Carruthers Creek Watershed Plan: Surface Water Quality Characterization

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This study was funded by the Region of Durham

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Foreword

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

This four year study will build upon the goals, objectives, and management recommendations established in the 2003 Watershed Plan for Duffins Creek and Carruthers Creek, thereby ensuring a continuum of management efforts to achieve the desired ecological and sustainability objectives for the watershed.

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

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1. Introduction

1.1 Carruthers Creek Watershed Plan Study Area

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

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

Carruthers Creek's headwaters form to the south of the Oak Ridges Moraine in the City of Pickering. Both the east and west branches of the creek originate north of Concession 8; the confluence is immediately north of Taunton Road and the creek enters Lake Ontario in the Town of Ajax. Carruthers Creek contains a total of 61 kilometres of stream channels. Historically, portions of the watershed would have supported cold water fish populations including Brook trout, Atlantic salmon, Slimy sculpin, and Mottled sculpin. Instream barriers to fish movement in the watershed adversely impact the aquatic system by limiting access to feeding and spawning areas, increasing water temperature, and affecting sediment transport. In addition, some instream structures increase water velocities to the point where fish passage is prevented. Instream structures that act as barriers to fish passage include dams, weirs, road and rail crossings, and some culverts.

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

Environmentally Significant Areas: the coastal Carruthers Marsh and the Carruthers Creek Forest, a few hundred metres inland.

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

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

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

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

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

This report has been prepared as part of the scoping and characterization phase of the watershed planning process, in which current watershed conditions are presented in the form of technical reports covering a range of subject areas, including groundwater quality and quantity, headwater drainage features, surface water quantity and quality, fluvial geomorphology, aquatic systems, terrestrial systems.

The purpose of this document is to report on current and past water quality conditions to:
1. Create benchmark water quality conditions,
2. Determine variability between sites, and
3. Identify some of the factors influencing water quality in Carruthers Creek.

1.2 Surface Water Quality Characterization

1.2.1 Flow conditions

Stream flow is one of the main drivers in aquatic systems. Natural flow can be dynamic, fluctuating with changes in seasons and environmental conditions such as precipitation. Highest flows are often associated with snow melt and rain events, while dry periods in summer (or during winter freeze up) can be more indicative of groundwater baseflow influences. The water quality monitoring work will characterize both baseflow and storm flow water quality in the Carruthers Creek watershed.

TRCA collects water quality data at one site near the mouth of Carruthers Creek as part of the Regional Watershed Monitoring Program (RWMP). Samples are collected once a month and often reflect low flow conditions. Runoff can impact water quality, therefore it is necessary to understand both storm flow and baseflow water quality conditions with respect to aquatic biota and loadings to Lake Ontario.

Low flow conditions are observed during dry weather; at this time, flow in the creek is assumed to be comprised mainly of groundwater inputs (TRCA, 2003) and the creek water quality likely reflects that of the source aquifer. Nutrients, bacteria, and other contaminants generally enter the creek during dry weather flows from chemical and physical resuspension of stream bed and bank sediments that were deposited during previous wet weather events.

Over time, natural features (e.g., forests and wetlands) have been converted to agricultural and urban land use in Carruthers Creek watershed. The natural features that once helped to regulate flows and filter nutrients/contaminants during storm events have been reduced, resulting in flows which are more “flashy”, and in water quality that reflects the flashy nature of the creek. Baseflow/low flow variability will be measured and augmented with wet flow events to determine the variability in sample concentrations and resulting median values which take into account the nutrients pulsed from the watershed.

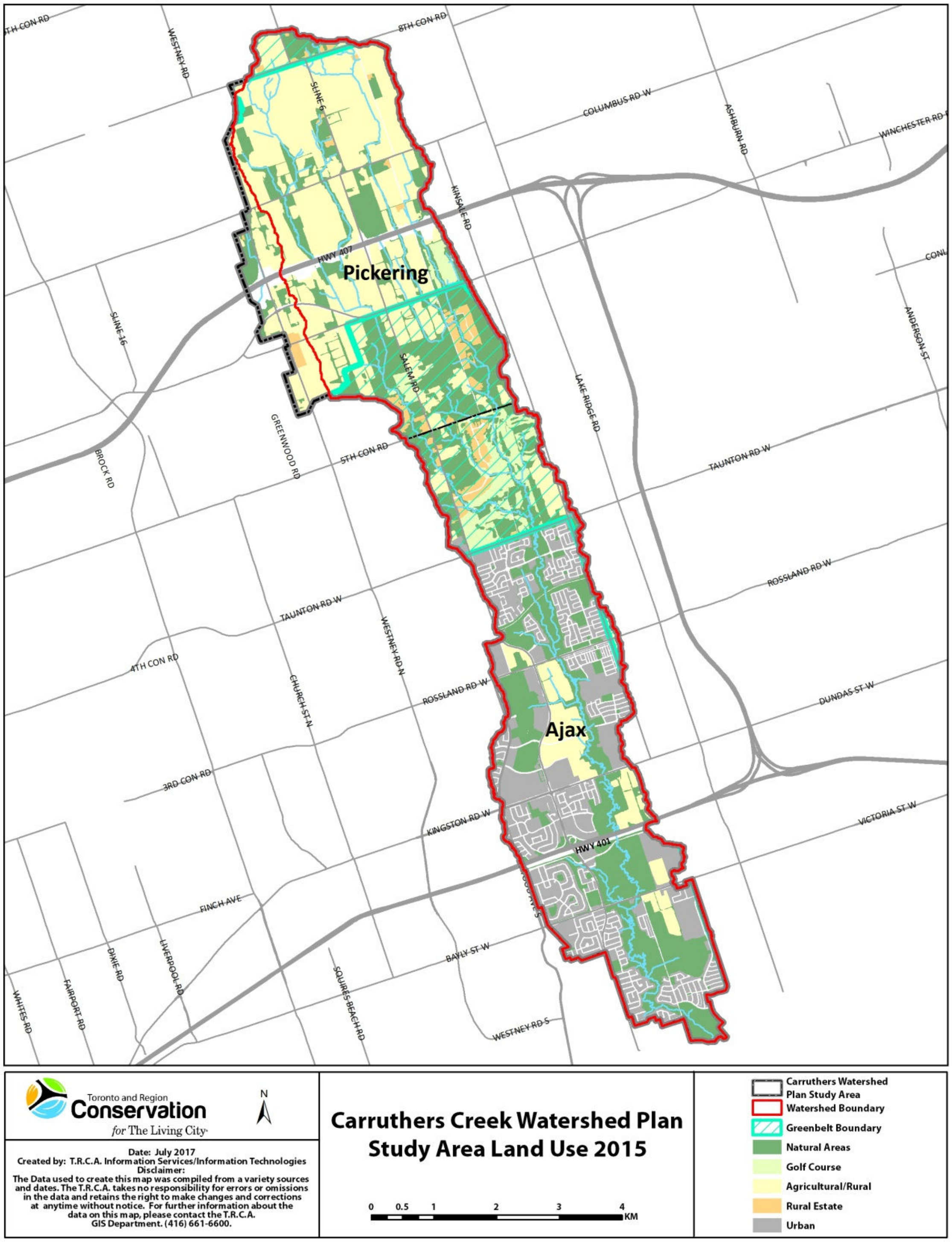

Figure 1: Carruthers Creek Watershed Plan Study Area as of 2015.

1.2.2 Land use

The headwaters of Carruthers Creek are largely rural containing a combination of natural and agricultural land. Soils here are predominantly fine-grained silt and clay, which can promote less infiltration, resulting in higher overland runoff, and increased opportunities to carry nutrients/pollutants directly to the creek (TRCA, 2002). Potential influences to surface water quality in Carruthers Creek include two golf courses, large scale nursery operations, in addition to livestock, equine, and cash crop operations. Commercial fill operations located between Highway 7 and 5th Concession on the west branch of Carruthers Creek, as well as residential subdivision development south of Highway 7 on both the west and east branches may also be factors.

The east branch of Carruthers Creek contains the variety of land uses and potential influences to the creek mentioned above, and also contains a large lot residential subdivision served by septic systems. Septic systems have the potential to leak nutrients/pollutants into the creek if not properly situated and maintained.

Widespread construction of the Highway 407 expansion eastward over Carruthers Creek to Highway 412 occurred in both 2015 and 2016. In contrast to Highway 7, which also crosses Carruthers Creek, runoff from Highway 407 is treated with stormwater ponds. The newly expanded Highway 407 was opened to traffic in June 2016, shortly after the water quality sampling was completed for this report, therefore results in this report thus include the construction period.

Downstream, between Taunton Road and Lake Ontario, the watershed has experienced intense urban development resulting in increased soil compaction and paved ground, which create impervious surfaces. These characteristics can facilitate greater stormwater runoff to the creek thereby increasing discharge, bed scouring, and incision of the banks in the creek increasing suspended solids and particle-bound and dissolved nutrients to the creek. Stormwater itself can also carry a number of pollutants and nutrients to the creek including suspended solids, phosphorus, chlorides, and *E. coli*.

Since 2002, TRCA has monitored surface water quality across its watersheds through the Regional Watershed Monitoring Program. Water quality samples are collected monthly at sites unique to TRCA properties, as well as some sites that have been adopted from Ontario's Provincial Water Quality Monitoring Network (PWQMN). The water quality grab samples are analysed for a standard suite of water quality parameters, including heavy metals, nutrients and bacteria, to help understand the impacts of land use on the water quality of the local streams and watercourses that ultimately flow into Lake Ontario.

One of the RWMP sampling sites is in the lower reaches of Carruthers watershed (Figure 2), in a predominantly urban area (Station 107002). For the purpose of this characterization, two additional water quality stations, in the headwaters of Carruthers north (CC011) and south (CC005) of the Lake

Iroquois shoreline, were examined. These sampling locations represent rural lands with predominantly natural and agricultural influences. The water quality sampling locations at Squires Road (CC005) and the one near the mouth of the creek (107002) represent conditions upstream and downstream of urban influences.

This report also contains and considers supporting and pre-existing data. Precipitation and flow data provide information on the environmental conditions used to delineate between wet and dry weather flows. In addition, approximately 2.5 km south of the RWMP site, closer to Lake Ontario, there is an historical PWQMN station where data were collected between 1964 and 1993 (Station 107001); this station was discontinued in 1993. Currently, there is no PWQMN station in the Carruthers Creek watershed. These data are the only historical data available for the watershed, and will be used as a basis for comparison to historical watershed conditions.

1.2.3 Water Quality Indicators of Interest

A number of selected key water quality parameters are the focus for this report. These parameters include: phosphorus, nitrogen compounds, suspended solids, chlorides, *E. coli*, and dissolved oxygen. There will also be some information presented on metals.

Phosphorus is considered a limiting nutrient that can potentially influence eutrophication, and is required for plant and algae growth, which can reduce water clarity and oxygen concentrations. Sources of phosphorus can include fertilisers in both agricultural and urban settings, and erosion from construction sites, streams banks, and agricultural fields. The interim in stream phosphorus Provincial Water Quality Objective (PWQO) for the protection of aquatic life is 0.03 mg/L.

Nitrogen has similar sources and effects as phosphorus, however, ammonia and nitrate (forms of nitrogen) can be potentially toxic in aquatic systems. These nitrogen species are often formed during the nitrification of ammonia to nitrate. Although there is not a PQWO for nitrate, high levels are thought to stress aquatic life (e.g., 1-10 mg/L) and the Canadian Water Quality Guideline for short term and long term exposure are 124 mg NO3-N /L and 3.0 mg NO3-N /L, respectively. Unionized ammonia (all forms of ammonia with the exception of NH_4^+) has a PWQO of 0.02 mg/L for the protection of aquatic life; this species can have acute, chronic, and sub-lethal to lethal effects in fish.

Suspended sediments influence nutrient and particulate bound contaminant transport, water clarity, and aesthetics. Many nutrients and contaminants can bind with sediment particles, increasing their mobility and transport. Suspended sediments have the ability to affect aquatic life by impairing fish spawning areas and habitats, in addition to abrading fish gills. Sources of suspended solids can include erosion from agricultural areas, stream banks and beds, and construction sites. Additional urban suspended solids source may include, but are not limited to, roadside “grit”, soil, tire particles, and other debris. There is no PWQO for suspended solids, but there is a Canadian Water Quality Guideline (CWQG) which recommends that to protect aquatic life, suspended solid concentrations should not exceed natural background levels by more than 25 mg/L.

Chloride can be released by natural weathering, however, it is also linked to activities associated with human presence such as sewage discharge (e.g., leaking septic systems), industrial discharge, and road salt. The CWQG suggests that aquatic life may become impaired at chronic long-term exposure levels of 120 mg/L, and acute, short-term exposure levels of 640 mg/L.

Escherichia coli (*E. coli*) is a bacteria indicative of faecal matter from either animal or human origin. Stormwater runoff often transports *E. coli* from pet and wildlife faeces (and bacteria potentially bound to suspended sediment) into watercourses. The PWQO limits *E. coli* concentrations to 100 counts per 100 mL, however, this is based on recreational use and a geometric mean of at least 5 samples. *E. coli* concentrations in this characterization report will be used to examine overall aquatic health, and as an indicator of potential bacterial inputs into the watershed and not as an indicator of recreational use.

Dissolved oxygen is vital for aquatic life. Low concentrations of dissolved oxygen create uninhabitable conditions and cause stress responses in aquatic organisms. The PWQO for dissolved oxygen ranges from 5.0 to 6.0 mg/L for cold water biota (life stage dependent), however, the PWQO for warm water species (4.0 mg/L) has been used in this report for comparison since it is lower.

Trace metals such as copper and zinc can be present in natural soils, however, urban sources can also cause an enrichment in concentration. Copper can be found in a number of items such as water pipes, electronics, metal alloys, wiring, but it is also present in many insecticides and fungicides (Boyd et al., 2001). Similarly, zinc can be found in galvanized and plated metals, dyes, paints, and is even released as car tires ware (Boyd et al., 2001; Bradl, 2005). Both metals can be released as combustion products associated with automobiles. Copper and Zinc have PWQOs of 0.005 mg/L and 0.02 mg/L, respectively.

Figure 2. Study area for Carruthers Creek watershed plan with sampling locations (CC011, CC005, 107002), and local precipitation (HY015) and stream (Hy089, HY090, and HY013) gauges.

2. Methods

2.1 2015/2016 Dataset

Stream water quality samples were collected approximately monthly from June 2015 to May 2016 at all sites. The sample stations included the RWMP site (107002) which is routinely collected by TRCA, as well as samples at sites CC005 and CC011 which were collected specifically for this watershed plan. A monthly sample was collected at each site, plus an additional five (5) samples which targeted wet weather flow, for a total of 17 samples per site. Samples were available outside of June 2015 to May 2016 at CC005 and 107002. Table 1 outlines the time periods in which data are available at each station. Parameters measured at CC011, CC005, and 107002 can be found in Appendix A.

Table 1. Available data from surface water grab samples in Carruthers Creek watershed.

Station	Location	Years
CC011 (new station)	Rural headwater	June 2015 - May 2016
CC005 (new station)	Above urban center	June 2016 – December 2016
107002 (RWMP station)	Below urban center	2009 – 2016 (monthly)
107001 (retired PWQMN station)	Near Carruthers Creek mouth	1963 - 1993

2.1.1 Field Collection

Grab samples were collected according to the Ontario Ministry of the Environment and Climate Change (OMOECC) Provincial Water Quality Monitoring Network (PWQMN) sampling protocol (OMOE 2003). Samples were collected on predetermined dates, independent of weather conditions (i.e., rain or shine), stored in a cooler with ice, and delivered to a laboratory for analysis usually within 24 hours of sampling. All samples collected at CC005 and CC011 were analysed at the York-Durham Regional Environmental Laboratory (YD-REL) between June 2015 and December 2016. Samples from 107002 were analyzed at YD-REL between June 2015 and May 2016, and at the City of Toronto from June 2016 – December 2016 with the exception of phosphate which remained at YD-REL. Samples were analysed for a standard set of water quality indicators (Appendix A). If sample results were not detectable, the method detection limit was substituted as the result. Measurements of water temperature, conductivity, dissolved oxygen and pH were taken in the field using a handheld water quality probe (e.g., YSI Pro Dss Multiparameter Water Quality Meter).

2.1.2 Precipitation, Discharge, and Water Temperature

Precipitation data from TRCA's RWMP rain gauge HY015 in Claremont were used to approximate if the grab samples were collected during low flow (i.e., limited stormwater runoff) or during a high flow event when there was a significant amount of stormwater runoff comprising the sample. During the winter months, precipitation data for Environment Canada's gauge at the Courtice Water Pollution Control Plant in Oshawa ("Oshawa WWCP" station 6155878) was used instead of the RWMP station which does not operate during the winter months. If there was less than 5 mm of precipitation in the 72 hours preceding the sample, the sample was considered to be a "low flow" sample due to minimal flow response in the creek to the volume of precipitation. If there was more than 5 mm of precipitation in the 72 hours preceding the sample, the sample was considered to be a "runoff" sample.

Water level was continuously recorded every 15 minutes at stations CC011, CC005, and 107002. Post-data verification, data is corrected and stage-discharge curves were used to calculate discharge. In-stream water temperature was recorded every 15 or 30 minutes at 14 locations from the headwaters to the mouth of Carruthers Creek using a combination of onset hobo water temperature pro v2 and u24 series conductivity data loggers (Figure 2 in the Carruthers Creek Watershed Plan: Aquatic Habitat and Community Characterization). Temperature loggers were attached to a rebar, and installed in-stream where flow and shade were present. Conductivity loggers were installed on a t-bar in a perforated PVC protective housing.

2.1.3 Data Summaries

A data summary (minimum, maximum, average, and median) was completed for all sample sites. In addition, the data set was summarised by approximate stream flow (low flow versus runoff) to look for differences in the dataset. If results were non-detect, the detection limit was substituted for the analytical result.

2.1.4 Comparison to Water Quality Objectives

Water quality results were compared to the Provincial Water Quality Objectives (PWQO; OMOEE 1994). The PWQO are a set of numerical and narrative criteria which serve as chemical and physical indicators representing a satisfactory level for surface waters which is protective of all forms of aquatic life and/or the protection of recreational water uses based on public health and aesthetic considerations. When PWQO were not available, other objectives such as the Canadian Water Quality Guidelines for the Protection of Aquatic Ecosystems (CWQG; CCME 2007) were used.

2.2 Long-term temporal trends

Data from PWQMN site 107001 (located on Shoal Point Road, just north of Carruthers Marsh, approximately 3 km downstream from site 107002) were analyzed for temporal trends between 1966 and 1993 or 1994 for chloride, total phosphorus, total suspended solids, and turbidity) and between 1982 and 1993 for zinc. These trends were then qualitatively compared with the patterns observed in the more limited 2009 to 2016 dataset from site 107002 (also downstream of the urban center). These sites were not co-located as the historical 107001 site may have been influenced by backwater effects from Lake Ontario. Since these sites are not co-located, time trend analysis cannot be completed on all data between 1960 and 2016. Instead, median annual values were calculated for each analyte for years with greater than six samples. A Mann-Kendall trend analysis was used on median concentrations of historical PWQMN data (between the 1960s and 1990s at site 107001) only. These data are plotted along with the 2009 – 2015 median concentrations from the RWMP site (107002) to see if any general patterns can be observed (e.g. both sites independently appear to have increasing/decreasing/plateauing patterns). Insufficient data from site 107002 prevented trend analysis at the new location, however, general inferences are made based on qualitative data patterns.

2.3 Site and wet-dry year comparison

Data collected between January 2015 and December 2016 from the RWMP station were grouped into years (Jan-Dec 2015: wet, Jan-Dec 2016: dry) and compared seasonally and annually for chloride, nitrate, phosphate, total phosphorus, and TSS. Using a subset of the RWMP data from May 2015 to December 2016, site differences were assessed between CC005 and 107002 with a Mann-Whitney rank sum test as a normality test failed for each water quality parameter. Data were grouped into seasons (summer: June, July, August; fall: September, October, November; and winter: December) and year and were analysed using a two-way ANOVA for CC005 (June to December 2015 and June to December 2016) and 107002 (January 2015 to December 2016) separately.

3. Results & Discussion

3.1 Precipitation, Discharge, and Water Temperature

Precipitation events and discharge are interrelated and will influence water quality in Carruthers Creek (Figure 3). Total precipitation exceeded the 30 year - 1981-2010 ECCC climate normal (892 mm) in 2015 (985 mm), and fell below the climate normal in 2016 (614 mm; although 27 days were missing from the 2016 ECCC precipitation record). This would suggest that 2015 was a "wet" year and 2016 a "dry" year relative to the 30 year climate normal, indicating that water quality results cover a range of climatic conditions. Mean water temperatures within Carruthers Creek between May and October were generally warmer within the "dry" year (2016) and cooler within the "wet" year (2015) with the exception of May and September (Figure 4). Temperatures increased from Spring to Summer, and were lowest between October and December. Note that winter temperatures are not included in this generalization. Overall, temperatures were often higher downstream of CCWP-05 than they were upstream of this site.

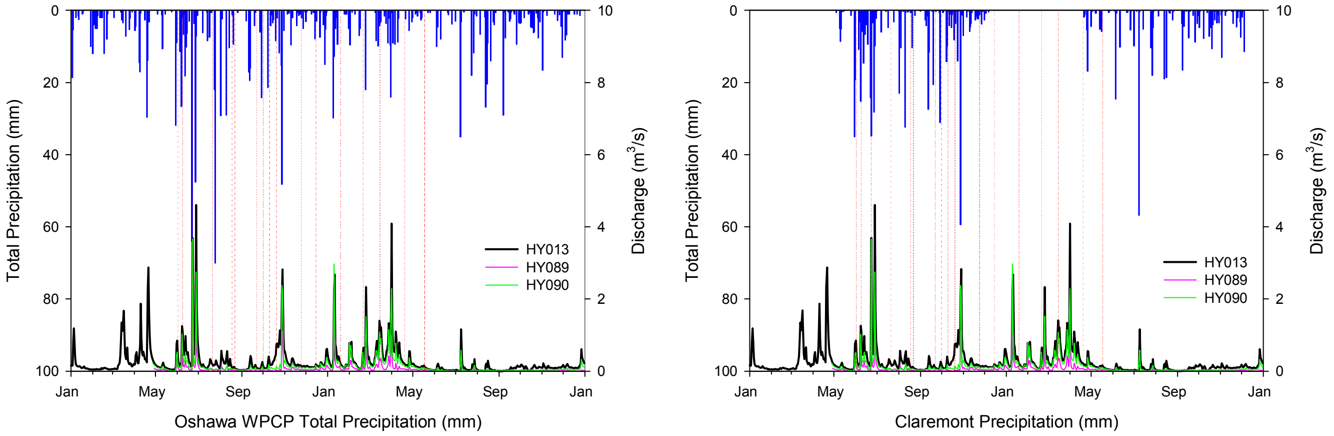

Figure 3. Daily precipitation at the Oshawa water pollution control plant (ECCC station 6155878) and Claremont (HY015) and preliminary discharge data from above and below the Lake Iroquois shoreline (HY089 west branch and HY090 at Tauton Rd, respectively), and near the mouth of Carruthers Creek (HY013) for 2015 and 2016. Discharge data are provisional. Vertical red lines indicate sampling dates.

Discharge appears to respond to precipitation events (i.e., higher discharge after precipitation) recorded at the Claremont station (HY015; Figure 3). With an abundance of rainfall in 2015, it is possible that the ground is saturated with water increasing the potential for overland runoff, erosion, and creek scour. Provisional discharge magnitude increases after the Lake Iroquois shoreline (HY089 versus HY090) as the east and west branches join. At this point, it is likely that there is an increase in groundwater contributions. Significant discharge has been observed north of Highway 7, and is expected to be the result of groundwater from the upper aquifer system (TRCA, 2003). Provisional discharge is more similar between HY090 (at Taunton) and HY013 (by the mouth), but greater at the mouth suggesting additional inputs between the two sites. This is not surprising since this encompasses the urban region of the watershed which contains increased impervious surfaces affecting stormwater contributions to the creek.

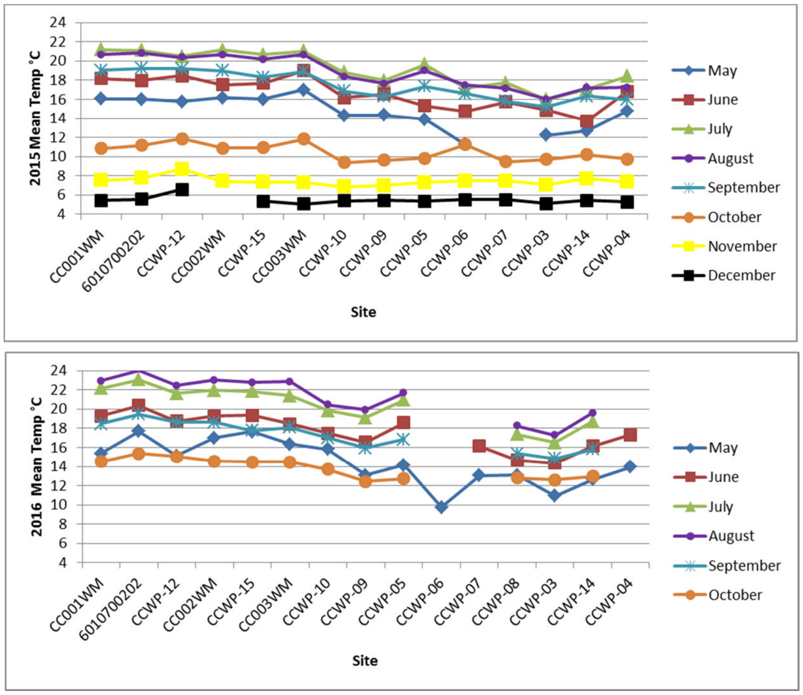

Figure 4. Mean in-stream water temperature in Carruthers Creek from the headwaters (CCWP-04) to the mouth of the creek (CC001WM). Sites are organized from the mouth to the headwaters. See Figure 2 in the Carruthers Creek Watershed Plan: Aquatic Habitat and Community Characterization for locations. Note that station 6010700202 is analogous to 107002 in Figure 2 of the current report.

3.2 2015/2016 Water Quality Summary

Summarised results for all analytes are presented in table format in Appendices A1 and A2. Median and maximum results are also presented in graphic format in Appendices B1 and B2. Results for specific analytes (ammonia, chloride, *E. coli*, nitrate, nitrite, phosphate, total phosphorus, TSS, lab-measured turbidity, and copper) are highlighted in the section below.

3.2.1 Total Ammonia

Total ammonia concentrations ranged between not detectable at a 0.008 mg N/L detection limit and 0.121 mg/L (Appendix A1). The overall median total ammonia results were highest at station 107002 near the mouth of Carruthers Creek, compared to the two upstream stations (Figure 5). When broken down by flow type, it is clear that there is a much higher input of total ammonia into the streams near station CC011 during dry weather (Appendix A2).

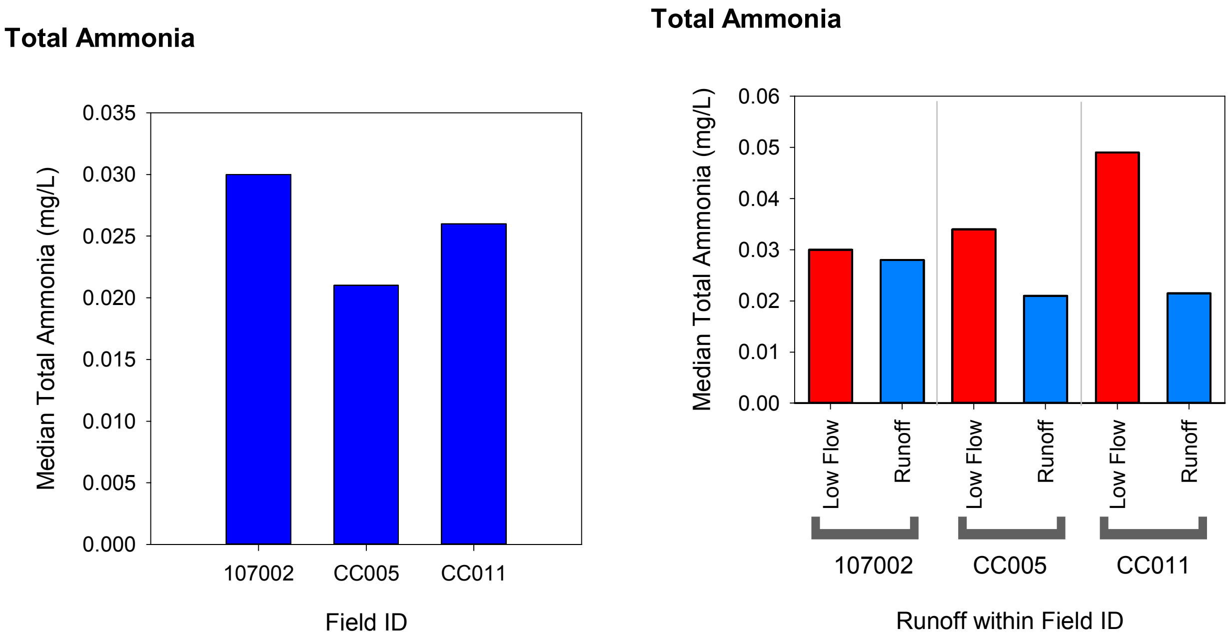

Figure 5. Median total ammonia concentrations as mg-N/L for all 2015/2016 samples (n=17) and separated by flow type (low flow: n=7; runoff: n=10).

Ammonia is a toxic form of nitrogen and a component of human and animal sewage and/or from the microbial decomposition of organic matter. Since Ammonia concentrations are elevated during low flow events, and are higher in the upstream sites, it could be entering the water system from a combination of agricultural practices such as fertiliser application, and by the process of ammonification which is the production of ammonia by micro-organisms as they decompose all living things (e.g., plants and animals) and their waste products. Un-ionized ammonia has a PWQO and is calculated based on the total ammonia concentration, temperature, and pH of the water. Temperatures were only collected during the 12 monthly samples which were comprised of 7 low flow samples and 5 runoff events. During the 2015-2016 sampling period, the un-ionized ammonia PWQO (0.02 mg/L) for the protection of aquatic life was met in all of the monthly samples with median values illustrated in Figure 6.

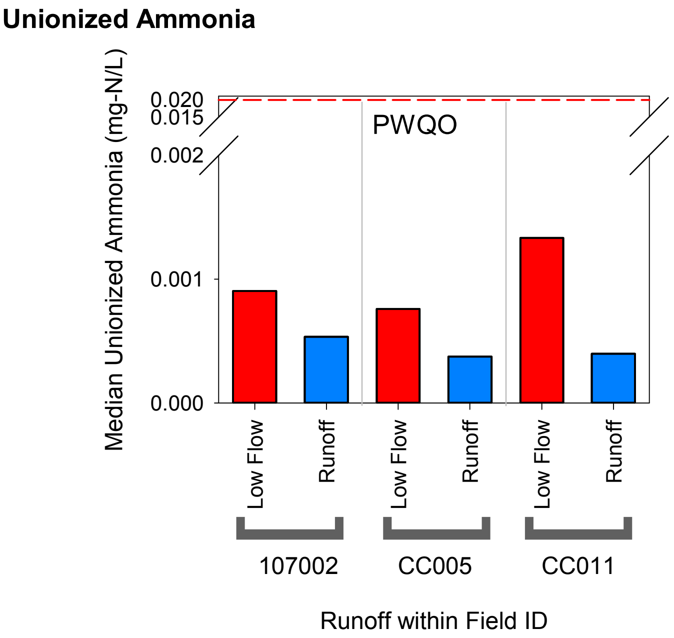

Figure 6. Median unionized ammonia concentrations for a subset of 2015/2016 samples (n=12) and separated by flow type (low flow: n=7; runoff: n=5).

3.2.2 Chloride

Chloride concentrations ranged between 25 mg/L (at CC011) and 302 mg/L (at 107002) (Appendix A1). Median chloride concentrations were highest near the mouth of the Carruthers Creek where urban density is the highest, and lowest in the headwaters where urban density is the lowest (Figure 7). This is corroborated by the lowest and highest chloride concentrations mentioned above.

Road salt is applied to paved roads in the winter as a de-icing agent. It is comprised mainly of sodium and chloride (NaCl), but can also contain some additives and impurities. It is possible that spring and winter runoff samples will have higher chloride concentrations in runoff samples, but sample resolution does not allow for this comparison with certainty. The results for sodium were very similar to the chloride results (see Appendices A and B). Median chloride concentrations at site 107002, near the mouth of Carruthers Creek, were 175 mg/L, which exceeded the CWQG of 120 mg/L for chronic long-term exposure by aquatic organisms with 94% of the samples in exceedance (Figure 7). There were no exceedances for acute short-term exposure (600 mg/L).

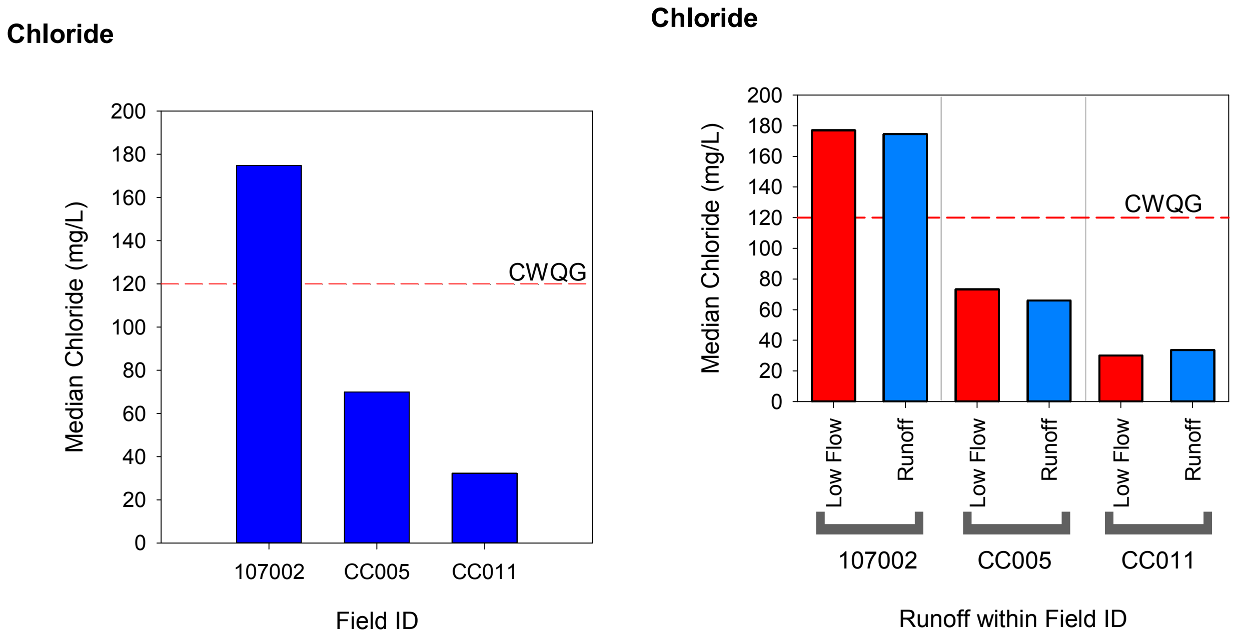

Figure 7. **Median chloride concentrations for all 2015/2016 samples (n=17) and separated by flow type (low flow: n=7; runoff: n=10).**

3.2.3 *E. coli*

Median *E. coli* counts were similar at all 3 sites ranging from 110 to 140 CFU/100 mL (Figure 8) with a range of non-detect at 1 CFU/100 mL to 5600 CFU/100 mL below the urban region (Appendix A1). When summarised according to flow, there was clearly more *E.coli* during precipitation events entering the headwaters than at the downstream station (Figure 8). Median *E. coli* counts of all of the data exceeded the PWQO of 100 CFU/100 mL for recreational use but median *E. coli* counts during precipitation events were greater reaching 640 CFU/100 mL at the headwaters location. *E. coli* measures are only used as a descriptor of aquatic health and conditions, in addition to looking at relative sources of faecal matter coming into the creek at different locations. The PWQO is for recreational use and only used as a benchmark as Carruthers Creek is not used for swimming.

Mean *E. coli* counts (Figure 9) ranged between 475 and 706 counts/100 mL for all samples, with highest means observed by the mouth of Carruthers Creek and lowest mean concentrations in the headwaters at CC005. Similar patterns of increasing means downstream from headwater to creek mouth were observed during runoff periods, where counts ranged from 754 to 1133 counts/100 mL. During runoff events, mean concentrations at all sites exceeded the recreational PWQO, however, it is important to note that these are not geometric means from each sampling event, such as those used to calculate recreational use. *E. coli* concentrations during periods with <5mm precipitation ranged between 75

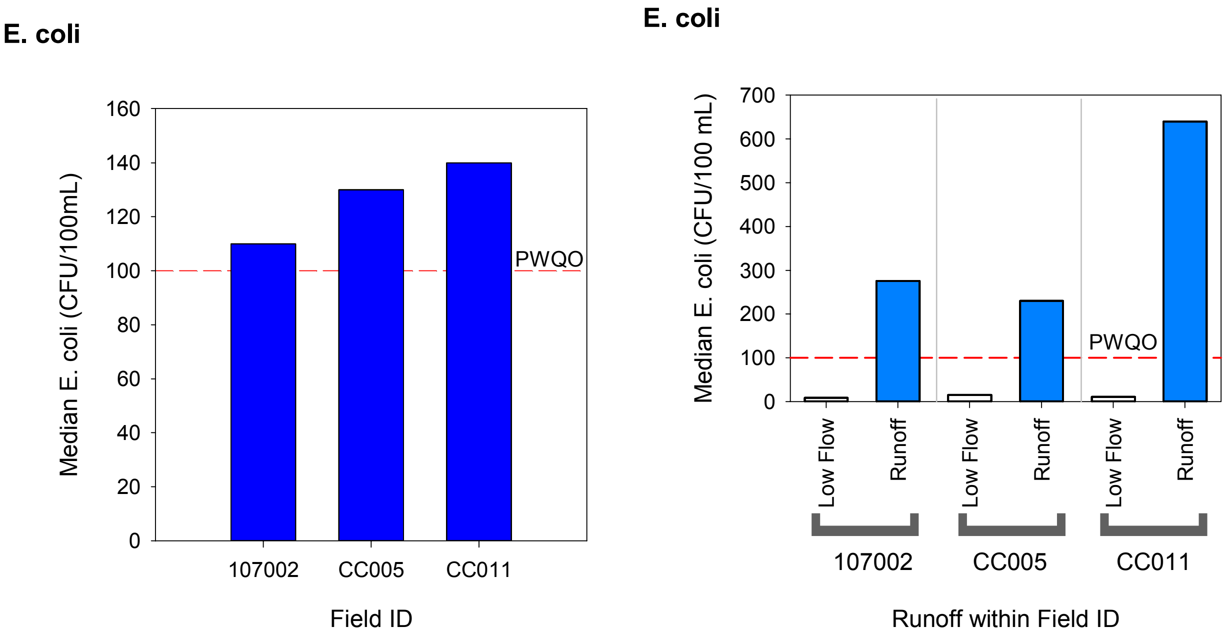

Figure 8. Median *E. coli* counts for all 2015/2016 samples (n=17) and separated by flow type (low flow: n=7; runoff: n=10).

and 95 counts/100 mL. Results suggest that there may be additional *E. coli* sources from the urban area.

Maximum *E. coli* counts (Figure 10) during precipitation events at all three sites exceeded the PWQO of 100 CFU/100 mL. Maximum *E. coli* counts were highest at station 107002 (5600 CFU/100 mL) during a precipitation event on October 2015, with 24mm of rainfall within the 24 hours prior to sampling.

E.coli indicates the presence of faecal matter of human or animal origin, and when present it is an indicator that other bacteria, viruses, and/or pathogens that can infect humans or warm-blooded animals can also be present. The PWQO is, however, based on a geometric mean which must be met for recreational water use, not for aquatic health. In terms of aquatic health in Carruthers Creek and bacteria contributions from the watershed, *E.coli* concentrations reveal that faecal matter is likely present in the creek and can be pulsed into the creek during rain events in both the headwaters and downstream from the urban center.

Although *E. coli* concentrations are generally higher in the headwater areas associated with agricultural inputs, the highest concentration measured was downstream from the urban center. *E. coli* levels exceeding 100 CFU/100 mL require beach closures. The loadings from Carruthers Creek could contribute to elevated bacteria levels in the Lake Ontario nearshore and potentially cause closures of Pickering Beach, west of the mouth of Carruthers Creek, based on the direction of currents

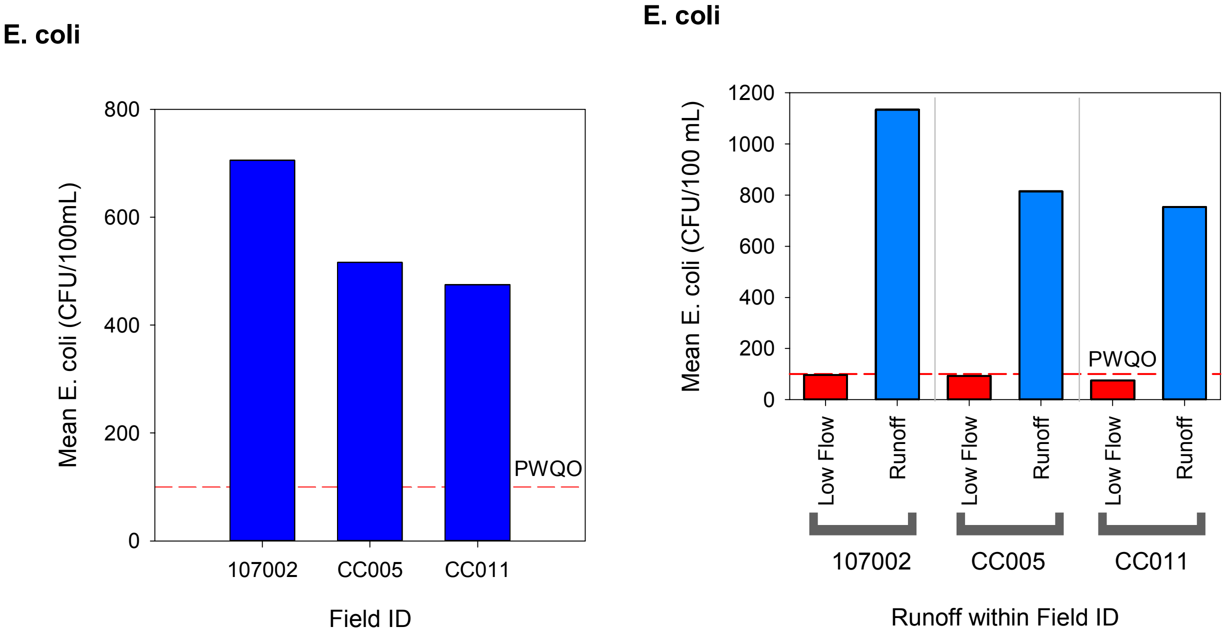

Figure 9. Mean *E. coli* counts for all 2015/2016 samples (n=17) and separated by flow type (low flow: n=7; runoff: n=10).

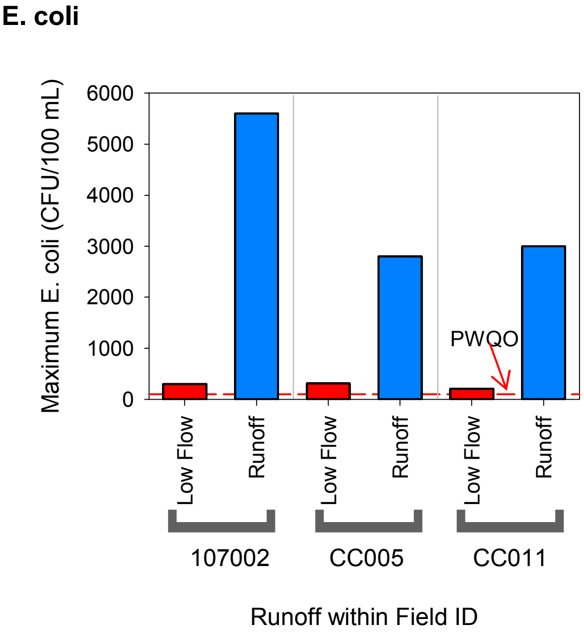

Figure 10. Maximum *E. coli* counts separated by flow type (low flow: n=7; runoff: n=10).

in the lake. In 2015, Pickering Beach was closed for 29% of the swimming season (June to September) due to elevated bacteria levels (Durham Regional Health Department, 2016) during which time 100% of the samples from the current monitoring program downstream of the urban center near the mouth of Carruthers at 107002, exceeded the PWQO. Please note that these are discrete samples and not the geometric mean of 5 samples as required by the PWQO objective for recreational water use. This is similar to earlier reports where Pickering Beach was closed 31% of the time due to elevated *E. coli* levels (TRCA, 2002).

3.2.4 Nitrate & Nitrite

Nitrate concentrations ranged between 0.18 and 6.96 mg N/L and were highest at station CC011 in the headwaters of Carruthers Creek (Appendix A). When broken down by flow type, there appears to be a higher input of nitrate to the streams near station CC011 during dry weather (Figure 11). This is not corroborated by the maximum nitrate value which was 6.96 mg N/L during a runoff event at CC011 (Table A2), however, this nitrate value is anomalously high and associated with the largest rain event captured during the 2015-2016 sampling season (54mm within 72 hours of the sample time).

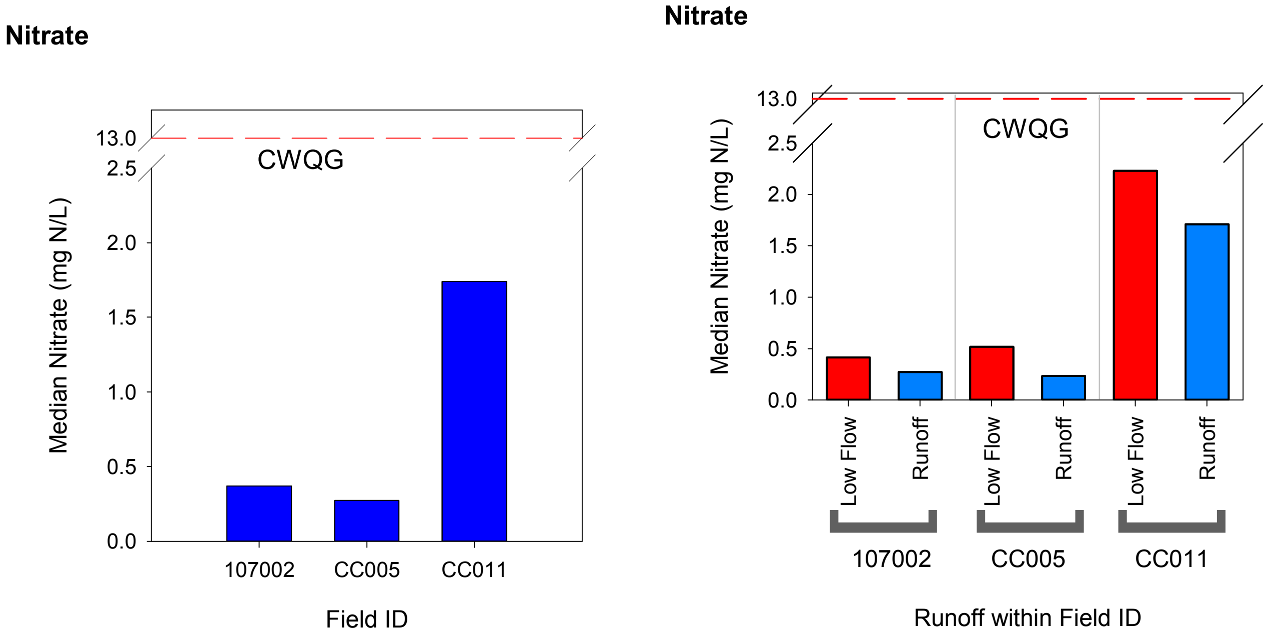

Figure 11. Median nitrate concentrations for all 2015/2016 samples (n=17) and separated by flow type (low flow: n=7; runoff: n=10). Results are compared to the chronic nitrate Canadian Water Quality Guideline of 13 mg N/L.

Nitrate is highly soluble, stable over a wide range of conditions, and can be transported easily in stream waters. Although not a limiting nutrient for plant growth, high nitrate (e.g., 1-10 mg/L) can affect eutrophication and also cause aquatic stress with chronic toxic effects in amphibian species at concentrations of 2.5 mg/L (Rouse et al., 1999). Major sources of nitrate include lawn and garden fertiliser, eroded soil particles from construction sites, stream banks, and agricultural fields. With higher nitrate values associated with low flow, it is likely that nitrate could potentially be entering the water system from groundwater influences or leaking septic systems. It is also likely that delivery from agricultural fields and construction erosion are increasing nitrate concentrations in the headwaters during runoff events. Despite the many potential influences in the headwaters, nitrate did not exceed the long-term exposure CWQG of 13 mg N/L for the protection of aquatic life. Nitrate concentrations appear lower than those reported in the 2002 Carruthers Creek State of the Watershed Report, where high levels (5mg/L) were monitored in the west branch at Highway 7 (TRCA, 2002).

Median nitrite concentrations were similar between stations 107002 and CC011 and low in comparison to nitrate concentrations (Figures 11 and 12). The range in nitrite concentrations was not appreciable (non-detect at 0.001 mg N/L to 0.032 mg N/L) compared to nitrate (Appendix A). Splitting the sampling events between low flow and runoff flows illustrated that there was not much difference in median nitrite concentrations within the different flow periods. Low ammonia and nitrite concentrations and elevated nitrate concentrations suggest that ammonia and nitrite are being nitrified by bacteria to nitrate.

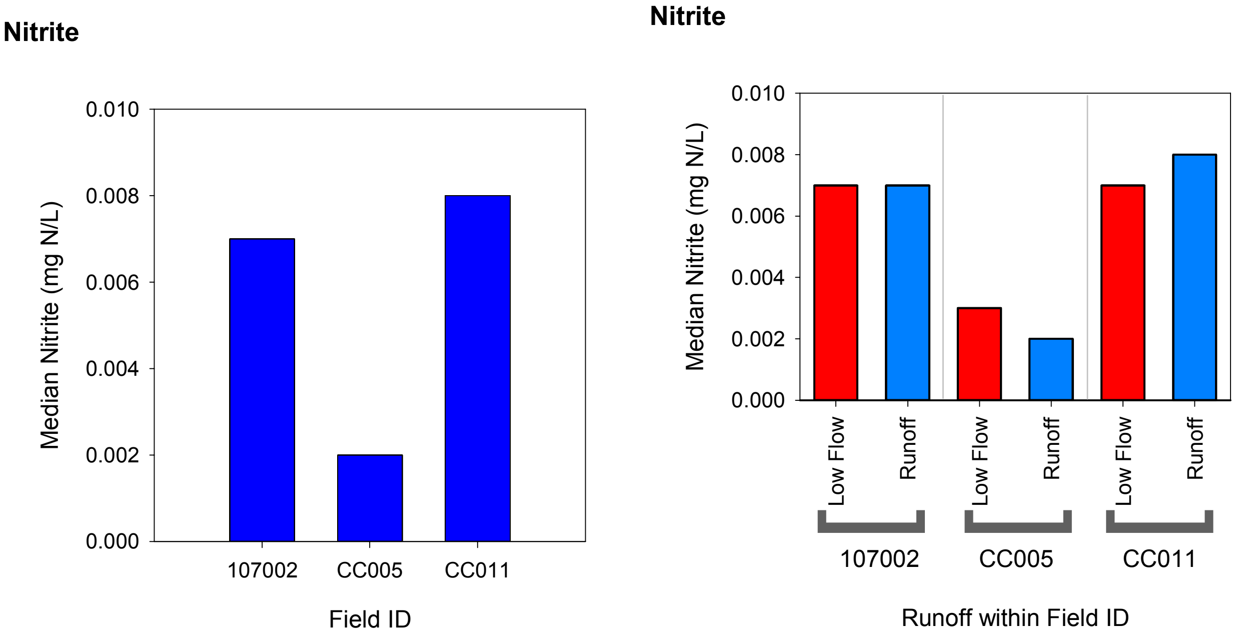

Figure 12. Median nitrite concentrations for all 2015/2016 samples (n=17) and separated by flow type (low flow: n=7; runoff: n=10).

3.2.5 Phosphate

Median phosphate concentrations were greatest in the headwaters and lowest at the downstream stations (Figure 13) with overall concentrations ranging between non-detect at 0.002 mg P/L and 0.094 mg/L (Appendix A). Summarising concentration according to flow shows that there was more phosphate during precipitation events (Figure 13) with a maximum value of 0.094 mg P/L in the headwaters and more similar maximum values of 0.025 and 0.034 mg P/L at CC005 and 107002 respectively (Appendices A and B). Concentrations by the mouth of the creek during low flow and runoff events are slightly elevated in comparison to CC005, suggesting that there could be additional phosphate sources between the two sites (Figure 13).

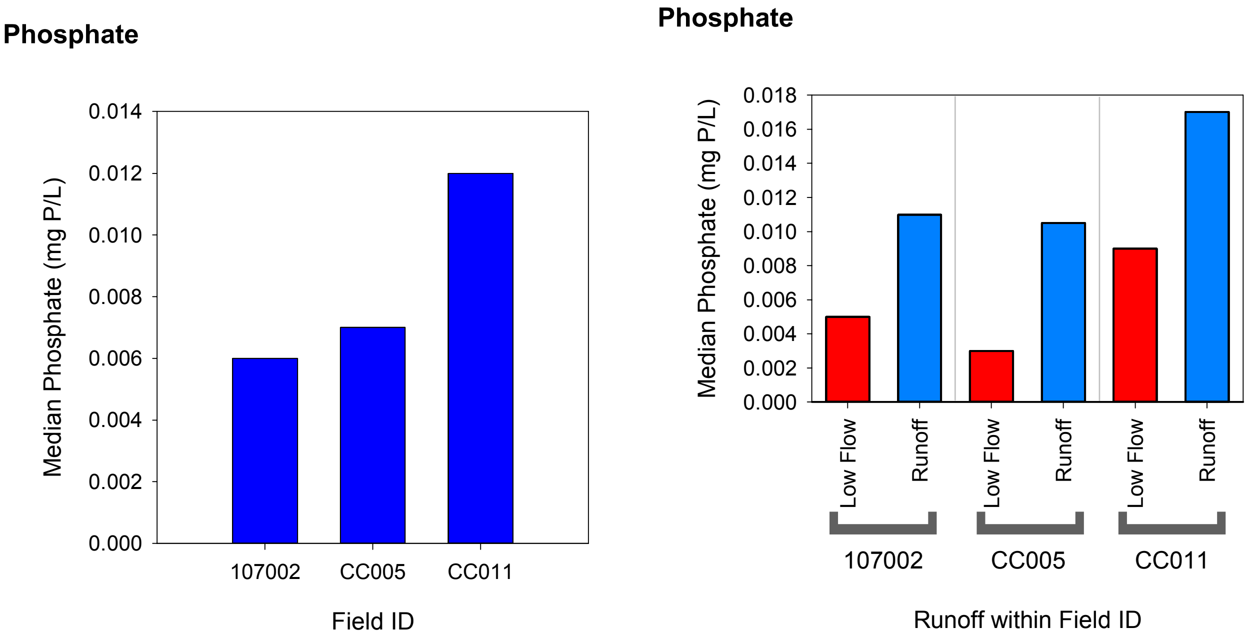

Figure 13. Median phosphate concentrations for all 2015/2016 samples (n=17) and separated by flow type (low flow: n=7; runoff: n=10).

Phosphate is often considered to be an indicator of the soluble bioavailable form of total phosphorus required for plant growth, and plant and animal metabolic activity. Currently, there are no water quality objectives for phosphate, however, small amounts can have a large effect on the aquatic ecosystem, and measured concentrations can support plant and algal growth. Potential sources of phosphate in the headwaters could include animal waste, sewage, fertiliser, eroded soil, and stream banks. Downstream, it is possible that lawn and garden fertilisers, and possibly the impurities in road salt, could contribute.

3.2.6 Total Phosphorus

Median total phosphorus concentrations were elevated at CC011 and 107002, exceeding the PWQO at both locations (Figure 14). Total phosphorus concentrations are greater at all sites during runoff events, with maximum concentrations reaching 0.454 mg P/L and 0.217 mg P/L at the headwaters, and downstream of the urban area, respectively (Appendix A). Nearly 60% of the samples exceeded the PWQO of 0.03mg P/L downstream of the urban area (107002), while approximately 70% of the samples exceeded PWQOs at CC011. It is likely that there are additional sources of phosphorus between the upper and lower stations as CC005 has lower concentrations and fewer PQWO exceedances. This could suggest that the east branch in the headwaters has lower concentrations than the west branch, or that groundwater contributions have less phosphorus and dilute creek phosphorus. Median phosphorus concentrations met the PWQO during low flow downstream from the Lake Iroquois shoreline, but nearly half of these low flow samples exceeded the PWQO.

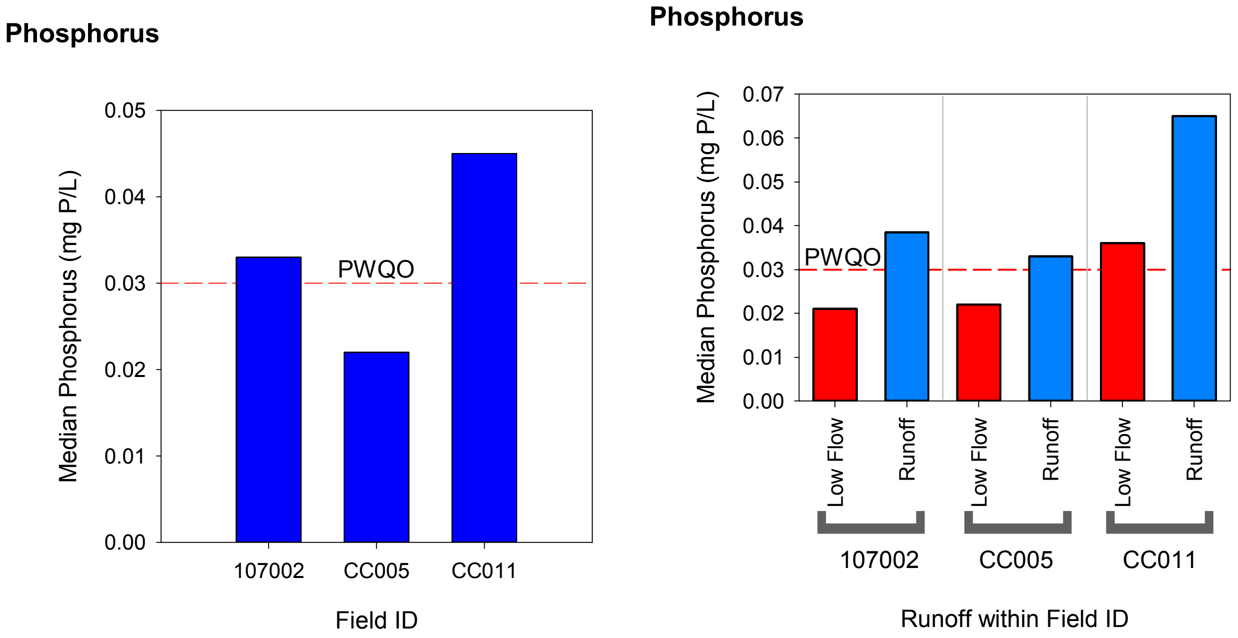

Figure 14. Median total phosphorus concentrations for all 2015/2016 samples (n=17) and separated by flow type (low flow: n=7; runoff: n=10).

Phosphorus is a limiting nutrient for plant growth in most inland waters (e.g., Carruthers Creek) and is considered the principal cause of eutrophication in receiving waters such as Lake Ontario. Major sources of phosphorus in the headwaters are likely due to fertilisers used on the agricultural fields and golf courses, and eroded soil from construction sites (e.g., Highway 407 construction), stream banks, and agricultural fields. Phosphorus easily binds to clay rich and other soil particles and is transported to the creek during overland flow events as soils are eroded and/or washed away. As a result, phosphorus concentrations are often greater in wet weather, as seen in Carruthers Creek. Median concentrations between 1988 and 1993 were reported as 0.04 mg/L and attributed to disturbed soils at construction sites from increasing urbanisation (TRCA, 2002).

There also appears to be a phosphorus source before the lower reaches of the creek. Although phosphorus was phased out of detergents in the 1970s, lawn and garden fertilisers still contain this nutrient. Some U.S. States recognize the impurities in rock salt can impact environmental health (e.g., NH DES, 2017), and impurities can include phosphorus (Marsalek, 2003). In addition, beet juice has been added as a de-icing agent in the Greater Toronto Area which can also be a potential phosphorus source if washed into to the Creek through meltwater.

3.2.7 Total Suspended Solids

Total suspended solids (TSS) concentrations ranged between 2 and 300 mg/L (Appendix A). Median TSS concentrations were greatest in the areas dominated by agriculture, compared with two (2) sites downstream of the Lake Iroquois shoreline (Figure 15). Concentrations met the guideline of 30 mg/L between 47% and 94% of the time. TSS concentrations were higher in the runoff samples than in the low flow samples, with the highest concentration observed in the headwaters probably due to Highway 407 construction and agricultural activity upstream of this station. Precipitation and high flow events can cause scour within the creek, and entrain and transport sediment downstream. Agricultural and construction zones, such as those in the northern reaches of the watershed are prime locations for sediments to be washed into the creek. There is likely an additional TSS source between stations 107002 and CC005, as median runoff concentrations appear to be greater downstream of the urban area. Between 1988 and 1993, median TSS concentrations were around 15 mg/L and were reported to have not significantly changed over the years (TRCA, 2002) indicating that current median TSS appears to have improved from past conditions.

During runoff events, TSS concentrations show similar patterns to TP concentrations, which is not surprising as a portion of phosphorus binds to, and is thereby transported by, suspended sediments. The bioavailability of this particulate phosphorus is not known, but likely contains a bioavailable component which is transported to the lake.

Redside Dace have been observed in Carruthers Creek and are a species listed as endangered under Ontario's *Endangered Species Act*. Creeks and rivers in the Greater Toronto Area house a large proportion of Redside Dace populations in Ontario, where the species is often restricted to the headwaters (MNRF, 2016). Threats to the Redside Dace population include loss of suitable habitat which is compounded by increased erosion, and sedimentation associated with urban regions and construction sites. To see their prey, Redside Dace require clear water, making them highly sensitive to suspended particles. Suspended solid concentrations should not exceed 25 mg/L above background. In the headwaters, median TSS concentrations only exceed this value and the CWQG during runoff events.

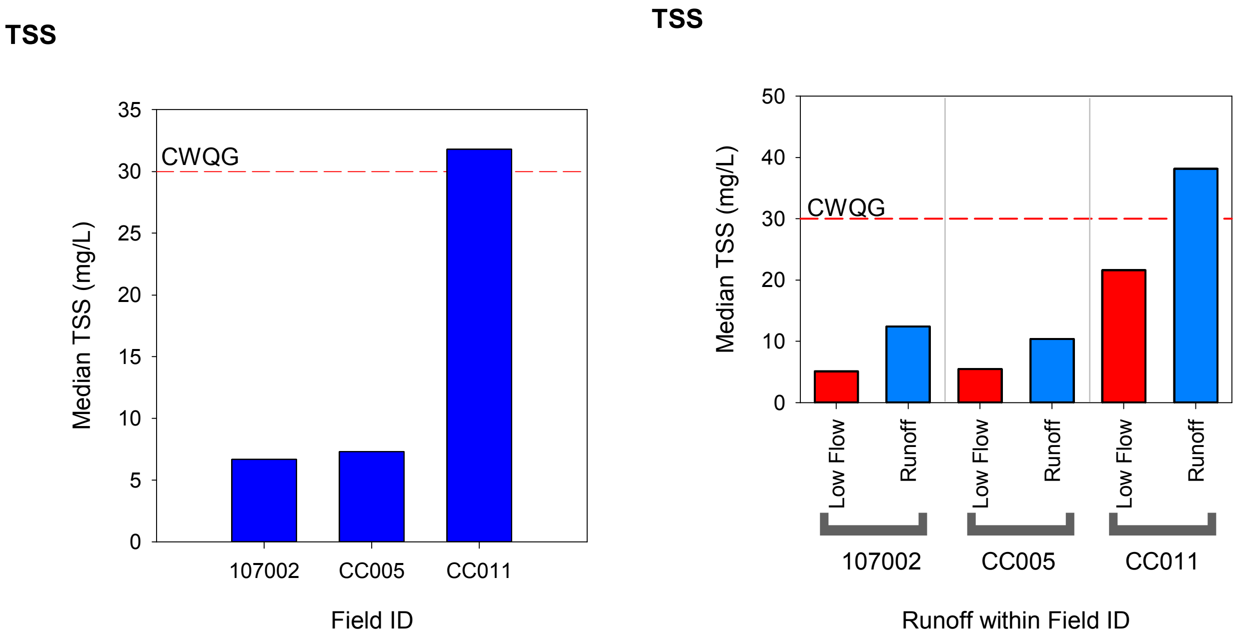

Figure 15. Median TSS concentrations for all 2015/2016 samples (n=17) and separated by flow type (low flow: n=7; runoff: n=10).

3.2.8 Turbidity

Median turbidity concentrations were greatest in the areas dominated by agriculture and active Highway 407 construction and lowest below the Lake Iroquois shoreline where groundwater influences are likely at a maximum (Figure 16). Patterns between sites differed from TSS, with higher median concentrations observed downstream of the urban area than at CC005. However, similar to TSS, turbidity concentrations were higher in the runoff samples than in the low flow samples (Figures 15 and 16). When flows were elevated, turbidity concentrations ranged between 0.19 and 233 NTU (Appendix A), and exceeded the CWQG most commonly in the headwaters.

Maximum turbidity concentrations are high at 107002 during runoff events, transporting turbid waters at times exceeding the CWQG to the lake (Figure 17). Maximum values exceed the CWQG at all times except during low flow events by the mouth of the creek. Turbidity levels were reported to have increased in the mid-1980s resulting from construction and wet weather (TRCA, 2002) so it is not surprising that concentrations are still elevated during runoff events.

Turbidity differs from TSS in that it is a measure of the amount of light that is scattered by the particles within the water column. It measures the relative clarity and can be used to indicate that there are changes in TSS concentrations without measuring TSS, as an increase in particles means that more light will be scattered. The differences observed between TSS and turbidity suggest that the turbid water during runoff events is cloudy/murky, and is also affected by dissolved coloured material such as dissolved organic carbon.

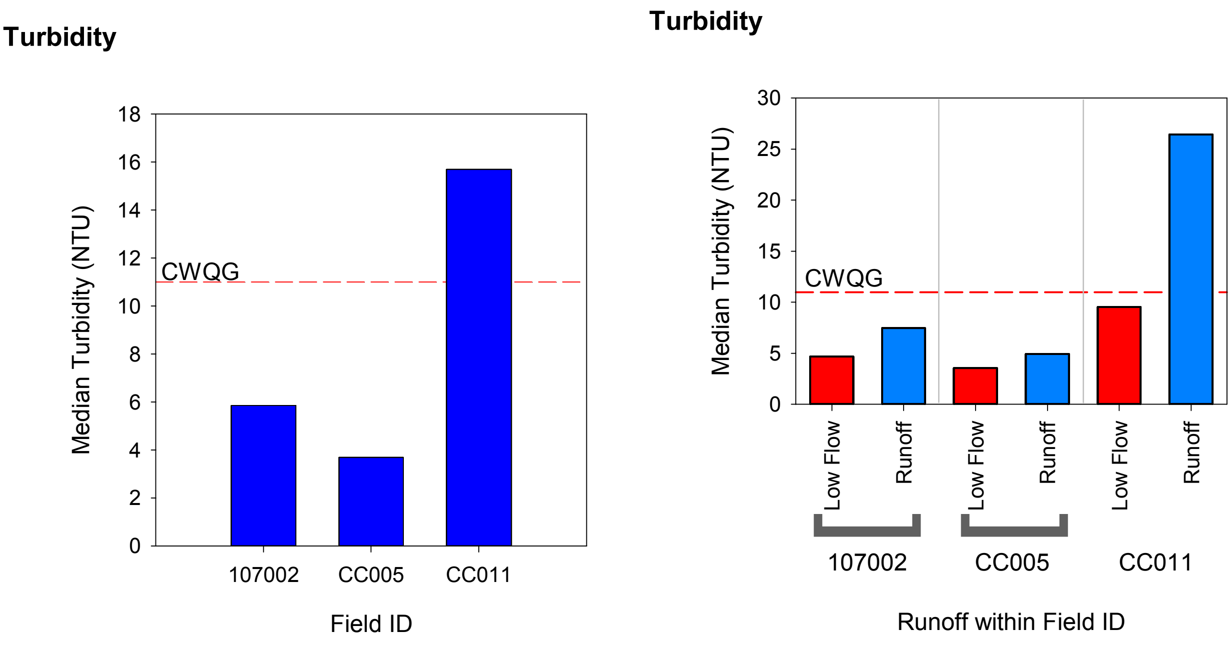

Figure 16. Median Turbidity concentrations for all 2015/2016 samples (n=17) and separated by flow type (low flow: n=7; runoff: n=10).

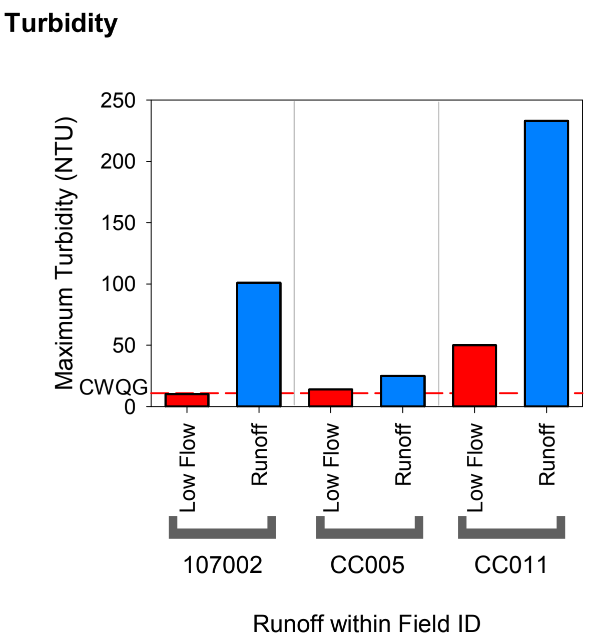

Figure 17. Maximum Turbidity concentrations separated by flow type (low flow: n=7; runoff: n=10).

3.2.9 Copper

Copper concentrations ranged between non-detectable at a 0.0005 mg/L detection limit and 0.0048 mg/L (Appendix A). Median copper concentrations were greatest at CC011 and 107002, with higher concentrations observed during runoff events (Figure 18). It is likely that there are additional sources of copper between the upper and lower stations as CC005 has lower concentrations than CC011 and 107002. There were no exceedances of the PWQO of 0.005 mg/L at any site.

The general patterns observed for copper were similar to many other metals such as aluminum, vanadium, and zinc. Metals can be found naturally in the environment, but some are toxic to aquatic life at elevated levels. Copper and zinc can originate from urban and industrial land use activities and are popular in stormwater runoff (Marselek and Shroeter, 1988). Vanadium can be found naturally in the environment, in food, and released during the burning of fuel oils. The majority of metals measured were either below the detectable limits of the lab, or present in concentrations that did not exceed PWQOs.

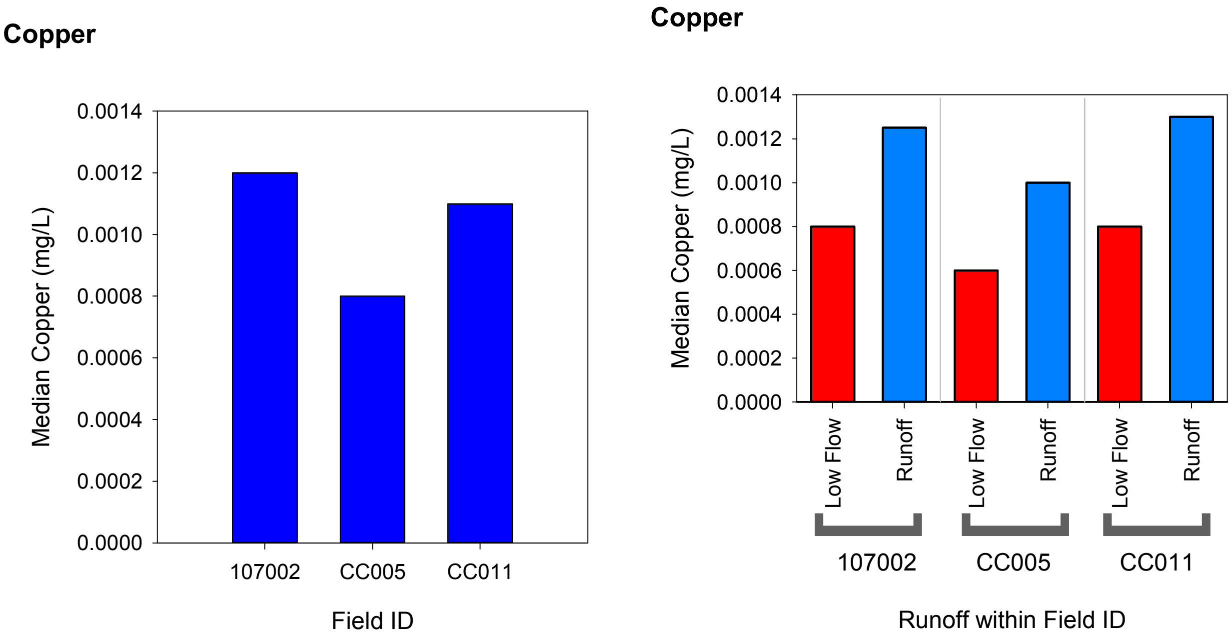

Figure 18. Median copper concentrations for all 2015/2016 samples (n=17) and separated by flow type (low flow: n=7; runoff: n=10).

3.3 Comparison to Water Quality Objectives

Water quality results were compared against 23 different water quality objectives. There were no exceedances of the associated objectives for 12 analytes: antimony, arsenic, beryllium, cadmium, copper, lead, molybdenum, nickel, nitrate, pH, vanadium, zinc. For 9 analytes (chloride, cobalt, *E. coli*, fluoride, iron, phosphorus, selenium, TSS, and turbidity), the associated objective was exceeded on at least one occasion. Dissolved oxygen did not fall below the PWQO for aquatic species in any sampling event. Table 2 summarises the exceedances for 10 objectives. Summarised data are presented in Appendices A1 and A2. Red shaded cells indicate an exceedance of the associated water quality guideline, whether it be a PWQO or a CWQG.

The chloride and fluoride exceedance counts were greatest at site 107002, near the mouth of Carruthers Creek, where urban density is highest. Chloride, as previously discussed, could reflect the greater amounts of road salt used in urban areas versus agricultural areas. Fluoride could also be representative of an urban signal through weathering and/or suspended solid transport associated with increased stormwater runoff (e.g., apatite contains both phosphorus and fluoride), contributions of fluorinated municipal water, or possibly due to the application of phosphate fertiliser and pesticides (Environment Canada, 2001).

Table 2. Surface water grab sample compared to water quality objectives.

Analyte	Objective	WQ Site	# Samples Exceed Objective (n=17)	% Samples Exceed Objective
Chloride (chronic)	120 mg/L	107002	16	94
		CC005	0	0
		CC011	0	0
Chloride (acute)	640 mg/L	107002	0	0
		CC005	0	0
		CC011	0	0
Cobalt, Total	0.0009 mg/L	107002	1	6
		CC005	0	0
		CC011	3	18
Escherichia coli (*E. coli*)	100 CFU/100mL	107002	9	53
		CC005	9	53
		CC011	9	53
Fluoride	0.12 mg/L	107002	9	53
		CC005	3	18
		CC011	4	24
Iron, Total	0.3 mg/L	107002	5	29
		CC005	3	18
		CC011	9	53
Phosphorus, Total	0.03 mg/L	107002	10	59
		CC005	7	41
		CC011	12	71
Selenium, Total	0.001 mg/L	107002	1	6
		CC005	0	0
		CC011	3	18
Solids, Suspended (TSS)	30 mg/L	107002	3	18
		CC005	1	6
		CC011	9	53
Turbidity	11 NTU	107002	3	18
		CC005	2	12
		CC011	9	53

Exceedances of Cobalt and Selenium PWQOs showed similar patterns, with the headwaters having higher exceedances than the mouth of the creek. Since there were no exceedances at CC005, these metals are introduced between the two sites.

Total phosphorus, total suspended solids, turbidity and iron also showed similar patterns of exceedances to each other with the number of exceedances declining from CC011 > 107002 > CC005.

Similar to Cobalt and Selenium, since exceedances are greater by the mouth than they are below the Lake Iroquois shoreline, suggests that there are sources of the parameters (TP, TSS, Iron, and turbidity) between CC005 and the mouth of creek. It is not surprising that these four parameters show similar patterns as they can be interrelated. Phosphorus can, in part, be bound to suspended solids. Apatite, a particulate form of phosphorus, also contains other components such as iron, calcium, chlorine, and even fluorine. In phosphorus rich waters, turbidity may increase with the increase in solids and organic matter such as decaying material or algae.

3.4 Long-term trends

Long-term trends are presented for four analytes (chloride, total phosphorus, TSS, turbidity) which had almost 30 years of data (~1963-1993), and for zinc which had over 10 years of data (~1982-1993). The sampling location moved approximately 2.5 km north of the historical station sampled between 1966 and 1993 or 1994, hence the data from 2009 to 2016 are plotted as second series since they are not directly comparable. In addition, data from 2002 to 2008 are not included due to concerns over reliability of sample analysis causing insufficient samples.

3.4.1 Chloride

Annual median chloride concentrations are presented in Figure 19. The graph clearly shows an upward trend in chloride concentrations since the initial sampling in 1965. A Mann-Kendall trend analysis shows a significant increasing trend from 1966 to 1993 (p value = 0.000). Earlier sampling included winter samples, but the early winter months were not sampled as consistently as they are in the current data. This may have slightly lowered the annual median chloride values but would not have affected the general trend. Although the sampling location changed to the RWMP site, the general pattern in the 2009 to 2016 data remains the same. The median annual chloride concentration in 2011 was 134 mg/L. This was the first year the annual median exceeded the CWQG of 120 mg/L for chronic exposure. The annual median has exceeded the chronic exposure guideline several times since the initial exceedance. There are insufficient data from the new sampling location for a significant trend analysis.

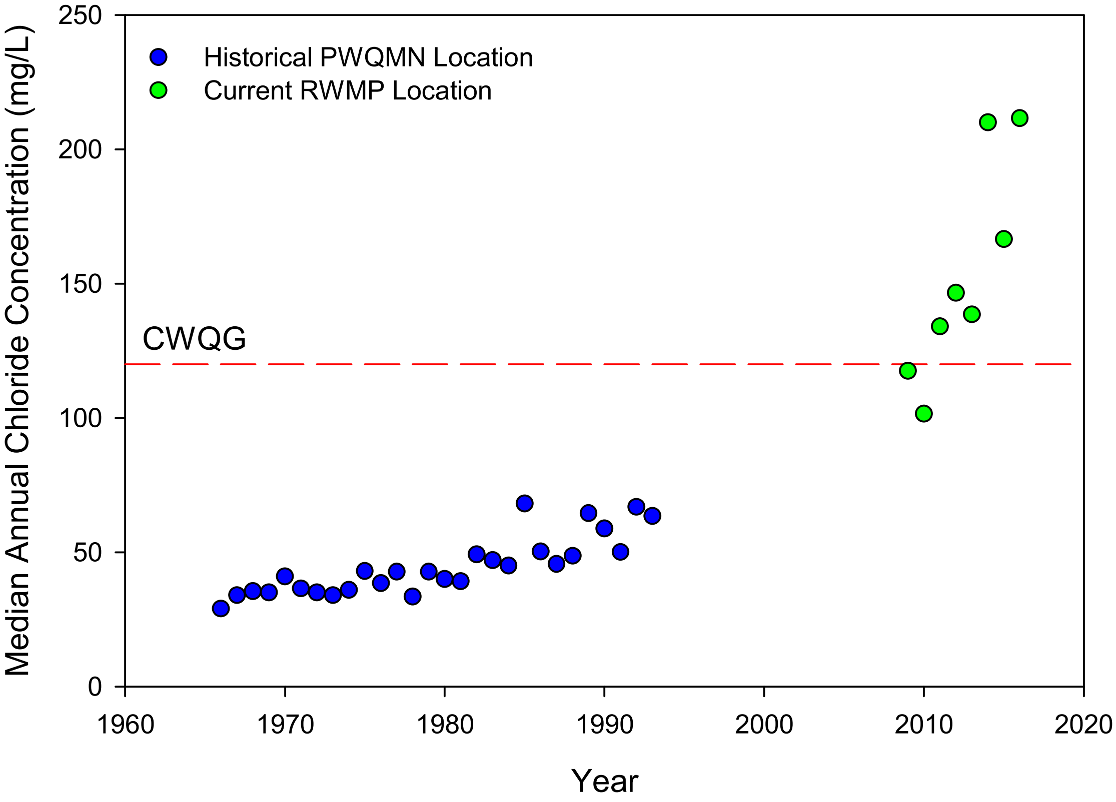

Figure 19. Annual median chloride concentrations over time (historical PWQMN R^2 = 0.7117; current RWMP R^2 = 0.7570).

3.4.2 Total Phosphorus

Annual median total phosphorous concentrations are presented in Figure 20. Due to the data gap and change in sampling locations, it is unclear whether there has been a slight decrease in annual median total phosphorus concentrations. With only eight years of eligible data at the new location, it is unclear if the decline in TP in recent years is actually a decline, or whether there is a plateau in values. The analytical detection method for total phosphorus has changed several times over the time span of this dataset and further work is needed to clarify whether there is a significant trend. Trend analysis suggests that there could be a slight decreasing trend in the historical data, but this is not significant (p-value = 0.115). However, it is apparent that the majority of median concentrations have exceeded the PWQO since the 1966. This remains in the current dataset 2.5 km north of the original PWQMN station.

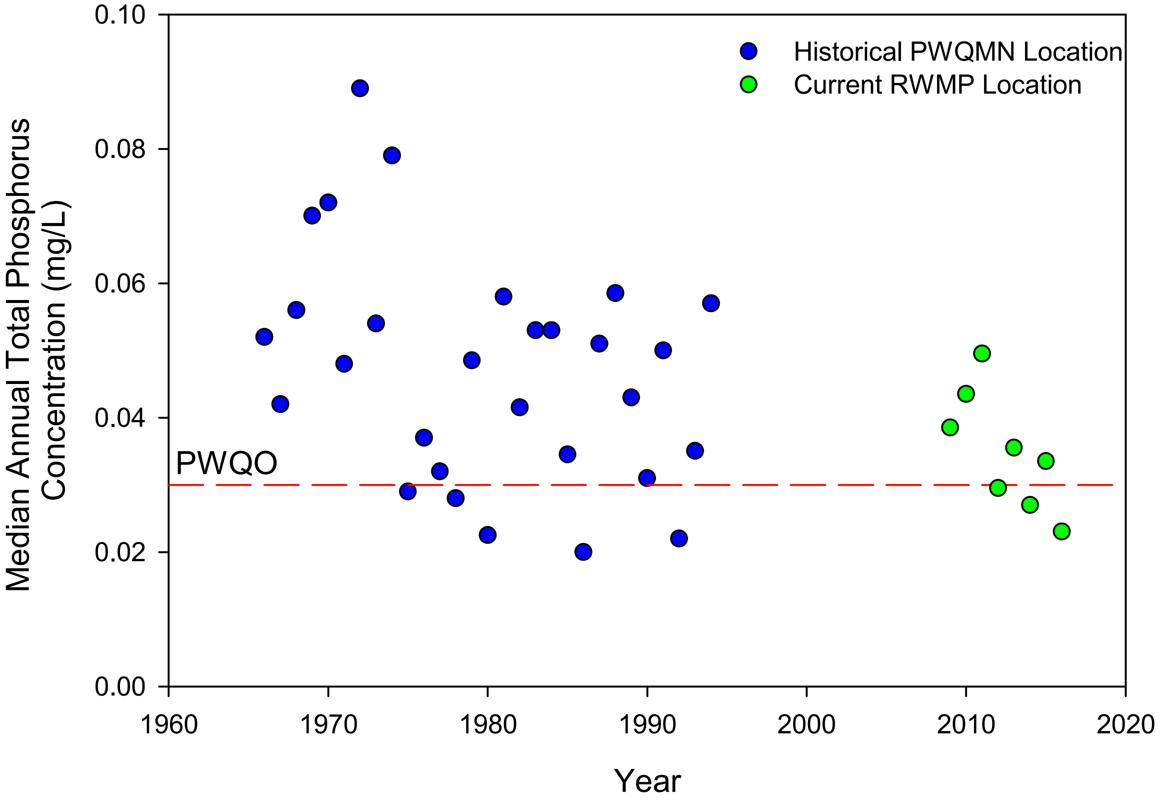

Figure 20. Annual median total phosphorus concentrations over time (historical PWQMN R^2 = 0.142; current RWMP R^2 = 0.5370).

3.4.3 Total Suspended Solids

Median annual TSS concentrations are presented in Figure 21. There appears to be a slight decreasing trend over time in the historical PWQMN data, however, a Mann-Kendall trend analysis shows no significant trend (p-value = 0.494). The most recent data at the current station show declining median values, but there are insufficient data for a trend analysis. These data could be declining, or they could be plateauing, but the median concentrations appear to be within the range observed with the data downstream. One reason for a potential apparent decline could be the change in sampling location as the current site is situated upstream of the silt/clay substrates of old lake deposits, whereas the original sampling location was influenced by these deposits (Bowen, pers. comm.). There is a chance that the historical data could be elevated as runoff events would scour these silt/clay banks and cause resuspension of additional silt/clay materials in comparison to the current sampling location.

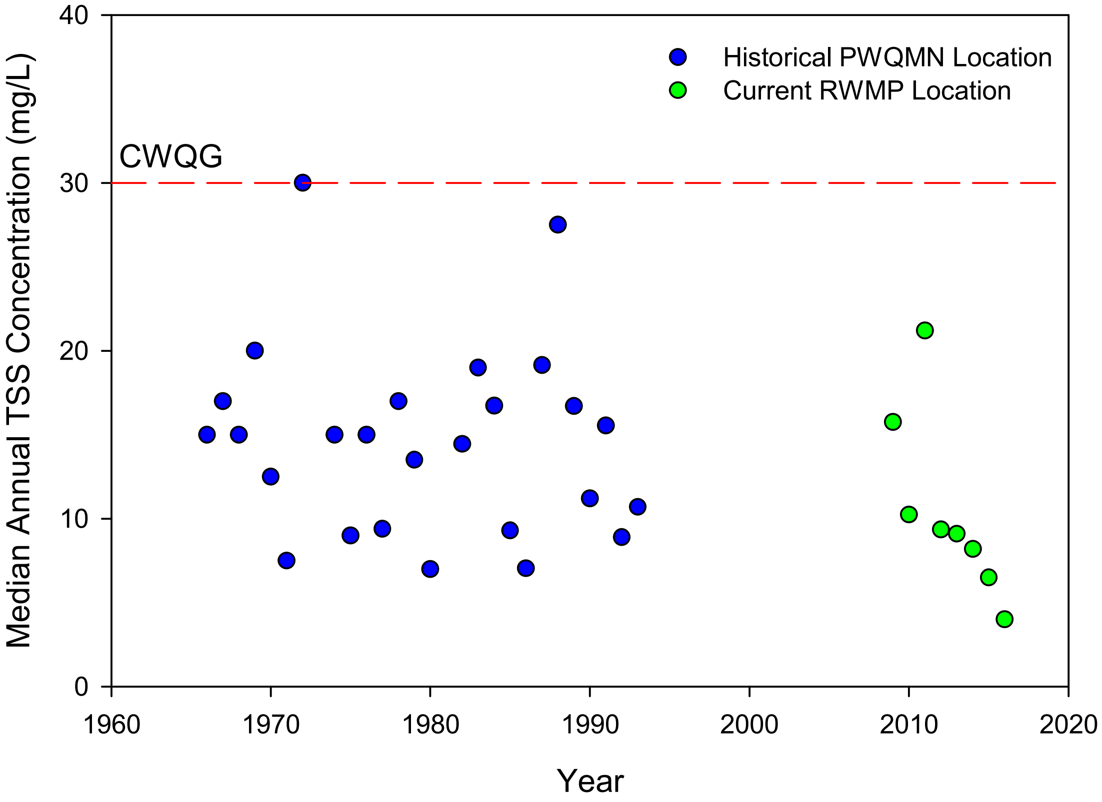

Figure 21. **Annual median TSS concentrations over time (historical PWQMN R^2 = 0.0141; current RWMP R^2 = 0.5604).**

3.4.4 Turbidity

Annual median turbidity values over time are presented in Figure 22. There does not appear to be a trend in the historical data (p-value = 0.378). It is possible that turbidity values are decreasing at the new location in recent years, however, conclusive results are not possible at this time due to limited data. This figure should be interpreted with caution as the dataset prior to 2000 was from site 107001, which may have been influenced by Lake Ontario. Similar to TSS, the apparent decline could also be due to a change in sampling location. The difference in sediment materials between the two sites could contribute to the differences observed between the two datasets (Bowen, pers. comm.).

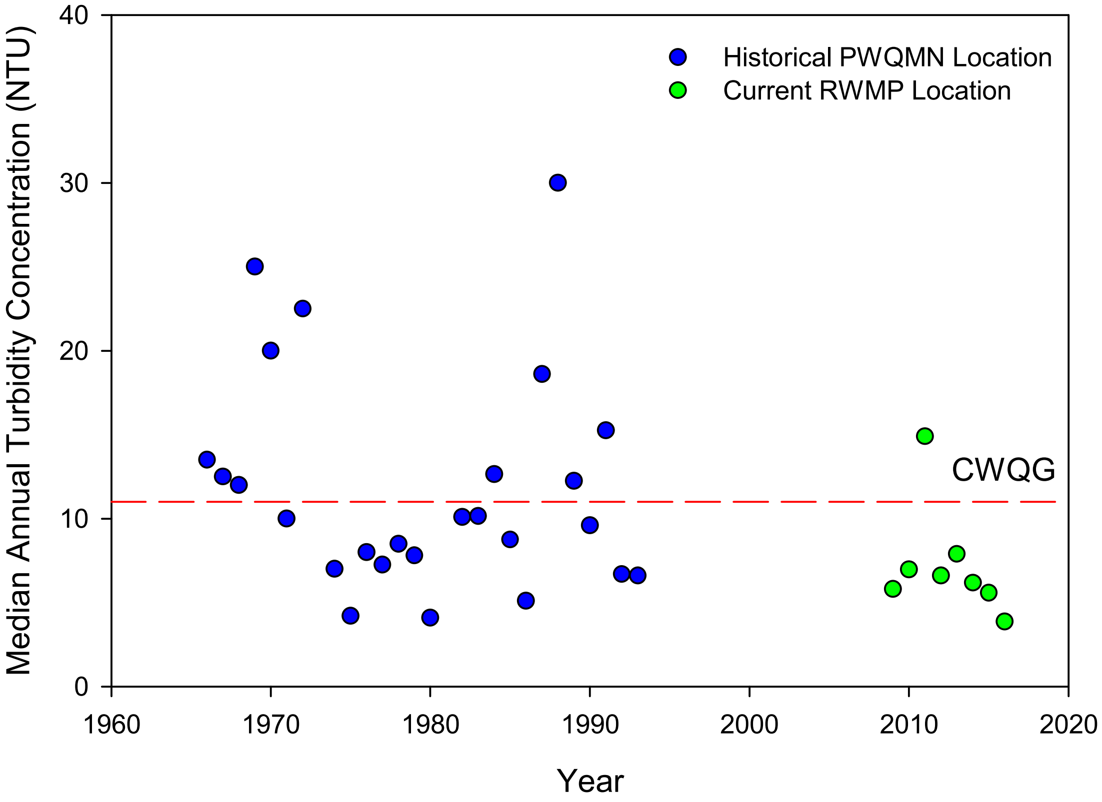

Figure 22. Annual median turbidity values over time (historical PWQMN R^2 = 0.0212; current RWMP R^2 = 0.1592).

3.4.5 Zinc

Median annual zinc concentrations over time are presented in Figure 23. The historical PWQMN time-series appears to show a slight increasing trend between 1982 and 1993 at the original PWQMN location (p-value 0.086). At the current sampling location, it appears that concentrations are declining in comparison to those from pre-2000, but this apparent trend needs to be interpreted with caution. In addition to the change in sampling location, analytical detection methods to zinc (and most metals) have changed over time. The figure appears to show that the minimum detection limit (lowest value provided by the laboratory) pre-2000 was higher than in the recent dataset. The change in detection limit is likely what is driving the pattern.

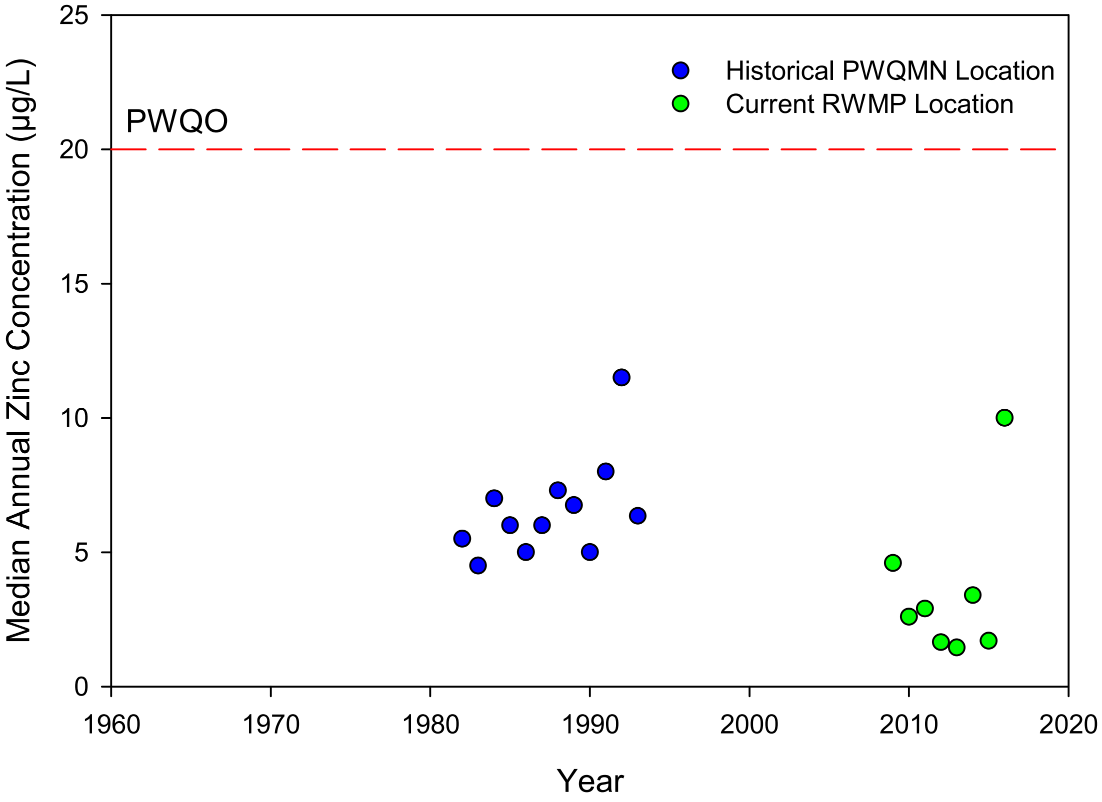

Figure 23. Annual median zinc concentrations over time (historical PWQMN $R^2 = 0.2999$; current RWMP $R^2 = 0.1284$).

3.5 Site and wet-dry year comparison

3.5.1 RWMP CC005 versus 107002 comparison

Available RWMP data from 2015 and 2016 were compared between CC005 and 107002 for chloride, nitrate, phosphate, total phosphorus, and TSS. Nitrate, not nitrate + nitrite, was analysed as RWMP samples from June to December 2016 were analysed at the Toronto Water Lab and reported as such. No statistical differences were evident between CC005 and 107002 based on the current dataset according to the p-values displayed in Table 3, except for chloride. The difference in mean chloride concentrations between CC005 and 107002 is greater than would be expected by chance, with a statistically significant difference between the sites upstream and downstream of the urban area. The lack of difference observed for the remaining parameters is not surprising since the majority of these samples are likely considered to be low flow/baseflow samples.

Table 3. Comparison of June 2015-December 2016 RWMP water quality between CC005 and 107002.

Water quality parameter	p-value
Chloride	<0.001
Nitrate	0.342
Phosphate	0.906
Total phosphorus	0.465
TSS	0.413

3.5.2 Chloride wet-dry and seasonal comparison

In 2015, chloride concentrations followed a seasonal pattern, with concentrations elevated in the winter and spring and higher concentrations observed downstream of the urban area (Figure 24). In 2016, concentrations generally follow the same pattern with the exception of an anomalously elevated concentration observed at 107002 in June and at CC005 in September.

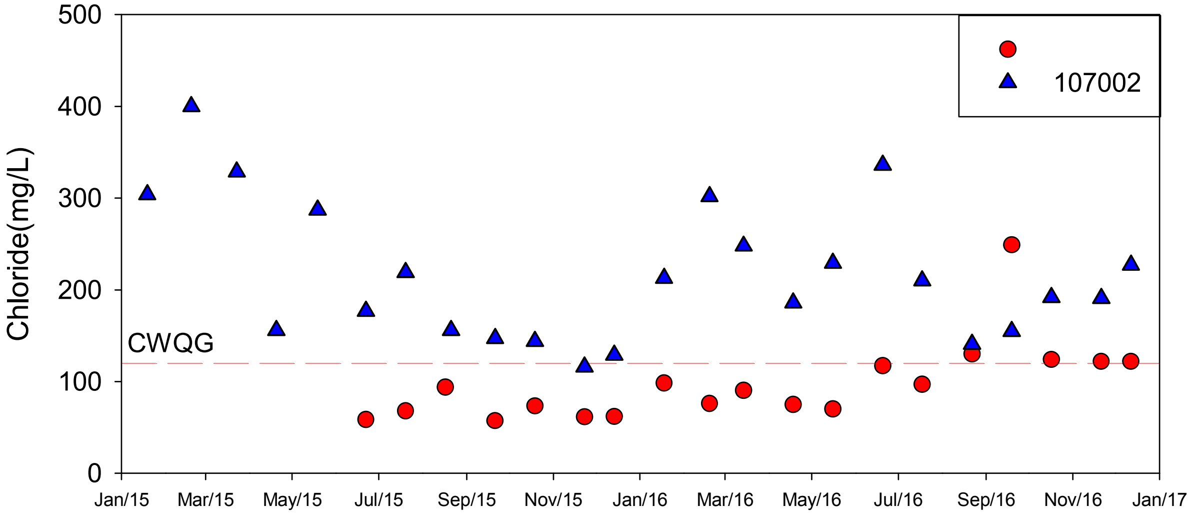

Figure 24. Regional Water Monitoring Program chloride concentrations in 2015 and 2016 at CC005 and 107002.

A two-way ANOVA on a subset of the CC005 data (from June to December, 2015 and June to December, 2016) indicates there is a statistical difference between mean chloride concentrations in 2015 and 2016 (p-value 0.021), although there is not a statistical difference between season (summer: June-August; fall: September-November; winter: December). In contrast, there is no statistical difference between the mean chloride concentrations during dry and wet years at 107002.

3.5.3 Nitrate wet-dry and seasonal comparison

Nitrate concentrations followed similar seasonal patterns to chloride, with greatest concentrations observed in the winter and spring. Nitrate is soluble and is likely transported during winter and spring melt events when discharge is elevated (Figure 25). Low concentrations observed in the summer likely reflect low flow or baseflow contributions.

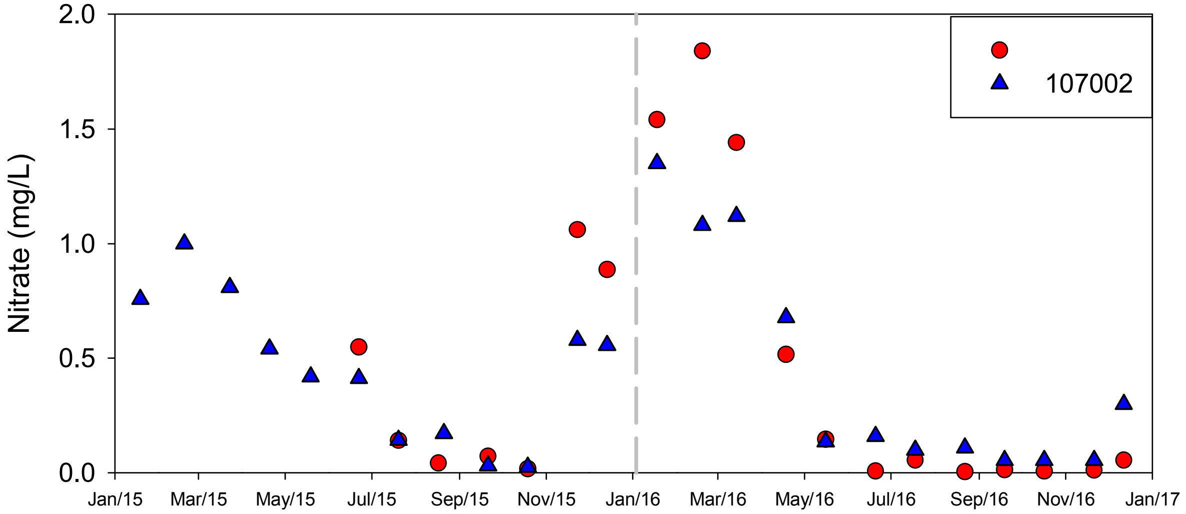

Figure 25. Regional Watershed Monitoring Program nitrate concentrations in 2015 and 2016 at CC005 and 107002.

Although there is a statistical difference in mean concentrations between the wet and dry years at CC005 (p-value 0.042), there is not a statistical difference between summer, fall, and winter seasonal mean concentrations. This is likely due to the sampling time frame of June to December, with only one winter sample to assess. In contrast, there is no statistical difference between mean concentrations in 2015 versus 2016 at site 107002 (p-value 0.871), but there is a difference between seasons (p value 0.002) which takes into account the full winter. The drought conditions observed in 2016 and the increased snow cover in winter that year (compared with 2015), could contribute to the similarity in mean concentrations between 2015 and 2016 by potentially increasing the 2016 mean nitrate concentration.

3.5.4 Phosphate wet-dry and seasonal comparison

Phosphate concentrations were similar between CC005 and 107002, with higher concentrations observed in winter and spring (Figure 26). Patterns are less obvious than with nitrate concentrations, and could reflect a difference in the source, transformation, or differential use of phosphate between the sampling locations.

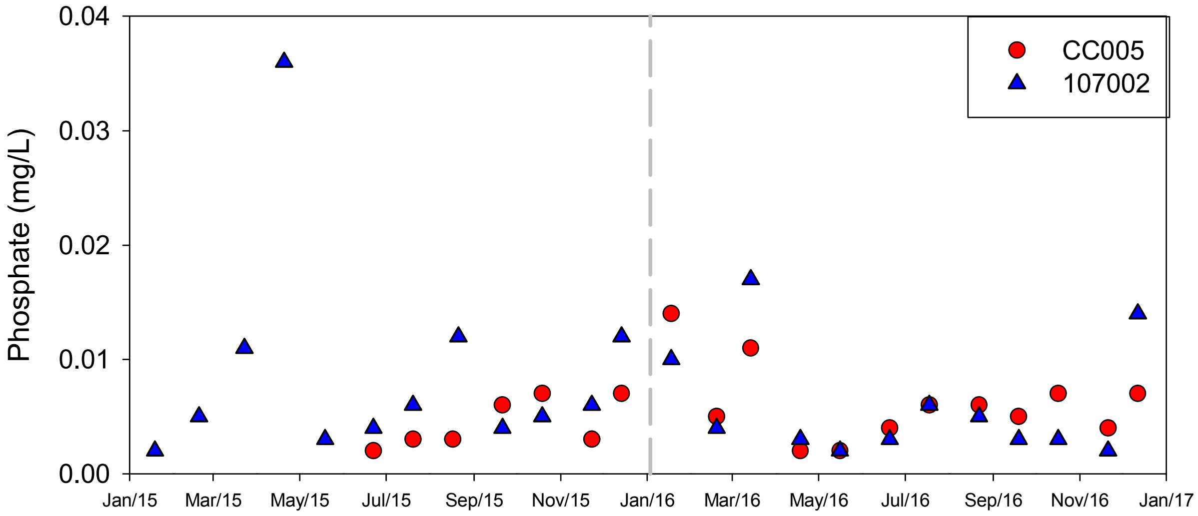

Figure 26. Regional Watershed Monitoring Program phosphate concentrations in 2015 and 2016 at CC005 and 107002.

There is no statistical difference in mean concentrations between the wet and dry years at CC005 (p-value 0.341), and no statistical difference between summer, fall, and winter seasonal mean concentrations (p-value 0.080) using an alpha cutoff value of 0.05. The seasonal p-value is close to 0.05 with the limited dataset, so there is a possibility that once data from 2017 have been collected/analysed the significance may change. At site 107002, there is no statistical difference between mean concentrations in 2015 versus 2016 (p-value 0.363), and no difference between seasons (p value 0.305).

3.5.5 *Total Phosphorus wet-dry and seasonal comparison*

Total phosphorus concentrations were elevated during times when snow melts might occur, with the highest concentrations often observed in March and April (Figure 27). Generally, concentrations were greater at 107002, than at CC005 with some exceptions, but as previously discussed this difference is not significant.

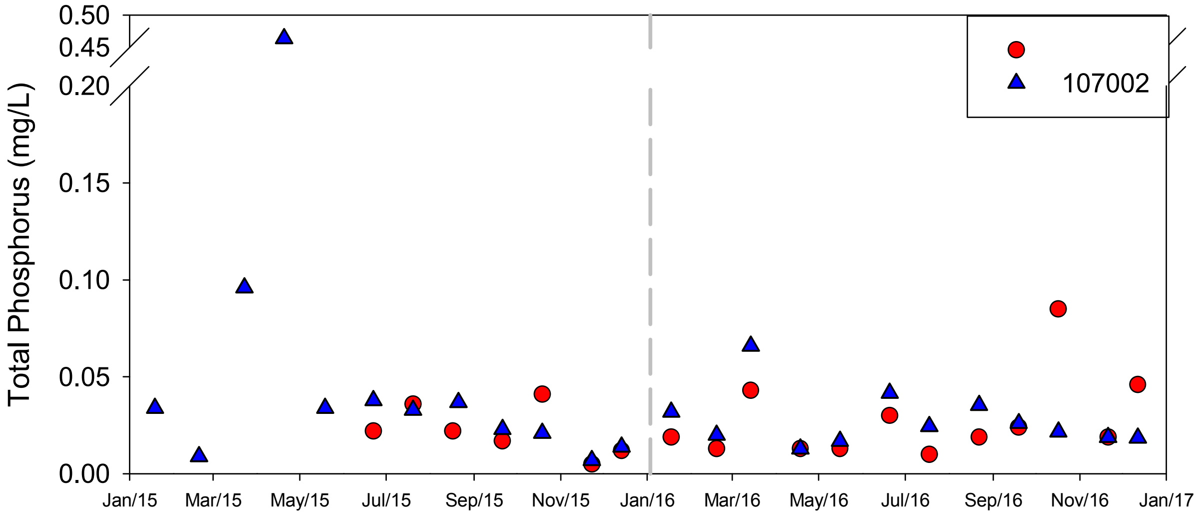

Figure 27. Regional Watershed Monitoring Program total phosphorus concentrations in 2015 and 2016 at CC005 and 107002.

There is no statistical difference in mean total phosphorus concentrations between the wet and dry years (CC005 p-value = 0.251 ; 107002 p-value = 0.260) or between seasons (CC005 p-value = 0.787 ; 107002 p-value = 0.190) at either sampling location with the current dataset.

3.5.6 *TSS wet-dry and seasonal comparison*

Total suspended solids follow nearly an identical pattern to total phosphorus with elevated concentrations observed when flows are expected to be enhanced (Figure 28). The similarity between TSS and total phosphorus continues to support that a large component of TP is in particulate format.

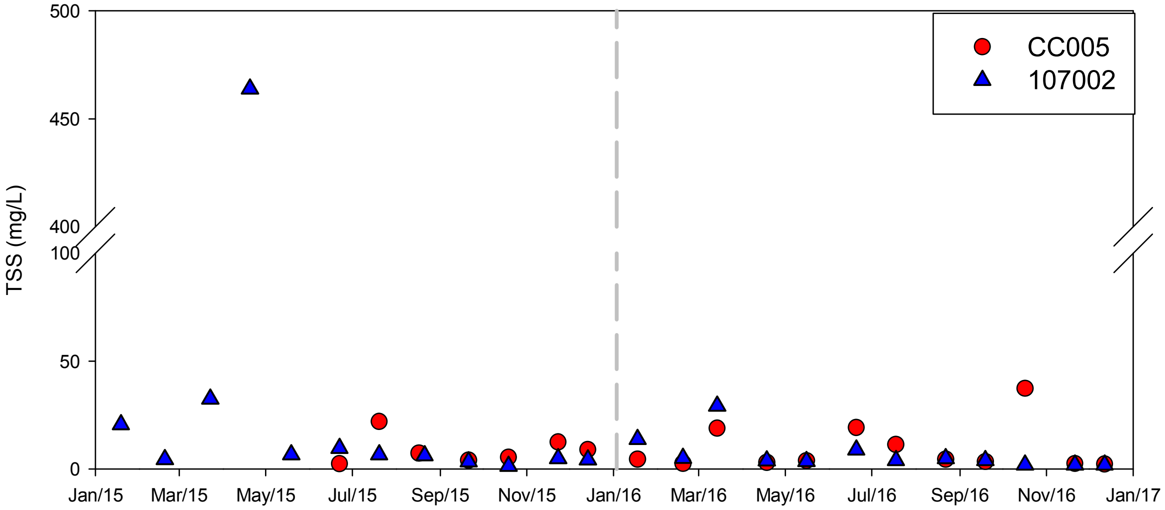

Figure 28. Regional Watershed Monitoring Program TSS concentrations in 2015 and 2016 at CC005 and 107002.

Similar to total phosphorus, there is no statistical difference in mean TSS concentrations between the wet and dry years (CC005 p-value = 0.947 ; 107002 p-value = 0.296), or between seasons (CC005 p-value = 0.846 ; 107002 p-value = 0.316) at either sampling location with the current dataset.

4. Conclusions

Surface water quality in Carruthers Creek is variable and reflects the local sources, contributions, and land use in the watershed.

The headwaters, influenced by major highway construction and agricultural influences, contain elevated concentrations of total phosphorus, phosphate, total ammonia, *E. coli*, TSS, turbidity, and some trace metals during runoff events. Elevated soluble and particulate components during runoff events indicate that over land transport and erosion are important to the observed water quality in the creek. Median nitrate concentrations were often similar during both low flow and runoff events, which could indicate that groundwater influences may also have similar nitrate.

Below the Lake Iroquois shoreline, upstream of the urban development, concentrations were reduced for the majority of the parameters, except chloride concentrations which increased. If groundwater contributions are substantial in this area and groundwater quality is improved in the agricultural headwaters, decreases in concentrations are not unexpected, as it would dilute in-stream concentrations. The observed increase in chloride concentrations may be due to the residential estate subdivision influences in the eastern branch of the creek.

Chloride levels regularly exceed the threshold for the protection of aquatic life and are concentrated in the reaches of the creek with urban influences. Increased concentrations of total ammonia, nitrite, phosphate, turbidity, and trace metals are often observed downstream of the urban area over concentrations upstream of the urban area. As expected, concentrations of many water quality variables were elevated during runoff flow/wet weather, particularly phosphorus, *E. coli*, nitrate, TSS, and some trace metals. Exceedances of the PWQOs and CWQGs were often second highest at the urban area sampling location. Although trace metals were elevated during wet weather, they did not exceed PWQOs. However, chloride exceeded the CWQG 16/17 times downstream of the urban area, illustrating the effects that urbanisation can have on the watercourse during both dry and wet periods. This suggests that stormwater and erosion aid in the transport of nutrients and pollutants from the urban area.

Understanding watershed delivery of nutrients, pollutants and materials that affect water quality in the nearshore of Lake Ontario is fundamental to inform management of both the lake and the watersheds that drain into it. While in-lake and tributary water quality studies are underway at the same time as the Carruthers Watershed Plan update, they are not a component of the initial phase of the watershed study. However, TRCA continues to collaborate with Federal and Provincial scientists to monitor, model, and report on tributary loads from the Carruthers Watershed and to follow the transport and mixing of these loads and watershed runoff upon entry to the Ajax waterfront – work that has been on-going since the mid-1990s. As information becomes available on the land-lake connections, this knowledge base will be incorporated into future water quality management recommendations for the Carruthers Watershed.

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Appendices

A. Water Quality Summary Tables
B. Water Quality Summary Graphs

Appendix A.

Appendix A1. Summary of 17 water quality samples collected approximately monthly from June 2015 to May 2016

			Minimum			Maximum			Average			Median		
ANALYTE	**Unit**	**PWQO**	**107002**	**CC005**	**CC011**	**107002**	**CC005**	**CC011**	**107002**	**CC005**	**CC011**	**107002**	**CC005**	**CC011**
Alkalinity, Total	mg/L		126	181	186	266	326	309	192	270	265	191	279	270
Aluminium, Total	mg/L		0.04	0.02	0.05	1.16	0.39	1.51	0.21	0.08	0.37	0.12	0.04	0.26
Ammonia, Total	mg/L		0.008	0.008	0.008	0.088	0.055	0.121	0.036	0.025	0.039	0.030	0.021	0.026
Anions	meq/L		7.07	5.41	5.24	15.20	9.51	8.01	9.96	8.20	7.01	9.57	8.28	6.91
Antimony, Total	mg/L	0.02	0.0004	0.0004	0.0002	0.0010	0.0010	0.0009	0.001	0.0007	0.0006	0.0007	0.0007	0.0005
Arsenic, Total	mg/L	0.005	0.0005	0.0004	0.0005	0.0007	0.0005	0.0008	0.001	0.0005	0.0005	0.0005	0.0005	0.0005
Barium, Total	mg/L		0.041	0.040	0.039	0.063	0.070	0.072	0.049	0.053	0.057	0.047	0.052	0.056
Beryllium, Total	mg/L	1.1	0.0001	0.0001	0.0001	0.0005	0.0005	0.0005	0.000	0.0005	0.0005	0.0005	0.0005	0.0005
Bromide, Total	mg/L		0.04	0.04	0.04	0.20	0.08	0.08	0.08	0.05	0.04	0.08	0.04	0.04
Cadmium, Total	mg/L	0.0005	0.0001	0.0001	0.0001	0.0005	0.0005	0.0005	0.000	0.0005	0.0005	0.0005	0.0005	0.0005
Calcium, Total	mg/L		62	68	64	139	135	123	93	112	101	92	110	106
Cations	meq/L		7.14	5.58	5.38	15.70	9.95	8.44	10.09	8.40	7.14	9.76	8.43	7.32
Chloride	mg/L	120/640[1]	116	57	25	302	98	68	183	72	35	175	70	32
Chromium, Total	mg/L		0.0005	0.0005	0.0005	0.0026	0.0029	0.0042	0.001	0.0007	0.0009	0.0005	0.0005	0.0005
Cobalt, Total	mg/L	0.0009	0.0004	0.0003	0.0005	0.0012	0.0005	0.0013	0.00054	0.0005	0.00063	0.0005	0.0005	0.0005
Conductivity, Specific	µS/cm		715	516	489	1500	888	738	979	751	622	953	759	628
Copper, Total	mg/L	0.005	0.0005	0.0005	0.0005	0.0048	0.0019	0.0033	0.001	0.0009	0.0013	0.0012	0.0008	0.0011
Escherichia coli (E. coli)	CFU/100mL	100	1	3	1	5600	2800	3000	706	517	475	110	130	140
Fluoride	mg/L	0.12[1]	0.08	0.07	0.07	0.20	0.14	0.13	0.124	0.11	0.11	0.13	0.11	0.11
Hardness, Total	mg/L		185	199	184	413	403	365	280	333	310	284	330	329
Ionic Balance	%		0.01	0.38	0.01	1.75	2.52	4.43	0.67	1.19	1.59	0.56	1.13	1.06
Iron, Total	mg/L	0.30	0.17	0.11	0.12	1.72	0.72	1.66	0.37	0.26	0.48	0.24	0.23	0.37
Langelier Index			1.4	1.2	1.2	2.1	1.9	1.8	1.8	1.7	1.6	1.8	1.7	1.6
Lead, Total	mg/L	0.005	0.0005	0.0002	0.0005	0.0025	0.0007	0.0035	0.001	0.0005	0.0009	0.0005	0.0005	0.0005
Magnesium, Total	mg/L		8	7	6	16	16	17	12	13	14	12	14	14
Manganese, Total	mg/L		0.0165	0.0267	0.0221	0.1680	0.0999	0.1940	0.055	0.0526	0.0706	0.0435	0.0439	0.0475
Molybdenum, Total	mg/L	0.04	0.0005	0.0005	0.0002	0.0025	0.0025	0.0025	0.002	0.0024	0.0024	0.0025	0.0025	0.0025
Nickel, Total	mg/L	0.025	0.0006	0.0005	0.0005	0.0024	0.0018	0.0026	0.001	0.0009	0.0011	0.0008	0.0008	0.0009
Nitrate	mg/L	550/1500[1]	0.03	0.02	0.40	1.35	1.84	6.96	0.44	0.61	2.15	0.37	0.27	1.74
Nitrates (Nitrate + Nitrite)	mg/L		0.03	0.02	0.41	1.36	1.85	6.98	0.45	0.61	2.16	0.39	0.28	1.76
Nitrite	mg/L		0.001	0.001	0.003	0.022	0.011	0.032	0.008	0.003	0.011	0.007	0.002	0.008
Nitrogen, Total Kjeldahl (TKN)	mg/L		0.23	0.17	0.36	1.14	0.91	1.70	0.53	0.49	0.65	0.50	0.46	0.58
pH	Units	6.5-8.5	8.0	8.1	8.0	8.5	8.5	8.4	8.2	8.2	8.2	8.2	8.2	8.2
Phosphate (SRP/Orthophosphate)	mg/L		0.002	0.002	0.002	0.034	0.025	0.094	0.009	0.008	0.020	0.006	0.007	0.012
Phosphorus, Total	mg/L	0.03	0.007	0.005	0.012	0.217	0.114	0.454	0.044	0.031	0.091	0.033	0.022	0.045
Potassium, Total	mg/L		2.0	1.2	1.3	3.0	5.4	5.1	2.4	2.3	2.2	2.2	2.0	2.0
Selenium, Total	mg/L	0.001[1]	0.0003	0.0003	0.0005	0.0018	0.0009	0.0024	0.0006	0.0005	0.0009	0.0005	0.0005	0.0005
Sodium, Total	mg/L		61	32	14	169	49	37	102	39	21	98	39	18
Solids, Dissolved (TDS)	mg/L		479	293	283	871	599	486	607	481	405	589	472	400
Solids, Suspended (TSS)	mg/L	30[2]	2	2	4	157	45	300	20	11	59	7	7	32
Strontium, Total	mg/L		0.211	0.196	0.171	0.416	0.381	0.432	0.302	0.314	0.321	0.302	0.314	0.320
Sulphate	mg/L		31.3	9.5	15.5	59.8	95.6	67.4	44.5	35.7	31.6	43.1	32.4	28.6
Titanium, Total	mg/L		0.01	0.01	0.01	0.25	0.27	0.25	0.10	0.11	0.10	0.06	0.09	0.07
Turbidity	NTU	11[3]	0.19	0.32	0.24	101	25	233	13	6	42	6	4	16
Vanadium, Total	mg/L	0.006	0.0005	0.0005	0.0005	0.0038	0.0014	0.0043	0.001	0.0006	0.0014	0.0010	0.0005	0.0015
Zinc, Total	mg/L	0.02	0.0005	0.0005	0.0007	0.0147	0.0049	0.0086	0.003	0.0013	0.0032	0.0017	0.0011	0.0025

[1] Water Quality Guideline for the Protection of Aquatic Life (CCME)

[2] Water Quality Guideline for the Protection of Aquatic Life (CCME); baseline assumed to be 5 mg/L, should not exceed baseline +25 mg/L

[3] Water Quality Guideline for the Protection of Aquatic Life (CCME); baseline assumed to be 3 NTU, should not exceed baseline +8 NTU

Appendix A2. Summary of 17 water quality samples collected approximately monthly from June 2015 to May 2016 broken down into low flow versus runoff

			Minimum						Maximum						Average						Median					
			107002		CC005		CC011		107002		CC005		CC011		107002		CC005		CC011		107002		CC005		CC011	
ANALYTE	**Unit**	**PWQO**	**Low (n=7)**	**Runoff (n=10)**	**Low (n=7)**	**Runoff (n=10)**	**Low (n=7)**	**Runoff (n=10)**	**Low (n=7)**	**Runoff (n=10)**	**Low (n=7)**	**Runoff (n=10)**	**Low (n=7)**	**Runoff (n=10)**	**Low (n=7)**	**Runoff (n=10)**	**Low (n=7)**	**Runoff (n=10)**	**Low (n=7)**	**Runoff (n=10)**	**Low (n=7)**	**Runoff (n=10)**	**Low (n=7)**	**Runoff (n=10)**	**Low (n=7)**	**Runoff (n=10)**
Alkalinity, Total	mg/L		126	135	253	181	232	186	266	258	326	304	299	309	206	183	291	255	271	260	204	180	295	252	277	268
Aluminium, Total	mg/L		0.052	0.040	0.015	0.024	0.056	0.054	0.144	1.160	0.153	0.394	0.342	1.510	0.097	0.297	0.046	0.107	0.184	0.505	0.100	0.176	0.034	0.065	0.147	0.322
Ammonia, Total	mg/L		0.008	0.010	0.008	0.008	0.008	0.008	0.088	0.088	0.055	0.048	0.104	0.121	0.034	0.038	0.027	0.023	0.049	0.033	0.030	0.028	0.034	0.021	0.049	0.022
Anions	meq/L		7.07	7.97	7.69	5.41	6.08	5.24	15.20	12.00	9.46	9.51	7.60	8.01	10.27	9.74	8.53	7.97	6.81	7.16	9.90	9.47	8.54	8.13	6.86	7.36
Antimony, Total	mg/L	0.02	0.0006	0.0004	0.0005	0.0004	0.0005	0.0002	0.0009	0.0010	0.0010	0.0010	0.0008	0.0009	0.0007	0.0007	0.0007	0.0007	0.0006	0.0006	0.0007	0.0007	0.0007	0.0007	0.0007	0.0005
Arsenic, Total	mg/L	0.005	0.0005	0.0005	0.0005	0.0004	0.0005	0.0005	0.0006	0.0007	0.0005	0.0005	0.0008	0.0007	0.0005	0.0006	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Barium, Total	mg/L		0.041	0.044	0.043	0.040	0.039	0.044	0.062	0.063	0.070	0.070	0.056	0.072	0.049	0.049	0.056	0.051	0.051	0.061	0.047	0.046	0.056	0.048	0.052	0.063
Beryllium, Total	mg/L	1.1	0.0005	0.0001	0.0005	0.0001	0.0005	0.0001	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Bromide, Total	mg/L		0.04	0.04	0.04	0.04	0.04	0.04	0.20	0.08	0.08	0.08	0.04	0.08	0.09	0.07	0.05	0.05	0.04	0.04	0.08	0.08	0.04	0.04	0.04	0.04
Cadmium, Total	mg/L	0.0005	0.0005	0.0001	0.0005	0.0001	0.0005	0.0001	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Calcium, Total	mg/L		66	62	101	68	79	64	139	120	135	132	116	123	100	88	117	108	101	102	95	84	120	108	106	106
Cations	meq/L		7.14	8.06	7.82	5.58	6.13	5.38	15.70	12.30	9.85	9.95	7.83	8.44	10.44	9.85	8.72	8.18	7.03	7.22	10.00	9.53	8.62	8.29	7.32	7.27
Chloride	mg/L	120/640[1]	116	129	58	57	25	27	302	248	94	98	34	68	182	184	72	72	30	38	177	175	73	66	30	34
Chromium, Total	mg/L		0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0026	0.0005	0.0029	0.0005	0.0042	0.0005	0.0010	0.0005	0.0008	0.0005	0.0011	0.0005	0.0006	0.0005	0.0005	0.0005	0.0005
Cobalt, Total	mg/L	0.0009	0.0005	0.0004	0.0005	0.0003	0.0005	0.0005	0.0005	0.0012	0.0005	0.0005	0.0005	0.0013	0.0005	0.0006	0.0005	0.0005	0.0005	0.0007	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Conductivity, Specific	uS/cm		715	717	720	516	532	489	1500	1200	857	888	691	738	1015	954	781	731	612	629	984	945	776	748	627	639
Copper, Total	mg/L	0.005	0.0007	0.0005	0.0005	0.0005	0.0005	0.0005	0.0012	0.0048	0.0010	0.0019	0.0015	0.0033	0.0009	0.0017	0.0007	0.0011	0.0009	0.0016	0.0008	0.0013	0.0006	0.0010	0.0008	0.0013
Escherichia coli (E. coli)	CFU/100mL	100	1	4	3	4	1	1	300	5600	310	2800	210	3000	95	1133	92	815	75	754	9	275	15	230	11	640
Fluoride	mg/L	0.12[1]	0.08	0.08	0.07	0.08	0.07	0.08	0.20	0.15	0.14	0.13	0.12	0.13	0.14	0.12	0.11	0.11	0.10	0.11	0.13	0.12	0.11	0.11	0.10	0.12
Hardness, Total	mg/L		199	185	301	199	259	184	413	353	403	388	350	365	300	266	350	320	311	309	285	254	358	320	329	325
Ionic Balance	%		0.09	0.01	0.38	0.47	0.41	0.01	1.75	1.40	2.02	2.52	3.24	4.43	0.81	0.58	1.06	1.28	1.61	1.58	0.78	0.40	1.13	1.03	1.49	1.02
Iron, Total	mg/L	0.30	0.179	0.171	0.112	0.164	0.115	0.164	0.265	1.720	0.418	0.719	0.555	1.660	0.210	0.488	0.224	0.282	0.304	0.610	0.191	0.315	0.193	0.231	0.249	0.438
Langelier Index			1.6	1.4	1.6	1.2	1.2	1.3	2.1	2.0	1.9	1.8	1.8	1.7	1.8	1.7	1.8	1.7	1.6	1.6	1.8	1.8	1.8	1.7	1.6	1.6
Lead, Total	mg/L	0.005	0.0005	0.0005	0.0005	0.0002	0.0005	0.0005	0.0005	0.0025	0.0005	0.0007	0.0006	0.0035	0.0005	0.0008	0.0005	0.0005	0.0005	0.0012	0.0005	0.0005	0.0005	0.0005	0.0005	0.0006
Magnesium, Total	mg/L		8.6	8.0	12.0	6.9	12.3	6.0	16.0	15.0	16.0	15.0	16.5	17.4	12.5	11.3	14.4	12.4	14.4	13.2	13.0	11.0	14.4	13.0	14.3	14.1
Manganese, Total	mg/L		0.0165	0.0191	0.0307	0.0267	0.0221	0.0362	0.0829	0.1680	0.0903	0.0999	0.0969	0.1940	0.0437	0.0634	0.0515	0.0534	0.0454	0.0882	0.0426	0.0506	0.0415	0.0445	0.0431	0.0643
Molybdenum, Total	mg/L	0.04	0.0025	0.0005	0.0025	0.0005	0.0025	0.0002	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0023	0.0025	0.0023	0.0025	0.0023	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
Nickel, Total	mg/L	0.025	0.0006	0.0007	0.0005	0.0006	0.0005	0.0005	0.0014	0.0024	0.0018	0.0014	0.0013	0.0026	0.0008	0.0011	0.0009	0.0008	0.0008	0.0013	0.0008	0.0009	0.0008	0.0008	0.0006	0.0009
Nitrate	mg/L	550/1500[1]	0.026	0.031	0.018	0.026	0.400	0.719	1.080	1.350	1.840	1.540	3.180	6.960	0.443	0.438	0.595	0.619	1.996	2.258	0.413	0.271	0.516	0.232	2.230	1.710
Nitrates (Nitrate + Nitrite)	mg/L		0.026	0.032	0.018	0.026	0.411	0.726	1.090	1.360	1.850	1.540	3.200	6.980	0.450	0.446	0.600	0.622	2.004	2.270	0.427	0.284	0.519	0.236	2.240	1.725
Nitrite	mg/L		0.001	0.001	0.001	0.001	0.003	0.004	0.014	0.022	0.006	0.011	0.025	0.032	0.007	0.009	0.003	0.003	0.011	0.012	0.007	0.007	0.003	0.002	0.007	0.008
Nitrogen, Total Kjeldahl (TKN)	mg/L		0.23	0.29	0.17	0.36	0.42	0.36	0.61	1.14	0.50	0.91	0.70	1.70	0.46	0.58	0.39	0.56	0.54	0.73	0.42	0.51	0.40	0.54	0.58	0.62
pH (lab)	Units	6.5-8.5	8.1	8.0	8.1	8.1	8.0	8.0	8.5	8.4	8.5	8.3	8.4	8.3	8.3	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2
Phosphate (SRP/Orthophosphate)	mg/L		0.003	0.002	0.002	0.002	0.002	0.003	0.007	0.034	0.007	0.025	0.021	0.094	0.005	0.011	0.004	0.011	0.010	0.026	0.005	0.011	0.003	0.011	0.009	0.017
Phosphorus, Total	mg/L	0.03	0.007	0.014	0.005	0.012	0.017	0.012	0.053	0.217	0.041	0.114	0.095	0.454	0.026	0.056	0.022	0.038	0.045	0.123	0.021	0.039	0.022	0.033	0.036	0.065
Potassium, Total	mg/L		2.0	2.0	1.2	1.4	1.3	1.4	3.0	3.0	3.0	5.4	2.0	5.1	2.5	2.4	2.0	2.6	1.7	2.6	2.2	2.3	2.0	2.1	1.7	2.6
Selenium, Total	mg/L	0.001[1]	0.0005	0.0003	0.0005	0.0003	0.0005	0.0005	0.0005	0.0018	0.0005	0.0009	0.0012	0.0024	0.0005	0.0006	0.0005	0.0005	0.0006	0.0010	0.0005	0.0005	0.0005	0.0005	0.0005	0.0008
Sodium, Total	mg/L		61	65	33	32	15	14	169	142	47	49	21	37	100	103	38	39	18	23	98	98	40	37	18	20
Solids, Dissolved (TDS)	mg/L		479	489	437	293	364	283	871	711	599	545	486	462	630	591	507	463	404	406	616	556	528	468	381	414
Solids, Suspended (TSS)	mg/L	30[2]	1.5	3.5	2.4	3.9	6.5	3.9	11.4	157.0	22.0	45.3	49.6	300.0	6.2	29.8	7.9	13.2	23.0	83.8	5.1	12.4	5.5	10.4	21.6	38.2
Strontium, Total	mg/L		0.234	0.211	0.252	0.196	0.246	0.171	0.416	0.375	0.364	0.381	0.336	0.432	0.314	0.293	0.322	0.308	0.300	0.336	0.304	0.291	0.347	0.305	0.302	0.343
Sulphate	mg/L		37.4	31.3	14.0	9.5	17.2	15.5	59.8	52.1	51.7	95.6	31.7	67.4	46.9	42.8	30.9	39.0	24.6	36.6	47.8	42.4	31.5	33.1	24.9	29.6
Titanium, Total	mg/L		0.0363	0.0096	0.0690	0.0050	0.0519	0.0076	0.2110	0.2450	0.2160	0.2700	0.1780	0.2500	0.0915	0.0994	0.1089	0.1128	0.0927	0.1044	0.0625	0.0591	0.0873	0.0830	0.0669	0.0628
Turbidity	NTU	11[3]	2.99	0.19	1.68	0.32	2.60	0.24	10.40	101.00	14.10	25.20	50.00	233.00	5.40	17.81	4.91	6.67	18.05	58.10	4.70	7.49	3.57	4.95	9.53	26.45
Vanadium, Total	mg/L	0.006	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0012	0.0038	0.0007	0.0014	0.0019	0.0043	0.0008	0.0013	0.0005	0.0006	0.0010	0.0018	0.0005	0.0011	0.0005	0.0005	0.0007	0.0015
Zinc, Total	mg/L	0.02	0.0008	0.0005	0.0005	0.0005	0.0010	0.0007	0.0022	0.0147	0.0020	0.0049	0.0068	0.0086	0.0014	0.0041	0.0011	0.0015	0.0026	0.0035	0.0013	0.0023	0.0011	0.0011	0.0026	0.0023

[1] Water Quality Guideline for the Protection of Aquatic Life (CCME)

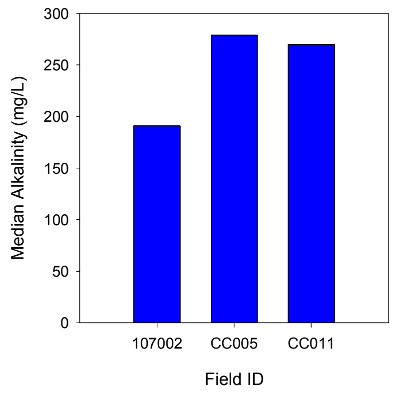
[2] Water Quality Guideline for the Protection of Aquatic Life (CCME); baseline assumed to be 5 mg/L, should not exceed baseline +25 mg/L

[3] Water Quality Guideline for the Protection of Aquatic Life (CCME); baseline assumed to be 3 NTU, should not exceed baseline +8 NTU

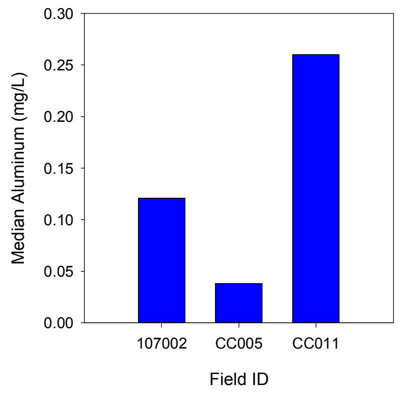
Appendix B.

Appendix B1. Median water quality values by site (n=17) for 2015/2016

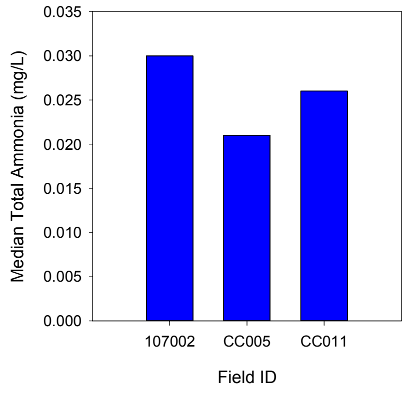
Alkalinity



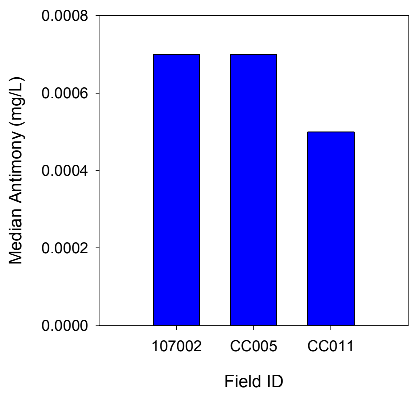
Aluminum



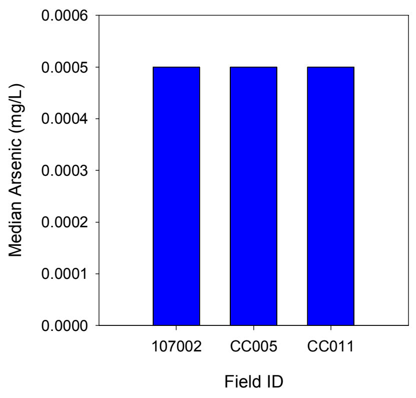
Total Ammonia



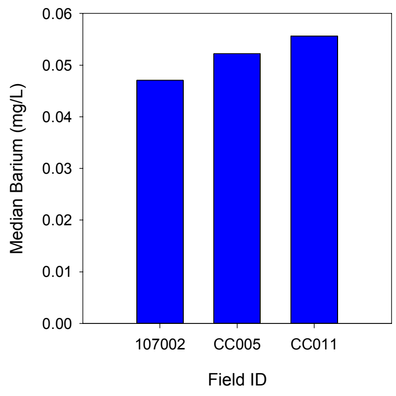
Antimony



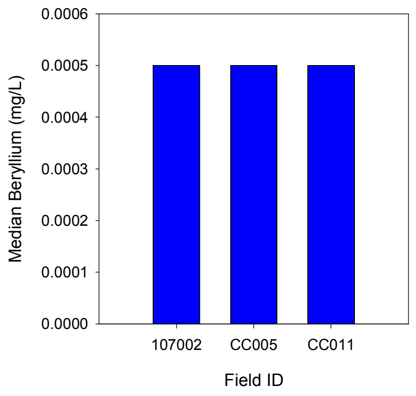
Arsenic



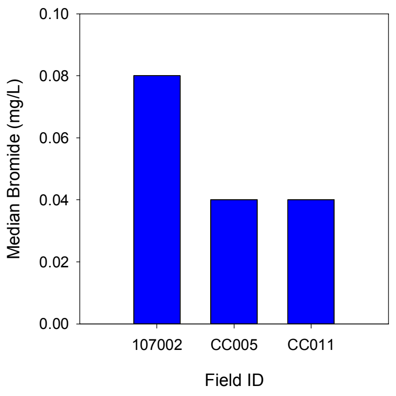
Barium



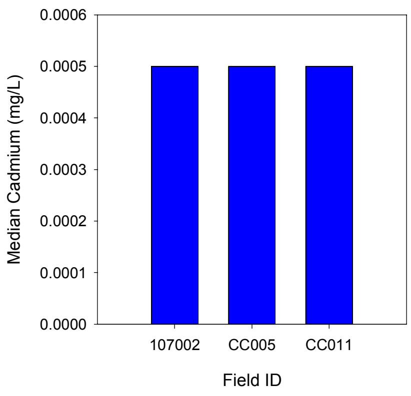
Beryllium



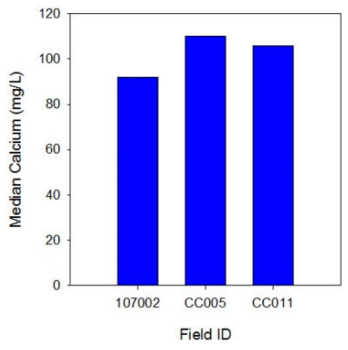
Bromide



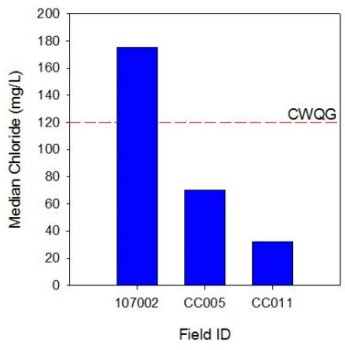
Cadmium



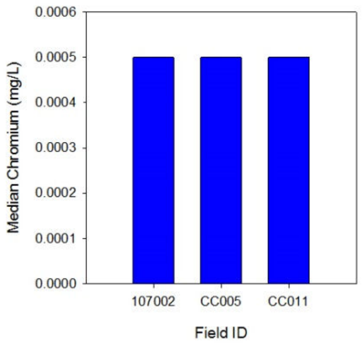
Calcium



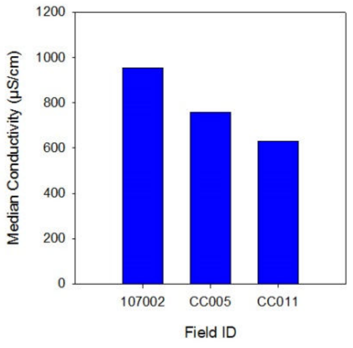
Chloride



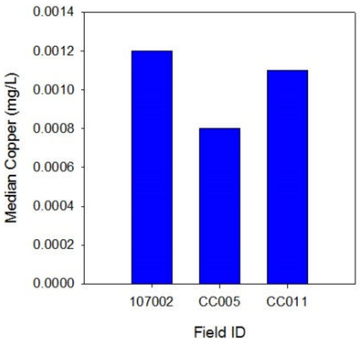
Chromium



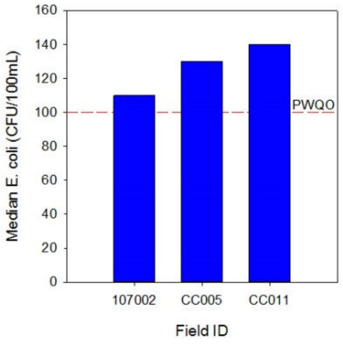
Conductivity



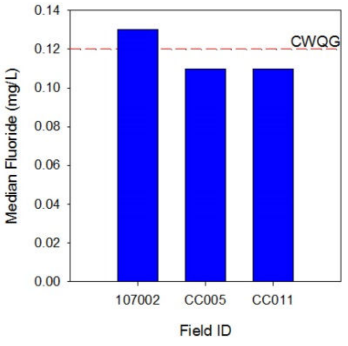
Copper



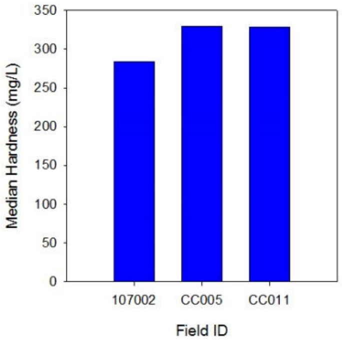
E. coli



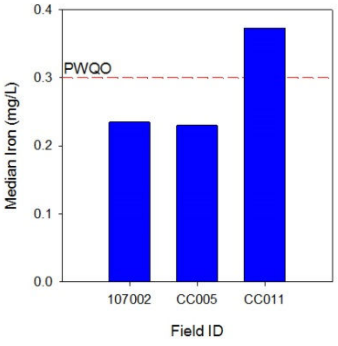
Fluoride



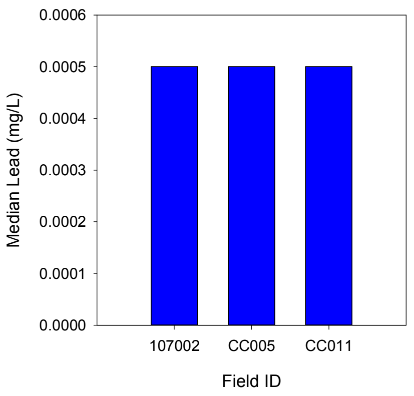
Hardness



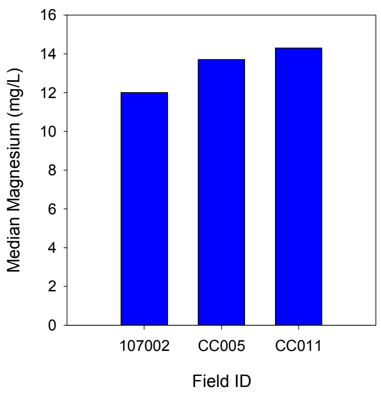
Iron



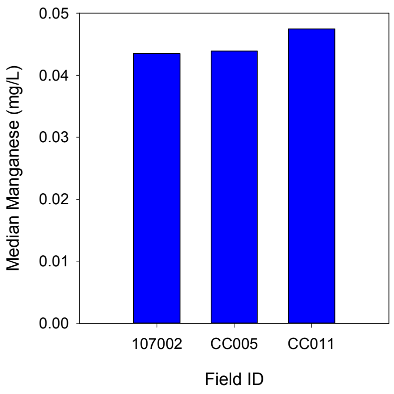
Lead



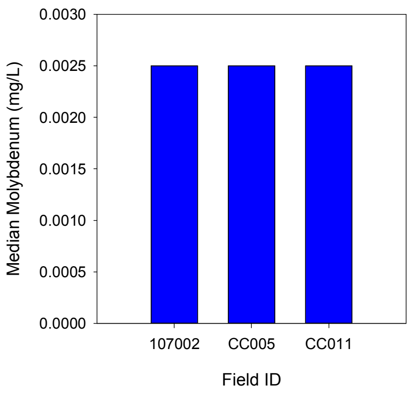
Magnesium



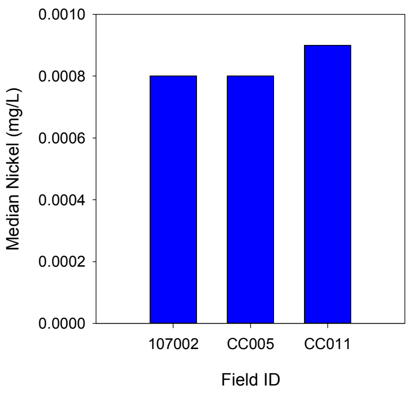
Manganese



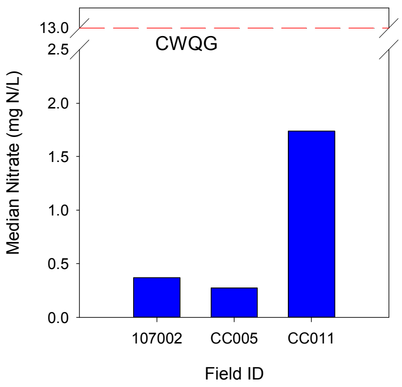
Molybdenum



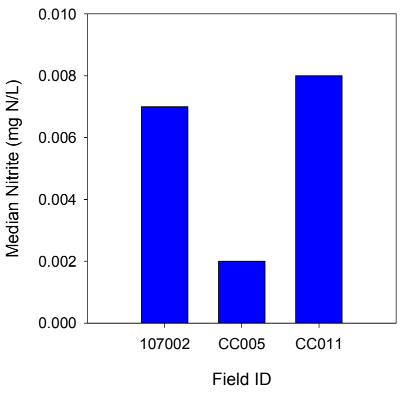
Nickel



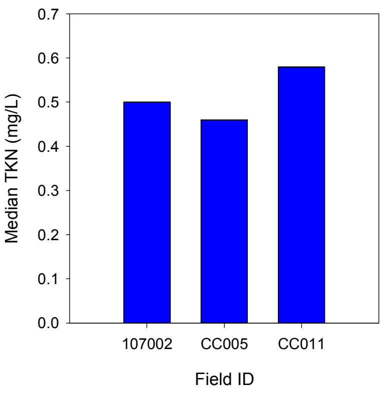
Nitrate



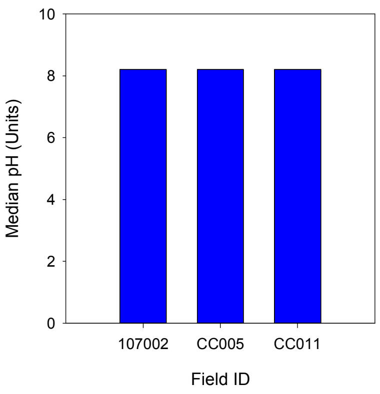
Nitrite



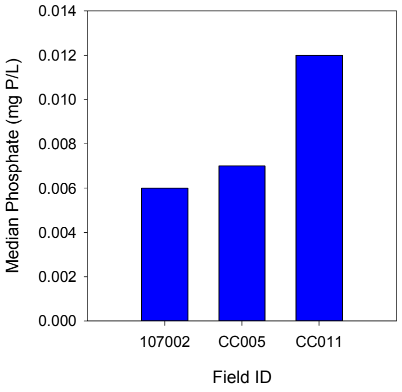
TKN



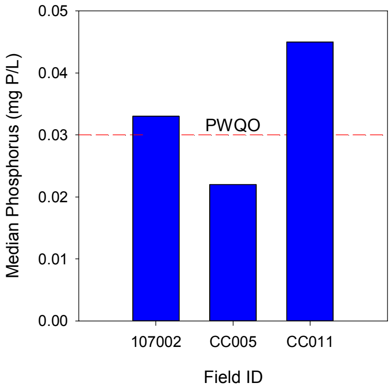
pH



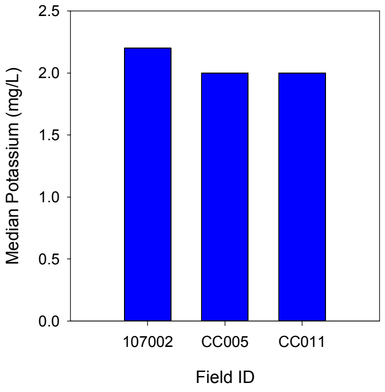
Phosphate



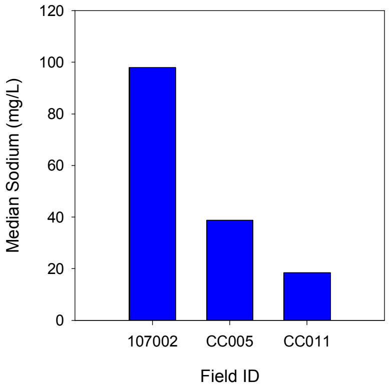
Phosphorus



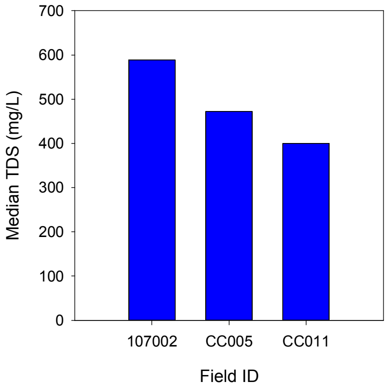
Potassium



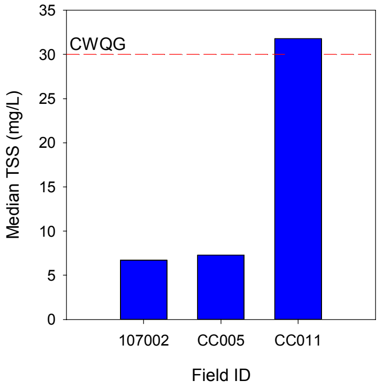
Sodium



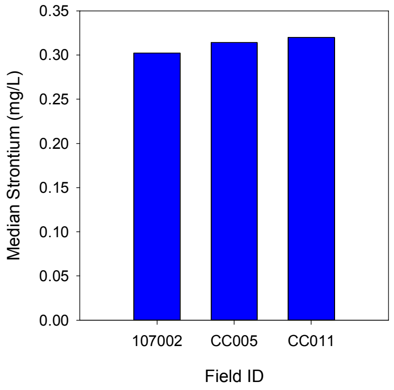
TDS



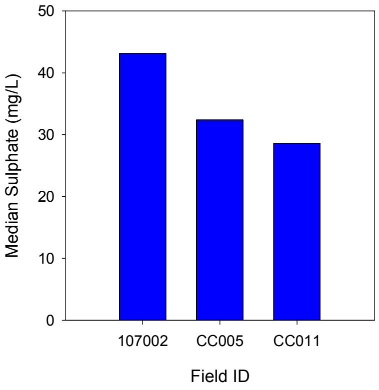
TSS



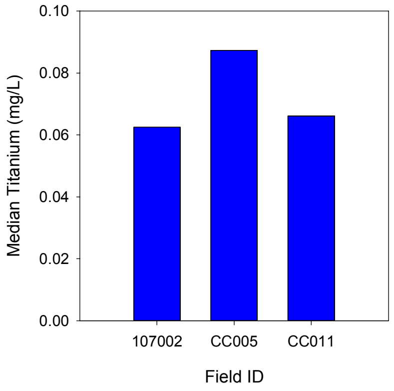
Strontium

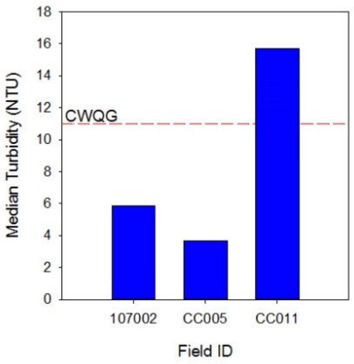
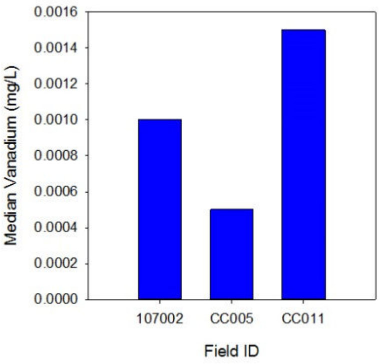
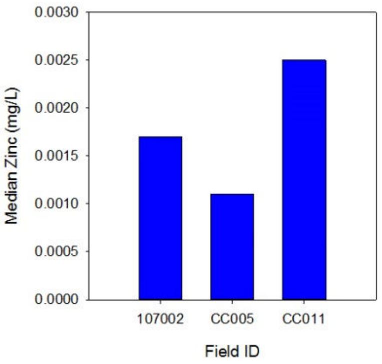


Sulphate



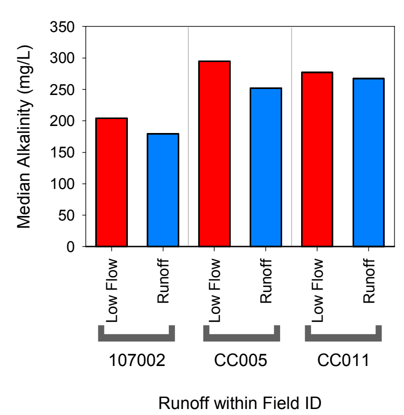
Titanium



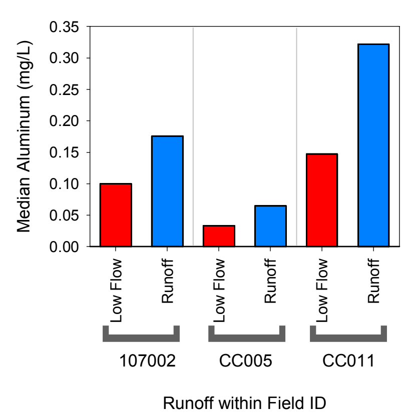
Turbidity	**Vanadium**	**Zinc**
		

Appendix B2. Median water quality values by site (n=17) for low flow (n=7) versus runoff (n=10)

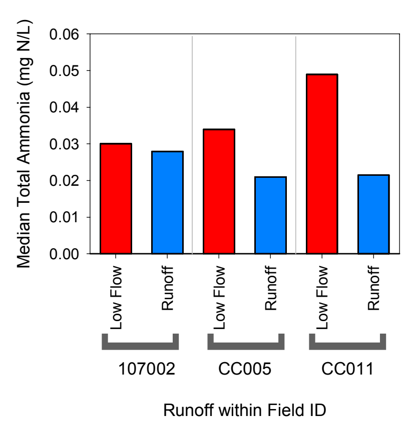
Alkalinity



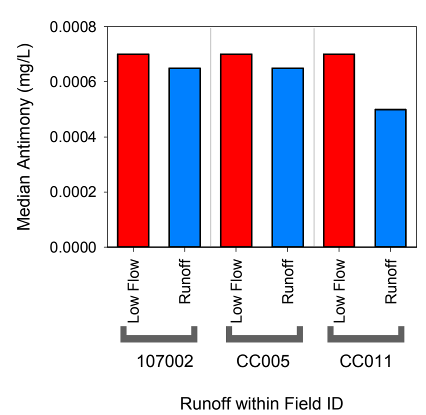
Aluminum



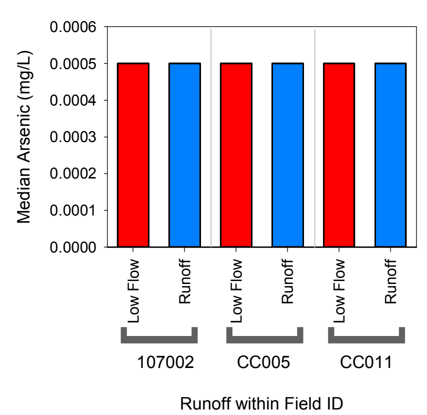
Total Ammonia



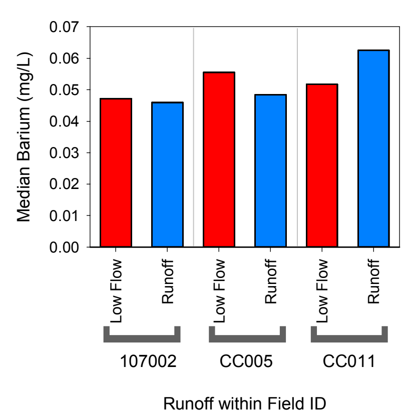
Antimony



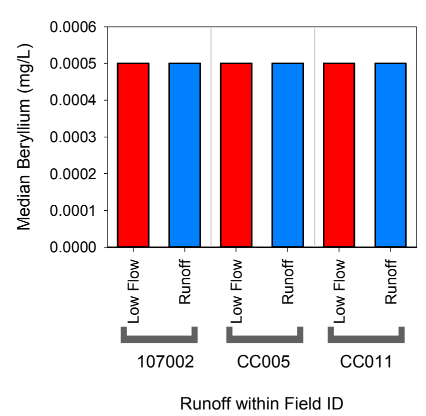
Arsenic



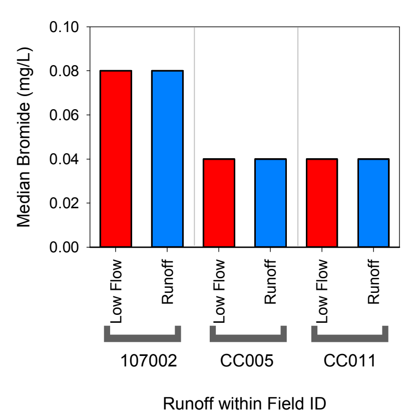
Barium



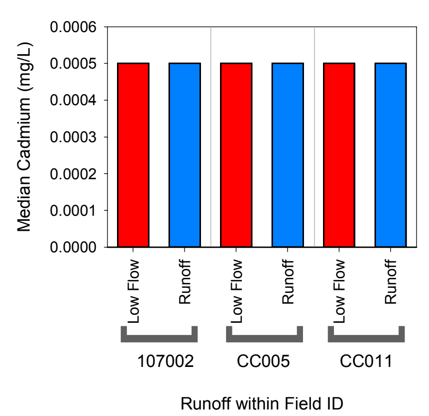
Beryllium



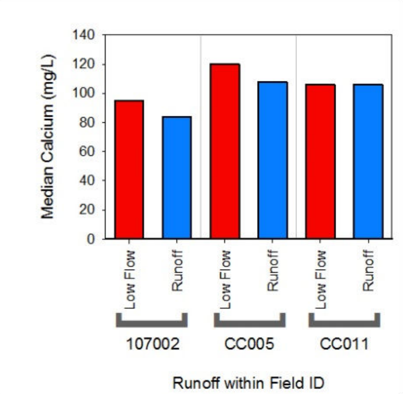
Bromide



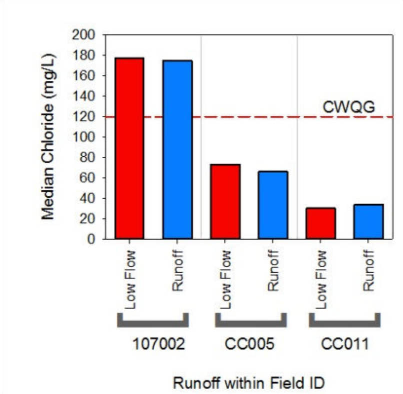
Cadmium



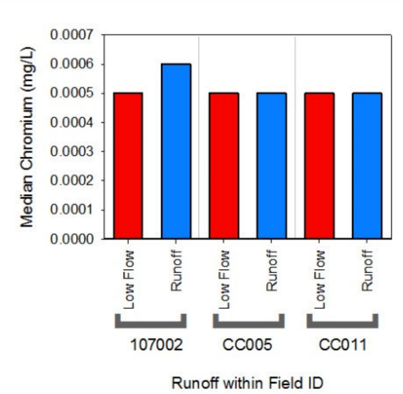
Calcium



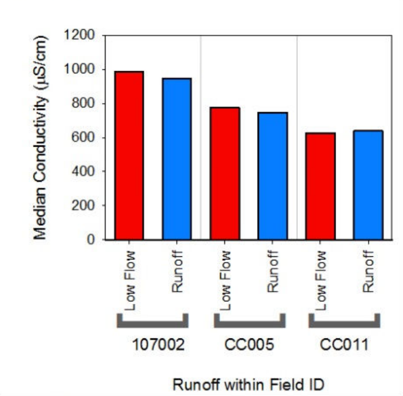
Chloride



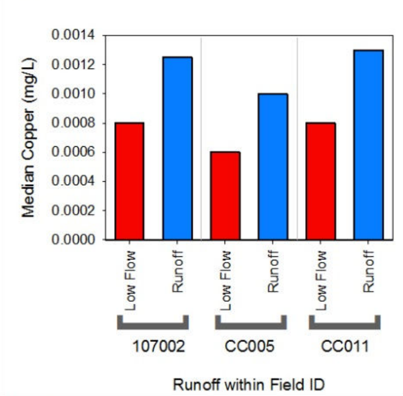
Chromium



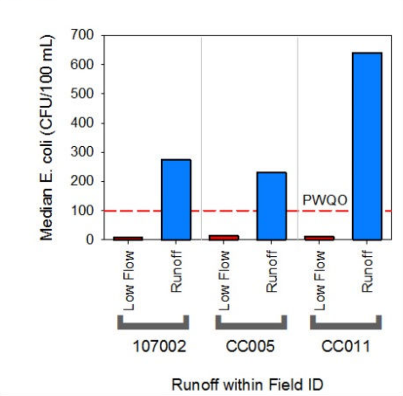
Conductivity



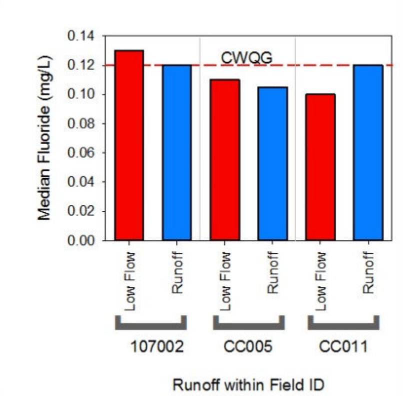
Copper



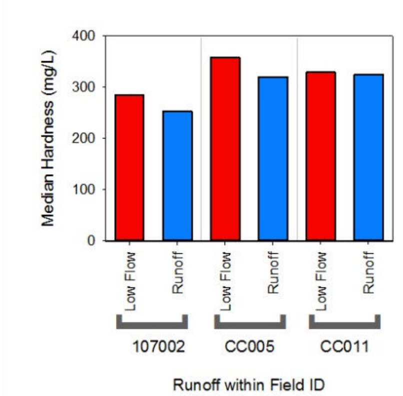
E. coli



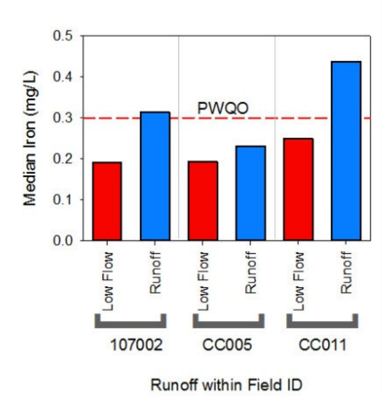
Fluoride



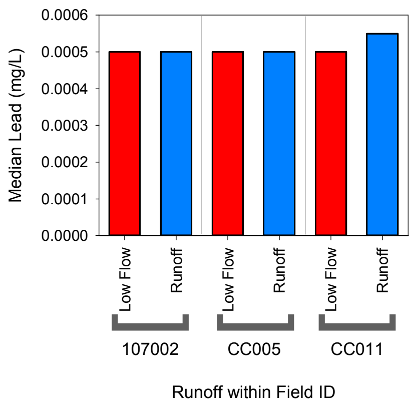
Hardness



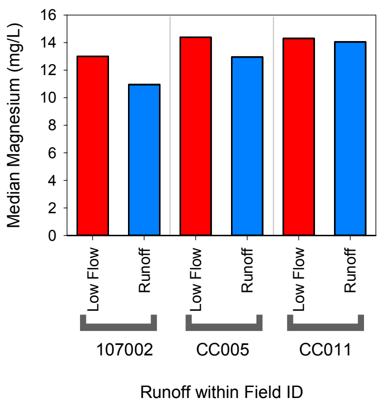
Iron



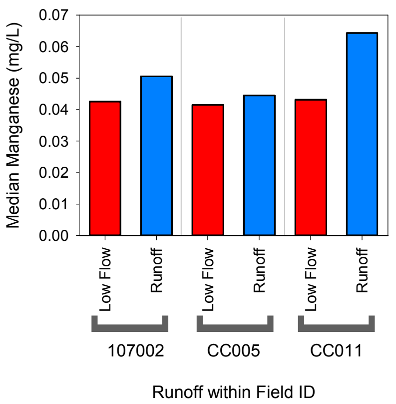
Lead



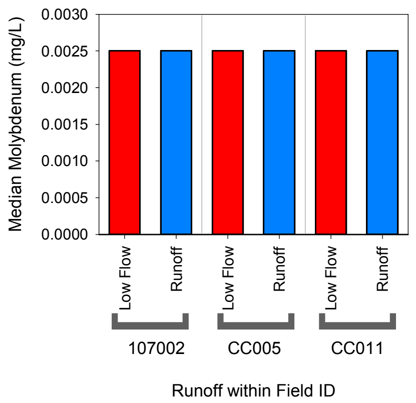
Magnesium



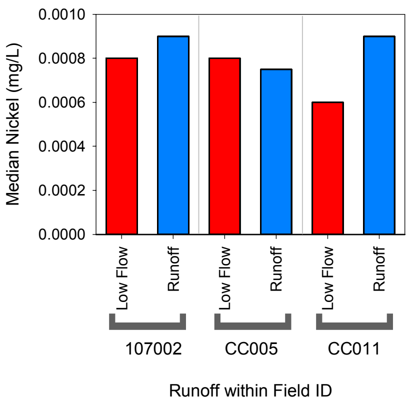
Manganese



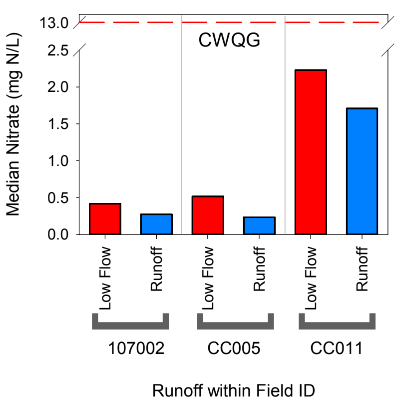
Molybdenum



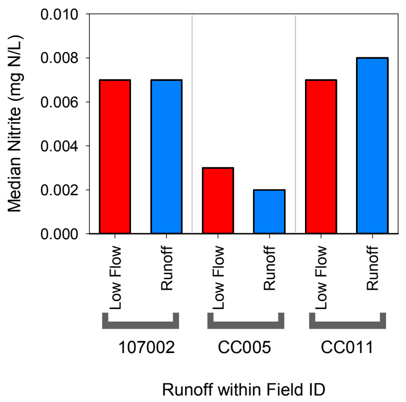
Nickel



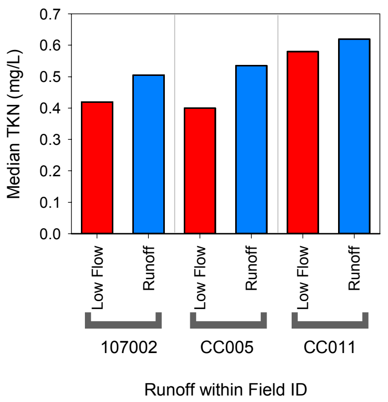
Nitrate



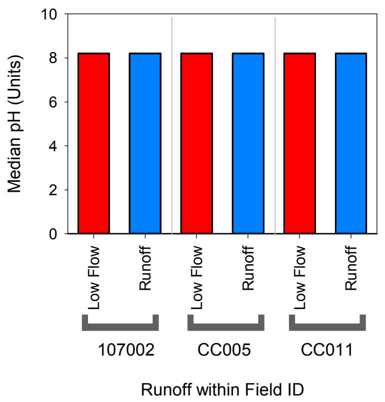
Nitrite



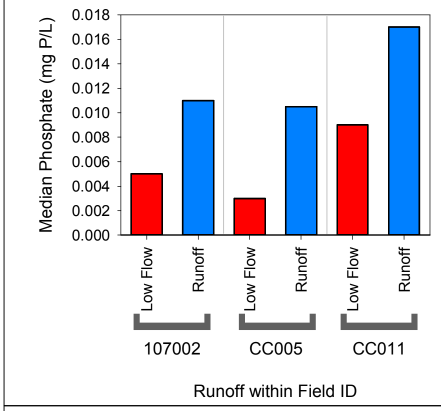
TKN



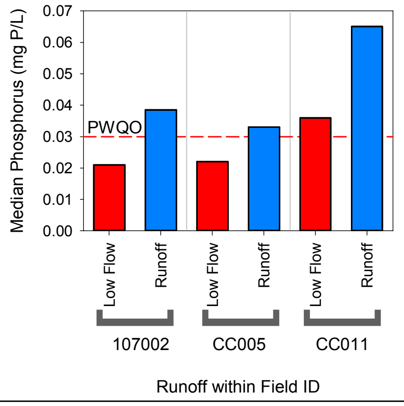
pH



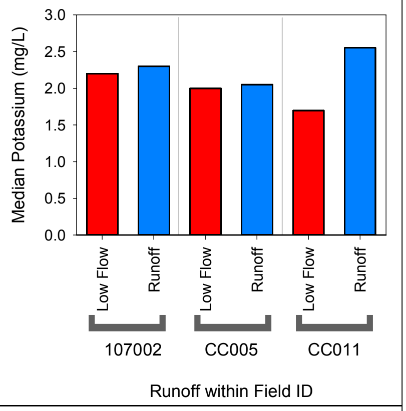
Phosphate



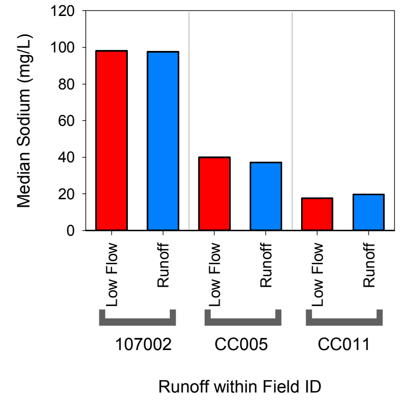
Phosphorus



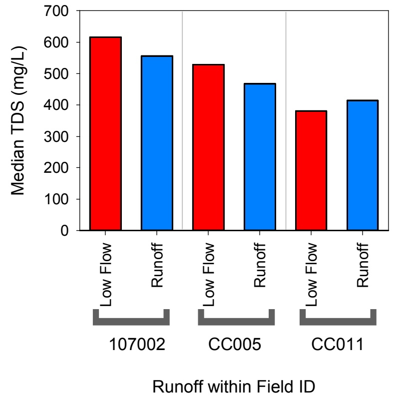
Potassium



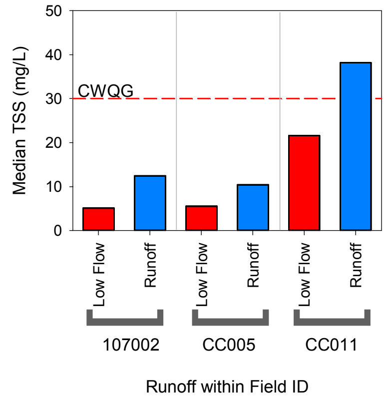
Sodium



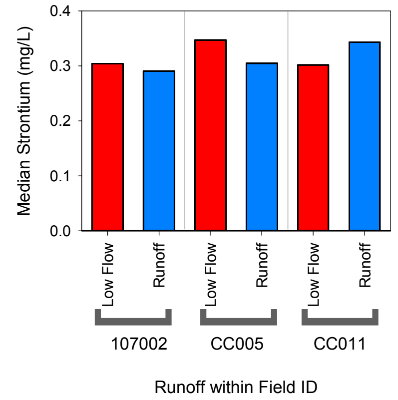
TDS



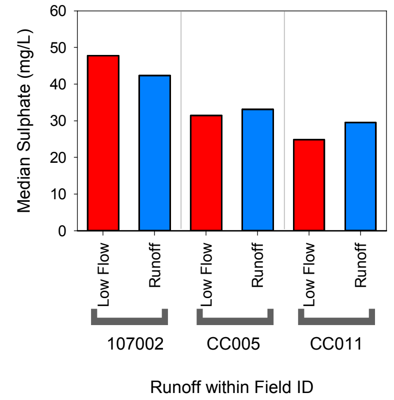
TSS



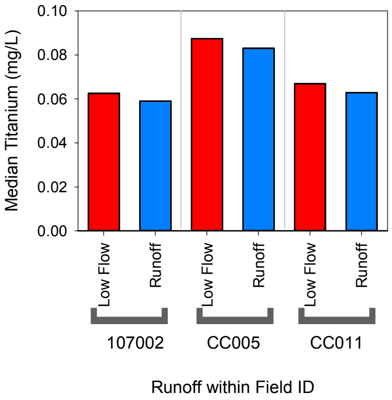
Strontium



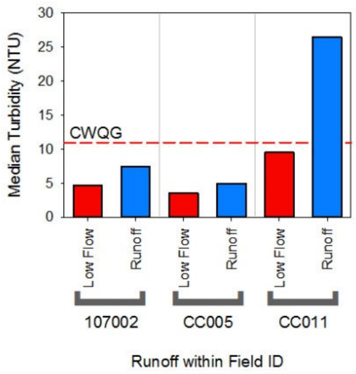
Sulphate



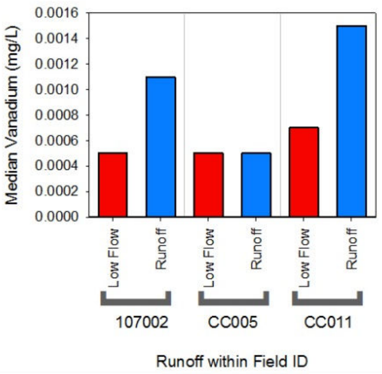
Titanium



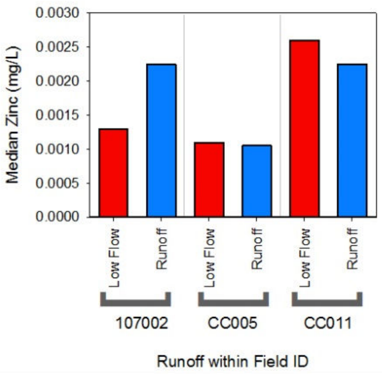
Turbidity



Vanadium

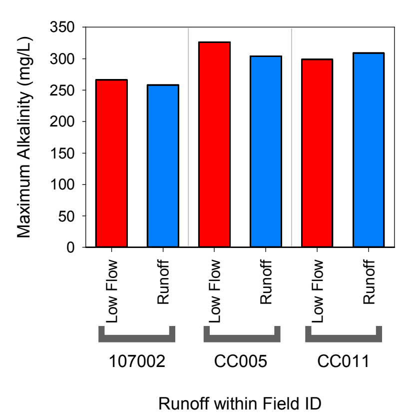


Zinc

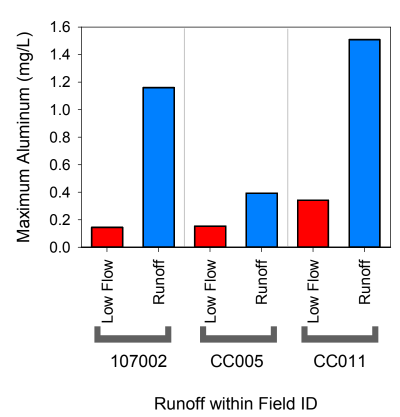


Appendix B3. Maximum water quality values by site (n=17) for low flow (n=7) versus runoff (n=10)

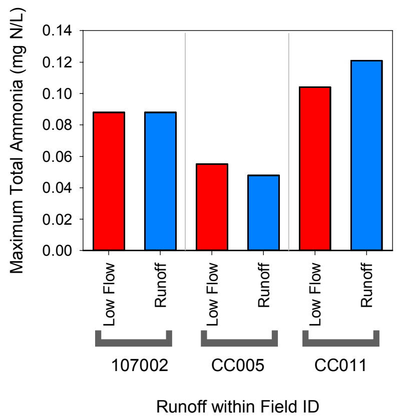
Alkalinity



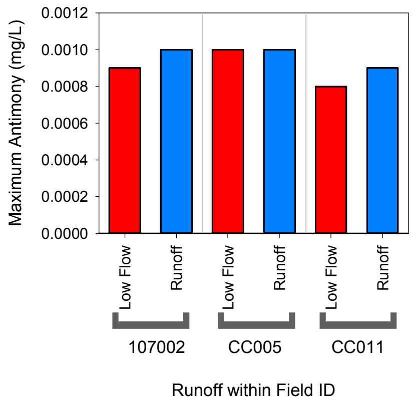
Aluminum



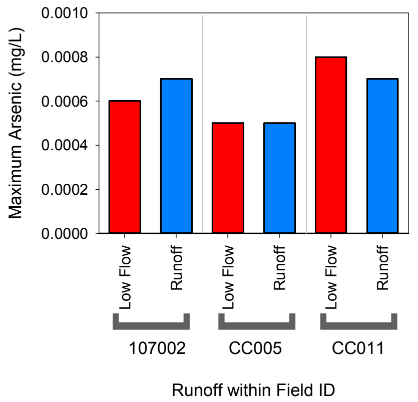
Total Ammonia



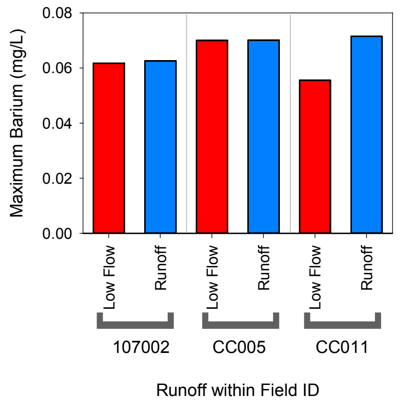
Antimony



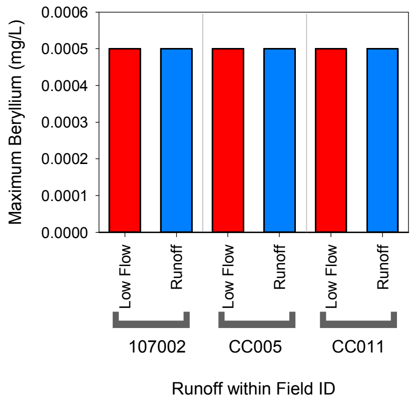
Arsenic



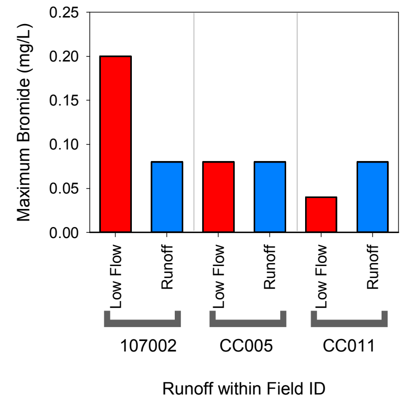
Barium



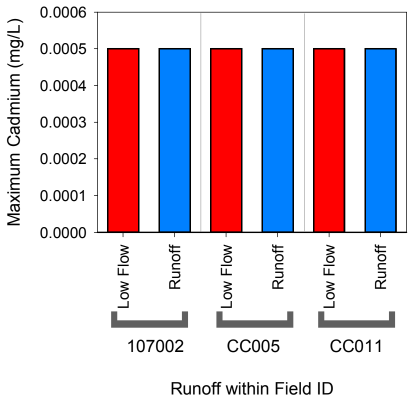
Beryllium



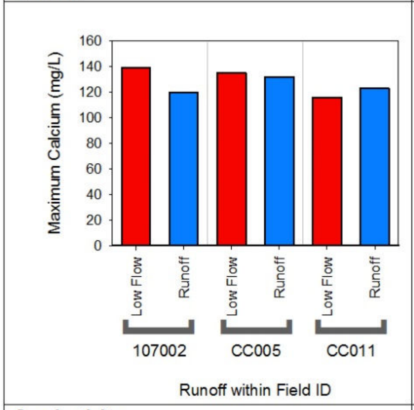
Bromide



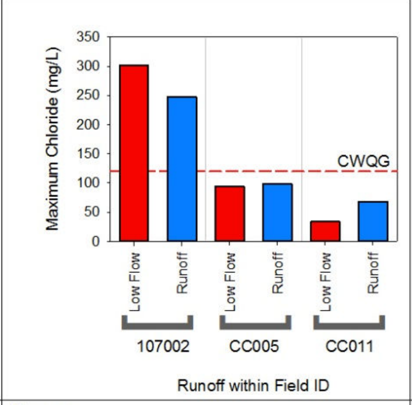
Cadmium



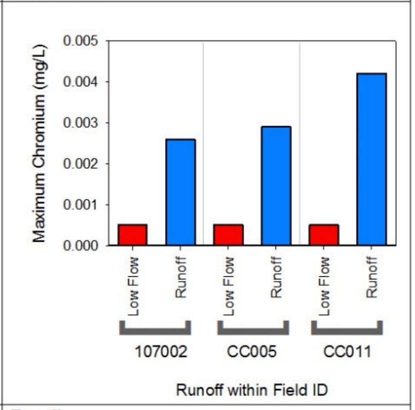
Calcium



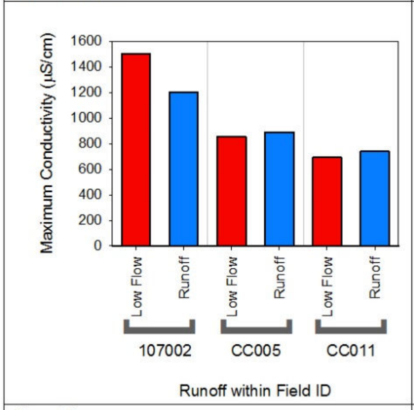
Chloride



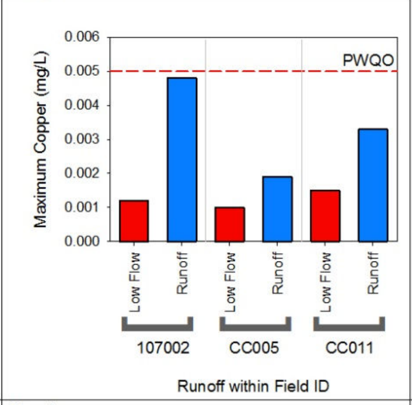
Chromium



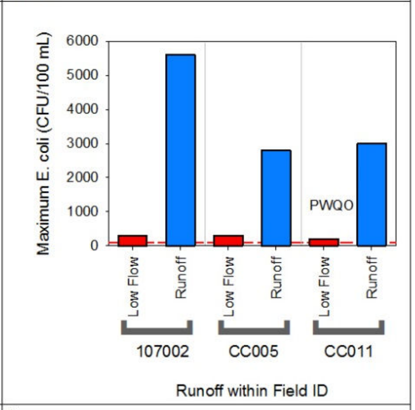
Conductivity



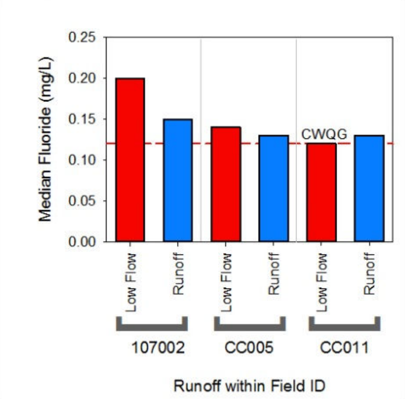
Copper



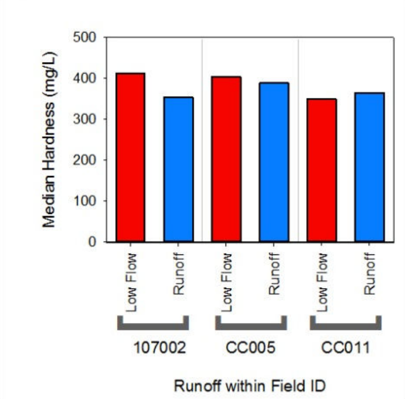
E. coli



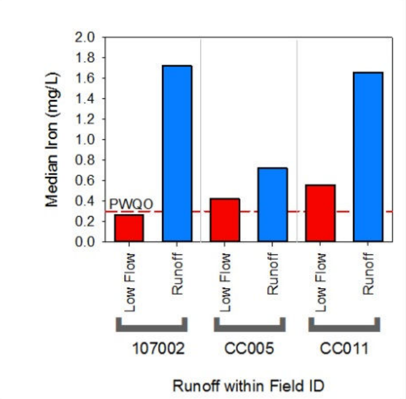
Fluoride



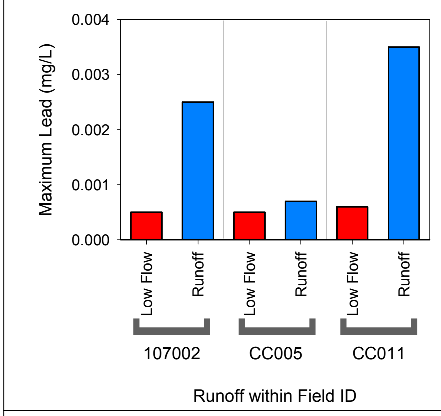
Hardness



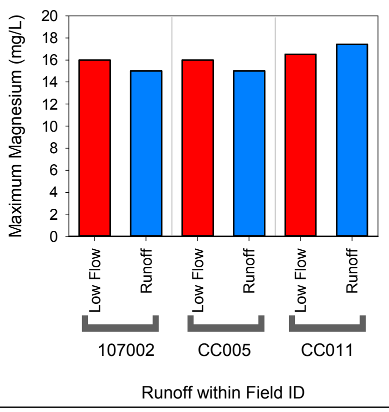
Iron



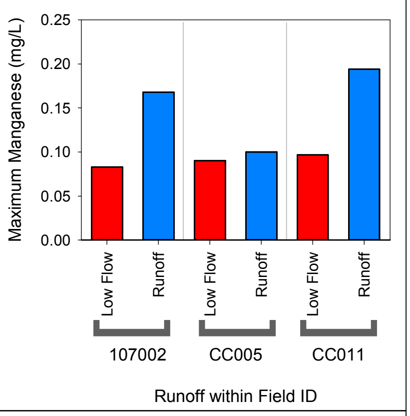
Lead



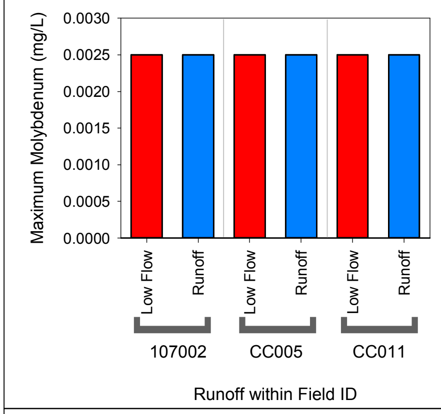
Magnesium



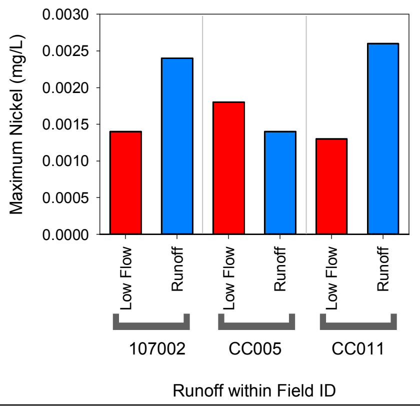
Manganese



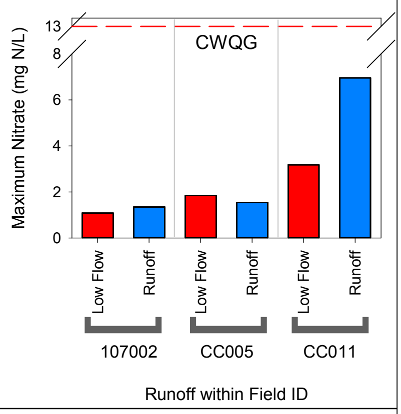
Molybdenum



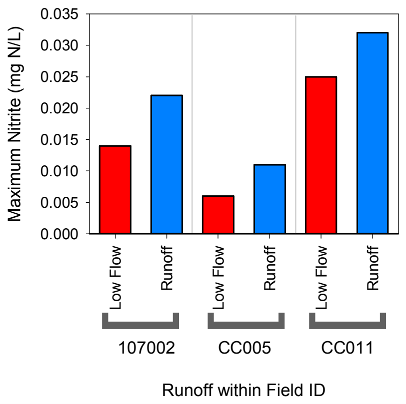
Nickel



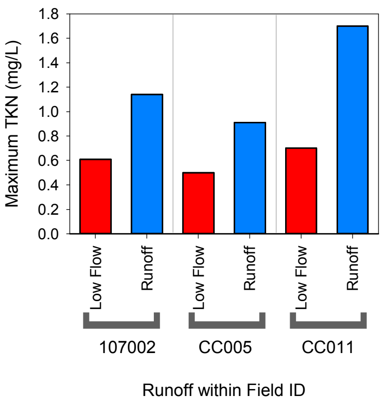
Nitrate



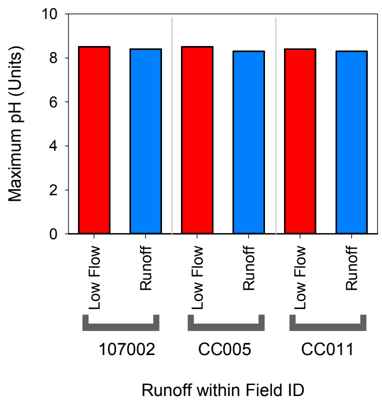
Nitrite



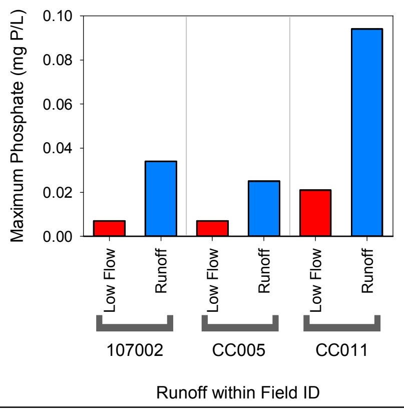
TKN



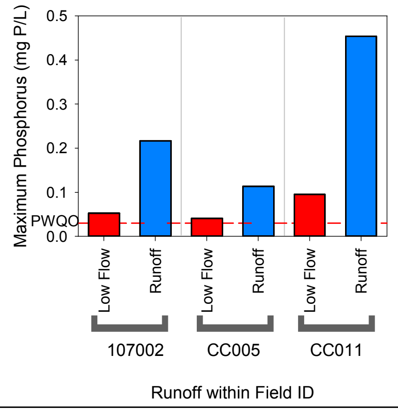
pH



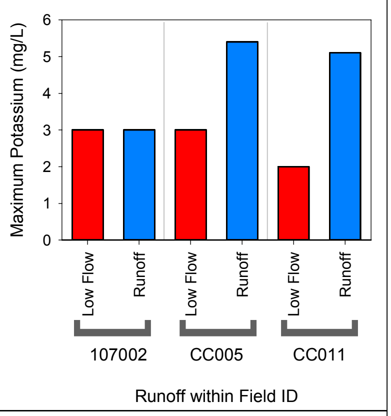
Phosphate



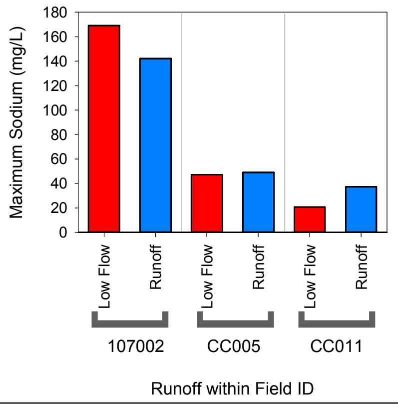
Phosphorus



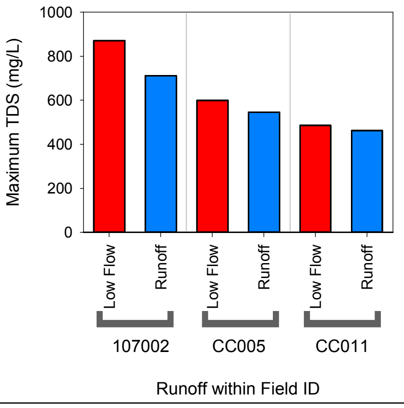
Potassium



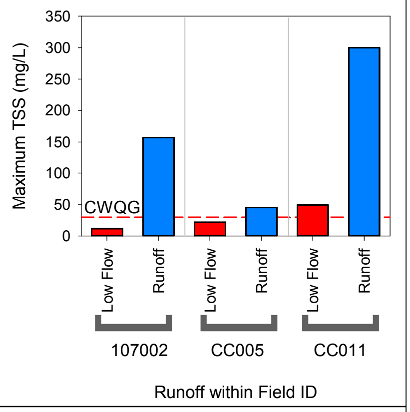
Sodium



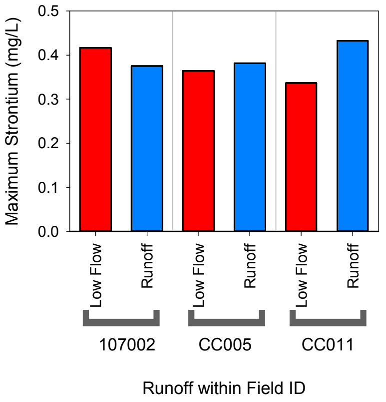
TDS



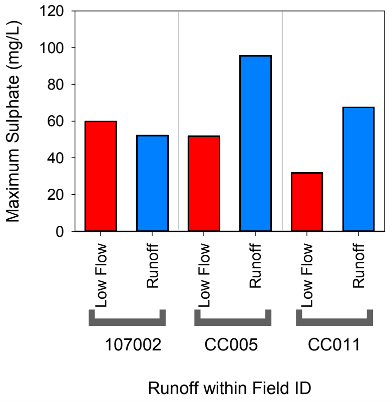
TSS



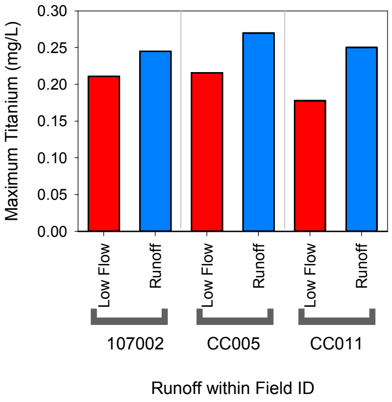
Strontium



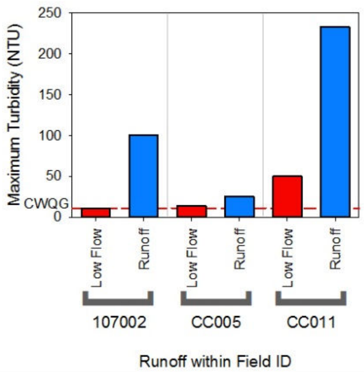
Sulphate



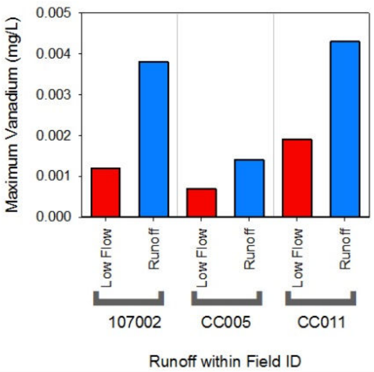
Titanium



Turbidity



Vanadium



Zinc