Dissolved oxygen concentrations ranged from 9-13 mg/L. Water temperature ranged from 6-25˚C across sampling years (Appendix 7.3.5).

3.1.2 Cruickston Creek

For a complete list of tested parameters and associated values for Cruickston Creek, refer to Appendix 7.3.

Inorganic Concentrations

No sites on Cruickston exceeded the CCME chronic or acute thresholds for chloride. Chloride concentrations did not change seasonally or spatially within the creek (Appendix 7.3.2).

Metals

Aluminum and iron thresholds were exceeded at sites at Cruickston Creek. Concentrations of lead also neared the PWQO threshold at C5 in fall sampling (Table 4).

Table 4: Metals that exceeded threshold values at Cruickston Creek.

Site	**Total Aluminum**		**Total Iron**		**Total Lead**	
	Spring	Fall	Spring	Fall	Spring	Fall
C7	73*	52	170	ND	ND	ND
C4	53	25	120	ND	ND	ND
C1	110**	45	280*	ND	0.77	ND
C2	20	16	ND	ND	ND	ND
C5	12	60	ND	380**	ND	0.95*

ND indicates that no traces were detected
**Indicates that the threshold was exceeded
*indicates that the level is more than 90 per cent of the threshold level

Nutrients

The total phosphorus threshold (30µg/L) was exceeded at site C4 in fall of 2015 (Table 5). The total nitrate nitrogen threshold was not exceeded at any site on Cruickston Creek (Table 6).

Table 5: Total phosphorus (µg/L) concentrations at Cruickston Creek sampled in the spring and fall of 2015 (Chow-Fraser & Fraser, 2016).

Stream	**Site**	**Season**	**Concentration (µg/L)**	**Mean (µg/L)**
Cruickston	C1	Fall	24.02	25.63
	C1	Fall	27.25	
	C1	Spring	25.63	27.25
	C1	Spring	28.86	
	C4	Fall	96.65	91.81
	C4	Fall	86.97	
	C4	Spring	28.86	23.21
	C4	Spring	17.56	

Table 6: Total nitrate nitrogen concentrations (mg/L) at Cruickston Creek in the spring and fall of 2015 (Chow-Fraser & Fraser, 2016).

Stream	Site	Season	Concentration (mg/L)	Mean (mg/L)
Cruickston	1	Fall	1.08	1.28
	1	Fall	1.4	
	1	Fall	1.36	
	1	Spring	1.6	1.573
	1	Spring	1.6	
	1	Spring	1.52	
	4	Fall	1.52	1.4
	4	Fall	1.4	
	4	Fall	1.28	
	4	Spring	2.32	2.267
	4	Spring	2	
	4	Spring	2.48	

Physicochemical Properties

Physicochemical properties varied between years and seasons, but generally fell within Ontario guidelines (Government of Ontario 1994) as well as acceptable ranges from the 2014 ***rare*** Environmental Management Plan (Appendix 7.4.1). Generally, pH ranged from 7-9 in 2009-2015, with a few exceptions (Appendix 7.3.6). Conductivity values ranged from 0.5-0.6 ms/cm which falls within the normal range for southern Ontario streams (Government of Ontario 2016). Conductivity anomalies were documented in spring 2012 and spring and fall 2015. These measurements were likely the result of user or machine error as they were within the conductivity range of distilled water. Dissolved oxygen concentrations ranged from 7-12 mg/L. Above average concentrations were noted in spring 2006. Below average concentrations were recorded at sites in fall 2009 and spring 2015. Temperature commonly ranged from 10-17 ˚C with values reaching as low as 6 ˚C and as high as 21 ˚C (Appendix 7.3.6).

3.1.3 Newman Creek

For a complete list of tested parameters and the associated values for Newman Creek, refer to Appendix 7.3.

Inorganics

No site exceeded the CCME chloride thresholds; however, chloride concentrations generally decreased with distance downstream. The greatest concentration was recorded at NM4 and the lowest at NM1 (Figure 9).

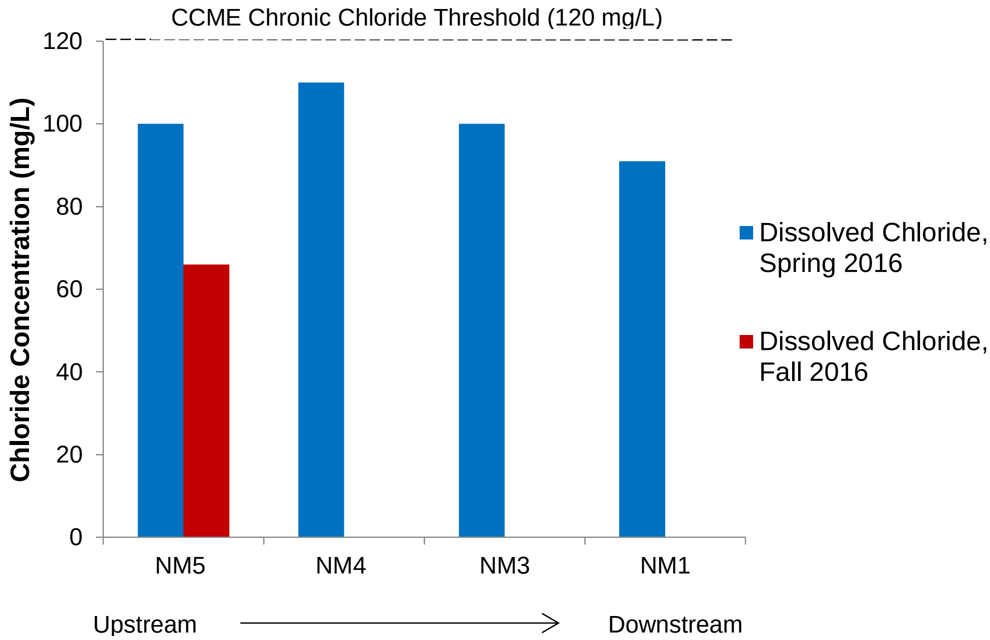


Figure 9: Dissolved Chloride concentration at Newman Creek in 2016. Dashed line indicates CCME chronic chloride threshold level.

Metals

Aluminum, arsenic, iron, and lead thresholds were exceeded at Newman Creek. Aluminum and iron concentrations were exceeded during spring sampling at all sites except for NM3 (Table 7). Site NM1 reported arsenic concentrations 22 times higher than the threshold.

Sites NM1 and NM5 had the highest metal concentrations whereas NM3 consistently had the lowest.

Table 7: Metals that exceeded threshold values at Newman Creek.

Site	Total Aluminum		Total Arsenic		Total Iron		Total Lead	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
NM1	130**	NA	110**	NA	34000**	NA	1.1**	NA
NM3	48	NA	ND	NA	110	NA	ND	NA
NM4	140**	NA	ND	NA	390**	NA	ND	NA
NM5	350**	59	1.4	NA	2000**	250**	0.87	ND

ND indicates that no traces were detected
**Indicates that the threshold was exceeded
*Indicates that the level is more than 90 per cent of the threshold level

Physicochemical Properties

Generally, physicochemical properties tested at both sites fell within Ontario guidelines (Government of Ontario 1994) and within acceptable ranges from the 2014 ***rare*** Environmental Management Plan. An exception occurred at site NM4, where the pH value was below the normal range of 6.5-8.5 at 4.94 (Appendix 7.3.6). Conductivity was not measured at Newman Creek.

3.1.4 Wetlands

For a complete list of tested parameters and the associated values for Blair Flats Wetland and Preston Flats Wetland, refer to Appendix 7.3.

Inorganics

Chloride Concentrations exceeded the CCME chronic thresholds at Preston Flats (120 mg/L). Chloride concentrations were more than four times higher in Preston Flats Wetland than Blair Flats Wetland in the spring and more than three times higher in the fall (Figure 10). Seasonal variation was noted in Preston Flats, with the highest concentrations occurring in spring.

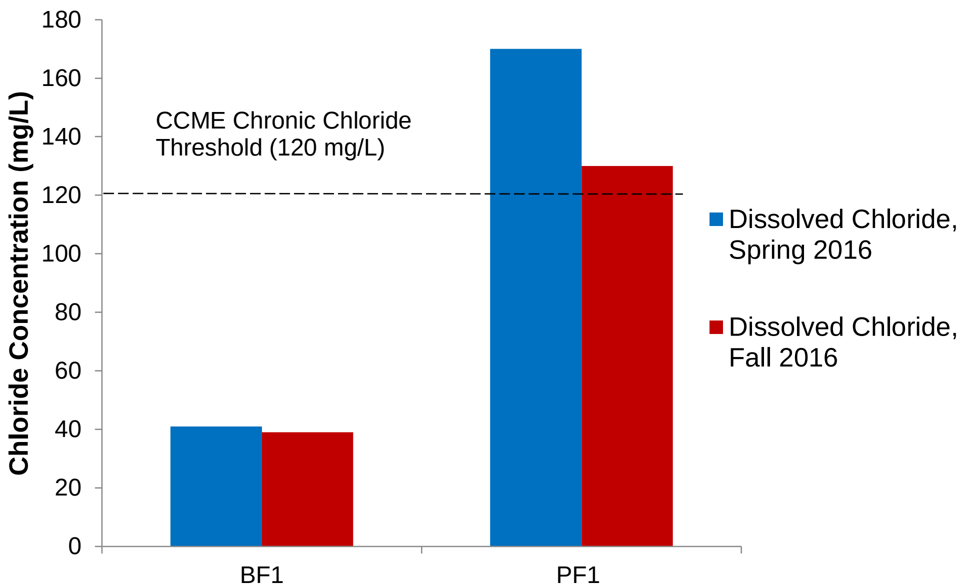


Figure 10: Dissolved Chloride concentration at the wetlands in 2016. Dashed line indicates CCME chronic chloride threshold level.

Metals

The thresholds for aluminum, iron and lead were exceeded at both wetland sites (Table 8). Samples exceeded zinc thresholds at Blair Flats in spring, 2016. Generally, higher concentrations of metals were reported in Blair Flats Wetland over Preston Flats Wetland.

Table 8: Metals that exceeded threshold values at Blair Flats and Preston Flats Wetlands, 2016.

Site	Total Aluminum		Total Copper		Total Iron		Total Lead		Total Zinc	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
BF1	720**	790**	4.7*	3.6	1200**	890**	3.1**	2.1**	28**	14
PF1	300**	520**	1.8	2.5	460**	930**	1.4**	1.9**	6.4	10

ND indicates that no traces were detected
**Indicates that the threshold was exceeded
*Indicates that the level is more than 90 per cent of the threshold level

Physicochemical Properties

With the exception of DO, water quality in Blair Flats generally fell within the normal range for Ontario watercourses (Government of Ontario 1994) as well as within acceptable ranges from the ***rare*** Environmental Management Plan. The pH ranged from 6-8. Conductivity values typically ranged from 0.6-0.7 ms/cm, with the lowest recorded value of 0.49 in fall 2009. DO concentrations ranged from approximately 3-8 mg/L with below average concentrations in spring 2015.

The physicochemical properties recorded at Preston Flats varied more considerably and some fell outside the Ontario normal range (Government of Ontario 1994). At Preston Flats the pH ranged from approximately 7-10. One measurement fell outside of the acceptable range identified in the ***rare*** Environmental Management Plan in spring 2012 (pH=9.79). Preston Flats had higher conductivity than Blair Flats and typically ranged from 0.9-1 ms/cm with the lowest recorded value of 0.65 in spring 2012. DO at Preston Flats had a lower range than Blair Flats (1-6 mg/L); however, Preston Flats generally had a higher DO when comparing wetlands within a year.

Wetland temperatures ranged between sampling years (9-20˚C) with one exceptionally high temperature recorded at Preston Flats in spring 2012 (31˚C, Appendix 7.3.8).

3.2 Water Quality Discussion

3.2.1 Inorganic Concentrations

Chloride threshold levels were only exceeded at Preston Flats; however, chloride levels at Newman Creek approached the acute CCME threshold. Preston Flats Wetland is located in close proximity to a major roadway that may represent a potential source of excess chloride from salt used to de-ice the road surface during the winter months. Chloride used in de-icing can contaminate groundwater and enter watercourses during periods of runoff, increasing chloride levels in near-by watercourses (Oliver et al. 1974). Agricultural practices in close proximity to Preston Flats Wetland may also have contributed to the observed chloride levels, as pesticides and fertilizers used in agriculture contain salts and also contribute chloride to surface and ground waters (Mullaney et al. 2009).

Chloride levels at Newman Creek were also considerably higher than at other locations (>100 mg/L) and approached the CCME chronic threshold. Chloride levels at Newman Creek may be influenced by the use of domestic fertilizer in the nearby suburban housing development (Oliver et al. 1974) and should be monitored in future years, particularly considering the planned addition of a subdivision in close proximity to the creek headwaters, and the expansion of the storm water pond.

Generally, the position of a site relative to the road does not appear to have an impact on chloride concentrations. Although sites closest to the road would be expected to have higher chloride concentrations due to run off from salt and calcium chloride used in de-icing during winter months, this only occurred at Bauman Creek. Chloride concentrations at Bauman Creek were lowest at the farthest site upstream from the road (B4). It is possible that because B4 is both the most upstream and farthest from the road, it was less susceptible to winter road run off or other sources of chloride.

At Bauman Creek and Preston Flats, spring chloride concentrations were higher than fall. Freshet periods resulting in high runoff may explain higher chloride concentrations observed in spring.

In comparison to the majority of regional waterbodies, chloride levels measured at ***rare*** waterbodies were low. For example, the City of Kitchener Storm Water Monitoring Management Monitoring Report (AECOM 2015) states that the average chloride concentration at ten out of twelve creeks exceeded the chronic CCME threshold. Acute thresholds have not been reached at the City of Kitchener monitoring sites; however, maximum concentrations were near the acute threshold (640 mg/L). Sampling at these sites also occurred during melt periods, increasing recorded chloride concentrations due to run-off from road de-icing salt applications (AECOM 2015). Slow leaching of persistent chloride from roadside soils or sediments can also occur, potentially elevating detected chloride levels later in the year (CCME 2011; Loomer and Cooke 2011; Stone et al. 2010). Although this may have occurred at ***rare*** and may be reflected in current data, sampling has not occurred strategically to capture peak levels of chloride during winter and early spring melt periods. Sampling timing at ***rare*** may help explain the relatively low chloride concentrations at ***rare*** waterbodies in comparison to regional values. Due to the overall low concentrations at all sampling locations in comparison to CCME threshold levels, it is unlikely that chloride is negatively affecting the aquatic species at the majority of sites; however, strategic sampling during melt periods would provide more information on maximum chloride concentrations in ***rare*** waterbodies.

3.2.2 Metal Concentrations

Bauman Creek

Aluminum, iron and lead thresholds were exceeded at site B2 during spring sampling. Aluminum is a naturally occurring element; however, anthropogenic influences, such as mining activities that expose geologic formations and acid rain, can increase natural concentrations (Butcher 1988). Bauman Creek is in close proximity to active mining activities south of its headwaters and is also surrounded by an expanding urban area, both of which may be influencing creek aluminum levels. Low pH levels are also known to influence aluminum concentrations; as acidity increases so do aluminum concentrations (Butcher 1988). However, Bauman Creek has near-neutral pH values and it is unlikely that pH is causing high aluminum levels at B2 (Butcher 1988).

Iron is commonly found in freshwater systems. According to Vuori (1995), mining of iron-enriched ores has contributed to increased iron concentrations in stream environments. Active mining operations south of Bauman Creek headwaters are potential causes of increased iron levels in the creek; however; no water quality data prior to the initiation of mining activities in the area exist and, therefore, comparisons are not possible. Variability in iron levels was found in Bauman Creek between seasons and sites, with no iron detected in the spring at B4 and fall at B2, contrasted by near or exceeded threshold levels in opposing seasons at each site. Although iron concentrations can vary seasonally (Eckström et al. 2016; Vuori 1995), it is unclear why each site shows such extreme variation.

According to Oliver et al. (1974), lead pollution can occur in localized areas due to industrial soils, urban air, and in roadside soils and plants. Therefore, site B2 may be negatively influenced by the leaching of roadside soils into the stream and through the urban air of Waterloo Region.

A study by Mudre and Ney (1986) identified that sites adjacent to highways contained two to five times higher metal concentrations than sites more than 200 m from the highway. This indicates that pollution is greatest downstream and closest to the source. Similarly, elevated concentrations of some metals were found at sites downstream of pollution points (Pandey and Singh 2017; Ruchter and Sures 2015; Schertzinger et al. 2017). Schertzinger et al. (2017) also found that metal concentrations were highest within 20 m of the pollution source. This helps to explain why higher concentrations of metals were detected downstream and close to Blair Road at site B2, but does not explain why similar concentrations of metals were not detected at B5. Additionally, it is unclear why aluminum levels at site B4 approached the threshold, despite its distance from the potential sources of aluminum within the watershed.

Cruickston Creek

High aluminum concentrations were recorded downstream at sites close to Blair Road. As previously stated, high concentrations of metals are commonly found downstream of and close to pollution sources. Monthly water temperatures measured at Cruickston Creek averaged between 8.48 °C and 11.55 °C between 2010 and 2012, and the maximum recorded temperature was 28.06 °C (MTE 2013). Moving water with high temperatures has been shown to contain higher concentrations of aluminum than cold, stagnant areas (Butcher 1988). The relatively high temperature at the creek may explain why measurements exceeded the aluminum threshold. Furthermore, C1 is located in an area of steeper gradient, which may be a factor in the particularly high aluminum levels present at the site (McCarter 2009).

The headwaters of Cruickston Creek are also in close relative proximity to southern mining activities. This may be affecting aluminum concentrations as well as iron concentrations, and may explain why the iron threshold was exceeded at the southernmost sampling site (C5).

Newman Creek

Newman Creek exceeded thresholds for four metals, with the highest metal concentrations identified at the most upstream and downstream locations. Only measurements at one site (NM3) were not above thresholds for any metals. Butcher (1988) reported that high aluminum concentrations can result from water distribution systems (i.e. pipes connecting storm drains to storm water ponds), which may be the source of high aluminum concentration at site NM5. Aluminum levels also increase with lower pH; this may explain high aluminum concentrations at site NM4 where a pH of 4.94 was recorded. Although acid rain can also increase the acidity of water and result in higher aluminum levels (Butcher 1988), it is unlikely that this is the case at Newman creek considering near neutral pH levels of the other sampled sites. Downstream accumulation and urban runoff may be impacting the concentrations of aluminum and lead at site NM1. Similar to the other creeks, high concentrations of iron may also be attributed to nearby mining.

According to the CCME (2001), herbicide, pharmaceutical and glass industries use arsenic compounds during manufacturing and the largest natural source of arsenic is the weathering of rocks and soils; however, it is unlikely such causes resulted in the relatively high levels present in isolation at site NM1. Due to its proximity to a major roadway, it is possible that illegal dumping of pollutants has occurred.

Wetlands

Wetland sites may also be subject to influences of agriculture, mining, and urbanization, as aluminum, iron, and lead concentrations were exceeded at both wetland sites across seasons. As both wetlands are in close proximity to major roadways and located in low-lying areas, runoff pollution is very likely. In Blair Flats, threshold exceeding zinc levels may be attributed to aerial deposition from industries and surface runoff (ATSDR 2005; CCME 1999b). Other sources of zinc include the erosion of soil particles and weathering of rocks, minerals, and certain other sediments (ATSDR 2005). High levels of copper (near the PWQO threshold) at Blair Flats may be influenced by weathering of copper minerals or other human inputs (Government of Ontario 1994). Run-off from construction, roadwork, or roads is likely a source of high copper levels at Blair Flats.

Considering that Preston Flats and Blair Flats are exposed to similar anthropogenic pressures, it is unclear why metal concentrations were generally higher at Blair Flats. Seasonal flooding of Preston Flats may offer an explanation for observed differences. Flooding can result in the dilution or concentration of metals, or in pH changes that impact metal retention and release from minerals, organic matter, clay minerals, and iron oxides (Gambrell 1994; Speelmans et al. 2007). It is possible that seasonal flooding dilutes metal concentrations at Preston Flats, or possibly immobilizes metals in soils (Speelmans et al. 2007; Wright and Reddy 2015).

In future monitoring and analysis, it should be considered that the Bauman Creek restoration project in December 2016 redirected flow towards the eastern side of Blair Flats Wetland, altering water levels at the Blair Flats sampling site. Additionally, the flooding of Blair Flats Wetland that occurred in June 2017 and winter 2017-2018 may have also impacted observed metal concentrations.

Potential Impacts

Regardless of cause, high metal levels can pose threats to aquatic organisms and the overall health and function of ecosystems. Fish populations, Brook Trout specifically, have shown increased stress levels and a reduced tolerance to aluminum with age (Butcher 1988; Cleveland et al. 1991). Gill flaring has been shown during early stages of exposure, and as exposure increases, effects such as changes in skin colour, termination of feeding, and gill mucus can occur (Butcher 1988). In extreme cases, fish mortality can occur (Cleveland et al. 1991). Considering the known presence of Brook Trout in Bauman Creek (section 3.5), high aluminum levels may be a concern for ***rare***. As fish populations are known to reside in close proximity to site B2, which exceeded thresholds for three metals, further management is necessary to ensure the health and safety of the aquatic organisms in the vicinity of this site.

Certain invertebrate taxa have shown tolerance to short-term aluminum exposure including Chironomids. Crustaceans; however, have a lower tolerance to aluminum, even during short-term exposure (Butcher 1988), and may be affected by high aluminum concentrations at some sites. The lethality of aluminum to other benthic invertebrate taxa is unclear (Butcher 1988).

Similar to aluminum, high iron levels can result in a decline in benthic invertebrate and fish species diversity and abundance (Vuori 1995). Vuorinen et al. (1999) documented rapid Brook Trout death when iron levels were 3.2 mg/L at a pH of 5.5. The same study found that an increase in iron in moderately acidic waters can be harmful to fish. Furthermore, fish cannot recover quickly from gill damage caused by iron in cold water (Vuorinen et al. 1999). High levels of iron may be a concern for benthic invertebrate diversity and abundance, which can decline as a result of prolonged exposure to iron (Vuori 1995).

Lead is classified as a toxic substance in Schedule I of the Canadian Environmental Protection Act. High lead levels are a serious hazard and can affect all aspects of the aquatic system. This metal can be transferred through the food chain and is toxic for fish (Oliver et al. 1974). Increased lead levels can result in mortality, a decline in benthic invertebrate abundance and diversity, and abnormal development of aquatic organisms (CCME 1999a).

The high level of zinc found at Blair Flats has the potential to impact the benthic invertebrate community and may result in decreased diversity and abundance, increased species mortality, and species behavioural changes. Specific taxa that are known to be impacted by increased zinc concentrations include Gastropoda, Amphipoda, Chironomidae, and Annelida (CCME 1999b).

Arsenic is known to be toxic to fish, invertebrates, and plant species (CCME 2001), and continued monitoring is needed to determine the long-term averages and potential sources of arsenic at Newman Creek.

Concentrations of other metals were not exceeded at any locations and it is unlikely that there have been resultant negative impacts to the aquatic systems at ***rare.***

3.2.3 Nutrient Concentrations

Land use practices that may be affecting phosphorus concentrations at ***rare*** locations include surface and subsurface runoff of fertilizer from neighbouring agricultural fields, domesticated fertilizer use on lawns and domestic animal manure (Carpenter et al. 1998; Reddy et al. 1999). The Storm Water Management Monitoring Report for the City of Kitchener (AECOM 2015) reports high phosphorus concentrations in monitored waterbodies, with nine of twelve waterbodies exceeding the phosphorus concentration threshold (0.03 mg/L). Considering that high phosphorus levels are common for the region but only one site on Cruickston Creek exceed phosphorus threshold levels at ***rare***, it seems that ***rare*** waterbodies have been less impacted than the local average.

High phosphorus concentrations in the aquatic environment can lead to algal blooms, low DO and biodiversity loss, including fish death (Carpenter et al. 1998). Phosphorus should be sampled frequently, particularly in Cruickston Creek, where one site has exceeded the threshold and the other site has been very close to the threshold across multiple sampling years. Additionally, reliable phosphorus measurements of Newman Creek and the wetland sites would be useful in evaluating the health of those waterbodies.

Nitrate nitrogen thresholds were not exceeded at any sites, nor did measured values approach threshold levels, and therefore it is unlikely it has negatively affected the quality of ***rare*** waterbodies.

3.2.4 Physicochemical Properties

Generally, physicochemical properties at all locations fell within normal ranges for Ontario watercourses, with three exceptions. First, several DO measurements from the wetlands were below normal ranges. Dissolved oxygen values lower than 4 mg/L can negatively impact aquatic species present within watercourses, favouring individuals with high tolerance to low DO levels, and reducing the habitat quality for other species. Second, two pH values above the desired range were recorded at Blair Flats in 2012; however, it is possible these values are the result of machine error. Third, an exception occurred at site NM4, where the pH value fell below the normal range. As mentioned, low pH values can contribute to changes in metal retention and availability, decreasing the suitability of ecosystems for aquatic life.

3.3 Benthic Macroinvertebrates Results

3.3.1 Bauman Creek

Sampling at Bauman Creek has resulted in the identification of 24 taxonomic groups, with a range of between 8 and 16 groups found during each sampling event. The most abundant taxa groups were Amphipoda, Chironomidae, and Isopoda.

Site ratings, based on combined reference metrics, indicate that there was no clear directional trend in health at Bauman Creek (Table 9, Table 10).

Based on calculated metrics, sites downstream of Blair Road were more impaired relative to upstream sites, with the farthest upstream sites generally unimpaired across metrics independently and when metrics are combined. For example, Figures 11 and 12 demonstrate the difference in per cent EPT at upstream and downstream sites, and Figure 13 demonstrates the difference between percent Oligochaeta at upstream and downstream sites.

The Shannon-Wiener Diversity Index determined all sites to be impaired. For a complete list of taxonomic groups found and metric values see Appendix 7.3.

Table 9: Site designations at Bauman Creek in spring 2006 to 2015. Site rating is determined based on the majority designation across indicator metrics. Designations (I, PI or U) are displayed for each metric where possible. Refer to Appendix 7.3 for corresponding metric values.

Year	Site	Designations (I, PI, U) based on metric values					
		Shannon-Wiener Diversity Index	Percent EPT	Percent Oligochaeta	Richness	HBI	Site Rating
2006	B1	I	U	U	I	PI	PI
	B2	I	U	U	I	U	U
	B3	I	U	U	I	U	U
	B4	I	U	U	I	U	U
	B5	NA	NA	NA	NA	NA	NA
2009	B1	I	PI	U	U	PI	PI
	B2	I	I	U	U	PI	PI
	B3	I	U	U	I	U	U
	B4	I	U	U	I	U	U
	B5	NA	NA	NA	NA	NA	NA
2012	B1	NA	NA	NA	NA	NA	NA
	B2	NA	NA	NA	NA	NA	NA
	B3	I	PI	PI	I	PI	PI
	B4	I	U	U	U	U	U
	B5	I	I	U	I	PI	I
2015	B1	NA	NA	NA	NA	NA	NA
	B2	I	I	U	U	PI	PI
	B3	I	PI	U	U	U	U
	B4	I	U	PI	I	U	PI
	B5	I	I	U	U	PI	PI

Impaired =I, Potentially Impaired=PI, Unimpaired= U

Table 10: Site designations at Bauman Creek in fall 2006 to 2015. Site rating is determined based on the majority designation across indicator metrics. Designations (I, PI or U) are displayed for each metric where possible. Refer to Appendix 7.3 for corresponding metric values.

Year	Site	Designations (I, PI, U) based on metric values					
		Shannon-Wiener Diversity Index	Percent EPT	Percent Oligochaeta	Richness	HBI	Site Rating
2006	B1	I	I	I	I	I	I
	B2	I	I	PI	U	I	I
	B3	NA	NA	NA	NA	NA	NA
	B4	I	U	U	I	U	U
	B5	NA	NA	NA	NA	NA	NA
2009	B1	I	I	PI	I	I	I
	B2	I	I	PI	I	I	I
	B3	I	U	U	U	U	U
	B4	I	U	U	U	U	U
	B5	NA	NA	NA	NA	NA	NA
2012	B1	NA	NA	NA	NA	NA	NA
	B2	NA	NA	NA	NA	NA	NA
	B3	I	U	PI	I	U	PI
	B4	I	U	U	U	U	U
	B5	I	I	U	I	PI	I
2015	B1	NA	NA	NA	NA	NA	NA
	B2	I	I	PI	U	PI	PI
	B3	I	U	U	U	U	U
	B4	I	U	U	U	U	U
	B5	I	I	U	U	PI	PI

Impaired =I, Potentially Impaired=PI, Unimpaired= U

Per Cent Taxa

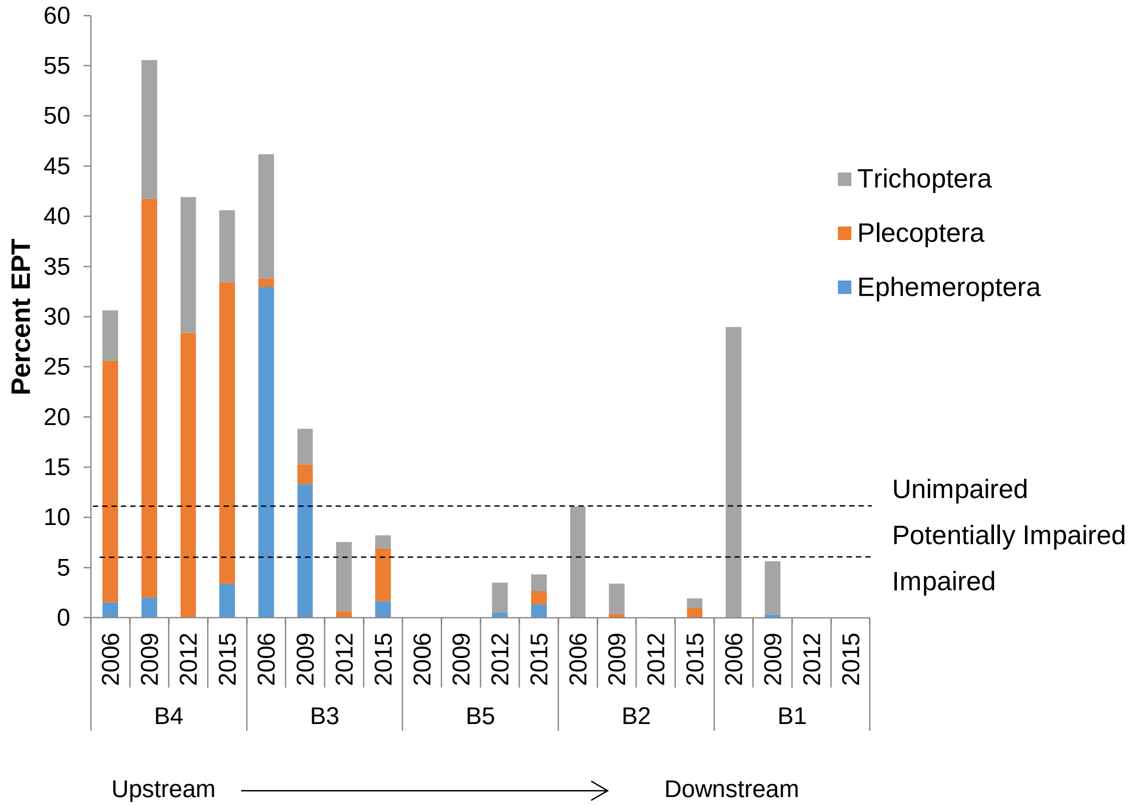


Figure 11: Per cent EPT at Bauman Creek from spring sampling in 2006 to 2015. EPT is the combined per cent Trichoptera, Plecoptera and Ephemeroptera. Per cent EPT below the lower dashed line (<5) indicates that the sites are impaired, between the lines (5-10) potentially impaired and above the upper line unimpaired.

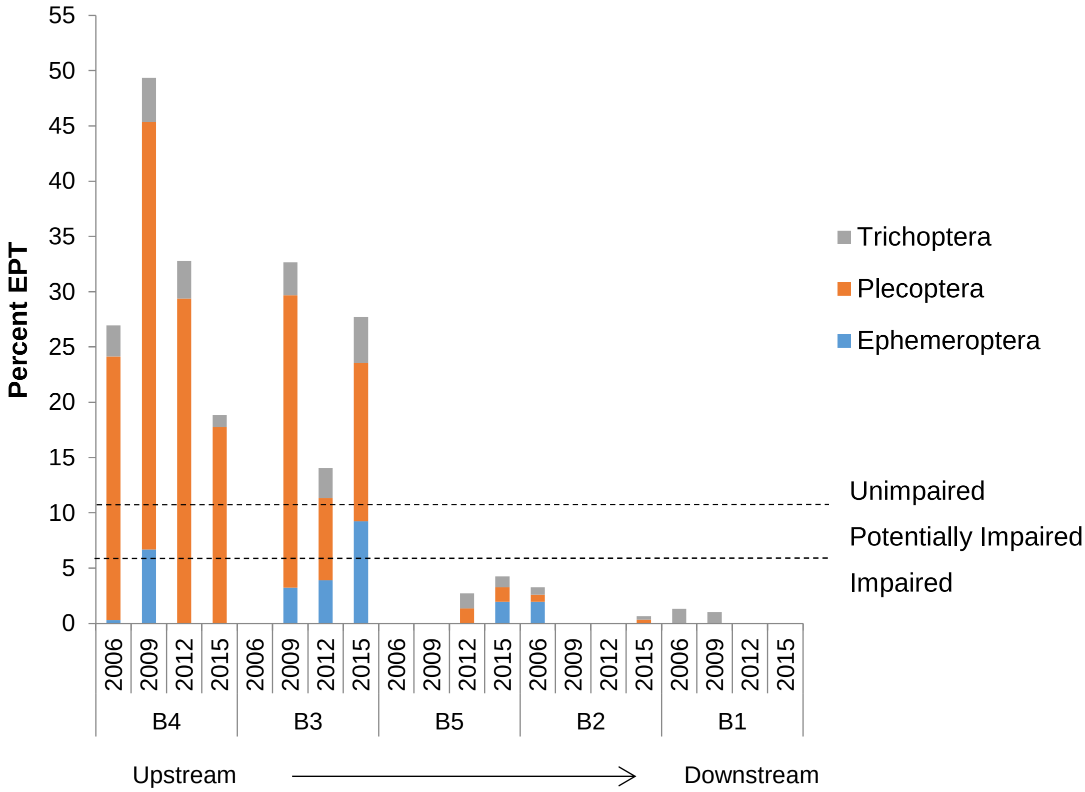


Figure 12: Per cent EPT at Bauman Creek from fall sampling in 2006 to 2015. EPT is the combined per cent Trichoptera, Plecoptera and Ephemeroptera. Per cent EPT below the lower dashed line (<5) indicates that the sites are impaired, between the lines (5-10) potentially impaired and above the upper line unimpaired.

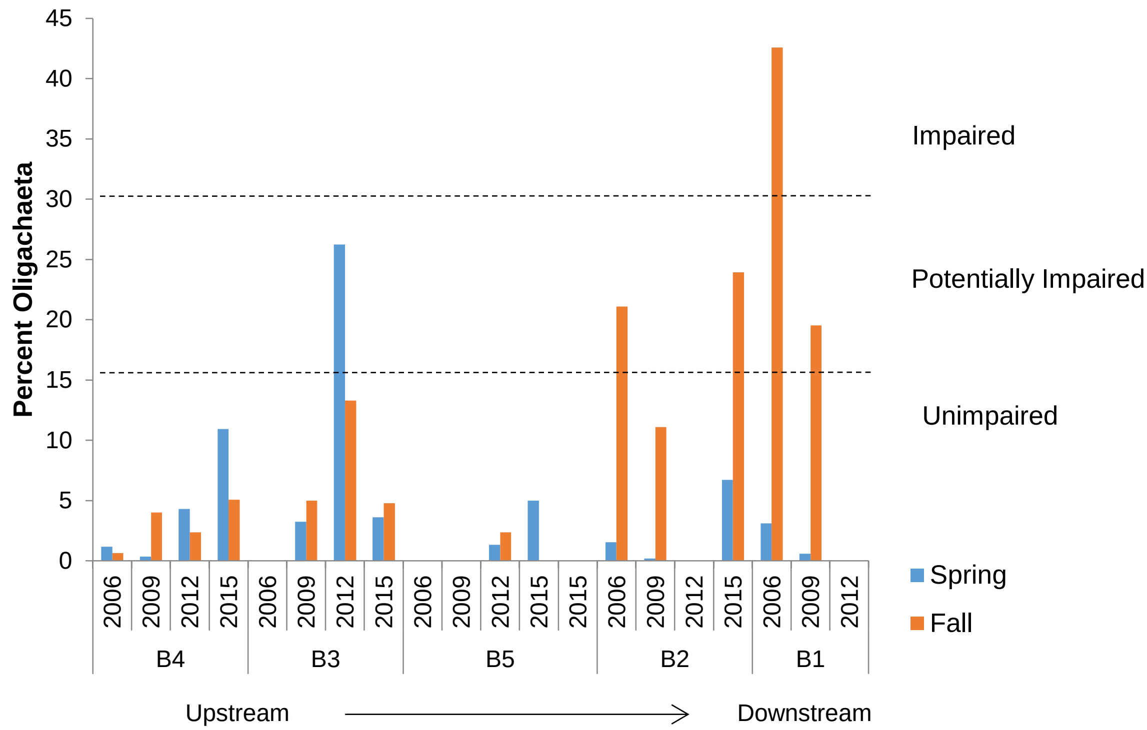


Figure 13: Per cent Oligochaeta at Bauman Creek in spring and fall 2006 to 2015. Per cent Oligochaeta above the upper dashed line (>30) indicate that the site is impaired, between the lines (10-30) potentially impaired, and below the bottom line (<10) unimpaired.

3.3.2 Cruickston Creek

Sampling at Cruickston Creek has resulted in the identification of 25 different taxonomic groups, with a range of between 7 and 18 groups found during each sampling event. The most abundant taxa groups were Chironomidae, Trichoptera, and Oligochaeta.

Site ratings indicate that there has not been a substantial change in impairment over time in the spring or fall at Cruickston Creek (Table 11 and Table 12). Metrics demonstrate annual, seasonal, and spatial variation in site impairment, and site impairment does not appear to be influenced by the location of the sites at Cruickston Creek (i.e. upstream or downstream locations or proximity to disturbances). In general, the creek has been unimpaired more than impaired in both seasons, although impairment was higher in the fall than in the spring. Site C2 is the only site with a site rating of unimpaired across years and seasons.

There was an increase in taxa richness at C3 in the spring and fall of 2015 after the removal of the culvert. At C4, taxa richness increased in fall but decreased in spring in comparison to the previous sampling seasons (Figure 14). Density increased at C3 and decreased at C4 in spring 2015 immediately following culvert removal. In fall 2015, both sites had a higher density than in all previous sampling periods (Figure 15).

All sites were considered impaired based on the Shannon-Wiener Diversity Index. For a complete list of taxonomic groups found and metric values see Appendix 7.3.

Table 11: Site designations at Cruickston Creek in spring 2006 to 2015. Site rating was determined based on the majority designation across indicator metrics. Designations (I, PI or U) are displayed for each metric where possible. Refer to Appendix 7.3 for corresponding metric values.

Year	Site	Designations (I, PI, U) based on metric values					
		Shannon-Wiener Diversity Index	Percent EPT	Percent Oligochaeta	Richness	HBI	Site Rating
2006	C1B	I	PI	I	I	PI	I
	C2	I	U	U	U	U	U
	C5	NA	NA	NA	NA	NA	NA
2009	C1B	I	U	U	U	U	U
	C2	I	U	U	U	U	U
	C5	I	I	U	I	PI	I
2012	C1B	I	U	PI	U	U	U
	C2	I	U	U	U	U	U
	C5	I	U	U	I	U	U
2015	C1B	I	I	I	U	I	I
	C2	I	U	U	U	U	U
	C5	I	U	U	U	PI	U

Impaired =I, Potentially Impaired=PI, Unimpaired= U

Table 12: Site designations at Cruickston Creek in fall 2006 to 2015. Site rating was determined based on the majority designation across indicator metrics. Designations (I, PI or U) are displayed for each metric where possible. Refer to Appendix 7.3 for corresponding metric values.

Year	Site	Designations (I, PI, U) based on metric values					
		Shannon-Wiener Diversity Index	Percent EPT	Percent Oligochaeta	Richness	HBI	Site Rating
2006	C1B	I	U	I	U	PI	PI
	C2	I	U	U	U	U	U
	C5	NA	NA	NA	NA	NA	NA
2009	C1B	I	U	U	I	U	U
	C2	I	U	U	I	U	U
	C5	I	PI	U	I	I	I
2012	C1B	I	I	I	U	PI	I
	C2	I	U	U	U	U	U
	C5	I	I	U	I	PI	I
2015	C1B	I	U	I	U	U	U
	C2	I	I	U	U	U	U
	C5	I	U	U	U	U	U

Impaired =I, Potentially Impaired=PI, Unimpaired= U

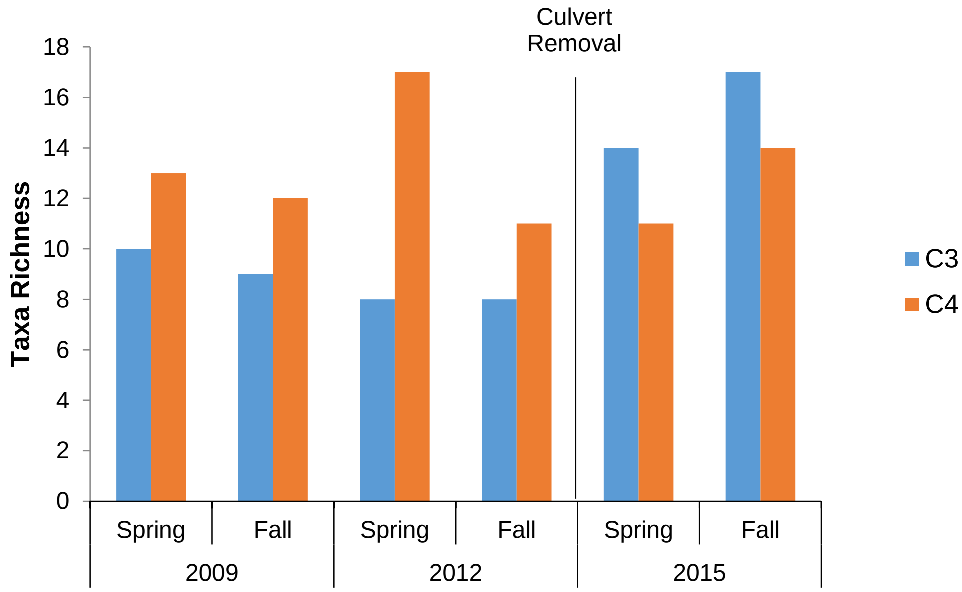


Figure 14: Taxa Richness at sites C3 and C4 at Cruickston Creek before and after culvert removal.

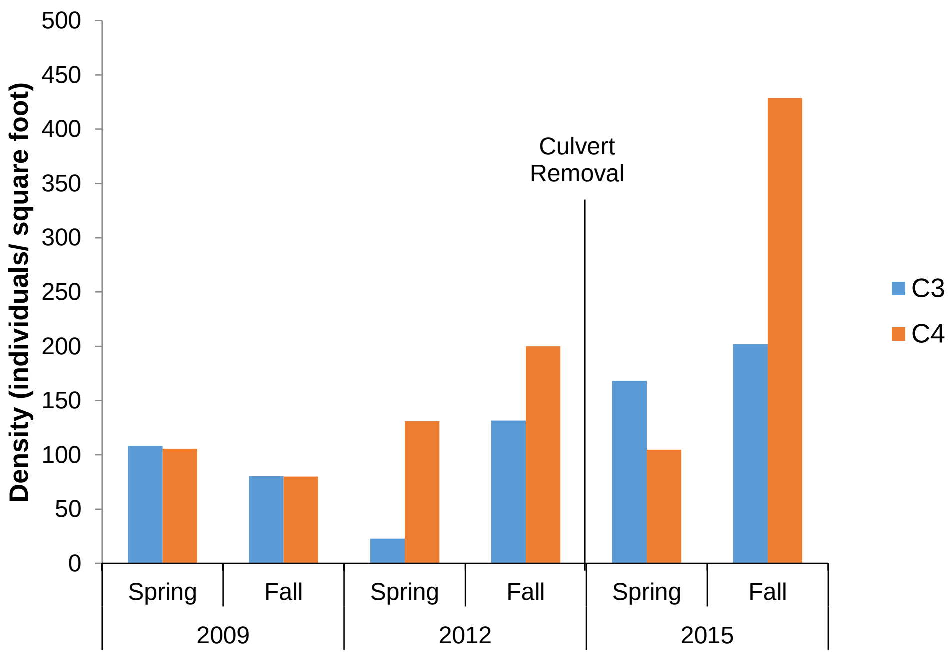


Figure 15: Density at sites C3 and C4 before and after culvert removal. Density is the number of individuals per square foot.

3.3.3 Newman Creek

Sampling at Newman Creek has resulted in the identification of 11 different taxonomic groups, with a range of 10 to 11 groups found during each sampling event. The most abundant taxa groups were Oligochaeta, Chironomidae, and Isopoda.

Both sites on Newman Creek was designated as impaired based on site ratings, and all metric values indicated that sites were either impaired or potentially impaired (Table 13). For a complete list of taxonomic groups found and metric values see Appendix 7.3

Table 13: Site designations at Newman Creek in spring 2016. Site rating was determined based on the majority designation across indicator metrics. Designations (I, PI or U) are displayed for each metric where possible. Refer to Appendix 7.3 for corresponding metric values.

Year	Site	Designations (I, PI, U) based on metric values					
		Shannon-Wiener Diversity Index	Percent EPT	Percent Oligochaeta	Richness	HBI	Site Rating
2016	NM3	I	PI	I	I	PI	I
	NM4	I	PI	I	I	I	I

Impaired =I, Potentially Impaired=PI, Unimpaired= U

3.3.4 Wetlands

Sampling at Blair Flats has resulted in the identification of 23 different taxonomic groups, with a range of 6 to 14 groups found during each sampling event. The most abundant taxa groups were Oligochaeta, Chironomidae, and Gastropoda.

Sampling at Preston Flats has resulted in the identification of 22 different taxonomic groups, with a range of 9 to 15 groups found during each sampling event. The most abundant taxa groups were Amphipoda, Chironomidae, and Oligochaeta.

Both wetlands were considered impaired or potentially impaired across years and seasons with the exception of Preston Flats in fall 2009. (Table 14, Table 15). Blair Flats was more impaired than Preston Flats across years and seasons, and both wetlands have shown more impairment in recent years. All sites were classified as impaired based on Shannon-Wiener Diversity Indices across years and seasons. For a complete list of taxonomic groups found and metric values see Appendix 7.3.

Table 14: Site designations at Blair Flats and Preston Flats Wetlands in spring 2009 to 2015. Site rating was determined based on the majority designation across indicator metrics. Designations (I, PI or U) are displayed for each metric where possible. Refer to Appendix 7.3 for corresponding metric values.

Year	Site	Designations (I, PI, U) based on metric values					
		Shannon-Wiener Diversity Index	Percent EPT	Percent Oligochaeta	Richness	HBI	Site Rating
2009	BF-1	I	I	U	U	PI	PI
	PF-1	I	PI	U	U	PI	PI
2012	BF-1	I	I	I	U	I	I
	PF-1	I	U	I	U	PI	PI
2015	BF-1	I	I	I	I	I	I
	PF-1	I	I	I	I	PI	I

Impaired =I, Potentially Impaired=PI, Unimpaired= U

Table 15: Site designations at Blair Flats and Preston Flats Wetlands in fall 2009 to 2015. Site rating was determined based on the majority designation across indicator metrics. Designations (I, PI or U) are displayed for each metric where possible. Refer to Appendix 7.3 for corresponding metric values.

Year	Site	Designations (I, PI, U) based on metric values					
		Shannon-Wiener Diversity Index	Percent EPT	Percent Oligochaeta	Richness	HBI	Site Rating
2009	BF-1	I	PI	PI	U	PI	PI
	PF-1	I	U	U	I	U	U
2012	BF-1	I	I	I	I	I	I
	PF-1	I	I	PI	I	PI	I
2015	BF-1	I	I	I	U	PI	I

Impaired =I, Potentially Impaired=PI, Unimpaired= U

3.4 Benthic Macroinvertebrates Discussion

There are no reference sites and metrics available at ***rare***, so the best available reference metrics were used for comparison. These values may not be completely effective at identifying the health of sites and act as points of comparison rather than as absolute indicators. Additionally, reference metric values were developed for lotic systems, but were also used for ***rare*** wetlands, and interpretation of health at wetlands in particular should be done with caution. There is currently an effort by the Ontario Benthos Biomonitoring Network to develop regional reference metrics based on the best available sites that would aid in the analysis of benthic data. When available, these data will be and asset to ***rare*** and other groups collecting and analyzing benthic data.

In analysis of ecosystem monitoring, it is also important to remember that ecological changes in health are not always linear and do not always occur over a short time frame (Hastings 2016; Lindenmayer and Likens 2010). Long-term data collection will increase confidence, reduce error in interpretation and allow for the establishment of long-term trends (Lindenmayer and Likens 2010; Lohner and Dixon 2013). Therefore, it is important that preliminary results are interpreted carefully with consideration that as more data is collected and reference values improve, analysis capabilities and confidence will increase.

Below, preliminary trends from data collection to date are discussed, using best available reference metrics as noted above.

3.4.1 Metrics and Taxa Richness

Shannon-Wiener Diversity Index (H) values indicate that all sites at all sampling locations were impaired. Given that H places weight on species richness, and sites were often considered to be impaired based on richness measures as well (i.e. pooled taxa), this is not surprising. However, these indices should be considered carefully as some individuals were identified to order and not family level, possibly impacting the recorded richness. Additionally, H recorded at other organizations are similar to those recorded at ***rare***. For example, Lake Simcoe Region Conservation Authority (2013) reported H values between 1 and 2, the Grand River Conservation Authority (MacDougall et al 2012) reported between 0.8 and 2.3, Conservation Halton (2012) reported between 1.2 and 3.4 and City of Kitchener between 1.34 and 2.67. None of these ranges are particularly high; however it is important to consider how comparable the water bodies sampled are to ***rare*** creeks. The most relevant would be water bodies that Conservation Halton sampled, which ranged between first and fourth order streams. Therefore, while traditional interpretation points to impaired systems, sampling locations at ***rare*** appear to fall within typical regional ranges based on available data.

3.4.2 Seasonal Differences in Creek Health

Seasonal differences in spring and fall sampling at ***rare*** water bodies do not necessarily indicate a change in health. Instead, differences may reflect changes in benthic communities in response to natural changes in abundance and recruitment between seasons (Alden et al. 1997), or habitat changes, such as streambed drying (Bae et al. 2012; Datry 2012). For example, benthic invertebrate assemblages can change with dry periods, shifting toward species that are more tolerant of dry environments and commonly found in temporary rivers (Datry 2012). Given the ephemeral nature of Newman and Cruickston Creeks, these effects may be especially apparent. Therefore, it is important to consider seasons separately when assessing trends over time. That being said, a review of temporal sampling strategies indicates that the direction and magnitude of long-term trends was very similar between seasons (Alden et al. 1997), suggesting that seasons should exhibit similar trends overtime (i.e. spring and fall sampling exhibit the same trend over time). This trend has not been observed at any creeks at ***rare***, which could indicate that more years of sampling are required to allow for the formation of trends. Particularly in ephemeral creeks, environmental and human influences could also explain why the predicted homogeneity in trends between seasons has not been observed.

3.4.3 Bauman Creek

Although a temporal pattern was not clear based on site ratings at Bauman Creek, there was a clear spatial trend in site health. Upstream sites were less impaired than downstream sites during sampling years, possibly because they are less likely to be affected by runoff from Blair Road (Chow Fraser and Fraser 2016). This pattern was strongest with per cent EPT and per cent Oligochaeta metrics; however, it existed in all metrics values to some degree, indicating that the upstream sites are healthier than the downstream sites. Additionally, B5, which was the most impaired site across seasons and years, is the closest to the road and is also a downstream site; further indicating proximity to the road may be impacting creek health. Generally, this pattern coincides with areas of high metal and chloride concentrations within the creek. Aluminum, iron, and lead concentrations were exceeded at site B2, which may have impacted the health of BMI at that site; however, metals were not exceeded at B5, and, therefore, were unlikely the cause of impairment.

The physicochemical properties of Bauman Creek water fell within guidelines for Ontario watercourses likely did not have a negative impact on BMI communities in the creek (Government of Ontario, 1994).

3.4.4 Cruickston Creek

Generally, Cruickston Creek has been unimpaired more than impaired and there was great variability in site impairment over time. Although no trends or patterns in the level of impairment over time or space were observed, several noteworthy observations can be made:

(1) all sites were impaired in fall 2012 except C2;
(2) impairment was higher in the fall than the spring;
(3) site C2 was unimpaired across seasons and years; and
(4) restoration sites generally increased in density and richness after the culvert removal in 2015.

The high impairment levels in fall 2012 may be a result of the drought in the summer of 2012. Droughts can reduce riffle and habitat zones, increase predation and competition, and alter the habitat in terms of food quality and quantity (Bae et al. 2012). Although physicochemical properties fell within threshold levels, other factors such as food availability, substrate, organic particulate matter, and competition between species may have impacted the more sensitive groups and reduced taxa richness (Hemphill 1988; Lamouroux et al. 2004). Ephemeroptera, Plecoptera, and Trichoptera, for example, are extremely sensitive groups (Bazinet et al. 2010) and would react quickly to disturbances and changes in their environment, likely explaining the observed drops in per cent EPT and resultant increase in impairment at the majority of sites in fall 2012. Similarly, Oligochaeta, which are tolerant to disturbances and are able to survive in conditions unfavourable to many other groups would not be as affected by drought conditions, and, therefore, were prevalent in numbers that were classified as impaired at most sites.

It is unclear why site C2 has been unimpaired across years when all other sites have shown variability. Site C2 and C5 are located upstream and farthest from roads, and both sites are located in close proximity to agricultural fields, but C5 was variable in impairment across years. Given the similar documented canopy cover, dominant substrate and physicochemical properties at the sites (Appendix 7.3), it is possible that other factors were responsible for the variability. Site C2 did not exceed metal thresholds and detected metals were present at relatively low levels. All other sites on Cruickston exceeded at least one metal threshold, offering a possible explanation for the health at C2. Metals were only sampled in 2016; however anthropogenic sources surrounding ***rare*** have been fairly consistent over time. Barring a dumping or similar occurrence, it is likely that metals have been fairly consistent at sites at Cruickston Creek over sampling years.

The removal of the perched culvert seems to have had a positive effect on BMI to date. In general, it appears that richness and density are responding positively to the change. However, time lags may occur in changes to ecological systems post restoration (Hastings 2016), and therefore the effects of the restoration will evolve with time. Although observed increases in health are a positive sign post-restoration, it is important to remember that natural fluctuations occur and that conclusions cannot be drawn on the success of the project with minimal data. After two more years of monitoring, a comparison of means of BMI endpoints can be conducted to determine the significance of changes in these parameters.

Physicochemical properties varied between years and seasons; however, common ranges fell within Ontario guidelines (Government of Ontario 1994), and it is unlikely that ranges are affecting BMI at Cruickston Creek.

Two of the most abundant taxonomic groups found at sites (Oligochaeta and Chironomidae) are considered indicators of poor health and one is considered an indicator of good health (Trichoptera; TRCA 2009). It is positive that one of the top three most abundant taxa found at Bauman Creek is considered an indicator of good health.

Overall, health at Cruickston Creek has been variable, but has been unimpaired more than impaired over time.

3.4.5 Newman Creek

The majority of reference values indicated impairment at both sites at Newman Creek, with exceptions designated as potentially impaired. DO, pH and conductivity threshold ranges were not exceeded (Appendix 7.4.2) and unlikely contributed to the poor health observed at Newman Creek; however, exceedances of iron, aluminum, and arsenic may be impacting aquatic life (see section 3.14). Additionally, the ephemeral nature of Newman Creek likely contributes to low species richness and low observations of intolerant taxonomic groups. Low flow and periods of drought can alter habitat quality (Bae et al. 2012), making it unsuitable for more sensitive species and reducing species richness (Datry 2012), but can be tolerated by less tolerant groups like Oligochaeta which are more able to live in stagnant, silty environments. Oilgochaeta were the most abundant taxa found during sampling, along with other tolerant taxa (Chironomidae and Isopoda).

The adjacent subdivision, which redirects waters that previously flowed into Newman Creek, likely contributes to the ephemerality of the creek. In addition to loss of water levels and flow, the headwaters of Newman Creek have been converted into a storm water retention pond which contributes to pollution in the creek. Plans to expand the subdivision and the storm water pond increase the need to continue monitoring changes in the BMI life of Newman Creek.

3.4.6 Wetlands

Comparison of calculated metrics to reference values indicates poor health at wetland sites, with Blair Flats impaired more often than Preston Flats. Dominant taxonomic groups at both wetlands are tolerant (Oligochaeta, Chironomidae, Gastropoda) or generally very abundant groups with variance in species sensitivity (i.e. Amphipoda), which is what would be expected in an environment with poor health.

Poor health at wetland sites may be attributed to stagnant water in both wetlands that is unable to drain (Chow-Fraser and Fraser 2016). Agricultural runoff would, therefore, remain in the wetlands for longer than in a lotic system, potentially impacting BMI life. Additionally, metal threshold exceedances at both wetlands likely affect BMI (see section 3.2). At Preston Flats, it is likely that chloride concentrations contribute to low BMI health.

In addition to pollution build-up in stagnant water, lack of flow and delivery of DO limits the BMI groups that are able to survive. For example, per cent EPT was dominated by Ephemeroptera, which are able to live in lentic environments, whereas Plecoptera and Trichoptera prefer higher flows. Additionally, Gastropoda, which were found in large number at Blair Flats, are often found in high numbers where there is low water velocity, and are representative of low oxygen levels and organic enrichment (TRCA 2009). Data collection over several years confirms that DO levels are below threshold and are likely impacting species composition at wetland sites (Appendix 7.3.8).

Finally, it is possible that health at the wetlands is affected by substrate and availability of food sources. BMI groups have differing food preferences and many obtain their food differently from closely related species (Alan et al. 1999); it is possible that some of these sources are not available at the wetland sites. It is likely that Blair Flats and Preston Flats have different food sources or availability, which may help explain why Blair Flats showed poorer health based on BMI than Preston Flats.

Although pH can affect BMI, it is unlikely that pH is affecting benthic macroinvertebrate diversity at either site, considering that the majority of measurements generally do not fall outside of PWQO threshold.

In summary, the wetland sites have had poor health across years, and monitoring should continue to ensure any declines in health are noted and management can occur if determined to be necessary.

3.5 Fisheries Results and Discussion

No fish were collected at Newman Creek or Cruickston Creek in 2016. Brook Trout and Brook Stickleback were found in all sites on Bauman Creek in 2016. Brook Trout were the only species collected in 2009; however, other fish species have been documented via sampling and visual confirmation in previous years (1994 and 2001). In 2016, Brook Trout and Brook Stickleback were in near equal proportions (56% and 44%, respectively) at the downstream sites. At the upstream location, Brook Trout dominated the site representing 85% of individuals caught (Figure 16). Brook Stickleback is a common and widespread species found throughout Ontario (Holm et al. 2009), and is known in the Grand River. This species could have entered the Bauman Creek system from the Grand River during times of high flow (although surface water connection to the Grand had not been observed in the last decade prior to 2016 sampling), or could have been introduced via any number of natural or anthropogenic causes. For example, they are a known prey for many piscivorous birds (Wootton1976) and could have been introduced through being mishandled or dropped by a predator. Although not a warning sign for declining health, Brook Stickleback could have impacts on the stream as predators of benthic invertebrates, primarily amphipods and aquatic insect larvae, including chironomids (Holm et al. 2009; Moodie 1986), and also as a potential food source for larger Brook Trout (Holm et al. 2009).

Species age class and body size are components used to assess fish stock and define population dynamics. To assess fisheries populations at ***rare***, these measurements can be used to determine changes in biomass, mortality levels and expected recruitment over the long-term monitoring program. With these data, we have the ability to make quantitative predictions and provide advice on management strategies needed to improve or maintain the current population (Bonfil 2005).

The fish population in Bauman Creek has remained relatively stable over the years, showing a slight shift toward a younger and smaller Brook Trout population in 2016 (Figure 17). The majority of individuals captured in 2009 and 2016 were within 51-100 mm length classes. In 2009, no individuals were found in the smallest length class (0-50 mm), and in 2016 no individuals were found in the largest length class (201-250 mm). Similarly, Brook Trout age class has remained relatively stable. Most individuals captured belonged to the 1+ age class in both sampling years. Individuals caught in 2016 belonged to the 1+ and 2+ age classes while in 2009 fish fell within in the 1+, 2+ and 3+ age classes (Figure 18). A shift towards a smaller sized and younger population of Brook Trout is acceptable in Bauman Creek because of the age Brook Trout reach sexual maturity, their life-span, and the overcrowding potential. Brook Trout reach sexual maturity at a relatively young age, and although the exact age of maturity varies based on individual growth and location condition, it is commonly between two to three years of age (Scott and Crossman 1998). A study from McFadden et al. (1967) found that males and females reach sexual maturity at different age classes; males at an earlier age than females. In their first year of life, some males can become sexually mature, and by the third year, all males are mature. Females; however, only become sexually mature in their second and third years of life. A study by Witzel and MacCrimmon (1983) reported that Brook Trout, independent of sex, reach sexual maturity between 84-290 mm body size, which is between one and three years of age according to the Brook Trout age class chart from Scott and Crossman (1998). Furthermore, Brook Trout are a relatively short-lived species, commonly only living until five years of age and never beyond eight years (Scott and Crossman 1998). Finally, for small streams like Bauman Creek, it is common to have large numbers of small sized fish, less than 254 mm (total length) as a result of overcrowding (Scott and Crossman 1998). Currently, recruitment into the Brook Trout population is low; however, as the population increases, so too should recruitment, which will lead to a wider range of age classes and sizes present within the creek. The addition of restored spawning habitat on the north side of Blair Road may also impact the observed Brook Trout population at ***rare*** and will be monitored moving forward.

Trout biomass has been linked to a variety of factors, including micro-community biomass, per cent pool area, temperature, flow rates, benthic invertebrate biomass, canopy cover, and pH (Bowlby and Roff 1986; Marschall and Crowder 1996; Xu et al. 2010). Marschall and Crowder (1996) found that Brook Trout populations were relatively resilient to a reduction in the largest sized fish, since they are capable of reproducing at a small size, so the slight downward shift in size observed in Bauman Creek may not have significant impact on the breeding population. Creek velocities in 2016 ranged from 0.2 m/s to 0.3 m/s, while in 2009, velocity was measured at 0.5 m/s. Measurement tools were upgraded between sampling years and so this change in velocity more likely reflects the increased accuracy in methods than actual documented change. Low summer flow in smaller tributaries such as Bauman Creek has been shown to reduce survival in large fish but not in other size classes (Xu et al. 2010). Congruent with this, Brook Trout have been found spawning in regions with slower velocities (0.176 m/s), likely due to the small size in which they reach sexual maturity (Witzel and Maccrimmon 1983). During the 2009 and 2016 sampling periods, temperatures ranged from 12 °C to 16 °C during sampling throughout Bauman Creek. Xu et al. (2010) found that higher summer temperatures reduced survival of all sizes of Brook Trout. Specifically, temperature can influence foraging and growth in Brook Trout; 13 °C is the optimal temperature in which both attributes will increase. As temperatures rise above the optimal value, foraging and growth will decline (Baldwin 1957). Therefore, continued monitoring and management of Bauman Creek is necessary if Brook Trout habitat is to be maintained. Refer to Appendix 7.3.26 for the 2016 raw data.

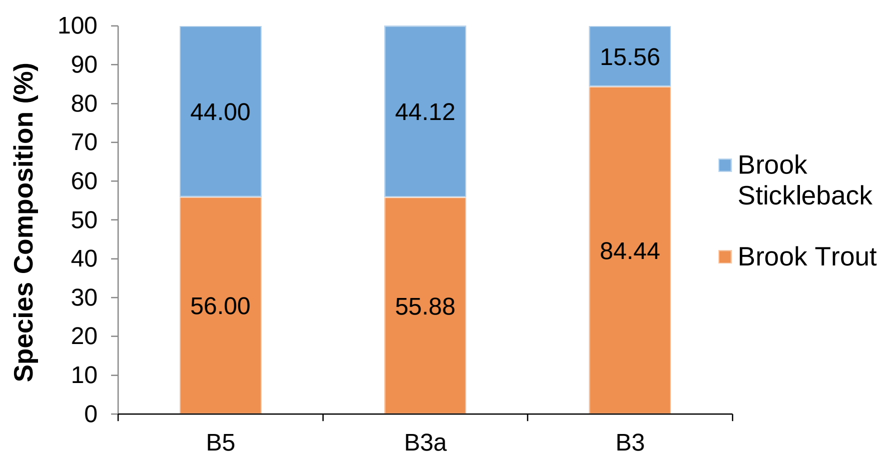


Figure 16: Per cent composition of species caught at sites B5, B3a, and B3 in Bauman Creek in 2016.

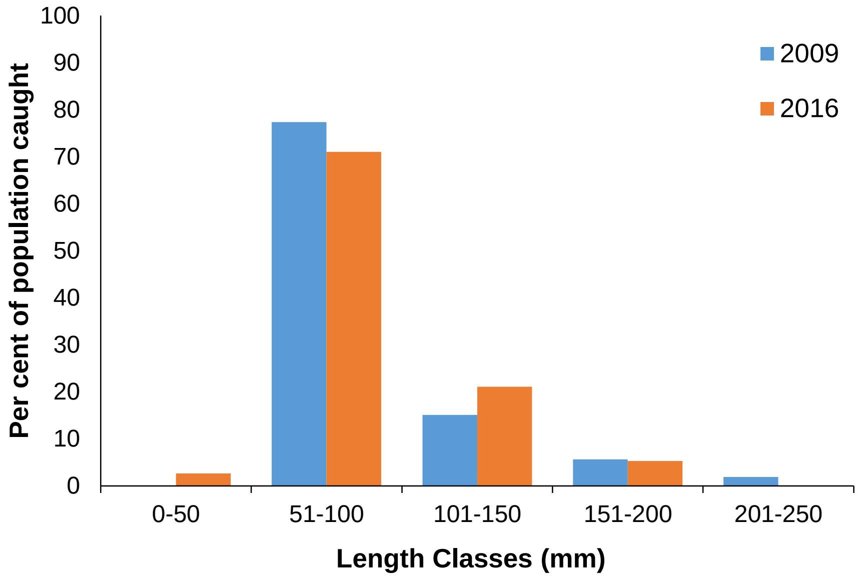


Figure 17: Per cent Brook Trout population caught in major length classes in Bauman Creek in 2009 and 2016.

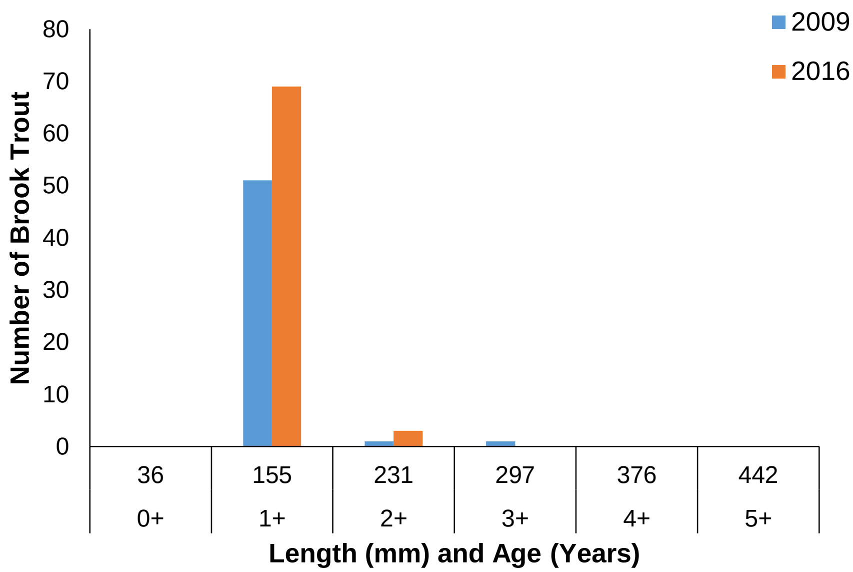


Figure 18: Comparison of Brook Trout age classes in Bauman Creek in 2009 and 2016

4.0 Summary and Conclusions

4.1 Creeks

Health at ***rare*** creeks has been variable over sampling years, and clear temporal trends have not been observed at any sites. Generally, BMI health metrics indicate that upstream sites are less impaired than downstream sites, particularly at Bauman Creek. Additionally, proximity to pollutant sources, particularly to roads, appears to have had an impact on recorded metals, chloride concentrations, and BMI health. The most abundant taxonomic groups found at creeks were generally tolerant taxa known to be found in polluted areas, which is not surprising given the various water quality measurements that exceeded threshold levels or fell outside of threshold ranges. Seasonal variation also existed in both water quality and benthic sampling results, which may reflect variances in anthropogenic or environmental pressures during different seasons, such as the ephemerality of Cruickston and Newman Creeks.

BMI health at restoration sites on Cruickston Creek have shown increases in density and richness since restoration; however, only one year of data has been collected which does not allow for a powerful analysis at this point.

Bauman and Cruickston Creek did not strongly differ in health based on BMI reference metrics; however, health at Newman Creek was relatively low. BMI data from Newman Creek was only collected in 2016 and more collection is necessary to determine if impairment is the normal state of the creek. Similarly, water quality was lowest at Newman Creek based on collected parameters, and likely contributed to poor BMI health. Considering the planned expansion of the subdivision adjacent to Newman creek as well as the storm water pond, it is likely that this creek will undergo future stresses and changes in regards to both pollution and flow.

No fish were detected in Cruickston Creek or Newman Creek in 2016 sampling, which may be the result of low water levels at the time of sampling. At Bauman Creek, there has been a slight shift towards a younger and smaller sized Brook Trout population in 2016 compared to 2009; however, at this point it is unclear whether this indicates a decline in stability. These changes may have been influenced by negative water quality parameters in Bauman Creek. The restoration project that occurred at Bauman Creek in December 2016 will likely have an impact on life at Bauman Creek. In particular, the project was designed to improve Brook Trout habitat in the creek, and monitoring of fish populations will be important to determine the success of the restoration project. Additionally, consideration of the flooding that occurred in June 2017 and winter 2017-2018 will be important, as it may have influenced distributions of BMI and fish, as well as water quality measurements at Bauman Creek.

Continued monitoring of water quality, BMI and fish populations will be important to capture long-term data trends in stream health.

4.2 Wetlands

Generally, BMI indices indicated that health at wetland sites was low, and that BMI health at Blair Flats was lower than at Preston Flats. However, these indices are not designed for wetlands and therefore may not yield the most accurate designation of health. Seasonal variation was less apparent in wetland sites than in creeks at ***rare***.

Water quality measurements were also low at both sites, and likely contribute to poor BMI health at both sites. Water quality was generally lower at Blair Flats than Preston Flats, which mirrors health designations at wetland sites. Given that wetlands are exposed to similar stressors, it is possible that seasonal flooding of Preston Flats is contributing to observed differences.

Water quality and BMI distribution at Blair Flats Wetland may have also been affected by the Bauman Creek restoration project as well as 2017-2018 flooding, which may impact monitoring site locations and interpretation of data collected in the future.

5.0 Recommendations

The following recommendations are based on results from monitoring and consultation with experts Mark Pomeroy and Joe Keene.

5.1 Water Quality

As exceedances have occurred in all of the ***rare*** watercourses, it is necessary to monitor the sites more regularly to determine if the site is naturally high in the parameter in question or if it is being negatively impacted. The following recommendations for sampling frequency and additions to sampled parameters would allow for a more thorough representation of water quality at ***rare***.

1. Metals with extreme measurements should be tested in the next aquatic monitoring year (2018). Specifically, site NM1 should be resampled for arsenic in the near future as high concentrations were reported at NM1.
2. Total phosphorus and total nitrate-nitrogen levels should be tested at all waterbodies during each aquatic monitoring year. Contracting this sampling will allow for the most accurate results. If resources are limited, samples could be reduced to three sites per creek- the most upstream and downstream sites and one central site. This testing should be occasionally supplemented with year-round data.
3. Total suspended solids should be sampled in combination with other water monitoring to identify baselines and trends. According to Lewis et al. (2002), total suspended solids parallel the seasonal and yearly changes in a watercourse, mainly during various levels of discharge and during storm events. The same study also reported that total suspended solids are influenced by climate, soils, geology, and hydrology and more frequent sampling will better describe sediment transport in the watercourse. Total suspended solids should be processed every aquatic monitoring year, and supplemented with occasional year-round data.
4. Documentation of water levels at Newman Creek should be ongoing to inform sampling. Currently, it is known that Newman Creek has minimal flow. However, depth measurements and photographs are needed during periods of high, medium, and low flows. Water loggers were installed in all creeks in April 2017 and water levels will be monitored from installation onwards. At each flow level (high, medium, and low), water levels should be documented in prospective sampling areas to inform when and where sampling is most appropriate.
5. Chloride concentrations should be sampled strategically to capture melt periods and determine maximum chloride levels which can be compared to acute toxicity thresholds and regional values.

5.2 Benthic Macroinvertebrates

In order to make year to year comparisons at each site and document long-term changes, we recommend switching to a quantitative sampling method beginning in 2018. Although kick-sweep sampling can provide estimations of diversity and richness, fixed area sampling, such as surber sampling will provide better indication of relative abundances of taxonomic groups within populations, and allow for quantitative assessment of BMI populations over time. Quantitative sampling will allow us to better answer questions of interest to ***rare*** and will inform best management practices and conservation decisions. In order to facilitate the change in protocol:

1. A surber sampler can be used for shallow creek sites with flow while an Ekman Dredge would be most appropriate in a wetland and in deeper stagnant areas of creeks (Jones et al. 2007). In stream environments, three replicate samples should be taken in the most critical habitat where possible; riffles (Jones et al. 2007). Although best practice involves sorting the entire

sample, if time constraints exist the sample can be split into equal proportions (subsamples) and final counts can be extrapolated from the sorted subsample. If warranted, the quantitative data could be supplemented with qualitative data in various habitats.

2. Existing preserved samples should be identified to the lowest level of taxonomy. This will allow for more accurate metric calculations, and a more detailed analysis of the changes occurring in the watercourse. First, preserved samples should be sorted to the 27 OBBN course level groups. At least 10 per cent of the originally sorted specimens should be re-sorted or confirmed by an experienced staff member to ensure proper sorting. The specimens should then be taken to a professional benthic taxonomist for further identification.
3. Samples need to be fixed with formaldehyde for 24 hours initially after sampling and then transferred into ethanol for preservation if benthic genetic work is to be completed in the future at ***rare***.
4. If kick-sweep samples do occur, increase 100-count of benthic invertebrates from 110 to 125 as an accuracy buffer.
5. Continue to monitor on a three-year timetable as possible, never monitoring less than once every 5 years.

To account for changes resulting from the new housing development that is proposed south of Newman Creek, it is necessary to alter benthic sampling according to construction progress:

1. Sampling should occur two years prior to construction beginning, and at least once during construction.
2. Sampling should also continue one to two years after construction is complete. If no significant changes occurred in the creek during this time period, sampling can resume every three years.

Given the ephemeral nature of Newman Creek, benthic sampling periods should be altered to times when flows are most appropriate.

5.3 Fisheries

The following recommendations aim to improve fish detection at ***rare*** creeks.

1. In future years, ***rare*** should consider applying for separate licenses for each creek. Known Brook Trout spawning in Bauman Creek limits the available sampling window to summer months (July to September). For Newman Creek especially, consistent flow is restricted to spring and early summer and would require sampling outside of this limited window.
2. A more intensive sampling protocol (i.e. DFO protocol) should be identified and used for sampling in Cruickston Creek and Newman Creek. As no fish have been documented in Cruickston Creek during either 2009 or 2016 sampling, a more intensive sampling program is needed to definitively confirm the presence of fish in these creeks.
3. Cruickston Creek sampling should be completed earlier in the spring season to accommodate sampling in the downstream reaches of the creek.
4. Sampling at Newman and Cruickston creeks should be completed simultaneously as both experience low flows and could be combined under one sampling permit.

6.0 References

AECOM. 2015. 2015 Stormwater Management Monitoring Report. City of Kitchener, Kitchener, Ontario, Canada.

Agency for Toxic Substances and Disease Registry (ATSDR). 2005. Toxicological profile for Zinc. Department of Health and Human Services, Public Health Service. Atlanta, Georgia, U.S.

Alan, P.C., Palmer, M.A., and Crowl, T.A. 1999. The Role of Benthic Invertebrate Species in Freshwater Ecosystems: Zoobenthic species influence energy flows and nutrient cycling. BioScience. 49(2): 119-127.

Alden, R.W., Weisberg, S.B., Ranasinghe, J.A., and Dauer, D.M. 1997. Optimizing temporal sampling strategies for benthic environmental monitoring programs. Marine Pollution Bulletin. 34(11): 913-922.

Baldwin, N.S. 1957. Food Consumption and Growth of Brook Trout at Different Temperatures. Transactions of the American Fisheries Society. 86(1): 323-328.

Bae, M., Chon, T., and Park. Y. 2012. Characterizing differential responses of benthic macroinvertebrate communities to floods and droughts in three different stream types using a Self-Organizing Map. Ecohydrology. 7(1): 115-126.

Barbour, M.T., Gerritsen, J., Griffith, G. E., Frydenborg, R., McCarron, E., White, J. S., and Bastian, M. L. 1996. A Framework for Biological Criteria for Florida Streams Using Benthic Macroinvertebrates. Journal of the North American Benthological Society. 15(2): 185-211.

Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates, and fish, second edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Barfoot, S. 2003. An aquatic ecological assessment and management plan for a second-order southern Ontario Stream. Waterloo, Ontario, Canada.

Bazinet, N. L., Gilbert, B.M., and Wallace, A. M. 2010. A comparison of urbanization effects on stream benthic macroinvertebrates and water chemistry in an urban basin and urbanizing basin in southern Ontario, Canada. Water Qual. Res. J. Can. 45(3): 327-341.

Bonfil, R. 2005. The purpose of stock assessment and the objectives of fisheries management. In Musick, J.A., R. Bonfil (Eds.), Management techniques for elasmobranch fisheries. (pp.6-14). Rome, Italy: FAO Fisheries Technical Paper. No. 474.

Borisko, J.P., Kilgour, B.W., Stanfield, L.W., and Jones, F.C. 2007. An evaluation of Rapid Bioassessment Protocols for Stream Benthic Invertebrates in Southern Ontario, Canada. Water Quality Research Journal of Canada. 42(3): 184-193.

Bowlby, J.N., and Roff, J.C. 1986. Trout Biomass and Habitat Relationships in Southern Ontario Streams. Transactions of the American Fisheries Society. 115(4): 503-514.

Butcher, G.A. 1988. Water quality criteria for aluminum: Technical appendix. Water Quality Unit, Resource Quality Section, Water Management Branch, British Columbia Ministry of Environment and Parks.

Canadian Council of Ministers of the Environment (CCME). 1999a. Canadian sediment quality guidelines for the protection of aquatic life: Lead. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Canadian Council of Ministers of the Environment (CCME). 1999b. Canadian sediment quality guidelines for the protection of aquatic life: Zinc. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Canadian Council of Ministers of the Environment (CCME). 2001. Canadian water quality guidelines for the protection of aquatic life: Arsenic. Updated. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Canadian Council of Ministers of the Environment (CCME). 2004. Canadian water quality guidelines for the protection of aquatic life: Phosphorus: Canadian Guidance Framework for the Management of Freshwater Systems. In: Canadian environmental quality guidelines, 2004, Canadian Council of Ministers of the Environment, Winnipeg.

Canadian Council of Ministers of the Environment (CCME). 2011. Canadian water quality guidelines for the protection of aquatic life: Chloride. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N., and Smith, V.H. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications. 8(3): 559-568.

Chow-Fraser, P., and Fraser, G.E. 2016. Ecosystem health assessment of streams in the ***rare*** **Charitable Research Reserve**. Department of Biology, McMaster University, Hamilton, Ontario, Canada.

City of Cambridge, 2014. Cambridge West Master Environmental Servicing Plan. Cambridge, Ontario, Canada.

Conservation Halton. 2012. Long Term Environmental Monitoring Program 2012 Bronte Creek, Urban Creeks and Supplemental Monitoring. Conservation Halton, Burlington, Ontario, Canada.

Conservation Halton. 2017. Ecological Monitoring Protocols. Conservation Halton, Burlington, Ontario, Canada.

Cleveland, L., Little, E.E., Ingersoll, C.G., and Hunn, J.B. 1991. Sensitivity of brook trout to low pH, low and elevated aluminum concentrations during laboratory pulse exposures. Aquatic Toxicology. 19(4): 303-317.

CH2M Gore & Storrie Ltd. 1997. Blair, Bechtel, and Bauman Creeks Subwatershed Plan. Ontario, Canada.

Datry, T. 2012. Benthic and hyporheic invertebrate assemblages along a flow intermittence gradient: Effects of duration of dry events. Freshwater Biology. 57(3): 563-574.

Ekström, S.M., Regnell, O., Reader, H.E., Nilsson, P.A., Löfgren, S., and Kritzberg, E.S. 2016. Increasing concentrations of iron in surface waters as a consequence of reducing conditions in the catchment area. Journal of Geophysical Research: Biogeosciences. 121(2): 479-493.

Environment Canada. 2005a. Canadian water quality guidelines: Phosphorus. National Guidelines and Standards –Office, Ottawa, ON.

Environment Canada. 2005b. Canadian water quality guidelines: Nitrate. National Guidelines and Standards –Office, Ottawa, ON.

Environment Canada. 2012. Canadian Aquatic Biomonitoring Network: Field Manual. Wadeable streams –Office, Dartmouth, NS.

Gambrell, R. 1994. Trace and toxic metals in wetlands - a review. Journal of Environmental Quality. 23(5): 883-891.

Gleick, P.H. 1996. Basic water requirements for human activities: Meeting Basic Needs. Water International. 21(2): 83-92.

Gleick, P.H. 2000. A look at twenty-first century water resources development. Water International. 25(1): 127-138.

Government of Ontario. 1994. Water Management: Policies Guidelines Provincial Water Quality Objectives of the Ministry of Environment and Energy. Queen’s Printer for Ontario. ISBN 0-7778-8473-9 rev.

Government of Ontario. 2016. Provincial (Stream) Water Quality Monitoring Network. Retrieved from:https://www.ontario.ca/data/provincial-stream-water-quality-monitoring-network.

Groffman, P., Baron, M., Blett, J., Gold, S., Goodman, T., Gunderson, A., Wiens, G. 2006. Ecological Thresholds: The Key to Successful Environmental Management or an Important Concept with No Practical Application? Ecosystems. 9(1): 1-13.

Hastings, A. 2016. Timescales and the management of ecological systems. Proceedings of the National Academy of Sciences of the United States of America. 113(51): 14568-14573.

Hemphill, N. 1988. Competition between two stream dwelling filter-feeders, Hydropsyche oslari and Simulium virgatum. Oecologia. 77(1): 73-80.

Herman, M., Nejadhashemi A. 2015. A review of macroinvertebrate and fish based stream health indices. Ecohydrology & Hydrobiology. 15: 53–67.

Hilsenhoff, W.L. 1988. Rapid field assessment of organic pollution with a family-level biotic index. Journal of North American Benthological Society. 7: 65-68.

Holm, E., Mandrak, N., and Burridge, M. 2009. The ROM field guide to freshwater fishes of Ontario. Royal Ontario Museum Science Publications, Toronto, Ontario, Canada.

Holton, S. 2006. Aquatic and Terrestrial Monitoring at ***rare*** **Charitable Research Reserve**. ***rare*** **Charitable Research Reserve**, Cambridge, Ontario, Canada.

Hunter and Associates. 2016. ***rare*** Water Resources Report [Draft]. Hunter and Associates, Mississauga Ontario, Canada.

Jones, C., Somers, K.M., Craig, B., and Reynoldson, T.B. 2007. The Ontario Benthos Biomonitoring Network Protocol Manual. Ontario Ministry of the Environment, Dorset, Ontario, Canada.

Kilgour, B. W. 1998. Developing an index of nutrient status based on rapid assessment methodology for collecting benthic macroinvertebrates. Water Systems Analysts, Guelph, Ontario.

Kilgour, B. W., and Barton, D.R. 1999. Associations between stream fish and benthos across environmental gradients in southern Ontario, Canada. Freshwater Biology, 41 pp. 553-566

Lake Simcoe Region Conservation Authority. 2013. 2013 Environmental Monitoring Report. New Market, Ontario, Canada.

Lamouroux, N., Dolédec, S., and Gayraud, S. 2004. Biological traits of stream macroinvertebrate communities: Effects of microhabitat, reach, and basin filters. Journal of the North American Benthological Society. 23(3): 449-466.

Lewis, D.J., Tate, K.W., Dahlgren, R.A., and Newell, J. 2002. Turbidity and Total Suspended Solid Concentration Dynamics in Streamflow from California Oak Woodland Watersheds. USDA Forest Service General Technical Report. PSW-GTR-184.

Lindenmayer, D.B., and Likens, G.E. 2010. The science and application of ecological monitoring. Biological Conservation, 143(6): 1317-1328.

Lohner, T., and Dixon, W. 2013. The value of long-term environmental monitoring programs: An Ohio River case study. Environmental Monitoring and Assessment.185(11): 9385-9396.

Loomer, H.A. and Cooke, S. 2011. Water Quality in the Grand River Watershed: Current Conditions and Trends (2003-2008). Grand River Conservation Authority, Cambridge Ontario. October 2011 draft.

MacDougall, T.M., and Ryan, P.A. 2012. An Assessment of Aquatic Habitat in the Southern Grand River, Ontario: Water Quality, Lower Trophic Levels, and Fish Communities. Lake Erie Management Unit, Provincial Services Division, Fish and Wildlife Branch, Ontario Ministry of Natural Resources. Port Dover, Ontario, Canada.

Magurran. A.E. 2004. Measuring biological diversity. Blackwell Publishing, Malden, Massachusetts, U.S.

Marschall, E.A., and Crowder, L.B., 1996. Assessing Population Responses to Multiple Anthropogenic Effects: A Case Study With Brook Trout. Ecological Applications. 6(1): 152-167.

McCarter, J. 2009. Ecological Monitoring at ***rare* Charitable Research Reserve**. ***rare* Charitable Research Reserve**, Cambridge, Ontario, Canada.

McFadden, J.T., Alexander, G.R., and Shetter, D.S. 1967. Numerical Changes and Population Regulation in Brook Trout *Salvelinus fontinalis*. Journal of the Fisheries Research Board of Canada. 24(7): 1425-1459.

Merritt, R.W., Cummins, K.W. 1996. An introduction to the aquatic insects of North America. 3rd ed. Kendall/Hunt Publishing Company. Iowa, U.S.

Moodie, G.E.E. 1986. The population biology of *Culaea inconstans,* the brook stickleback, in a small prairie lake. Canadian Journal of Zoology. 64: 1709-1717

MTE consultants. 2013. C2534-200 Technical Memorandum. Kitchener, Ontario, Canada.

Mudre, J., and Ney, M. 1986. Patterns of accumulation of heavy metals in the sediment of roadside streams. Archives of Environmental Contamination and Toxicology. 15(5): 489-493.

Mullaney, J.R., Lorenz, D.L., and Arntson, A.D. 2009. Chloride in Groundwater and Surface Water in Areas Underlain by the Glacial Aquifer System, Northern United States. U.S. Geological Survey Scientific Investigations Report 2009-5086.

Munkittrick, K. R., and Dixon, D.G. 1989. A holistic approach to ecosystem health assessment using fish population characteristics. Hydrobiologia. 188(1): 123-135.

Oliver, B.G., Milne, J.B., and LaBarre, N. 1974. Chloride and Lead in Urban Snow. Water Pollution Control Federation. 46(4): 766-771.

Pandey, J., and Singh, R. 2017. Heavy metals in sediments of Ganga River: Up- and downstream urban influences. Applied Water Science. 7(4): 1669-1678.

Portt, C. B., Coker, G. A., Mandral, N. E., and Ming, D.L. 2008. Protocol for the detection of fish Species At Risk in Ontario Great Lakes Area (OGLA). Fisheries and Oceans Canada. Ontario, Canada.

rare Environmental Management Plan, 2014. ***rare* Charitable Research Reserve**. Cambridge, Ontario, Canada.

rare Environmental Management Action Plan, 2015. ***rare* Charitable Research Reserve**. Cambridge, Ontario, Canada.

Reddy, K.R., Kadlec, R.H., Flaig, E., and Gale, P.M. 1999. Phosphorus Retention in Streams and Wetlands: A Review. Critical Reviews in Environmental Science and Technology. 29(1): 83-146.

Regional Aquatic Monitoring Plan (RAMP), N.D. Water and Sediment Quality in the Athabasca River Basin. Retrieved from http://www.ramp-alberta.org/river/water+sediment+quality.aspx; November 12, 2015.

Richardson, J.S. and M.J. Jackson. 2002. Aquatic Invertebrates. Pp. 300-323 In: Perrow, M.R. and Davy, A. (Eds.) Handbook of Ecological Restoration, Volume 1. Cambridge University Press. Cambridge, United Kingdom.

Ruchter, and Sures. 2015. Distribution of platinum and other traffic related metals in sediments and clams (Corbicula sp.). Water Research. 70: 313-324.

Schertzinger, G., Ruchter, N., and Sures, B. 2017. Metal accumulation in sediments and amphipods downstream of combined sewer overflows. Science of the Total Environment, Science of the Total Environment. 616-617: 1199-1207.

Speelmans, M., Vanthuyne, D.R.J., Lock, K., Hendrickx, F., Du, G., Tack, F.M.G., and Janssen, C.R. 2007. Influence of flooding, salinity and inundation time on the bioavailability of metals in wetlands. Science of the Total Environment. 380(1): 144-153.

Stanfield, L. (editor). 2013. Ontario Stream Assessment Protocol. Version 9.0. Fisheries Policy Section. Ontario Ministry of Natural Resources, Peterborough, Ontario, Canada.

Scott, W.B., and E.J. Crossman. 1973. Freshwater Fisheries of Canada. Bull. Fish. Res. Board Can. 184. [1998 Reprint] Galt House Publications Ltd, Oakville, Ontario, Canada.

Stone, M., DEmelko, M.B., Marsalek, J., Price, J. S., Rudolph, D. L., Saini, H., and Tighe, S. L. 2010. Assessing the Efficacy of Current Road Salt Management Programs. University of Waterloo and the National Water Research Institute, Ontario, Canada.

Suozzo, K. 2005. The use of aquatic insects and benthic macroinvertebrate communities to assess water quality upstream and downstream of the Village of Stamford wastewater treatment facility. Proceedings of the 38th Annual Report of the SUNY Oneonta Biological Field Station, Biological Field Station, Cooperstown, U.S.

Thorne, R. J., and Williams, P, W. 1997. The response of benthic macroinvertebrates to pollution in developing countries: A multimetric system of bioassessment. Freshwater Biology. 37(3): 671-686.

Toronto and Region Conservation Authority (TRCA). 2009. Don River Water Plan: Surface Water Quality – Report on Current Conditions. Toronto, Ontario, Canada.

Vuori, K-M. 1995. Direct and indirect effects of iron on river ecosystems. Ann. Zool. Fennici. 32: 317-329.

Vuorinen P.J., Keinänen, M., Peuranen, S., and Tigerstedt, C. 1999. Effects of iron, aluminum, dissolved humic material and acidity on grayling (Thymallus thymallus) in laboratory exposures, and a comparison of sensitivity with brown trout (Salmo trutta). Boreal Environmental Research. 3: 405-419.

Walsh, C.J., Roy, A.H., Feminella, J.W., Cottingham, P.D., Groffman, P.M., and Morgan II, R.P. 2005. The urban stream syndrome: current knowledge and the search for a cure. The Journal of North American Benthological Society. 24(3): 706-723.

Witzel, L.D., and Maccrimmon, H.R. 1983. Redd-Site Selection by Brook Trout and Brown Trout in Southwestern Ontario Streams. Transactions of The American Fisheries Society. 112(6).

Wootton, R. J. 1976. The biology of the sticklebacks. Academic Press, London, New York, San Francisco.

Wright, A.L and Reddy, K.R. 2015. Reactivity and Mobility of Metals in Wetlands. University of Florida. Gainesville, Florida.

Xu, C.L., Letcher, B.H., and Nislow, K.H. 2010. Size-dependent survival of brook trout *Salvelinus fontinalis* in summer: effects of water temperature and stream flow. Journal of Fish Biology. 76: 2342-2369.

7.0 Appendix

7.1 Field Sampling and Lab Processing

Appendix 7.1.1: Coordinates for all water monitoring sites at ***rare***.

Benthic and Water Quality Monitoring Sites			
WaterBody	**Site**	**UTM Coordinates**	
Bauman Creek	B1	4803525 N	551814 E Zone 17T
Bauman Creek	B2	4803530 N	551366 E Zone 17T
Bauman Creek	B3	4803315 N	551290 E Zone 17T
Bauman Creek	B4	4802861 N	551189 E Zone 17T
Bauman Creek	B5	4803530 N	551362 E Zone 17T
Cruickston Creek	C1A	4802892 N	552647 E Zone 17T
Cruickston Creek	C1B	4802892 N	552647 E Zone 17T
Cruickston Creek	C2	4802588 N	552558 E Zone 17T
Cruickston Creek	C3	4803000 N	552689 E Zone 17T
Cruickston Creek	C4	4802975 N	552667 E Zone 17T
Cruickston Creek	C5	4802449 N	552532 E Zone 17T
Cruickston Creek	C7	4803029 N	552700 E Zone 17T
Newman Creek	NM1	4802882 N	552899 E Zone 17T
Newman Creek	NM3	4802672 N	552783 E Zone 17T
Newman Creek	NM4	4802629 N	552802 E Zone 17T
Newman Creek	NM5	4802470 N	552777 E Zone 17T
Blair Flats Wetland	BF1	4803522 N	551196 E Zone 17T
Preston Flats Wetland	PF1	4804371 N	550657 E Zone 17T
Fisheries Monitoring Sites			
Bauman Creek	B5	4803506 N	551363 E Zone 17T
Bauman Creek	B3A	4803401 N	551340 E Zone 17T
Bauman Creek	B3	4803315 N	551290 E Zone 17T
Cruickston Creek	C7	4803026 N	552701 E Zone 17T
Cruickston Creek	C4	4802939 N	552650 E Zone 17T
Cruickston Creek	C1	4802863 N	552633 E Zone 17T
Cruickston Creek	C2	4802588 N	552558 E Zone 17T
Cruickston Creek	C5	4802449 N	552532 E Zone 17T

Appendix 7.1.2: Benthic invertebrate equipment for sample collection and processing.

	Equipment
Sample Collection	Clip Board
	Benthic invertebrate monitoring field sheets
	Blank paper
	Writing utensils (pencils and permanent marker)
	OBBN Manual
	500µm mesh D-net
	1 large bucket (5 gallon)
	500µm sieve
	Rinse bottle
	Ladel
	Chest waders
	Kestrel 3000 pocket weather station
	Quanta Water Quality Meter
	Thermometer
	Clear ruler
	Metre stick
	Stop-watch
	wide-mouth sample bottles
	Permanent markers and masking tape (for labeling bottles)
	Flagging tape
	GPS unit
	Camera
	Utility knife
Sample Processing	Benthic invertebrate monitoring lab sheets
	Formeldyhyde
	Ethanol alcohol (diluted to 70%)
	Small funnels
	Nitrile gloves and safety glasses
	Extra light sources
	500µm sieve
	Medium bucket (for "bucket" sub-sampling method)
	Label
	White sorting trays
	Rinse bottle
	Forceps (fine- and large-tipped)
	Waste water bucket
	Petri dishes
	Dissection microscope
	Taxonomic keys / OBBN manual
	Vials for perserving samples
	Permanent markers and masking tape (for labeling vials)

Appendix 7.1.3: Sample benthic invertebrate field data sheet front and back.

Benthic Sample Collection Form

Project Number: Dare B5 Station ID: B5

Project Manager: C. Head Date (yyyymmdd): 2016/09/01

Project Name: Dare Benthic Sampling

Descriptive Location: North of Blair Rd, 40m downstream of road culvert, open grassland area

UTM coordinates: 4803525 easting 551814 northing zone: 17T datum: NAD 83

Sampling Method: Kick + Sweep

Number of Replicates: 3 Sampling Duration (minutes) (if applicable): 3min

Supporting Samples Collected (circle if applicable): water sediment TOC sediment grain size other:

Estimated Average Stream Width (m): 2 Water Clarity/Colour: Clear/none

***In-Situ* Supporting Measurements** (measured at water/sediment interface)

Water Temperature: 10°C Dissolved Oxygen: 8

Air Temperature: 20°C pH: 8

Time: 9:30am Conductivity: 0.5

Replicate 1 (all observations pertain to individual grabs)

Number of Jars: 2

Depth (m): 0.75

Water Velocity (m/s): 1

Macrophytes: none (sparse) common abundant

Algae: none sparse (common) abundant

Substrate description/odour: no

Replicate 2 (all observations pertain to individual grabs)

Number of Jars: 3

Depth (m): 1

Water Velocity (m/s): 0.5

Macrophytes: none (sparse) common abundant

Algae: none sparse (common) abundant

Substrate description/Odour: No

Replicate 3 (all observations pertain to individual grabs)

Number of Jars: 1

Depth (m): 1

Water Velocity (m/s): 1.5

Macrophytes: none (sparse) common abundant

Algae: (none) sparse common abundant

Substrate description/Odour: No

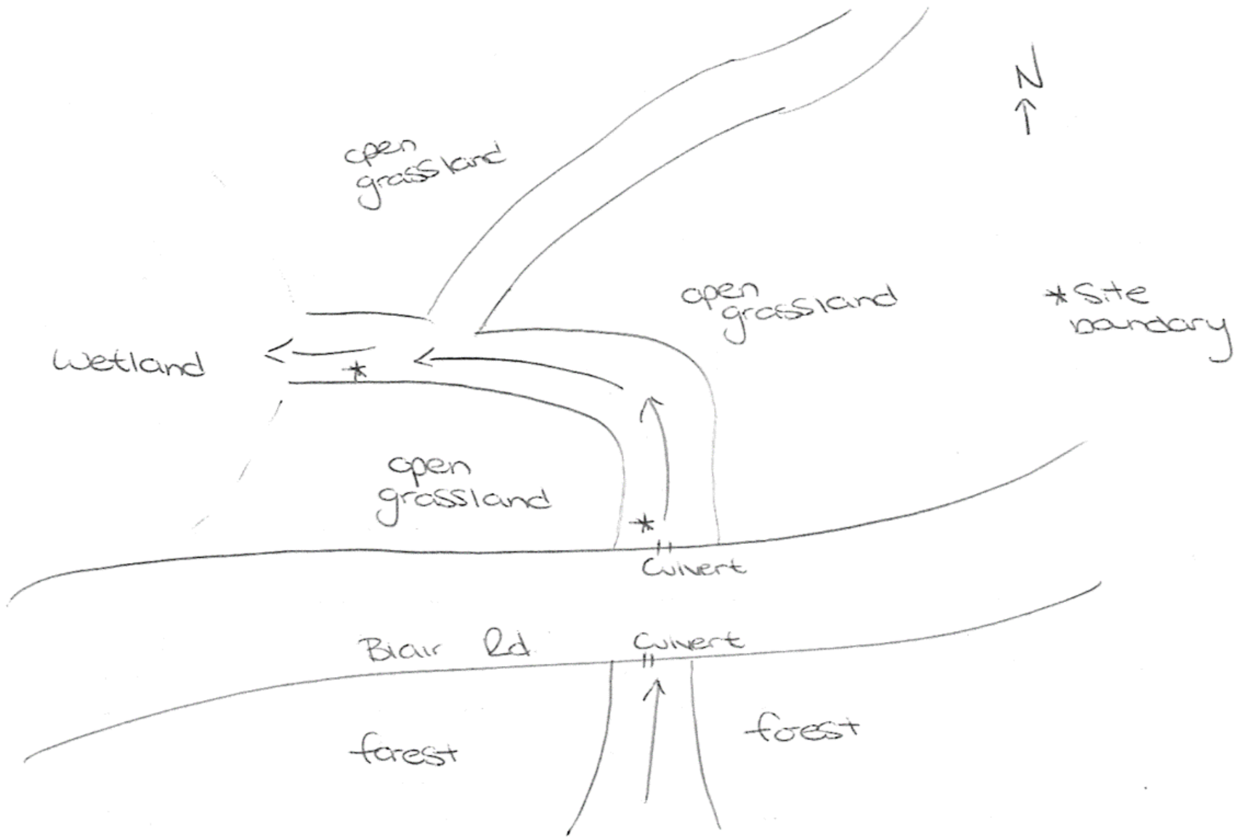
Field Staff: C. Head

(station diagram on back)

Appendix 7.1.3: Cont'd

Station Diagram:

(include North Arrow, Flow Direction and Road Names if applicable)



Field Staff: C. Head

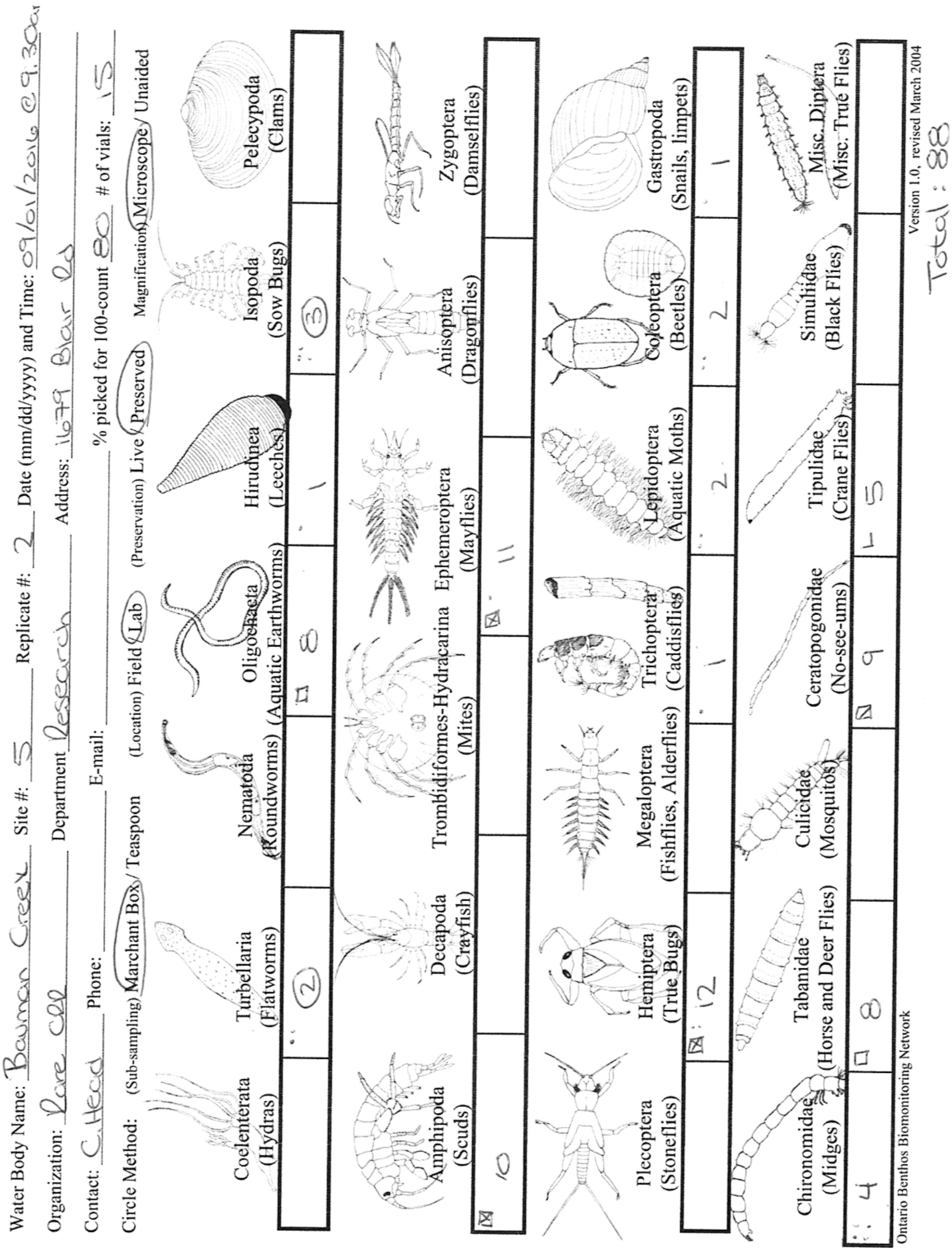
J. Quinn

Notes By: C. Head

Other Notes:

Quality Control: This form is complete (✓) & legible (✓). QA/QC by: (signature) CH

Appendix 7.1.4: Sample benthic invertebrate lab data sheet from OBBN manual (Jones et al. 2007).



Water Body Name: Bauman Creek Site #: 5 Replicate #: 2 Date (mm/dd/yyyy) and Time: 09/01/2016 @ 9:30a

Organization: Rare Ce[?] Department: Research Address: 1679 Blair Rd

Contact: C. Head Phone: E-mail: % picked for 100-count 80 # of vials: 15

Circle Method: (Sub-sampling) Marchant Box / Teaspoon (Location) Field / Lab (Preservation) Live / Preserved Magnification: Microscope / Unaided

Coelenterata (Hydras)	
Turbellaria (Flatworms)	2
Nematoda (Roundworms)	
Oligochaeta (Aquatic Earthworms)	8
Hirudinea (Leeches)	1
Isopoda (Sow Bugs)	3
Pelecypoda (Clams)	
Amphipoda (Scuds)	10
Decapoda (Crayfish)	
Trombidiformes-Hydracarina (Mites)	
Ephemeroptera (Mayflies)	11
Anisoptera (Dragonflies)	
Zygoptera (Damselflies)	
Plecoptera (Stoneflies)	
Hemiptera (True Bugs)	12
Megaloptera (Fishflies, Alderflies)	
Trichoptera (Caddisflies)	1
Lepidoptera (Aquatic Moths)	2
Coleoptera (Beetles)	2
Gastropoda (Snails, limpets)	1
Chironomidae (Midges)	4
Tabanidae (Horse and Deer Flies)	8
Culicidae (Mosquitos)	
Ceratopogonidae (No-see-ums)	9
Tipulidae (Crane Flies)	5
Simuliidae (Black Flies)	
Misc. Diptera (Misc. True Flies)	

Ontario Benthos Biomonitoring Network

Version 1.0, revised March 2004

Total: 88

Appendix 7.1.5: Water quality equipment for sample collection and analysis.

Equipment	
Sample collection	Hydrolab Quanta Multi-Probe Meter
	Wide-mouthed sample bottles
	Permanent Markers and pencils
	Masking tape
	Water quality field data sheets
	Clip board
	Chest waders (optional)
	GPS unit
	Kestrel 3000 pocket weather station
	Industry-supplied sample bottles for additional analysis

Appendix 7.1.6: Sample water quality field data sheet.

Stream Parameter Field Data Sheet

Date (mm/dd/yyy):
Agency: ***rare*** **Charitable Research Reserve**
Investigators:

Air Temp (°C):
Weather:

Stream Name	Site #	Time	GPS	Site Description	Water Temp (°C)	Conductivity (us/cm)	pH	DO (mg/L)

Notes:

Appendix 7.1.7: Sample water quality lab data sheet.

Lab Analysis Data Sheet

Processing Date (mm/dd/yyy) and time: 11/09 2016
Agency: ***rare* Charitable Research Reserve**
Processors: C. Head

Site #	Field Sampling Date and Time	Nitrate-Nitrogen (mg/L) with error			Nitrate-Nitrogen (mg/L) average with error	Nitrate-Nitrogen (mg/L) corrected value	Phosphorous (mg/L) with error			Phosphorous (mg/L) average with error	Phosphorous (mg/L) corrected value
B5	11/02/2016 4:30pm	0.2	0.2	0.2	0.2	0.19	2.7	2.7	2.7	2.7	1.7

Notes:

Appendix 7.1.8: Fisheries equipment for field sampling.

Equipment	QUANTITY	*rare Supplied*	Individually Supplied	Rented from Hoskin
Electrofisher (LR-24 Electrofisher)	1			*
Charged Batteries (at least one spare)	1			*
Anode pole and accompanying connector cables for the backpack	1			*
Cathode and accompanying connector cable for the backpack	1			*
Non-breathable Chest Waders (for every person)	3	*		
Shoulder length rubber electrofishing gloves (for every person)	3	*		
Hat (for every person)	3		*	
Polarized Sunglasses (for every person)	3		*	
Long handled Electrofishing Nets (all netters + spare)	2	*		
Large Buckets with handles for holding fish	3	*		
Aquarium dip nets (2-4)	4	*		
Bowl or small rubber made (with high sides) for weighing fish	4	*		
Weighing scale (for both individual and bulk sizes)	1	*		
Measuring board	1	*		
Fish ID key	1		*	
Tape measure	1	*		
Safety kit	1	*		
Fish sampling forms on waterproof paper		*		
Pencils	2+	*		
Clipboard	1	*		
Non-powdered Gloves (fish handling)	3+	*		
YSI metre	1	*		
GPS	1	*		
Metre Stick	1	*		
Thermometer	1	*		
Sample bottle for filling the buckets	2	*		

Appendix 7.1.9: Sample electrofishing field data sheet.

Page 1 of 1

- Electrofishing Record and Catch Results

Project Number: RareB5
Station Number: B5
Project Name: Rare Electrofishing
Pass No. (if applicable): 3
Project manager: C. Head
Date (yyyymmdd): 2016/09/01
Descriptive Location: North of Blair Rd, 40m downstream of road culvert, open meadow area
UTM coordinates: 4803525 easting 551814 northing zone 17T

Fishing Method (circle one): (Backpack) Boat
Unit Model/Make: LR-24 Smith Root
Sampling Method (circle one): (even) habitat transect spot

Effort (Electrofishing Seconds): 1150, 1000|||| Number of Netters: 1 Number of Anodes: 1

Settings

Frequency (Hz): 25 Voltage (volts): 170 Current (Amps): 0.27 Power (Watts): 59

Station Information

Length of Stream Surveyed (m): 40m

Station Characteristics:
Width (m): Range 0.5, 1, 0.75 Average: 0.75
Depth (m): Range 0.25, 0.75, 0.5 Average: 0.33

Water Clarity/Colour: Clear/none
Water Velocity if Measured (m/s): 0.3
Temperature (°C): 9°C
Conductivity (uS/cm): 0.5
pH: 8
Dissolved Oxygen (mg/L): 8.75

Catch Data

Species	Number of Fish	Species	Number of Fish
BRTR	27		
BRST	12		

Fish Measurements on Separate Sheet? Y (N)

Field Staff: C. Head, J. Quinn
Notes By: C. Head

(Station Diagram on Back)

7.2 Data Analysis

Appendix 7.2.1: Benthic invertebrate's tolerance values used in HBI analysis.

Taxon	Common Name	Tolerance Value
Amphipoda	Scud	6
Anisoptera	Dragonfly	5
Ceratopogonidae	No-see-ums	6
Chironomidae	Midges, some of which are bloodworms	7
Coleoptera	Beetle	4
Coelenterata	Hydra	8
Culicidae	Mosquito	5
Decapoda	Crayfish	5
Diptera, Misc.	Misc. True Flies	N/A
Ephemeroptera	Mayfly	5
Gastropoda	Snail	8
Hemiptera	True Bug	5
Hirudinea	Leech	8
Isopoda	Sowbug	8
Lepidoptera	Aquatic Moth	5
Megaloptera	Hellgrammite, Alderfly, Dobsonfly	4
Nematoda	Roundworm	8
Oligochaeta	Aquatic Worm	8
Pelecypoda	Clams and Mussels	6
Plecoptera	Stonefly	1
Simuliidae	Blackfly	6
Tabanidae	Horsefly	5
Tipulidae	Cranefly	3
Trichoptera	Caddisfly	4
Trombidiformes-Hydracarina	Water mite	6
Turbellaria	Flatworm	8
Zygoptera	Damselfly	7

Appendix 7.2.2: Reference Metrics, adapted from the 2017 Conservation Halton Ecological Monitoring Protocol.

Metric	Unimpaired	Possibly Impaired	Impaired	Source
% EPT	>10	5-10	<5	Conservation Halton (2017))
Taxa Richness (total)	>13		<13	Conservation Halton (2017)
% Oligochaeta	<10	10-30	>30	Conservation Halton (2017)
SDI	>4	3-4	<3	Conservation Halton (2017)
HBI	<6	6-7	>7	Conservation Halton (2017)

7.3 Raw Data and Metrics

Appendix 7.3.1: Bauman Creek raw water quality data from spring (top) and fall (bottom) 2016 (Note: ND stands for Not Detected.

		Bauman Creek			
		B2	B5	B3	B4
Total Suspended Solids	mg/L	24	50	8	18
Dissolved Chloride (Cl)	mg/L	38	38	39	22
Metals					
Total Aluminum (Al)	ug/L	180	45	33	29
Total Arsenic (As)	ug/L	ND	ND	ND	ND
Total Barium (Ba)	ug/L	73	72	72	85
Total Boron (B)	ug/L	12	12	11	ND
Total Cadmium (Cd)	ug/L	ND	ND	ND	ND
Total Calcium (Ca)	ug/L	84000	85000	84000	75000
Total Cobalt (Co)	ug/L	ND	ND	ND	ND
Total Copper (Cu)	ug/L	2.1	ND	ND	ND
Total Iron (Fe)	ug/L	300	ND	ND	ND
Total Lead (Pb)	ug/L	1.1	ND	ND	ND
Total Magnesium (Mg)	ug/L	28000	29000	28000	27000
Total Manganese (Mn)	ug/L	29	8.2	7.9	4.5
Total Molybdenum (Mo)	ug/L	ND	ND	ND	ND
Total Nickel (Ni)	ug/L	ND	ND	ND	ND
Total Potassium (K)	ug/L	880	860	810	800
Total Silicon (Si)	ug/L	4800	4800	4600	4700
Total Sodium (Na)	ug/L	19000	20000	19000	8600
Total Strontium (Sr)	ug/L	100	110	100	79
Total Titanium (Ti)	ug/L	6.8	ND	ND	ND
Total Uranium (U)	ug/L	0.41	0.40	0.35	0.31
Total Vanadium (V)	ug/L	1.1	0.80	0.76	0.74
Total Zinc (Zn)	ug/L	5.7	ND	ND	ND

Appendix 7.3.1: Cont'd

		Bauman Creek			
		B2	B5	B3	B4
Total Suspended Solids	mg/L	5	5	4	47
Dissolved Chloride (Cl)	mg/L	33	34	34	20
Metals					
Total Aluminum (Al)	ug/L	13	21	17	70
Total Barium (Ba)	ug/L	65	67	70	100
Total Boron (B)	ug/L	12	13	12	12
Total Calcium (Ca)	ug/L	72000	71000	75000	66000
Total Copper (Cu)	ug/L	ND	ND	ND	ND
Total Iron (Fe)	ug/L	ND	ND	ND	130
Total Lead (Pb)	ug/L	ND	ND	ND	0.63
Total Magnesium (Mg)	ug/L	26000	25000	26000	24000
Total Manganese (Mn)	ug/L	3.7	4.7	5.7	17
Total Nickel (Ni)	ug/L	ND	ND	ND	ND
Total Potassium (K)	ug/L	940	920	960	1000
Total Silicon (Si)	ug/L	4400	4400	4400	4400
Total Sodium (Na)	ug/L	19000	18000	19000	7300
Total Strontium (Sr)	ug/L	93	91	96	72
Total Titanium (Ti)	ug/L	ND	ND	ND	ND
Total Uranium (U)	ug/L	0.35	0.34	0.36	0.30
Total Vanadium (V)	ug/L	0.54	0.56	0.55	0.77
Total Zinc (Zn)	ug/L	ND	ND	ND	ND

Appendix 7.3.2: Cruickston Creek raw water quality data from spring (top) and fall (bottom) 2016 (Note: ND stands for Not Detected).

		Cruickston Creek				
		C7	**C4**	**C1**	**C2**	**C5**
Total Suspended Solids	mg/L	13	8	15	5	3
Dissolved Chloride (Cl)	mg/L	14	13	14	14	14
Metals						
Total Aluminum (Al)	ug/L	73	53	110	20	12
Total Arsenic (As)	ug/L	ND	ND	ND	ND	ND
Total Barium (Ba)	ug/L	56	57	60	63	62
Total Boron (B)	ug/L	ND	ND	ND	ND	ND
Total Cadmium (Cd)	ug/L	ND	ND	ND	ND	ND
Total Calcium (Ca)	ug/L	83000	82000	81000	87000	80000
Total Cobalt (Co)	ug/L	ND	ND	ND	ND	ND
Total Copper (Cu)	ug/L	ND	ND	ND	ND	ND
Total Iron (Fe)	ug/L	170	120	280	ND	ND
Total Lead (Pb)	ug/L	ND	ND	0.77	ND	ND
Total Magnesium (Mg)	ug/L	27000	27000	26000	28000	26000
Total Manganese (Mn)	ug/L	34	31	80	29	36
Total Molybdenum (Mo)	ug/L	ND	ND	ND	ND	ND
Total Nickel (Ni)	ug/L	ND	ND	ND	ND	1.2
Total Potassium (K)	ug/L	730	700	710	730	690
Total Silicon (Si)	ug/L	4100	4000	4000	4100	3700
Total Sodium (Na)	ug/L	2600	2600	2600	2700	2600
Total Strontium (Sr)	ug/L	84	82	81	85	79
Total Titanium (Ti)	ug/L	ND	ND	ND	ND	ND
Total Uranium (U)	ug/L	0.58	0.58	0.58	0.59	0.53
Total Vanadium (V)	ug/L	0.60	0.54	0.51	ND	ND
Total Zinc (Zn)	ug/L	ND	ND	ND	ND	ND

Appendix 7.3.2: Cont'd

		Cruickston Creek				
		C7	**C4**	**C1**	**C2**	**C5**
Total Suspended Solids	mg/L	27	6	9	2	32
Dissolved Chloride (Cl)	mg/L	14	14	14	14	14
Metals						
Total Aluminum (Al)	ug/L	52	25	45	16	60
Total Barium (Ba)	ug/L	62	63	63	73	86
Total Boron (B)	ug/L	13	13	12	12	12
Total Calcium (Ca)	ug/L	74000	76000	74000	77000	77000
Total Copper (Cu)	ug/L	ND	ND	ND	ND	ND
Total Iron (Fe)	ug/L	ND	ND	ND	ND	380
Total Lead (Pb)	ug/L	ND	ND	ND	ND	0.95
Total Magnesium (Mg)	ug/L	26000	26000	26000	26000	26000
Total Manganese (Mn)	ug/L	12	8.1	20	14	130
Total Nickel (Ni)	ug/L	ND	ND	ND	ND	ND
Total Potassium (K)	ug/L	1100	1100	1000	880	880
Total Silicon (Si)	ug/L	4300	4300	4200	4000	3900
Total Sodium (Na)	ug/L	2900	3000	2900	2900	2900
Total Strontium (Sr)	ug/L	81	81	81	81	79
Total Titanium (Ti)	ug/L	ND	ND	ND	ND	ND
Total Uranium (U)	ug/L	0.57	0.58	0.58	0.60	0.60
Total Vanadium (V)	ug/L	0.55	0.52	0.57	ND	0.56
Total Zinc (Zn)	ug/L	ND	ND	ND	ND	ND

Appendix 7.3.3 Newman Creek raw water quality data from spring (top) and fall (bottom) 2016 (Note: ND stands for Not Detected).

		Newman Creek			
		NM1	**NM3**	**NM4**	**NM5**
Total Suspended Solids	mg/L	230	5	11	44
Dissolved Chloride (Cl)	mg/L	91	100	110	100
Metals					
Total Aluminum (Al)	ug/L	130	48	140	350
Total Arsenic (As)	ug/L	110	ND	ND	1.4
Total Barium (Ba)	ug/L	130	26	31	55
Total Boron (B)	ug/L	32	14	14	17
Total Cadmium (Cd)	ug/L	ND	ND	ND	ND
Total Calcium (Ca)	ug/L	70000	73000	72000	75000
Total Cobalt (Co)	ug/L	ND	ND	ND	ND
Total Copper (Cu)	ug/L	ND	ND	1.1	2.3
Total Iron (Fe)	ug/L	34000	110	390	2000
Total Lead (Pb)	ug/L	1.1	ND	ND	0.87
Total Magnesium (Mg)	ug/L	24000	20000	20000	19000
Total Manganese (Mn)	ug/L	740	14	130	840
Total Molybdenum (Mo)	ug/L	ND	ND	ND	ND
Total Nickel (Ni)	ug/L	ND	ND	ND	ND
Total Potassium (K)	ug/L	240	1100	1200	2300
Total Silicon (Si)	ug/L	8700	2000	1900	1800
Total Sodium (Na)	ug/L	78000	57000	64000	60000
Total Strontium (Sr)	ug/L	270	140	150	160
Total Titanium (Ti)	ug/L	8.4	ND	5.6	11
Total Uranium (U)	ug/L	ND	0.20	0.17	0.18
Total Vanadium (V)	ug/L	1.2	ND	0.69	1.5
Total Zinc (Zn)	ug/L	7.2	ND	ND	5.4

Appendix 7.3.3: Cont'd

		Newman Creek
		NM5
Total Suspended Solids	mg/L	36
Dissolved Chloride (Cl)	mg/L	66
Metals		
Total Aluminum (Al)	ug/L	59
Total Barium (Ba)	ug/L	32
Total Boron (B)	ug/L	14
Total Calcium (Ca)	ug/L	56000
Total Copper (Cu)	ug/L	ND
Total Iron (Fe)	ug/L	250
Total Lead (Pb)	ug/L	ND
Total Magnesium (Mg)	ug/L	10000
Total Manganese (Mn)	ug/L	32
Total Nickel (Ni)	ug/L	ND
Total Potassium (K)	ug/L	510
Total Silicon (Si)	ug/L	1600
Total Sodium (Na)	ug/L	39000
Total Strontium (Sr)	ug/L	110
Total Titanium (Ti)	ug/L	ND
Total Uranium (U)	ug/L	ND
Total Vanadium (V)	ug/L	ND
Total Zinc (Zn)	ug/L	ND

Appendix 7.3.4: Blair Flats and Preston Flats raw water quality data from spring (top) and fall (bottom) 2016.

		Wetlands	
		BF1	**PF1**
Total Suspended Solids	mg/L	220	29
Dissolved Chloride (Cl)	mg/L	41	170
Metals			
Total Aluminum (Al)	ug/L	720	300
Total Arsenic (As)	ug/L	ND	1.3
Total Barium (Ba)	ug/L	96	57
Total Boron (B)	ug/L	15	20
Total Cadmium (Cd)	ug/L	0.11	ND
Total Calcium (Ca)	ug/L	110000	49000
Total Cobalt (Co)	ug/L	0.55	ND
Total Copper (Cu)	ug/L	4.7	1.8
Total Iron (Fe)	ug/L	1200	460
Total Lead (Pb)	ug/L	3.1	1.4
Total Magnesium (Mg)	ug/L	29000	22000
Total Manganese (Mn)	ug/L	98	23
Total Molybdenum (Mo)	ug/L	ND	1.8
Total Nickel (Ni)	ug/L	1.7	ND
Total Potassium (K)	ug/L	750	2800
Total Silicon (Si)	ug/L	1500	690
Total Sodium (Na)	ug/L	25000	110000
Total Strontium (Sr)	ug/L	110	720
Total Titanium (Ti)	ug/L	20	11
Total Uranium (U)	ug/L	0.35	0.53
Total Vanadium (V)	ug/L	2.7	3.2
Total Zinc (Zn)	ug/L	28	6.4

Appendix 7.3.4:Cont'd

		Wetlands	
		BF1	**PF1**
Total Suspended Solids	mg/L	240	180
Dissolved Chloride (Cl)	mg/L	39	130
Metals			
Total Aluminum (Al)	ug/L	790	520
Total Barium (Ba)	ug/L	88	72
Total Boron (B)	ug/L	15	27
Total Calcium (Ca)	ug/L	72000	78000
Total Copper (Cu)	ug/L	3.6	2.5
Total Iron (Fe)	ug/L	890	930
Total Lead (Pb)	ug/L	2.1	1.9
Total Magnesium (Mg)	ug/L	29000	20000
Total Manganese (Mn)	ug/L	24	240
Total Nickel (Ni)	ug/L	1.3	1.0
Total Potassium (K)	ug/L	2400	2300
Total Silicon (Si)	ug/L	4300	5000
Total Sodium (Na)	ug/L	22000	76000
Total Strontium (Sr)	ug/L	97	1300
Total Titanium (Ti)	ug/L	22	18
Total Uranium (U)	ug/L	0.46	0.30
Total Vanadium (V)	ug/L	2.4	2.1
Total Zinc (Zn)	ug/L	14	10

Appendix 7.3.5: Bauman Creek physicochemical properties in Spring and Fall from 2006-2015.

Year/ Season	Site	Dissolved oxygen (mg/L)	pH	Temperature Air (˚C)	Temperature Water (˚C)	Conductivity (ms/cm)
Spring 2006	B1	14	13	NA	NA	NA
	B2	22	14	NA	NA	NA
	B3	11	10	NA	NA	NA
	B4	NA	13	NA	NA	NA
Fall 2006	B1	8	9.5	NA	NA	NA
	B2	5	9	NA	NA	NA
	B4	13.5	12	NA	NA	NA
Spring 2009	B1	6.88	7.97	31.4	22.38	0.005
	B2	7.55	8.13	31.4	21.12	NA
	B3	10.8	8.46	23.6	13.8	0.00617
	B4	9.9	8.06	23.6	12.21	0.00638
Fall 2009	B1	7.85	7.31	12.3	8.37	0.757
	B2	9.47	7.58	11.5	8.85	0.598
	B3	11.05	8.08	11.1	9.5	0.542
	B4	10.15	7.9	12.1	10.05	0.543
Spring 2012	B3	7.67	7.11	25.2	25.30	NA
	B4	10.12	7.74	25.8	19.40	0.53
Fall 2012	B3	12.19	8.15	8.3	7.25	0.632
	B4	10.71	8	9.4	7.74	0.633
	B5	12.3	8.5	14.7	6.45	0.628
Spring 2015	B2	10.55	> 8*	30.2	15.5	0.020
	B3	10.5		25.8	14.4	0.625
	B4	11.55		24.6	14.25	0.015
	B5	12.15		28	14.4	0.629
Fall 2015	B2	11.22	8.28	28.6	13.96	0.591
	B3	9.61	8.24	26.5	15.19	0.589
	B4	9.63	7.83	26.7	14.98	0.593
	B5	13.2	8.3	31.3	15.08	0.583

*All sites were not sampled for all parameters in all years; NA is marked in years when sites were not sampled.

Appendix 7.3.6: Cruickston Creek physicochemical properties in Spring and Fall from 2006-2015

Year / Season	Site	Dissolved oxygen (mg/L)	pH	Temperature		Conductivity (ms/cm)
				Air (°C)	Water (°C)	
Spring 2006	C1B	21	17	NA	NA	NA
	C2	21	16	NA	NA	NA
Fall 2006	C1B	17	11	NA	NA	NA
	C2	9	8.5	NA	NA	NA
Spring 2009	C1	11.28	9.18	13	11.15	0.501
	C2	9.79	8.91	13	11.53	0.506
	C3	10.95	9.2	10	11.94	0.489
	C4	10.31	9.2	10	11.75	0.483
	C5	NA	NA	19.4	14	NA
Fall 2009	C1	10.51	8.44	19.1	10.52	0.523
	C2	9.27	7.48	12.6	10.45	0.511
	C3	10.32	8.51	16.3	9.75	0.536
	C4	10.34	8.41	18.9	10.31	0.525
	C5	4.95	6.97	11.5	10.3	0.532
Spring 2012	C1A	7.61	12.56	25.7	21.6	NA
	C1B	7.61	12.56	25.7	21.6	NA
	C2	9.48	7.96	23.1	18.2	0.002
	C3	10.59	7.95	28.7	16.88	0.337
	C4	10.31	7.47	29.6	15.68	0.637
	C5	9.98	7.72	21.7	13.38	0.565
Fall 2012	C1A	12.46	7.2	6.2	6.54	0.588
	C1B	7.07	7.51	13.4	10.67	0.576
	C2	8.98	7.95	9.4	10.21	0.586
	C3	17.81	7.33	14.8	6.96	0.581
	C4	12.66	7.54	13.9	6.48	0.583
	C5	7.23	7.44	9.6	9.64	0.604
Spring 2015	C1A	9.13	7.32	20.8	15.95	0.551
	C1B	11.66	7.22	20.5	16.75	0.011
	C2	1.02	7.38	28.2	17.14	0.483
	C3	9.3	2.86	23.1	17.36	0.534
	C4	9.55	3.19	28.2	17.63	0.540
	C5	8.54	7.05	21.2	14.7	0.541
Fall 2015	C1B	10.5	8.3	26.6	17.6	0.050
	C2	8.7	8	24	17.8	0.003
	C3	10.2	7.78	22.7	16.68	0.004
	C4	9.27	5.9	28.5	18.06	0.005
	C5	9.04	7.8	22.8	15.3	0.540

*All sites were not sampled for all parameters in all years; NA is marked in years when sites were not sampled.

Appendix 7.3.7: Newman Creek physicochemical properties in spring 2016.

Year / Season	Site	Dissolved oxygen (mg/L)	pH	Temperature		Conductivity (ms/cm)
				Air (˚C)	Water (˚C)	
Spring 2016	NM3	8.2	6.76	29.5	20	NA
	NM4	8.07	4.94	25	17.5	NA

*All sites were not sampled for all parameters in all years; NA is marked in years when sites were not sampled.

Appendix 7.3.8: Blair and Preston Flats physicochemical properties in spring and fall from 2009-2015.

Year / Season	Waterbody	Dissolved oxygen (mg/L)	pH	Temperature		Conductivity (ms/cm)
				Air (˚C)	Water (˚C)	
Spring 2009	Blair Flats	NA	NA	17.5	18	NA
	Preston Flats	NA	NA	19	20.5	NA
Fall 2009	Blair Flats	5.61	7.9	14.7	13.36	0.488
	Preston Flats	1.1	7.13	15.6	13.21	0.973
Spring 2012	Blair Flats	8.65	6.24	29.5	20.77	0.651
	Preston Flats	19.85	9.79	29.8	31.74	0.648
Fall 2012	Blair Flats	3.64	7.75	18.2	7.25	0.68
	Preston Flats	14.5	8.64	18.2	9.03	0.952
Spring 2015	Blair Flats	0.73	6.83	25.6	18.01	0.735
	Preston Flats	0.88	6.92	23.3	19.78	0.959
Fall 2015	Blair Flats	3.62	7.75	15.4	9.06	0.619
	Preston Flats	6.35	7.41	20.8	18.3	1.041

*All sites were not sampled for all parameters in all years; NA is marked in years when sites were not sampled.

Appendix 7.3.9: Presence (P) or Absence (A) of taxonomic groups in samples from ***rare*** waterbodies across sampling years.

Taxonomic Group	Bauman Creek	Cruickston Creek	Newman Creek	Blair Flats Wetland	Preston Flats Wetland
Amphipoda	P	P	A	P	P
Anisoptera	P	P	A	P	P
Ceratopogonidae	P	P	P	P	P
Chironomidae	P	P	P	P	P
Coelenterata	A	A	A	A	A
Coleoptera	P	P	A	P	P
Culicidae	P	P	A	P	P
Decapoda	A	P	A	A	A
Ephemeroptera	P	P	A	P	P
Gastropoda	P	P	P	P	P
Hemiptera	P	P	A	P	P
Hirudinea	P	P	A	P	P
Isopoda	P	P	P	P	P
Lepidoptera	P	P	P	A	A
Megaloptera	P	P	A	P	P
Misc. Diptera	P	P	A	P	P
Nematoda	P	P	A	P	P
Oligochaeta	P	P	P	P	P
Pelecypoda	P	P	P	P	P
Plecoptera	P	P	P	P	P
Simuliidae	P	P	A	A	A
Tabanidae	P	P	P	A	P
Tipulidae	P	P	P	P	P
Trichoptera	P	P	P	P	P
Trombidiformes	P	P	A	P	P
Turbellaria	P	P	A	P	A
Zygoptera	A	A	A	P	P

Appendix 7.3.10: Shannon-Wiener Diversity Index and Simpson Complement Index and Shannon's Equitability Index values for Bauman Creek spring and fall from 2006-2015.

Site	Season Sampled	Year Sampled	Shannon-Wiener Diversity Index	Simpson Complement Index	Shannon's Equitability Index
B1	Spring	2006	1.93	0.82	0.80
		2009	1.90	0.82	0.74
		2012	NA	NA	NA

		2015	NA	NA	NA
	Fall	2006	1.56	0.72	0.65
		2009	1.60	0.72	0.65
		2012	NA	NA	NA
		2015	NA	NA	NA
B2	Spring	2006	1.24	0.54	0.52
		2009	1.17	0.54	0.46
		2012	NA	NA	NA
		2015	1.59	0.71	0.57
	Fall	2006	1.75	0.78	0.66
		2009	1.78	0.77	0.71
		2012	NA	NA	NA
		2015	1.53	0.69	0.58
B5	Spring	2006	NA	NA	NA
		2009	NA	NA	NA
		2012	1.04	0.49	0.42
		2015	1.69	0.75	0.64
	Fall	2006	NA	NA	NA
		2009	NA	NA	NA
		2012	1.17	0.58	0.51
		2015	1.29	0.52	0.49
B3	Spring	2006	1.69	0.75	0.71
		2009	1.68	0.71	0.68
		2012	1.32	0.62	0.55
		2015	1.37	0.53	0.51
	Fall	2006	NA	NA	NA
		2009	1.43	0.64	0.54
		2012	1.30	0.60	0.63
		2015	1.73	0.70	0.65
B4	Spring	2006	1.60	0.74	0.67
		2009	1.67	0.76	0.70
		2012	1.87	0.79	0.71
		2015	2.11	0.84	0.76
	Fall	2006	1.70	0.78	0.68
		2009	1.89	0.79	0.76
		2012	1.93	0.80	0.75
		2015	2.05	0.83	0.74

*All sites were not sampled in all years; NA is marked in years when sites were not sampled.

Appendix 7.3.11: Shannon-Wiener Diversity and Simpson Complement Indices and Shannon's Equitability Index values for Cruickston Creek spring and fall from 2006-2015.

Site	Season Sampled	Year Sampled	Shannon-Wiener Index	Simpson Complement Index	Shannon's Equitability Index
C1A	Spring	2006	NA	NA	NA
		2009	NA	NA	NA
		2012	2.03	0.86	0.88
		2015	2.46	0.91	0.81
	Fall	2006	NA	NA	NA
		2009	NA	NA	NA
		2012	1.54	0.68	0.62
		2015	NA	NA	NA
C1B	Spring	2006	1.61	0.73	0.67
		2009	2.10	0.85	0.79
		2012	2.18	0.85	0.75
		2015	1.32	0.61	0.51
	Fall	2006	1.85	0.76	0.70
		2009	2.05	0.84	0.82
		2012	1.07	0.45	0.42
		2015	1.92	0.78	0.73
C2	Spring	2006	1.79	0.74	0.70
		2009	1.88	0.80	0.71
		2012	1.89	0.80	0.72
		2015	2.12	0.85	0.77
	Fall	2006	2.15	0.85	0.81
		2009	1.62	0.68	0.65
		2012	2.17	0.85	0.80
		2015	1.94	0.81	0.30
C5	Spring	2006	NA	NA	NA
		2009	1.84	0.79	0.77
		2012	1.69	0.78	0.70
		2015	1.95	0.82	0.74
	Fall	2006	NA	NA	NA
		2009	1.70	0.74	0.71
		2012	1.39	0.64	0.67
		2015	1.87	0.79	0.69

*All sites were not sampled in all years; NA is marked in years when sites were not sampled.

Appendix 7.3.12: Shannon-Wiener Diversity and Simpson Complement Indices and Shannon's Equitability Index values for Newman Creek spring 2016.

Site	Season Sampled	Year Sampled	Shannon-Wiener Diversity Index	Simpson Index	Shannon's Equitability Index
NM3	Spring	2016	1.8	0.78	0.75
NM4		2016	1.58	0.74	0.69

Appendix 7.3.13: Shannon-Wiener Diversity and Simpson Complement Indices and Shannon's Equitability Index values for Blair and Preston Flats spring and fall from 2009-2015.

Site	Season Sampled	Year Sampled	Shannon-Wiener Diversity Index	Simpson Complement Index	Shannon's Equitability Index
BF-1	Spring	2009	1.52	0.68	0.57
		2012	1.05	0.56	0.41
		2015	1.36	0.66	0.57
	Fall	2009	1.95	0.82	0.74
		2012	1.12	0.64	0.62
		2015	1.53	0.68	0.60
PF-1	Spring	2009	1.98	0.82	0.73
		2012	1.71	0.71	0.63
		2015	1.70	0.75	0.74
	Fall	2009	1.45	0.68	0.58
		2012	1.66	0.75	0.67
		2015	1.17	0.58	0.53

Appendix 7.3.14: Raw Hilsenhoff Biotic Index (HBI) values for Bauman Creek spring and fall from 2006-2015.

Year/ Season	Site #	Mean HBI	Standard Error
Spring 2006	B1	6.01	0.33
	B2	5.86	0.12
	B3	5.48	0.42
	B4	4.99	0.22
	B5	NA	NA
Fall 2006	B1	7.05	0.16
	B2	7.12	0.08
	B3	NA	NA
	B4	4.74	0.36
	B5	NA	NA
Spring 2009	B1	6.44	0.26
	B2	6.38	0.02

	B3	5.75	0.12
	B4	3.65	0.46
	B5	NA	NA
Fall 2009	B1	7.23	0.06
	B2	7.17	0.19
	B3	4.60	0.58
	B4	4.06	0.39
	B5	NA	NA
Spring 2012	B1	NA	NA
	B2	NA	NA
	B3	6.31	0.24
	B4	4.40	0.21
	B5	6.45	0.30
Fall 2012	B1	NA	NA
	B2	NA	NA
	B3	5.92	0.10
	B4	4.53	0.18
	B5	6.55	0.07
Spring 2015	B1	NA	NA
	B2	6.80	0.11
	B3	5.69	0.10
	B4	4.71	0.61
	B5	6.47	0.17
Fall 2015	B1	NA	NA
	B2	6.68	0.17
	B3	5.22	0.44
	B4	5.37	0.19
	B5	6.17	0.30

*All sites were not sampled in all years; NA is marked in years when sites were not sampled.

Appendix 7.3.15: Raw Hilsenhoff Biotic Index (HBI) values for Cruickston Creek spring and fall from 2006-2015.

Year/ Season	Site #	Mean HBI	Standard Error
Spring 2006	C1A	NA	NA
	C1B	6.64	0.52
	C2	5.18	0.27
	C3	NA	NA
	C4	NA	NA
	C5	NA	NA
Fall 2006	C1A	NA	NA
	C1B	6.70	0.54
	C2	4.59	0.28
	C3	NA	NA
	C4	NA	NA
	C5	NA	NA
Spring 2009	C1A	NA	NA
	C1B	4.58	0.26
	C2	4.76	0.57
	C3	5.97	0.18
	C4	5.68	0.19
	C5	6.29	0.18
Fall 2009	C1A	NA	NA
	C1B	5.94	0.57
	C2	4.59	0.47
	C3	6.08	0.14
	C4	5.63	0.47
	C5	7.10	0.13
Spring 2012	C1A	5.11	0.70
	C1B	5.28	0.24
	C2	5.31	0.68
	C3	6.72	0.50
	C4	5.98	0.13
	C5	4.40	0.18
Fall 2012	C1A	6.65	0.21
	C1B	6.72	0.83
	C2	5.03	0.61
	C3	7.87	0.02
	C4	7.53	0.14
	C5	6.18	NA
Spring 2015	C1A	5.18	0.62
	C1B	7.20	0.53

	C2	5.00	0.68
	C3	5.91	0.09
	C4	5.20	0.30
	C5	6.15	0.10
Fall 2015	C1A	NA	NA
	C1B	5.70	0.34
	C3	5.93	0.33
	C4	6.52	0.52
	C5	5.29	0.20

*All sites were not sampled in all years; NA is marked in years when sites were not sampled.

Appendix 7.3.16: Raw Hilsenhoff Biotic Index (HBI) values for Newman Creek spring 2016.

Year/ Season	Site #	Mean HBI	Standard Error
Spring 2016	NM3	6.92	0.23
	NM4	7.24	0.01

Appendix 7.3.17: Raw Hilsenhoff Biotic Index (HBI) values at Blair and Preston Flats in spring and fall from 2009-2015.

Year/ Season	Site #	Mean HBI	Standard Error
Spring 2009	BF-1	6.81	0.86
	PF-1	6.43	0.33
Fall 2009	BF-1	6.87	0.45
	PF-1	5.98	0.30
Spring 2012	BF-1	7.61	0.24
	PF-1	7.09	0.06
Fall 2012	BF-1	7.71	0.26
	PF-1	6.35	0.08
Spring 2015	BF-1	7.73	0.11
	PF-1	7.26	0.13
2015 Fall	BF-1	7.05	0.42
	PF-1	6.74	0.24

Appendix 7.3.18: Per cent Taxa at Bauman Creek sites from 2006-2015.

Year / Season	Site #	% Ephemeroptera	% Plecoptera	% Trichoptera	% EPT	% Oligochaeta
Spring 2006	B1	0	0	28.97	28.97	3.1
	B2	0	0	11.08	11.08	1.54
	B3	32.94	0.88	12.35	46.17	0
	B4	1.55	24.03	5.04	30.62	1.16
	B5	NA	NA	NA	NA	NA
Fall 2006	B1	0	0	1.32	1.32	42.57
	B2	1.95	0.65	0.65	3.25	21.1
	B3	NA	NA	NA	NA	NA
	B4	0.31	23.82	2.82	26.95	0.63
	B5	NA	NA	NA	NA	NA
Spring 2009	B1	0.3	0	5.34	5.64	0.59
	B2	0	0.4	2.99	3.39	0.2
	B3	13.31	1.95	3.57	18.83	3.25
	B4	2.02	39.73	13.8	55.55	0.34
	B5	NA	NA	NA	NA	NA
Fall 2009	B1	0	0	1.03	1.03	19.52
	B2	NA	NA	NA	NA	11.08
	B3	3.24	26.43	2.99	32.66	4.99
	B4	6.67	38.67	4	49.34	4
	B5	NA	NA	NA	NA	NA
Spring 2012	B1	NA	NA	NA	NA	NA
	B2	NA	NA	NA	NA	NA
	B3	0	0.66	6.89	7.55	26.23
	B4	0	28.38	13.53	41.91	4.29
	B5	0.54	0	2.95	3.49	1.34
Fall 2012	B1	NA	NA	NA	NA	NA
	B2	NA	NA	NA	NA	NA
	B3	3.91	7.42	2.73	14.06	13.28
	B4	0	29.39	3.38	32.77	2.36

	B5	0	1.35	1.35	2.7	2.36
Spring 2015	B1	NA	NA	NA	NA	NA
	B2	0	0.96	0.96	1.92	6.71
	B3	1.64	5.25	1.31	8.2	3.61
	B4	3.41	30.03	7.17	40.61	10.92
	B5	1.33	1.33	1.66	4.32	4.98
Fall 2015	B1	NA	NA	NA	NA	NA
	B2	0	0.33	0.33	0.66	23.93
	B3	9.24	14.33	4.14	27.71	4.78
	B4	0	17.75	1.09	18.84	5.07
	B5	1.96	1.31	0.98	4.25	5.56

*All sites were not sampled in all years; NA is marked in years when sites were not sampled.

Appendix 7.3.19: Per cent Taxa at Cruickston Creek sites from 2006-2015.

Year / Season	Site #	% Ephemeroptera	% Plecoptera	% Trichoptera	%EPT	% Oligochaeta
Spring 2006	C1A	NA	NA	NA	NA	NA
	C1B	1.71	0.57	4.29	6.57	34.86
	C2	1.35	9.46	13.18	23.99	0.68
	C3	NA	NA	NA	NA	NA
	C4	NA	NA	NA	NA	NA
	C5	NA	NA	NA	NA	NA
Fall 2006	C1A	NA	NA	NA	NA	NA
	C1B	0	0.36	11.39	11.75	43.77
	C2	2.4	19.52	26.37	48.29	5.14
	C3	NA	NA	NA	NA	NA
	C4	NA	NA	NA	NA	NA
	C5	NA	NA	NA	NA	NA
Spring 2009	C1A	NA	NA	NA	NA	NA
	C1B	24.05	20.27	18.9	63.22	6.19
	C2	7.42	17.1	29.35	53.87	2.26
	C3	29.85	3.69	11.38	44.92	29.23
	C4	43.85	1.58	7.57	53	15.46
	C5	0	0.083	0.055	0.138	0.038
Fall 2009	C1A	NA	NA	NA	NA	NA
	C1B	0.42	4.66	28.39	33.47	8.05
	C2	0.42	13.98	53.39	67.79	2.54
	C3	0	2.07	23.65	25.72	29.05
	C4	0	3.33	28.75	32.08	8.33
	C5	0	0	7.23	7.23	3.61
Spring 2012	C1A	0	26.83	7.32	34.15	4.88
	C1B	1.7	18.03	11.56	31.29	11.22
	C2	0.33	11.26	28.48	40.07	3.31
	C3	0	0	19.12	19.12	50
	C4	12.47	2.04	18.07	32.58	13.49
	C5	0	30.91	7.26	38.17	0

Fall 2012	C1A	0	0	2.41	2.41	22.07
	C1B	0	0	2.56	2.56	73.93
	C2	2.81	8.99	30.9	42.7	6.18
	C3	0	0.25	0	0.25	92.91
	C4	0	0	0.5	0.5	84.5
	C5	0	0	2.44	2.44	2.44
Spring 2015	C1A	1.16	1.74	4.65	7.55	11.63
	C1B	0.44	0.87	2.18	3.49	57.21
	C2	5.21	16.94	14.01	36.16	3.58
	C3	5.75	0	23.02	28.77	21.23
	C4	16.88	0	26.11	42.99	9.55
	C5	0	10.34	8.05	18.39	4.02
Fall 2015	C1A	NA	NA	NA	NA	NA
	C1B	0	7.95	19.21	27.16	7.62
	C2	0	0.153	0.113	0.266	0.032
	C3	0.17	0.99	24.59	25.75	15.68
	C4	0.39	1.17	9.41	10.97	23.25
	C5	0	26.6	6.4	33	3.03

*All sites were not sampled in all years; NA is marked in years when sites were not sampled.

Appendix 7.3.20: Per cent Taxa in Newman Creek in spring 2016.

Year / Season	Site #	% Ephemeroptera	% Plecoptera	% Trichoptera	%EPT	% Oligochaeta
Spring 2016	NM3	0	0.31	8.67	8.98	38.39
	NM4	0	0	7.44	7.44	39.58

Appendix 7.3.21: Per cent Taxa in Blair and Preston Flats from 2009-2015.

Year / Season	Site #	% Ephemeroptera	% Plecoptera	% Trichoptera	% EPT	% Oligochaeta
Spring 2009	BF1	1.74	0.29	0	2.03	4.35
	PF1	8.02	0	0	8.02	4.63
Fall 2009	BF1	9.87	0	0	9.87	19.31
	PF1	30.34	0	0.31	30.65	1.55
Spring 2012	BF1	0	0	0.24	0.24	54.59
	PF1	10.26	0.32	0.64	11.22	50
Fall 2012	BF1	0	0	0	0	47.45
	PF1	2.01	0	0	2.01	11.74
Spring 2015	BF1	0	0	0	0	40.49
	PF1	0	0	0	0	40.19
Fall 2015	BF1	0.4	0	0	0.4	51.61
	PF1	2.9	0	0	2.9	9.18

Appendix 7.3.22: Taxa richness at Bauman Creek sites from spring and fall 2006-2015.

Year / Season	Site #	Mean Taxa	Pooled Taxa
Spring 2006	B1	10	11
	B2	7.33	11
	B3	8.33	11
	B4	7.67	11
	B5	NA	NA
Fall 2006	B1	8.33	11
	B2	10	14
	B3	NA	NA
	B4	8.67	12
	B5	NA	NA
Spring 2009	B1	9.33	13
	B2	9.67	13
	B3	9	12
	B4	8	11
	B5	NA	NA
Fall 2009	B1	9.67	12
	B2	9.33	12
	B3	9.67	14
	B4	8.33	13
	B5	NA	NA
Spring 2012	B1	NA	NA
	B2	NA	NA
	B3	8	11
	B4	9.67	14
	B5	8.67	12
Fall 2012	B1	NA	NA
	B2	NA	NA
	B3	6.33	8
	B4	9.67	13
	B5	7.33	10
Spring 2015	B1	NA	NA
	B2	9.67	16
	B3	11.67	15
	B4	12.33	11
	B5	8.67	14
Fall 2015	B1	NA	NA
	B2	9.33	14
	B3	10.33	14

	B4	11.33	16
	B5	9.67	14

*All sites were not sampled in all years; NA is marked in years when sites were not sampled.

Appendix 7.3.23: Taxa richness at Cruickston Creek sites from spring and fall 2006-2015.

Year / Season	Site #	Mean Taxa	Pooled Taxa
Spring 2006	C1A	NA	NA
	C1B	7.33	11
	C2	9.33	13
	C3	NA	NA
	C4	NA	NA
	C5	NA	NA
Fall 2006	C1A	NA	NA
	C1B	10.67	14
	C2	12	14
	C3	NA	NA
	C4	NA	NA
	C5	NA	NA
Spring 2009	C1A	NA	NA
	C1B	11.67	14
	C2	9.67	13
	C3	8	10
	C4	9.67	13
	C5	8.2	11
Fall 2009	C1A	NA	NA
	C1B	9.67	12
	C2	8.33	12
	C3	7.67	9
	C4	8.67	12
	C5	7	11
Spring 2012	C1A	5.33	10
	C1B	12	18
	C2	9.67	14
	C3	5	8
	C4	11.33	17
	C5	8.33	11
Fall 2012	C1A	9	12
	C1B	8	13
	C2	9.67	15
	C3	4.67	8

	C4	9.33	11
	C5	8	8
Spring 2015	C1A	11.67	21
	C1B	7.33	13
	C2	10.67	16
	C3	10.67	14
	C4	9	11
	C5	9.33	15
Fall 2015	C1A	NA	NA
	C1B	11.67	14
	C2	10	15
	C3	11	17
	C4	9.67	14
	C5	10.33	15

*All sites were not sampled in all years; NA is marked in years when sites were not sampled.

Appendix 7.3.24: Taxa richness at Newman Creek in spring 2016.

Year / Season	Site #	Mean Taxa	Pooled Taxa
Spring 2016	NM3	8.67	11
	NM4	7.33	10

Appendix 7.3.25: Taxa richness at Blair and Preston Flats from spring and fall 2009-2015.

Year / Season	Site #	Mean Taxa	Pooled Taxa
Spring 2009	BF1	8	14
	PF1	10.33	15
Fall 2009	BF1	9.33	14
	PF1	8.33	12
Spring 2012	BF1	7.67	13
	PF1	10.67	15
Fall 2012	BF1	3.33	6
	PF1	8	12
Spring 2015	BF1	6.67	11
	PF1	6.67	10
Fall 2015	BF1	7.67	13
	PF1	7	9

Appendix 7.3.26: Fisheries data collected at Bauman Creek in 2016.

Site	Species	# Fish (Cumulative)	Total Length (mm)	Forked Length (mm)	Individual Fish Weight (grams)	Stickleback Batch Weight
B5	Brook Trout	1	95	90	9	9 grams total for 10 individual stickleback (one of 11 total stickleback captured was not included in measurement)
B5	Brook Trout	2	80	78	7	
B5	Stickleback	3	45	45		
B5	Brook Trout	4	96	92	6	
B5	Brook Trout	5	135	132	17	
B5	Brook Trout	6	85	82	6	
B5	Brook Trout	7	134	128	24	
B5	Brook Trout	8	73	69	2	
B5	Stickleback	9	45	45		
B5	Brook Trout	10	99	95	10	
B5	Stickleback	11	37	37		
B5	Stickleback	12	45	45		
B5	Brook Trout	13	67	65	3	
B5	Brook Trout	14	158	155	44	
B5	Brook Trout	15	178	175	65	
B5	Stickleback	16	36	36		
B5	Stickleback	17	45	45		
B5	Stickleback	18	42	42		
B5	Stickleback	19	50	50		
B5	Brook Trout	20	72	69	3	
B5	Brook Trout	21	81	78	7	
B5	Brook Trout	22	105	103	12	
B5	Stickleback	23	44	44		
B5	Stickleback	24	37	37		
B5	Stickleback	25	50	50		
B3a	Brook Trout	1	78	74	5	9 grams total for 15 individual stickleback
B3a	Brook Trout	2	80	75	5	
B3a	Stickleback	3	43	43		
B3a	Stickleback	4	50	50		
B3a	Stickleback	5	44	44		
B3a	Stickleback	6	52	52		
B3a	Stickleback	7	43	43		
B3a	Stickleback	8	49	49		
B3a	Brook Trout	9	79	76	6	
B3a	Brook Trout	10	86	84	6	
B3a	Brook Trout	11	121	118	18	

B3a	Stickleback	12	48	48		
B3a	Brook Trout	13	78	73	5	
B3a	Brook Trout	14	154	150	34	
B3a	Stickleback	15	48	48		
B3a	Brook Trout	16	84	81	5	
B3a	Stickleback	17	43	43		
B3a	Brook Trout	18	80	78	4	
B3a	Brook Trout	19	87	84	7	
B3a	Brook Trout	20	69	65	3	
B3a	Stickleback	21	47	47		
B3a	Brook Trout	22	98	97	10	
B3a	Stickleback	23	47	47		
B3a	Brook Trout	24	116	112	15	
B3a	Brook Trout	25	150	147	36	
B3a	Brook Trout	26	67	65	3	
B3a	Brook Trout	27	128	122	24	
B3a	Stickleback	28	49	49		
B3a	Stickleback	29	46	46		
B3a	Stickleback	30	43	43		
B3a	Stickleback	31	46	46		
B3a	Brook Trout	32	94	90	8	
B3a	Brook Trout	33	78	75	6	
B3a	Brook Trout	34	83	80	4	
B3	Brook Trout	1	64	61	2	1st run batch weight = 6grams / 4 individuals 2nd run batch weight = 1grams / 1 individual 3rd run batch weight = 2 grams / 2 individuals TOTAL BATCH WEIGHT = 9 grams / 7 individuals
B3	Brook Trout	2	84	80	3	
B3	Stickleback	3	46			
B3	Brook Trout	4	101	96	6	
B3	Brook Trout	5	81	76	5	
B3	Brook Trout	6	96	90	5	
B3	Brook Trout	7	94	90	6	
B3	Brook Trout	8	84	81	4	
B3	Brook Trout	9	92	88	8	
B3	Brook Trout	10	84	80	5	
B3	Brook Trout	11	78	75	6	
B3	Stickleback	12	53			
B3	Stickleback	13	53			
B3	Brook Trout	14	103	99	11	
B3	Brook Trout	15	113	108	17	
B3	Stickleback	16	50			
B3	Brook Trout	17	76	73	6	
B3	Brook Trout	18	160	153	38	

B3	Brook Trout	19	146	140	37	
B3	Brook Trout	20	83	80	6	
B3	Brook Trout	21	80	76	6	
B3	Brook Trout	22	94	90	9	
B3	Brook Trout	23	147	145	40	
B3	Brook Trout	24	153	150	37	
B3	Brook Trout	25	104	101	13	
B3	Brook Trout	26	81	77	5	
B3	Brook Trout	27	79	75	5	
B3	Brook Trout	28	78	75	4	
B3	Brook Trout	29	136	130	25	
B3	Stickleback	30	49			
B3	Brook Trout	31	66	63	3	
B3	Brook Trout	32	95	91	8	
B3	Brook Trout	33	89	86	6	
B3	Brook Trout	34	89	85	5	
B3	Brook Trout	35	88	84	7	
B3	Brook Trout	36	87	85	5	
B3	Brook Trout	37	79	75	3	
B3	Brook Trout	38	126	124	13	
B3	Brook Trout	39	86	83	4	
B3	Brook Trout	40	77	74	3	
B3	Brook Trout	41	50	48	1	
B3	Stickleback	42	44			
B3	Brook Trout	43	88	84	6	
B3	Brook Trout	44	93	89	7	
B3	Stickleback	45	50			

7.4 Reference Data

Appendix 7.4.1: Variation of indicator values for key attributes at Bauman Cruickston Creek identified in 2014 Environmental Management Plan.

Key Attribute	Indicator	Poor	Fair	Good	Very Good	Range Source
Water Quality	Dissolved Oxygen(mg/L)	<6.5	6.5-9.5	≥9.5		Canadian Council of Ministers of the Environment, 1999
	pH			6.5-9		Environment Canada, 2011
	Conductivity (μS/cm)			≤500[a]		Carr and Rickwood, 2008
Benthic Invertebrate	%EPT (Ephemeroptera –	0-1%	2-5%	6-10%	>10%	Toronto and Region Conservation

Community Assemblage	Plecoptera – Trichoptera)					Authority, 2009
Stability of Fluvial Geomorphology	Bank Erosion Hazard Index	Bank erosion and stress have not yet been measured for Cruickston Creek or Bauman Creek				Rosgen, 2008
	Near Bank Shear Stress					

[a] A groundwater-fed stream on calcareous bedrock will have high conductivity values at base flow under most conditions, without it being indicative of a water quality problem.

Appendix 7.4.2: Federal and Provincial water quality thresholds and Regional Values. Regional Values taken from City of Kitchener 2015 Storm Water Management Monitoring Program report. Levels above listed thresholds are of concern with the exception 1) Dissolved Oxygen levels, where levels below listed threshold are of concern and 2) pH, where values outside the indicated range are of concern.

Parameter	**Threshold**	**Source**	**Regional Values (Site Averages)**
Chloride	120 mg/L (chronic) 640 mg/L (acute)	CCME	39.6 - 399.0 mg/L
Aluminum	75 µg/L @ pH 6.5-9	PWQO	N/A
Iron	300 µg /L	PWQO	N/A
Copper	5 µg/L (> 20 mg/L CaCO3)	PWQO	1-6.8 µg/L
Zinc	20 µg/L	PWQO	5-33 µg/L
Lead	1-5 µg/L dependant on hardness	PWQO	1-5 µg/L
Nickel	25 µg/L	PWQO	N/A
Vanadium	6 µg/L	PWQO	N/A
Boron	200 µg/L	PWQO	N/A
Arsenic	5 µg/L	PWQO	N/A
Molybdenum	40 µg/L	PWQO	N/A
Cadmium	0.5 µg/L (> 100 mg/L CaCO3)	PWQO	N/A
Cobalt	0.9 µg /L	PWQO	N/A
Phosphorous	30 µg/L (streams)	PWQO	10- 140 µg/L
Nitrate-Nitrogen	13 mg/L NO3-	CWQO	0.26-3.76 mg/L
Dissolved Oxygen	4 mg/L (Cold Water 5-8°C) 5 mg/L @ (Warm Water 4-7°C)	PWQO	N/A
pH	6.5-8.5	PWQO	7.3-8.07
Conductivity	NA	NA	635-2467 (µs/cm)