MECP Order # 1-J25YB Item 1b Chedoke Creek Natural Environment and Sediment Quality Assessment and Remediation *Report*

Hamilton, Ontario
Project # TPB188127

Prepared for:

City of Hamilton

71 Main Street West, Hamilton, Ontario L8P 4Y5

January 24, 2019

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Prepared for:

City of Hamilton
71 Main Street West, Hamilton, Ontario L8P 4Y5

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Date January 24, 2019

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January 24, 2019

Mr. Mani Seradj, P.Eng.
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City of Hamilton
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Re: MECP Order # 1-J25YB Item 1b
Chedoke Creek Natural Environment and Sediment Quality Assessment and Remediation Report, City of Hamilton

Dear Sir,

Wood Environment & Infrastructure Solutions (Wood) is pleased to submit the attached report for the City of Hamilton for its submission to the Ministry of the Environment, Conservation, and Parks (MECP) in partial fulfilment of Provincial Officer's Order # 1-J25YB. Should you have any comments or question, please feel free to contact any of the undersigned.

Sincerely,

Wood Environment & Infrastructure Solutions
a Division of Wood Canada Limited

Per: Lance Lumbard, MS, MBA, CLP
Senior Scientist

Per: Ron Scheckenberger, M.Eng., P.Eng.
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BOD	Biochemical oxygen demand (5-day)
Chl-a	Chlorophyll-a (corrected for pheophytins)
CPUA	Catch per unit area
cfu	Colony-forming unit
CSO	Combined sewer overflow
DO	Dissolved oxygen
E. coli	Escherichia coli
EC	Environment Canada
EPT	Ephemeroptera, Plecoptera and Trichoptera taxonomic groups
HBI	Hilsenhoff Biotic Index
LEL	Lowest effect level (PSQG)
MECP	Ministry of the Environment, Conservation and Parks
mg/L	Milligrams per litre
MOE	Ontario Ministry of the Environment
OBBN	Ontario Benthos Biomonitoring Network
PAHs	Polynuclear Aromatic Hydrocarbons
PSQG	Provincial Sediment Quality Guidelines
QA/QC	Quality Assurance / Quality Control
qPCR	Quantitative polymerase chain reaction
RBG	Royal Botanical Gardens
SEL	Severe effect level (PSQG)
SU	Standard units (for pH)
TID	Total invertebrate density
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
ug/L	Micrograms per litre

1.0 Introduction

Wood Environment & Infrastructure Solutions (Wood) has been retained by the City of Hamilton to provide services specifically related to the assessment of the combined sewer overflow (CSO) event into Chedoke Creek for the period of January, 2014 to July, 2018. Wood has evaluated remediation requirements for the Chedoke Creek, along with the preparation of a Conceptual Remedial Action Plan, as required by the Ministry of the Environment, Conservation and Parks (MECP) Provincial Officer's Order (# 1-J25YB). This report provides the findings of the sediment quality and characterization field studies, biota sampling surveys (benthic invertebrates and aquatic habitat) and analysis of existing data (fish community and water quality), as well, the report presents a Conceptual Remedial Action Plan, including alternatives assessment and recommendations.

2.0 Methodology

2.1 Sediment Quality and Characterization

The ultimate goal of the sediment quality and characterization assessment has been to provide information and interpretation of the current status of the sediment deposited in Chedoke Creek, and to support remediation design alternatives. In particular, the sediment characterization study has supported the assessment of the spatial extent of existing conditions and wastewater pollution in the creek. The sediment characterization and quality assessment provided in this report pertain to the existing soft sediments within the creek and do not solely represent impacts attributable to the combined sewer overflow (CSO) event from the Main/King CSO facility for the period of January 2014 to July 2018. Meaning, the data analysis and results describe the existing conditions which inherently include other confounding factors such as other sources of contaminants (e.g., other CSOs and urban runoff). To this end, the scope of work has been established to collect data in a manner to provide an understanding of the following:

- Relative sediment depth (i.e., sediment stratigraphy, depth to parent material, to assist in extrapolation of sediment quantity);
- Current bathymetry;
- Sediment consistency (i.e., material properties);
- Sediment quality analysis; and
- Extent of impact

The sediment quality analysis has provided an initial level of screening with respect to the potential for disposal under Ontario Regulation (O.Reg.) 153/04 Records of Site Condition – Part XV.1 of the *Environmental Protection Act*, specifically comparing to Table 1 background site conditions for sediment. The sediment quality data were also compared to the Provincial Sediment Quality Guidelines (PSQGs) within the context of aquatic biota health.

The PSQGs are guidelines which promote the protection of aquatic life and are based on sound scientific information. The PSGQ lowest effect limit values are equal to the O. Reg. 153/04 values. According to the PSQG document, three levels of effects are prescribed that reflect potential chronic and long-term effects of contaminants on benthic invertebrates; the three levels are:

- **No effect Level:** fish and sediment-dwelling organisms are not affected by chemicals in the sediment; the sediment is considered clean;

- **Lowest effect level (LEL):** level of sediment contamination that can be tolerated by the majority of the sediment-dwelling benthic invertebrates; the sediment is considered to be clean to marginally contaminated; and
- **Severe effect level (SEL):** level of sediment contamination at which pronounced disturbance of the sediment-dwelling community can be expected; the sediment is considered heavily contaminated.

2.1.1 Sediment Thickness, Characterization and Bathymetry

Sediment core and/or grab sampling has been conducted within Chedoke Creek at ten (10) locations. The core sample locations shown on Figure 2-1 include two locations (C1 and C2) where a single location of accumulated sediment was sampled (three core tubes each), whereas the remaining core sample locations included three (3) replicate samples (three core tubes per replicate sample) collected across each transect (east, centre and right replicate sample locations). Samples have been collected from depositional areas. The transects have been positioned equidistant from each other, except for the closer spacing near the culvert outlet. Transects have been positioned starting from the upstream limit of the sample area, down to the outlet of the creek to Cootes Paradise, near Princess Point.

Sediment cores have been collected using a manually-driven core sampler for discrete interval sediment sampling down to the parent material (and/or refusal) where possible. Sediment aliquots have been extruded from the cores at each of these locations in incremental strata (0 to 15 centimeters [cm], 15 to 30 cm and >30 cm). Photographs of complete cores have been taken and catalogued for further visual interpretation as necessary (Appendix A2). Cores have been separated into individual containers (amber glass jars) for analysis to provide depth related assessment of parameters of interest.

Sediment grab samples have been taken using a petite ponar dredge sampler, collecting material from the bioactive sediment strata (upper 10 cm). These samples have been collected for particle size analysis and co-located with the benthic invertebrate community samples as described in Section 2.2.1.

Soft sediment depth has been identified through reaching refusal with the manually-driven sampler at coring transects and has been recorded to provide an indication of bathymetric condition and an estimate of soft sediment volume (Appendix B2). The total water depth was measured from surface to sediment-water interface, and the total depth of sediment to refusal was also documented at each replicate sample location. The substrate encountered at refusal was typically a hardpacked, fine sand or clay material at all coring locations, thereby allowing measurement of the soft sediments full thickness. To be clear, the incremental sample representing the >30 cm strata included a portion of the refusal material at the bottom of the core that was homogenized with the overlying soft sediment. The shallow conditions throughout much of the creek precluded the use of conventional sonar bathymetry which would have been unsuitable (impossible nearshore) and less accurate than the manually measured depths. A summary of the total water depth and soft sediment thickness is provided in Appendix B (Table B1-1).

2.1.2 Sediment Quality

Sediment samples have been collected and retained in laboratory provided amber glass jars and food grade plastic bags (particle size and genetic analysis), pre-labelled with the sample ID, date and time of collection, as well as required analysis. A laboratory provided chain of custody has been submitted with each sample shipment thereby ensuring all samples have been tracked and logged per laboratory quality assurance and control practices.

Sediment core aliquots and grab samples have been kept cool and transported to the laboratory for analysis of the following parameters:

- qPCR – genetic analysis of sediment that identifies the relative abundance (%) of municipal sewage-based bacteria in the sample for comparison to natural sources of bacteria;
- Ammonia (NH3+NH4);
- Total Kjeldahl Nitrogen (TKN);
- Total Phosphorus;
- Total Metals (including: zinc, lead, copper); and
- O.Reg 153/04 Polycyclic Aromatic Hydrocarbons (PAH).

Sediment grab samples have also been analyzed for the following parameters:

- Sediment grain size analysis; and
- Pore water analysis for biochemical oxygen demand (BOD), faecal coliforms and dissolved oxygen (DO).

2.2 Natural Environment

The purpose of collecting natural environment (biological) information has been to assess the current condition of Chedoke Creek within the context of aquatic ecology. The information is intended to serve as a baseline for future assessment of potential improvements, following the implementation of remediation options. The biological study has been conducted consistent with a longitudinal gradient approach (sampling from upstream to downstream) in Chedoke Creek to identify the potential change in aquatic community health. The biological assessment has been conducted to target two main groups of biota: benthic invertebrates and fish. The fish community was not sampled as part of this study, however benthic invertebrate sample collection was conducted, as described in the following. These community data have been complemented by the collection of general habitat features and analysed within the context of the sediment quality and grain size data, collected as part of the sediment characterization (Section 2.1.2).

2.2.1 Benthic Invertebrate Community

Benthic invertebrate sampling has been conducted in tandem with sediment quality assessments. Sampling has been conducted at seven (7) sampling transects co-located with the sediment grab sampling transects (Figure 2-1). Benthic invertebrates have been sampled from each of 3 replicate grabs within each transect. This approach has provided a total of 21 samples for analysis by an accredited invertebrate taxonomist. Information collected at each sampling station has included a description of benthic habitat (water depth, observed water velocity, substrate type, aquatic vegetation and available cover).

Sampling at each station has been conducted using a petite ponar dredge sampler. Each replicate grab sample has been individually sieved in the field (using 500 micron [µm] mesh sieve bucket), as per the Ontario Benthos Biomonitoring Network (OBBN): Protocol Manual (MOE 2007). Samples have been preserved in the field (using 10% buffered formalin) and analyzed by an experienced taxonomist following accepted protocols and quality assurance and control measures (EC 2012). All invertebrates have been identified to the lowest practical level. In addition, a voucher collection has been compiled from each area sampled, for future reference or for confirmation by a second trained taxonomist (if required). Benthic invertebrate community metrics of interest for analysis have included the following:

- Total invertebrate density (TID);

- Taxon richness;
- Simpson's Evenness Index;
- Simpson's Diversity Index;
- Proportion of individuals belonging to the Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) [% EPT];
- Hilsenhoff Biotic Index (HBI) was also calculated for each transect, as it provides an estimate of the overall tolerance of the invertebrate community to organic pollution;
- Taxa density; and
- Taxa proportion.

TID has been reported as the total number of all individuals of all taxonomic categories expressed per unit area (individuals per square metre). Area has been based on the dimensions of the collection equipment (Petite Ponar; 0.023 m^2). A total invertebrate density value has been calculated for each replicate sample location.

Taxonomic richness has been reported as the total number of taxa groups at each sample station, based on the lowest practical level of taxonomic identification. Taxonomic richness is directly related to diversity and health of the invertebrate community. The TID and richness calculations can reveal ecologically relevant aspects of the benthic community. For example, stations with high invertebrate density and low richness may suggest the existing conditions can support a small niche of specialized taxa, reflect homogeneous habitat conditions, and may be indicative of a benthic invertebrate community with predominantly stress tolerant taxa. Whereas, high TID and richness can reflect a heterogeneous habitat with a broad range of stress tolerant and intolerant taxa. Taxonomic richness is also used to calculate other invertebrate community metrics such as Simpson's Evenness discussed below (Smith & Wilson, 1996).

Simpson's Diversity Index is a descriptor of both the abundance patterns and taxonomic richness of the community (EC, 2012). This is a common metric included in benthic biomonitoring programs and can support assessments in conjunction with the other metrics included in this study. Simpson's diversity index is heavily weighted towards the most abundant species in the sample, while being less sensitive to species richness. This measure has been calculated by determining the proportion of individuals that each taxonomic group at a sample location contributes to the total number of individuals at the sample location. This index represents the probability that two individuals randomly selected from a sample will belong to different families. Simpson's diversity ranges from zero to one, with higher values representing greater diversity. Simpson's diversity index has been calculated according to Krebs (1985):

$$D = 1 - \sum_{i=1}^{s} (p_i)^2$$

where: D = Simpson's index of diversity
s = the total number of taxa (group) at the station
pi = the proportion of the i^{th} taxon (group) at the station

Simpson's Evenness Index is similar to Simpson's Index of Diversity but is a measure of how the abundance of individuals are distributed within the taxonomic groups inhabiting the sample location. Evenness refers to how evenly taxa are distributed within the community. Evenness ranges between zero and one; a community with a high number of individuals of one group and few of other groups has low evenness and a low evenness value closer to zero. Evenness was calculated according to Smith and Wilson (1996):

$$E = 1/\sum_{i=1}^{S}(p_i)^2/S$$

where: E = Evenness
p_i = the proportion of the i^{th} taxon (group) at the station
S = the total number of taxa (group) at the station

The HBI estimates the overall tolerance of the benthic invertebrate community in a sampled area, weighted by the relative abundance of each taxonomic group (family, genus, etc.). Organisms have been assigned a tolerance number from 0 to 10 pertaining to that group's known sensitivity to organic pollutants; 0 being most sensitive, 10 being most tolerant. The HBI has been calculated according to Hilsenhoff (1988):

$$HBI = \frac{\sum n_i x a_i}{N}$$

where: n = number of specimens in taxa i
a = tolerance value of taxa i
N = the total number of specimens in the sample

The assessment of these endpoints has provided a basis of understanding for the geographic distribution of organic pollution and a baseline condition for comparison to future remediation scenarios.

2.2.2 Fish Community

Annual fish community sampling has been undertaken by the Royal Botanical Gardens (RBG) since 2001 utilizing two (2) 50 metre (m) electrofishing survey transects (C1 and C2) located in Chedoke Creek upstream of the confluence with Cootes Paradise (Figure 2-1). Two other sample transect locations positioned near the outlet of the creek, and further afield within Cootes Paradise, were sampled annually and provide context for comparison to creek transect as part of the data analysis and review. The available data include total catch by species for each transect, however, electrofishing seconds were not provided for the full period of record. Fish community data have been used to calculate the catch per unit area (number of fish per 50 m transect), species richness, total catch, as well as the relative proportion of generalist, piscivore and specialist species within each catch, and the relative proportion of stress tolerant, intolerant and intermediate species within each catch, as an indication of community complexity. These data have been reported for the current condition of Chedoke Creek as a general indicator of health, and to provide a baseline for comparison to the same metrics following remedial actions.

2.2.3 Aquatic Habitat

Aquatic habitat can be described in numerous ways, including observations of stream morphology, substrate composition, in-stream cover, aquatic macrophyte species and presence, and riparian habitats. During the initial reconnaissance site visit (September 5, 2018), it was determined that qualitative observations of the existing creek habitat would be conducted during the sediment and benthic invertebrate sampling event. These observations were then recorded on field sampling notes and habitat features were documented using photographs provided within Appendix A of this report.

2.3 Water Quality Assessment Methods

Various entities including McMaster, Zenon, City of Hamilton, Hamilton Environmental Lab, RBG, and Hamilton Conservation Authority (HCA) have been collecting water quality data within Chedoke Creek and downstream in Cootes Paradise for decades. The water quality data supplied by these organizations provide a means of assessing the aquatic ecosystem health based on various chemical, physical, and biological characteristics of the water, as well as impacts that may be associated with sources of contamination. Through this investigation, Wood reviewed and analysed the available water quality data between 1999 and 2018 for stations in Chedoke Creek and Cootes Paradise. The stations evaluated in included CP-11 (the first station downstream of the Main/King CSO); stations CC-2, CC-3, and CC-9 (upstream of the Main/King CSO); and stations CP-1, CP-2, and CP-20 (within Cootes Paradise). Figures 4-5.1 and 4-5.2 indicate the locations of these stations.

Water quality data are available for numerous parameters, however, total phosphorus (TP) and Escherichia coli (E. coli) were chosen as representative water quality parameters and were used to compare station CP-11 with upstream conditions (CC-2, CC-3, and CC-9) and conditions in Cootes Paradise (CP-1, CP-2, and CP-20). Both parameters are often used to indicate changes in water quality and to assess potential impairments associated specifically with sewer overflows. Additional water quality parameters including pH, ammonia, dissolved oxygen (DO), chlorophyll-a (Chl-a), and total suspended solids (TSS) were also reviewed for CP-11 and Cootes Paradise stations CP-1, CP-2, and CP-20.

Water quality data, including data collected from Chedoke Creek and Cootes Paradise stations, are often subject to a wide range of variability with a limited number of collection events spaced at irregular intervals. The limited temporal resolution of Chedoke Creek and Cootes Paradise station data requires careful consideration and use of the appropriate statistical tools. The statistical methods utilized to evaluate the available water quality are provided in the following.

The Mann-Whitney U non-parametric statistical test was selected for evaluation of Chedoke Creek and Cootes Paradise data because it is robust against outliers and large data gaps, and data are not required to conform to a particular distribution for non-parametric analyses. The Mann-Whitney U test calculates the statistical significance of the difference in median concentrations between two periods. For the purposes of the Mann-Whitney U test, data from station CP-11 was divided into the period before and after the gate 1 opening. The time periods evaluated included the period from January 5, 2009 to September 24, 2012 and the period between May 26, 2014 and September 27, 2018. No data were available for the period between September 24, 2012 and May 26, 2014. P-values less than 0.05 indicate statistical significance and further indicates that the two datasets are significantly different from one another.

Insufficient data exist to employ the Mann-Whitney U test to compare the period prior to the start of the gate opening event with the periods after gate 1 was open, after gate 2 had failed, and the period following the correct adjustment of both gates. Therefore, additional analyses of median values of TP, E. coli, and other water quality data were performed on an objective basis, to include four distinct time periods coinciding with the operational conditions of the Main/King CSO. The first period included the available data collected between January 5, 2009 and January 27, 2014 and includes a data gap from September 25, 2012 through January 27, 2014. The second period begins January 28, 2014 with the gate opening and ends December 31, 2017, prior to the failure of gate 2. The third period was evaluated for the data collected between January 1, 2018 and July 18, 2018 when gate 1 was open and gate 2 had failed. The fourth period began after both gates had been adjusted for proper operation on July 18, 2018 and included available data through September 2018.

Figure 2-1: Sediment, Benthic Invertebrate and Fish Sample Locations

3.0 Results and Interpretation – Sediment Quality and Characterization

3.1 Sediment Thickness and Characterization

Soft sediment thickness across the sample location transects showed greater accumulation of sediments along the west shoreline throughout the creek. Measured sediment thickness ranged from 0.10 to 0.70 m (mean thickness 0.37 m) along the west shoreline compared to 0.04 to 0.59 m (mean thickness 0.26) along the east shoreline and 0.03 to 0.66 m (mean thickness 0.32 m), near the centre of the creek. In general, the upstream sample locations including C-1, C-2, G-1 and G2 contained less soft sediment (thickness range 0.06 to 0.37 m) compared to the most downstream sample locations C-5/G-6 and C-6/G-7 (thickness range 0.44 to 0.70 m).

A photographic record of each sample transect, grab samples and homogenized samples is provided in Appendix A1, with representative photographs of sediment cores at each coring location provided in Appendix A2. Data regarding field sampling observations, water depth and soft sediment thickness measurements and laboratory sediment quality analyses are provided in Appendix B1. Soft sediment thickness and bathymetry figures are provided in Appendix B2.

The produced sediment thickness mapping is based on irregular and sparse data collection efforts, which were primarily focused on providing sediment chemistry and sediment quality data and not a detailed map of the thickness of deposited material. Future regular and thorough sediment thickness data collection efforts will provide a clearer representation, which may result in changes to the final volume of soft sediment material estimates within the creek.

The upper strata (0 to 15 cm) sample aliquots are commonly composed of fine grained sediments (silt, clay, fine sand), with some coarse-grained sands and cobble present near the bottom of the strata. These samples are loosely consolidated, less firm than pudding consistency. Some upper strata samples were described in the field as having a strong metallic or petro-chemical odour, and most were dark in colour (black or brown). A summary of the field sampling observations and measurements is provided in Appendix B (Table B1-1).

The mid-strata (15 to 30 cm) sample aliquots are a mix of fine and coarse-grained sediments. These mid-strata samples are mostly well-consolidated material that maintained the core tube shape when extruded into the sample bowl. Colour ranges from black to brown to grey and orange, with some samples described as having a metallic or petro-chemical odour, like the surface strata samples.

The lower strata (>30 cm) sample aliquots are also a mix of fine and coarse-grained sediments, with a greater proportion of coarse-grained constituents observed. These samples were well-consolidated and colour typically ranged from brown to orange and grey, with some samples described as having a metallic or petro-chemical odour. This colour suggests parent material was encountered, as it resembles the red clay found throughout the Niagara escarpment region.

Particle size data from the grab sample locations (0 to 10 cm) are presented in Figure 3-1 and Appendix B1 (Table B1-3). The particle size data show higher percentage of coarse material are present in the upstream sample locations (G1 to G3), with higher proportions of fine-grained material (silt and clay) in the downstream locations where deeper sediment depths are observed.

3.2 Sediment Quality

BOD, Bacteria and Faecal Coliforms

Natural organic detritus and organic waste from waste water treatment plants and agricultural and urban runoff, acts as a food source for water-borne bacteria. Bacteria decompose these organic materials using dissolved oxygen (DO), thus reducing the DO present for fish and other aquatic biota (e.g., invertebrates). Biochemical oxygen demand (BOD) is a measure of the amount of oxygen that bacteria will consume while decomposing organic matter under aerobic conditions. When effluent (e.g., Main/King CSO) containing high BOD levels are discharged to a receiver (e.g., Chedoke Creek), this effluent accelerates bacterial growth in the receiver and consumes the available oxygen. The reduction of DO concentrations in the water column can persist as long as the BOD-rich effluent is discharged. Once the discharge stops, the receiver generally re-aerates due to atmospheric mixing and during algal photosynthesis when oxygen is released into the water. However, as long as organic sediments are present, the BOD at the water/sediment interface will likely be high compared to mineral sand or other inorganic material that does not consume as much oxygen. During low flow conditions, the BOD of the sediment can continue to impact the DO concentration in the water column. This is particularly true when algal cells are consuming oxygen during respiration when no sunlight is available. Sediment BOD and algal respiration can have dramatic impacts to water column DO prior to sunrise. These effects are magnified during warmer conditions when the DO carrying capacity of water is lower and biological activity is accelerated.

The highest porewater BOD results were found at sample transect C-5/G-6 immediately upstream of the Princess Point bridge, as shown on Figure 3-2, with the next highest BOD value observed at the G-3 sample transect located upstream of the Kay Drage Park bridge. These results indicate organic compounds are present in higher amounts at these sample locations and therefore require more oxygen for microbial metabolism, which typically suggests impaired environmental quality. The area of Chedoke Creek at transects G-3 and C-5/G-6 also contained the highest amount of organic material, which coincides with field observations indicating slower water velocities and increased settling of suspended solids at these locations.

The DO concentrations for these locations are also shown on Figure 3-2, with a longitudinal gradient of higher concentration upstream and lower concentration downstream. These higher upstream DO concentrations are likely attributable to the faster flowing water and associated habitat within the area near the culvert outlet, that have less sediment accumulation compared to the slower moving water in the downstream reaches, as discussed further in Section 4.3. Low dissolved oxygen concentration associated with the organic sediments in Chedoke Creek likely reduces the diversity of benthic invertebrates and favours a few tolerant species. This, in turn, limits the available food sources for fish (ref. Section 4.1).

The bacteroidetes and faecal coliform sample results show the highest concentrations were found at the C-3/G-5 sample transect, downstream of the Kay Drage Park bridge (Figure 3-3). Faecal coliform in surface waters are present due to fecal excrement of humans (sewage releases), livestock and wildlife. The qPCR results show the highest human and total bacteroidetes were present in the surface strata (0 to 15 cm) at the C-3C replicate sample located near the west shoreline shows. Concentrations in the mid-strata aliquot (15 to 30 cm) of C-3C were also higher than most other mid-strata samples. The bacteroidetes and faecal coliform results from the downstream sample transects show lower concentrations, with most of the lowest values at the C-6/G-7 sample location within Cootes Paradise (further from the Main/King CSO source).

Unlike chemical contaminants, bacterial indicator species (i.e., faecal coliform) of potential pathogenic contamination are normally not persistent outside of a living host and the current concentrations will likely continue to decline during periods when no sewage discharge is occurring. However, pathogenic contamination of the sediments within Chedoke Creek may present an ongoing risk to human health. The persistence of potential human pathogens is unknown and avoidance of direct contact with the sediments is recommended. It should be noted that permitted CSOs which may periodically discharge to Chedoke Creek continue to present an ongoing potential source of faecal coliform bacteria and potentially pathogenic organisms.

Nutrients

Nutrient contamination from nitrogen and phosphorus-rich organic sediments and other sources (e.g. inorganic fertilizers) is an ecological concern within Chedoke Creek and downstream receiving waters. Growth of planktonic and epiphytic algal species is often accelerated by external (stormwater) and internal (sediment) sources of nitrogen, phosphorus, or both. An over-abundance of algae tends to limit light penetration thereby precluding growth of submerged and emergent plant species which may provide habitat and sediment stabilization. Phosphorus tends to be the nutrient limiting algal growth in freshwater systems. External sources of nutrients are the most difficult to control and represent an ongoing source of potential contamination within Chedoke Creek and downstream, regardless of the operational condition of the Main/King CSO. Furthermore, external nutrients other than those contributed by the Main/King CSO have likely been contributing to water quality problems within Chedoke Creek and its downstream receiving waters for decades.

Sediment quality nutrients of interest include ammonia+ammonium, total phosphorus and total Kjeldahl nitrogen (TKN), all of which were found in the highest concentration within the surface strata (0 to 15 cm) at the C-3/G-5 sample transect, specifically the C-3C sample location (Figure 3-4). The next highest surface strata nutrient concentrations were found at the C-4C sample location, and both locations were positioned near the west shoreline, in areas of soft organic sediment. These sample locations were situated between the Kay Drage Park and Princess Point bridges, showing higher nutrient concentrations are present within this reach and are mostly higher than the surface strata within the Cootes Paradise sample location (C-6/G-7). Nearly all TKN concentrations in surface strata were above the PSQG LEL (550 µg/g), suggesting these sediments contain a level of contamination that can be tolerated by the majority of sediment-dwelling organisms, but not necessarily stress-intolerance taxa as discussed in Section 4.1. Total phosphorus concentrations in all sediment strata samples were greater than the PSQG LEL (600 µg/g) between transects C-4 and C-6/G-7, with the highest concentrations observed at transect C-5/G-6. The phosphorus SEL (2,000 µg/g) was not exceeded by any sample concentration.

Previous sediment quality studies conducted by the RBG in 2006 and 2013 documented nutrient parameters at two locations (CC-1 and CC-2) positioned further northwest from the 2018 C-6/G-7 sample location (Figure 2-1). RBG sediment sample collection protocols differed from those followed during the 2018 study; however, comparison between study results provides a qualitative context of nutrient concentrations in the upper strata sediments within Cootes Paradise. Sediment TKN concentrations at the RBG locations were similarly elevated above the PSQG LEL. For example, the 2006 and 2013 RBG TKN concentrations ranged from 1,250 to 1,390 µg/g at station CC-1 and from 1,010 to 1,330 µg/g at station CC-2, both greater than the PSQG LEL (550 µg/g). These results were all greater than the TKN concentrations measured at the 2018 C-6/G-7 location (900 to 1,000 µg/g) and were comparable to the TKN concentrations of the 0 to 15 cm strata between transects C-3/G-5 and C-5/G-6 (Figure 3-4). This suggests that TKN enrichment has occurred downstream in Cootes Paradise prior to the event, but it remains unclear when, or how, the enrichment occurred.

The RBG total phosphorous concentrations in 2006 and 2013 were 1,100 µg/g for both years at station CC-1 and ranged from 1,100 to 920 µg/g at station CC-2 between 2006 and 2013 (RBG 2013). These results were all above the PSQG LEL (600 µg/g), but greater than the 2018 total phosphorus concentrations measured at C-6/G-7 (778 to 814 µg/g) which is the closest 2018 sample location to the RBG stations. The total phosphorus concentrations measured in upper strata between transects C-3/G-5 and C-5/G-6 within the creek had concentrations within the range of the 2006 and 2013 results (2018 TP range 642 to 1,622 µg/g). This also suggests that total phosphorus enrichment has occurred downstream in Cootes Paradise prior to the event, but the means and timeframe of enrichment remain unclear.

The mid and lower strata aliquot sample results show nutrient concentrations were mostly higher than the surface strata concentrations at sample transects C-5/G-6 and C-6/G-7 (Figure 3-4). These nutrient concentrations within deeper sediment strata suggest legacy nutrient enrichment has occurred where sediments have accumulated in the slower-flowing, lower reaches of the creek and within Cootes Paradise.

It is important to note that while nutrient concentrations are high in most samples collected from less than 30 cm in depth, portions of the creek that were sandy (C-1 through C-3) and deep (> 30 cm) had the lowest total Kjeldahl nitrogen and total phosphorus concentrations. Deeper sediment samples (> 30 cm) collected downstream of C-3 were generally nutrient-enriched which is consistent with the depth of soft sediments in these areas. Presumably, a sandy sediment stratum with lower nutrient concentrations exists downstream of C-3, but further sampling at deeper intervals would be needed to identify the vertical elevation of this layer.

Metals

Metal concentrations were compared to the PSQG and O. Reg. 153/04 values. As noted earlier, the PSQGs are guidelines which promote the protection of aquatic life using LEL values (equal to the O. Reg. 153/04 concentrations), as well as the PSQG SEL criteria that indicate levels of sediment contamination at which pronounced disturbance of the sediment-dwelling biota community can be expected. The O. Reg. 153/04 sediment quality parameters per Table 1 of the Regulation (MOE 2011) are used to inform disposal options for contaminated sediments that include metals and polynuclear aromatic hydrocarbons (PAHs). The metal concentrations of soft sediments within the creek do not solely represent impacts attributable to the discharge event and include other confounding factors such as other sources of contaminants (e.g., other CSOs and urban runoff) however isolating these sources with the current data is not considered feasible.

Most of the highest heavy metal concentrations of interest (Cu, Pb and Zn) within surface strata (0 to 15 cm) were found between the C-3/G-5 and C-5/G-6 sample transects (Figure 3-5) which were similar to the results found for other parameters. Other metals with O. Reg. 153/04 and PSQG sediment quality values include arsenic, cadmium, cobalt, chromium, nickel and silver. Graphs of these metals and their respective regulation values are provided in Appendix B1.

The surface strata metal concentrations between the C-3/G-5 and C-5/G-6 sample transects were generally greater than the upstream or furthest downstream sample results. Overall, the deeper sediments contained higher concentrations of these metals at transect C-4 and further downstream. The C-5C sample location positioned near the west shoreline, upstream of the Princess Point bridge contained the highest mid and lower-strata metal concentrations. Unlike nutrients, metals pose a direct toxicity to living organisms and removal of soft sediment material containing these metals would likely be beneficial to the ecological conditions within Chedoke Creek and downstream.

Concentrations of copper, lead and zinc were generally greater than their respective PSQG LELs, but mostly below the SEL values (Figure 3-5). Arsenic, cadmium, chromium and silver concentrations were generally below the PSQG LEL values in the upstream locations as discussed in the following.

Arsenic, chromium and nickel concentrations are shown on Figure B1-2 for comparison to their respective O. Reg. 153/04 values. The arsenic and chromium concentrations for sample locations C-1 through C-3 are mostly below the regulation value, with concentrations greater than the regulation at sample locations C-4 through C-6. Nickel concentrations in the upper strata samples (0 to 15 cm) are all greater than the regulation value, with most of the mid and lower strata samples also greater than the regulation value. In general, most sediment quality parameters concentrations compared to PSQG LEL and O. Reg. 153/04 values show the highest concentrations in the downstream sample locations between sample transects C-4 and C-6. This likely is in part due to the increase in depositional conditions as noted in the particle size distribution results. This inherently means smaller sediment particles require slower water velocities to facilitate settlement out of the water column, as such the predominance of fine sediment particle size (e.g., silt and clay) shows the downstream sample locations are depositional. Increased metal concentrations are typically associated with fine particle size compared to coarse substrates (sand and gravel) observed in the upstream sample locations (C-1 through C-3).

Cobalt was the only metal concentration consistently below the PSQG LEL and O. Reg. 153/04 value, with the highest concentration (22 µg/g) being less than half the LEL value (50 µg/g). The cadmium and silver concentrations were mostly below their respective regulation values for sample locations C-1 through C-3 and replicate sample C-4A (near east shoreline). Cadmium and silver were above the PSQG LEL and O. Reg. 153/04 value for most of the strata sampled between transect C-4 and C-6 as shown on Figure B1-1.

Most PAH concentrations were greater than their respective O. Reg. 153/04 values as summarized in Appendix B (Table B1-2). Anthracene had the fewest regulation exceedances, and most of the mid and lower strata sample concentrations were consistently greater than the regulation values. The PAH results have been used to determine disposal options for removed (dredged) sediment, as further discussed in Section 5.0. Additional sampling at deeper intervals is necessary to refine this analysis and determine whether these exceedances exist below the organic layer. As noted, the PAH concentrations of soft sediments within the creek do not solely represent impacts attributable to the discharge event and include other confounding factors such as other sources of contaminants (e.g., other CSOs and urban runoff), however isolating these sources with the current data is not considered feasible.

Previous sediment quality studies conducted by the RBG in 2006 and 2013 also documented metal concentrations at the two locations noted in the nutrient discussion earlier. Cadmium, copper, iron, lead and zinc concentrations were greater than the PSQG LEL concentrations for all samples (CC-1 and CC-2); however, no concentrations exceeded the respective PSQG SEL values. Arsenic concentrations in 2006 at CC-1 and CC-2 were equal to the PQSG LEL (6 µg/g) and were below the LEL in 2013, 5.6 and 5.2 µg/g, respectively. All upper strata arsenic concentrations in the 2018 study were below the PSQG LEL. The RBG 2006 studies also documented PAH concentrations at the CC-1 and CC-2 sample locations (no PAH sampling conducted in 2013). The RBG 2006 PAH results show sediment sampled at CC-1 contained PAH concentrations less than the respective O. Reg. 153/04 values. PAH concentrations at RBG location CC-2, positioned further offshore than CC-1 within Cootes Paradise, were equal to, or greater than, many of the O. Reg. 153/04 values. All 2006 PAH concentrations were less than the 2018 PAH concentrations observed at the Chedoke Creek sample locations, including location C-6 positioned immediately downstream of the creek outlet into Cootes Paradise.

The 2018 results suggest legacy metal enrichment has occurred (prior to the Main/King CSO event), and removal may be beneficial. However, it is important to note other potential sources of metal enrichment are ongoing and likely occurred prior to the discharge event. These include, but are not considered limited to, other operating CSOs (e.g. Royal Tank) located upstream, the storm water drainage from the adjacent highway infrastructure and runoff from upstream urban environs (i.e., extensive roadway network) discharging to the creek, as well as other upstream sources (e.g., industrial and landfill sources). As noted earlier, establishing a clear distinction between legacy and event-based contamination is not considered feasible with the available data.

Similar to the nutrient-enrichment discussion above, the observed metal concentrations are lower in the sandier portions of the creek, above the C-3 sample location. The metal concentrations evaluated in sample locations downstream of C-3 are likely more representative of the organic material within Chedoke Creek. Additional sampling at deeper intervals would be necessary to determine whether metal concentrations decrease below the organic layer.

Radioisotopic Dating of Sediments

The physical and chemical characterizations discussed in this section suggest that some of the organic material within Chedoke Creek may be associated with the 2014-2018 discharge event. However, as noted, the sediments within Chedoke Creek are likely to have been derived from many different sources and time periods. The Main/King CSO and other permitted CSO systems also released sewage and stormwater to Chedoke Creek prior to the event, and continue to do so. The sediment characteristics from the prior discharge events are likely to be similar to, and indistinguishable from, the 2014-2018 Main/King CSO discharge event. The complex origin and fate of sediments within Chedoke Creek are likely to prevent a definitive means of identifying the sediments specifically associated with the 2014-2018 Main/King CSO discharge event. In certain cases, radioisotope data may be useful for classifying sediments based on their deposition periods. Wood has provided a brief summary of the potential to employ this this technology below.

The vertical distribution of several short-lived radioistopes in sediments can be used in some aquatic systems to estimate the sedimentation rate and thereby the age of sediment strata. For example, measurements of beryllium-7 (^{7}Be, half-life 53 d), lead-210 (^{210}Pb, half-life 22.3 y), and cesium-137 (^{137}Cs) have been used to date sediments over time-spans up to approximately 100 years (USGS 1998). ^{210}Pb can also be used to estimate age of sediments up to approximately 100 years. However, sediment redistribution can flatten or interrupt the ^{210}Pb profile. In this case, the basic models to interpret ^{210}Pb profiles are not accurate (Appleby 1998). The irregular channel morphology, minimal water depth and widely varying flows within Chedoke Creek likely result in substantial mixing and transport of especially the fine-grained and organic sediments that retain ^{210}Pb. These processes would prevent the formation of interpretable ^{210}Pb profiles. For this reason, Wood does not recommend attempts to apply radioisotopic dating methodologies to distinguish sediments deposited prior to, versus during, the 2014 – 2018 discharge event.

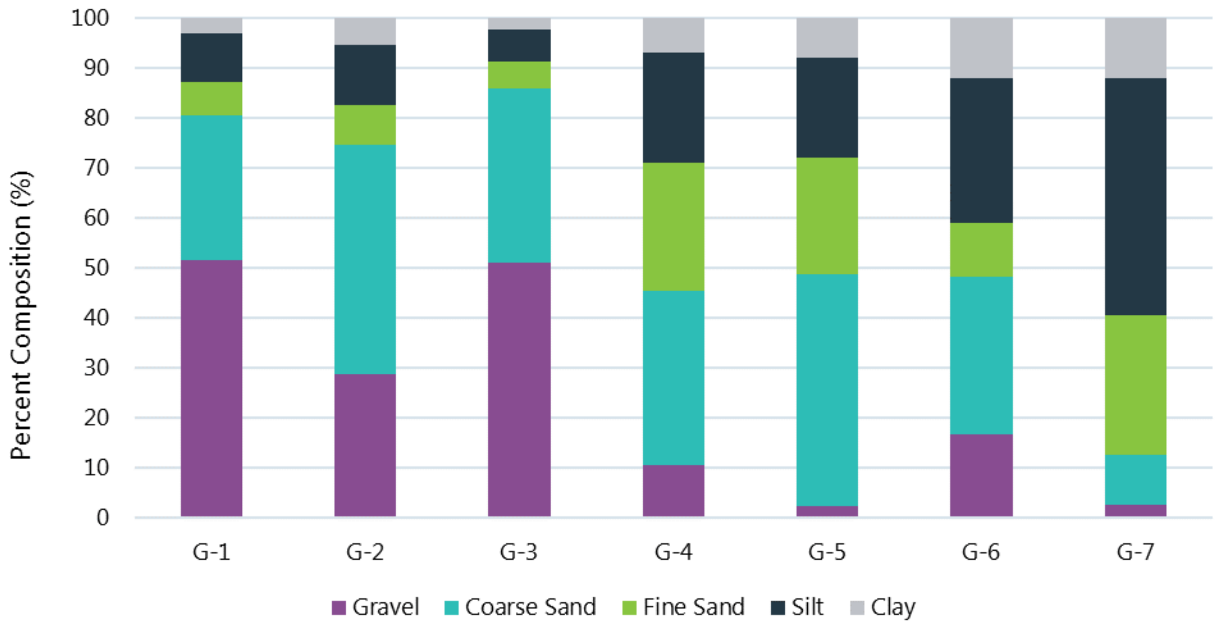


Figure 3-1: Sediment Particle Size Distribution by Grab Sample Location

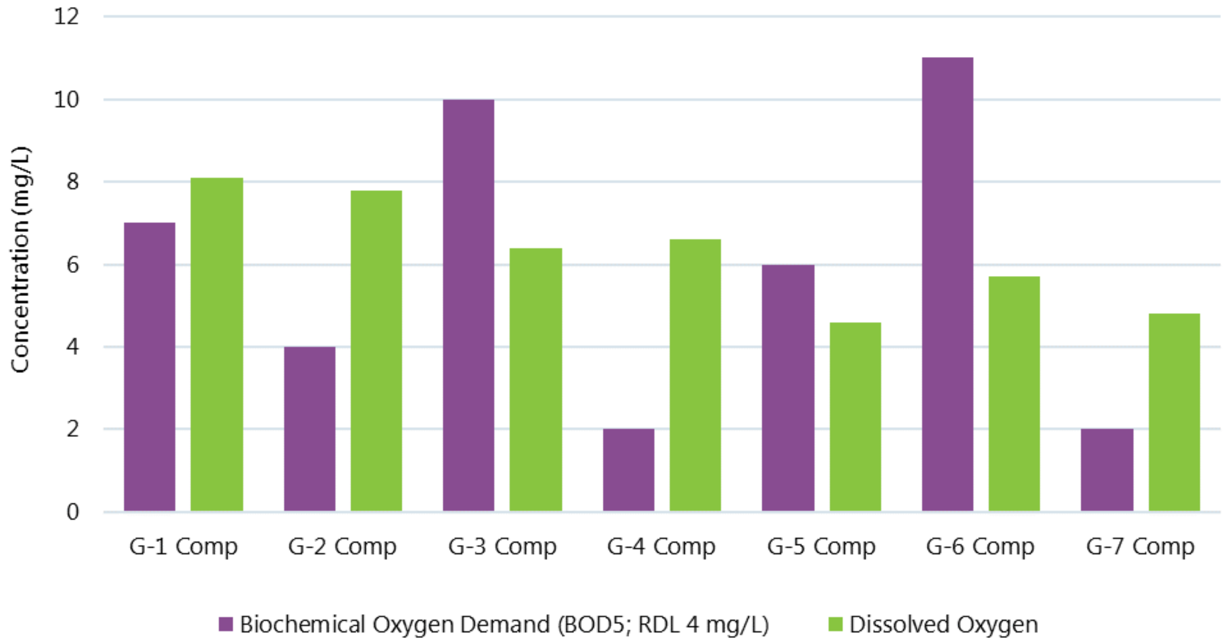


Figure 3-2: Sediment Biochemical Oxygen Demand and Dissolved Oxygen by Grab Sample Location

Figure 3-3: Sediment Bacteroidetes and Faecal Coliform by Core Sample Location

Note: The position of replicate samples within the creek are identified using A – near east bank, B – mid channel, C – near west bank.

Figure 3-4: Sediment Nutrient Concentrations – NH3+NH4, P, TKN by Core Sample Location

Note: The position of replicate samples within the creek are identified using A – near east bank, B – mid channel, C – near west bank.

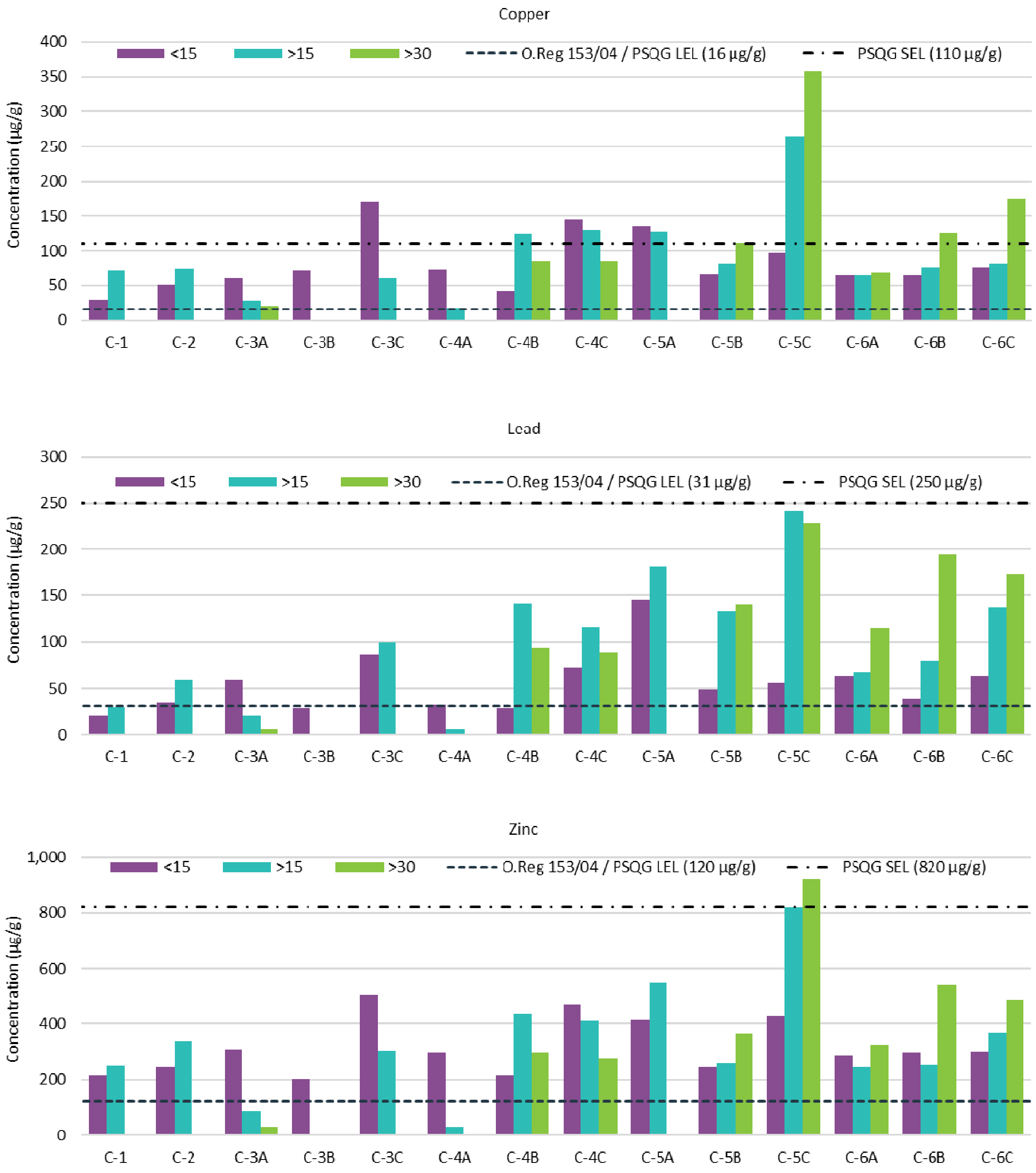


Figure 3-5: Sediment Metal Concentrations – Cu, Pb, Zn by Core Sample Location

Note: The position of replicate samples within the creek are identified using A – near east bank, B – mid channel, C – near west bank.

4.0 Results and Interpretation – Natural Environment

4.1 Benthic Invertebrate Community

Benthic macroinvertebrates are mainly exposed to contaminants in the surface water, meaning the tube-dwelling organisms that actively circulate overlying water through their tubes and those deposit feeders that are active bioturbators, effectively mixing the upper strata of the sediments (Warren et al., 1998; Hare et al., 2001; Wang et al., 2000 and 2001). However, organisms that do not pump overlying water through their tubes or burrows may take up significant amounts of contaminants from digested sediments and predators of those species will accumulate contaminants from their prey (Lee et al., 2000; Ahrens et al., 2001). Additionally, deposit feeders are typically less sensitive to toxicants than those that are exposed mainly via surface water, and higher abundance of these 'tolerant' taxa are used to indicate environmental degradation. For example, higher proportions of the benthic invertebrate community represented by generally stress-tolerant taxa including oligochaetes (aquatic worms) and chironomids (non-biting midges), as well as low taxa diversity and evenness, as discussed in the following shows Chedoke Creek represents an environmentally degraded system. Benthic macroinvertebrate community data within Chedoke Creek were not available prior to the discharge event for pre-discharge event comparison. As such, the 2018 benthic macroinvertebrate community data provide a measurement of the existing conditions and do not solely represent impacts attributable to the discharge event. Other confounding factors such as other sources of contaminants (e.g., other CSOs and urban runoff) have likely contributed to the environmentally degraded state of the creek, however as noted earlier, establishing a clear distinction as to the attributable sources is not considered feasible with the available data.

The benthic invertebrate community metrics of interest are graphically shown on Figures 4-1 and 4-2, with tabular summaries provided in Appendix C (Tables C-1 and C-2). Taxa richness and TID were generally higher at the upstream sample locations and lower at the downstream reaches (Figure 4-1). Aquatic habitat within the subject creek reach is discussed in Section 4.3; however, it is important to note the upstream sample locations contained higher proportions of coarse substrate particles, as well as micro-habitat heterogeneity than the downstream sample transects. Differences in habitat complexity are known to influence community metrics, such as taxa richness.

Simpson's Diversity Index represents the probability that two individuals randomly selected from a sample will belong to different taxa groups. Mean diversity index values ranged from 0.05 to 0.49, showing low to moderate diversity existed within these sample transects (Figure 4-1).

Simpson's Evenness Index mean values ranged from 0.35 to 0.80, showing moderate to high evenness, indicating the community contains a moderate number of individuals of one group and comparable proportions of individuals belonging to other groups (Figure 4-1).

The HBI is an inference to water quality based on the tolerance levels of invertebrate taxa. The HBI values (0 to 10) range from potentially excellent water quality at index values between 0.00 and 3.75 to potentially very poor quality of water at index values between 7.26 and 10.00 (Hilsenhoff 1988). Mean HBI values for the Chedoke Creek samples ranged from 6.0 to 6.2, meaning the benthic invertebrate community tolerance level suggests fairly poor water quality (per the HBI water quality categories) typically associated with high concentrations of organic pollutants (Figure 4-2).

Taxa density and proportions have been calculated using five (5) taxonomic groups; Tubificidae, Isopoda, Chironominae, Orthocladinae and Other taxa (those taxa contributing less than 5% density or relative proportion to the community). The tubificids were found in the highest densities at sample transects G-2 and G-3, whereas chironomids were most abundant at transects G-3 and G-7 (Figure 4-2). The taxa proportion analysis has shown decreasing tubificid proportions with increasing chironomid proportions from upstream to downstream (Figure 4-2). Both taxa groups are tolerant to environmental stress and prefer fine-grained sediments, like those found in Chedoke Creek, and dominance of these groups can be an indicator of impaired environmental quality and their abundance could be attributed to the scarcity of supportive habitat, in addition to degraded conditions in the water column and sediment (i.e. habitat).

4.2 Fish Community

The fish community survey data provided by the RBG are summarized in Appendix C (Table C-3). These data show both indigenous and non-indigenous fish species are present within the subject creek. The non-indigenous species include Common Carp, Goldfish (hybrids of these species), Round Goby, Rudd and White Perch. Most species encountered during the surveys prefer warm water, with some species belonging to the cool water thermal guild. The catch per unit area (CPUA) was calculated as the number of fish caught per 50 m transect each year. It is understood that the electrofishing seconds varied among years (not available for the full period of record) and the total seconds was typically greater when more fish were present (collected); however, the CPUA provides a surrogate comparison among sample transects to show trends over time (Figure 4-3). The RBG fish community sampling commonly occurred in August within the period of record and the most recent data were collected August 24, 2018 after the CSO gate was closed. As such, the 2018 data, as well as subsequent fish community monitoring may show changes in community structure related to post-CSO event fish community data. The CPUA results for C1 are more variable than C2, with both sample transect data showing a decline from 2015 to 2017 that is also shown for transect M5 near the outlet of Chedoke Creek. Transect B2 data show most lower CPUA values and is located further afield into Cootes Paradise. The CPUA results for C1 and C2 both show some increase between 2017 and 2018 (Figure 4-3). Overall fish abundance generally declines as a response to environmental degradation (Fausch et al. 1990).

The fish species richness results show generally lower values from 2014 to 2017 compared to the 2001 to 2011 period (Figure 4-3). Richness increased between 2017 and 2018 at C1 and C2; however, continued to decrease at M5. These species richness results are influenced by lower CPUA values, since less common or abundant species are not detected.

The relative proportion of fish species tolerant of environmental stress (degradation) is shown in Figure 4-3. Tolerant species commonly include carps, suckers, sunfishes and basses, with the transect-specific species list provided in Appendix C (Table C-3). Trends throughout the period of record show an increase of stress tolerant species in 2014/2015 at the C1, C2 and M5 transects, with a decrease from peak proportions at all transects in 2018 (Figure 4-3). Transect C1 showed the greatest difference between 2017 and 2018, with the relative proportion of tolerant fish species reported at 88.9% to 32.7%, respectively.

The relative proportion of trophic guilds shows an increase in generalist species during 2014 and 2015, with a decline from 2016 to 2018 but higher proportions than previously recorded (Figure 4-4). The increased proportion of trophic generalist species is a known fish community response to environmental degradation (Fausch et al. 1990). An inverse trend in the proportion of specialist species is shown with a decline during 2014 and 2015, followed by an increase in 2016, and the most recent (2018) results are still below historic values. The relative proportion of piscivore species at transects C1 and C2 within the creek has increased recently (2017 to 2018), possibly suggesting recent improvement of environmental quality, since the proportion of top-piscivores are indicative of healthy fish communities.

In general, the fish community survey data show changes typically indicative of environmental stresses during the discharge event time period; however, some recent (2018) data suggest improvement in these community metrics and future monitoring will be required to confirm these early trends.

4.3 Aquatic Habitat

Field observations at each sample locations included photographs facing upstream and downstream, as well as examples of in-stream cover, structures or riparian habitat. The upstream reaches of the subject Chedoke Creek reach near the culvert outlet contained sample locations G-1, G-2, C-1 and C-2 (Figure 2-1). The G-1 sample location was positioned on the concrete culvert apron that extends downstream, as part of the wingwall structure. Sediment was accumulated in a localized deposit along the west bank, which extended downstream to the C-1 and C-2 sample locations. No in-stream cover was noted on the concrete apron, and fish were not observed in this area.

The C-1, C-2 and G-2 sample locations were positioned downstream of the concrete apron, with steep sloping banks, flat bottom morphology, and boulders noted throughout the channel. The east bank included an armour stone retaining wall and newly replanted riparian vegetation. The thalweg meandered from the east to west side of the creek within this reach, and most of the flow travelled along a channel near the west bank. Some in-stream coarse woody debris (logs) were observed, as well as anthropogenic debris (garbage, lay-flat hose and geotextile cloth) throughout the channel. One dead Rudd (*Scardinius erythrophthalmus*), a non-indigenous fish species, was noted along the east bank and this species' presence in Chedoke Creek has been documented during the RBG fish community surveys in 2017.

Sample location G-3 was positioned near the downstream extent of the observable elevation changes (i.e. moving water versus flat water) and some flow was apparent at this transect. The east bank had a gradual slope, with a steep sloping west bank and most of the stream flow travelling near that side. Overhanging mature trees along the west bank provide cover and in-stream structure was available at fallen trees/logs and root systems exposed by erosion.

Sample location G-4 was positioned downstream of the Hamilton Conservation Authority CP-11 Outlet water quality monitoring station (culvert outlet). The east bank was comprised of armour stone blocks and coarse aggregate (gravel) with steep sloping sides. Stream flow (velocity) was not observed at this location since this area is likely at the same elevation as Cootes Paradise. The west bank had mature overhanging trees and a gradual sloping bank, with occasional boulders noted throughout the channel. Occasionally adult Common Carp were encountered in this reach due to the shallow conditions (easily seen), but no small-bodied fish or other individuals were noted.

Sample location G-3/G-5 was positioned downstream of the Kay Drage Park bridge. A surface layer of green algae (resembling cyanobacteria; "blue-green algae") was observed mostly near the west bank, but the bloom also extended across the channel at other locations between this transect and the Princess Point bridge. Armour stone blocks were present on both banks, however, the steeper sloping east side had less near-shore vegetation overhanging the creek compared to the riparian vegetation growing close to the edge of water along the west bank. Fallen trees were observed near this sample location, as well as plywood and lumber debris.

Sample location C-4 was positioned mid-way between the Kay Drage Park bridge (near transect C-3/G-5) and the Princess Point bridge (near transect C-5/G-6), immediately upstream of a corrugated steel pipe culvert outlet from the east bank. Both banks contained armour stone blocks and a steep sloping near-shore bottom. Riparian vegetation provided overhanging cover and some in-stream structure.

Sample location C-5/G-6 was positioned upstream of the Princess Point bridge, with armour stone blocks lining the east bank and a gradual sloping bottom along the west bank. The replicate sample near the east side was not wadeable, and the riparian vegetation provided overhanging and some in-stream cover along both banks. Fish were observed feeding at the water surface but could not be identified.

Sample location C-6/G-7 was positioned within Cootes Paradise, west of the main flow path. This location had a shallow water depth (0.25 m) with coarse woody debris observed nearby. The three samples were collected around the boat (port side, starboard side and in front of bow) as this location was not within the channel. Consequently, habitat observations were made in the surrounding area. Adult Common Carp were encountered while accessing this location and small-bodied fish species were also observed feeding at the water surface.

The aquatic habitat 2018 field observations have documented creek morphology, in-stream cover, structures and riparian habitat in order to support interpretation of the sediment quality and biota data collected within Chedoke Creek. These observations have documented the existing conditions and inherently do not solely represent potential impacts to habitat attributable to the discharge event. Other confounding factors such as other sources of contaminants (e.g., other CSOs and urban runoff) have likely also contributed to the aquatic habitat conditions within the creek, however as noted earlier, establishing a clear distinction as to the attributable sources is not considered feasible with the available data.

4.4 Water Quality Assessment

Water quality sampling locations within Chedoke Creek, Cootes Paradise, and the surrounding areas are shown in Figures 4-5.1 and 4-5.2. The statistical analyses discussed in Section 2.3 were conducted using data from the Cootes Paradise Glen Road outfall station (CP-11) near the confluence of Chedoke Creek and Cootes Paradise, three stations upstream of the Main/King CSO (CC-2, CC-3, CC-9), and three stations within Cootes Paradise (CP-1, CP-2 and CP-20). The period of record (POR) considered for the long term analyses varies by station but was approximately 4 years before (pre-2014 period between 2009-2012) and 4 years after the start (post-2014 period between 2014 and 2018) of the event. Actual dates for each analysis are provided with each respective figure and no data were available for the year 2013. The detailed POR for all data used in analysis is included in Table 4-1.

The available time series data for stations CP-11 in Chedoke Creek and CP-1, CP-2, and CP-20 in Cootes Paradise suggest elevated TP and E. coli concentrations at CP-11 beginning in 2014 with concentrations increasing through mid-2018 (Figures 4-6 and 4-7). Following the end of the event in July 2018, both TP and E. coli concentration returned to conditions similar to pre-2014. Peak E. coli concentrations at station CP-1 appeared to increase between 2014 and 2018 but there was no apparent change in TP or E. coli concentration at stations CP-2 or CP-20. While CP-2 and CP-20 are not normally downstream of Chedoke Creek, they may exhibit similar conditions to CP-1 during low flow and periods of reverse flow due to wind-driven seiche from Lake Ontario.

Median TP concentrations at station CP-11 for pre-2014 and post-2014 were 0.19 mg/L and 0.42 mg/L, respectively as shown in Figure 4-8. The Mann-Whitney test showed the difference in TP concentration medians to be statistically significant, indicating that the post-2014 TP median concentration was greater than pre-2014. Figure 4-9 indicates the median E. coli concentration for pre-2014 (510 cfu/100 mL) was significantly lower than the post-2014 median value (12,300 cfu/100 mL). The results of the Mann-Whitney U test indicate that a potential step trend change occurred for both parameters, with concentrations of TP and E. coli being significantly higher after January 2014.

The plots in Figures 4-10 and 4-11 show that concentrations of both TP and E. coli were substantially higher at station CP-11 than in the upstream stations at CC-2, CC-3, and CC-9, until the end of the spill event. The maximum concentrations at station CP-11 tended to occur during mid-summer dry periods, when there was less rainfall and snowmelt to dilute the concentrations from the Main/King CSO. After July 18, 2018, the station CP-11 TP concentrations decreased by nearly an order of magnitude (i.e. 90% reduction) from values approaching 3 mg/L to concentrations similar to values observed at the upstream stations, which were below 0.3 mg/L. The reduction in E.coli concentration was more pronounced with a decrease from nearly 5 million cfu/100 ml to a mean of approximately 5,700 cfu/100 ml. This represents a decrease of three orders of magnitude (i.e. 99.9% reduction) during the midsummer dry period following the end of the event and was similar to concentrations found at the upstream stations.

Figures 4-12 through 4-17 show the median concentrations for TP, E. coli, pH, ammonia, dissolved oxygen and TSS for station CP-11 during the four periods described in Section 2.3 The values are discussed here objectively since insufficient data are available to perform a more robust statistical analysis.

In general, the medians at station CP-11 for TP. E. coli, ammonia, and TSS, were lowest prior to 2014, increased between 2014 and 2017 increased again in early 2018, and decreased in late 2018. Median pH was highest prior to 2014, decreased between 2014 and 2017, decreased and again in early 2018, and increased in late 2018. Mean dissolved oxygen concentration was similar during the pre-2014 and 2014-2017 periods, decreased in early 2018 and increased in late 2018. It is important to note that interpretation of the medians from the 2018 period is difficult because many of these parameters are likely influenced by seasonality.

Figures 4-18 through 4-23 present TP, ammonia, TSS, dissolved oxygen (as % saturation), pH, and chlorophyll-a data from stations CP-1, CP-2, and CP-20 for the period between 2009-2018. All three downstream stations show a marked increase in dissolved oxygen in mid-2017 which may signify a concentrated algal bloom and the associated oxygen production. Ammonia concentration at the downstream station, CP-1, shows a peak in mid-2018 followed by a sharp decline. The ammonia concentrations observed at stations CP-2 and CP-20 for the 2014-2018 period do not appear substantially different than concentrations prior to 2014. The total suspended solids (TSS) concentration appears fairly similar between 2009 and 2018 at stations CP-1, CP-2 and CP-20. The available chlorophyll-a data are insufficient to provide an objective assessment of stations CP-1, CP-2, or CP-20 before, or after, 2014.

In summary, the water quality at station CP-11 near the confluence of Chedoke Creek and Cootes Paradise declined significantly after 2014 based on the available TP and E. coli concentration dataset. An analysis of median data since mid-2018 suggests a dramatic improvement in water quality at station CP-11 although additional data are necessary to evaluate the statistical significance. It is unclear whether the Cootes Paradise stations CP-1, CP-2, and CP-20, have been directly impacted by the Chedoke Creek discharge event. Dissolved oxygen concentrations collected from CP-1, CP-2 and CP-20 during 2017 suggest a significant algal bloom may have occurred during this time, however, there are insufficient chlorophyll-a data to confirm.

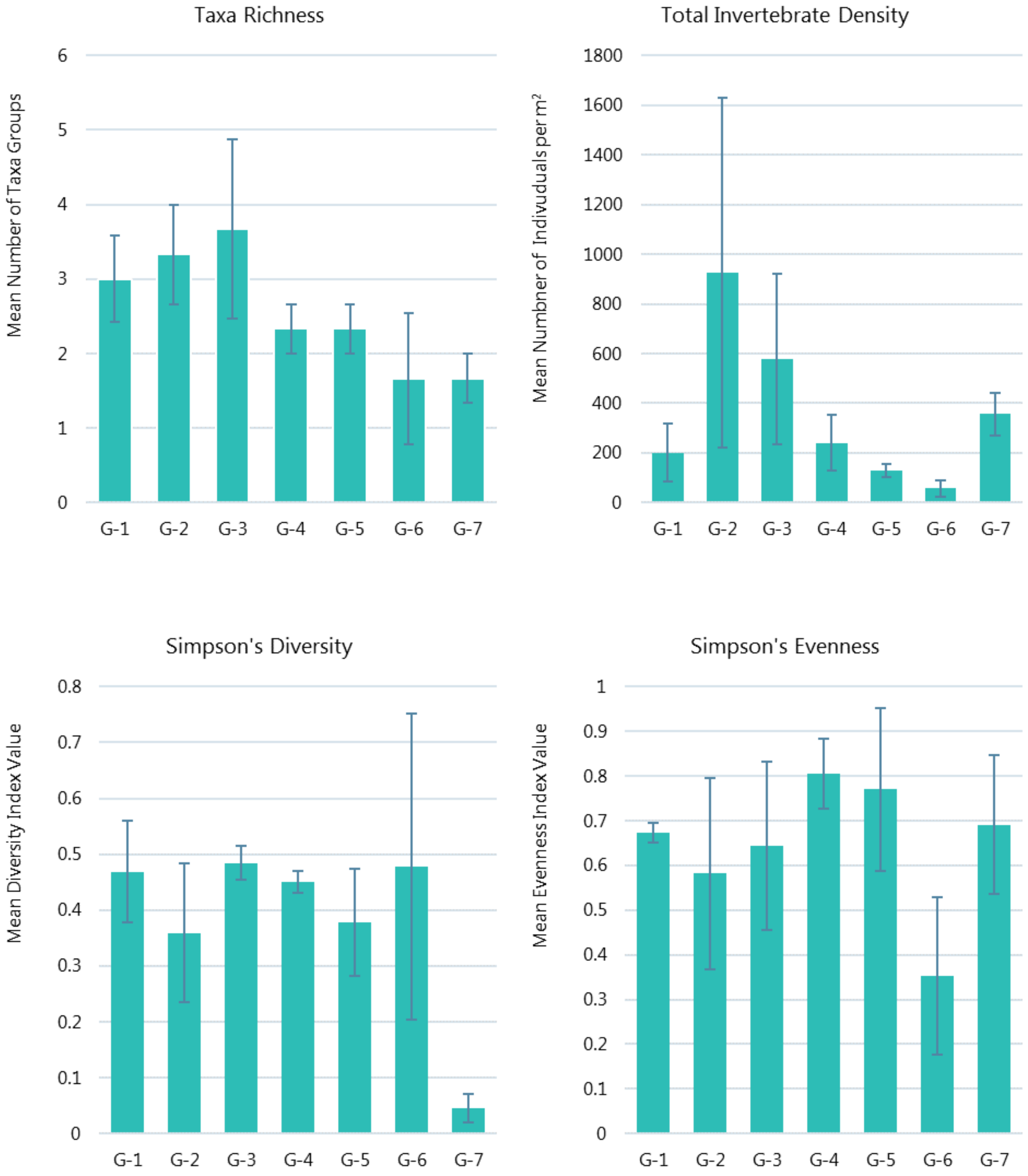


Figure 4-1: Benthic Invertebrate Community – Richness, Total Invertebrate Density, Diversity and Evenness

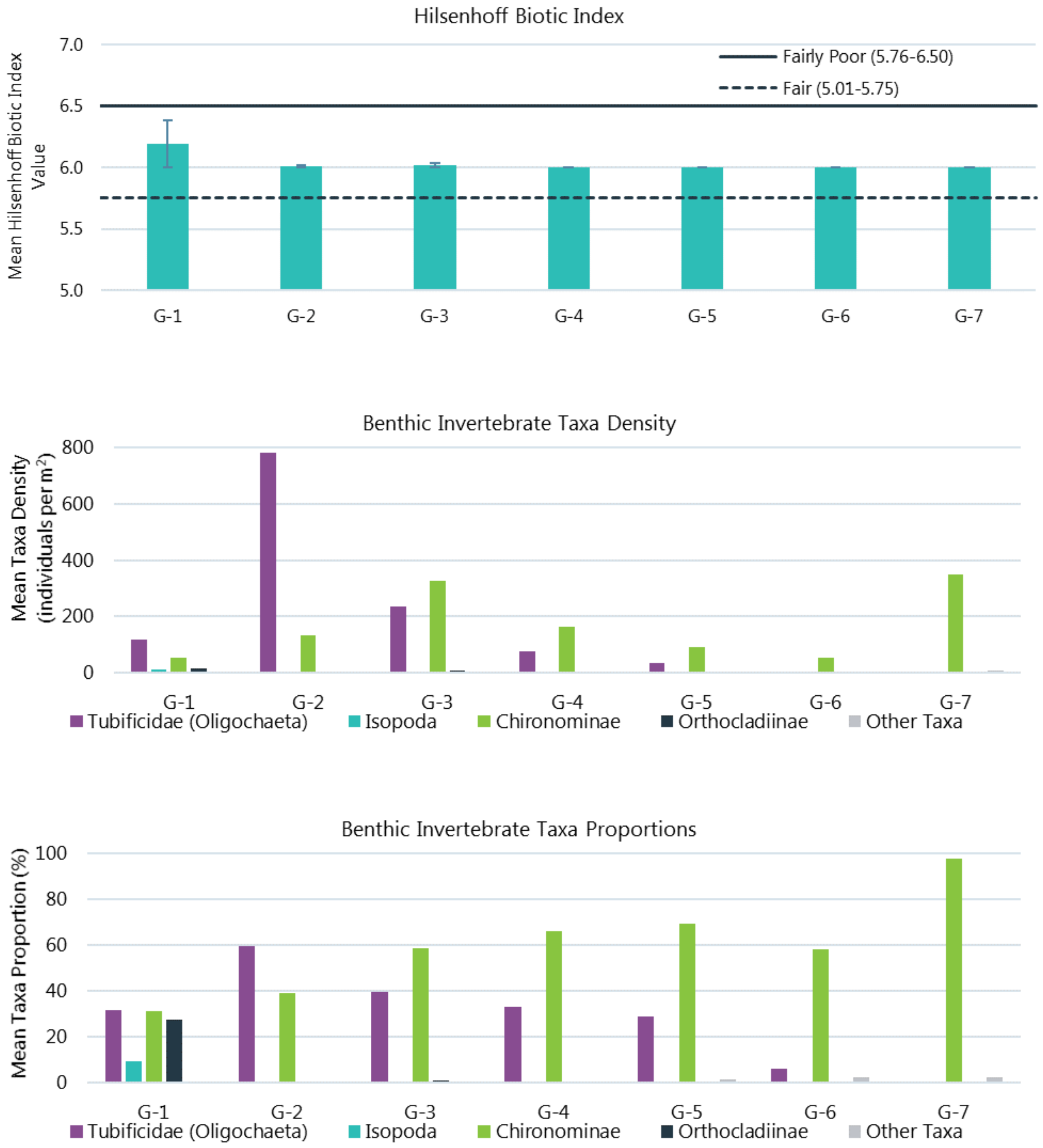


Figure 4-2: Benthic Invertebrate Community – HBI, Taxa Density and Taxa Proportion

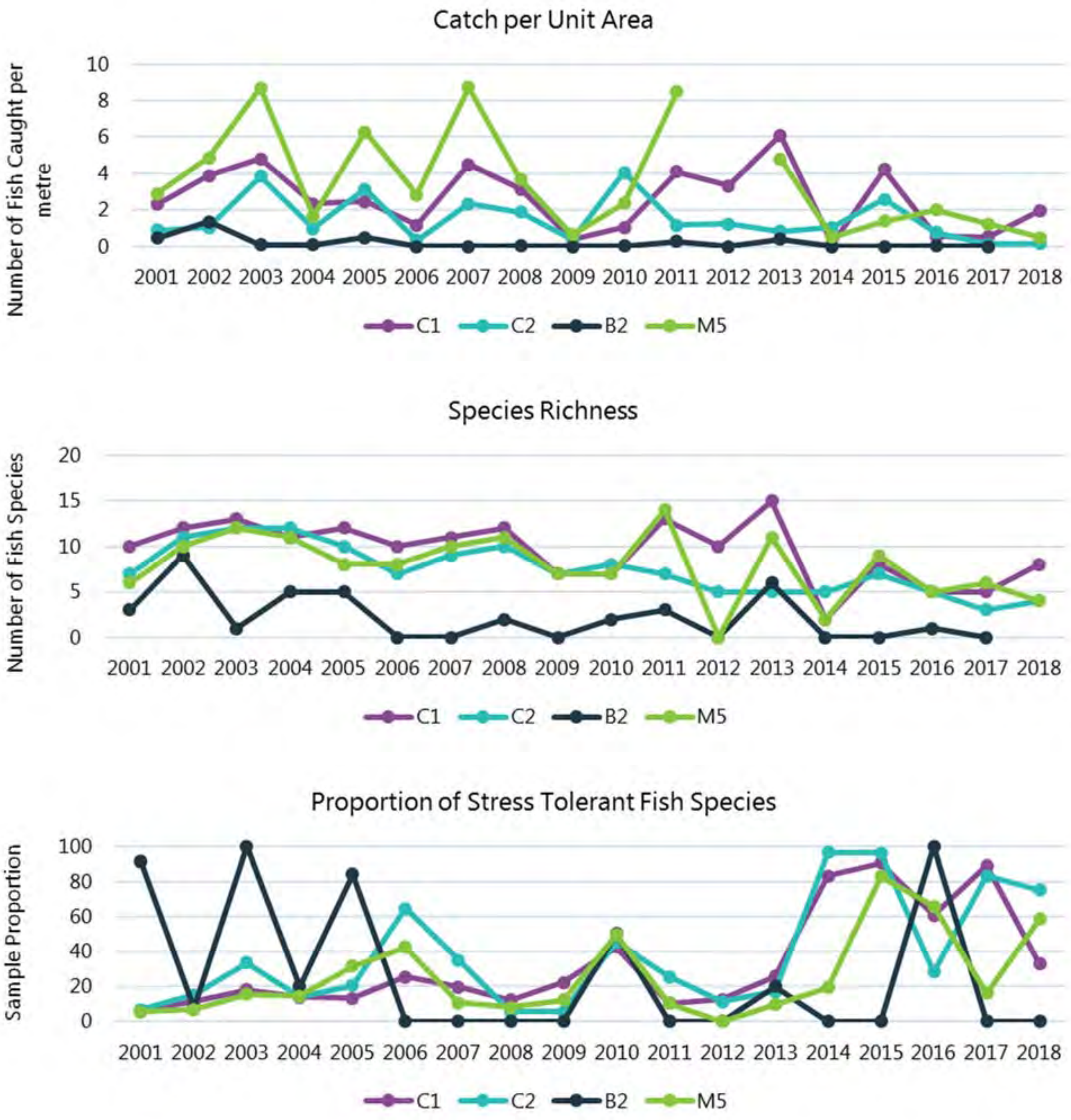


Figure 4-3: Fish Community – CPUA, Richness and Proportion of Stress Tolerant Species

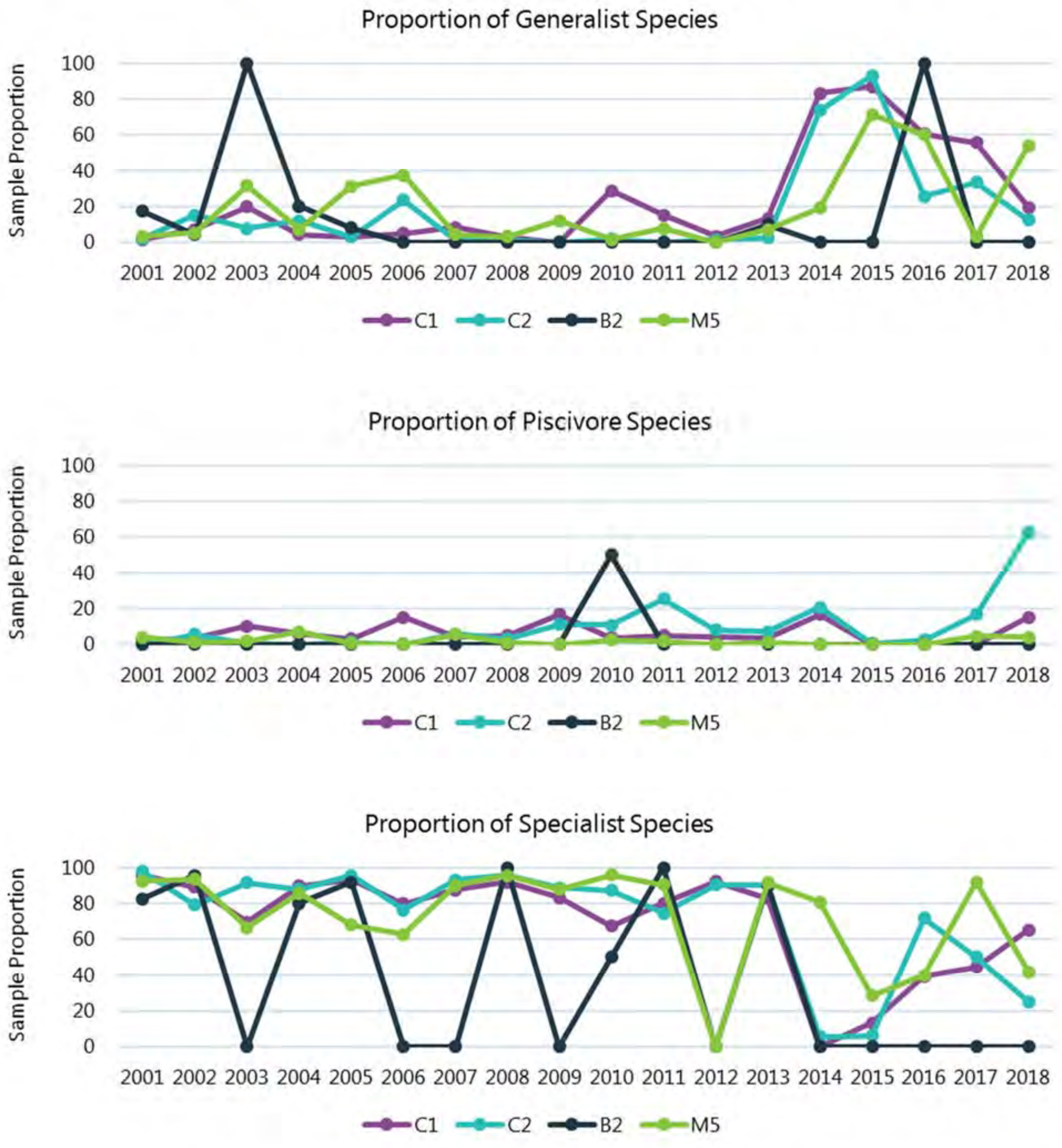
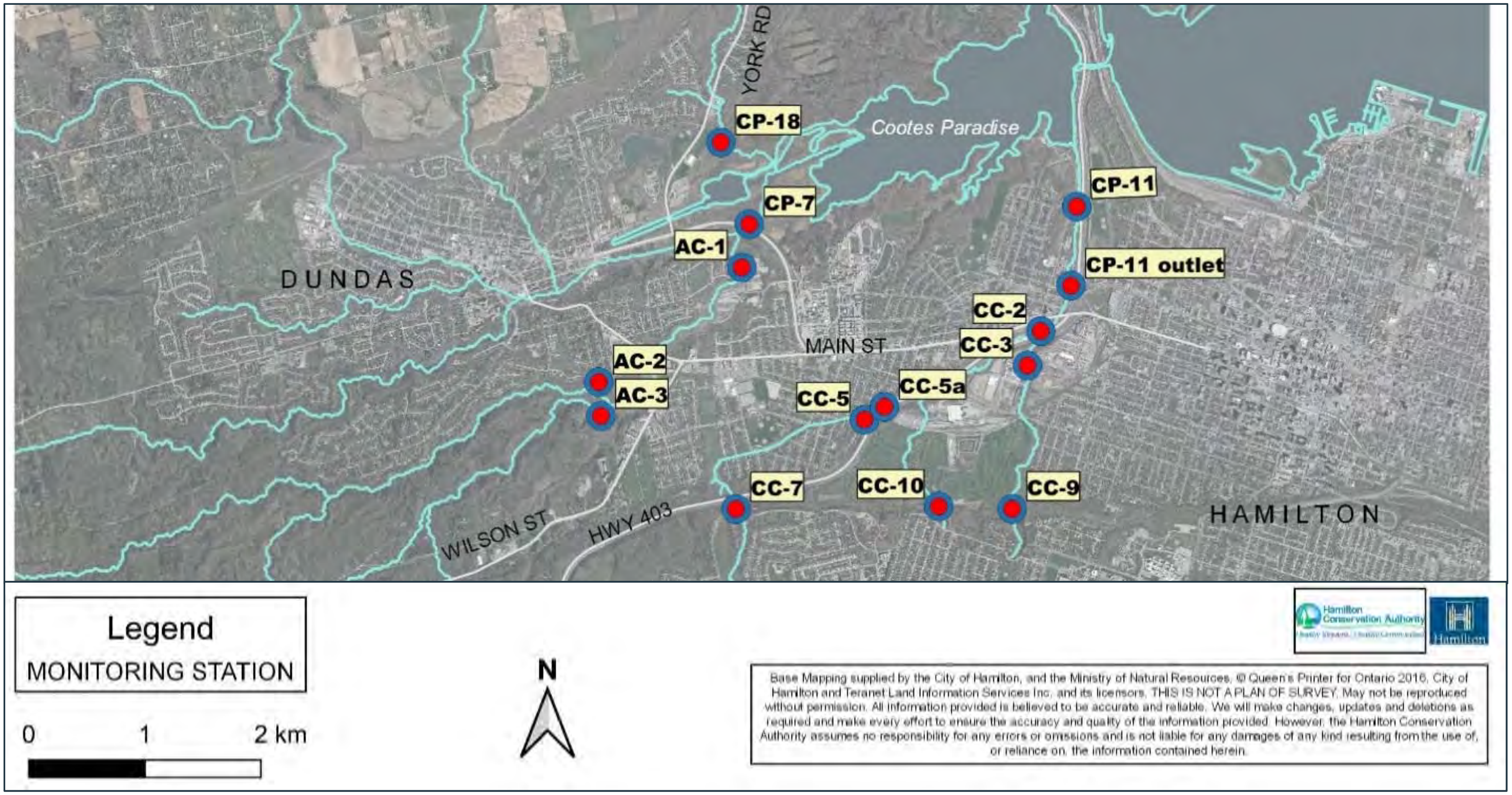


Figure 4-4: Fish Community – Proportion of Generalist, Piscivore and Specialist Species



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Source: Figure provided by the City of Hamilton

Figure 4-5.1: Map of Chedoke Creek and Cootes (ref. HCA, City of Hamilton) Paradise Monitoring Stations

Note: Data used for analyses were from the affected station (CP-11) and upstream stations (CC-2, CC-3, and CC-9).

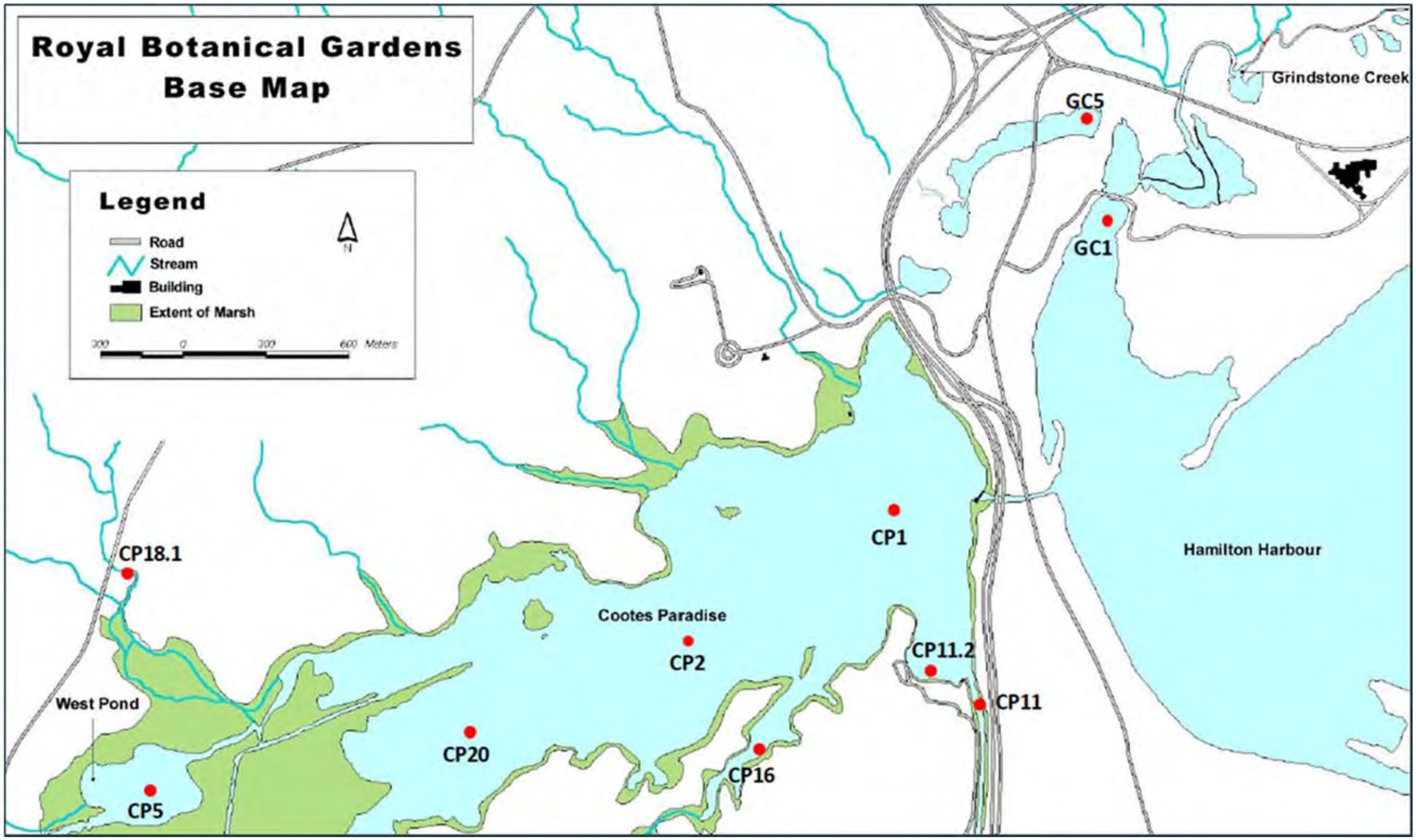

Figure 4-5.2: Map of Royal Botanical Gardens Monitoring Stations (Courtesy of Royal Botanical Gardens)

Note: Data used for analyses were from the affected station (CP11) and downstream stations (CP1, CP2, and CP20).

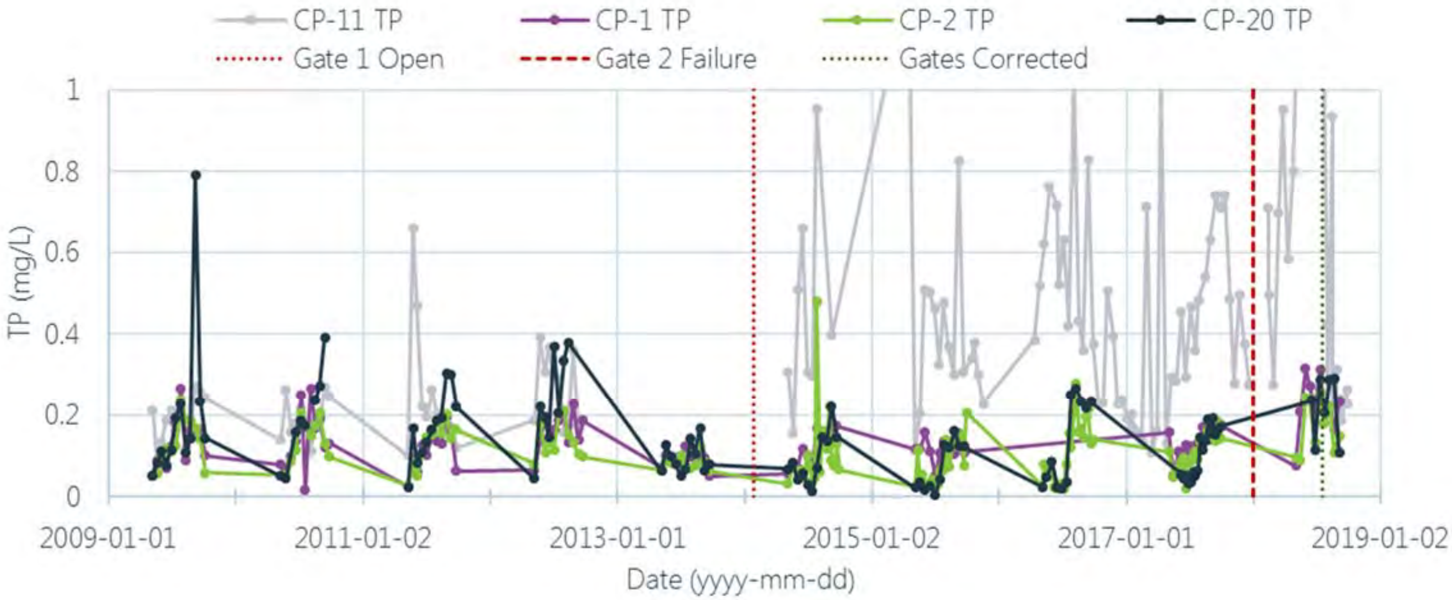

Figure 4-6: Total Phosphorus (TP) Time Series at CP-11 and Cootes Paradise Stations

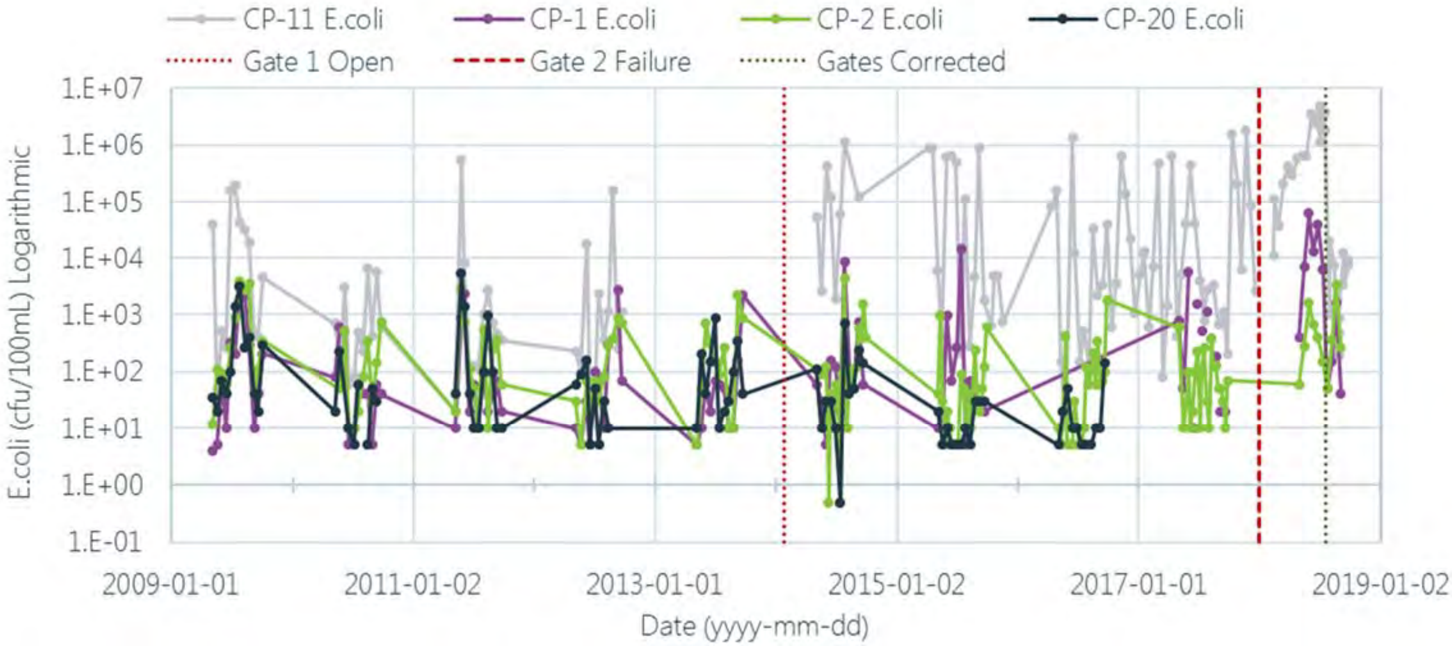

Figure 4-7: Escherichia coli (E. coli) Time Series at CP-11 and Cootes Paradise stations

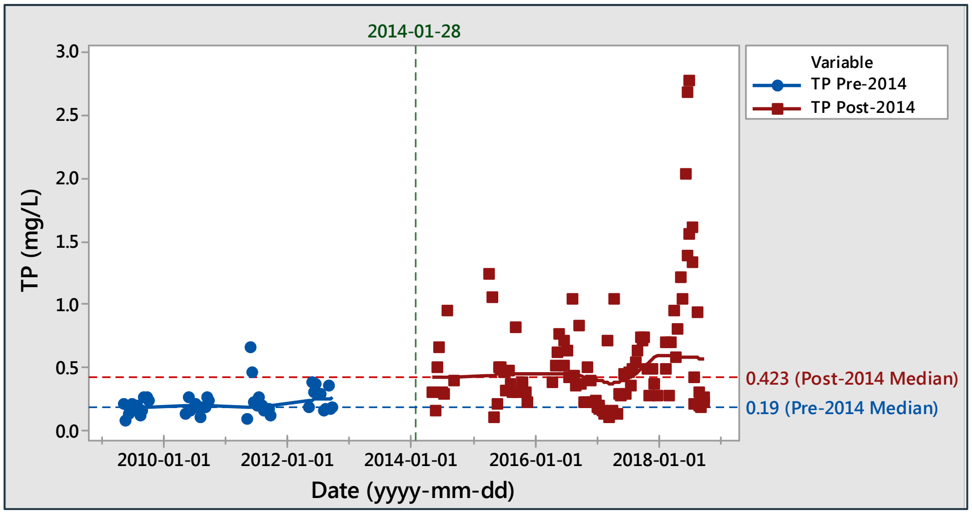

Figure 4-8: Mann-Whitney U Results for CP-11 TP Pre-2014 vs Post-2014 (p-value<0.0001)

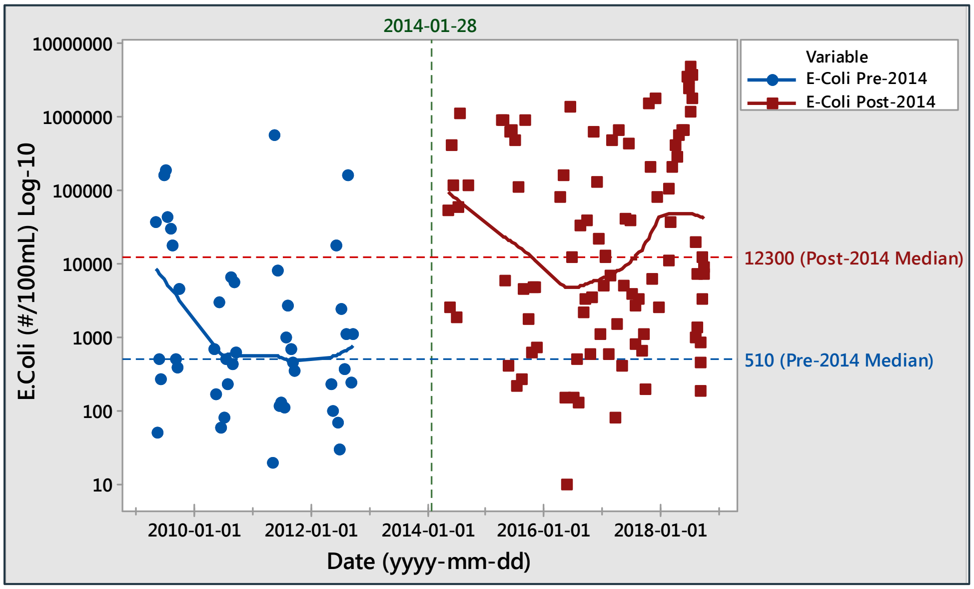

Figure 4-9: Mann-Whitney U Results for CP-11 E. coli Pre-2014 vs Post-2014 (p-value<0.0001)

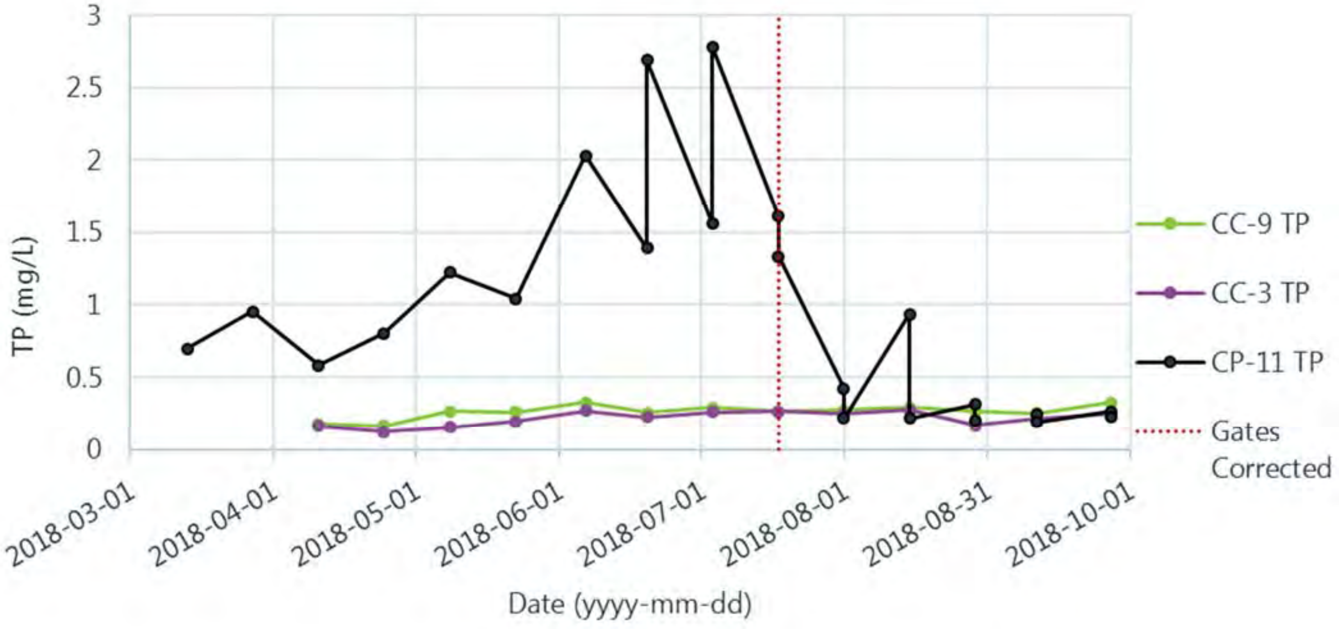

Figure 4-10: TP Concentrations in CP-11 and Upstream Stations

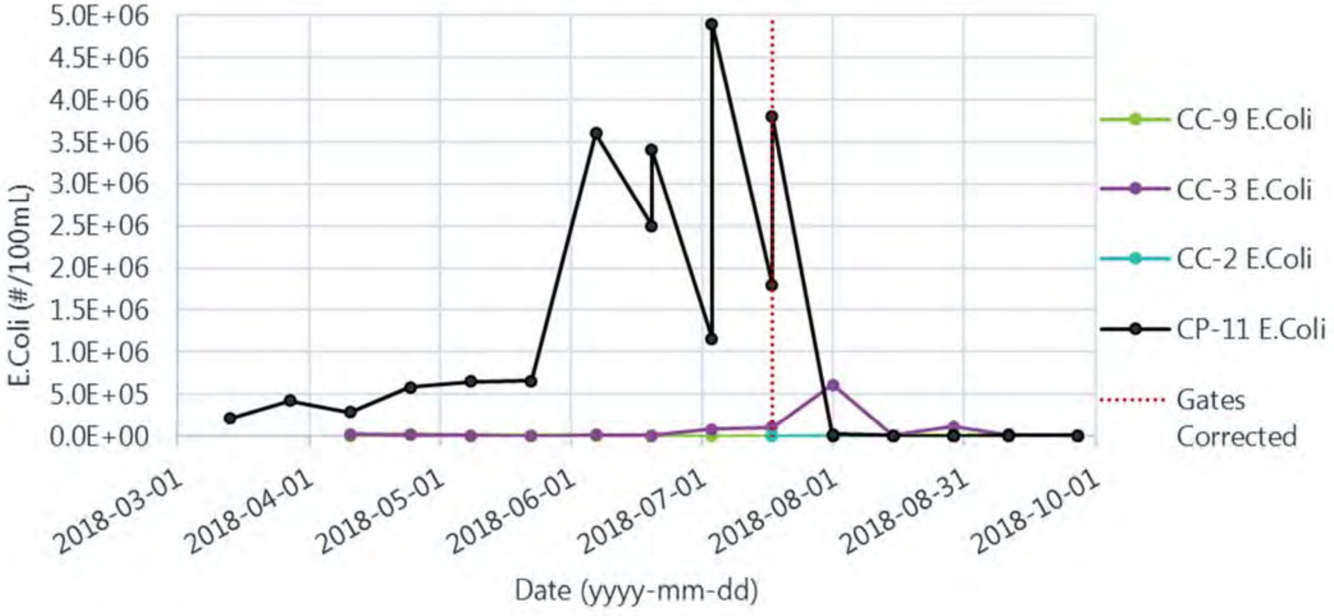

Figure 4-11: E. coli Concentrations in CP-11 and Upstream Stations

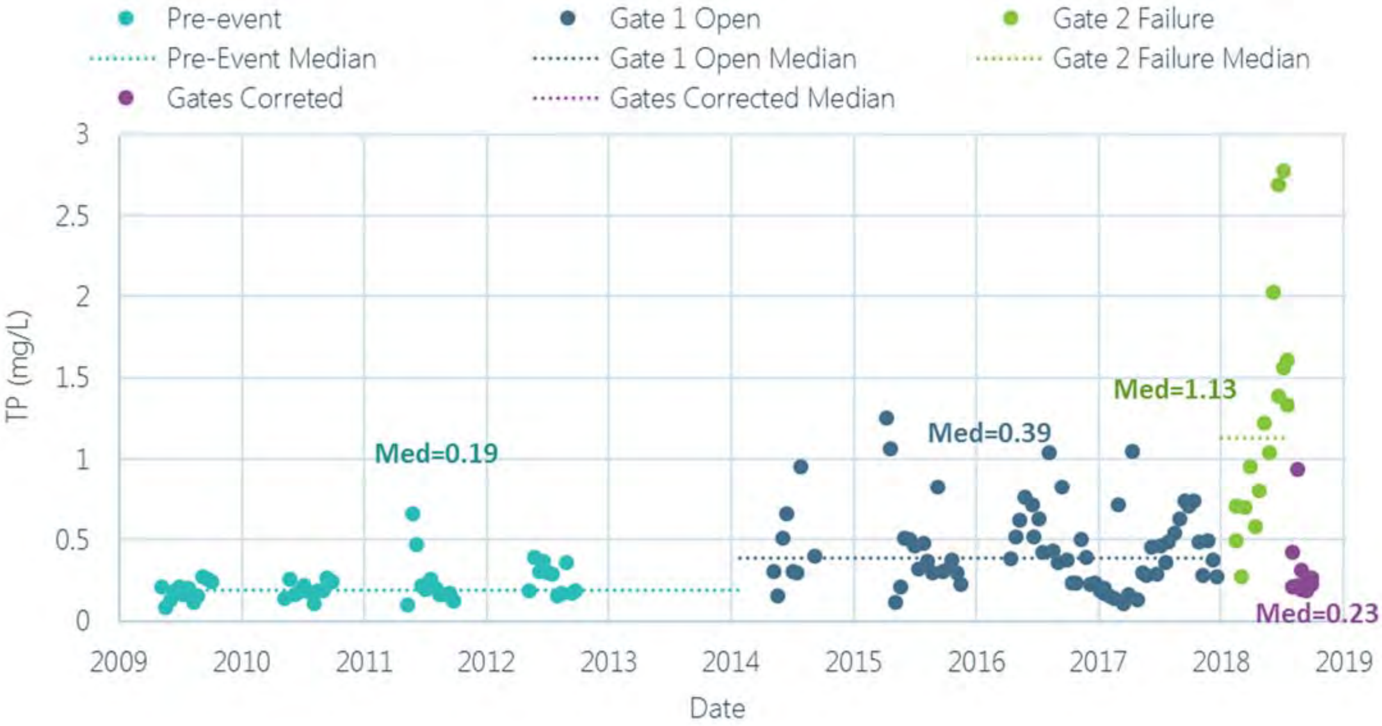

Figure 4-12: CP-11 TP Scatterplot with Medians for Event Time Periods

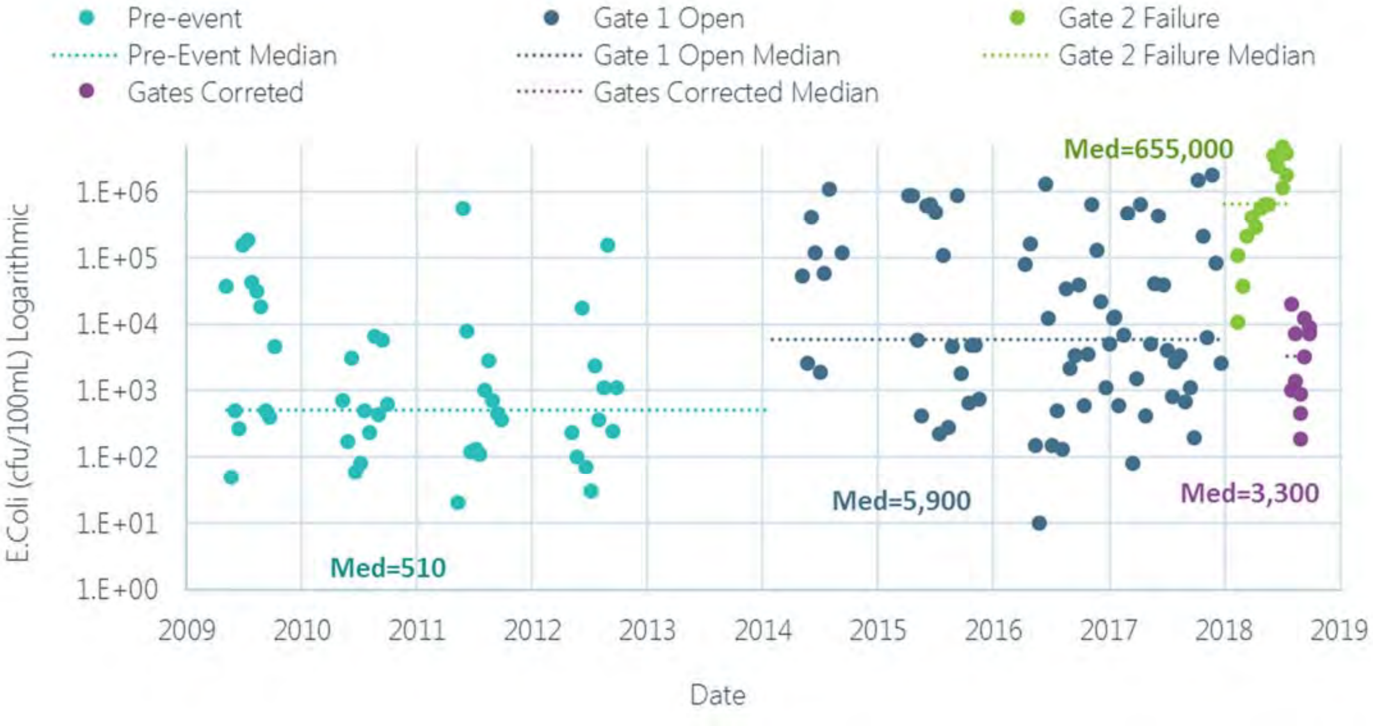

Figure 4-13: CP-11 E. coli Scatterplot with Medians for Event Time Periods

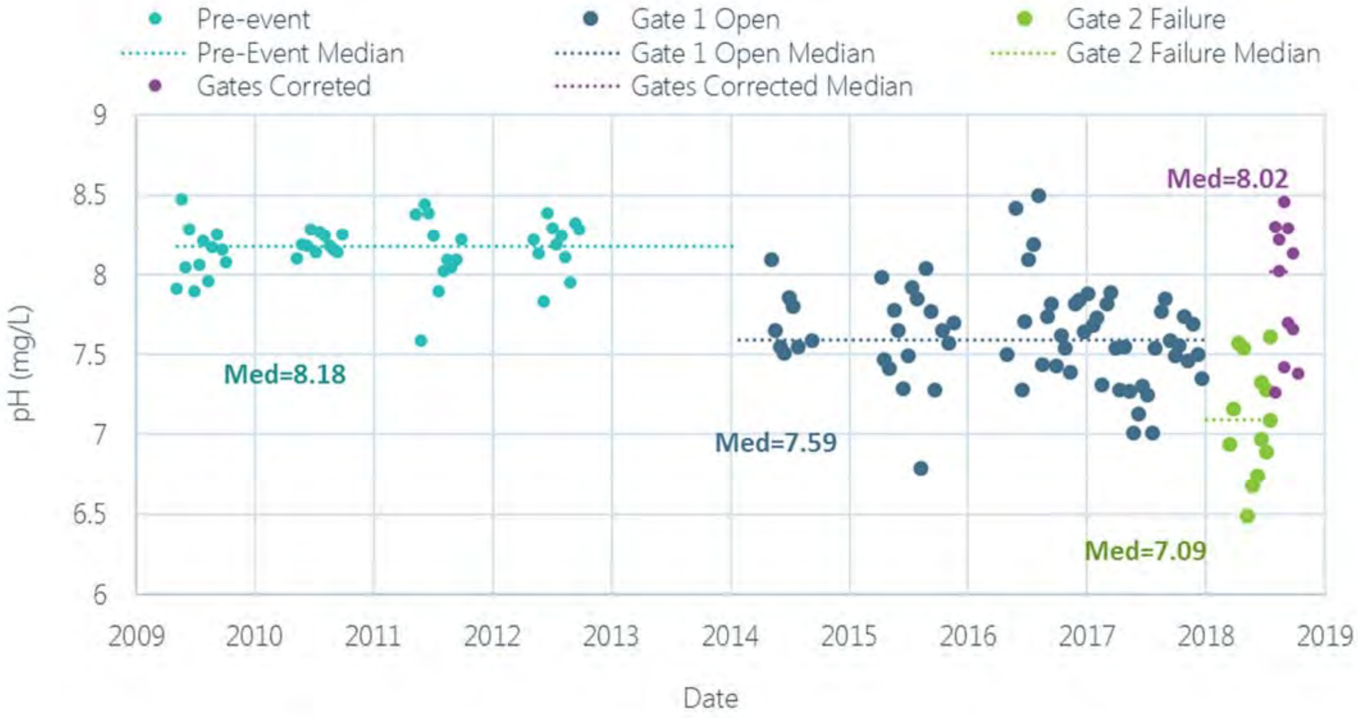

Figure 4-14: CP-11 pH Scatterplot with Medians for Event Time Periods

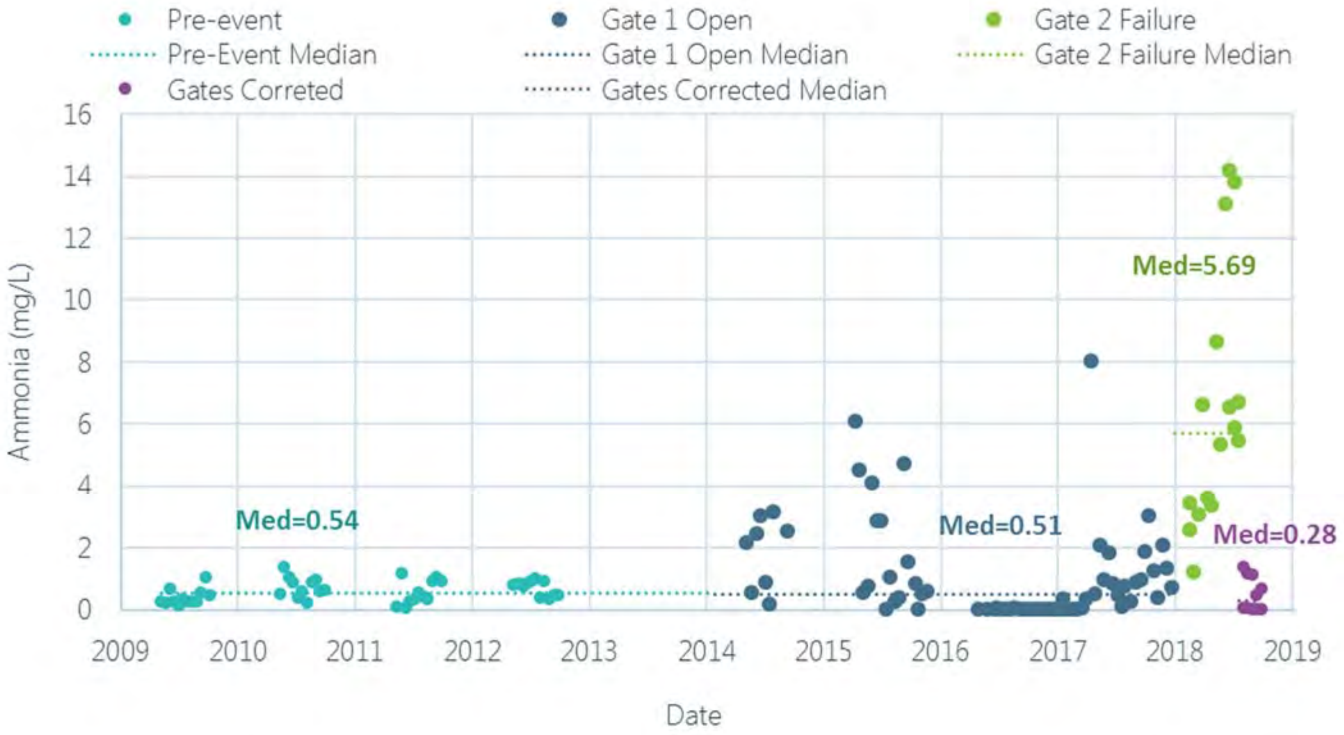

Figure 4-15: CP-11 Ammonia Scatterplot with Medians for Event Time Periods

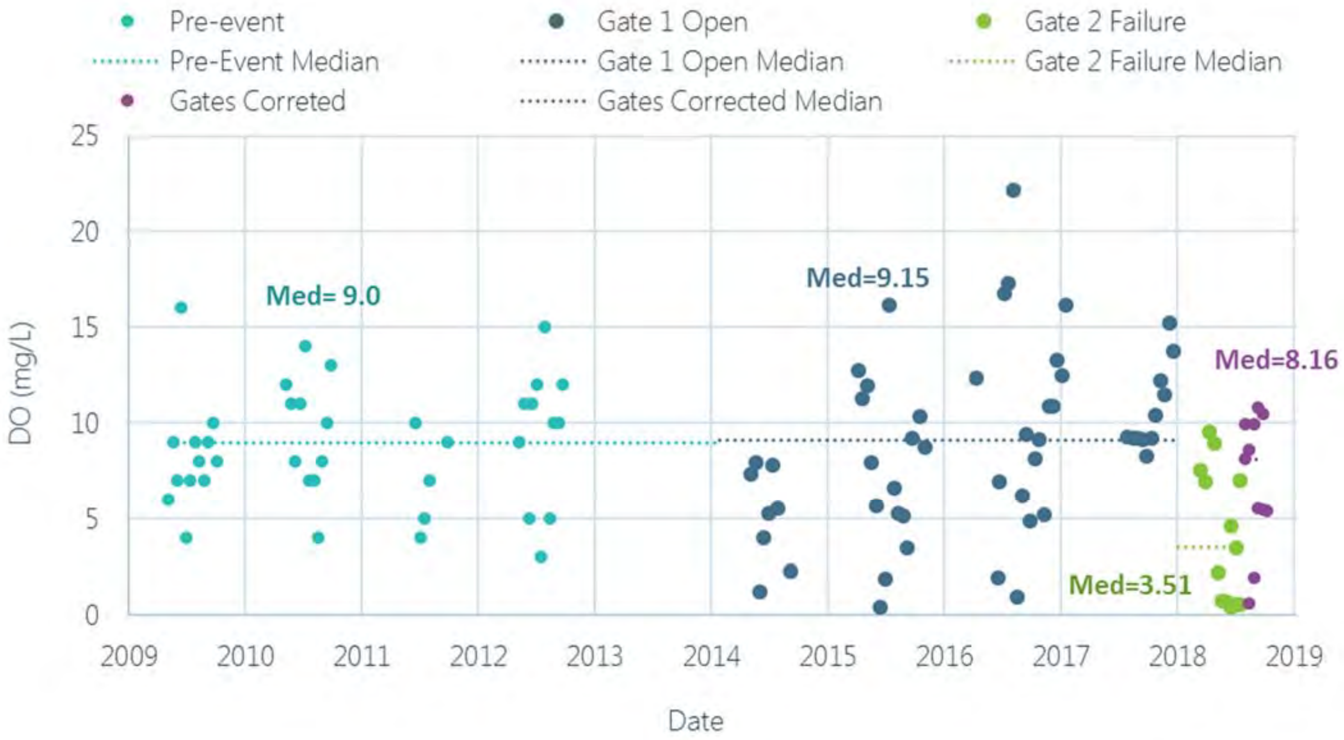

Figure 4-16: CP-11 Dissolved Oxygen (DO) Scatterplot with Medians for Event Time Periods

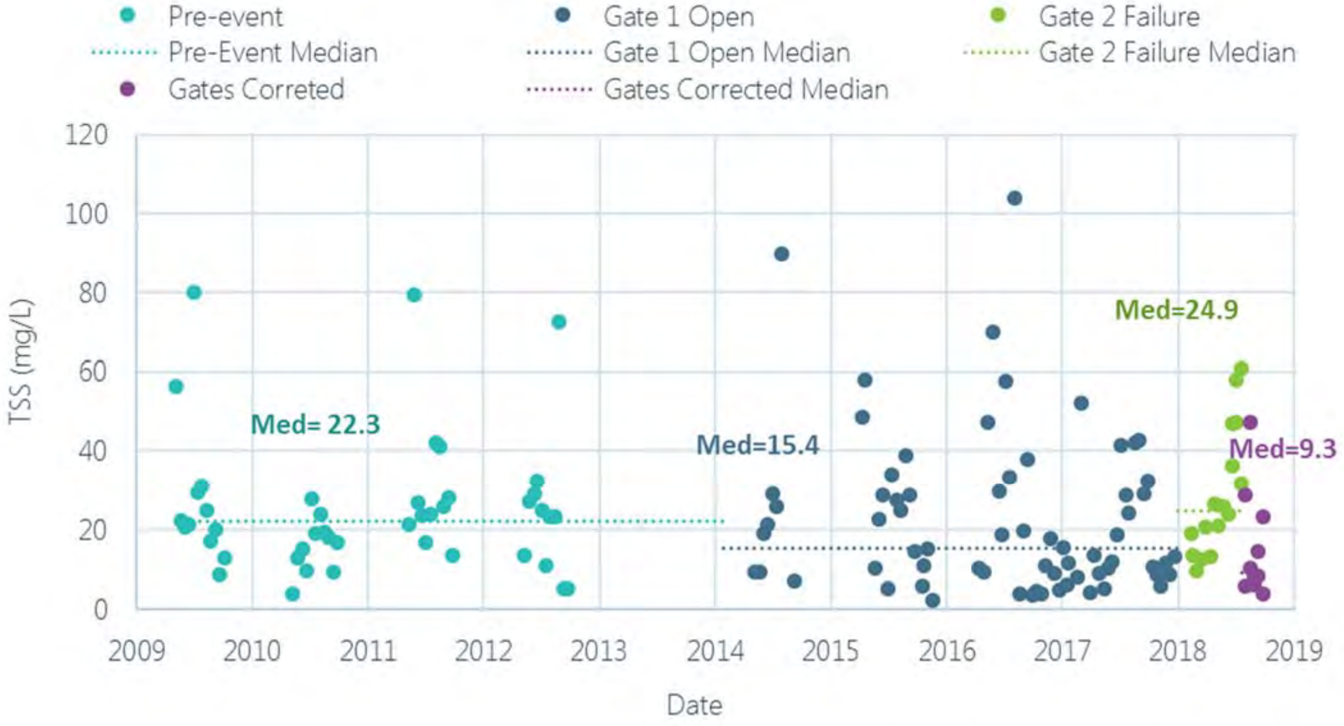

Figure 4-17: CP-11 Total Suspended Solids (TSS) Scatterplot with Medians for Event Time Periods

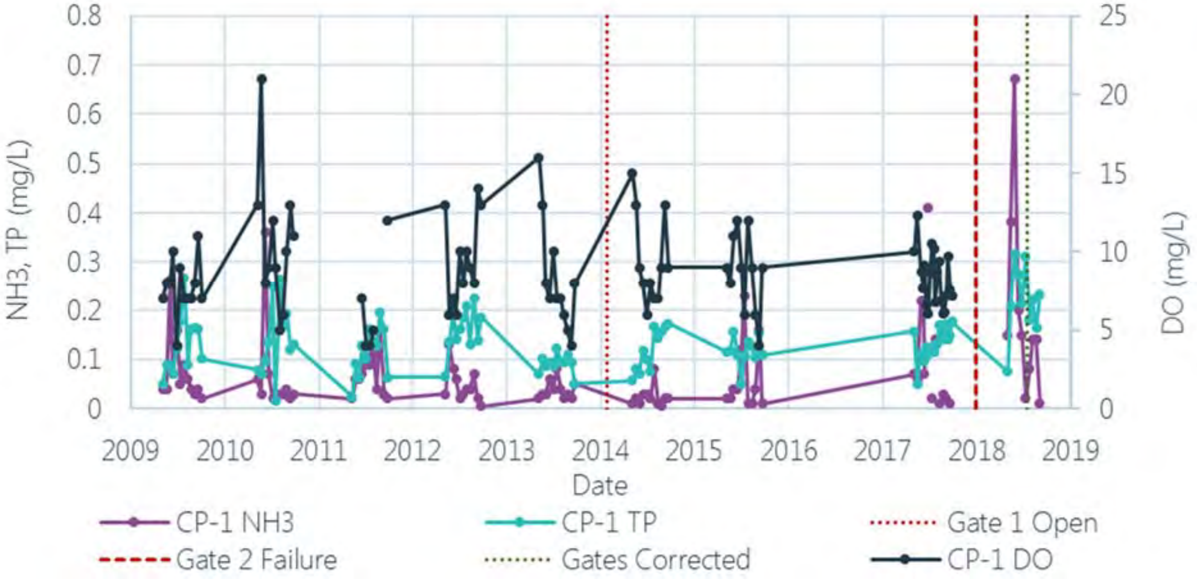

Figure 4-18: CP-1 Ammonia (NH3), Total Phosphorus (TP), and Dissolved Oxygen (DO)

Figure 4-19: CP-1 Total Suspended Solids (TSS), Chlorophyll-a (Chl-a), and pH

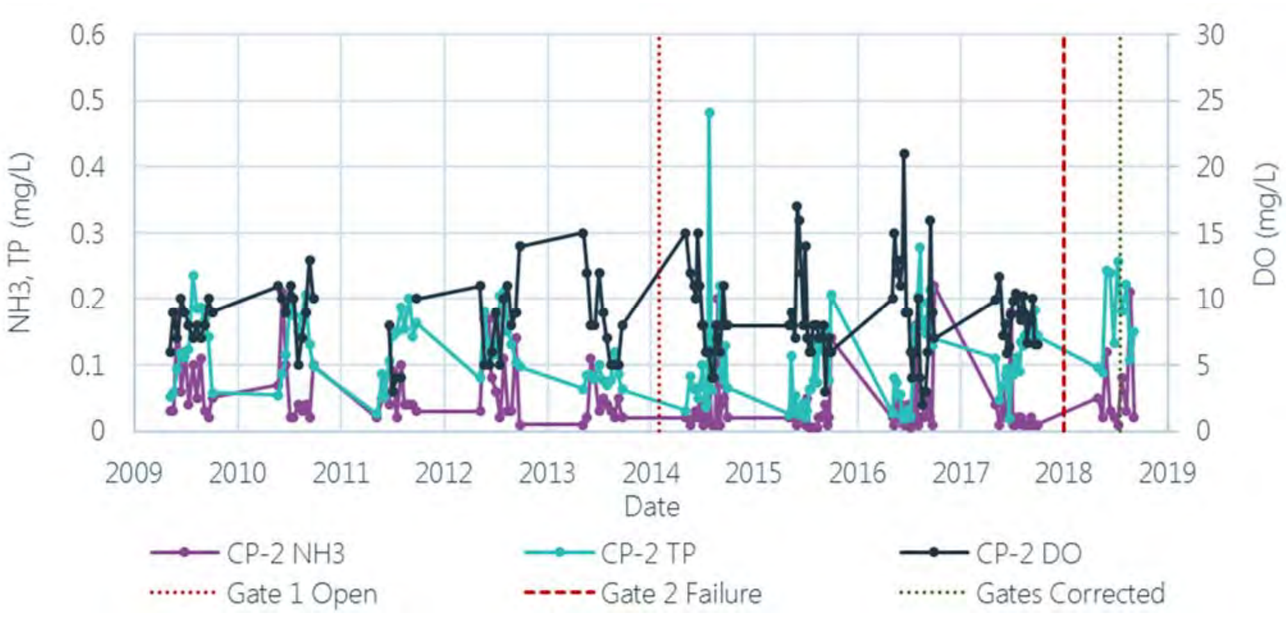

Figure 4-20: CP-2 Ammonia (NH3), Total Phosphorus (TP), and Dissolved Oxygen (DO)

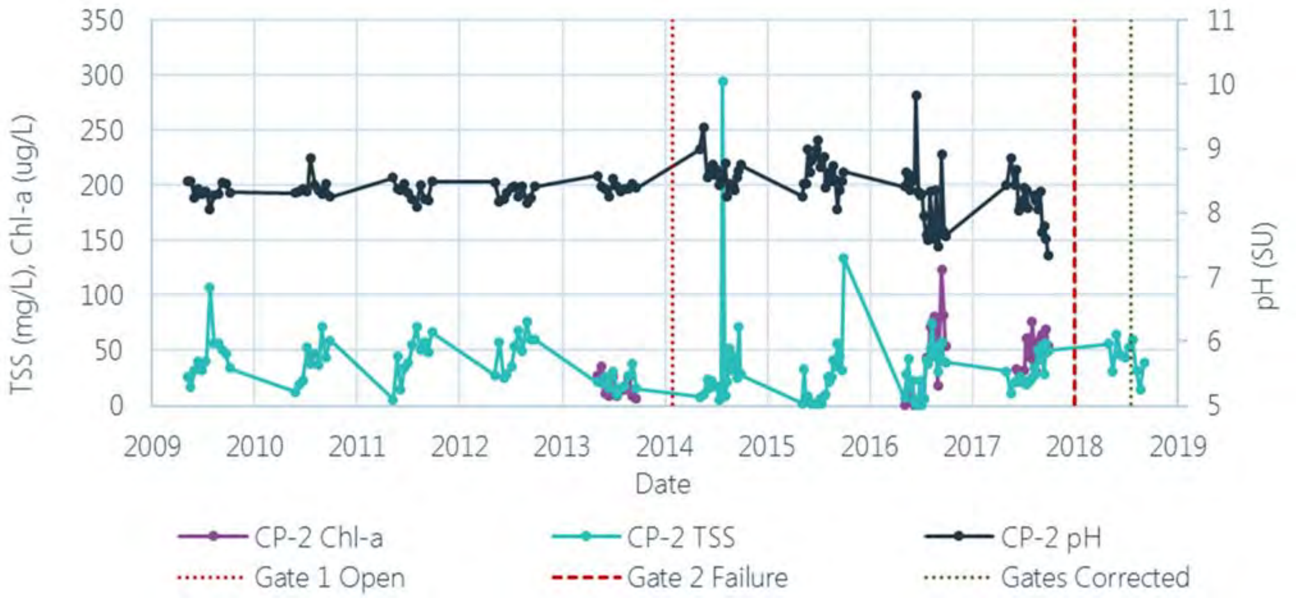

Figure 4-21: CP-2 Total Suspended Solids (TSS), Chlorophyll-a (Chl-a), and pH

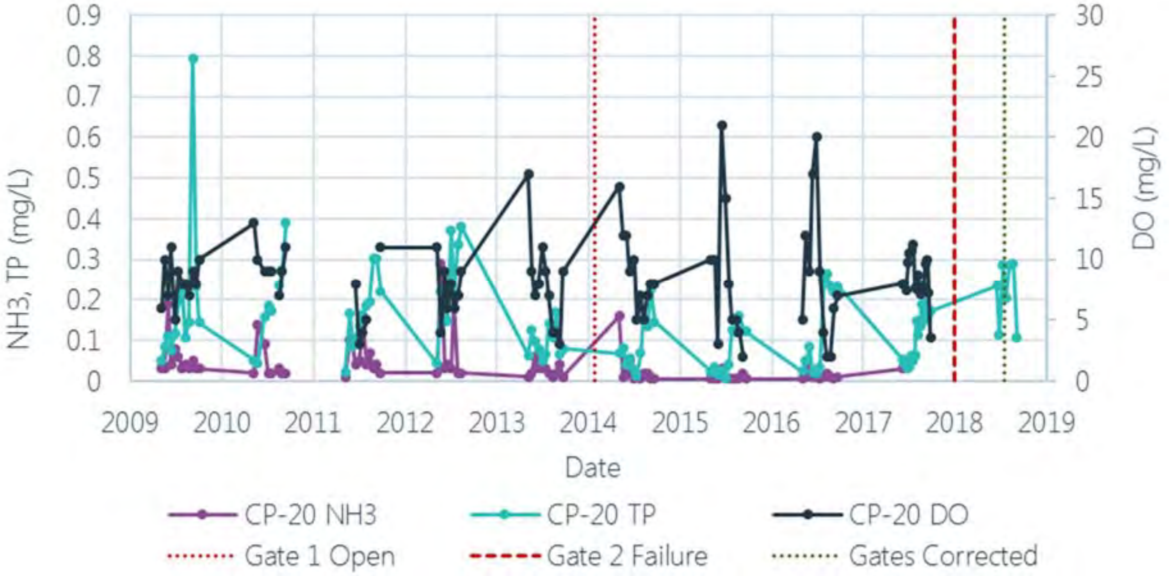

Figure 4-22: CP-20 Ammonia (NH3), Total Phosphorus (TP), and Dissolved Oxygen (DO)

Figure 4-23: CP-20 Total Suspended Solids (TSS), Chlorophyll-a (Chl-a), and pH

Table 4-1: Period of Record (POR) of Water Quality Data used in Assessment

Station	Parameter	Units	Start Date	End Date	N
CP-11	Total Phosphorus	mg/L	5/7/2009	9/27/2018	142
CP-11	Escherichia coli	cfu/100mL	5/7/2009	9/27/2018	143
CP-11	pH	SU	5/7/2009	10/10/2018	136
CP-11	Ammonia	mg/L	5/7/2009	9/27/2018	140
CP-11	Dissolved Oxygen	mg/L	5/7/2009	10/10/2018	116
CP-11	Chlorophyll-a (corrected)	ug/L	5/8/2013	5/8/2013	1
CP-11	Total Suspended Solids	mg/L	5/7/2009	9/27/2018	139
CP-1	Total Phosphorus	mg/L	5/6/2009	9/5/2018	108
CP-1	Escherichia coli	cfu/100mL	5/6/2009	9/5/2018	99
CP-1	pH	SU	5/6/2009	9/27/2017	96
CP-1	Ammonia	mg/L	5/6/2009	9/5/2018	100
CP-1	Dissolved Oxygen	% saturation	5/6/2009	9/27/2017	92
CP-1	Chlorophyll-a (corrected)	ug/L	5/7/2013	9/20/2017	28
CP-1	Total Suspended Solids	mg/L	5/6/2009	9/5/2018	100
CP-2	Total Phosphorus	mg/L	5/7/2009	9/5/2018	149
CP-2	Escherichia coli	cfu/100mL	5/7/2009	9/5/2018	149
CP-2	pH	SU	5/7/2009	9/27/2017	137
CP-2	Ammonia	mg/L	5/7/2009	9/5/2018	149
CP-2	Dissolved Oxygen	% saturation	5/7/2009	9/27/2017	133
CP-2	Chlorophyll-a (corrected)	ug/L	5/7/2013	9/27/2017	50
CP-2	Total Suspended Solids	mg/L	5/7/2009	9/5/2018	149
CP-20	Total Phosphorus	mg/L	5/7/2009	9/27/2017	107
CP-20	Escherichia coli	cfu/100mL	5/7/2009	9/21/2016	83
CP-20	pH	SU	5/7/2009	9/27/2017	98
CP-20	Ammonia	mg/L	5/7/2009	6/7/2017	84
CP-20	Dissolved Oxygen	% saturation	5/7/2009	9/27/2017	94
CP-20	Chlorophyll-a (corrected)	ug/L	5/8/2013	9/27/2017	39
CP-20	Total Suspended Solids	mg/L	5/7/2009	6/7/2017	84
CC-9	Total Phosphorus	mg/L	4/11/2018	9/27/2018	13
CC-9	Escherichia coli	cfu/100mL	4/11/2018	9/27/2018	13
CC-3	Total Phosphorus	mg/L	4/11/2018	9/27/2018	13
CC-3	Escherichia coli	cfu/100mL	4/11/2018	9/27/2018	13
CC-2	Total Phosphorus	mg/L	--	--	0
CC-2	Escherichia coli	cfu/100mL	7/18/2018	8/29/2018	4

5.0 Remedial Action Plan

5.1 Existing Conditions and Discharge Event Loading Estimates

Examination of existing conditions within Chedoke Creek indicates that a layer of organic material approximately 16 m wide with a mean thickness of approximately 0.27 m (+/-) is present along the roughly 1,275 m (+/-) creek bed between the Main King CSO and Cootes Paradise. Mean thickness has been used in this section for ease of discussion, however, sediment thickness is highly variable within Chedoke Creek in the study area and additional bathymetric data should be collected prior to implementation of any remediation project. The volume of organic material (defined as soft sediment as identified in Section 3) that is currently within Chedoke Creek is estimated to be approximately 5,600 m^3 (+/-). The organic sediments are underlain by firmer, sandier material. Chemical analysis indicates the organic material is nutrient-rich and bacteriological analysis indicates that it may be a potentially significant source of faecal coliform bacteria. In addition, the concentrations of metals and polyaromatic hydrocarbons (PAHs) are generally higher than the regulatory limits for standard sediment disposal.

As discussed in Section 3.2, metal and PAH concentrations were not measured in Chedoke Creek prior to the 2018 investigation. PAH concentrations, were lower in Cootes Paradise prior to the discharge event. However, metal concentrations were elevated downstream in Cootes Paradise prior to the discharge event suggesting that upstream sources of pollutants were present prior to the Main/King CSO discharge event. PAHs and metals are commonly associated with both wastewater and stormwater and multiple sources exist within Chedoke Creek watershed as discussed above.

Based on elevated concentrations of faecal coliform and nutrients, the soft sediments within Chedoke Creek may have been deposited over the duration of the discharge event, although as noted earlier, they may also be associated with CSO discharge prior to 2014. It has been estimated that a total suspended solids (TSS) load of over 2,375 tonnes was discharged to Chedoke Creek between 2014 and 2018. During low flow and low velocity conditions, much of the larger, heavier particulate material would likely have settled within portions of Chedoke Creek downstream of the Main King CSO. During higher flow and velocity conditions, some of the TSS load may have been mobilized and transported downstream to Cootes Paradise. Soft sediment collected from Chedoke Creek indicates moisture content of 40% or less, which suggests that this material is relatively dense and consistent with settling and consolidation of suspended particulate material in the discharge.

While dense organic sediments are present within Chedoke Creek, solids from the discharge event have likely settled over a range of in-situ conditions which may exist downstream of Chedoke Creek. The potential range of resulting in-situ sediment volume based on the total TSS discharged during the event (2,375 tonnes) can be estimated from the following table derived for wastewater sludges as described in Metcalf and Eddy (2004):

% solids*	Specific Gravity of Sludge	Estimated Volume of Sludge (m^3)
1	1.003	236,820
2	1.006	118,070
5	1.014	46,820
10	1.029	23,070
15	1.045	15,160
20	1.061	11,200
30	1.094	7,240
40	1.129	5,260

*Assumes specific gravity of solids is 1.4

The equation used to calculate the above specific gravity of sludge is as follows:

$$\frac{1}{S_{sl}} = \frac{P_s}{S_s} + \frac{P_w}{S_w}$$

S_{sl}=specific gravity of sludge
Ps= percent solids expressed as a decimal
S_s=specific gravity of solids, assume 1.4
P_w=percent water expressed as a decimal
S_w=specific gravity of water, assume 1.0

The equation used to calculate the estimated volume of sludge is as follows:

$$V = \frac{Ms}{\rho_w S_{sl} P_s}$$

V=volume, m^3
M_s=mass of dry solids, kg
ρ_w=specific weight of water, 10^3 kg/m^3
S_{sl}=Specific gravity of the sludge
P_s=percent solids expressed as a decimal

The sludge volume of 5,260 m^3 estimated using the total 2,375 tonnes of TSS loading at 40% solids is similar to the approximate in-situ volume of 5,600 m^3 discussed earlier. Solids content in the upper 15 cm of stations C-3 and C-4 ranged between 40 and 50% (Appendix B, Table B1-2a). Other locations were higher in solids content indicating that 40% is likely a conservative estimate. This suggests that the solid organic mass within Chedoke Creek is similar to the solids mass discharged during the spill event.

Total Kjeldahl nitrogen loading during the discharge event is estimated to be 312 tonnes. Based on the concentrations from samples collected in soft sediment, approximately 560 tonnes of total Kjeldahl nitrogen are present within Chedoke Creek.

Total phosphorus mass within the Chedoke Creek soft sediments is estimated to be 3.3 tonnes while total loading from the event is estimated to be 47 tonnes. Hence, less than ten percent of the TP remains in the sediment, suggesting that the balance of the mass may have been transported downstream as dissolved phosphorus. This is consistent with the relatively high concentrations of TP in the water column in Chedoke Creek and downstream in Cootes Paradise between 2014 and 2018.

Based on the coarse data collected for the preliminary analysis, it appears that both solids and total Kjeldahl nitrogen loading from the discharge event may be addressed by removing the soft sediments delineated within the subject reach of the Chedoke Creek, downstream of the Main King CSO. However, approximately 90% of the total phosphorus mass load appears to have be solubilized or transported downstream.

5.2 Alternatives Assessment

The Chedoke Creek alternatives assessment has involved analysis of a no-action alternative and further development of remediation options and a project scope based on the analysis of current (2018) conditions as previously described, and estimated pollutant loading during the event.

The ecological conditions within Chedoke Creek were likely degraded long before the beginning of the spill event in 2014. The 2013 aerial photography indicates that Chedoke Creek had no identifiable emergent or submerged aquatic vegetation between the Main King CSO discharge structure and Cootes Paradise prior to the event (Figures 5-1 through 5-3). Similar conditions existed in 2017, as shown in Figures 5-1 through 5-3. Changes since the 2014 condition are not immediately apparent in the aerial photography but, based on current (2018) conditions, as described in the foregoing, appear to be primarily related to the accumulation of organic sediments that have resulted in increased nutrient export, bacteriological contamination, low dissolved oxygen, and physical smothering, as well as habitat loss for those species dependent on sandy substrates. As discussed previously, it is not possible to determine the exact source of these pollutants and some of the material has likely been transported downstream of Chedoke Creek into Cootes Paradise and likely further into Hamilton Harbour. In addition, future accumulation and pollutant loading is likely since multiple CSOs and stormwater outfalls exist upstream.

5.2.1 No-Action Alternative

The no-action alternative was evaluated to consider the expected impacts if no remediation occurs within the subject reach of the Chedoke Creek. The no-action alternative is discussed below.

Section 4.4 indicated water quality improvements were apparent immediately following proper adjustment of the Main/King CSO gates. The degree of water quality improvement within the section of Chedoke Creek downstream of the Main/King CSO will depend largely on the contribution of upstream sources which will vary depending on runoff conditions. During low flow conditions, water quality within Chedoke Creek will likely be affected primarily by internal contributions (e.g., sediment nutrient flux and resuspension) and organic material deposited within the creek which may significantly degrade water quality leading to excessive planktonic algal growth and loss of submerged aquatic vegetation. However, during higher flows, much of the internal contribution from these organic sediments will be diluted and carried downstream. The organic material transported downstream may however continue to contribute to ongoing water quality problems within Cootes Paradise and Hamilton Harbour although the magnitude of the impacts may not be discernable from other sources of contaminants to these water bodies due to dilution. Additional CSO discharges are also likely during high flows which will also make it difficult to isolate potential impacts from the Main/King CSO spill event.

As discussed in Section 5.1, the estimated mass of organic material and TKN currently within Chedoke Creek is similar to the overall loading estimated for the duration of the spill event. Much of the TP from the spill event appears to have been transported downstream, but significant mass is still present within the creek. As noted earlier, the source of the material is not certain and conditions prior to the spill event suggest that the ecological conditions of Chedoke Creek had already been significantly impacted, so removal is not likely to restore Chedoke Creek. However, unless removed, the organic material currently in Chedoke Creek will likely result in additional loading to Cootes Paradise as it is transported and redeposited downstream. The overall impact of the loading will likely be relatively small compared to the total loading to Cootes Paradise and beyond from the surrounding watershed, however, the potential impact area will be much larger. Greater nutrient flux from sediments washed downstream would be likely since it would have more contact with the water column and may result in additional algal growth and loss of submerged aquatic vegetation. Therefore, the no-action alternative is not recommended.

5.2.2 Remediation Alternatives

The remediation alternatives focus on addressing the organic material within the subject reach of the Chedoke Creek, within the management unit boundaries defined on Figure 5-4. Regardless of the specific source of the organic sediments within Chedoke Creek, it appears that the solids and total nitrogen mass may be addressed by a remediation project within the current existing condition study boundaries.

Potential impairments from the organic material within Chedoke Creek can be addressed (in order from least, to most, effective), by physical capping; chemical inactivation (to bind bioavailable phosphorus), or by direct removal. An assessment of each of these alternatives is provided in the following sections; the advantages and disadvantages of the alternatives discussed in the following sections are also provided within Table 5-1 as they relate to functional effectiveness, environmental effectiveness, economics, and social benefits.

5.2.3 Physical Capping

Physical capping is accomplished by applying a cover of clean material on top of the contaminated sediment to effectively eliminate or reduce biogeochemical and physical interaction with the overlying water column. The type of material used depends on the pollutant and degree of isolation needed but ranges from bentonite clay, uncontaminated organic material to sand. Some remediation projects have successfully utilized cleaner organic material as a cover to reduce pesticide contamination (SJRWMD, 2016). Sand caps have been used effectively to improve water quality in canal systems where nutrient contamination has been problematic. However, this method is best suited for lentic systems where bottom conditions are relatively uniform and water depth is sufficient to reduce scouring, sediment transport, and resuspension. Irregular channel morphology, minimal water depth and periodic high flows within Chedoke Creek would provide highly variable settling velocities, which would limit the effectiveness of any attempt to effectively cap the existing organic material. In addition, dense material such as sand, would tend to displace the more fluid organic material thereby limiting the effectiveness of this alternative. Therefore, for these reasons, sediment capping is not recommended as the selected remediation alternative.

5.2.4 Chemical Inactivation

Chemical inactivation of sediment is utilized worldwide to reduce the release of phosphorus from sediments to the water column via processes such as diffusion and resuspension. Several methods can be utilized, but the primary chemicals applied are liquid aluminum sulfate (alum) and lanthanum-based clay mixes, such as Phoslock^{TM}. Of the two chemicals, Phoslock^{TM} is the one typically selected for use in Canada due to regulatory agency concerns. Like capping, chemical inactivation is typically utilized in lentic systems with deeper water. This generally prolongs the effectiveness of the binding process and limits the release of sediment derived phosphorus. However, unlike capping, chemical inactivation treatments have a defined capacity to bind phosphorus, regardless of their ultimate disposition. Under dry and low flow conditions, Chedoke Creek could potentially be dammed and treated with Phoslock^{TM} to provide sufficient contact for sediment nutrient inactivation. The prescribed phosphorus reduction would be achieved whether the chemical stays within Chedoke Creek or migrates downstream.

It is important to note that chemical inactivation specifically targets phosphorus, which is a primary nutrient of concern, but would likely result in very little impact (benefit) on nitrogen or other sources of potential waste-derived bacterial and pathogen contamination within Chedoke Creek. In addition, high flow conditions that occur within Chedoke Creek may scour the sediment surface causing the chemical amendment to be transported downstream. This would leave the remaining sediment exposed to the water column where it could continue to cause water quality impairments to Chedoke Creek. Given the flocculent nature of Phoslock^{TM}, it is unlikely that this material would stay in place during high flow. Although chemical inactivation would provide an effective means of overall phosphorus load reduction, it is not recommended as the selected remediation alternative since the intent is to remediate potential impacts from other constituents, in addition to phosphorus. This alternative would not address nitrogen loading or the biological oxygen demand of the organic sediments.

5.2.5 Direct Removal

Physical removal of the organic sediment within Chedoke Creek will directly address the three primary sources of potential impairment including nutrient contamination, bacteriological contamination, and habitat loss. Dredging can be accomplished either through mechanical means or by use of hydraulic dredge equipment. Hydraulic dredging is recommended in Chedoke Creek over mechanical means for several reasons. Mechanical dredging would not be practicable due to the limited width of the creek, the density of riparian vegetation, and lack of continuous access. Hydraulic dredging provides nearly complete containment of the dredge slurry along the pumping route, which reduces exposure of the sediments to the atmosphere that could cause odour or other problems, if the material were to be handled by an excavator. Additionally, the dredge slurry from a hydraulic dredge can be easily routed to the wastewater system for dewatering and ultimate treatment and disposal, thus avoiding potential issues related to dredged material storage, dewatering, and handling operations, which are generally space intensive and costly. Complete removal of this material by hydraulic dredging is recommended as the primary means of remediation. The recommended hydraulic dredge concept plan is further discussed in the following sections.

Table 5-1 Alternatives Assessment Summary

Alternative	Functional Effectiveness	Environmental Effectiveness	Economics	Social Benefits
No Action	Long-term breakdown or burying of organic sediment resulting in downstream transport and dilution	Existing contaminants may be transported downstream to Cootes Paradise and further downstream where they will be diluted but may still support excessive algal growth and other impairments	No capital cost	The City intends to restrict access to Chedoke Creek so there will be no direct social benefits from the no action alternative
Physical Capping	Possibly effective but depends on fluidity of soft sediments. May not remain in place.	Provides a barrier which limits contact with the water column and could provide stable substrate	Relatively expensive because this involves transportation and placement of large quantities of clean fill	The City intends to restrict access to Chedoke Creek so there will be no direct social benefits
Chemical Inactivation	Only effective at reducing phosphorus release	Promotes indirect water quality response as a result of decreased phosphorus load. However, 90% of phosphorus load is no longer in Chedoke Creek	Least expensive option, but does not address anything other than phosphorus load	Potential downstream water quality improvements, benefits to Chedoke Creek during low flow as long as chemical stays in place
Direct Removal	Removes the source of contamination	Restores the original creek bed and removes the contaminated organic layer while reducing the oxygen demand	Moderately expensive but nearby sewer mains create a significant economic advantage for disposal	The City intends to restrict access to Chedoke Creek so there will be no direct social benefits

5.3 Hydraulic Dredging of Targeted Organic Material

As noted, hydraulic dredging provides an efficient means to remove the target sediments down to a specific elevation without the need to disturb areas outside of the necessary dredge footprint. For the Chedoke Creek remediation effort, the dredging template is proposed to extend down approximately 15 to 20 cm below the natural sand or gravel bottom to ensure the targeted sediments are effectively removed. The proposed overdepth dredging (15 – 20 cm) is partially based on dredging industry standards and partially on the reasonable and practical pipeline size of the hydraulic dredge equipment that would likely be deployed in this remediation effort.

As noted, the volume of organic material that is currently considered to be within Chedoke Creek is estimated to be approximately 5,600 m^3 (+/-). It is recommended that an additional roughly 6,400 m^3 (+/-) of natural sand or gravel bottom be removed as sub-excavation to effectively capture migrated constituents. Therefore, the total proposed dredge volume is currently estimated to be 12,000 m^3 (+/-). Additional detailed pre- and post-dredge surveys will be required before project commencement and following project completion.

Given the importance of maintaining workable water depths for sediment removal by dredging, the approximately 1,275 m (+/-) channel will likely be divided into at least three sections or "management units." as shown in Figure 5-4. Management unit sizes and number will vary based on the size of the proposed hydraulic dredging equipment and pumps the selected contractor will mobilize to the site.

The first management unit is proposed to extend north from the outfall/plunge pool roughly 425 m (+/-) to point south of Macklin Street North as it enters Kay Drage Park. The second management unit would extend 320 m (+/-) from the end of the first unit and ends approximately 30 m north of the private road that connects Macklin Street North to Kay Drage Park. The third unit would likely extend north roughly 520 m (+/-) to the junction with Cootes Paradise.

At the northern end of each management section, starting with unit one, the selected contractor would install a cofferdam system. Before dredging, the water level in each management unit would be raised and maintained at an elevation 2 to 3 m above the top of the sediments to allow a hydraulic dredge to be deployed and operated. The majority of the needed additional water would be pumped south from Cootes Paradise, while some portion of that water will come from that discharged through the outfall/plunge pool and precipitation. Care must be taken not to raise the water levels to the point that could cause flooding, disrupt the operation of the outfall/plunge pool, or interfere with the recently installed leachate system outfall that lines a portion of the eastern bank of Chedoke Creek.

5.3.1 Conceptual Dredge Design

The conceptual dredging project is based on the best available information for current conditions as shown in Figure 5-4. Given the potential risks associated with public contact and need for special handling and disposal, standard methodology for upland dewatering and stockpiling of dredged solids (e.g., belt presses) is not recommended. Significant wastewater conveyance infrastructure is located near the project area, which provides a safe, convenient, and economic means of handling the dredge slurry from Chedoke Creek subject to meeting the provisions in the Sewer-Use By-Law.

Areas of approximately 1,000 m^2 or larger with potential hydraulic pipeline access to Chedoke Creek and direct access to a sanitary sewer line or sewer force main, which lay adjacent to Chedoke Creek, were reviewed as possible material handling locations. Only the Kay Drage Park project area met these criteria. Determining the final Kay Drage Park project area, operational creek heights, site layouts, etc. will require agreements with the City of Hamilton and users of the Kay Drage Park, additional data collection, and analysis of the proposed site Kay Drage Park area footprint. Following this site-specific data collection, it will be necessary to perform the necessary engineering design, acquire permits, and develop final tender and construction documents (plans and specifications).

As with most dredge projects, dredged material transportation, dewatering, and final placement of the dredged material are generally the most challenging and costly elements. Wood has identified a potential location for initial material management and dewatering within the Kay Drage Park (see Figure 5-4). The conceptual project details discussed in the following, assume that the Kay Drage Park area is available and suitable for the project needs.

During the dredging operation within each management unit, the hydraulic dredge is proposed to sweep the creek bottom and send a slurry of dredged material and mostly water to the temporary Kay Drage Park work yard area. The inflowing dredged slurry will be fed to a series of mechanical dewatering equipment (filter presses, sand shakers, hydrocyclones, etc.), of the contractor's choosing, to separate debris, gravel, sand, from the incoming slurry. The separated debris, gravel, and sand can then either be stored and used as needed; returned to the creek bottom; or used in future remediation projects within Cootes Paradise and the surrounding area. The remaining effluent, comprised of the targeted sediments and dredged water would then be routed (pumped) to the Woodward Wastewater Treatment Plant for final processing and disposal.

Preliminary calculations based only on the amount and types of sediments to be dredged, indicate that a dredge material management area (DMMA) would cover approximately 3,000 to 6,000 m^2 (+/-) and consist of several small temporary storage areas and a larger open work area. While additional storage area may prove to be beneficial to reduce overall transportation cost, it is not at this point considered necessary

Based on Wood's preliminary review of the upland areas available, the central or northern portions of Kay Drage Park will likely serve as the preferred location for the construction the DMMA within the Kay Drage Park area. Importantly, this location would allow for direct road access, movement of construction equipment, and direct hydraulic pipeline access for the transportation of the dredge slurry and the return of targeted sediments back to the Woodward Wastewater Treatment Plant for final processing and disposal.

5.3.2 DMMA Construction and Operation

As noted earlier, the DMMA will require direct hydraulic pipeline access from Chedoke Creek to the Woodward Wastewater Treatment Plant. The DMMA will require direct road access for the movement of construction equipment. The DMMA will ideally have a total temporary storage capacity of at least 5,000 m^3 (+/-) which would allow continuous dredging seven days a week during daylight hours. The DMMA site could be partially lighted to allow the selected contractor to continuously dewater and decant the dredged material seven days a week, 24 hours a day.

The slurry stream would be directed through the selected contractor's designed series of traditional mechanical dewatering techniques (e.g., hydrocyclones, filter presses) at the DMMA site. The coarse dredged material (gravel, sandy sediments, and debris) needs to be captured by the mechanical dewatering techniques and would be sorted, stacked, and temporarily stored. Afterwards, this coarse dredged material would be transported to the final disposal location (to be determined).

The remaining processed slurry stream would then be directed to the Wastewater Treatment Plant for final treatment and disposal. As the slurry stream leaves the mechanical dewatering area and travels to the Woodward Wastewater Treatment Plant, the selected contractor will have the opportunity to introduce chemical additives (flocculants or coagulants) to the slurry stream. Any flocculants or coagulants will require pre-approval through the permitting process, including the Sewer-Use By-Law. Notwithstanding, introducing chemical additives is not anticipated to be necessary. However, it may be deemed beneficial, following a complete review of the outlined process.

5.3.3 Natural Resources Impact Avoidance and Beneficial Placement

The dredge project should be designed to avoid unnecessary impacts to the existing ecosystem within the subject reach of the Chedoke Creek and downstream. Turbidity control is of primary concern with any dredge project. Hydraulic dredging is generally much less prone to turbidity issues than mechanical dredging because most of the disturbed material is entrained by the suction head. Turbidity will be controlled by the contractor using the cofferdam systems which will be arranged to maximize settling time within the work area prior to releasing discharges downstream.

The dredge and associated equipment will be staged, deployed, and operated in a way that limits disturbance of the riparian habitat. In most cases, it is likely that the dredge and associated equipment will be transferred to Chedoke Creek using a crane. Pipelines will be transported, installed, and fixed in place using a corridor that results in the least ecological disturbance.

Additional impact avoidance measures will be reviewed during the pre-design and detailed design stage. This review will also include an assessment of the pumping and sand removal process that will likely be an integral part of the overall dredge process stream. Ultimate placement of sandy material will be evaluated based on its physical and chemical properties.

Further details related to the preferred dredging process, and associated implementation details and considerations, along with permitting and costing, are outlined in Deliverable 1c.

Notes:

1- Project No.: TPB188127

2- Data Source - City of Hamilton 2017 Imagery, Wood, 2013 ESRI Imagery

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 11/26/2018
Revised:AB
Checked By:LL

Figure 5-1
2013 & 2017 Imagery
Chedoke Creek
Hamilton, Ontario
Canada

Path: V:\TPB188127_Chedoke_Creek\MXD\2017_2013_Imagery_5-1.mxd

Figure 5-1: 2013 and 2017 Imagery Chedoke Creek, Hamilton, Ontario Canada

Figure 5-2: 2013 and 2017 Imagery Chedoke Creek, Hamilton, Ontario Canada

Figure 5-3: 2013 and 2017 Imagery Chedoke Creek, Hamilton, Ontario Canada

Figure 5-4: Project Concept Sketch

6.0 References

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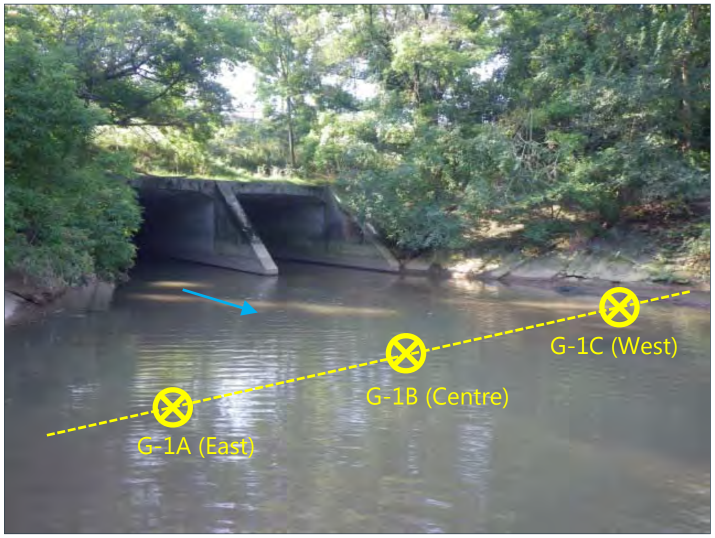
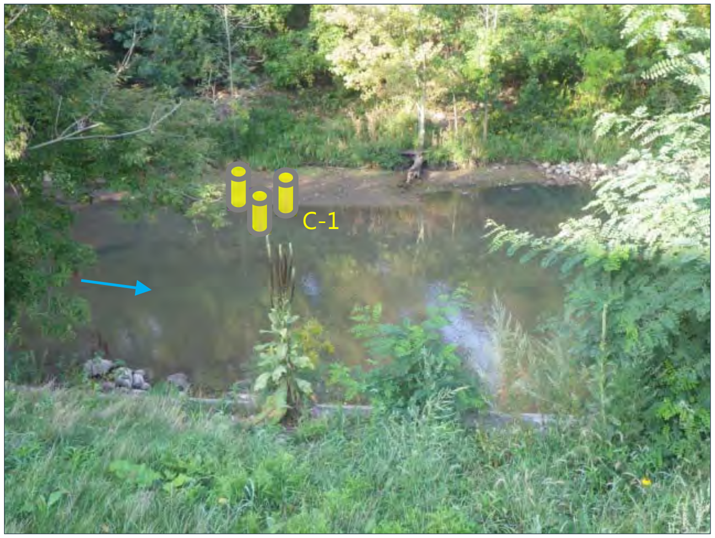
Appendix A

Sample Location Photo Record



Replicate grab locations at transect G-1 downstream of culvert.

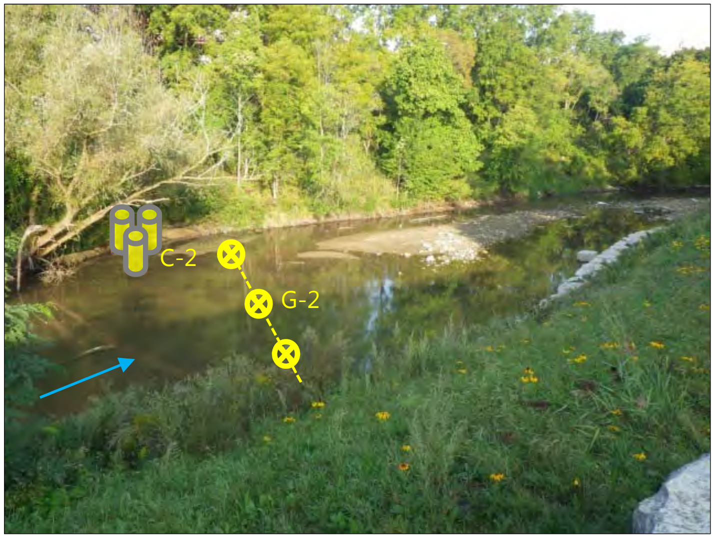


Core sampling location C-1 near west bank on concrete apron.

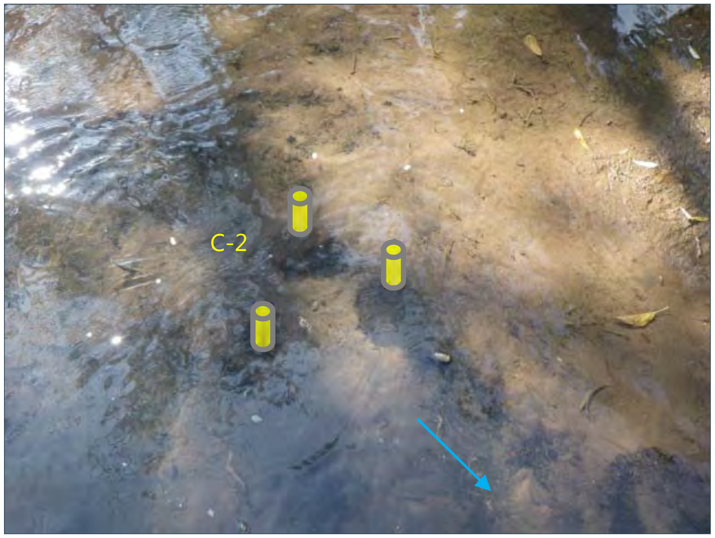
Core sample from C-1.

Sieved benthic invertebrate community grab sample from G-1.

Plate A1-1: Sample Location C1 and Transect G1



Grab sample G-2 transect and core sample C-2 location.



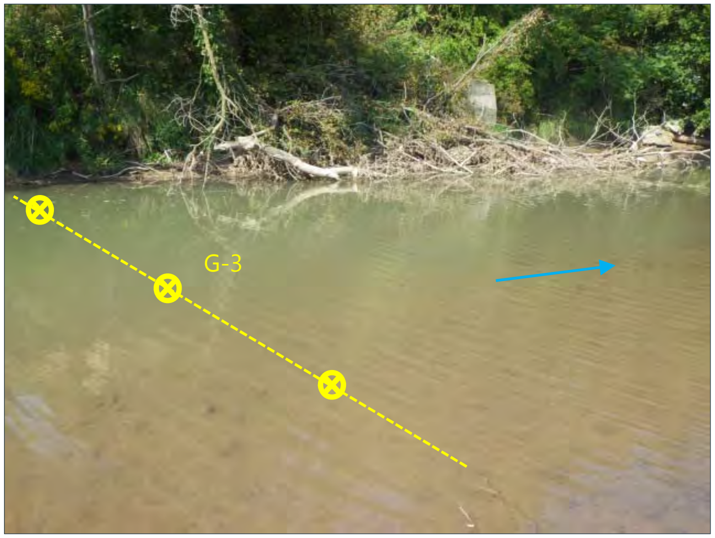
Core sample C-2 location, after cores were obtained.

C-2 core strata prior to homogenizing.

Sieved benthic invertebrate community grab sample from G-2.

Plate A1-2: Sample Location C-2 and Transect G-2

Facing upstream from the G-3 sample transect.



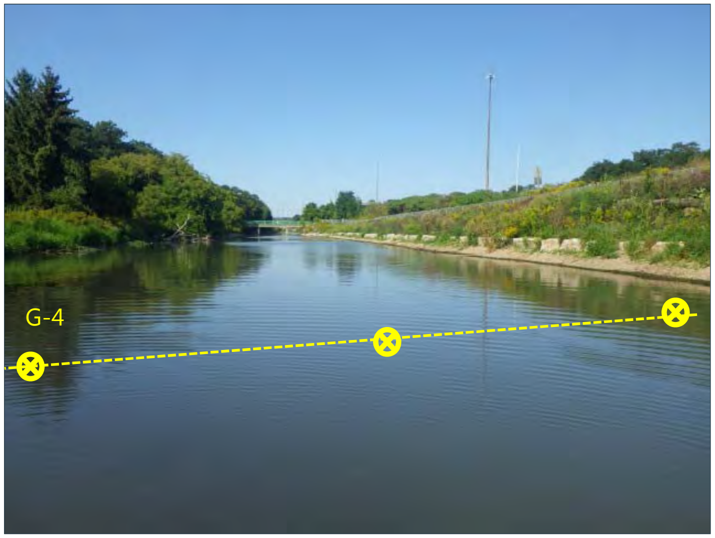
Facing across creek at G-3 sample transect from east bank.

Facing downstream, note silt curtain further downstream.

Sieved benthic invertebrate community grab sample from G-3.

Plate A1-3: Sample Transect G-3

Facing upstream from sample transect G-4, note culvert at left.



Facing downstream from sample transect G-4.

Facing culvert located upstream of sample transect on east bank.

Sieved benthic invertebrate community grab sample from G-4.

Plate A1-4: Sample Transect G-4


Facing upstream from sample transect C-3/G-5.


Facing across creek at sample transect C-3/G-5 from east bank.


Facing downstream from sample transect C-3/G-5.

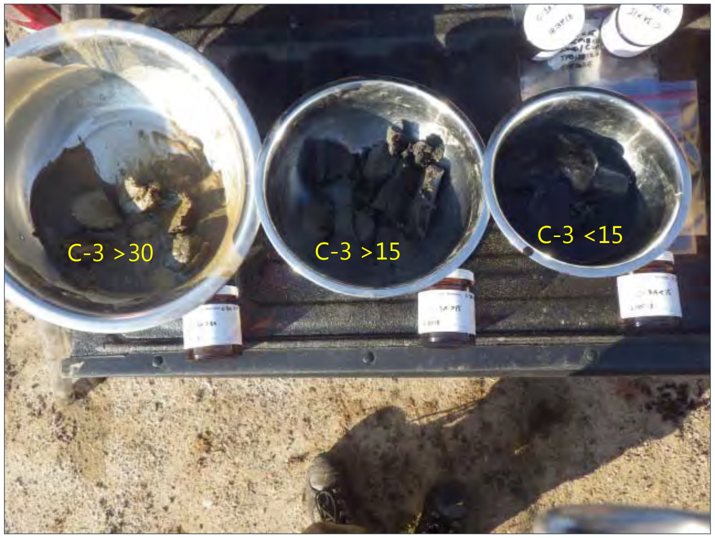

Algae bloom near west bank at sample transect C-3/G-5.

Plate A1-5: Sample Transect C-3/G-5

Facing upstream at sample transect C-3/G-5, note steep bank.

Example of core tubes with sample from C-3.

Benthic invertebrate sample prior to sieving.



C-3 core strata prior to homogenizing.

Plate A1-6: Sample Transect C-3/G-5

Facing upstream at sample transect C-4.

Facing downstream at sample transect C-4.

Facing across creek from west bank at C-4, note culvert.

C-4 core strata prior to homogenizing.

Plate A1-7: Sample Transect C-4

Facing upstream from east bank at C-5/G-6.

Facing across creek from east bank.

Facing downstream from east bank.

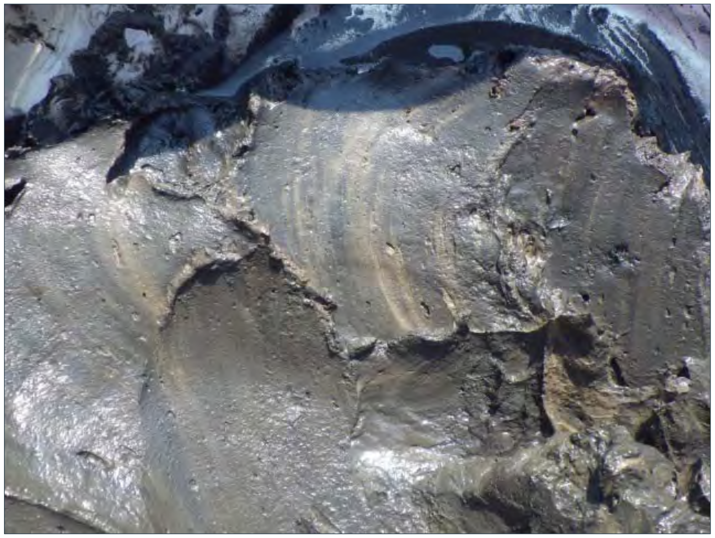
Example of east bank armour stone and willow riparian vegetation.

Plate A1-8: Sample Location C-5/G-6

Homogenized core sample.

Example of a core tube with sample from replicate near west bank.

C-5 core strata prior to homogenizing.



Mottling observed in lower strata during homogenization.

Plate A1-9: Sample Location C-5/G-6


Core tubes at C-6, facing public boat launch at park.

C-6 core strata prior to homogenizing.


Core tubes at C-6, facing outlet of Chedoke Creek.


Sieved benthic invertebrate community grab sample from G-7.

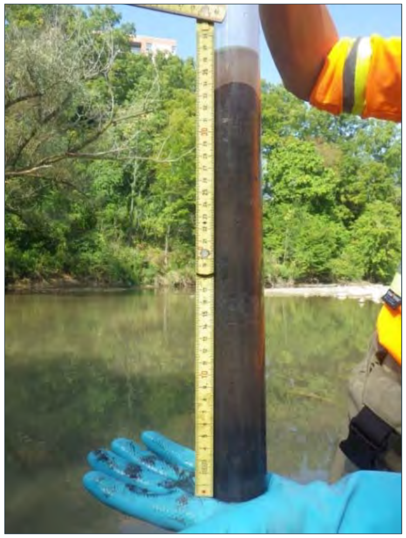
Plate A1-10: Sample Location C-6/G-7

Appendix A2

Core Sample Photo Record

Core tube at C-1, full depth profile.

C-1 core, upper strata.



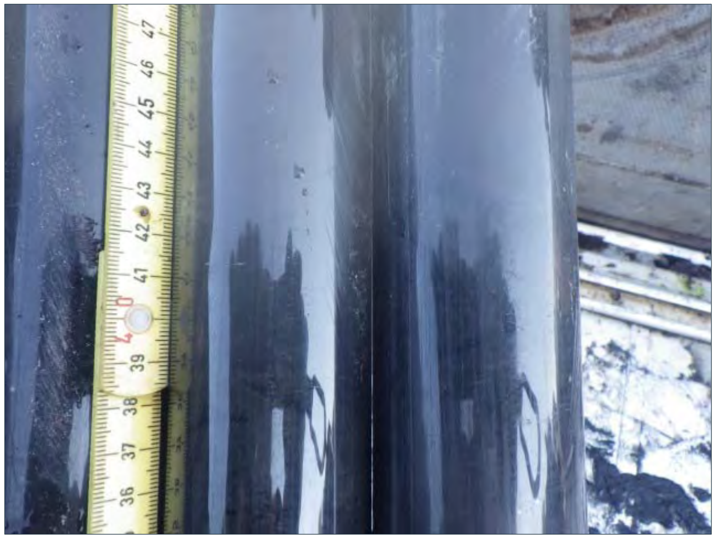
Core tube at C-2, full depth profile.

C-2 core, upper strata.

Plate A2-1: Core Sample Locations C-1 and C-2

Core tubes at C-3 west, full depth profiles.

Core tubes at C-3 centre, full depth profile.



C-3 centre, upper strata.

C-3 centre, lower strata.

Plate A2-2: Core Sample Location C-3

Core tubes at C-4 west, full depth profiles.

Core tube at C-4 centre, full depth profile.

Core C-4 west, upper strata at sediment-water interface.

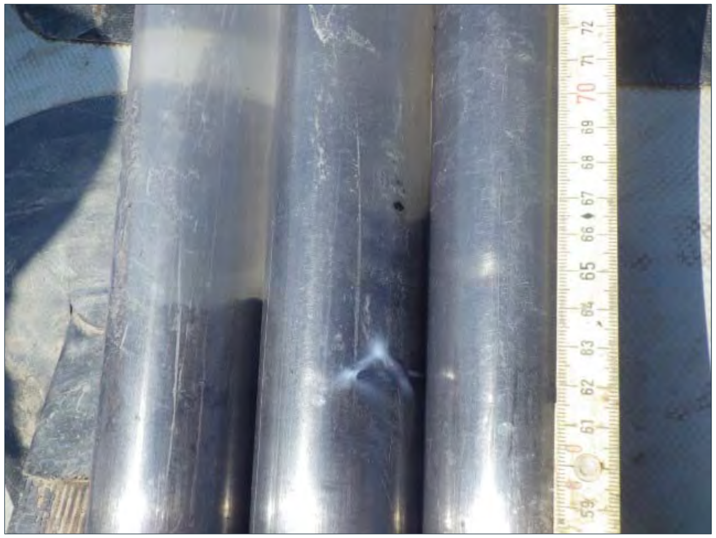
Core C-4 centre, mid-lower strata at horizon.

Plate A2-3: Core Sample Location C-4

Core tube at C-5 west, full depth profile.

Core tubes at C-5 centre, full depth profile.

Core C-5 west, upper strata at sediment-water interface.



Core C-5 centre, upper strata.

Plate A2-4: Core Sample Location C-5

Core tube at C-6, full depth profile.

Core C-6, upper strata.

Plate A2-5: Core Sample Location C-6

Appendix B1

Field Observations and Data Analysis

Table B1-1 Field Sediment Sampling Observations Summary

Sample Transect	Position	UTM Easting	UTM Northing	Water Depth (m)	Sediment Thickness (m)	Field Observations / Comments
G-1	Centre	589751.55	4790591.21	0.25	0.06	Brown sed, coarse sand with gravel base
	East	589754.00	4790592.00	0.29	0.17	Red/brown sed, coarse grained base
	West	589749.04	4790590.31	0.10	0.12	Brown/black sed, metallic odour
C-1	West	589742.86	4790604.74	0.23	0.32	Brown/black sed, metallic odour
G-2	Centre	589743.48	4790624.03	0.26	0.09	Black, gravel with coarse sand and some fines
	East	589751.26	4790620.33	0.35	0.15	Black, gravel with coarse sand and few fines
	West	589733.69	4790628.93	0.04	0.37	Black/brown fines with detritus, metallic odour
C-2	West	589733.69	4790628.93	0.04	0.37	Black/brown fines with detritus, metallic odour
G-3	Centre	589733.63	4790729.78	0.65	0.05	Brown/black, fines
	East	589738.00	4790727.00	0.19	0.04	Brown/black, fines
	West	589729.19	4790732.24	0.90	0.10	Brown/black, fines, metallic odour
G-4	Centre	589801.00	4791008.00	0.43	0.03	Black, fine grained with strong petro odour
	East	589810.26	4791007.84	0.44	0.04	Black, fine grained with strong petro odour
	West	589790.63	4791007.95	0.47	0.13	Black, loosely consolidated, strong petro odour
C-3 / G-5	Centre	589815.41	4791293.16	1.02	0.41	Black muck, fine sand, brown base fine sand
	East	589823.72	4791292.47	0.96	0.30	Black muck, fine sand, brown base fine sand
	West	589807.26	4791293.95	0.45	0.34	Black much, fine black sand/muck base
C-4	Centre	589828.92	4791481.48	1.00	0.58	Black silty sand, mild petro odour
	East	589836.82	4791481.44	1.04	0.35	Black, silty sand, no odour
	West	589820.47	4791481.28	0.83	0.61	Black, silty sand, coarse sand base, petro odour
C-5 / G-6	Centre	589795.41	4791747.73	0.86	0.65	Black, loosely consolidated, strong petro odour
	East	589806.95	4791752.28	0.95	0.44	Black, fine-coarse sand, petro odour
	West	589784.56	4791743.55	0.48	0.70	Black, loosely consolidated, strong petro odour
C-6 / G-7	Bow	589717.75	4791923.38	0.25	0.66	Black, fine silty sand, strong perto odour
	Port	589720.75	4791923.38	0.25	0.59	Black, fine silty sand, strong perto odour
	Starboard	589714.75	4791923.38	0.25	0.65	Black, fine silty sand, strong perto odour

Notes:

1. Grab samples were comprised of the upper 0.10 m of soft sediment and the above table shows total soft sediment thickness at each sample transect and replicate sample position within the creek.
2. Sediment thickness values at grab locations were determined using a manually driven core tube pushed through the soft sediment to a depth of refusal per thickness determination protocols used at the core sample locations.
3. The collocated core and grab samples were collected at the same position within the creek, as such the water depth and soft sediment thickness measured during coring also represented the soft sediment thickness at the grab location.

Table B1-2a Sediment Quality Laboratory Results Summary

Sample Transect			C-1		C-2	
Location			N/A	N/A	N/A	N/A
Nutrients and Bacteria	**O.Reg 153/04 PSQG LEL †**	**PSQG SEL**	C-1<15	C-1>15	C-2<15	C-2>15
Faecal Coliform (cfu/100g)			12000	0	21000	0
NH3+NH4 (as N %)			0	0.02	0.02	0.02
TKN (as N %)	0.055 †	0.48	0.05	**0.06**	**0.1**	**0.08**
Total Phosphorus	600 †	2,000	598	**934**	**837**	**937**
Moisture Content (%)			27.1	37.8	31.1	28
Total Metals by ICPMS						
Antimony (Sb)			0	0	0	0
Arsenic (As)	6 †	33	3.6	4.7	4.6	6
Barium (Ba)			110	120	91	88
Beryllium (Be)			0.43	0.44	0.4	0.38
Boron (B)			17	16	15	13
Cadmium (Cd)	0.6 †	10	0.41	0.4	0.58	**1.1**
Chromium (Cr)	26 †	110	22	24	19	23
Cobalt (Co)	50		9.4	9.3	8.5	8.5
Copper (Cu)	16 †	110	**30**	**71**	**51**	**73**
Lead (Pb)	31 †	250	20	29	**34**	**59**
Molybdenum (Mo)			0.9	1.1	0.9	2.4
Nickel (Ni)	16 †	75	**23**	**23**	**20**	**21**
Selenium (Se)			0	0	0	0
Silver (Ag)	0.5		0.11	0.37	0.19	**1.2**
Thallium (Tl)			0.09	0.13	0.11	0.11
Uranium (U)			0.58	0.64	0.55	0.48
Vanadium (V)			18	19	17	18
Zinc (Zn)	120 †	820	**215**	**250**	**244**	**339**
PAHs						
Acenaphthene			1.49	0	0.26	0.28
Acenaphthylene			0	0	0	0
Anthracene	0.22		**4.69**	0.13	**0.43**	0.21
Benzo(a)anthracene	0.32		**6.6**	**0.85**	**1.79**	**1.27**
Benzo(a)pyrene	0.37		**6.01**	**0.87**	**1.71**	**1.36**
Benzo(b)fluoranthene			8.37	1.37	2.52	2.35
Benzo(ghi)perylene	0.17		**4.36**	**0.56**	**0.99**	**0.72**
Benzo(k)fluoranthene	0.24		**2.29**	**0.47**	**0.99**	**0.77**
Chrysene	0.34		**7.15**	**1.08**	**2.13**	**1.87**
Dibenzo(a,h)anthracene	0.06		**0.79**	**0.12**	**0.22**	**0.18**
Fluoranthene	0.75		**24.5**	**2.6**	**5.25**	**4.85**
Fluorene	0.19		**1.76**	0	**0.29**	**0.29**
Indeno(1,2,3-cd)pyrene	0.2		**3.45**	**0.5**	**0.9**	**0.68**
1-Methylnaphthalene			0	0	0	0.11
2-Methylnaphthalene			0	0	0	0.17
Methylnaphthalene, 2			0	0	0.16	0.28
Naphthalene			0	0	0.22	0.45
Phenanthrene	0.56		**16.5**	**1.2**	**3.63**	**4.39**
Pyrene	0.49		**18.9**	**2.09**	**4.06**	**3.69**

Table B1-2b Sediment Quality Laboratory Results Summary

Sample Transect			C-3					
Location			East			Centre	West	
Nutrients and Bacteria	**O.Reg 153/04 PSQG LEL †**	**PSQG SEL**	C-3A<15	C-3A>15	C-3A>30	C-3B<15	C-3C<15	C-3C>15
Faecal Coliform (cfu/100g)			19000	0	0	43000	45000	9000
NH3+NH4 (as N %)			0	0	0	0	0.04	0.02
TKN (as N %)	0.055 †	0.48	**0.08**	0.03	0	**0.06**	**0.19**	**0.06**
Total Phosphorus	600 †	2,000	**642**	**637**	563	**660**	**1622**	**929**
Moisture Content (%)			34.4	25.7	55.5	23.6	62.9	35.4
Total Metals by ICPMS								
Antimony (Sb)			0	0	0	0	0	0
Arsenic (As)	6 †	33	3.8	3.1	2.7	3.5	4.7	4.2
Barium (Ba)			69	40	34	85	120	80
Beryllium (Be)			0.28	0.24	0.21	0.33	0.44	0.31
Boron (B)			11	5	4	13	15	11
Cadmium (Cd)	0.6 †	10	**0.76**	**3.8**	0.07	0.39	**0.81**	**0.81**
Chromium (Cr)	26 †	110	16	12	7.3	26	**31**	26
Cobalt (Co)	50		6.4	6.2	5.1	7	8.6	6.9
Copper (Cu)	16 †	110	**60**	**29**	**20**	**71**	**170**	**61**
Lead (Pb)	31 †	250	**59**	20	6.1	28	**87**	**100**
Molybdenum (Mo)			0.6	0.3	0.2	0.7	2.4	1
Nickel (Ni)	16 †	75	16	15	10	**17**	**24**	**18**
Selenium (Se)			0	0	0	0	1	0
Silver (Ag)	0.5		0.3	0.46	0	0.37	**1.6**	0.47
Thallium (Tl)			0.12	0.08	0.06	0.11	0.23	0.13
Uranium (U)			0.46	0.43	0.32	0.58	0.88	0.53
Vanadium (V)			13	13	11	13	22	15
Zinc (Zn)	120 †	820	**310**	86	30	**202**	**505**	**305**
PAHs								
Acenaphthene			0	0	0	0.27	0	0.91
Acenaphthylene			0	0	0	0	0	0
Anthracene	0.22		0	0	0	**0.28**	0.12	**1.08**
Benzo(a)anthracene	0.32		**0.38**	0.12	0	**1.1**	**0.79**	**3.54**
Benzo(a)pyrene	0.37		**0.39**	0.12	0	**1.05**	**0.91**	**3.11**
Benzo(b)fluoranthene			0.71	0.21	0	1.64	1.76	4.96
Benzo(ghi)perylene	0.17		**0.23**	0	0	**0.44**	**0.54**	**1.23**
Benzo(k)fluoranthene	0.24		0	0.06	0	**0.63**	**0.52**	**1.48**
Chrysene	0.34		**0.5**	0.11	0	**1.34**	**1.23**	**4.04**
Dibenzo(a,h)anthracene	0.06		0	0	0	**0.12**	**0.13**	**0.35**
Fluoranthene	0.75		**1.1**	0.3	0	**3.7**	**2.56**	**10.3**
Fluorene	0.19		0	0	0	**0.26**	0	**1.04**
Indeno(1,2,3-cd)pyrene	0.2		0.2	0	0	**0.46**	**0.54**	**1.25**
1-Methylnaphthalene			0	0	0	0	0	0.28
2-Methylnaphthalene			0	0	0	0.1	0	0.37
Methylnaphthalene, 2			0	0	0	0.19	0.1	0.66
Naphthalene			0	0	0	0.24	0	1.2
Phenanthrene	0.56		0.39	0.06	0	**3.23**	**1.13**	**10**
Pyrene	0.49		**0.86**	0.25	0	**2.75**	**2.09**	**7.83**

Table B1-2c Sediment Quality Laboratory Results Summary

Sample Transect			**C-4**							
Location			**East**		**Centre**			**West**		
Nutrients and Bacteria	**O.Reg 153/04 PSQG LEL †**	**PSQG SEL**	C-4A <15	C-4A >15	C-4B <15	C-4B >15	C-4B >30	C-4C <15	C-4C >15	C-4C >30
Faecal Coliform (cfu/100g)			10000	0	17000	0	0	11000	0	0
NH3+NH4 (as N %)			0.01	0	0	0.01	0.01	0.03	0.02	0.01
TKN (as N %)	0.055 †	0.48	**0.1**	0.02	**0.06**	**0.07**	**0.06**	**0.16**	**0.09**	**0.08**
Total Phosphorus	600 †	2,000	**861**	**636**	**718**	**1140**	**909**	**1260**	**1090**	**881**
Moisture Content (%)			45.6	20.8	32.5	36	35.8	53.2	33	32.4
Total Metals by ICPMS										
Antimony (Sb)			0	0	0	0.8	1	0	1	0
Arsenic (As)	6 †	33	4.3	1.7	4.1	**6.8**	**7.1**	5.5	5.9	5.4
Barium (Ba)			80	16	70	217	145	141	201	143
Beryllium (Be)			0.35	0.16	0.32	0.52	0.48	0.46	0.39	0.41
Boron (B)			11	4	14	23	21	20	19	20
Cadmium (Cd)	0.6 †	10	**0.74**	0.09	0.56	**22**	**11**	**6.1**	**29**	**14**
Chromium (Cr)	26 †	110	22	6.3	19	**50**	**31**	**41**	**45**	**32**
Cobalt (Co)	50		7	3.5	6.8	14	13	11	13	11
Copper (Cu)	16 †	110	**72**	**18**	**42**	**124**	**85**	**145**	**129**	**86**
Lead (Pb)	31 †	250	**32**	6.2	28	**141**	**94**	**72**	**116**	**89**
Molybdenum (Mo)			1.2	0.1	0.8	1.1	0.9	1.8	1	0.8
Nickel (Ni)	16 †	75	**18**	7.5	**17**	**51**	**37**	**32**	**52**	**35**
Selenium (Se)			0	0	0	0	0	0.8	0	0
Silver (Ag)	0.5		**0.58**	0.06	0.27	**4.4**	**4.3**	**3.3**	**7.7**	**4.5**
Thallium (Tl)			0.16	0.04	0.12	0.15	0.14	0.2	0.11	0.11
Uranium (U)			0.64	0.3	0.48	0.67	0.6	0.76	0.55	0.58
Vanadium (V)			18	11	15	22	22	21	18	19
Zinc (Zn)	120 †	820	**298**	31	**215**	**437**	**300**	**472**	**412**	**275**
PAHs										
Acenaphthene			0	0	0	0.92	0.17	0.25	0.29	0.23
Acenaphthylene			0	0	0	0	0	0.11	0	0
Anthracene	0.22		0	0	0.15	**0.34**	0.21	**0.69**	**0.34**	**0.26**
Benzo(a)anthracene	0.32		**0.44**	0	**0.71**	**0.95**	**0.6**	**1.69**	**1.01**	**0.75**
Benzo(a)pyrene	0.37		**0.48**	0	**0.69**	**0.9**	**0.59**	**1.5**	**0.86**	**0.7**
Benzo(b)fluoranthene			1	0	1.26	1.6	0.96	2.79	1.5	1.18
Benzo(ghi)perylene	0.17		**0.37**	0	**0.41**	**0.51**	**0.37**	**0.77**	**0.44**	**0.41**
Benzo(k)fluoranthene	0.24		0.23	0	**0.3**	**0.5**	**0.31**	**0.7**	**0.47**	**0.32**
Chrysene	0.34		**0.66**	0	**0.89**	**1.23**	**0.7**	**2.01**	**1.02**	**0.88**
Dibenzo(a,h)anthracene	0.06		0	0	0	**0.13**	**0.09**	**0.2**	**0.11**	**0.1**
Fluoranthene	0.75		**1.41**	0	**2.12**	**2.95**	**1.51**	**4.5**	**2.76**	**1.98**
Fluorene	0.19		0	0	0.11	**0.6**	**0.25**	**0.47**	**0.54**	**0.36**
Indeno(1,2,3-cd)pyrene	0.2		**0.27**	0	**0.35**	**0.41**	**0.31**	**0.65**	**0.36**	**0.34**
1-Methylnaphthalene			0	0	0	0.85	0.29	0.15	0.73	0.47
2-Methylnaphthalene			0	0	0	1.07	0.44	0.15	0.84	0.74
Methylnaphthalene, 2			0	0	0	1.92	0.73	0.3	1.57	1.21
Naphthalene			0	0	0	0	0.06	0.14	0.14	0.07
Phenanthrene	0.56		**0.6**	0	**1.16**	**2.92**	**1.31**	**3.32**	**2.9**	**1.95**
Pyrene	0.49		**1.13**	0	**1.62**	**2.31**	**1.24**	**3.48**	**2.24**	**1.64**

Table B1-2d Sediment Quality Laboratory Results Summary

		Sample Transect	C-5							
		Location	**East**		**Centre**			**West**		
Nutrients and Bacteria	**O.Reg 153/04 PSQG LEL †**	**PSQG SEL**	C-5A <15	C-5A >15	C-5B <15	C-5B >15	C-5B >30	C-5C <15	C-5C >15	C-5C >30
Faecal Coliform (cfu/100g)			3000	1000	10000	0	0	0	0	1000
NH3+NH4 (as N %)			0.02	0.01	0	0	0.01	0.02	0.02	0.02
TKN (as N %)	0.055 †	0.48	**0.09**	**0.14**	0.05	0.02	**0.06**	**0.12**	**0.12**	**0.15**
Total Phosphorus	600 †	2,000	**978**	**1021**	**781**	**882**	**995**	**1120**	**1760**	**1820**
Moisture Content (%)			28.7	51.1	25.5	21.3	26.6	16.4	35.3	44.7
Total Metals by ICPMS										
Antimony (Sb)			1.3	1.1	0	0.9	1.3	0	1.9	1.7
Arsenic (As)	6 †	33	**12**	**16**	3.7	4.9	**6.2**	5.7	**9**	**9.1**
Barium (Ba)			210	265	85	143	209	134	398	397
Beryllium (Be)			0.57	0.85	0.36	0.34	0.39	0.45	0.51	0.51
Boron (B)			20	24	15	15	21	21	39	45
Cadmium (Cd)	0.6 †	10	**8.5**	**7.6**	**0.86**	**8.9**	**12**	**3.1**	**49**	**68**
Chromium (Cr)	26 †	110	**37**	**45**	20	**28**	**35**	**32**	**87**	**97**
Cobalt (Co)	50		11	12	7.9	11	15	10	22	21
Copper (Cu)	16 †	110	**136**	**127**	**66**	**82**	**111**	**97**	**265**	**358**
Lead (Pb)	31 †	250	**145**	**181**	**49**	**134**	**140**	**56**	**241**	**228**
Molybdenum (Mo)			2	3.3	0.9	0.6	0.7	1.5	1.3	1.5
Nickel (Ni)	16 †	75	**36**	**37**	**22**	**47**	**55**	**29**	**93**	**89**
Selenium (Se)			1	1.5	0	0	0	0.7	0.7	0.7
Silver (Ag)	0.5		**3**	**2.4**	**0.53**	**2.4**	**3.3**	**1.3**	**17**	**27**
Thallium (Tl)			0.17	0.25	0.13	0.1	0.11	0.2	0.17	0.18
Uranium (U)			0.59	0.81	0.56	0.46	0.51	0.69	0.73	0.78
Vanadium (V)			23	30	15	14	16	22	25	26
Zinc (Zn)	120 †	820	**414**	**546**	**244**	**258**	**364**	**428**	**818**	**922**
PAHs										
Acenaphthene			0	0	0	0.23	0	0	0.18	0.33
Acenaphthylene			0.18	0	0	0	0	0	0	0
Anthracene	0.22		**0.28**	0.14	0	**0.31**	0.13	0	**0.27**	**0.56**
Benzo(a)anthracene	0.32		**1.99**	**0.7**	**0.42**	**0.98**	**0.4**	**0.46**	**0.77**	**1.51**
Benzo(a)pyrene	0.37		**1.69**	**0.76**	**0.39**	**0.92**	0.34	**0.5**	**0.72**	**1.38**
Benzo(b)fluoranthene			2.16	1.04	0.63	1.28	0.54	0.96	1.35	2.37
Benzo(ghi)perylene	0.17		**0.98**	**0.6**	**0.31**	**0.59**	**0.24**	**0.38**	**0.45**	**0.89**
Benzo(k)fluoranthene	0.24		**0.72**	**0.37**	0	**0.45**	0	**0.25**	**0.34**	**0.6**
Chrysene	0.34		**1.76**	**0.72**	**0.47**	**1.06**	**0.42**	**0.68**	**0.96**	**1.75**
Dibenzo(a,h)anthracene	0.06		**0.26**	**0.14**	0	**0.13**	0	0	0	**0.21**
Fluoranthene	0.75		**2.99**	**1.3**	**1.15**	**2.74**	**0.97**	**1.44**	**2.39**	**4.37**
Fluorene	0.19		0.1	0.1	0	**0.27**	0.16	0	**0.44**	**0.67**
Indeno(1,2,3-cd)pyrene	0.2		**0.88**	**0.47**	**0.25**	**0.51**	0.19	**0.27**	**0.35**	**0.71**
1-Methylnaphthalene			0	0	0	0	0.12	0	0.42	0.89
2-Methylnaphthalene			0	0.12	0	0	0	0	0.33	1.05
Methylnaphthalene, 2			0.1	0.18	0	0.12	0.2	0	0.76	1.94
Naphthalene			0.15	0.18	0	0.13	0	0	0	0.17
Phenanthrene	0.56		**0.93**	**0.62**	**0.58**	**2.41**	**0.9**	**0.72**	**2.02**	**3.81**
Pyrene	0.49		**2.94**	**1.24**	**0.92**	**2.22**	**0.75**	**1.16**	**1.89**	**3.4**

Table B1-2e Sediment Quality Laboratory Results Summary

		Sample Transect	**C-6**								
		Location	**East**			**Centre**			**West**		
Nutrients and Bacteria	**O.Reg 153/04 PSQG LEL †**	**PSQG SEL**	C-6A <15	C-6A >15	C-6A >30	C-6B <15	C-6B >15	C-6B >30	C-6C <15	C-6C >15	C-6C >30
Faecal Coliform (cfu/100g)			1000	0	0	2000	0	0	4000	0	0
NH3+NH4 (as N %)			0	0.01	0.02	0	0	0.01	0	0.01	0.02
TKN (as N %)	0.055 †	0.48	**0.09**	**0.07**	**0.1**	**0.09**	0.05	**0.13**	**0.1**	**0.08**	**0.12**
Total Phosphorus	600 †	2,000	**814**	**827**	**1084**	**778**	**768**	**1444**	**809**	**1059**	**1370**
Moisture Content (%)			36.6	26.1	28.4	39.8	26	28.3	36.5	24.4	29.7
Total Metals by ICPMS											
Antimony (Sb)			0	0	0	0	0	1.4	0	0.8	1.5
Arsenic (As)	6 †	33	3.8	3.5	4.4	4.1	3.7	**6.9**	4.3	5.3	**6.6**
Barium (Ba)			82	80	127	88	70	228	85	136	237
Beryllium (Be)			0.36	0.29	0.34	0.36	0.3	0.45	0.37	0.4	0.43
Boron (B)			18	23	32	16	17	40	17	32	40
Cadmium (Cd)	0.6 †	10	**0.88**	**1.2**	**7.6**	**0.9**	**1.6**	**20**	**0.96**	**4.9**	**19**
Chromium (Cr)	26 †	110	23	21	**32**	**29**	18	**52**	23	**33**	**49**
Cobalt (Co)	50		7.5	6.9	9.8	7.7	6.7	15	7.9	11	16
Copper (Cu)	16 †	110	**64**	**65**	**69**	**64**	**76**	**126**	**76**	**81**	**<u>175</u>**
Lead (Pb)	31 †	250	**63**	**67**	**115**	**39**	**80**	**194**	**63**	**138**	**173**
Molybdenum (Mo)			0.9	0.6	0.6	1.1	0.6	1.2	0.9	0.8	0.9
Nickel (Ni)	16 †	75	**19**	**19**	**34**	**23**	**18**	**59**	**20**	**32**	**65**
Selenium (Se)			0	0	0	0	0	0	0	0	0
Silver (Ag)	0.5		0.44	**1.5**	**3.8**	0.46	**0.87**	**8.3**	**0.51**	**3.2**	**6.7**
Thallium (Tl)			0.14	0.1	0.1	0.16	0.1	0.15	0.15	0.12	0.12
Uranium (U)			0.5	0.42	0.46	0.57	0.43	0.58	0.56	0.52	0.53
Vanadium (V)			17	14	15	17	14	20	18	17	18
Zinc (Zn)	120 †	820	**285**	**245**	**324**	**300**	**253**	**540**	**303**	**368**	**489**
PAHs											
Acenaphthene			0	0	0.11	0	0	0.97	0	0.13	0.16
Acenaphthylene			0	0	0	0	0	0	0	0	0
Anthracene	0.22		0.13	0	0.18	0.14	0.14	**1.12**	0.14	0.2	**0.3**
Benzo(a)anthracene	0.32		**0.9**	**0.56**	**0.71**	**0.79**	**0.68**	**2.48**	**0.78**	**0.71**	**0.99**
Benzo(a)pyrene	0.37		**0.96**	**0.56**	**0.62**	**0.84**	**0.62**	**2.09**	**0.83**	**0.64**	**0.89**
Benzo(b)fluoranthene			1.66	0.93	0.98	1.33	1	2.92	1.46	0.96	1.3
Benzo(ghi)perylene	0.17		**0.68**	**0.39**	**0.37**	**0.55**	**0.36**	**1.2**	**0.47**	**0.52**	**0.66**
Benzo(k)fluoranthene	0.24		**0.44**	**0.28**	**0.32**	**0.54**	**0.3**	**1.11**	**0.39**	**0.34**	**0.52**
Chrysene	0.34		**1.26**	**0.71**	**0.77**	**1.06**	**0.76**	**2.51**	**1.05**	**0.8**	**1.1**
Dibenzo(a,h)anthracene	0.06		**0.13**	0	0	**0.11**	0	**0.27**	**0.11**	**0.1**	**0.14**
Fluoranthene	0.75		**2.68**	**1.44**	**1.67**	**2.19**	**1.66**	**6.15**	**2.12**	**1.83**	**2.5**
Fluorene	0.19		0	0	0.17	0	0.11	**1.06**	0	**0.23**	**0.33**
Indeno(1,2,3-cd)pyrene	0.2		**0.58**	**0.33**	**0.32**	**0.44**	**0.31**	**1.04**	**0.44**	**0.4**	**0.49**
1-Methylnaphthalene			0	0	0.11	0	0	0.65	0	0.22	0.27
2-Methylnaphthalene			0	0	0.14	0	0	0.51	0	0.21	0.28
Methylnaphthalene, 2			0	0	0.24	0	0	1.16	0	0.43	0.55
Naphthalene			0	0	0	0	0	0.44	0	0	0.1
Phenanthrene	0.56		**1.5**	0.52	**1.16**	**1**	**0.85**	**6.88**	**0.95**	**1.25**	**1.96**
Pyrene	0.49		**2.27**	**1.25**	**1.51**	**1.84**	**1.4**	**5.35**	**1.84**	**1.53**	**2.09**

Table B1-2f Sediment Quality Laboratory Results Summary

Sample Transect		PSQG SEL	G-1 Comp	G-2 Comp	G-3 Comp	G-4 Comp	G-5 Comp
Nutrients and Bacteria	**O.Reg 153/04 PSQG LEL †**						
Faecal Coliform (cfu/100g)			8000	16000	37000	38000	54000
NH3+NH4 (as N %)			0	0	0	0	0
TKN (as N %)	0.055 †	0.48	**0.09**	0.04	**0.06**	0.04	**0.08**
Total Phosphorus	600 †	2,000	**690**	**628**	**795**	**737**	**756**
Moisture Content (%)			21.8	22.2	25.1	30	40.6
Total Metals by ICPMS							
Antimony (Sb)			0	0	0	0	0
Arsenic (As)	6 †	33	3.8	3	3.9	3.6	3.9
Barium (Ba)			130	80	130	88	77
Beryllium (Be)			0.42	0.41	0.38	0.38	0.37
Boron (B)			17	17	15	14	13
Cadmium (Cd)	0.6 †	10	0.37	0.27	0.56	0.39	0.57
Chromium (Cr)	26 †	110	21	21	20	22	21
Cobalt (Co)	50		9.1	8.2	7.8	7.7	7.2
Copper (Cu)	16 †	110	**63**	**50**	**81**	**58**	**64**
Lead (Pb)	31 †	250	16	13	**50**	22	**42**
Molybdenum (Mo)			1.2	0.8	1.1	0.9	1.1
Nickel (Ni)	16 †	75	**22**	**21**	**21**	**20**	**21**
Selenium (Se)			0	0	0	0	0
Silver (Ag)	0.5		0.13	0.1	0.48	0.31	0.42
Thallium (Tl)			0.11	0.08	0.13	0.13	0.14
Uranium (U)			0.67	0.58	0.66	0.58	0.65
Vanadium (V)			18	16	18	16	17
Zinc (Zn)	120 †	820	**187**	**167**	**311**	**215**	**275**
PAHs							
Acenaphthene			0.83	0	0	0	0
Acenaphthylene			0	0	0	0	0
Anthracene	0.22		**0.99**	0.12	0	0	0.16
Benzo(a)anthracene	0.32		**2.96**	**0.38**	0.18	**0.34**	**0.68**
Benzo(a)pyrene	0.37		**2.4**	0.36	0.18	0.33	**0.68**
Benzo(b)fluoranthene			3.59	0.53	0.32	0.53	1.28
Benzo(ghi)perylene	0.17		**1.45**	**0.22**	0.13	**0.2**	**0.38**
Benzo(k)fluoranthene	0.24		**1.37**	0	0	0	**0.29**
Chrysene	0.34		**3.24**	**0.45**	0.26	**0.42**	**0.84**
Dibenzo(a,h)anthracene	0.06		**0.37**	0	0	0	0
Fluoranthene	0.75		**9.08**	**1.11**	0.59	**0.96**	**1.91**
Fluorene	0.19		**0.84**	0	0	0	0
Indeno(1,2,3-cd)pyrene	0.2		**1.34**	0.19	0.11	0.18	**0.32**
1-Methylnaphthalene			0.2	0	0	0	0
2-Methylnaphthalene			0.3	0	0	0	0
Methylnaphthalene, 2			0.49	0	0	0	0
Naphthalene			0.98	0	0	0	0
Phenanthrene	0.56		**9.53**	**0.73**	0.25	0.45	**0.94**
Pyrene	0.49		**6.75**	**0.85**	0.47	**0.76**	**1.48**

Notes:

1. O.Reg.153/04 – Ontario Regulation 153/04: Records of Site Condition – Part XV.1 of the Environmental Protection Act, Ministry of the Environment, 2011: Table 1 Background Site Condition Sediment Standards.
2. PSQG – Provincial Sediment Quality Guidelines for the protection of fish and sediment-welling organisms Table 1; LEL ꟸ – Lowest Effect Level, SEL – Severe Effect Level (MOE 2008).
3. Bold and shaded cells indicate exceedance of the O.Reg.153/04 / PSQG LEL value
4. Bold, underlined and shaded cells indicate exceedance of the O.Reg.153/04 and PSQG SEL value
5. All parameters measured in µg/g units unless otherwise stated

Table B1-3 Sediment Particle Size Distribution Summary

Particle Size	Grab Sample ID					
	G-1	G-2	G-3	G-4	G-5	G-6
Gravel	52	29	51	10	2	17
Coarse Sand	29	46	35	35	47	32
Fine Sand	7	8	5	26	23	11
Silt	10	12	6	22	20	29
Clay	3	5	2	7	8	12

Notes:

1. Particle size distribution results presented as percent contribution of each particle size fraction.

Table B1-4 qPCR Sediment Results

Sample ID	Human Associated Bacteroidetes			General Bacteroidetes		
	<15	15-30	>30	<15	15-30	>30
C-1	192	356	0	58800	158000	0
C-2	553	32.6	0	28200	480	0
C-3A	44.1	27.8	<5	17500	178	<5
C-3B	172	0	0	24900	0	0
C-3C	3850	800	0	415000	90000	0
C-4A	200	10	0	36800	16.4	0
C-4B	209	74.8	87.8	46700	644	458
C-4C	217	110	108	79800	1560	2130
C-5A	101	166	0	3390	150	0
C-5B	77	34.6	305	34300	200	321
C-5C	85.1	280	211	30200	874	1320
C-6A	22.3	4.1	3.55	7260	212	38.8
C-6B	32.3	<5	12	15200	559	42.3
C-6C	14	<5	26.1	6280	240	134
G-1 Comp	19	N/A	N/A	3300	N/A	N/A
G-2 Comp	87	N/A	N/A	19300	N/A	N/A
G-3 Comp	1120	N/A	N/A	143000	N/A	N/A
G-4 Comp	226	N/A	N/A	49500	N/A	N/A

Notes:

1. Microbial Insights, Knoxville TN conducted the quantitative polymerase chain reaction (qPCR) analysis.
2. qPCR results expressed as the number of gene copies per gram E+04.
3. Incremental strata defined as 0 to 15 cm interval, 15 to 30 cm interval and greater than 30 cm interval.
4. Sample ID position within the creek identified as; A = east bank, B = centre and C = west bank.
5. Analysis for Canada Goose Bacteroidetes (CGBACT-1 and CGBACT-2) results were below the detection limit 1.00E+04 for all samples.

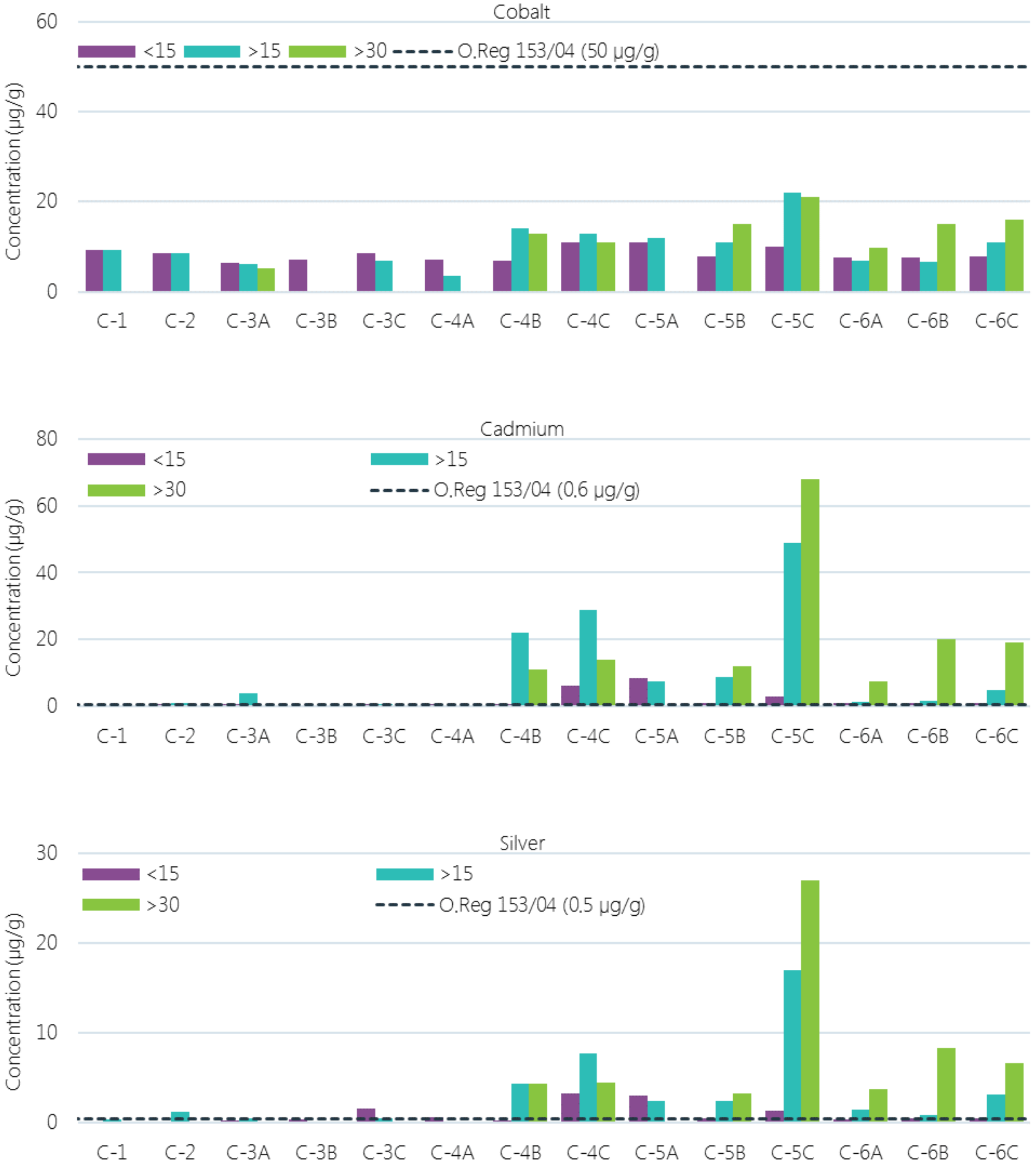
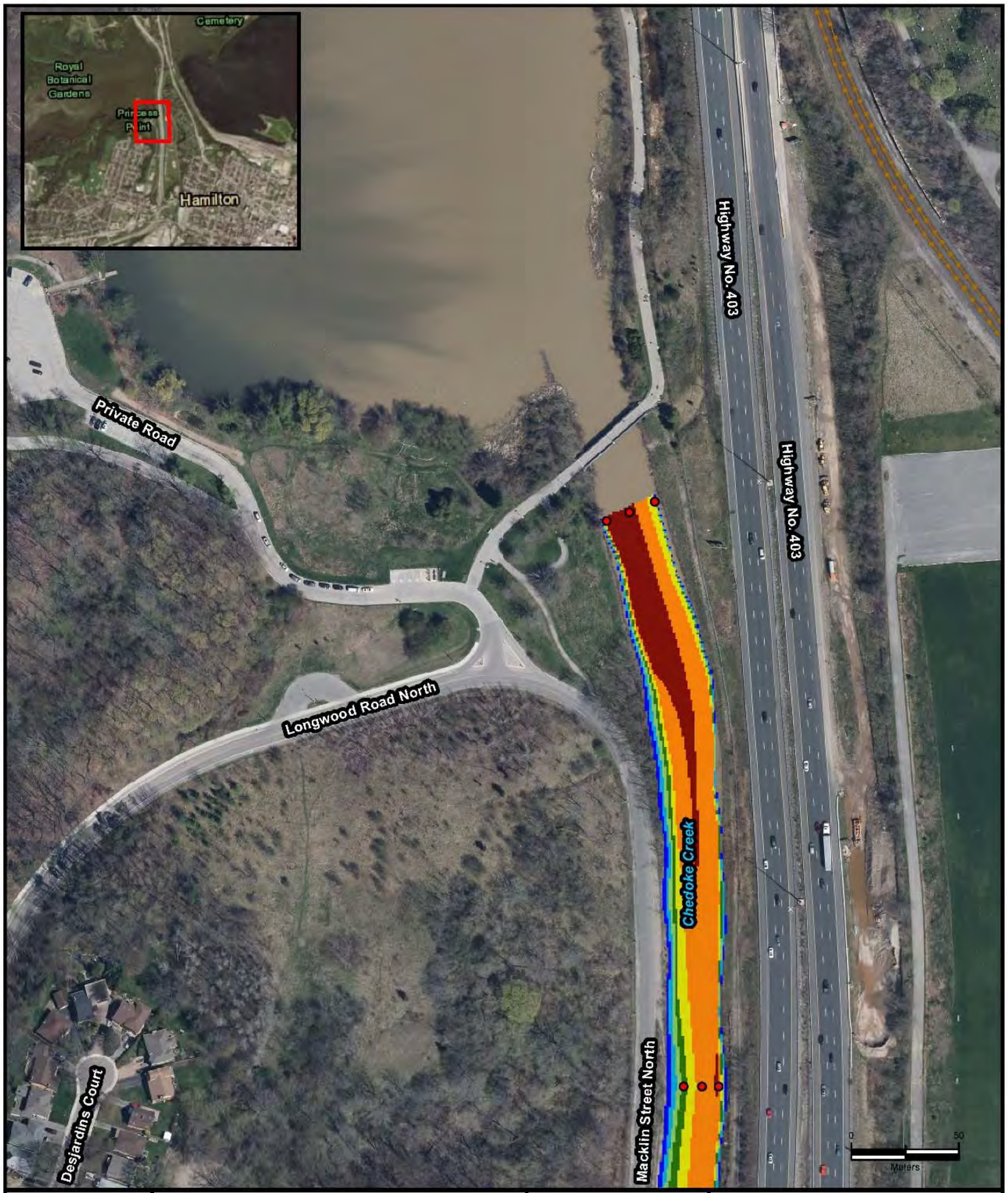


Figure B1-1: Sediment Metal Concentrations – Co, Cd, Ag by Core Sample Location

Figure B1-2: Sediment Metal Concentrations – As, Cr, Ni by Core Sample Location

Appendix B2

Sediment Thickness and Bathymetry Figures



Notes:

1- Project No.: TPB188127

2- Data Source - City of Hamilton 2017 Imagery, Wood, ESRI Imagery

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 11/08/2018
Revised:AB
Checked By:LL

Explanation of Features

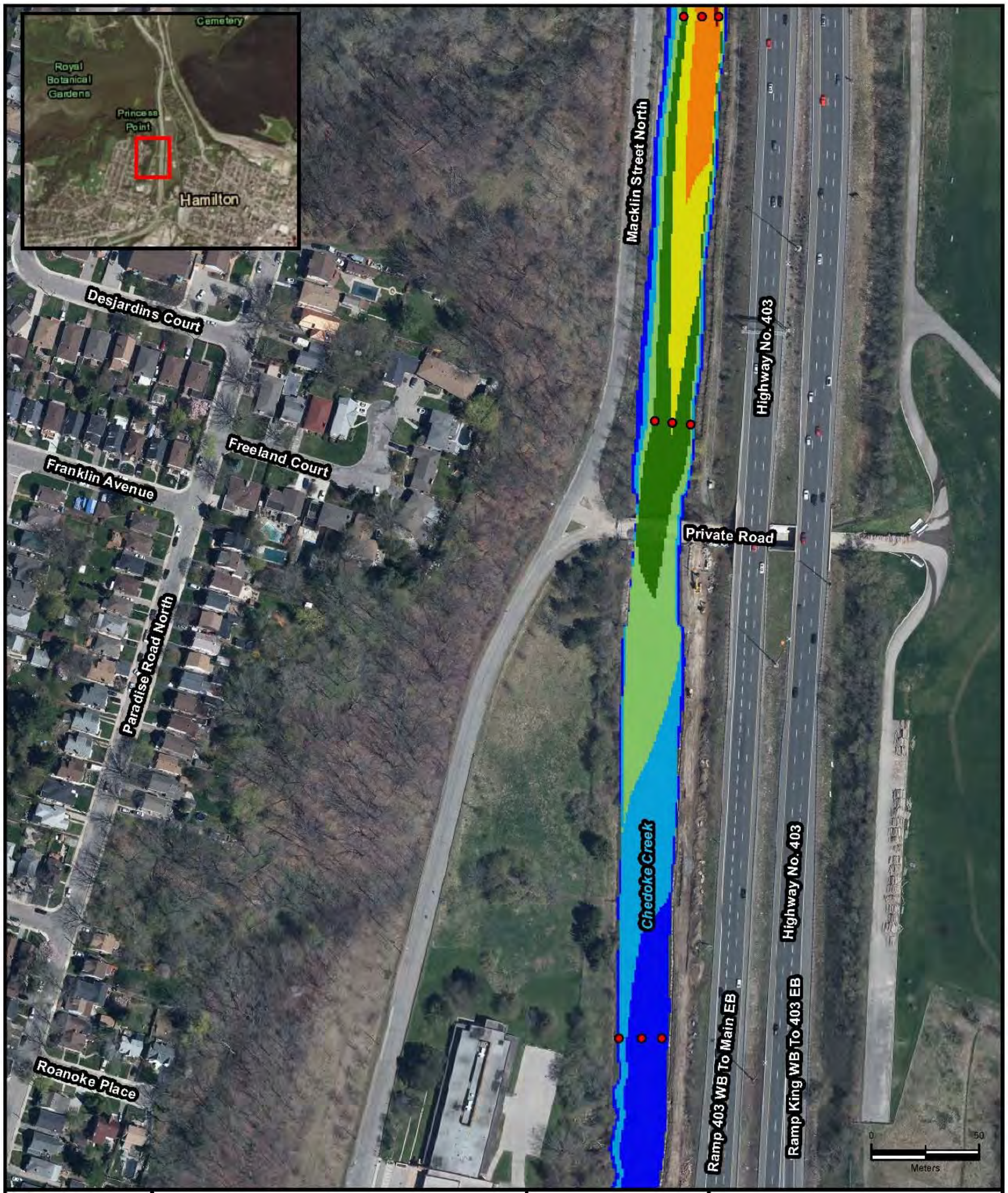
N

Railways	🟩 0.21 - 0.3
● Sediment Survey Points	🟩 0.31 - 0.4
Sediment Thickness (m)	🟨 0.41 - 0.5
🟦 0 - 0.1	🟧 0.51 - 0.6
🟦 0.11 - 0.2	🟥 0.61 - 0.7

wood.

Figure B2-1a
Soft Sediment Thickness
Chedoke Creek
Hamilton, Ontario
Canada

Path: V:\TPB188127_Chedoke_Creek\MXD\2017_Imagery_B2-1A_sediment.mxd



Notes:

1- Project No.: TPB188127

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3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 11/08/2018
Revised:AB
Checked By:LL

N

Explanation of Features

Railways
● Sediment Survey Points

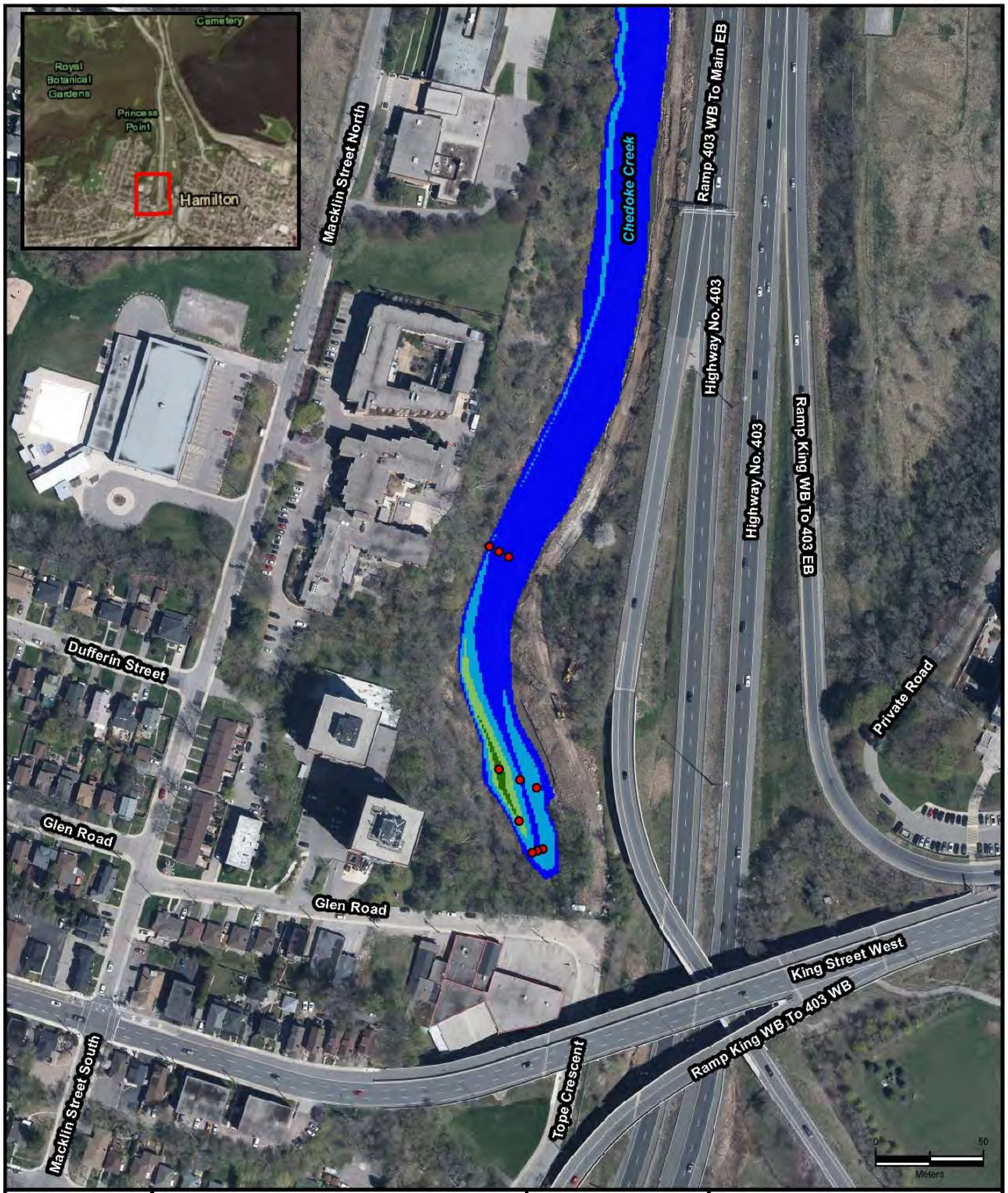
Sediment Thickness (m)

🟦 0 - 0.1
🟦 0.11 - 0.2
🟩 0.21 - 0.3
🟩 0.31 - 0.4
🟨 0.41 - 0.5
🟧 0.51 - 0.6
🟥 0.61 - 0.7

wood.

Figure B2-1b
Soft Sediment Thickness
Chedoke Creek
Hamilton, Ontario
Canada

Path: V:\TPB188127_Chedoke_Creek\MXD\2017_Imagery_B2-1B_sediment.mxd



Notes:

1- Project No.: TPB188127

2- Data Source - City of Hamilton 2017 Imagery, Wood, ESRI Imagery

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 11/08/2018
Revised:AB
Checked By:LL

Explanation of Features

N

- Railways
- ● Sediment Survey Points

Sediment Thickness (m)

- 🟦 0 - 0.1
- 🟦 0.11 - 0.2
- 🟩 0.21 - 0.3
- 🟩 0.31 - 0.4
- 🟨 0.41 - 0.5
- 🟧 0.51 - 0.6
- 🟥 0.61 - 0.7

wood.

Figure B2-1c
Soft Sediment Thickness
Chedoke Creek
Hamilton, Ontario
Canada

Path: V:\TPB188127_Chedoke_Creek\MXD\2017_Imagery_B2-1C_sediment.mxd

Notes:

1- Project No.: TPB188127

2- Data Source - City of Hamilton 2017 Imagery, Wood, ESRI Imagery

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 11/08/2018
Revised:AB
Checked By:LL

Explanation of Features

N

Railways

● Bathymetric Survey Points

DEM (meters)

High : 75.38

Low : 73.72

wood.

Figure B2-2a
Bathymetric Map
Chedoke Creek
Hamilton, Ontario
Canada

Path: V:\TPB188127_Chedoke_Creek\MXD\2017_Imagery_B2-2A_bathy.mxd

Notes:

1- Project No.: TPB188127

2- Data Source - City of Hamilton 2017 Imagery, Wood, ESRI Imagery

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 11/08/2018
Revised:AB
Checked By:LL

Explanation of Features

N

Railways

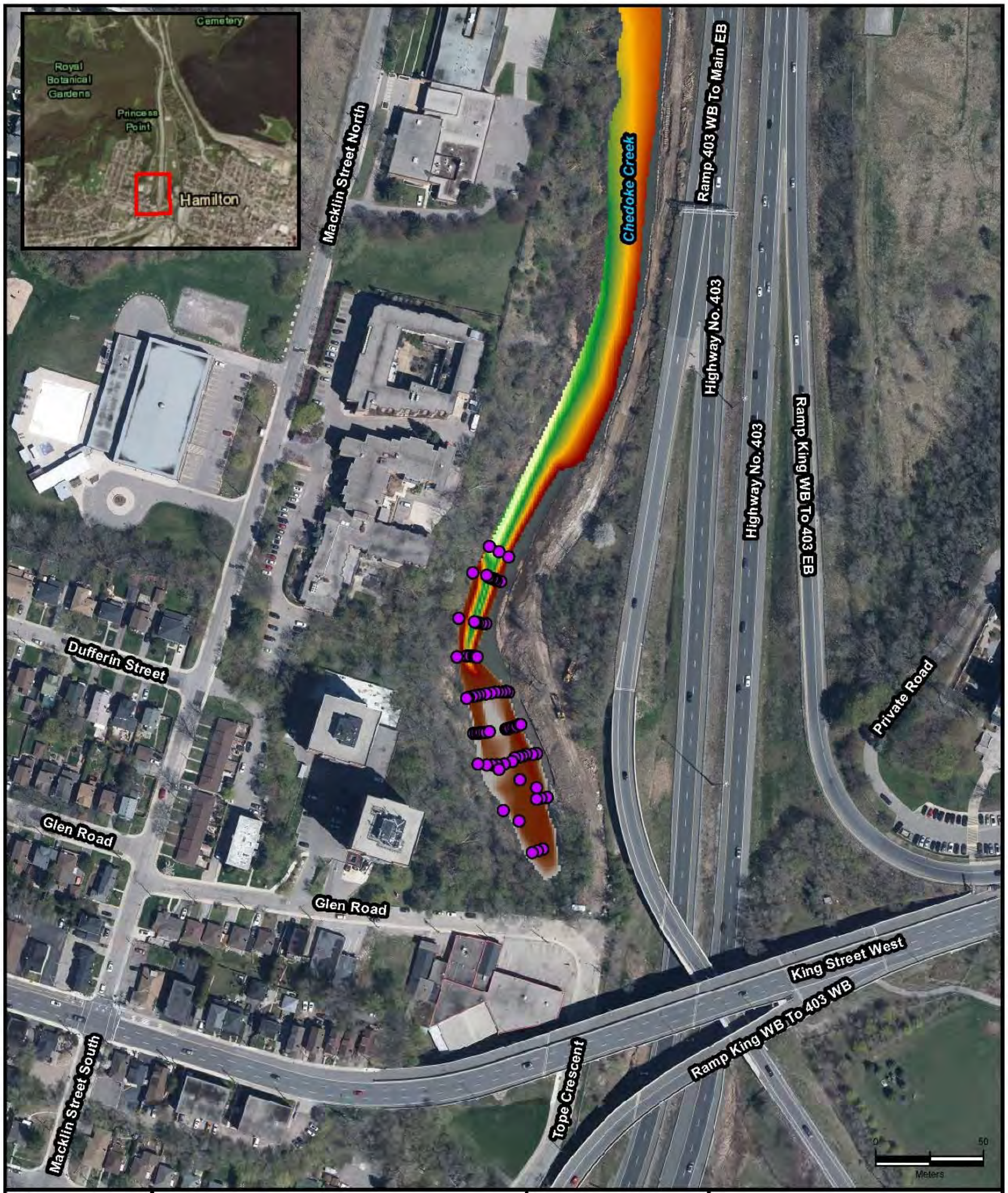
● Bathymetric Survey Points

DEM (meters)
High : 75.38
Low : 73.72

wood.

Figure B2-2b
Bathymetric Map
Chedoke Creek
Hamilton, Ontario
Canada

Path: V:\TPB188127_Chedoke_Creek\MXD\2017_Imagery_B2-2B_bathy.mxd



Notes:

1- Project No.: TPB188127

2- Data Source - City of Hamilton 2017 Imagery, Wood, ESRI Imagery

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 11/06/2018
Revised:AB
Checked By:LL

Explanation of Features

N

- Railways
- ● Bathymetric Survey Points

DEM (meters)
High : 75.38
Low : 73.72

wood.

Figure B2-2c
Bathymetric Map
Chedoke Creek
Hamilton, Ontario
Canada

Path: V:\TPB188127_Chedoke_Creek\MXD\2017_Imagery_B2-2C_bathy.mxd

Appendix C

Natural Environment Data Analysis

Table C-1a Benthic Invertebrate Community Metric Summary

Sample Transect	**G-1**			**G-2**			**G-3**			**G-4**		
Community Metric	**East**	**Centre**	**West**	**East**	**Centre**	**West**	**East**	**Centre**	**West**	**East**	**Centre**	**West**
Taxa Richness	**4**	**3**	**2**	**2**	**4**	**4**	**6**	**2**	**3**	**2**	**3**	**2**
Minimum	2			2			2			2		
Maximum	4			4			6			3		
Mean	3			3			4			2		
Standard Deviation	1.0			1			2			1		
Standard Error	0.6			0.7			1.2			0.3		
TID (individuals/m^2)	**139**	**39**	**424**	**74**	**377**	**2325**	**1255**	**130**	**346**	**446**	**225**	**52**
Minimum	39			74			130			52		
Maximum	424			2325			1255			446		
Mean	201			925			577			241		
Standard Deviation	200			1222			597			197		
Standard Error	115			705			345			114		
Simpsons Diversity	**0.61**	**0.49**	**0.30**	**0.50**	**0.47**	**0.11**	**0.53**	**0.50**	**0.43**	**0.42**	**0.49**	**0.44**
Minimum	0.30			0.11			0.43			0.42		
Maximum	0.61			0.50			0.53			0.49		
Mean	0.47			0.36			0.48			0.45		
Standard Deviation	0.16			0.21			0.05			0.03		
Standard Error	0.09			0.12			0.03			0.02		
Simpsons Evenness	**0.65**	**0.66**	**0.71**	**1.00**	**0.47**	**0.28**	**0.35**	**1.00**	**0.58**	**0.86**	**0.65**	**0.90**
Minimum	0.65			0.28			0.35			0.65		
Maximum	0.71			1.00			1.00			0.90		
Mean	0.67			0.58			0.64			0.80		
Standard Deviation	0.04			0.37			0.33			0.13		
Standard Error	0.02			0.21			0.19			0.08		
Hilsenhoff Biotic Index	**6.58**	**6.00**	**6.00**	**6.00**	**6.03**	**6.00**	**6.05**	**6.00**	**6.00**	**6.00**	**6.00**	**6.00**
Minimum	6.00			6.00			6.00			6.00		
Maximum	6.58			6.03			6.05			6.00		
Mean	6.19			6.01			6.02			6.00		
Standard Deviation	0.34			0.02			0.03			0.00		
Standard Error	0.19			0.01			0.02			0.00		

Table C-1b Benthic Invertebrate Community Metric Summary

Sample Transect	**G-5**			**G-6**			**G-7**		
Community Metric	**East**	**Centre**	**West**	**East**	**Centre**	**West**	**East**	**Centre**	**West**
Taxa Richness	**3**	**2**	**2**	**0**	**3**	**2**	**2**	**2**	**1**
Minimum	2			0			1		
Maximum	3			3			2		
Mean	2			2			2		
Standard Deviation	1			2			1		
Standard Error	0.3			0.9			0.3		
TID (individuals/m^2)	**169**	**143**	**78**	**0**	**61**	**113**	**485**	**195**	**390**
Minimum	78			0			195		
Maximum	169			113			485		
Mean	130			58			356		
Standard Deviation	47			56			148		
Standard Error	27			33			85		
Simpsons Diversity	**0.19**	**0.50**	**0.44**	**1.00**	**0.36**	**0.07**	**0.05**	**0.08**	**0.00**
Minimum	0.19			0.07			0.00		
Maximum	0.50			1.00			0.08		
Mean	0.38			0.48			0.05		
Standard Deviation	0.17			0.47			0.04		
Standard Error	0.10			0.27			0.02		
Simpsons Evenness	**0.41**	**1.00**	**0.90**	**0.00**	**0.52**	**0.54**	**0.53**	**0.55**	**1.00**
Minimum	0.41			0.00			0.53		
Maximum	1.00			0.54			1.00		
Mean	0.77			0.35			0.69		
Standard Deviation	0.31			0.31			0.27		
Standard Error	0.18			0.18			0.15		
Hilsenhoff Biotic Index	**6.00**	**6.00**	**6.00**		**6.00**	**6.00**	**6.00**	**6.00**	**6.00**
Minimum	6.00			6.00			6.00		
Maximum	6.00			6.00			6.00		
Mean	6.00			6.00			6.00		
Standard Deviation	0.00			0.00			0.00		
Standard Error	0.00			0.00			0.00		

Table C-2 Benthic Invertebrate Taxa Proportion Summary

Taxa	G-1	G-2	G-3	G-4	G-5	G-6	G-7
Tubificidae (Oligochaeta)	32.0	59.7	39.6	33.3	29.0	6.0	0.0
Isopoda	9.4	0.4	0.5	0.0	0.0	0.0	0.0
Chironominae	31.2	39.3	58.8	66.0	69.3	58.2	97.6
Orthocladiinae	27.4	0.4	0.9	0.0	0.0	0.0	0.0
Other Taxa	0.0	0.2	0.2	0.6	1.7	2.4	2.4
Ceratopogonidae	0.0	0.0	0.0	0.0	0.0	0.0	2.4
Prodiamesinae	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Tanypodinae	0.0	0.0	0.0	0.0	1.7	0.0	0.0
Sphaeriidae	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Lymnaeidae (Gastropoda)	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Physidae (Gastropoda)	0.0	0.0	0.0	0.6	0.0	0.0	0.0
Nematoda	0.0	0.0	0.1	0.0	0.0	2.4	0.0

Notes:

1. Values expressed as relative percent of total community proportion.
2. Grey shaded taxa are included in the "Other Taxa" relative community proportion values as these taxa contributed less than 5% to the overall community composition.

Table C-3a Fish Community Data Summary

Metric	Year	Sample Transect				Metric	Sample Transect			
		C1	C2	B2	M5		C1	C2	B2	M5
Catch per Unit Area (no. fish /50m)	2001	2.3	0.9	0.5	2.9	**Total Catch (no. of fish)**	115	45	23	145
	2002	3.9	1.1	1.4	4.9		195	53	68	243
	2003	4.8	3.8	0.1	8.7		241	192	5	435
	2004	2.3	1.0	0.1	1.7		117	50	5	84
	2005	2.5	3.1	0.5	6.3		123	157	25	315
	2006	1.2	0.3	0.0	2.8		59	17	0	142
	2007	4.5	2.3	0.0	8.7		225	117	0	437
	2008	3.2	1.9	0.0	3.7		158	94	2	184
	2009	0.4	0.4	0.0	0.7		18	18	0	33
	2010	1.0	4.1	0.0	2.4		52	203	2	119
	2011	4.1	1.2	0.3	8.5		205	59	14	424
	2012	3.3	1.2	0.0	N/A		166	62	0	N/A
	2013	6.1	0.8	0.4	4.8		305	41	20	241
	2014	0.1	1.1	0.0	0.5		6	53	0	26
	2015	4.2	2.6	0.0	1.4		212	129	0	70
	2016	0.6	0.8	0.0	2.0		28	39	1	100
	2017	0.5	0.1	0.0	1.2		27	6	0	62
	2018	2.0	0.2	N/A	0.5		98	8	N/A	24
Richness (no. fish species)	2001	10	7	3	6	**Proportion Stress Tolerant Species (%)**	6	7	91	6
	2002	12	11	9	10		11	15	7	7
	2003	13	12	1	12		18	33	100	15
	2004	11	12	5	11		14	14	20	14
	2005	12	10	5	8		13	20	84	31
	2006	10	7	0	8		25	65	0	42
	2007	11	9	0	10		20	35	0	11
	2008	12	10	2	11		12	5	0	8
	2009	7	7	0	7		22	6	0	12
	2010	7	8	2	7		42	45	50	50
	2011	13	7	3	14		10	25	0	10
	2012	10	5	0	0		13	11	0	N/A
	2013	15	5	6	11		26	17	20	10
	2014	2	5	0	2		83	96	0	19
	2015	8	7	0	9		91	96	0	83
	2016	5	5	1	5		61	28	100	66
	2017	5	3	0	6		89	83	0	16
	2018	8	4	N/A	4		33	75	N/A	58

Table C-3b Fish Community Data Summary

Metric	Year	Sample Transect				Metric	Sample Transect			
		C1	C2	B2	M5		C1	C2	B2	M5
Proportion Stress Intolerant Species (%)	2001	0.0	0.0	0.0	0.0	**Proportion Generalist Species (%)**	1.7	2.2	17.4	3.4
	2002	0.0	0.0	2.9	0.0		7.2	15.1	4.4	5.3
	2003	2.9	0.5	0.0	1.4		19.9	7.8	100.0	31.5
	2004	0.0	4.0	20.0	8.3		4.3	12.0	20.0	7.1
	2005	2.4	0.0	4.0	1.3		3.3	3.2	8.0	31.4
	2006	0.0	0.0	0.0	5.6		5.1	23.5	0.0	37.3
	2007	0.0	1.7	0.0	3.4		8.4	0.9	0.0	4.3
	2008	3.2	5.3	0.0	1.6		3.2	1.1	0.0	3.3
	2009	5.6	0.0	0.0	6.1		0.0	0.0	0.0	12.1
	2010	1.9	0.0	0.0	0.8		28.8	2.0	0.0	1.7
	2011	0.0	0.0	0.0	2.1		15.1	0.0	0.0	7.8
	2012	0.6	0.0	0.0	N/A		3.6	1.6	0.0	N/A
	2013	3.0	0.0	0.0	0.8		13.4	2.4	10.0	7.1
	2014	0.0	0.0	0.0	0.0		83.3	73.6	0.0	19.2
	2015	0.0	0.0	0.0	2.9		86.8	93.0	0.0	71.4
	2016	0.0	0.0	0.0	0.0		60.7	25.6	100.0	60.0
	2017	0.0	0.0	0.0	0.0		55.6	33.3	0.0	3.2
	2018	0.0	0.0	N/A	0.0		19.4	12.5	N/A	54.2
Proportion Piscivore Species (%)	2001	2.6	0.0	0.0	4.1	**Proportion Specialist Species (%)**	95.7	97.8	82.6	92.4
	2002	3.6	5.7	0.0	1.2		89.2	79.2	95.6	93.4
	2003	10.4	0.5	0.0	1.8		69.7	91.7	0.0	66.7
	2004	6.0	0.0	0.0	7.1		89.7	88.0	80.0	85.7
	2005	3.3	1.3	0.0	0.6		93.5	95.5	92.0	67.9
	2006	15.3	0.0	0.0	0.0		79.7	76.5	0.0	62.7
	2007	4.0	6.0	0.0	5.7		87.6	93.2	0.0	89.9
	2008	5.1	3.2	0.0	1.1		91.8	95.7	100.0	95.7
	2009	16.7	11.1	0.0	0.0		83.3	88.9	0.0	87.9
	2010	3.8	10.8	50.0	2.5		67.3	87.2	50.0	95.8
	2011	4.9	25.4	0.0	1.9		80.0	74.6	100.0	90.3
	2012	4.2	8.1	0.0	N/A		92.2	90.3	0.0	N/A
	2013	3.6	7.3	0.0	1.2		83.0	90.2	90.0	91.7
	2014	16.7	20.8	0.0	0.0		0.0	5.7	0.0	80.8
	2015	0.0	0.8	0.0	0.0		13.2	6.2	0.0	28.6
	2016	0.0	2.6	0.0	0.0		39.3	71.8	0.0	40.0
	2017	0.0	16.7	0.0	4.8		44.4	50.0	0.0	91.9
	2018	15.3	62.5	N/A	4.2		65.3	25.0	N/A	41.7

Limitations

Limitations

1. The work performed in the preparation of this report and the conclusions presented are subject to the following:
   a. The Standard Terms and Conditions which form a part of our Professional Services Contract;
   b. The Scope of Services;
   c. Time and Budgetary limitations as described in our Contract; and
   d. The Limitations stated herein.
2. No other warranties or representations, either expressed or implied, are made as to the professional services provided under the terms of our Contract, or the conclusions presented.
3. The conclusions presented in this report were based, in part, on visual observations of the Site and attendant structures. Our conclusions cannot and are not extended to include those portions of the Site or structures, which are not reasonably available, in Wood's opinion, for direct observation.
4. The environmental conditions at the Site were assessed, within the limitations set out above, having due regard for applicable environmental regulations as of the date of the inspection. A review of compliance by past owners or occupants of the Site with any applicable local, provincial or federal bylaws, orders-in-council, legislative enactments and regulations was not performed.
5. The Site history research included obtaining information from third parties and employees or agents of the owner. No attempt has been made to verify the accuracy of any information provided, unless specifically noted in our report.
6. Where testing was performed, it was carried out in accordance with the terms of our contract providing for testing. Other substances, or different quantities of substances testing for, may be present on-site and may be revealed by different or other testing not provided for in our contract.
7. Because of the limitations referred to above, different environmental conditions from those stated in our report may exist. Should such different conditions be encountered, Wood must be notified in order that it may determine if modifications to the conclusions in the report are necessary.
8. The utilization of Wood's services during the implementation of any remedial measures will allow Wood to observe compliance with the conclusions and recommendations contained in the report. Wood's involvement will also allow for changes to be made as necessary to suit field conditions as they are encountered.
9. This report is for the sole use of the party to whom it is addressed unless expressly stated otherwise in the report or contract. Any use which any third party makes of the report, in whole or the part, or any reliance thereon or decisions made based on any information or conclusions in the report is the sole responsibility of such third party. Wood accepts no responsibility whatsoever for damages or loss of any nature or kind suffered by any such third party as a result of actions taken or not taken or decisions made in reliance on the report or anything set out therein.
10. This report is not to be given over to any third party for any purpose whatsoever without the written permission of Wood. Wood acknowledges that the City is bound by the *Municipal Freedom of Information and Protection of Privacy Act* (Ontario), as amended, and that the information provided to the Municipality in connection with this Agreement may be subject to disclosure in accordance with the provisions of that Act.
11. Provided that the report is still reliable, and less than 12 months old, Wood will issue a third-party reliance letter to parties that the client identifies in writing, upon payment of the then current fee for such letters. All third parties relying on Wood's report, by such reliance agree to be bound by our proposal and Wood's standard reliance letter. Wood's standard reliance letter indicates that in no event shall Wood be liable for any damages, howsoever arising, relating to third-party reliance on Wood's report. No reliance by any party is permitted without such agreement.

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