Water Quality in the Grand River Watershed: Current Conditions & Trends (2003 – 2008)

H.A. Loomer and S.E. Cooke

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Executive Summary

The Grand River watershed in south-western Ontario is the largest Canadian watershed that drains to Lake Erie. Water quality in the Grand River is generally reflective of both the inherent geology and land use. The landscape through which the river flows is largely shaped by the underlying bedrock of marine origin and glacial deposits of varying qualities and has a great influence on the natural state of water quality in the river. The watershed supports some of the most intensive agricultural production in Ontario as well as a rapidly growing urban population in the cities of Guelph, Waterloo, Kitchener, Cambridge and Brantford. The river system is currently valued for many things, in particular as having a variety of angling and recreational activities; as a receiver of wastewater from 30 communities of varying sizes; a provider of drinking water for four communities and an aquatic ecosystem which supports a variety of valued flora and fauna.

Water quality monitoring is a fundamental part of an overall adaptive management strategy for managing water in a watershed. Monitoring and reporting on the state or condition of the resource is a strategic approach in which management actions can be identified to either maintain or improve conditions. The Grand River Conservation Authority, in partnership with the Ministry of the Environment, undertake routine monitoring of the chemical and physical character of the Grand River and its tributaries from March through to November at 28 sampling sites. In addition, the Grand River Conservation Authority maintains seven water quality monitoring stations at sentinel locations to continuously monitor the physical characteristics (e.g. dissolved oxygen, pH, conductivity and temperature) of the river. These data are required for applying an in-river model – the Grand River Simulation Model, which is a decision support tool for evaluating key management approaches (i.e. improved wastewater treatment) to improve water quality. These monitoring and modelling programs combine to provide the baseline information to understand the state of water quality in the watershed. However, a lack of systematic information on aquatic communities limits any evaluation of the overall aquatic health of the Grand River system.

This report is a summary of the chemical and physical characteristics of the Grand River and its tributaries from 2003 to 2008. Most of the water quality information is limited to the spring and summer seasons. Specific focus is placed on describing the general water quality in the context of the key water quality issues in the watershed including nutrient (phosphorus and nitrogen), chloride and suspended sediment concentrations. In addition, spatial trends, for example, evaluating how water quality changes from the head waters to the river mouth where it discharges to Lake Erie is explored. Conditions in the river are compared to existing objectives such as the provincial water quality objectives, the federal environmental quality guidelines or established basin-specific benchmarks. Investigation into the relationships between variables (e.g. total suspended sediment and total phosphorus; total phosphorus and flow) is also described.

The report is separated into eight chapters. The first chapter describes the background information on the watershed and the overall analytical approach. Chapters two through seven describes the general geology, land use and general state of water quality for each of the major subbasins. The final chapter provides an overview of the entire watershed and its influence on Lake Erie.

Upper Grand River Basin

The upper Grand River subbasin drains the Dundalk till plain. This area generates a lot of runoff during the spring which is captured in two major water bodies: Luther Marsh and Belwood Reservoir. These multi-purpose reservoirs are used to reduce flooding in downstream municipalities during high flow periods but also to augment flows in the river during the summer. Since much of this region is dedicated to extensive agriculture and wetland areas, the water quality upstream of the reservoir tends to be good as phosphorus and nitrogen levels are at or maybe slightly above the provincial objectives. Given that Belwood Reservoir receives much of the spring runoff from the headwater region; nutrients tend to accumulate in the reservoir. This, along with internal cycling of nutrients, tends to elevate nutrient levels throughout the summer which promotes the growth of algae in late summer and fall. The reservoir also acts as a source of nutrients to the river downstream.

Conestogo River Basin

The Conestogo subbasin has some of the most intensive agricultural production and some of the most intense municipal and tile drainage networks in the Grand River watershed. Very little of the watershed area is treed or has natural wetland areas. The upper subbasin drains a silty till plain, and similar to the upper Grand River subbasin, generates a significant amount of runoff during the spring. The runoff is collected and stored in the Conestogo reservoir to reduce flooding impacts downstream but also to supply water to the lower Conestogo River which then discharges to the Grand River near the village of Conestogo. The reservoir has consistently high phosphorus levels, likely as a result of the upstream runoff but also from internal nutrient cycling, which promotes yearly blooms of algae and cyanobacteria. Similar to Belwood, the Conestogo reservoir also acts as a source of nutrients to the river downstream. Given the geology and land use in this subbasin, water quality tends to be only fair or even marginal with clearly elevated nitrogen and phosphorus levels in the rivers.

Speed / Eramosa River Basin

Some of the best water quality can be found in the Speed/Eramosa River subbasin. The less-intensive land use, high percentage of treed and wetland areas, combined with the local geology – the upper reaches of the Paris-Galt Moraine and the sandier tills located in the upper Speed River subbasin, all combine to have good or even excellent water quality. Runoff from the upper Speed River is collected in Guelph Lake to reduce flooding downstream as well as augment Speed River flows in the summer. Nutrients tend to accumulate in the shallow lake resulting in regular algae blooms. The reservoir is also a nutrient source to the lower Speed River.

The City of Guelph is a large city on a small river. During low flow periods in the summer, the discharge of the Guelph wastewater treatment plant almost equals the discharge from the Guelph dam. However, a commitment to advanced wastewater treatment and wastewater treatment plant optimization goes a long way to minimize the city’s impact on the lower Speed River. This is clearly illustrated by the long-term monitoring of dissolved oxygen levels in the lower Speed River at Wellington Road 32. Oxygen levels are maintained above the provincial objective consistently. High nitrate levels in the river downstream of the city, however, are being identified as a concern now and into the future.

Nith River Basin

The Nith River flow is not regulated by large dams and reservoirs. The geology of the upper Nith River basin is a silty till which promotes substantive runoff during the springtime. It also has very intensive agricultural production and a dense municipal and tile drainage network. These factors combine to cause river water quality to be marginal in the headwater region. High phosphorus and total suspended sediments tend to be the predominant water quality issue in the upper and middle Nith River region. As the Nith River flows downstream, however, groundwater influx into the river from the Waterloo Moraine helps to moderate or improve phosphorus levels, especially during the summer. However, nitrate levels, likely from nitrate-rich groundwater, tend to increase as the river approaches its outlet to the Grand River in the town of Paris.

Central Grand River Region

The central Grand River region contains most of the watershed's population. Water in the Grand River through Fergus and Elora is sustained by discharges from Belwood Lake therefore; water quality in the river is a reflection of the water quality in the reservoir. Generally, nutrient levels in the river are at or slightly above the provincial objectives due to the biochemical processes in the lake (e.g. anoxic bottom waters). The effects of the cities of Elora and Fergus are generally minor on the Grand River, and the resulting water quality through this area is generally fair to good. Furthermore, the water discharged from the Shand Dam is cold and this, combined with good water quality, provides the optimal environment for a world-class brown trout tailwater fishery.

As the Grand River flows toward the Region of Waterloo, it collects flow from the Irvine, Canagagigue and Conestogo. High phosphorus concentrations during spring runoff are characteristic of the strong influence of non-point sources such as runoff from rural land use activities. Nitrate concentrations in these river systems tend to be 2 to 3 times higher than those found in the Grand River suggesting that these areas contribute substantially to the overall nitrate load to the Grand River above Bridgeport, especially during the low flows in the winter.

The Canagagigue Creek drains some of the most intensive agricultural lands in the watershed. Nutrient levels in the Canagagigue Creek are among the highest in the watershed. The Woolwich reservoir, built to ensure flows are sustained in the creek during the summer so that wastewater from Elmira can be assimilated, is highly eutrophic. This is a result of the extremely high levels of both total phosphorus and nitrate in the creek that flows into the reservoir. Canagagigue Creek below the town of Elmira is influenced by urban land use activities including road salt application and wastewater treatment plant discharges as is evident by the three-fold increase in chloride levels when compared to upstream concentrations.

As the Grand River flows through the Region of Waterloo, the effluent discharges from the five wastewater treatment plants have a great influence on the water quality in the river, especially during the summer. Very high nitrogen (e.g. ammonia) and phosphorus levels in this reach sustain prolific growth of macro-algae (e.g. Cladophora) and aquatic plants. Consequently, dissolved oxygen tends to fluctuate widely on a daily basis from the activity of the algae/plants causing some areas of the river to have periodic very low dissolved oxygen levels. These factors combine to have marginal to poor water quality within the Region of Waterloo. The Speed River flows into the Grand in Cambridge and, although the Speed River is a large tributary, it does not contribute significantly to the phosphorus levels already in the river. Chloride levels in the central Grand River, however, tend to be strongly influenced by the very high levels found in the Speed.

The Grand River tends to recover as it flows toward Paris from Cambridge, likely a result of the river flowing through a steep valley with a significant elevation change so that the river meanders through many riffle sections and gets re-oxygenated. Water quality also improves, likely as a result of a significant influx of groundwater, which helps to moderate the nutrient levels in the river.

At the southern end of the central Grand River region is an area referred to as the *Exceptional Waters* reach. The reach of the Grand River between Paris and Brantford brings together the right aquatic conditions that allow for a thriving warm-water fish community yet seasonally, it can support cold water and migratory fish. Cold water entering the river from upstream groundwater discharges in the Grand and Nith Rivers, as well as Whiteman's Creek - a cold water creek, help to moderate the water quality in this region. All of these factors combine to make the reach between Paris and Brantford good habitat for a wide range of species including smallmouth bass, walleye, northern pike and a unique resident population of rainbow trout. It is also home to several fish species at risk, such as the eastern sand darter, which are found in few locations in Canada.

Southern Grand River Region

The water quality in the southern Grand River subbasin is largely a reflection of the cumulative inputs from upstream, the underlying geology of the Haldimand Clay plain and the general morphology of the river (i.e. gently sloping topography which provides for a slow moving river). Although the City of Brantford is the only major urban area within this region, it appears to have a relatively minor influence on the large river. As the river flows onto the clay plain, sediment becomes suspended in the water column and the river becomes turbid. This phenomenon is the mechanism that helps to maintain high levels of phosphorus in the river as it flows downstream toward Dunnville and Port Maitland on Lake Erie. On the other hand, the high turbidity is a suitable environment for walleye, a highly valued fish species in the southern Grand.

The effects of dams on the lower Grand River are evident. The river's flow is slowed down and water tends to be impounded behind both the Caledonia and Dunnville dams. Total phosphorus levels tend to be elevated above the dams which suggest a build-up of fine sediments behind the dams. Consequently, these on-line dams/weirs both accumulate nutrients and recycle nutrients to the lower river. Further, periods of low oxygen in the river has also been shown through intensive monitoring surveys between Cayuga and Dunnville and pollution tolerant benthic organisms were found downstream of Cayuga during surveys done by the Ministry of Natural Resources between 2003-2005.

Overall, the water quality tends to be marginal to poor at the water quality monitoring sites in the southern Grand River. The high phosphorus levels in the river at Dunnville, about four to as much as ten times above the provincial objective of 0.03 mg/L, are generally considered to be a substantive contribution to the nearshore of the eastern basin of Lake Erie.

The assessment of water quality outlined in this report summarizes a more in-depth exploratory analysis of the available water quality data for a five year time period. It is an attempt to provide insight into the general state of the chemical and physical characteristics of the Grand River and its tributaries. Most of this information in this report is generated from the data collected as part of the Provincial Water Quality Monitoring Network that exists as a result of a strong partnership between the Grand River Conservation Authority and the Ministry of the Environment. These data provide the cornerstone for evaluating the state of the resource and, in many cases, provides the baseline data from which watershed management decisions - such as wastewater treatment plant upgrades, are made. As a result of this assessment, a number of recommendations are made regarding improving future data analysis, sampling regimes, monitoring and reporting:

Data analysis

1. A more in-depth analysis of the relationships between watershed stressors such as land use and water quality should be evaluated to better understand the mechanisms contributing to the improvement or degradation in water quality.

2. A more thorough and detailed loading analysis for all monitoring sites would indicate potential sources of nutrients and facilitate targeted remediation. Separate loads from point and nonpoint sources as well as reservoir outflows could be distinguished on a seasonal basis.

3. The influence of the Grand River on Lake Erie should be further investigated and nutrient export quantified.

4. A limnological investigation of all impoundments would provide improved information and guide management decisions with the goal to improve their water quality as well as their effect on downstream river reaches.

Sampling Regime

5. At a minimum, 12 samples per year should be taken at each long term monitoring site to characterize ambient water quality conditions throughout the year so that seasonal variability can be more adequately characterized.

6. Additional high flow sampling should be targeted during spring runoff and summer rainfall events. This will characterize the range of environmental conditions that exist in the watershed.

Monitoring

7. There is no long-term monitoring program focused on biological parameters in the Grand River watershed. Identify appropriate biological indicators and initiate biological monitoring that best integrates with the chemical and physical monitoring programs that best describes the health of the Grand River system.

8. Long-term monitoring is required for the multipurpose reservoirs. In particular, basic limnological characteristics and food web interactions of the main reservoirs should be determined, besides information on nutrients (nitrate, depth profiles of TP, phosphate), temperature and dissolved oxygen throughout the summer and algal biomass.

Reporting

9. Aside from nutrients, identify additional long-term indicators that can be used for progress measurement. Review monitoring activities so that these indicators will be collected annually.

10. Continue with annual high-level reporting of current conditions to report on progress to the Grand River Conservation Authority Board.

11. Every five years, prepare an in-depth technical report.

Acknowledgements

Reporting on water quality goes beyond analyzing the chemical and physical water quality data that have been collected for each site. As a result, this report is the result of contributions from many GRCA staff. We would like to thank the following individuals for their contribution to this report: S. Schifflet, hydrological data analysis; A. Wong, Agricultural Census data analysis; J. Pitcher, spatial data analysis and mapping; and M. Anderson, review of water quality analysis. Also, we thank G. Nurnberg, PhD for reviewing and editing a draft of the report. Further, we thank C. Walsh and G. Wheeler at the City of Guelph for allowing us to incorporate the water quality data collected on the Speed River above and below the wastewater treatment plant into this report.

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1. Introduction

The Grand River watershed is the largest drainage basin on the north-eastern shore of Lake Erie. It drains approximately 6,965 km^2 of south-western Ontario and extends from the small town of Dundalk in the headwaters to Dunnville at the mouth (Figure 1-1). The landscape through which the river moves is shaped by the underlying bedrock of marine origin, glacial deposits of varying qualities, and human activity in the form of urban and agricultural development (Figure 1-2, Figure 1-3; (Lake Erie Source Protection Region Technical Team 2008)). The pattern of the drainage network allows the watershed to be divided into six major subbasins with distinctly different natural and anthropogenic characteristics.

The Grand River is an actively managed river system that offers many services to its residents and visitors. Since the middle of the 20^{th} century, stream flows in the Grand River watershed have been regulated by seven multi-purpose reservoirs to manage seasonal flooding and augment extreme summer low flows. Further, it is a source of drinking water for many residents of the watershed; assimilates the wastewater from 30 growing communities; supports a world-class brown trout tailwater fishery; and is a haven for recreational activity such as canoeing and kayaking. It is also the largest Canadian tributary that discharges to Lake Erie. Consequently, monitoring and managing the quality of the water in the Grand River system has become exceedingly important. Future population growth, agricultural intensification, and changes in climate patterns are stressors which require the planning and implementation of innovative management approaches so that current watershed uses and values can be maintained and even improved for future generations.

Water quality monitoring programs provide a systematic approach to gather much needed information on current and long term water quality. Currently, the provincial water quality monitoring network, implemented in partnership with the Ministry of the Environment, provides for much of the chemical and physical data available on the Grand River and its tributaries. This information is supplemented by the Grand River Conservation Authority's (GRCA's) near-real time monitoring network which continuously monitors the physical characteristics of river water quality at seven locations. Furthermore, project specific monitoring provides for some more focused and detailed information to characterize specific river reaches and areas. These programs combine to provide the baseline information to understand the state of water quality in the watershed although the lack of information on aquatic communities limits any evaluation of the overall aquatic health.

Report Objectives & Scope

The objective of this report is to summarize the chemical and physical monitoring data collected between 2003 and 2008 from sites across the Grand River watershed (Figure 1-4). Specific objectives of this report are:

- To describe the current state of chemical and physical characteristics of water quality in the Grand River watershed through comparison with established water quality objectives or guidelines;

- To investigate seasonal (where data are available) and spatial trends in water quality in the watershed;

- To investigate spatial trends in water quality in the watershed as they affect the quality of the discharge to Lake Erie; and

- To evaluate the extent and value of the monitoring effort and identify knowledge gaps.

These objectives are addressed by separate chapters for each of the six major subbasins (Chapters 2 through 7). Each chapter summarizes land use and geological characteristics for each subbasin, river uses and relevant water quality monitoring data. The quality of water discharged to Lake Erie is addressed in Chapter 7. Chapter 8 - Water Quality: Watershed Trends, summarizes the overall state of water quality and presents conclusions pertinent to each subbasin and the Grand River watershed.

Figure 1-1. The topography of the Grand River Watershed with the major subbasins.

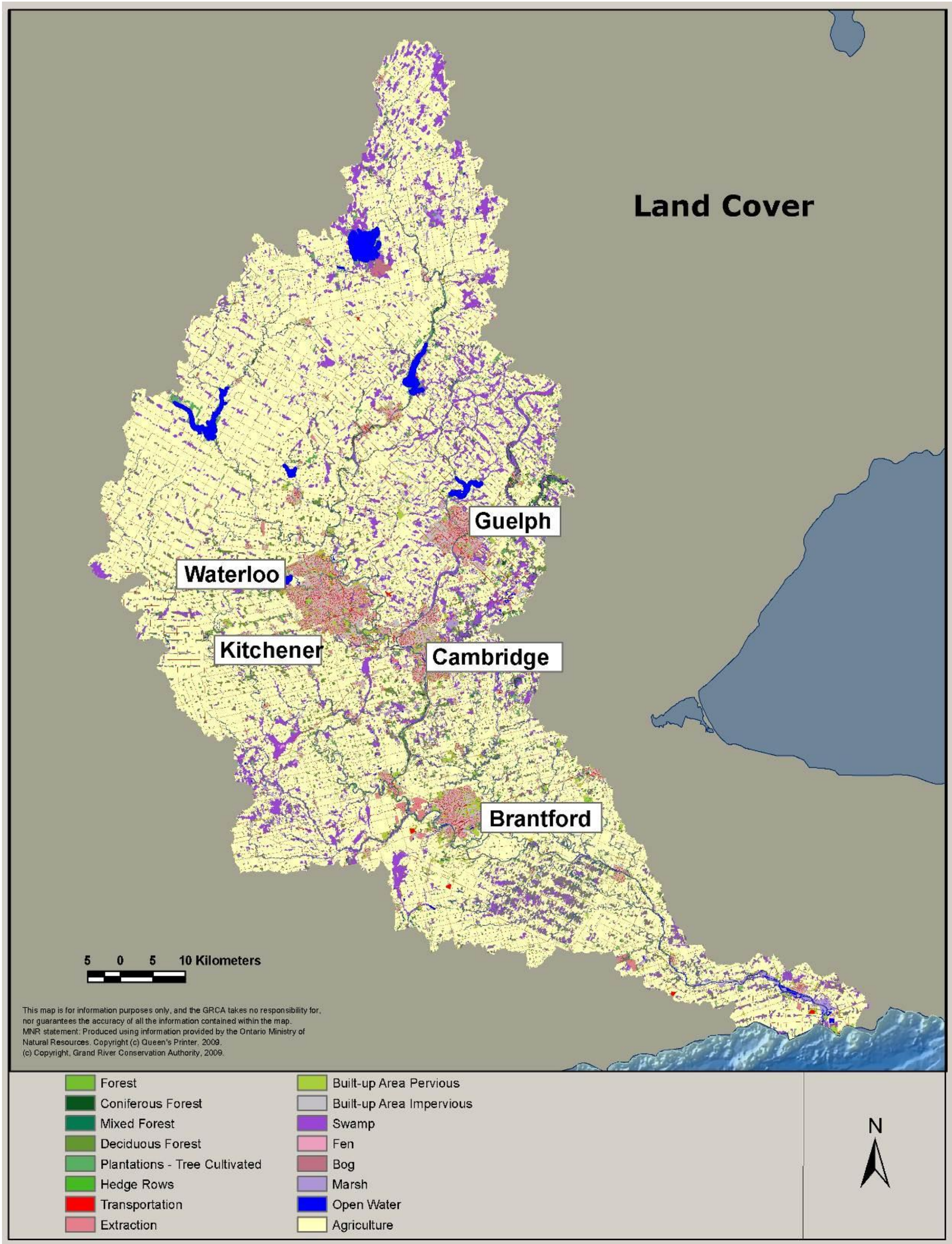


Figure 1-2: Land cover in the Grand River Watershed. Landcover based on 1999 Landsat aerial imagery.

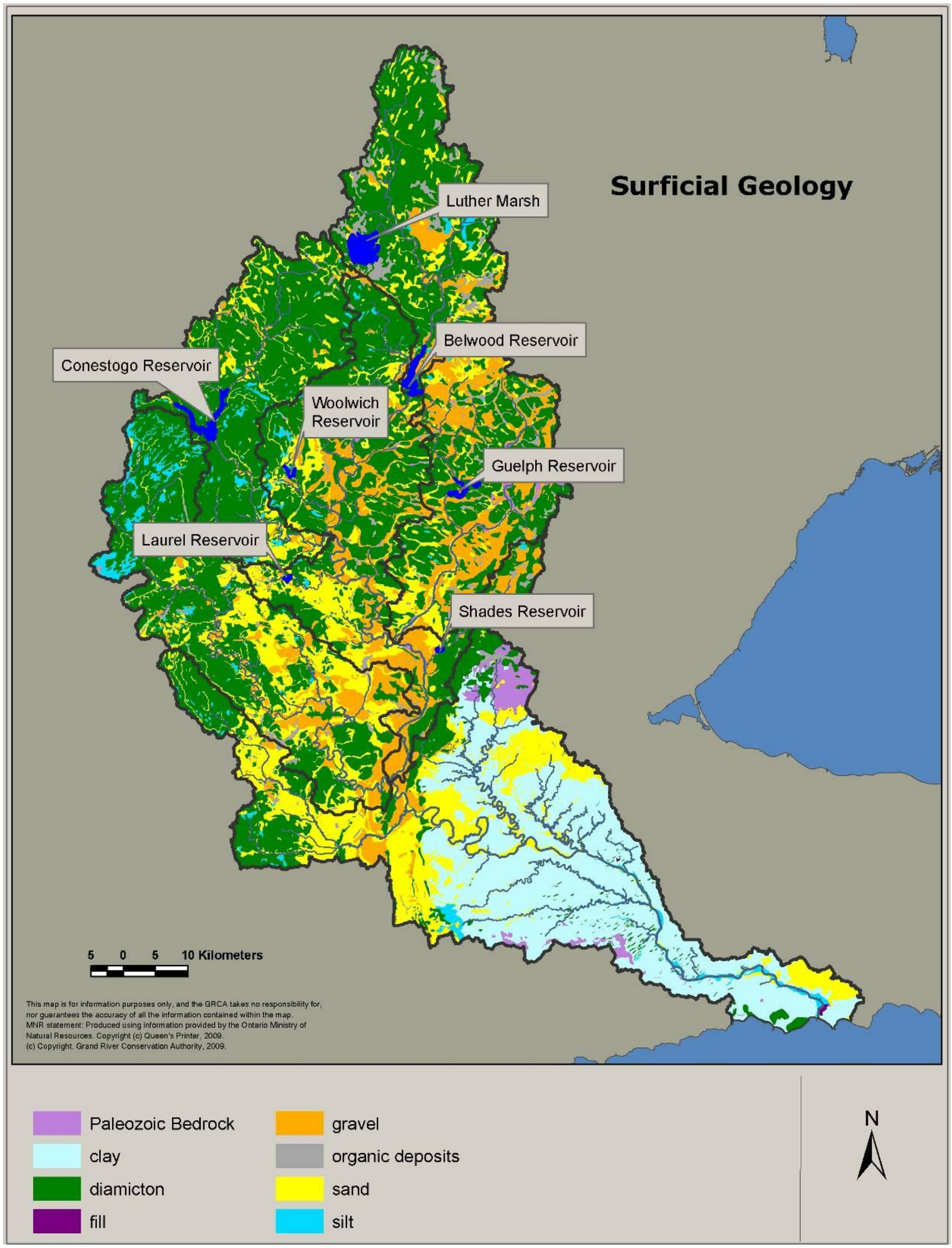


Figure 1-3: The surficial geology of the Grand River Watershed including the seven multi-purpose reservoirs. Surficial geology is based on Quaternary and Pleistocene geology maps by the Ontario Geological Survey.

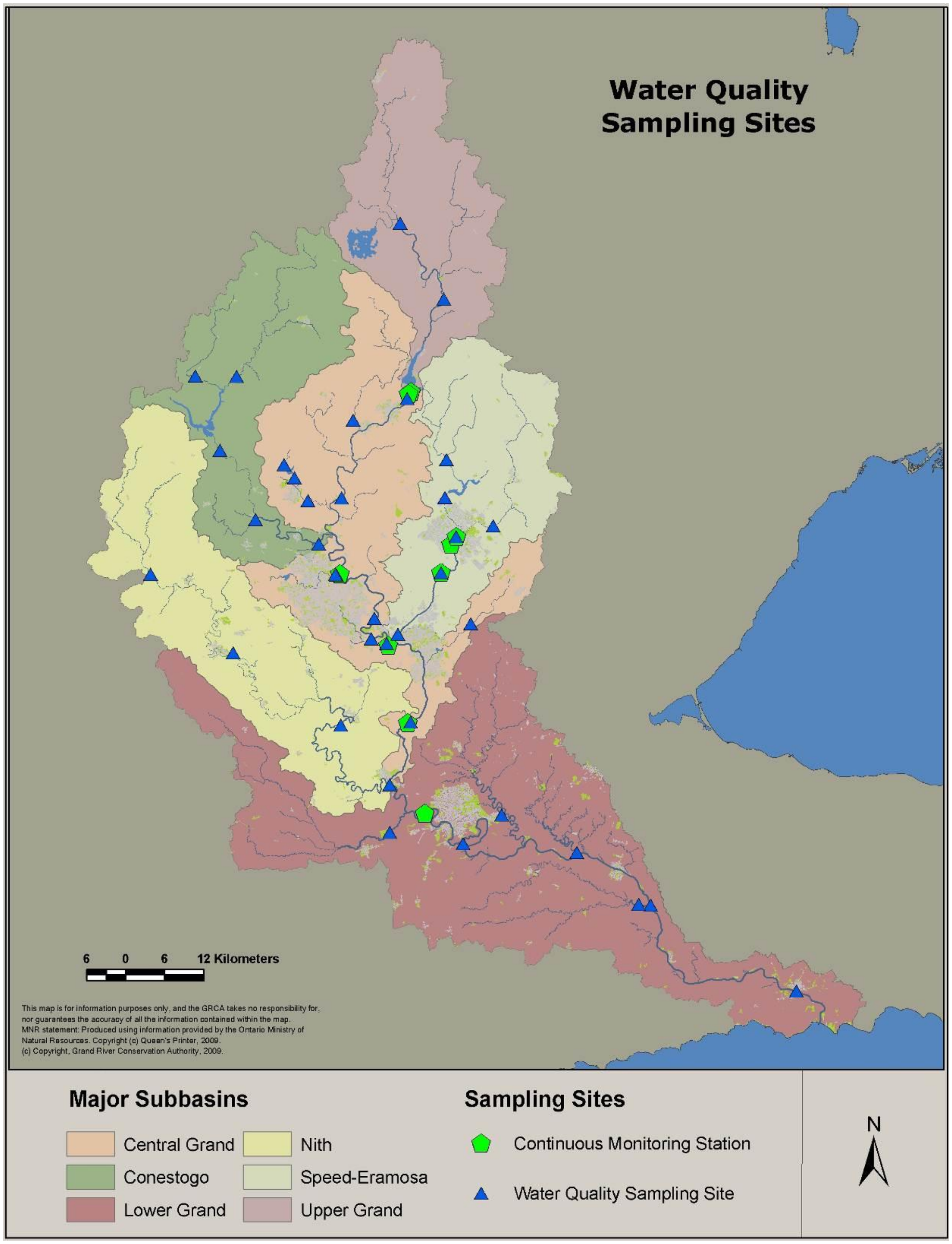


Figure 1-4: The location of the water quality sampling sites that are part of the Provincial Water Quality Monitoring Network and the continuous water quality monitoring stations in the Grand River watershed.

Watershed Characteristics

The Grand River drains an area that can be generally characterized by three distinct regions. The till plains in the head water regions permit only limited infiltration of precipitation and generate high quantities of surface run-off (Figure 1-3; Figure 1-5). Stream flows in this area are typically high in the spring and low in the summer. It is below these areas that multi-purpose reservoirs were built to catch the spring melt so that water from the reservoirs can augment river flows during the summer periods (Table 1-1; Figure 1-3). The central gravel and sand moraine complexes allow for significant groundwater recharge and subsequent groundwater discharge to surface water (Figure 1-5, Figure 1-8). The low-lying Haldimand clay plain in the southern region of the watershed generates high surface run-off and permits only limited groundwater recharge (Figure 1-3, Figure 1-5, Figure 1-8). The elevation profile of the river reflects the change from diamicton and tills to the clay plain and illustrates the change from a fast-moving river in the upper and central reaches to a slow-moving river in the lower reaches (Figure 1-7).

Table 1- 1. The seven major multi-purpose reservoirs in the Grand River watershed.

Subbasin	Reservoir
Upper Grand River	Luther Marsh Belwood (Shand Dam)
Conestogo River	Conestogo
Speed River	Guelph
Central Grand River	Woolwich Shade’s Mill Laurel Creek

Based on the drainage network, the watershed can be divided into six subbasins with distinctly different natural and anthropogenic characteristics (Figure 1-1; Figure 1-3). The upper Grand River, Conestogo River, Speed River, and Nith River subbasins all drain headwater regions and discharge to the central Grand River subbasin. Water flowing into the central Grand River region then moves to the southern Grand River subbasin before discharging into Lake Erie. The three tributaries, Whiteman’s Creek, Fairchild Creek, and McKenzie Creek drain most of the land in the southern Grand River subbasin.

Groundwater – surface water interactions are important processes in the Grand River watershed that can influence surface water quality. Groundwater recharge reduces run-off volume from snowmelt and rainfall. This process limits surface runoff – the predominant process that delivers contaminants like nutrients, sediment or chloride to surface water. Shallow groundwater also discharges to local surface water systems and helps to sustain base flows. For example, approximately 70 – 94% of annually recharged groundwater eventually reaches the river ((Aquaresource Inc. 2009)). As a result, the moraine complexes (e.g. Waterloo and Paris-Galt moraines) in the central Grand and Speed river subbasins strongly influence stream flows and subsequently, the water quality in these rivers (Figure 1-8; Figure 1-9).

Land cover and agricultural management practices also influence the movement, quantity and quality of surface waters. Agricultural lands cover a large area, ranging from 60 to 80% of each subbasin throughout the watershed, although intensity varies across subbasins (Figure 1-2). In particular, the proportion of the various crops grown in each subbasin is similar (Figure 1-11) while livestock densities and the use of tile drainage networks differ dramatically (Figure 1-10, Figure 1-12, Figure 1-13). Livestock densities for poultry, swine, and cattle are the highest in the Conestogo River subbasin, followed by the Nith River and the central Grand River subbasins (Figure 1-10). A significantly large proportion in the Conestogo and Nith River subbasins have random or systematic tile drainage networks relative to other subbasins (Figure 1-12, Figure 1-13) likely due to the predominance of tills.

Only 5% of the total watershed area is in urban development; however, most of it is concentrated in the central Grand and Speed river subbasins. This area includes the Region of Waterloo (Kitchener, Waterloo and Cambridge) and the City of Guelph where most of the watershed's population is concentrated (Figure 1-14). Many of the 30 municipal wastewater treatment plants are also located in the central Grand River region (Table 1-1).

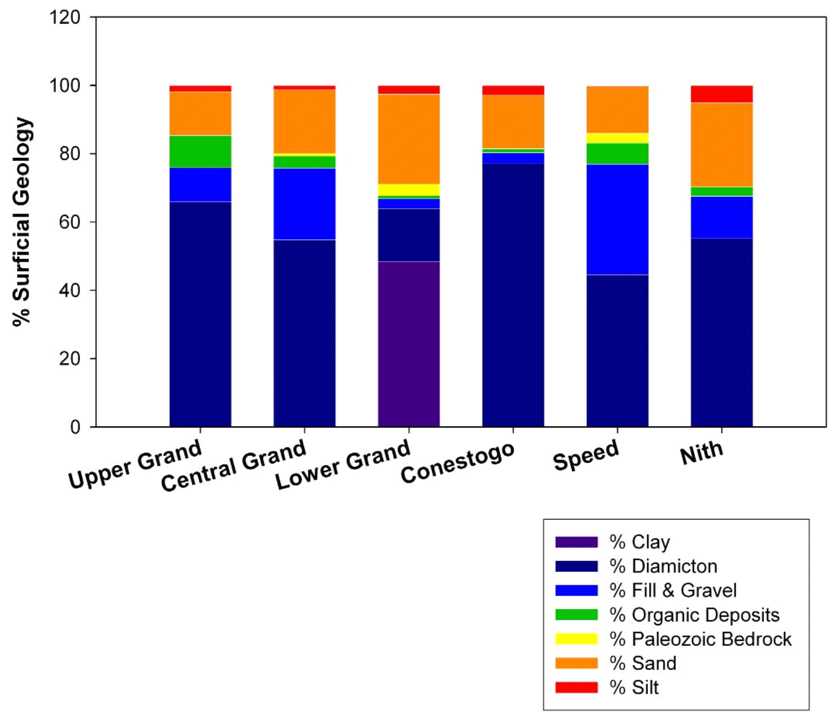


Figure 1-5: The proportion of different surficial geology categories in each of the major subbasins in the Grand River Watershed. (Summarized from quaternary and pleistocene geology maps by the Ontario Geological Survey)

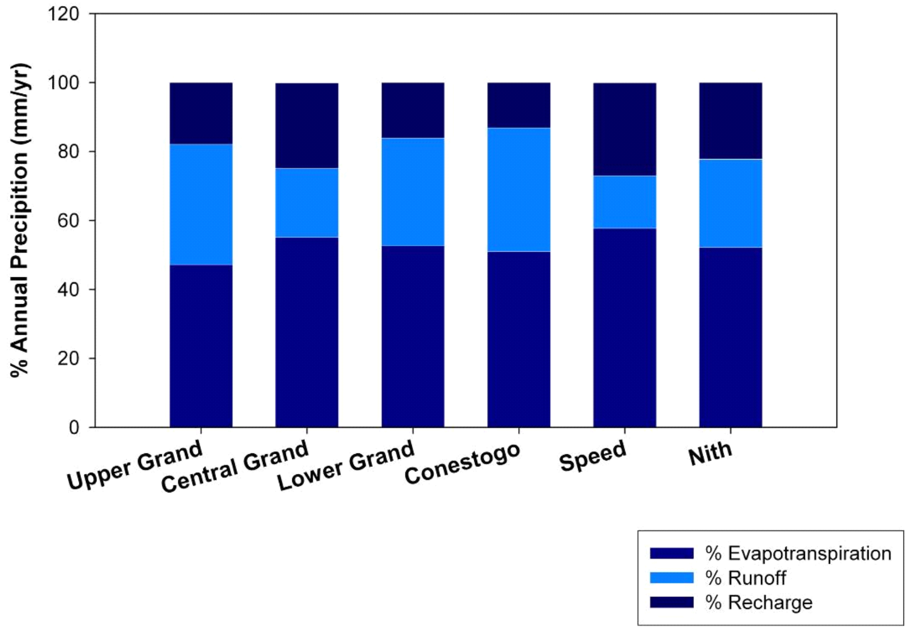


Figure 1-6: The proportion of annual precipitation which becomes runoff, is recharged, or lost through evapotranspiration in each of the major subbasins in the Grand River Watershed (adapted from GRCA Water Budget (Aquaresource Inc. 2009)).

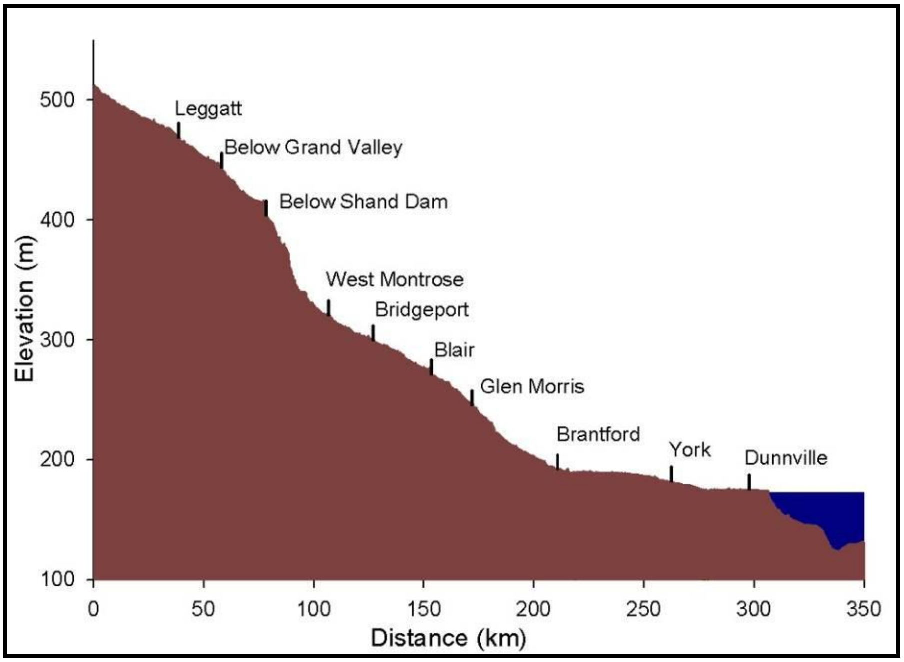


Figure 1-7: The change in elevation of the Grand River watershed from the headwater region near Dundalk to Port Maitland.

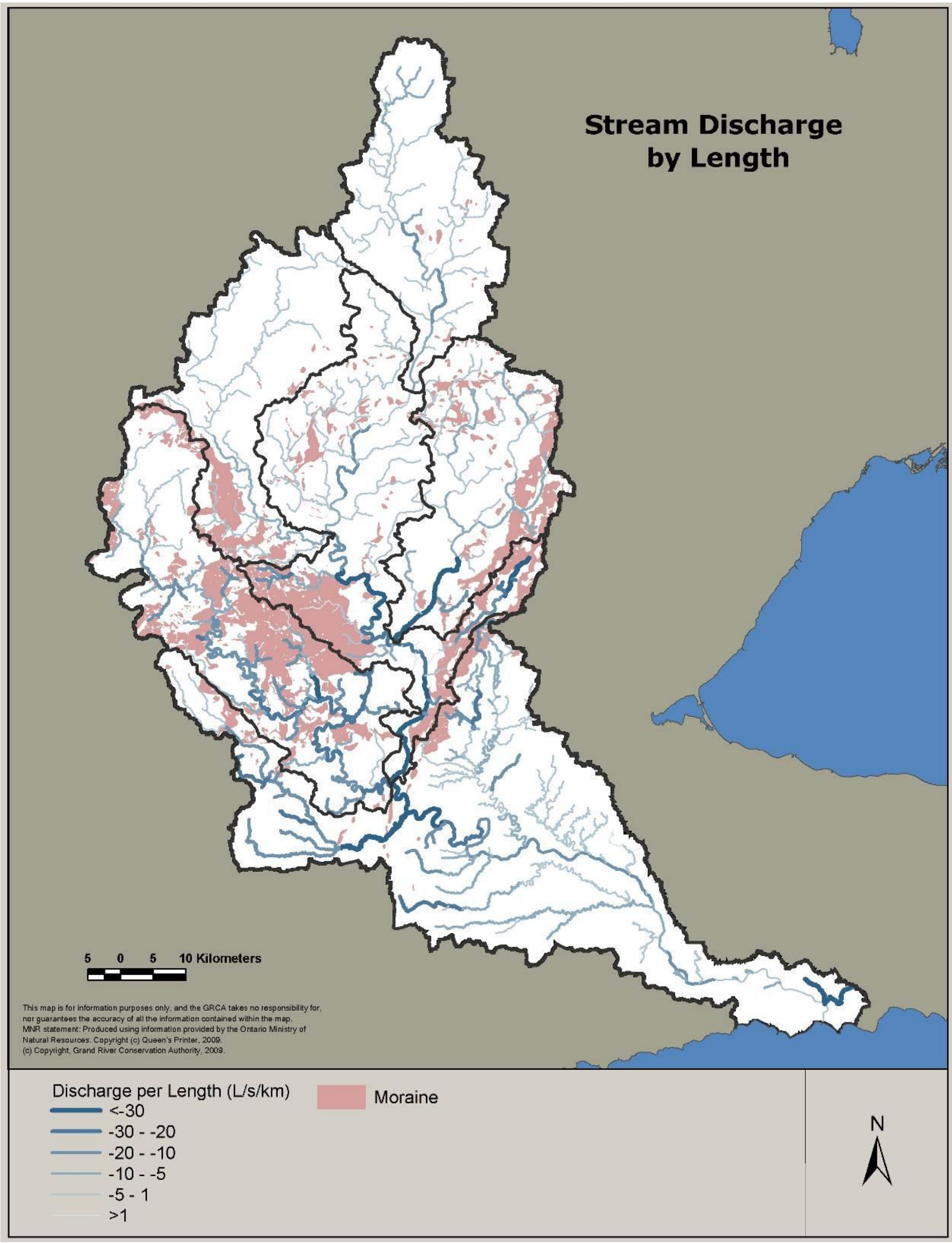


Figure 1-8: The discharge of ground water to streams in the Grand River determined from the water budget for the Grand River watershed ((Aquaresource Inc. 2009)).

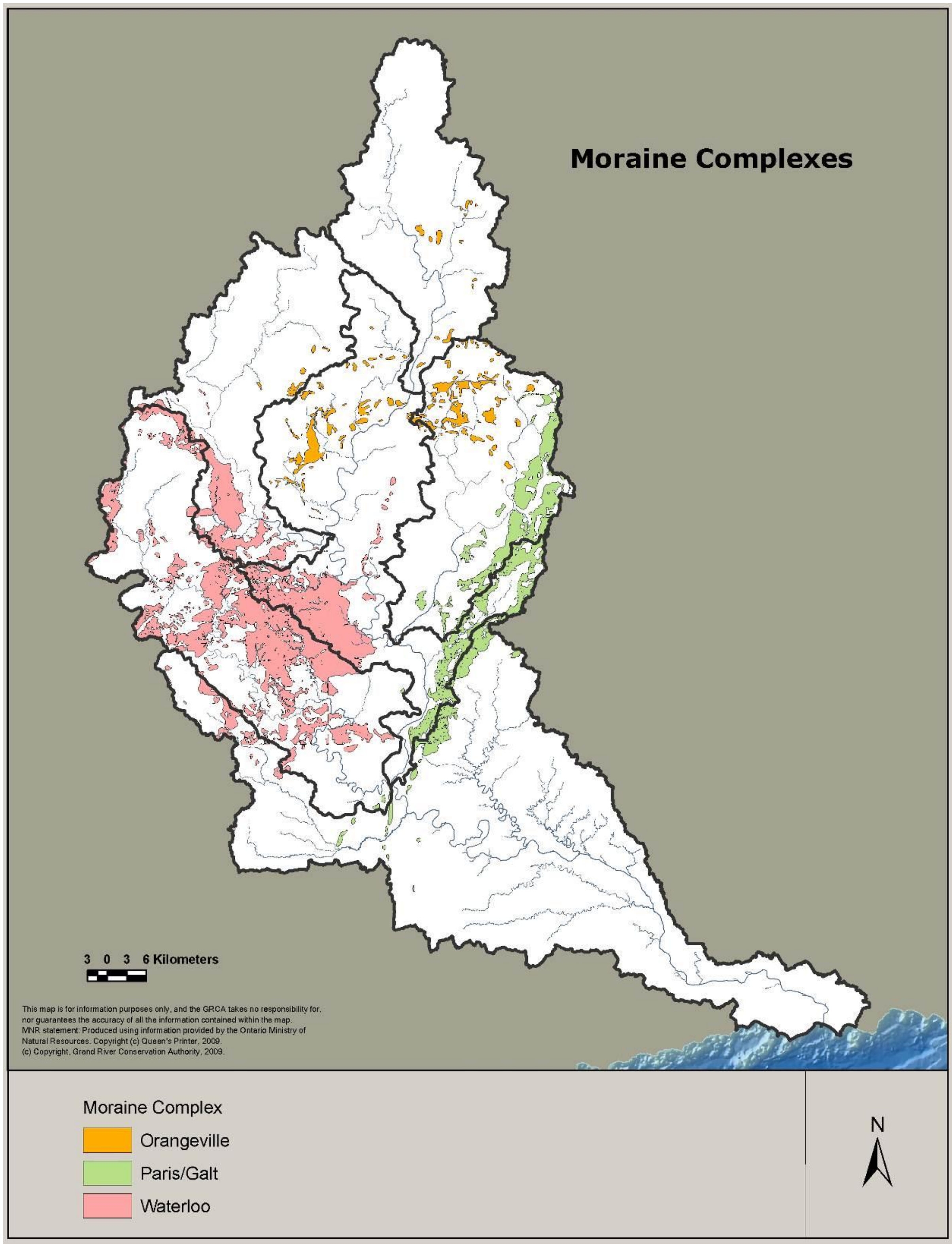


Figure 1-9: Moraine complexes in the Grand River watershed.

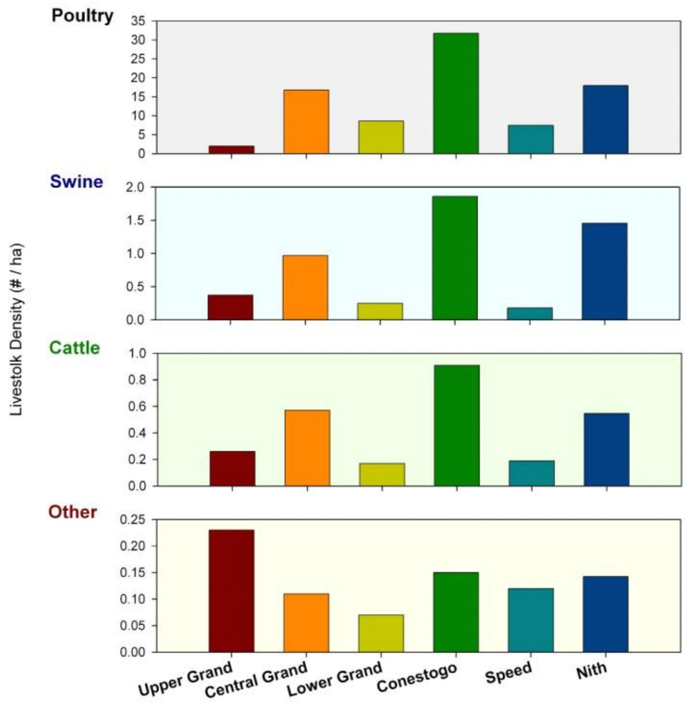


Figure 1-10: Livestock densities in each subbasin in the Grand River Watershed (adapted from Statistics Canada (2009), Population and Dwelling Counts, 92-150-GIE, 2006.)

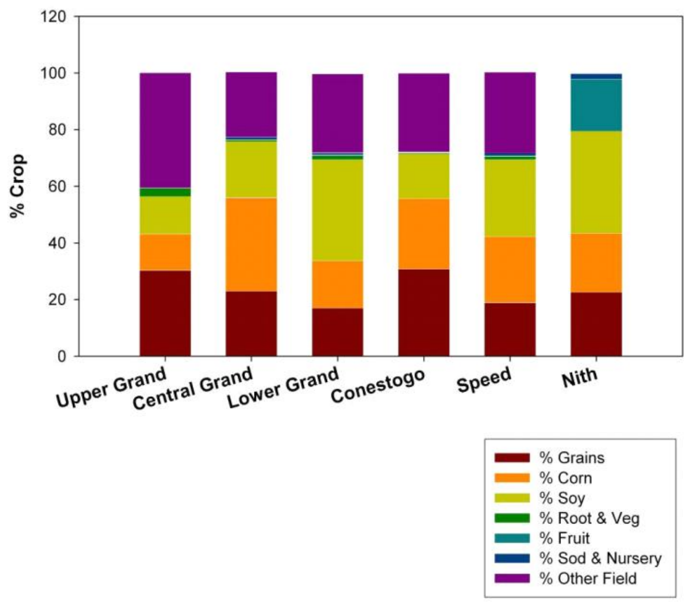


Figure 1-11: The proportion of various crops grown within each subbasin in the Grand River Watershed. (adapted from Statistics Canada (2009), Population and Dwelling Counts, 92-150-GIE, 2006.)

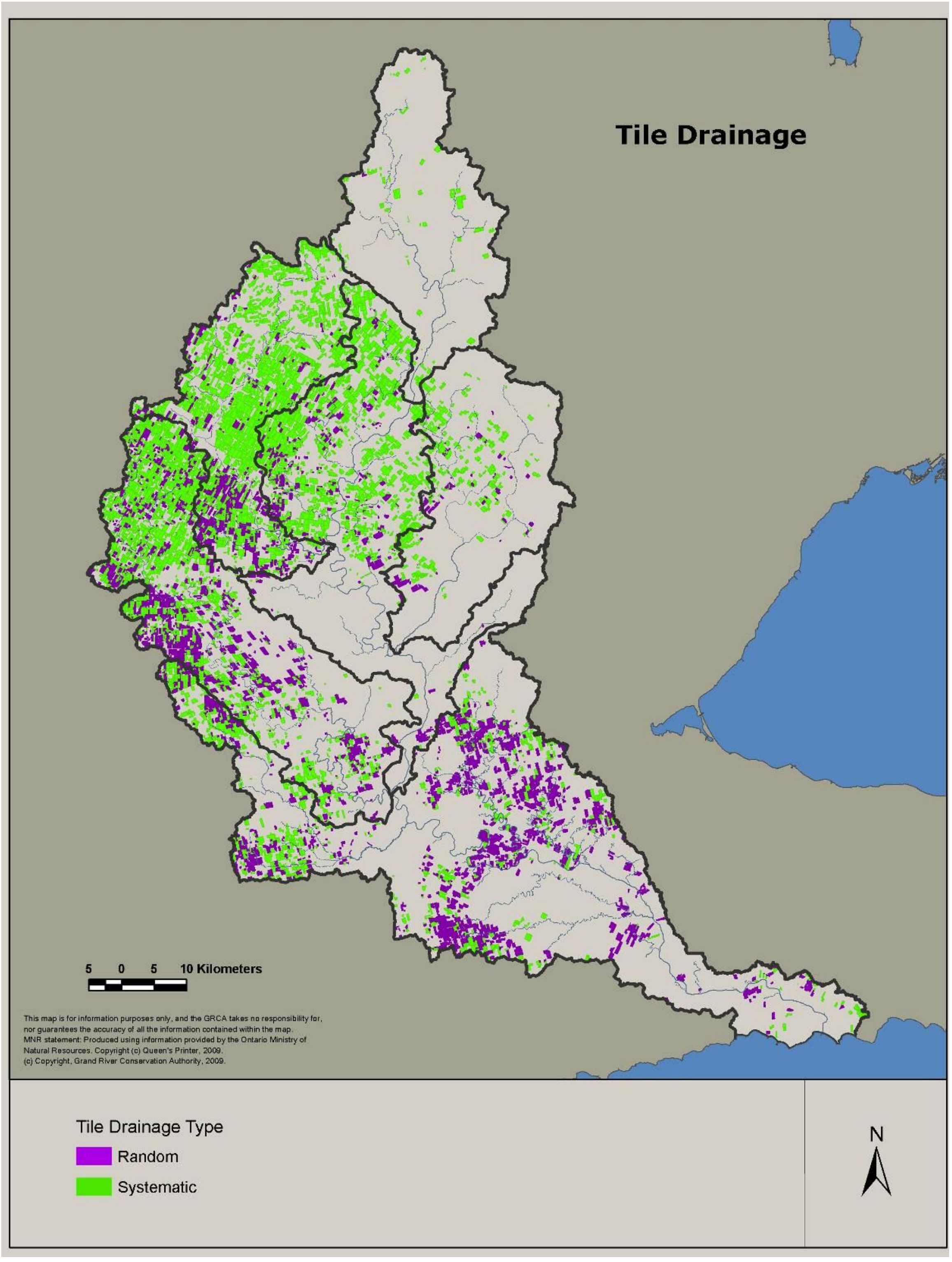


Figure 1-12: The distribution and classification of tile drainage in the Grand River Watershed.

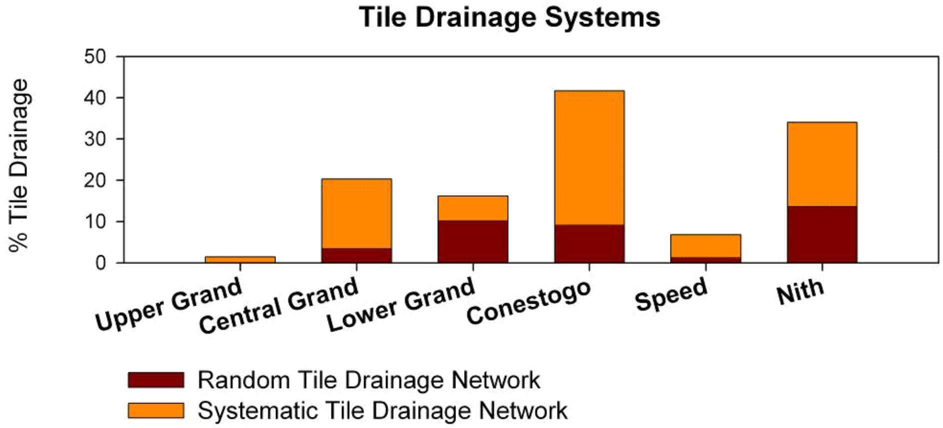


Figure 1-13: The percentage of land tile drained in each of the major subbasins in the Grand River Watershed.

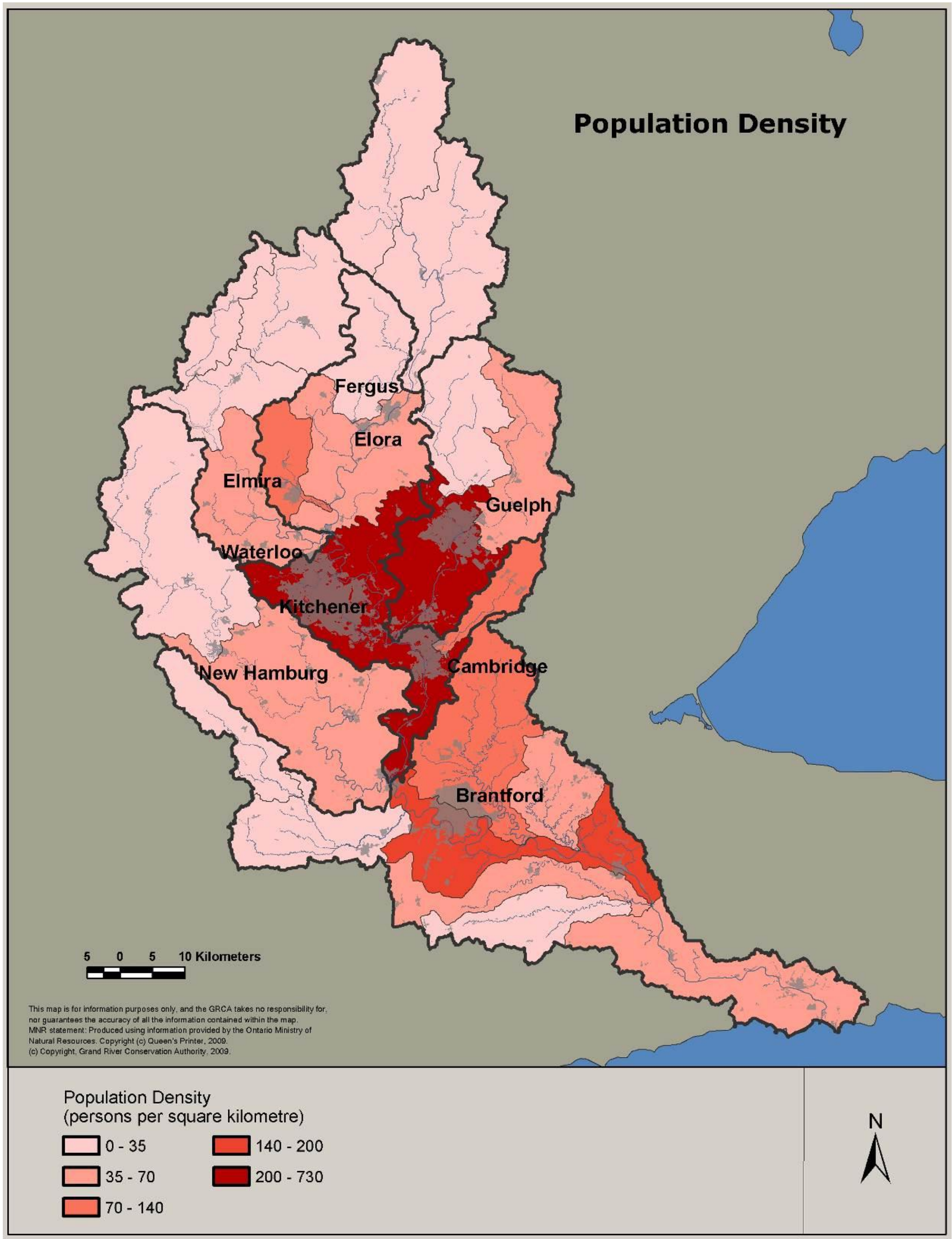


Figure 1-14: Population densities (persons/km^2) of the Grand River Watershed (adapted from Statistics Canada (Statistics Canada 2006)).

Table 1-1: The locations of municipal waste water treatment plants in the Grand River Watershed and the corresponding level of treatment and population served. Note the sewage lagoon for the Six Nations of the Grand River and the Mississaugas of the Credit are not included in this table.

Receiver	Facility	Treatment Level	Current Population Estimate[1]
Grand River	Dundalk Lagoon	Lagoon; continuous discharge & filtration	1,691
	Grand Valley WPCP	Secondary	1600
	Fergus WPCP	Tertiary	12,893
	Elora WPCP	Secondary	5,645
	Conestogo Golf Course Estates		269
	Waterloo WPCP	Secondary	127,829
	Kitchener WPCP	Secondary	229,988
	Preston WPCP	Tertiary	20,534
	Galt WPCP	Tertiary	84,080
	Paris WPCP	Secondary	11,993
	Brantford WPCP	Secondary	100,557
	Caledonia WPCP	Tertiary	9557
	Cayuga WPCP	Secondary	1815
	Dunnville	Secondary	5729
	Arthur WPCA	Tertiary	2770
Conestogo River	Drayton Lagoon	Lagoon	2600
	St. Jacobs WPCP	Tertiary	1,791
	Alt Heidelberg Estates		254
	Guelph WPCP	Tertiary	126,000
Speed River	Hespeler WPCP	Secondary	24,523
	Drumbo WPCP	Tertiary	803
Nith River	Plattsville Lagoon	Lagoon	1168
	Baden/New Hamburg WPCP	Tertiary	11,943
	Wellesley WPCP	Tertiary	2,965
	Ayr WPCP	Tertiary	4,394
	Elmira WPCP	Tertiary	9,725
Canagagigue Creek	Cainsville Lagoon	Lagoon	445
Fairchild Creek	St. George WPCP	Tertiary	3239
	St. George WPCP	Tertiary	3239

Watershed Uses & Values

The Grand River and its tributaries is a highly valued river system that offers many services. In addition to providing a source for drinking water for many residents, the river and its tributaries also receives the wastewater of 30 communities.

Many people use the river for recreation. Boating, including canoeing and kayaking are among the predominant summer activities along with sport fishing. The tailwater fishery below the Shand Dam is world-renowned and generates huge economic benefits for the communities in this area of the watershed.

The multi-purpose reservoirs not only provide a flood control function, it provides for many recreational activities for local residents and visitors each year. They support a strong warm-water fishery as well as provide for many water-oriented recreational activities such as sailing, windsurfing, and water skiing. Although the quality of the water in these reservoirs is important for recreational users, it also is essential for sustaining the downstream tailwater fishery, providing source water for downstream drinking water supplies as well as assist with the assimilation of municipal wastewater discharges.

The unique physiographic character of the central region of the Grand River watershed, specifically the Waterloo and Paris-Galt moraines and Norfolk Sand plain provide for many cool and cold water habitats valued for sustaining native brook, brown and resident rainbow trout populations (Figure 1-15). Further, these areas discharge cool groundwater into local streams or into the central Grand, between Galt and Paris, lower Speed River or central-lower Nith River directly which provides a moderating effect on both river temperatures and water quality. These groundwater discharges are an important contribution to the overall state of water quality in the central watershed and therefore the moraine complexes that provide groundwater discharge are valued.

Agricultural production in the watershed is also highly dependent on the river and its tributaries. Specifically, Whitemans Creek, in the southern Grand River subbasin supports irrigation for many cash crops. Throughout the watershed, the river and its tributaries are also likely a source of water for livestock.

The sometimes competing uses of the river require careful management while acknowledging tradeoffs. For example, while the river is required to assimilate treated wastewater from municipal sewage treatment plants, it is also expected to be a raw water supply for drinking water. These uses can be conflicting if wastewater treatment plants bypass or spill sewage into the river upstream of drinking water intakes. Further, a healthy aquatic community which supports valued fisheries requires a commitment from municipalities to ensure that wastewater discharges meet water quality objectives. Similarly, commitments are required from rural landowners to implement beneficial management practices to reduce nonpoint source impacts to surface waters. These activities require balancing both economic and environmental needs.

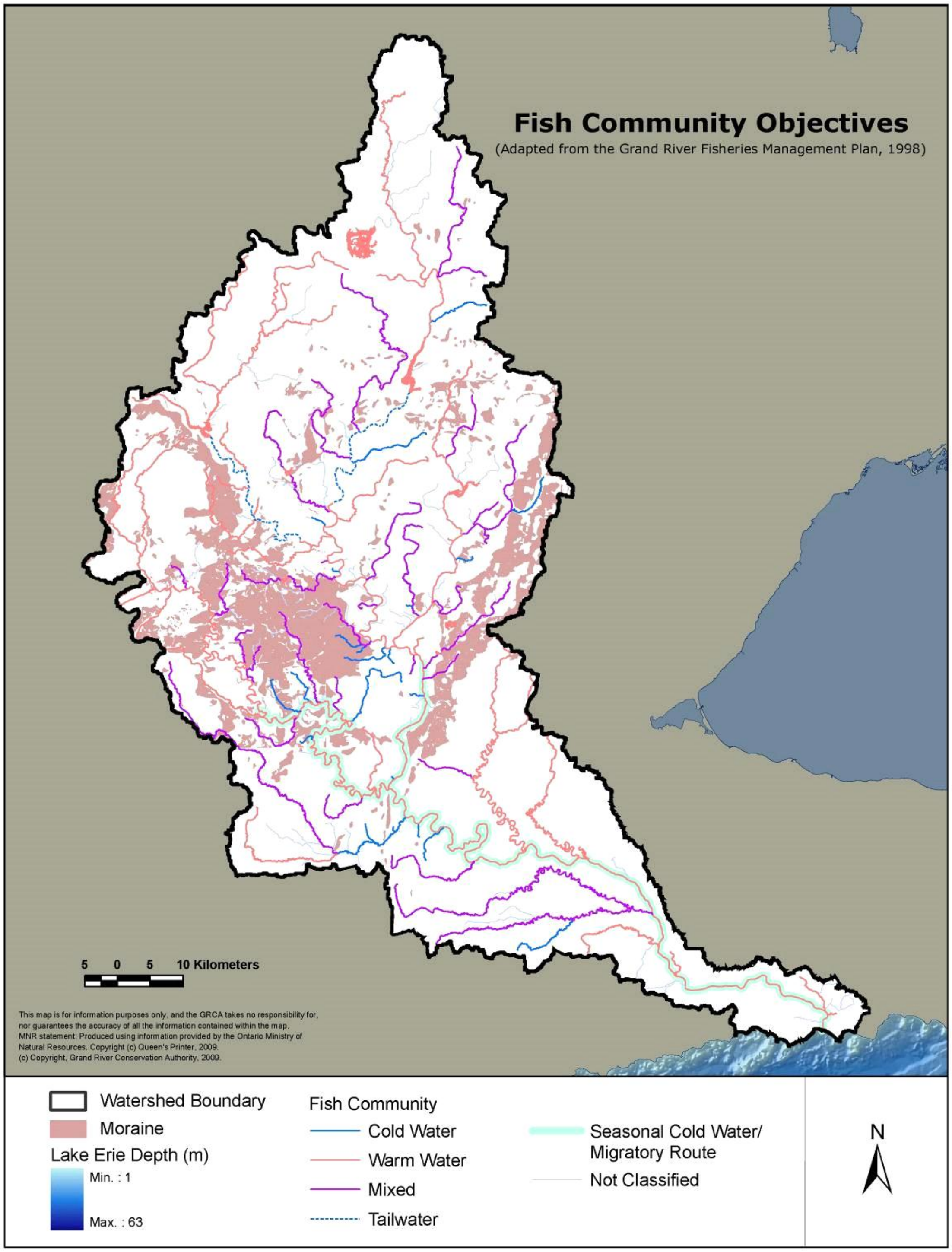


Figure 1-15: The classification of streams based on fish community objectives in the Grand River watershed (adapted from (GRFMPIC 1998)).

Water Quality Monitoring

The Provincial Water Quality Monitoring Network (PWQMN) program has been run in partnership between the Conservation Authorities and the Ontario Ministry of the Environment (MOE) across Ontario since the 1960's. The number of sites sampled in the Grand River watershed for the PWQMN has varied from a high of 44 sites to a low of 28. Between 2003 and 2008, 28 provincial sites were monitored (Table 1-2). In addition to the PWQMN sites, nine monitoring sites were added as part of the Grand River Conservation Authority's enhanced monitoring program, in 2004, to increase the spatial coverage of the water quality monitoring network. This program was funded by the GRCA and samples were analyzed by a private laboratory. Each of the 37 sites within the current monitoring network is sampled between eight and ten times per year to be consistent with the PWQMN program.

The objective of the PWQMN program is to characterization typical or ambient conditions. About eight grab samples are collected per year throughout the open water season (i.e. March – November). The Ministry of Environment (Ministry) is responsible for the laboratory analysis while the Grand River Conservation Authority (GRCA) is responsible for collecting at least eight samples per year between March and November. As a result the seasonal composition of the dataset favours the summer growing season. The absence of winter sampling means that early melt events and stable winter conditions are not characterized, but spring melt periods are documented by targeted sampling in late spring. Samples are taken more frequently at a downstream site (#16018403502, at the bridge in Dunnville) by the Ministry to characterize the Grand River's influence on Lake Erie.

Water samples are analyzed for routine chemistry including nutrients, suspended solids, dominant ions and chloride (Table 1-3) and evaluated according to provincial or federal water quality objectives or guidelines (Table 1-4). In addition to routine chemistry, dissolved oxygen, conductivity, pH and temperature are collected in the field at each sampling site using a handheld data sonde. Further, metals data are also collected at a subset of the PWQMN sites. However, samples collected for aluminum are not meaningful and are therefore, not summarized in this report. The aluminum objective is based on a clay free filtered sample but these samples were not filtered. At all sites aluminum was positively correlated with suspended solid concentrations ($p <$ 0.0001 – < 0.001) indicating that the free aluminum concentration was much lower and may not have exceeded the water quality objective. In addition, and on theoretical grounds, the general alkalinity in the watershed would preclude the occurrence of the free ion.

The GRCA operates a continuous water quality monitoring network that uses YSI™ data sondes at seven monitoring stations, generally located above and below municipal wastewater discharges, to collect discrete observations every 10 minutes for dissolved oxygen, pH, conductivity and temperature. The data are collected to support the Grand River Simulation Model (GRSM), which models the dissolved oxygen of the Grand and Speed Rivers in response to changes in both point and nonpoint nutrient loads. In addition, these stations provide valuable information on the state of the river in near-real time.

In addition to GRCA core programs, the GRCA has partnered with watershed municipalities to characterize water quality above and below municipal wastewater discharges. In 2008, the

GRCA worked with the City of Guelph to characterize the seasonal conditions in water quality above and below their municipal wastewater treatment plant.

Information from the four water quality monitoring programs described above was used for summarizing the general state of water quality.

Table 1-2. List of the 28 long term Provincial Water Quality Monitoring Network monitoring sites.

River	PWQMN Identification Number	Short ID Number	Site Description
Grand River	16018403902	39	Downstream of Grand Valley
	16018403702	37	Below Shand Dam
	16018410302	103	West Montrose
	16018401502	15	Bridgeport
	16018401202	12	Blair
	16018401002	10	Glen Morris
	16018402702	27	Brantford
	16018409202	92	York
	16018403502	35	Dunnville
Irvine River	16018410402	104	Irvine River
Canagagigue Creek	16018405102	51	Upper Canagagigue Creek
	16018401602	16	Lower Canagagigue Creek
Conestogo River	16018409102	91	Moorefield Creek
	16018410002	100	Upper Conestogo River
	16018407702	77	Conestogo River below Reservoir
	16018402902	29	Conestogo River near mouth
Speed River	16018410202	102	Eramosa River
	16018409902	99	Upper Speed River
	16018403602	36	Speed River at Road 32
	16018410102	101	Speed River at Preston
Nith River	16018403802	38	Alder Creek
	16018403202	32	Upper Nith River below New Hamburg
	16018400902	9	Nith River at mouth
Fairchild's Creek	16018404402	44	Upper Fairchild's Creek
	16018409302	93	Fairchild’s Creek near mouth
Whiteman’s Creek	16018410602	106	Whiteman’s Creek
Boston/MacKenzie Creek	16018409502	95	Boston Creek
	16018409602	96	MacKenzie Creek

Table 1-3: List of water quality parameters analyzed in grab water quality samples.

Parameter Category	Water Quality Variable
Nutrients	Total Phosphorus, Phosphate
	Total Kjeldahl Nitrogen
	Total Ammonia, Total nitrate
Solids	Total Suspended Solids
Major Ions/Anions	Chloride
Routine Chemical/ Physical	Hardness, pH, Alkalinity, Conductivity, Temperature, Turbidity, Dissolved Oxygen
Metals	Aluminum, Copper, Nickel, Lead, Zinc

Table 1-4: Water quality objectives used to evaluate water quality.

Category	Parameter	Objective	Jurisdiction
Nutrients	Total Phosphorus	0.03 mg/L	Ontario Ministry of the Environment
	Un-ionized Ammonia	0.0165 mg/L	Ontario Ministry of the Environment
	Nitrates (nitrate+nitrite)	2.93 mg/L	Canadian Environmental Quality Guideline
	Nitrite	0.060 mg/L	Ontario Ministry of the Environment
Major Ions/ Anions	Chloride	150 mg/L	British Columbia Approved Water Quality Guidelines, 2006 Edition
Routine Chemical/ Physical	Dissolved Oxygen (warm water fisheries; 25°C)	4 mg/L	Ontario Ministry of the Environment
	Temperature – cold water fisheries (summer conditions)	prolonged <20° C; periodically <22° C	Defined in (GRFMPIC 1998)
	Temperature – warm water fisheries (summer conditions)	prolonged >22° C	Defined in (GRFMPIC 1998)

All monitoring sites data were analyzed in a similar approach. However, some subbasins had supplementary datasets available and therefore, additional analyses were performed. For example, in the central Grand subbasin the continuous data set describes diurnal fluctuations in summer dissolved oxygen, temperature and pH so that the variation in un-ionized ammonia could be investigated. In this subbasin and the Speed River subbasin, continuous monitoring datasets were also analyzed to determine periods of critically low dissolved oxygen in the river.

Streamflow, Precipitation and Climate

Monthly stream flow, precipitation and air temperature were summarized into annual values to characterize the climate conditions between 2003 and 2008, because water quality in rivers and reservoirs is strongly influenced by climate (e.g., the amount and timing of rainfall and snowmelt).

Monthly levels of precipitation for 2003-2008 from selected monitoring sites were plotted against the long-term monthly average precipitation (40 year normal) to determine whether the years between 2003 and 2008 were wetter or dryer than usual. Similarly, long-term average monthly river flows were calculated (1948-2000) and graphed against recent (2003-2008) monthly means. Summer (June-Sep) air temperatures for a long term weather monitoring station in the watershed was summarized and compared against the five year running average air temperatures.

To consider such climatic fluctuation, specific sampling occasions were compared to conditions at sites with intense monitoring records. In particular, flows were compared to those at Brantford or specific gauging stations in the subbasin (Table 1-5), precipitation and temperature were compared to the site below Belwood Lake at Shand Dam.

Between 2003 and 2008 a range in climatic and flow conditions occurred (Figure 1-16). For example, 2003 was the coolest year while 2007 received the least precipitation and had the lowest flow, while 2008 had the most. On the whole, the study years from 2003 to 2008 fall within the range observed over the last 40 years.

Table 1-5. Flow Gauges used for characterizing water quality in each subbasin.

Subbasin	Flow Gauge ID	Flow Gauge Name
Upper Grand	GRCA at Leggat	Leggatt
Central Grand	02GA034	West Montrose
Conestogo	02GA039	Drayton
Speed	02GA015	Hanlon
Nith	02GA018	New Hamburg
Southern Grand	02GB001	Brantford

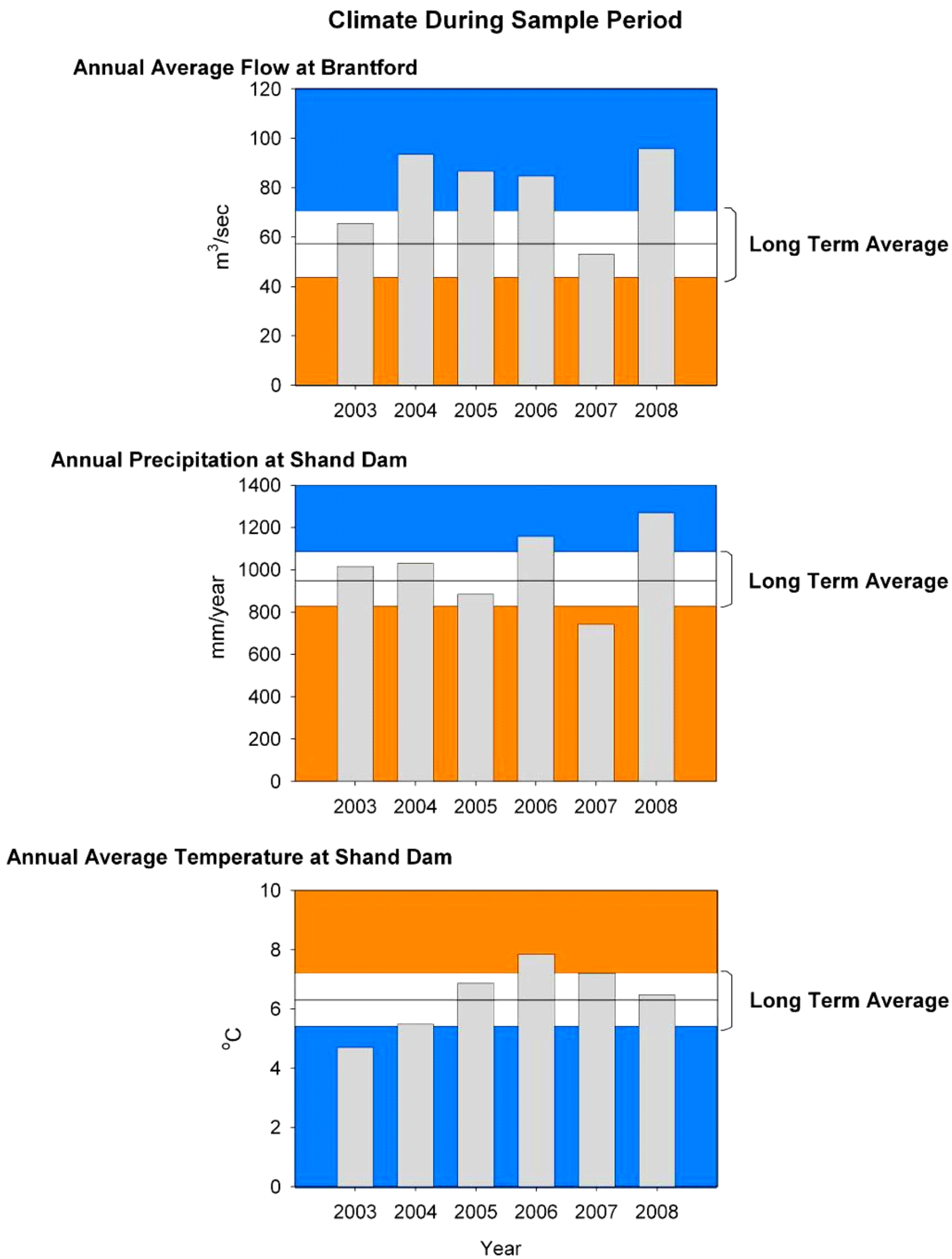


Figure 1-16: Annual average flows at Brantford and annual total precipitation and average temperature at Shand Dam between 2003 and 2008 relative to the long term average. (Note: one standard deviation above and below the long term average is indicated in white).

Typical temperature and flow conditions at Bridgeport

For the interpretation of water quality data it is important to consider seasonal influences. The hydrological cycles follow annual patterns which influence river water quality and the biological processes within a freshwater system. Sampling in different seasons can produce artificial between-site differences if data are lumped on an annual basis. Furthermore, datasets which characterize specific seasons or conditions cannot be extended to describe other seasonal conditions (i.e., low flow conditions are associated with different water quality issues than high flow events). Therefore, it is necessary to understand seasonal environmental conditions to determine how water quality differs between sites.

Stream water temperature and flow are two measurements which have distinct but divergent annual cycles and can be used as seasonal indicators. Based on these indicators, the sampling effort at monitoring sites was compared to the presiding (actual) conditions with three complementing methods by describing (1) the seasonal composition of the dataset, (2) the distribution of sampled flow and temperature, and (3) the representation of environmental extremes.

1) Based on the annual temperature and flow cycles, the year was divided into the four seasons (see Figure 1-17 as an example).

2) To determine seasonality among sampling sites, streamflows and temperatures were used from representative sites/stations. The Bridgeport water quality station was selected as a representative monitoring station for stream temperature cycles. A representative stream flow monitoring gauge was selected for each major subbasin (see Table 1-5). On each sampling date, the average daily statistic for stream flow and temperature was used for all sites in the subbasin. This approach was used in an attempt to identify differences between datasets other than stream temperature or flow.

3) Stream temperatures and flows for each discrete sampling event was presented as a percentage of the range of stream temperature and flows from representative continuous datasets for 2003-2008.

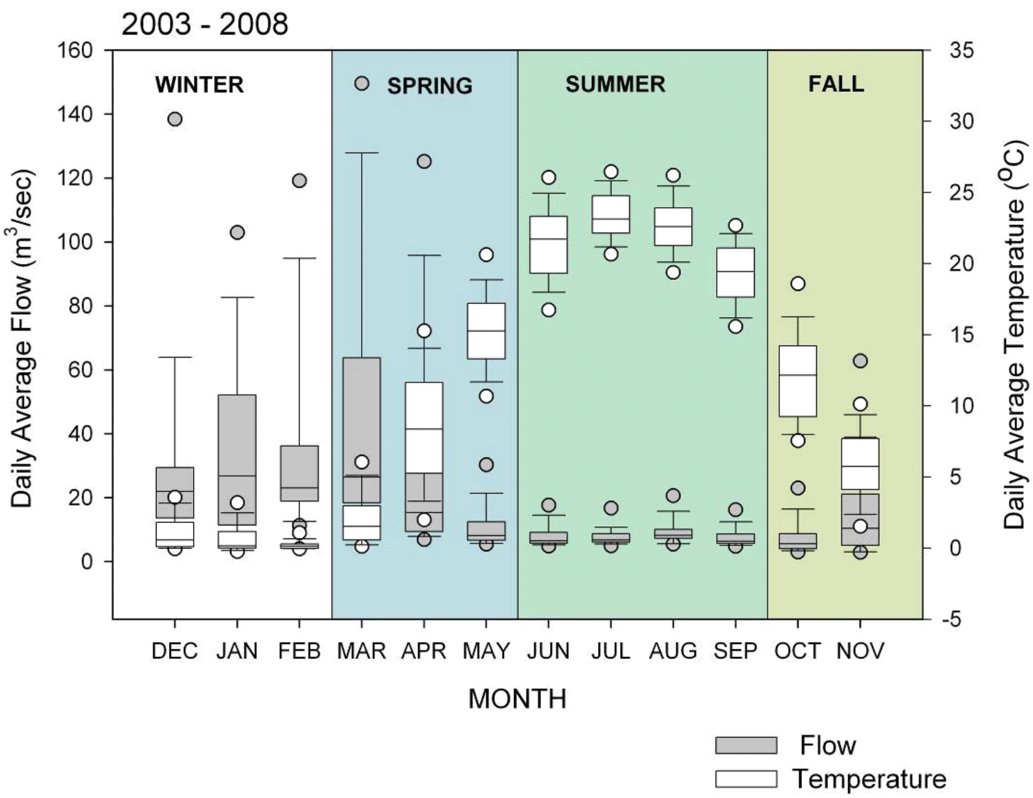


Figure 1-17: Monthly average temperature and flow in the Grand River at the continuous monitoring station at Bridgeport (2003-2008).

Data Analysis

Exploratory Analysis

Variables were presented visually as box and whisker plots (Figure 1-18). The box, horizontal line within the box, and the error bars represent the 25th and 75th percentiles, the median, and the 10th and 90th percentiles, respectively. The circles represent outliers. The data were compared to the water quality objectives when possible (Table 1-4).

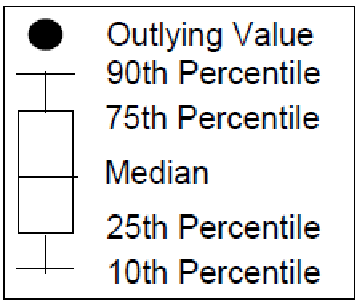


Figure 1-18. Description of the general statistics depicted in a box and whisker plot.

Non-parametric Statistical Analysis

For datasets that exceeded water quality objectives it was investigated whether these variables were correlated with seasonal indicators (stream flow and/or temperature). In this exercise, the sampled flow records were taken from the flow gauge most representative of the site and the sampled temperature records from sampled stream temperatures measured in-situ during sample collection. This approach differs from the analysis completed on the dataset assessment. Further, relationships between concentrations of select nutrients, chloride and suspended solids were explored by non-parametric Kendall correlation. In addition, variables for each site were compared with a Kruskal Wallis group comparison and contrasts were determined with the Bonniferoni error protection.

Loads and Nutrient Proportions

Occasionally, both, concentrations and loading rates (e.g. grams per second) were compared to assess spatial and temporal trends in water quality. This assisted with evaluating the influence of stream flows had on observed concentrations. Loading rates were calculated from measured flow corresponding to the location and timing of the water quality sample event.

Proportions of different chemical forms of nutrients are also presented as they can assist with evaluating in-stream cycling of nutrients ((Bernot and Dodds 2005; Withers and Jarvie 2008)).

Diurnal Dissolved Oxygen Cycles

Dissolved oxygen records of several continuous water quality monitoring stations (Hanlon, Wellington Rd. 32, Bridgeport, Blair, and Glen Morris) were investigate for annual and diurnal trends between 2003 and 2008. To assess annual trends the daily minimum dissolved oxygen concentrations were plotted by month. Dissolved oxygen concentrations between June and September were plotted by hour to assess the summer diurnal patterns. Only data are presented that fall between the 5^{th} and 95^{th} percentiles.

To contrast summer diurnal patterns between sites, hourly dissolved oxygen concentrations were differentiated with a Kruskal Wallis group comparison and post-hoc contrasts with Bonniferoni error protection. Hourly concentrations which were not significantly different from the subsequent hourly concentration were grouped together as either the maximum or minimum period in the diurnal curve.

2. Upper Grand River

Introduction

Watershed Characteristics

The upper Grand River subbasin drains about 783 km^2 of land in the headwaters of the Grand River watershed (Figure 1-4). Soils in this subbasin are tightly packed tills from the Dundalk till plain, which promotes high surface run-off (Figure 1-3). There are high spring flows and low summer flows in the upper Grand River region. Flows in the Grand River are somewhat controlled by the Luther Marsh which discharges to the Grand River near Leggatt. Belwood Lake is a multipurpose reservoir that is operated to collect the water from the upper Grand during the spring freshet. This provides valuable flood protection to downstream communities but it also supplies water throughout the summer months when streamflows in the central Grand River are low.

Land use in this subbasin (Figure 2-1; Table 2-1) is primarily agriculture (71%); however, it is less intense relative to other subbasins. Agriculture is mixed with the dominant crops being 'other field crops' (40%) and grains (30%) as defined in the Census of Agriculture (Statistics Canada 2009). Very little land area is tile drained (1.4%) (Figure 1-11, Figure 1-13). Densities for poultry, swine and cattle are 1.98, 0.3 and 0.26 animals/ha, respectively, which are comparably low to other subbasins in the Grand River watershed. However, 'other livestock' production is the highest in the upper Grand when compared to other subbasins (0.23 animals/ha; Figure 1-10).

Urban development covers three percent of the land base and supports a very low population density of 15 people per km^2 (Figure 1-14). Two relatively small wastewater treatment facilities discharge to the Grand River serving the municipalities of Dundalk and Grand Valley (Table 1-1).

Wetland covers a relatively large proportion (22%) of the subbasin largely due to the Luther Marsh (Figure 1-2, Table 2-1).

Watershed Uses & Values

The Luther Marsh and Belwood Lake provide significant services to both local and watershed-wide residents. The Luther Marsh Wildlife Management Area provides paddling, boating, fishing, hunting, and bird watching opportunities in and around the wetland. Belwood Lake provides fishing, boating, and swimming opportunities as well as seasonal residential (i.e. cottage) recreation. In addition to providing recreational activities, these reservoirs provide flood protection to downstream municipalities. Further, the water 'caught' in the reservoirs during spring freshet supplies water to the Grand River during low flow periods (e.g. summer and fall) to meet minimum flow targets for municipal water supply and wastewater assimilation.

Recreational fishing occurs predominantly in the reservoirs. However, a warm water fishery is supported above Grand Valley and in some of the tributaries while a cold water fishery is supported in one of the ground water fed streams, Butler Creek (Figure 1-15).

Table 2-1: Land cover in the Upper Grand River subbasin.

Region	**Land Cover (%)**			
	Agriculture	Urban	Treed Land	Wetland
upper-Upper Grand River (Headwaters to Leggatt)	66	3	4	28
lower-Upper Grand River (Leggatt to Shand Dam)	75	3	5	17
Overall	71	3	4	22

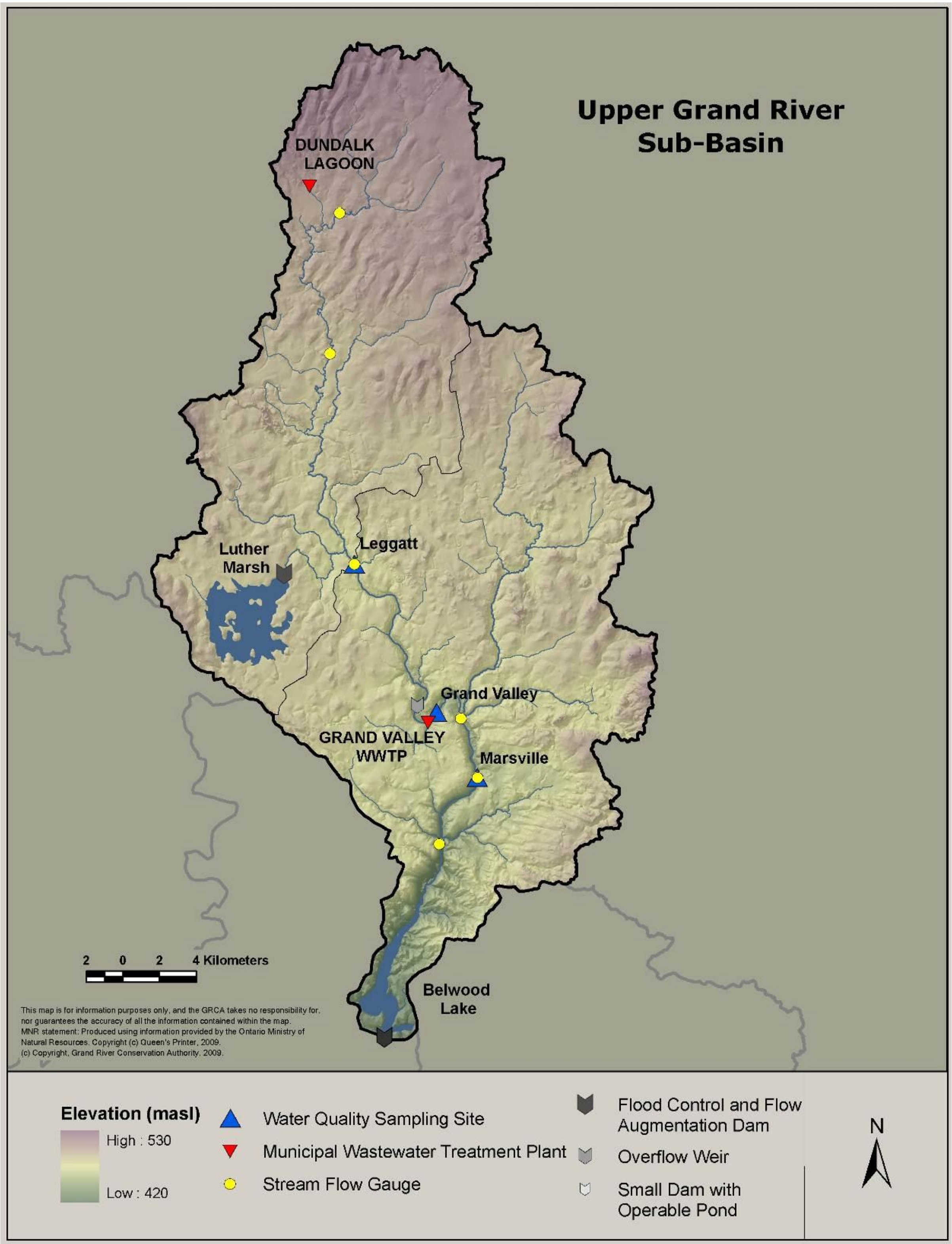


Figure 2-1: Water quality sampling sites, flow gauge locations, and point source inputs in the upper Grand River subbasin.

Subbasin Specific Monitoring

In the upper Grand River subbasin water chemistry was monitored at three sites between 2003 and 2008 (Figure 2-1, Figure 2-2, Table 2-2). Two of these sites, Leggatt and Marsville, started in 2004-2005 and are currently ongoing. The third site, Grand Valley, was sampled from 2003 to 2006. Monitoring results from the site just below the Belwood Lake reservoir on the Grand River are reported in this section to compare water quality above and below the reservoir, even though this site is part of the central Grand River subbasin.

Multiple flow gauges are located throughout the upper Grand River subbasin for the management of reservoirs and flood forecasting. Flow gauges at Leggatt and Marsville correspond with the water quality sampling sites and were used for data analysis. The gauge at Grand Valley is located downstream of the sampling site below a tributary input and therefore the Leggatt gauge flow record was used to determine the flows at the Grand Valley site.

Table 2-2: The river course sampled, site description, site number, and report short name for samples collected in the Upper Grand River subbasin.

Stream	Site Description	Site number	Report Short Name
Grand River	Rural community of Leggatt	16018409002	Leggatt
	East Luther-Amaranth Twp Line	16018403902	Grand Valley
	Conc. Rd. 13, NW of Marsville	16018406702	Marsville

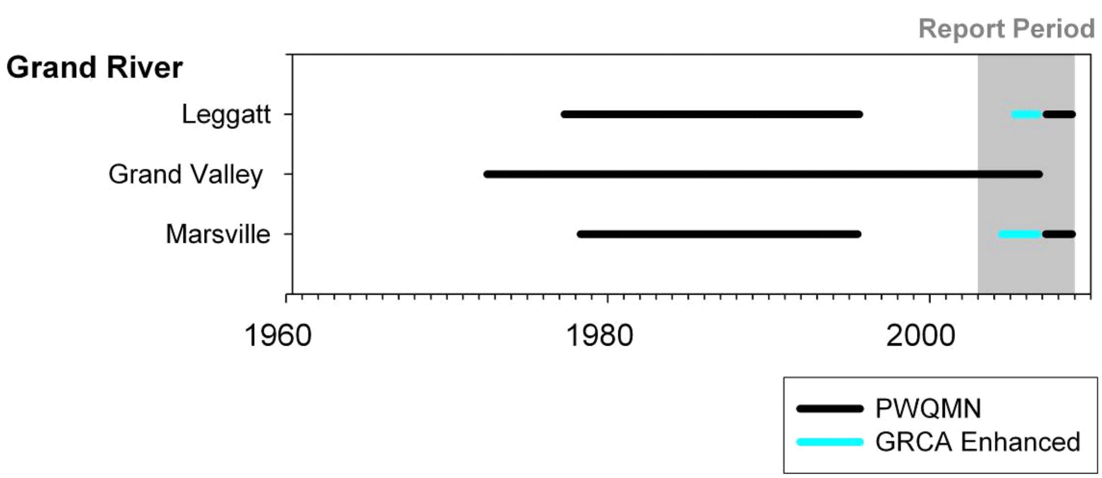


Figure 2-2: Sampling record for GRCA and Provincial Water Quality Monitoring Network sites in the upper Grand River subbasin.

Results

Dataset Description

About half of the of the water quality sampling was focused in the summer (Table 2-3). The seasonal distribution of the monitoring data is similar between sites. All datasets are biased toward summer and spring with less than 6 % of the dataset being composed of winter samples.

Table 2-3: Seasonal composition of water quality data in the upper Grand River subbasin.

Site	% of Samples Collected			
	Winter	Spring	Summer	Fall
Leggatt	0	36.7	53.3	10.0
Grand Valley	3.6	28.6	53.6	14.3
Marsville	2.5	30.0	52.5	15.0
Below Shand Dam*	6.4	29.8	48.9	14.9

* site located in the central Grand River subbasin

The sampled flow record was not significantly different between sites or from the record across all sites (p = 0.0872). However, the sampled temperature record was significantly warmer than the temperature record at all sites (p < 0.0001).

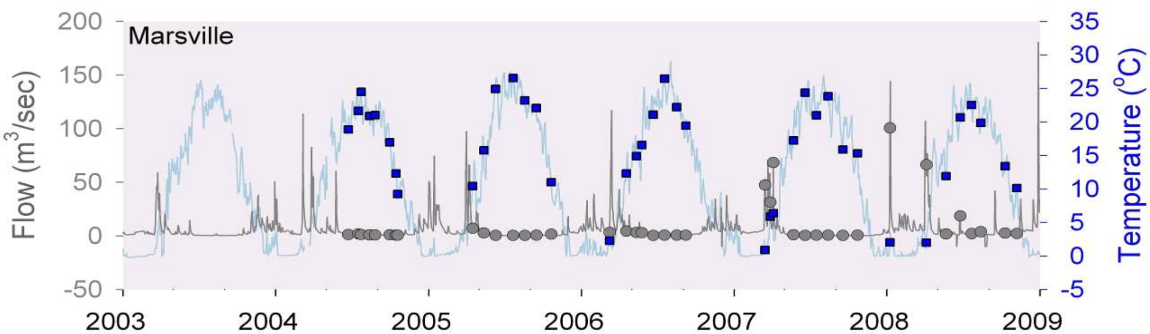


Figure 2-3: Daily average flow (grey line) and temperature (blue boxes) sampled at Grand River near Marsville sampling site relative to the flow timeseries at the Legatt flow gauge and Bridgeport temperature monitoring site between 2003 and 2008.

The range of flow sampled was a smaller percentage of the flow record between 2003 and 2008 at the Leggatt and Grand Valley sites (30-40%) and slightly higher at the Marsville site (55%; Figure 2-3, Table 2-4). The temperature range sampled represented the range in the temperatures record well (>80).

Table 2-4: The percent of the flow and temperature record sampled at each site in the upper Grand River subbasin.

Site	% Sampled Flow	% Sampled Temp
Leggatt	38	83
Grand Valley	32	90
Marsville	55	88
Central Grand River subbasin		
Below Shand Dam	52	91

Summer Water Temperature

Median water temperatures at the four sites ranged from 19 to 23°C below Shand Dam and at Grand Valley, respectively (Figure 2-4). Significantly higher summer temperatures occurred at Grand Valley relative to below Shand Dam ($p < 0.001$) and Marsville ($p < 0.05$).

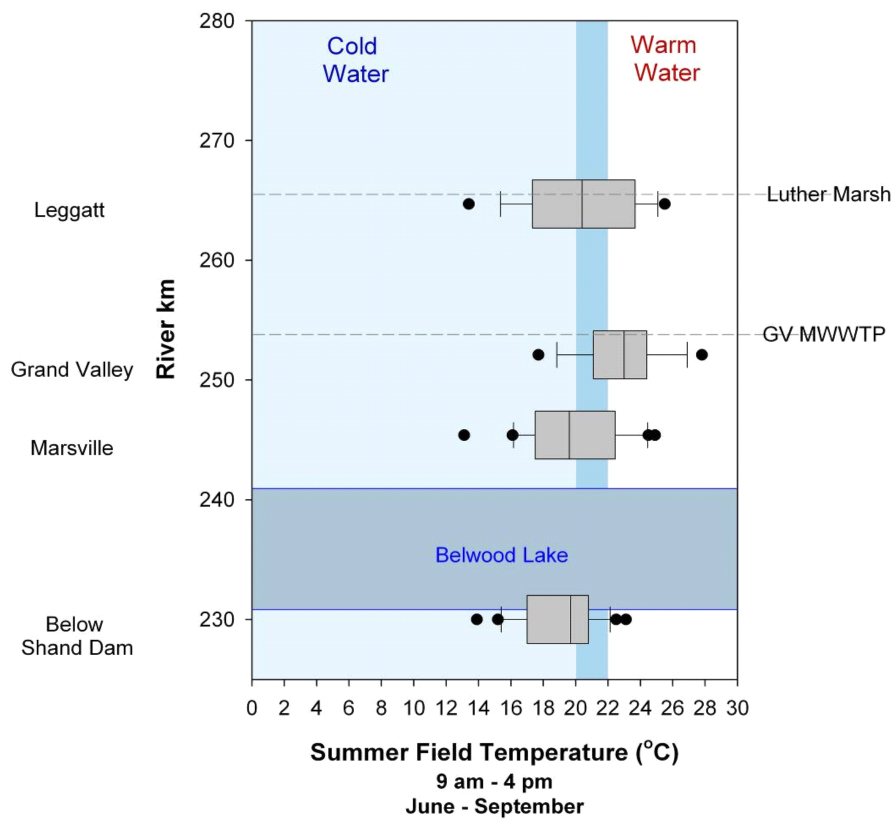


Figure 2-4: Box and whisker plots illustrating the range of summer (June – September) daytime (9 am - 4 pm) spot measurements of field temperatures collected in the upper Grand River subbasin.

Total Ammonia

Generally, total ammonia levels are low across the upper Grand River subbasin. However, total ammonia concentrations were significantly higher below Belwood Lake when compared to all other sites ($p < 0.0001$ for all contrasts; Figure 2-5).

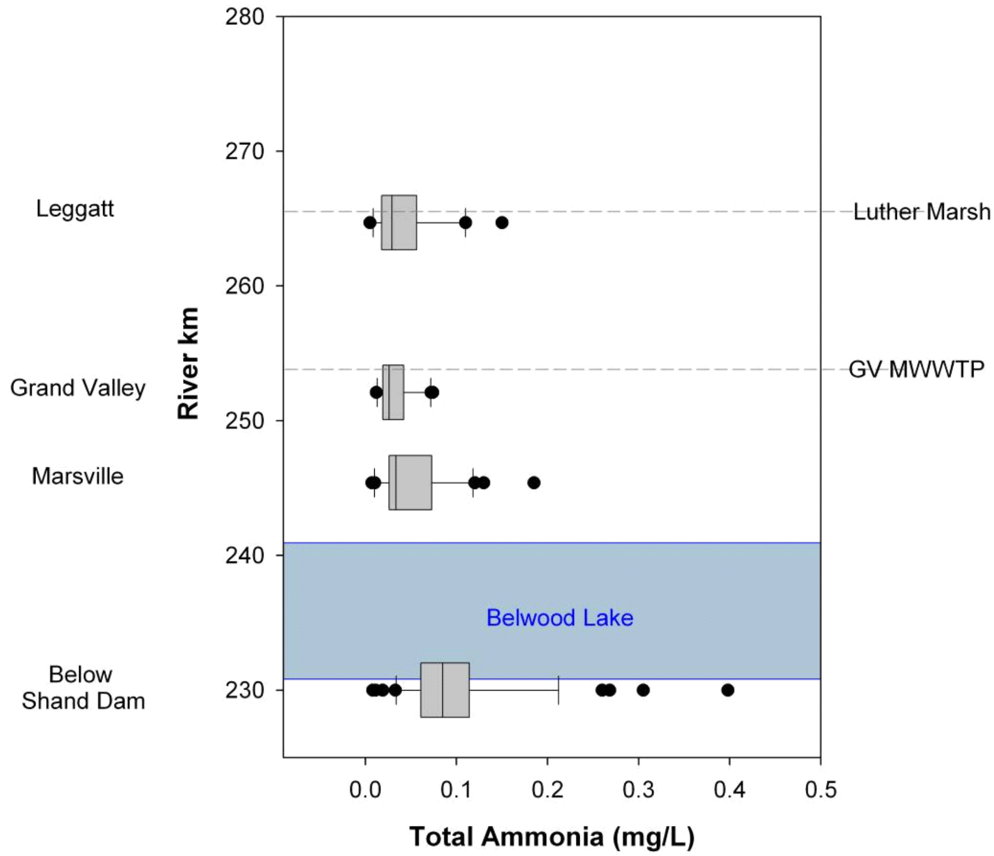


Figure 2-5: Box and whisker plots illustrating the range of total ammonia concentrations (mg/L) in the upper Grand River subbasin.

Total Nitrates

With the exception of a few samples, nitrate concentrations were below the water quality objective across all sites (Figure 2-6). Significantly lower concentrations were observed at Leggatt relative to below Belwood Lake ($p < 0.05$).

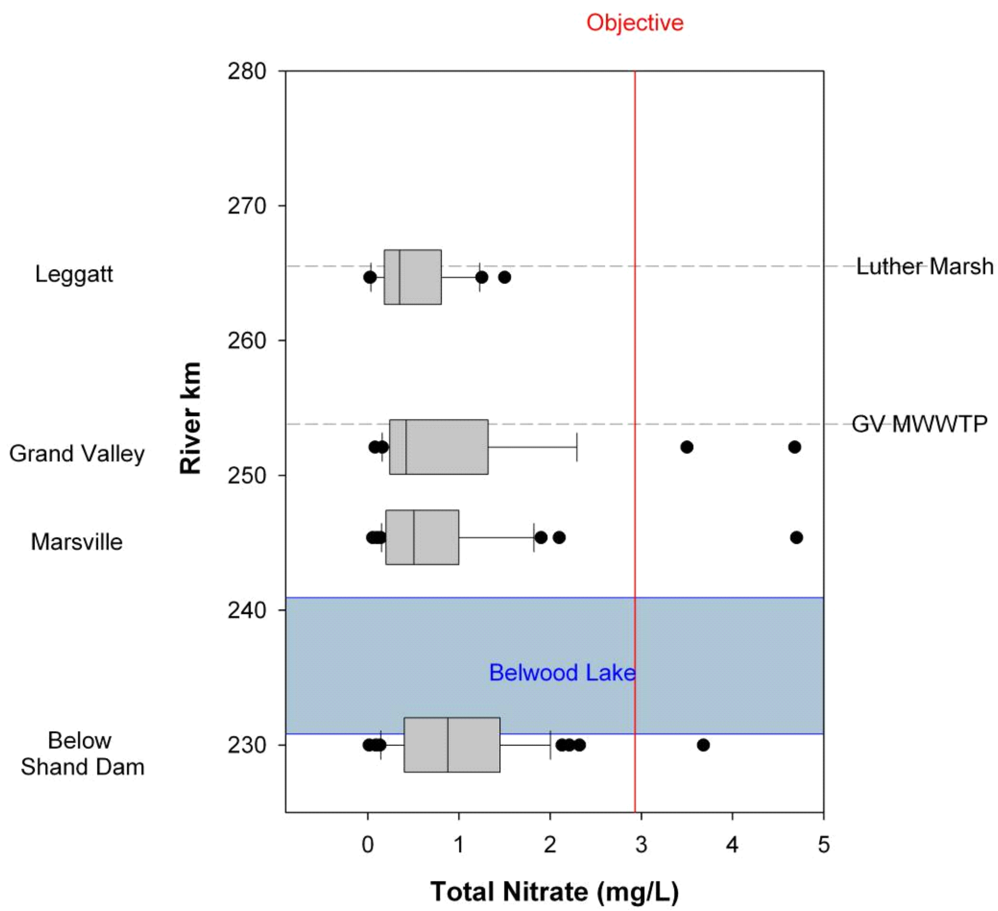


Figure 2-6: Box and whisker plots illustrating the range of total nitrates concentrations (mg/L) in the upper Grand River subbasin.

Total Phosphorus

Total phosphorus concentrations exceeded the PWQMN water quality objective in 25-75% of the samples collected across sites (Figure 2-7). Marsville had the lowest median concentration and was significantly lower than Grand Valley ($p < 0.05$).

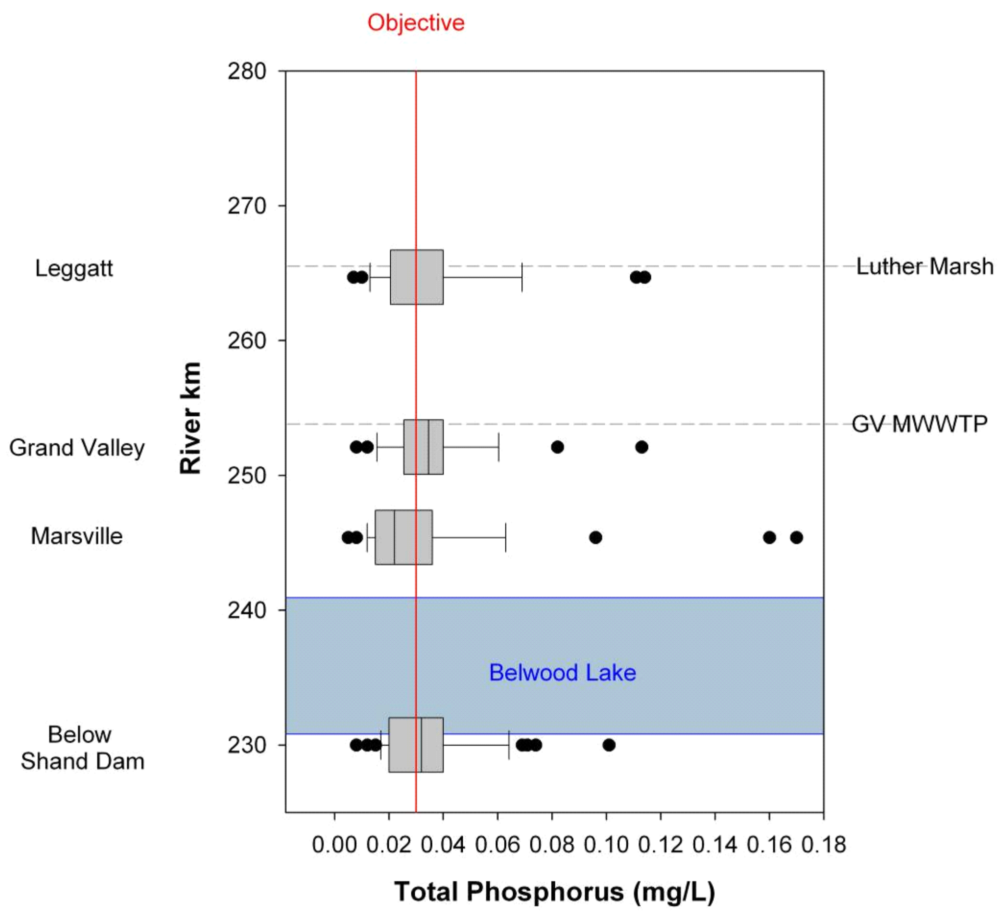


Figure 2-7: Box and whisker plots illustrating the range of total phosphorus concentrations (mg/L) in the upper Grand River subbasin.

Total phosphorus was not significantly correlated with flows (p = 0.1581 - 0.7209) or temperatures (p = 0.0867 - 0.9782) at Leggatt, Grand Valley, and Marsville. However, peak concentrations occurred during freshet events as observed relative to the hydrograph and indicated by high flows and low temperatures (Figure 2-8). Across sites, a strong correlation between total phosphorus and suspended solids was observed ($p < 0.0001$)

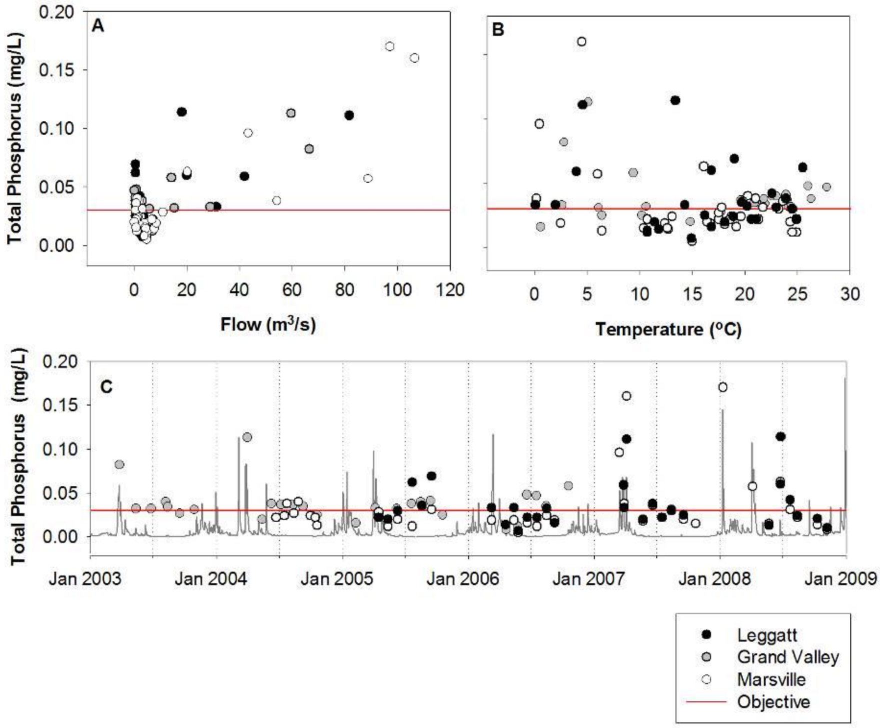


Figure 2-8: Total phosphorus by stream flow (A), stream water temperature (B), and with time in comparison to the hydrograph (C) in the upper Grand River subbasin.

Discussion

Water quality, as generally characterized by nutrient concentrations, in the upper Grand River subbasin is good relative to levels found elsewhere in the Grand River watershed. However, phosphorus levels tend to be at or above the PWQO which is typical for watersheds draining the Lake Erie Lowlands which are some of the most agriculturally intense and populated watersheds in Canada (Gartner Lee Ltd 2006). Phosphorus and total suspended sediment concentrations tend to peak during spring melt and therefore, the highest nutrient loads to Belwood Lake likely occur during this time although there are very little data available during the spring to quantify these loads. These spring loads likely act as a nutrient source for algae later in the summer. The increase in total phosphorus and total ammonia in the Grand River below Belwood Lake suggests that nutrient concentrations are elevated in the bottom waters of the reservoir which is indicative of hypoxic conditions. This internal source of phosphorus is also suggested to be a significant source that contributes to periodic blue-green (cyanobacteria) algal blooms in Belwood Lake during the late summer when the water column becomes mixed (Guildford 2006).

Given the importance of the upper Grand River subbasin in collecting water for storage in Belwood Lake, which in turn, provides water to downstream watershed users during the summer months, it is critical to maintain and improve water quality in this subbasin. Further, intensive shoreline development also likely contributes to added nutrient loads to the reservoir (Conestogo Rovers & Associates, 1999). Higher water quality in the upper Grand River subbasin would help to improve aquatic habitat and recreational activities both in Belwood Lake and to downstream users, including the tailwater fishery below the Shand Dam and municipalities who rely on the water to augment low summer flows that are used to assimilate wastewater effluents.

Conclusions & Recommendations

- Water quality in the upper Grand River subbasin is of good quality relative to other sites in the Grand River watershed and is characterized by elevated total phosphorus and suspended solids concentrations during spring melt. More frequent monitoring is recommended to fully characterize the seasonal water quality characteristics of the upper Grand River and its tributaries.

- Elevated concentrations of total phosphorus, particularly during spring melt likely reflects a large phosphorus load to Belwood Lake from the watershed.

- Very little water quality data exist for characterizing Belwood reservoir. A routine water quality monitoring program is recommended to start characterizing year-to-year variability.

- As Belwood Lake has experienced frequent cyanobacteria blooms, a long-term strategy that promotes best practices is recommended to assist in reducing watershed sources of phosphorus and nitrogen. A Lake Watch program could be considered to engage local cottagers and residents.

3. Conestogo River

Introduction

Watershed Characteristics

The Conestogo River drains approximately 819 km^2 stretching from north of Kenilworth to the village of Conestogo near Waterloo (Figure 1-4). The subbasin consists of two head water streams - Moorefield Creek and Conestogo River - which drain into Conestogo Lake, a multipurpose reservoir. Below the reservoir, the river joins with a few smaller tributaries before discharging to the Grand River north of Waterloo near the village of Conestogo.

Most of the upper subbasin drains the tavistock till, which tends to generate high quantities of surface run-off during rain and snowmelt events (Figure 1-3). Streams in this subbasin are described as *intermittent* - *warm* and are not sustained by ground water discharges (Figure 1-6, Figure 1-8, (Grand River Fisheries Management Plan Implementation Committee 2005)).

High surface run-off producing flooding and extreme low flow conditions are regulated in the lower portion of the subbasin by the Conestogo Reservoir. The management of flows in the Conestogo River also helps to regulates flows in the Grand River.

Most (83%) of the land use in this subbasin is agriculture (Figure 3-1, Table 3-1). Due to the low infiltration rates of the soils in this subbasin, agricultural production is highly dependent on tile drainage – 41% of the land base has tile drainage. The dominant crops in this subbasin are grains (23%), corn (33%), and soy (19%; Figure 1-11) and livestock density is the highest of all other subbasins (poultry 31.7 animals/ha, swine 1.86 animals/ha and cattle 0.9 animals/ha; Figure 1-10).

Urban development is limited to the towns of Arthur, Drayton and St. Jacobs. Urban land cover and population densities are higher in St. Jacobs (6% & 44 people/km^2, respectively) relative to Drayton and Arthur (3 – 4% & 12-22 people/km^2; Figure 1-14). Two municipal wastewater treatment plants discharge seasonally to the upper Conestogo River; one industry discharges to Moorefield Creek and one municipal plant discharge to the lower Conestogo River and one small facility discharges to Heidleberg Creek (Table 1-1).

Wetland and treed lands cover only 5% and 8% of the subbasin area, respectively (Figure 1-2, Table 3-1).

Table 3-1: The percentage of land cover devoted to agricultural activities, urban development, treed land, and wetlands in the Conestogo River subbasin.

Region	Land Cover (%)			
	Agriculture	Urban	Treed Land	Wetland
Upper Conestogo River 1 *(Headwaters)*	85	3	3	8
Moorefield Creek *(Headwaters to Creek Mouth)*	84	3	4	9
Upper Conestogo River 2 *(Below Headwaters to Reservoir)*	78	4	8	10
Lower Conestogo River *(Below Reservoir to Mouth)*	84	6	6	4
Total	83	4	5	8

Watershed Uses and Values

Conestogo Lake is a multipurpose reservoir similar to Belwood Lake. The reservoir and surrounding lands offer recreational activities such as fishing, swimming, and paddling and boating. The recreational use of this reservoir is impacted by blue-green algae blooms which occur periodically and tend to occur in the late summer, early fall (Guildford 2006).

The water released from this reservoir sustains flows in the lower Conestogo River and the Grand River. The flows in the Conestogo River also help to moderate point source inputs from downstream municipal wastewater treatment plants.

Given the local geology and lack of groundwater discharges, the Conestogo River subbasin generally sustains warm water fish communities. However, the tailwater below the Conestogo dam does support a limited brown trout fishery due to cooler waters being released from the dam (Figure 1-15).

Subbasin Specific Monitoring

In the Conestogo River subbasin there are currently 5 active monitoring sites (Figure 3-1, Figure 3-2, Table 3-2). Glen Allen, St. Jacob, and Moorefield Creek were monitored throughout 2003-2008. Wellington Rd. 7 was sampled 2003-2006, when it was replaced by Drayton that was sampled 2007-2008 and is currently active. Boomer Creek was sampled 2004-2007. In 2008 it was sampled at a different location and data from those samples are not included in this analysis.

Stream flow gauges that correspond with water quality sampling sites include sites above Drayton by Wellington Rd. 7, Moorefield Creek, Drayton, Glen Allen, and at St. Jacob. Stream flows for Boomer Creek were estimated using the data record from the flow gauge in Moorefield Creek.

Figure 3-1: The water quality sampling sites, flow gauge locations, and municipal wastewater treatment plants in the Conestogo River subbasin.

Table 3-2: The river course sampled, site description, site number, and report short name for samples collected in the Conestogo River subbasin.

Stream	Site Description	Site number	Report Short Name
Conestogo	Wellington County Rd. 7	16018410002	Wellington Rd. 7
	Wellington St. Drayton	16018407502	Drayton
	Steel Bridge, Glen Allan	16018407702	Glen Allan
	Waterloo County Rd. 22	16018402902	St. Jacobs
Moorefield	County Rd 10, Village of Moorefield	16018409102	Moorefield Creek
Stirton	8th Line, Peel Twp,	16018411802	n/a
Boomer	Hwy 17 South of Hawkesville	16018412702	n/a
	Hwy 17 near Linwood	4398002	Boomer Creek

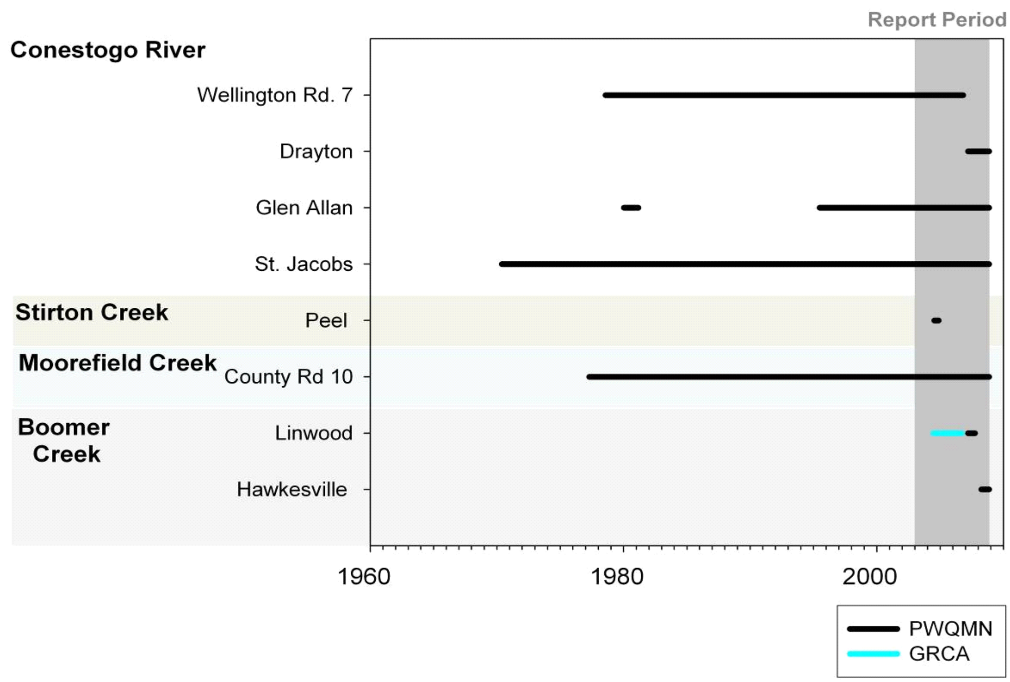


Figure 3-2: Sampling record for GRCA and Provincial Water Quality Monitoring Network sites in the Conestogo River subbasin.

Results

Dataset Description

The seasonal distribution of the monitoring data is similar between sites. All datasets are biased toward summer with most (~50%) of the data in the datasets being collected in the summer and less than 7% of the data in the datasets being composed of winter samples (Table 3-3).

Table 3-3: Seasonal composition of water quality data in the Conestogo River subbasin.

Site	**% of Samples Collected**			
	Winter	Spring	Summer	Fall
Wellington Rd. 7	0	28.6	57.1	14.3
Moorefield Creek	0	33.3	56.4	10.3
Drayton	0	46.2	53.8	0
Glen Allen	5.6	27.8	55.6	11.1
Boomer Creek	0	30.8	59.0	10.3
St. Jacobs	6.5	34.8	47.8	10.9

The sampled flow record was not significantly different between sites or from the record across all sites ($p = 0.0796$). However, the sampled temperature record was significantly warmer ($p < 0.0001$) than the temperature record at all sites, except at Drayton which was not different ($p = 2.5072$). No difference in the sampled temperatures were observed between sites ($p = 4.5948 - 20.2876$).

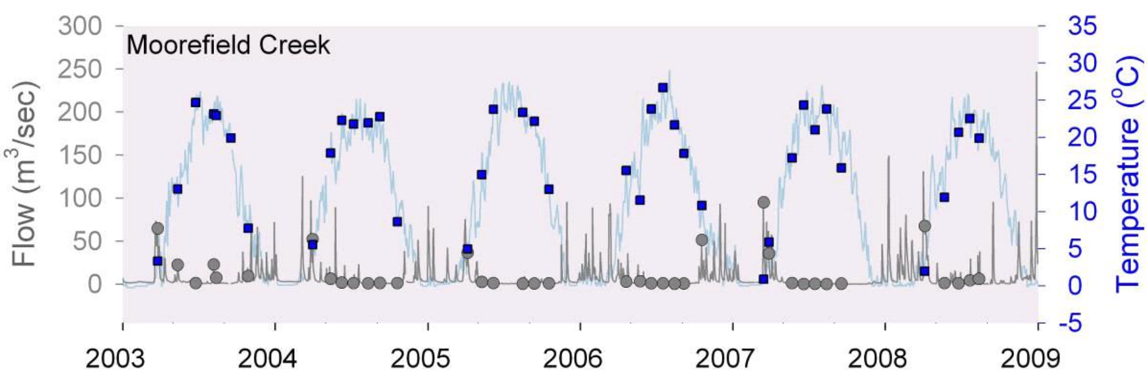


Figure 3-3: Daily average flow (grey line) and temperature (blue boxes) sampled at Moorefield Creek relative to the flow timeseries at the Drayton flow gauge and Bridgeport temperature monitoirng site between 2003 and 2008.

Flow and temperature records sampled at each site show similar low ranges across sites (26-39%; Table 3-4; Figure 3-3). This means that the observed range of flow and the peak flows were not well characterized. The temperature range sampled represented the range in the temperatures record well (74-91%; Table 3-4; Figure 3-3).

Table 3-4: The percent of the flow and temperature record sampled at each site in the Conestogo River subbasin.

Site	% Sampled Flow	% Sampled Temp
Wellington Rd. 7	26	74
Moorefield Creek	39	88
Drayton	39	76
Glen Allen	26	91
Boomer Creek	39	88
St. Jacobs	33	91

Summer Water Temperature

Median water temperature fell below 20°C at Glen Allen and in Boomer Creek (Figure 3-4). Glen Allen was significantly lower than St. Jacobs ($p < 0.05$) and Moorefield Creek ($p < 0.05$). No other significant between-site differences were observed.

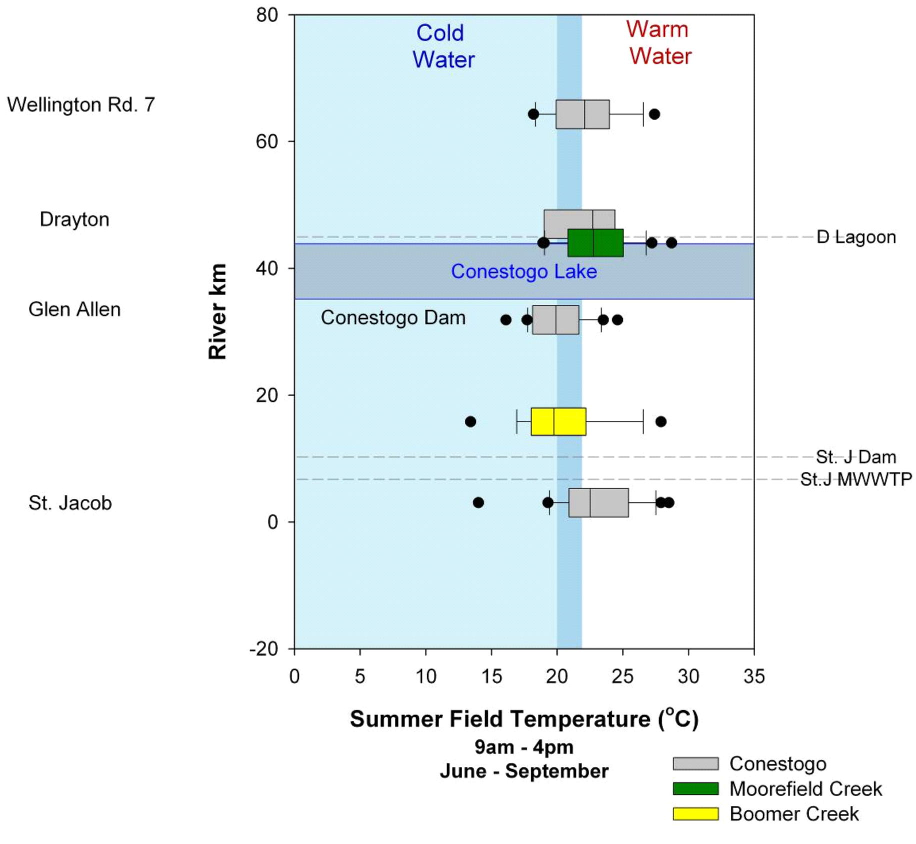


Figure 3-4: Box and whisker plots illustrating the range of summer (June – September) daytime (9am - 4 pm) field temperatures in the Conestogo River subbasin, 2003-2008.

Chloride

Chloride concentrations were below the water quality benchmark of 150 mg/L in all sites with the exception of Boomer Creek which was significantly higher than all other sites (Figure 3-5; $p < 0.0001$, for all contrasts). Chloride concentrations in Boomer Creek were negatively correlated with flow ($p < 0.01$) and positively correlated with temperature ($p < 0.05$, Figure 3-6).

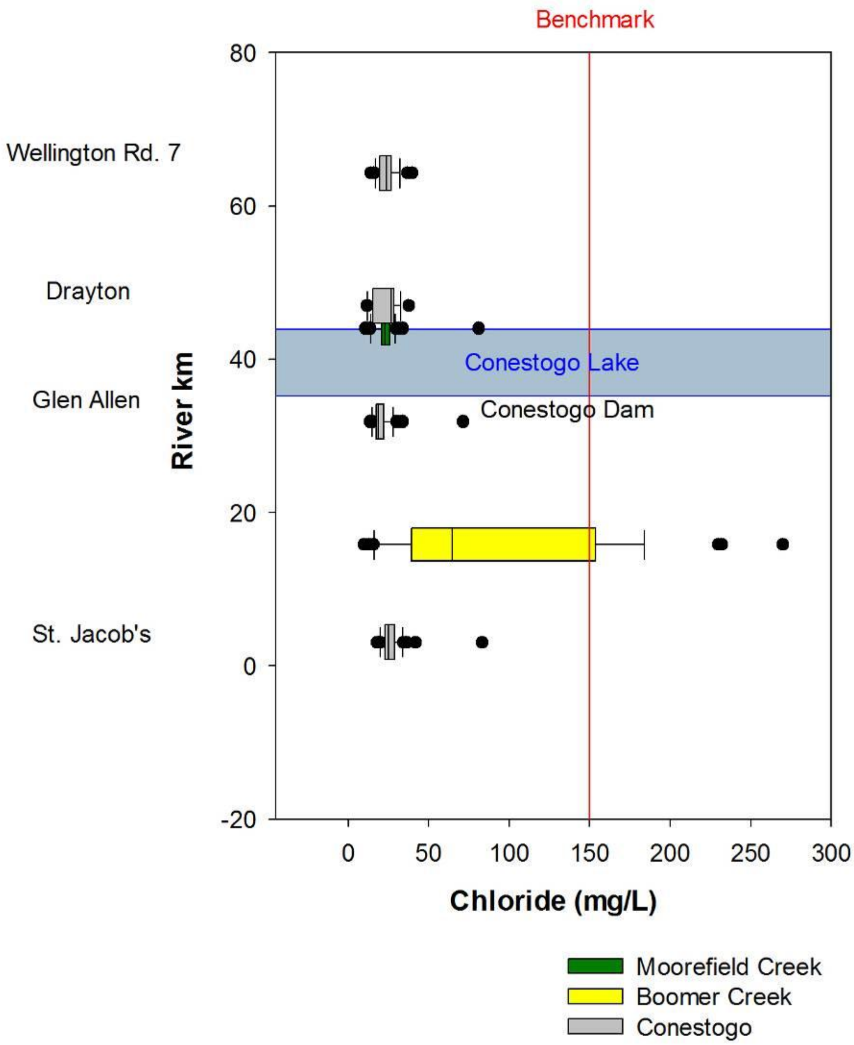


Figure 3-5: Box and whisker plots illustrating the range of chloride concentrations (mg/L) in the Conestogo River subbasin, 2003-2008, relative to the benchmark of 150 mg/L (red line).

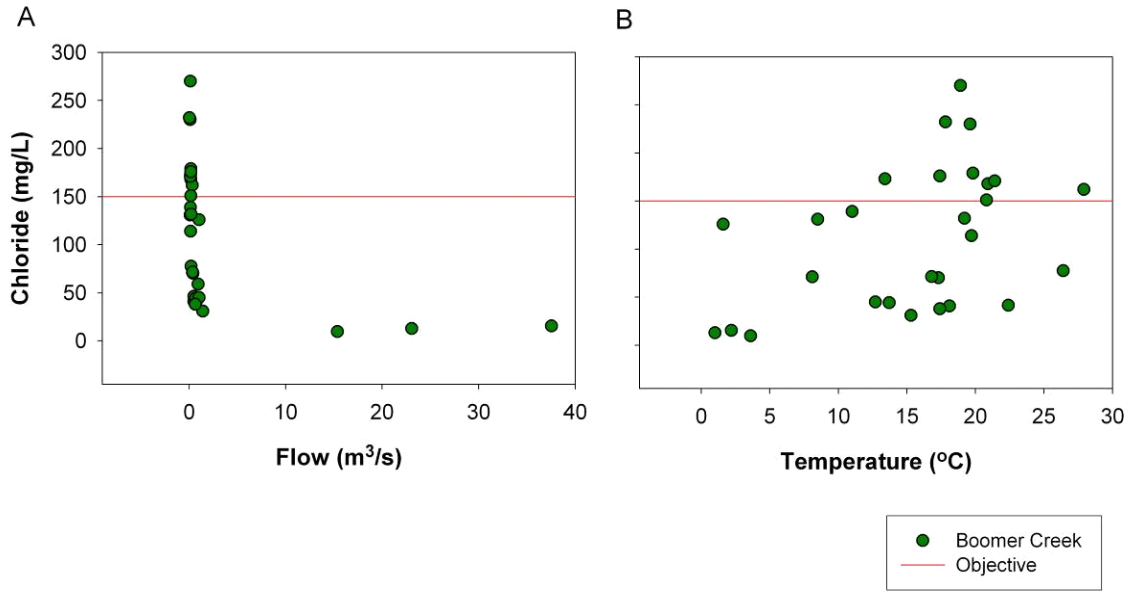


Figure 3-6: Chloride concentrations in Boomer Creek relative to flow (A) and field temperature (B).

Total Nitrates

Total nitrates exceeded the federal environmental quality guideline of 2.93 mg/L frequently at all sites in the Conestogo subbasin (Figure 3-7). Between sites, total nitrate concentrations were not significantly different (p = 0. 4921).

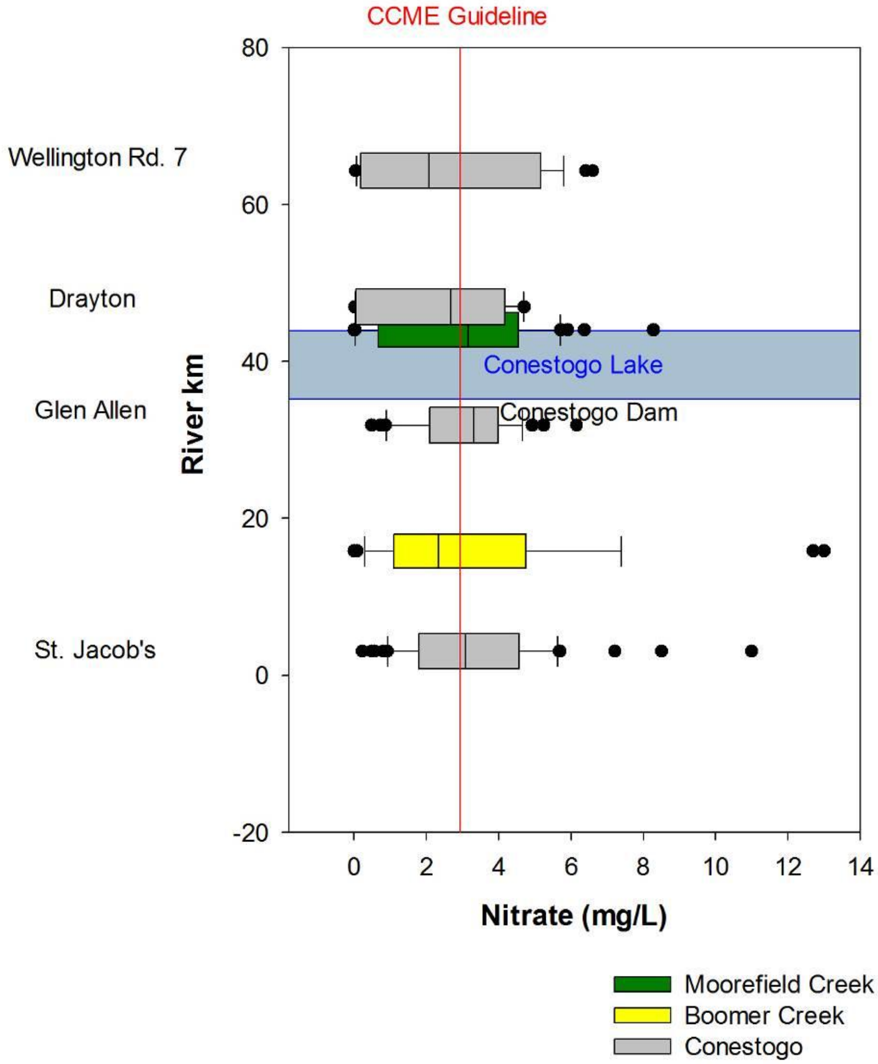


Figure 3-7: Box and whisker plots illustrating the range of total nitrates (mg/L) in the Conestogo River subbasin, 2003-2008, relative to the federal environmental quality guideline of 2.93 mg/L (red line).

Across sites, total nitrate concentrations were significantly negatively correlated with temperature (p <0.0001 – <0.05, Figure 3-8). With the exception of Glen Allen (p = 0.4103), total nitrates concentrations at all sites were positively correlated with flow (p < 0.0001 – < 0.001). Concentrations decrease throughout the growing season as lower concentrations were observed during the summer and higher concentrations were observed during the winter at all sites.

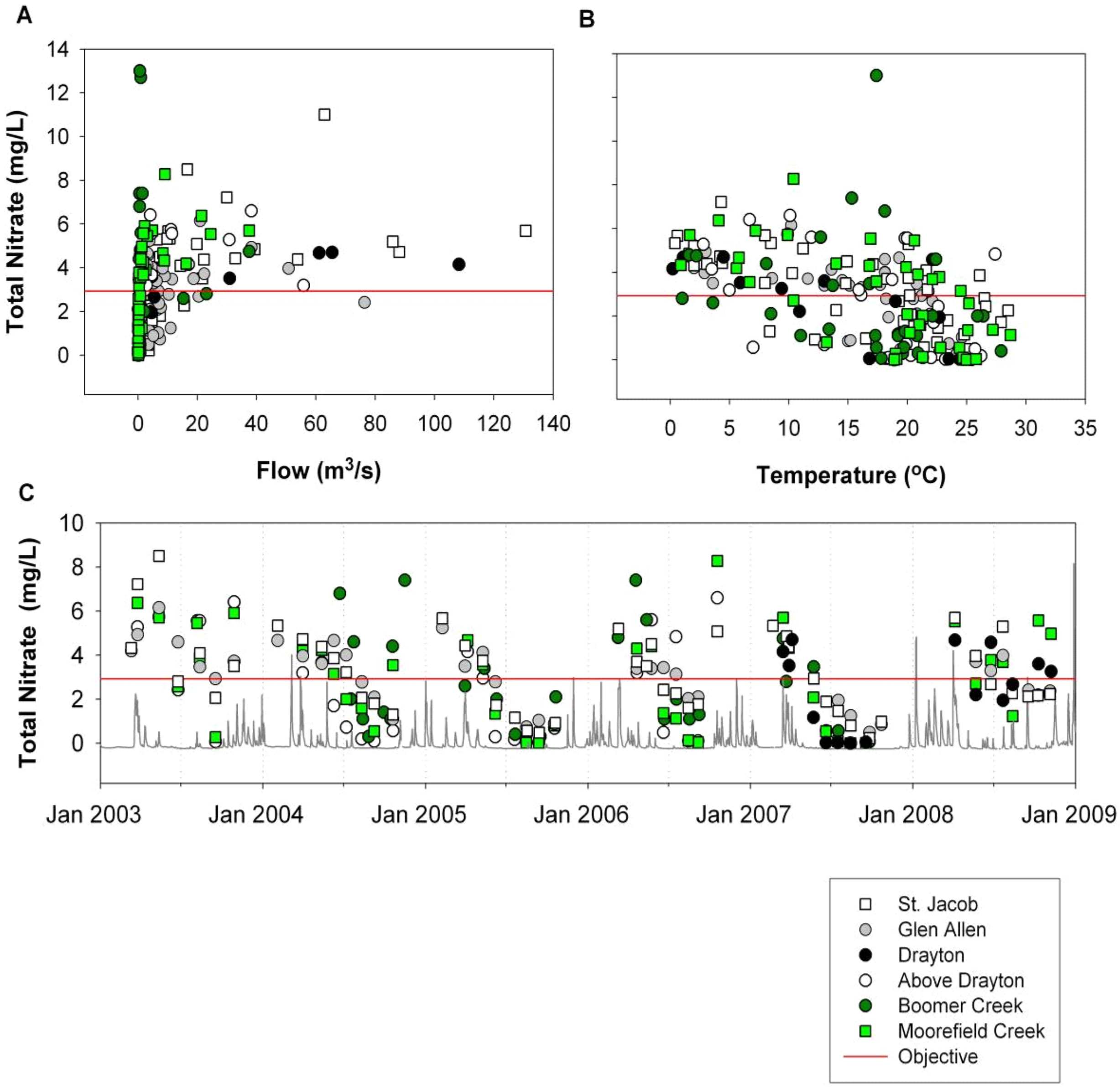


Figure 3-8: Total nitrate concentrations (mg/L) at water quality monitoring sites in the Conestogo River subbasin relative to sampled flow (A), field temperature (B), and time (C).

Total Phosphorus

Most of the samples from all sites had total phosphorus concentrations above the PWQO (Figure 3-9). In Boomer Creek, concentrations were significantly higher relative to the other sites (p < 0.0001). Further, total phosphorus concentrations at Glen Allen, below Conestogo Lake, were significantly greater than at those sites above the reservoir - Wellington Rd. 7 (p <0.01) and Moorefield Creek (p < 0.05).

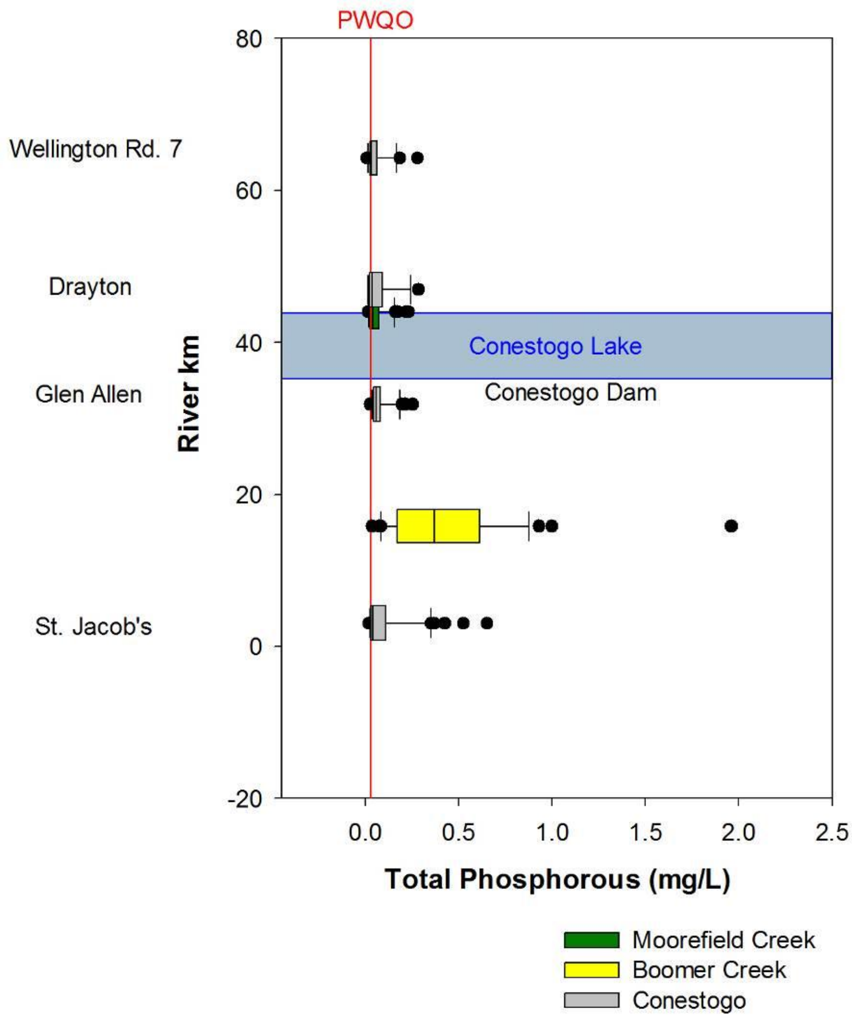


Figure 3-9: Box and whisker plots illustrating the range of total phosphorus concentrations (mg/L) in the Conestogo River subbasin, data from 2003-2008, relative to the Provincial Water Quality Objective of 0.03 mg/L.

Total phosphorus concentrations significantly correlated with temperature at St. Jacobs (p < 0.01, Figure 3-10) while total phosphorus was significantly correlated with flow at Drayton (p < 0.05), Glen Allen (p < 0.01), and St. Jacob (p < 0.0001). In general, total phosphorus concentrations appeared to be higher during higher stream flows and lower temperature at all sites with the exception of Boomer Creek where total phosphorus concentrations were equally elevated across flow and temperature regimes. Generally, less than 25% of the total phosphorus pool was soluble reactive phosphorus, an analytical measure of phosphate. Significant correlations between suspended solids and total phosphorus concentrations were observed across sites ($p < 0.0001 - < 0.05$).

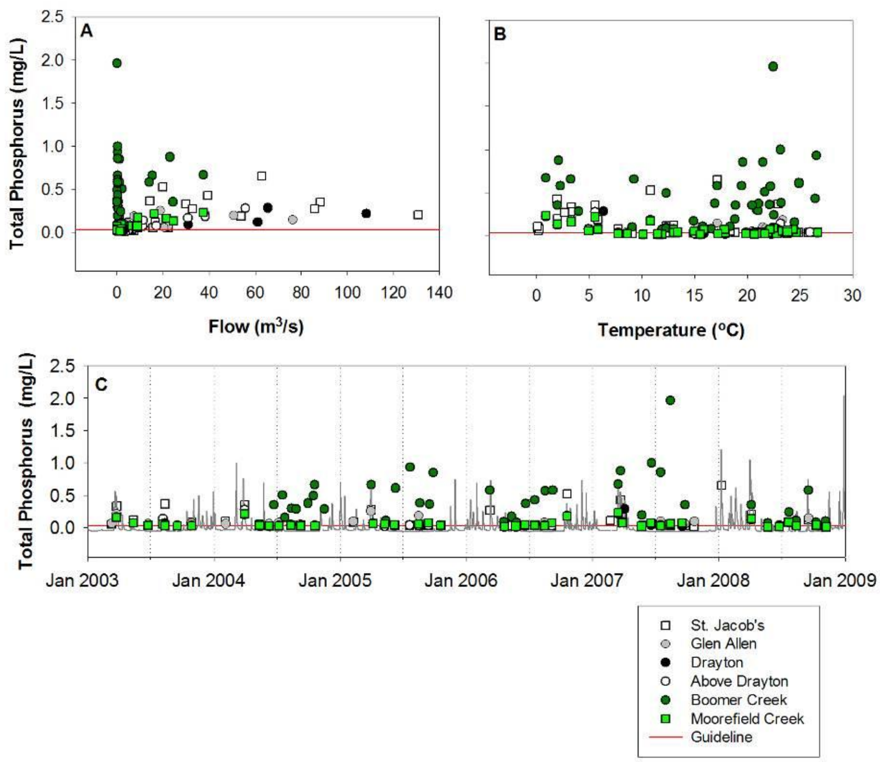


Figure 3-10: Total phosphorus concentrations (mg/L) at water quality monitoring sites in the Conestogo River subbasin relative to sampled flow (A) and field temperature (B), and time (C) between 2003-2008.

Discussion

Generally, eutrophic conditions, as characterized by high total phosphorus and nitrate concentrations, are the predominant water quality issue in the Conestogo River subbasin. Total phosphorus and nitrates tend to be above objectives both above and below the reservoir. However, analysis of the sampling record suggests that additional samples are needed to fully characterize the seasonal variability of water quality conditions in this subbasin.

High concentrations of total phosphorus and total nitrates along with a negative correlation between total nitrates and temperature may suggest a strong influence from groundwater and/or spring runoff as the highest concentrations were observed during major runoff events. These trends suggest a significant influence from nonpoint sources. Although there were no significant differences between sites above and below the reservoir, the discharge from the Conestogo reservoir may also play a role in maintaining and transferring high total phosphorus and total nitrate levels in the lower Conestogo River.

Similar to Belwood Lake, the highest total phosphorus concentrations and likely resulting loads appear to be generated during the spring freshet. These spring loads likely act as a nutrient source for algae later in the summer. The slightly elevated levels found in the Conestogo River below the dam suggest hypoxic conditions in the reservoir that facilitate significant internal nutrient cycling when conditions are right (e.g. vertical mixing of the water column in late summer). Watershed nonpoint sources combined with internal nutrient loading likely promotes the growth of blue-green algae (cyanobacteria) in the reservoir (Guildford 2006). Although Guildford (2006) collected some baseline information on the chemical and biological (algae) characteristics to identify mechanism responsible for causing cyanobacterial blooms, additional information is needed to understand the year-to-year variability of the water quality in the Conestogo reservoir.

Investigation of relationships between select variables shows that total phosphorus is correlated with suspended solid concentrations indicating that much of the phosphorus is in the particulate form and is moved within the river system by similar mechanisms. The predominance of tile drainage in this subbasin, however, may be influencing the delivery of phosphorus, either as total or phosphate, to streams.

Boomer Creek has the poorest water quality in the Conestogo River subbasin. Of particular concern are the total phosphorus and chloride concentrations. Total phosphorus is well above the water quality objective in all seasons. Given the high density of agricultural activity in the drainage area, elevated concentrations during high flows and low temperatures, as in spring melt, are a result of surface run-off. However, during low flow and high temperatures, elevated concentrations also occur. Interestingly, chloride concentrations were also elevated during base flow conditions. This is a trend commonly observed at sites influenced by point source inputs (Jarvie, 2006). Given the minimal urban and residential development and lack of point source inputs in this watershed, this observation is unexpected. Further investigation into the nutrient dynamics of this creek and sampling location is recommended.

The Boomer Creek sampling site is located downstream of a very small residential area (Linwood). While a point source is not known, the upstream development may influence this site rendering it unrepresentative of the general stream conditions. It is recommended that an additional site (at Hawksville) be monitored for comparison. Next, investigation in the sources for the obvious degradation should occur. High densities of livestock and tile drainage systems may more strongly influence nutrient concentrations relative to other regions of this subbasin.

Conclusions & Recommendations

- The major water quality concerns in the Conestogo River subbasin are elevated nutrient and suspended solid concentrations resulting from nonpoint agricultural sources across the watershed.

- The current dataset for all sampling sites on the Conestogo River does not characterize the flow regime. Therefore, additional flow-related monitoring is recommended to improve the characterization of water quality in this subbasin.

- Water quality in Boomer Creek is significantly degraded relative to other sites in the watershed and shows a distinct temporal trend. However, the current monitoring site(s) may not be representative of the entire tributary subbasin. Further assessment of these conditions at other sites in Boomer Creek is recommended.

- Very little water quality data exist for characterizing the Conestogo reservoir. A routine water quality monitoring program is recommended to start characterizing year-to-year variability. A Lake Watch program could be considered to engage local cottagers and residents.

- The current dataset is biased toward summer and spring sampling. To fully characterize seasonal differences in water quality, it is recommended that additional sampling be completed through the fall, winter and early spring time period.

4. Speed / Eramosa River

Introduction

Watershed Characteristics

The Speed-Eramosa River subbasin drains 780 km^2 on the eastern side of the Grand River watershed (Figure 1-4). Three regions can be distinguished: the Eramosa River; the Speed River above the Guelph Lake reservoir; and the Speed River below the reservoir which flows through the City of Guelph and flows into the Grand River in Preston, Cambridge (Figure 4-1).

The upper Speed River has a well-defined drainage network through the eroded Orangeville Moraine (Lake Erie Source Protection Region Technical Team 2008). Ground water discharges are comparably low and base flows are unstable (Figure 1-6, Figure 1-8). The Eramosa River drains the most northern portion of the Paris/Galt moraines which creates a hummochy topography that promotes infiltration and reduces surface run-off to the river. Base flows in this region are stable, a condition which is attributed to the significant ground water discharge ((Holysh, Pitcher et al. 2000; Lake Erie Source Protection Region Technical Team 2008; Aquaresource Inc. 2009)). Flows in the lower Speed River are stable due to the active management of the Guelph Lake reservoir and the Eramosa River. These two sources of water help to maintain base flows and provide for the assimilation of wastewater effluent discharges from the cities of Guelph and Hespeler (Table 1-1).

Agricultural activities in this subbasin are less intensive relative to the other subbasins with only 58% of the land base in agricultural production (Table 4-1) Crops are fairly evenly split between grains, corn, soy, and other field crops (18 -28%; Figure 1-11). Only six percent of the lands in the subbasin use tile drainage. Livestock production is relatively low with densities of swine and cattle being the lowest across the watershed (0.18 & 0.19 animals/ha, respectively) and poultry densities (7.44 animals/ ha) being second-lowest (Figure 1-10). Urban development in the lower stretch of the Speed River is substantially greater than in the other regions (26%, Table 4-1) because of the cities of Guelph and Hespeler. Urban land cover patterns are reflected by the human densities in the lower Speed (490.18 persons/km^2) relative to densities in the Eramosa River (20.13 pers./km^2) and the upper Speed River (44.87 pers./km^2; Figure 1-14).

Table 4-1: The percentage of land cover devoted to agricultural activities, urban development, treed land, and wetlands in the Speed River subbasin.

Region	Land Cover (%)			
	Agriculture	Urban	Treed Land	Wetland
upper Speed River *(Headwaters to Guelph Lake)*	68	3	6	23
Eramosa	60	6	14	20
lower Speed River *(Guelph Lake to Mouth)*	50	26	6	16
Total	59	12	9	20

Watershed Uses & Values

The Guelph Lake and Rockwood reservoirs and their respective conservation areas are highly valued for local recreational activities, including canoeing, swimming, and fishing. Additionally, stretches on the Speed River running through the City of Guelph are fringed by urban parks which promote interaction between the river and local residents.

Streams in the upper reaches of the Speed and Eramosa rivers as well as Hanlon Creek in the lower Speed River are suitable for native brook trout and related cold water fisheries (Figure 1-15,). The larger lower Speed River and the reservoirs are suitable for a warm water fishery dominated by top predators such as bass and pike (Grand River Fisheries Management Plan Implementation Committee 2005).

The upper Speed River drains into Guelph Lake, a multipurpose reservoir which is used to provide valuable flood protection as well as augment base flows in the Speed River downstream. The low flow augmentation from the reservoir, as well as flows from the Eramosa River, assists with assimilating the wastewater effluent from the municipalities of Guelph and Hespeler.

Subbasin Specific Monitoring

Six long term monitoring sites are established in the Speed River watershed. These sites are part of the Provincial Water Quality Monitoring Network that are sampled approximately 8-9 times per year between March and November. Two of the six sites were added more recently: Edinburgh Road in 2007 and Victoria Road in 2004 (Figure 4-1, Figure 4-2, Table 4-2). These sites were added to ensure appropriate reference sites were monitored above the city of Guelph's wastewater treatment plant. Further, the site below Guelph Lake also aids in understanding the water quality in the lake that is the source for the lower Speed River.

In addition to the six grab sampling sites, there are two continuous water quality monitoring stations: the Speed River at Edinburgh Road and at Road 32, above and below the City of Guelph's wastewater treatment plant, respectively.

In 2008, additional monitoring was completed in the vicinity of the City of Guelph's wastewater treatment plant to characterize seasonal conditions (e.g. winter, spring, summer and fall) in the river. In total, 24 grab samples (6 per season) were collected at an additional 14 sites to characterize near-field, far-field and tributary influences to the Speed River.

Flow gauges across the Speed River subbasin correspond with most water quality monitoring sites and are located above Guelph Lake, at the mouth of the Eramosa, Victoria Rd. and Hanlon Rd. in Guelph, and Beaverdale above Hespeler. Flows at the Edinburgh Rd. and Wellington Rd. 32 sites were taken from the Hanlon Rd. flow record.

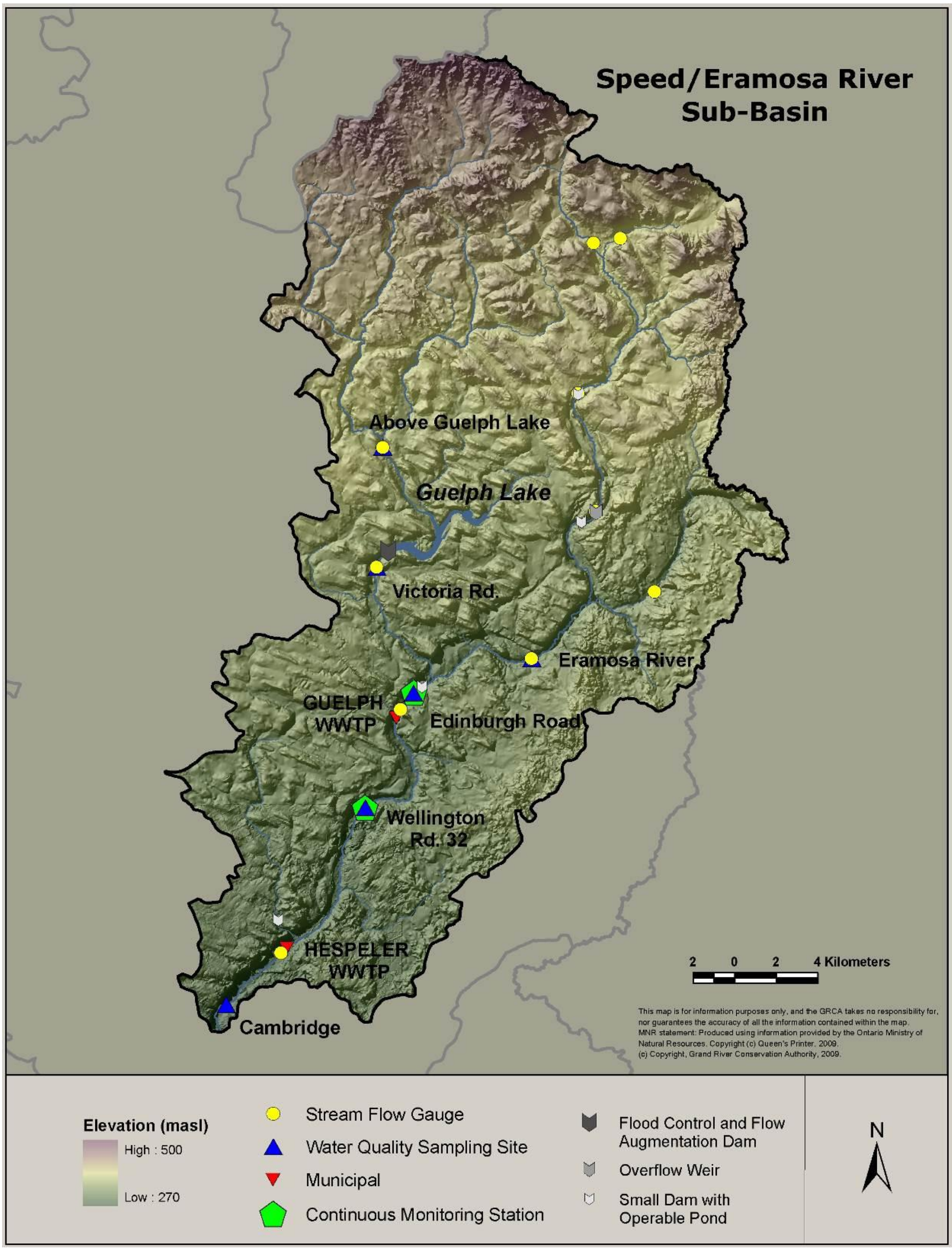


Figure 4-1: Long-term water quality sampling sites, flow gauge locations, municipal wastewater treatment plants and continuous monitoring stations in the Speed River subbasin monitored between 2003 and 2008.

Table 4-2: The river course sampled, site description, site number, and report short name for samples collected in the Speed River subbasin.

Stream	Site Description	Site number	Report Short Name
Speed	Armstrong Mills, above Guelph Lake	16018409902	Above Guelph Lake
	Victoria Road in Guelph	16018412602	Victoria Rd.
	Woodlawn Rd., Guelph	16018404302	n/a
	Edinburgh Rd, Guelph	16018403402	Edinburgh Rd.
	Wellington Rd. #32	16018403602	Wellington Rd. 32
	Highway #8, Cambridge	16018410102	Cambridge
Eramosa	Wellington Country Rd. 41, Arkell	16018410202	Eramosa
	Hwy #25	16018410902	n/a

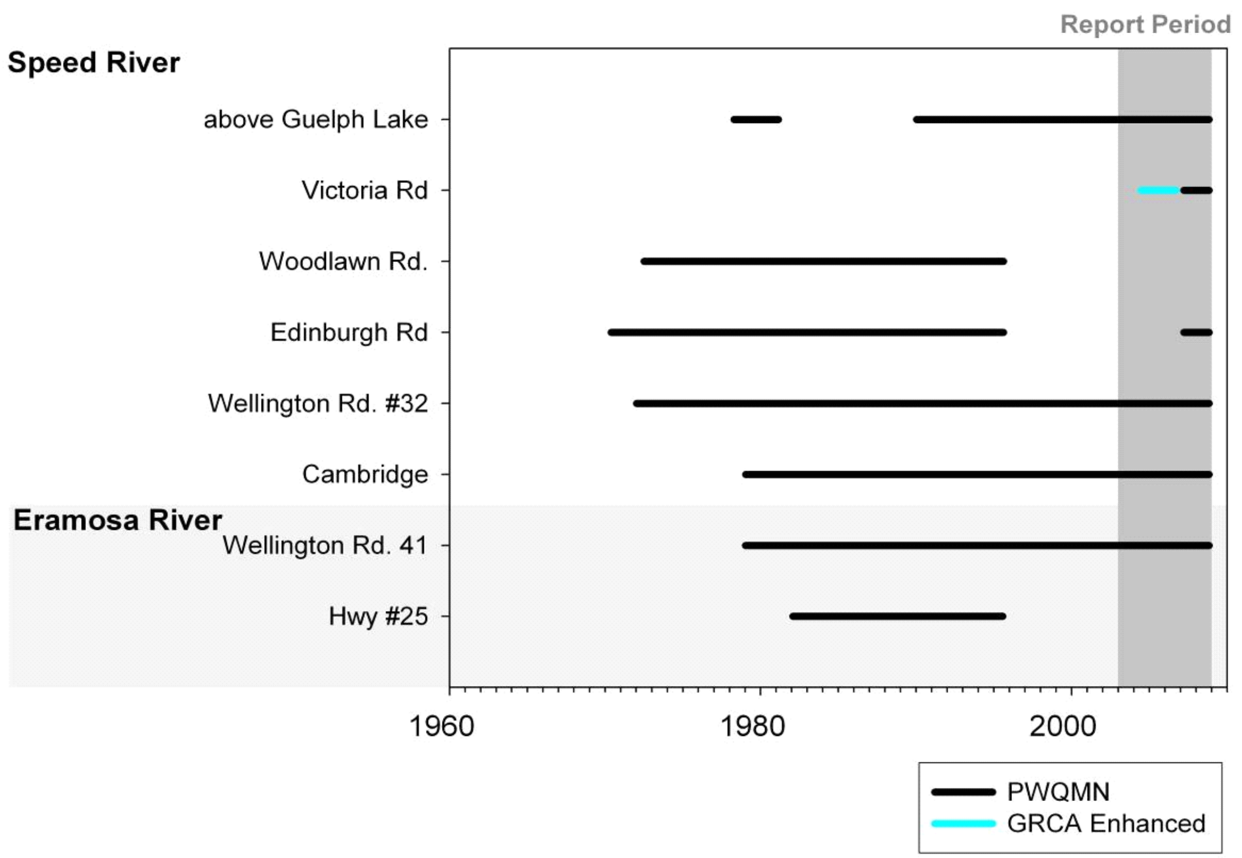


Figure 4-2: Sampling record for GRCA and Provincial Water Quality Monitoring Network sites in the Speed River subbasin.

Results

Dataset Description

The seasonal distribution of the data at the six long-term sites in the Speed River subbasin varied slightly between sites. All datasets reflected predominantly summer and spring conditions. The only sites with samples collected during the winter were Edinburgh Rd., Wellington Rd. 32, Cambridge and Eramosa. There were no samples taken in the fall at the Edinburgh Road sampling site.

Table 4-3: The proportion of site datasets representing winter, spring, summer, and fall in the Speed River Watershed

Site	% Sampled			
	Winter	Spring	Summer	Fall
Eramosa	2	35	48	15
Above Guelph Lake	0	33	57	10
Victoria Rd.	0	27	60	14
Edinburgh Rd.	20	33	47	0
Wellington Rd. 32	10	31	48	10
Cambridge	9	35	48	9

The sampled flow record was not significantly different between sites or from the observed record across sites (p = 0.1128, Figure 4-3, Table 4-4). However, the sampled temperature record was warmer than the temperature record at all sites except Edinburgh Rd. Between site differences in the temperature record were not significant.

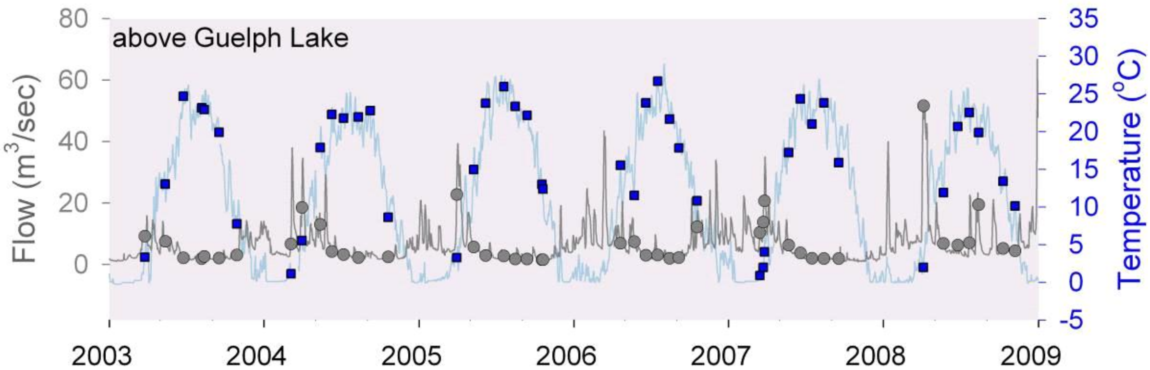


Figure 4-3: Daily average flow (grey line) and temperature (blue boxes) sampled above Guelph Lake relative to the flow timeseries at the Hanlon flow gauge and Bridgeport temperature monitoring site between 2003 and 2008.

The range of flows was well captured at all sites except at the mouth of the Eramosa and at Victoria Rd, where only 42% of the observed flow range was captured. The range in temperature was also well captured across all sites (Table 4-4).

Table 4-4: The percent of the flow and temperature record sampled at each site in the Speed River subbasin between 2003 and 2008.

Site	% Sampled	
	Flow	**Temp.**
Eramosa	42	91
Above Guelph Lake	99	88
Victoria Rd.	42	84
Edinburgh Rd.	98	83
Wellington Rd. 32	99	91
Cambridge	98	89

Summer Water Temperature

Summer temperatures were within the range required to support a cold water fishery, consistently falling below 20°C above Guelph Lake and in the Eramosa River (Figure 4-4). At Victoria Rd., Wellington Rd. 32, and Cambridge median summer temperatures were above 20°C which would support a warm water fishery. However, between site comparisons shows similar summer temperatures across most sites ($p = 1.43 – 14.19$) with the exception of the Cambridge site which was significantly warmer than all other sites ($p < 0.0001 – < 0.05$).

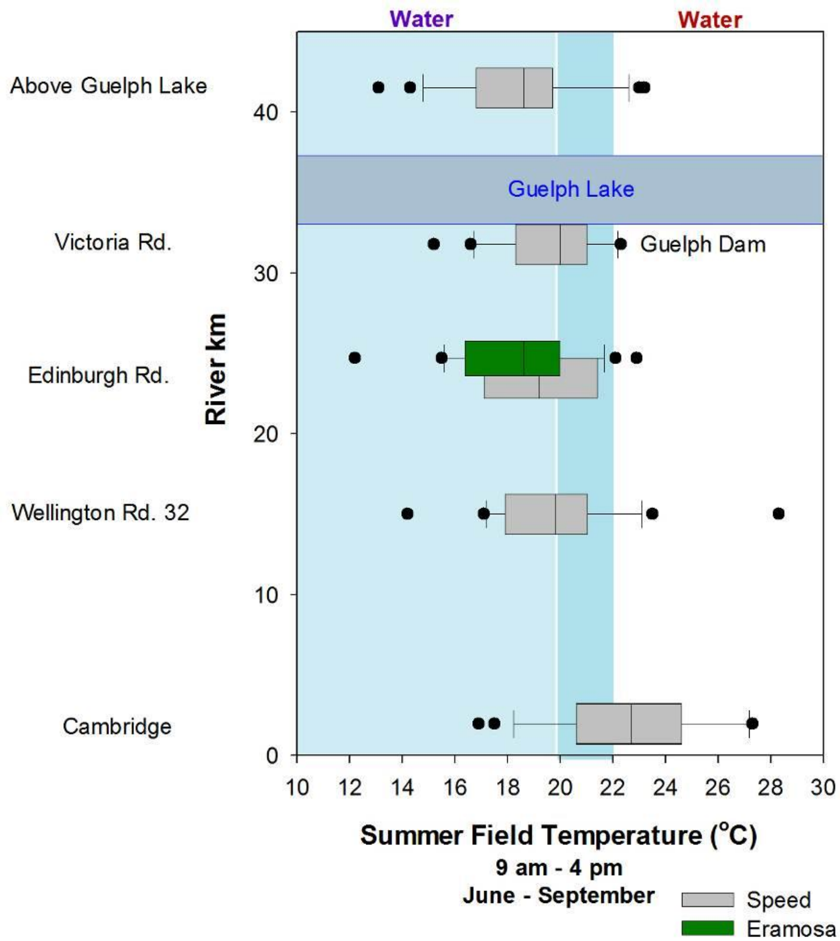


Figure 4-4: Box and whisker plots illustrating the range of summer (June – September) daytime (9 am - 4 pm) field temperatures in the Speed River subbasin.

Dissolved Oxygen

At the two continuous water quality monitoring stations on the Speed River, the daily minimum dissolved oxygen concentration are well above the provincial objective for warm water fish in the winter and spring months (December to April). Summer dissolved oxygen levels tend to be lowest with the daily minimums near the provincial objective during the summer months (July and August; Figure 4-5) at Wellington Road 32. This seasonal trend is more distinct at the Wellington Rd. 32 site, where the dissolved oxygen concentration approaches the water quality objective for warm water fisheries (4.0 mg/L).

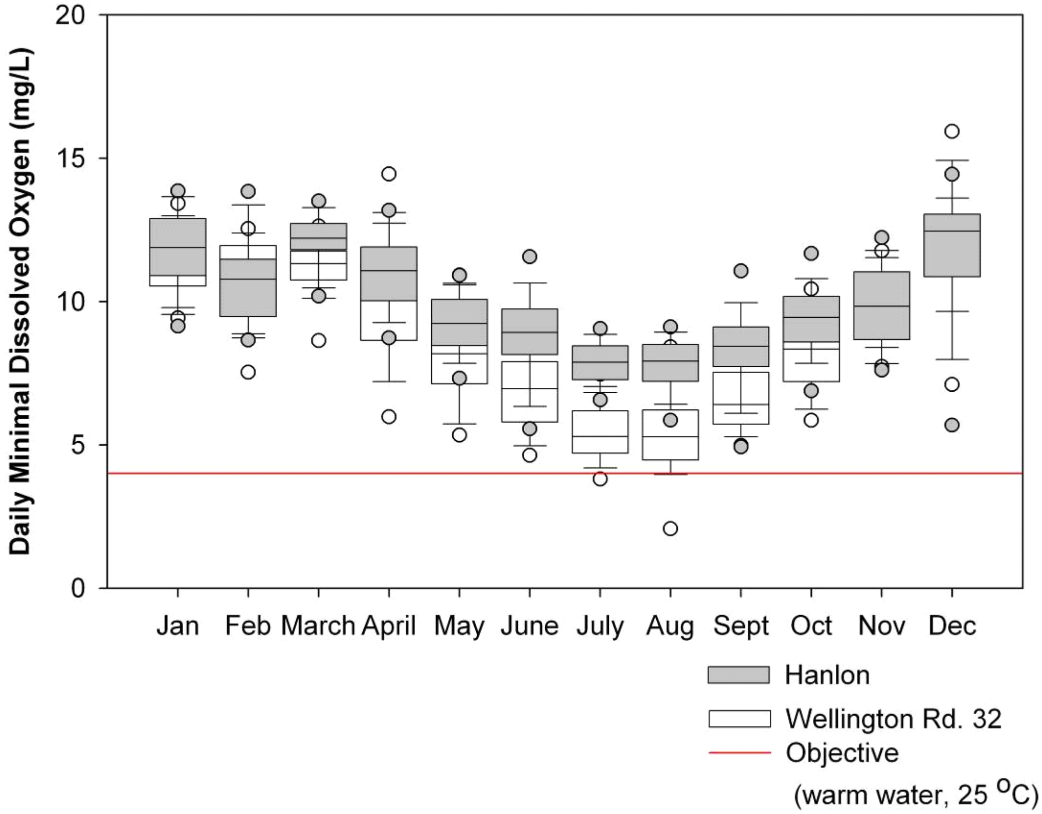


Figure 4-5: Box plots showing the distribution of the daily minimum dissolved oxygen concentrations (mg/L) at the Edinburgh Road and Wellington Rd. 32 continuous water quality monitoring stations on the Speed River for data between 2003 and 2008. The red line represents the objective of 4 mg/L for warm water fishes.

A strong diurnal variation in dissolved oxygen exists at the Wellington Rd. 32 monitoring station with concentrations ranging from 4.0 mg/L to 10 mg/L on a daily basis in the summer. Daily dissolved oxygen minimums tend to occur between 6am and 9am while the daily high concentrations tend to occur between 3 and 8pm. In contrast, there is no diurnal variation of dissolved oxygen at the Edinburgh Road (Hanlon) site (Figure 4-6).

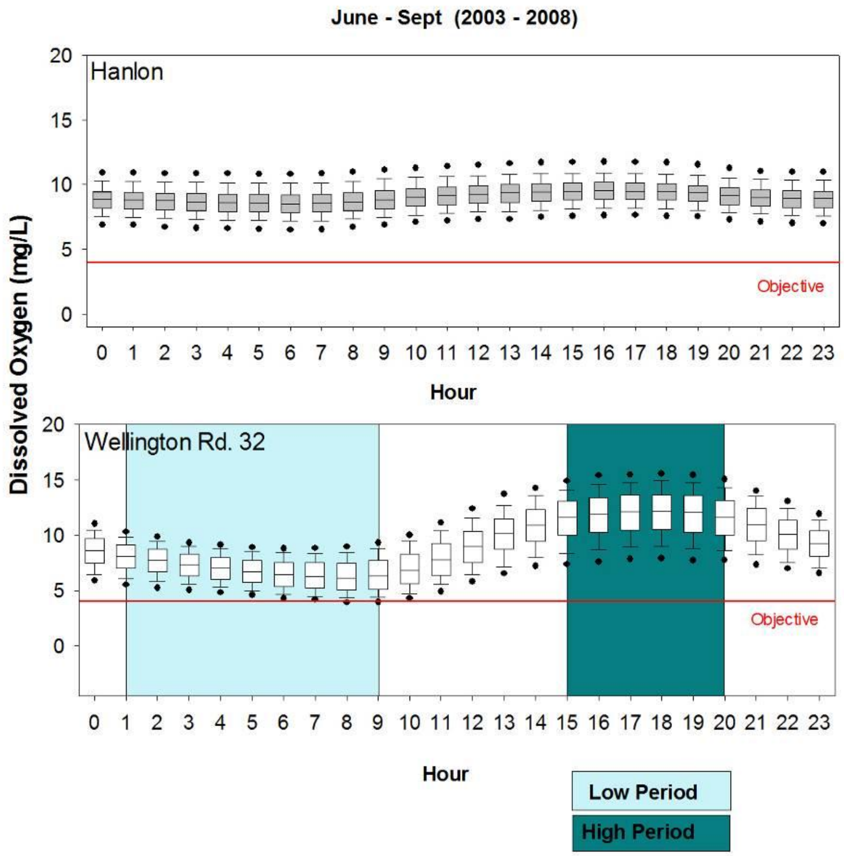


Figure 4-6: Box plots showing the range and distribution of dissolved oxygen concentrations between June and September at two continuous monitoring stations on the Speed River. The red line represents the objective of 4 mg/L for warm water fishes.

Chloride

Chloride concentrations are significantly higher at the sites below the City of Guelph at Wellington Road 32 and near the mouth of the Speed River in Cambridge relative to the four upstream sites ($p < 0.0001$). Chloride levels at these two downstream sites exceed the benchmark of 150 mg/L in 25% of the samples (Figure 4-7).

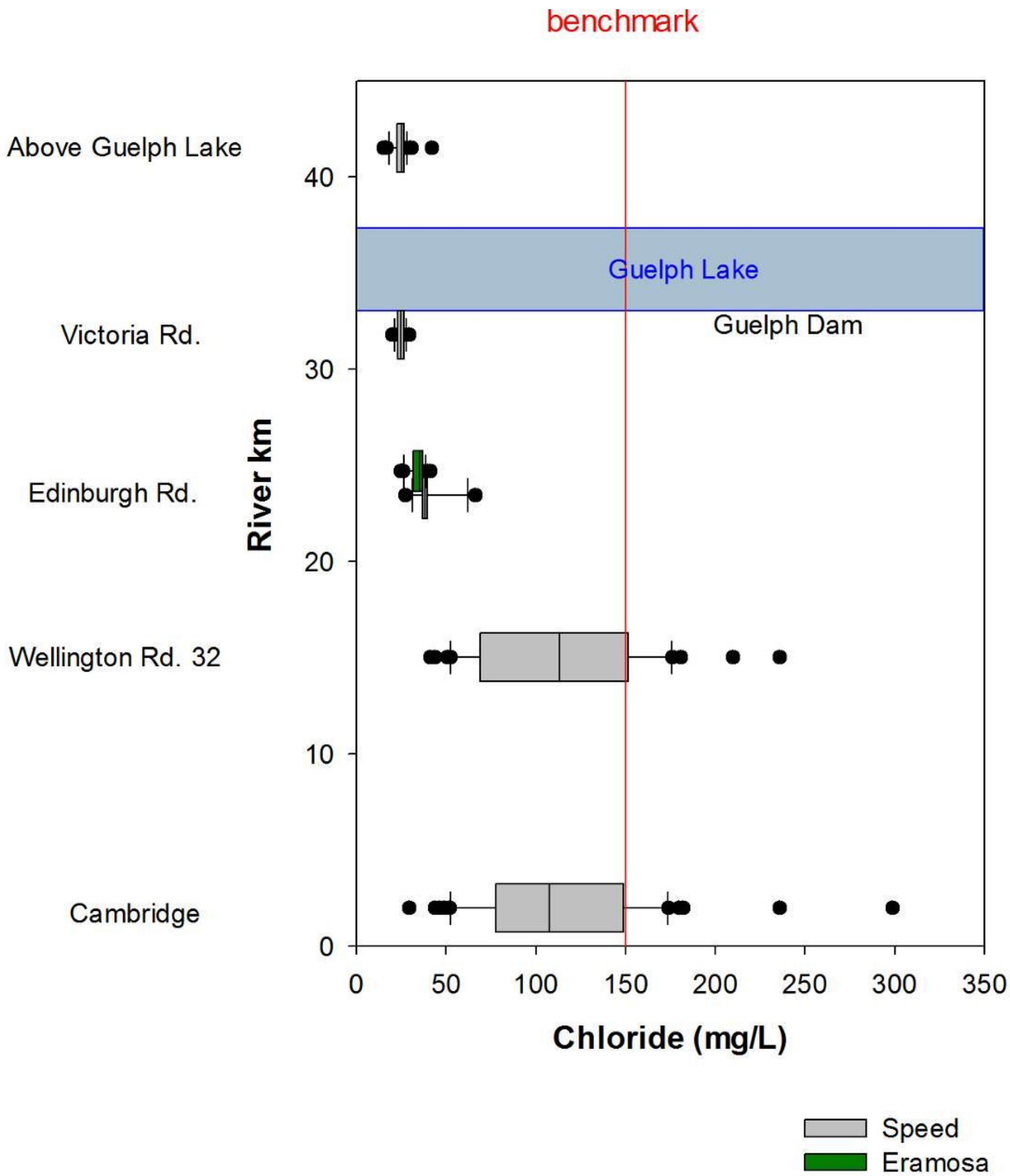


Figure 4-7: Box and whisker plots showing the range of chloride concentrations at monitoring sites in the Speed - Eramosa river subbasin between 2003 and 2008.

At Wellington Rd. 32 and in Cambridge, chloride concentrations were higher during summer periods and typically lower during winter and spring periods (Figure 4-8, C). Variable but high chloride concentrations were observed during the lowest temperatures and low flows. This pattern is reflected by the negative correlation between chloride and flow ($p < 0.0001$) and a less obvious relationship between chloride and temperature (Figure 4-8, A, B).

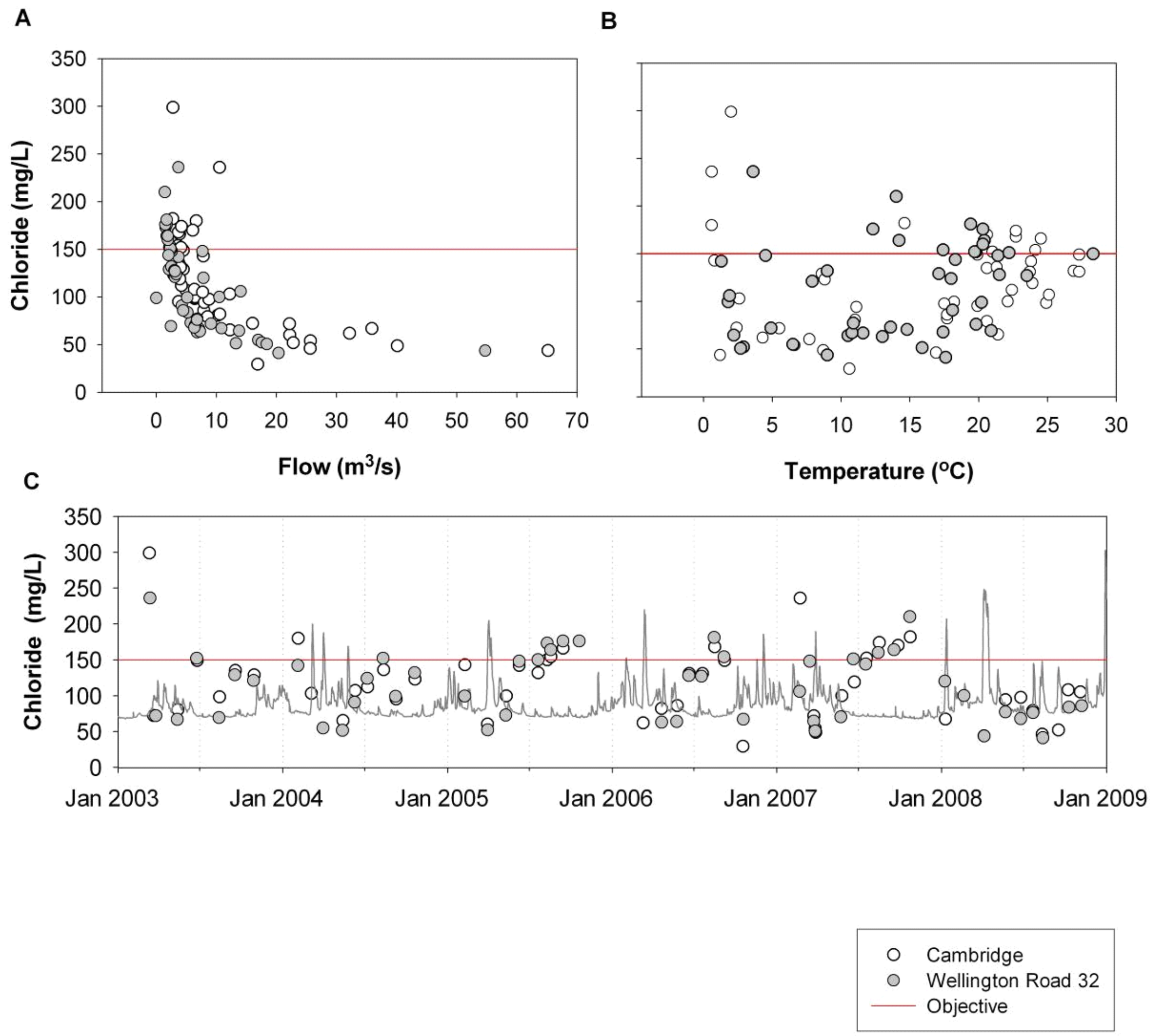


Figure 4-8: Chloride concentrations in the Speed River at Wellington Rd. 32 and in Cambridge relative to flow (A), field temperature (B), and time (C).

Summer low flow sampling in 2008 show increased chloride concentrations downstream of the Guelph municipal wastewater discharge and in the Northwest drain which follow a decreasing trend in the following 10 river kilometres (Figure 4-9). Elevated chloride concentrations were also observed in the Northwest drain and in Hanlon Creek.

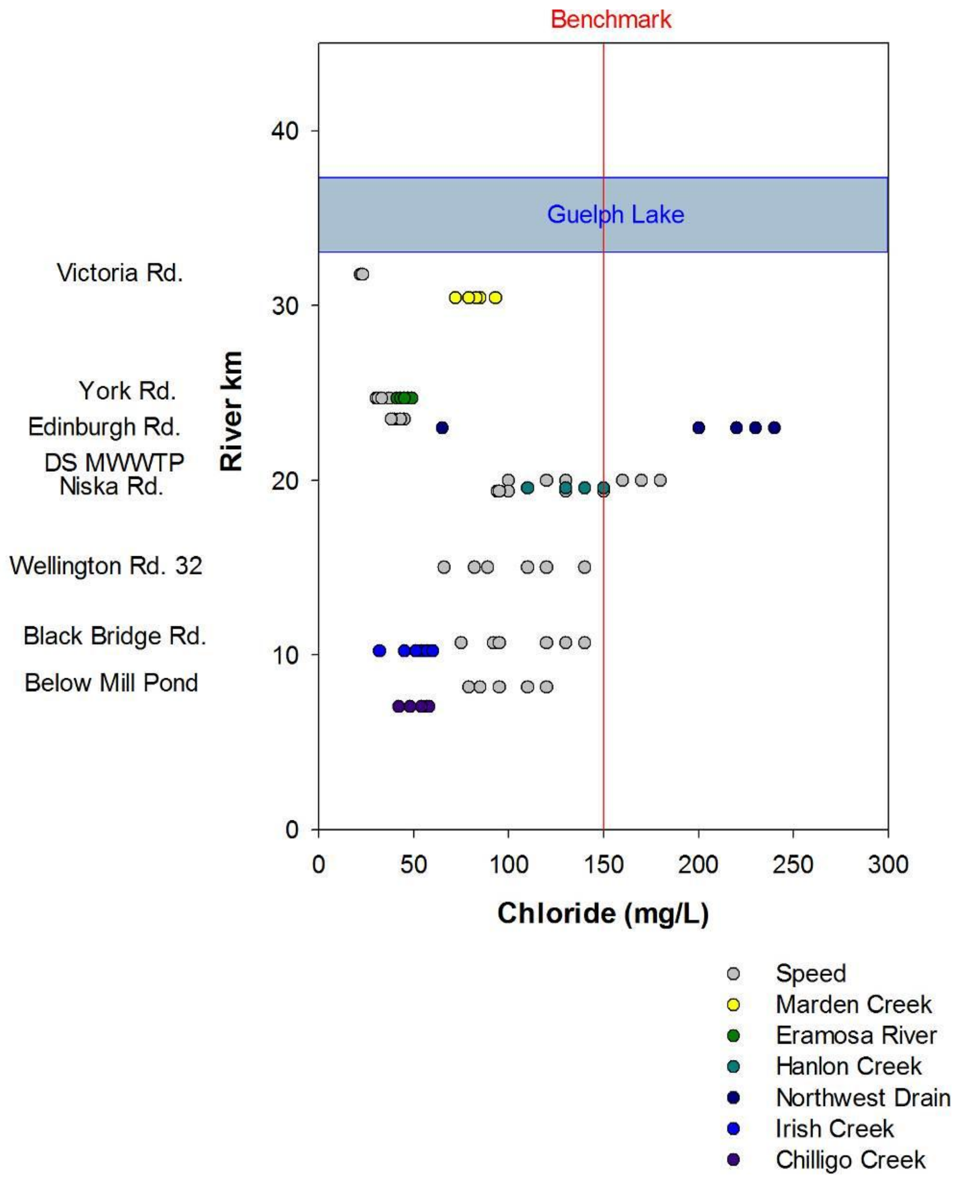


Figure 4-9: Chloride concentrations (mg/L) in the Speed River and select tributaries arranged by river kilometre between July and August 2008.

Un-ionized Ammonia

With the exception of a few outliers downstream of the Guelph Lake reservoir, un-ionized ammonia concentrations did not exceed the water quality objective in the Speed River subbasin. The lowest concentrations were observed above Guelph Lake and in the Eramosa River and the highest concentrations were observed at Victoria Rd. and in Cambridge on the Speed River.

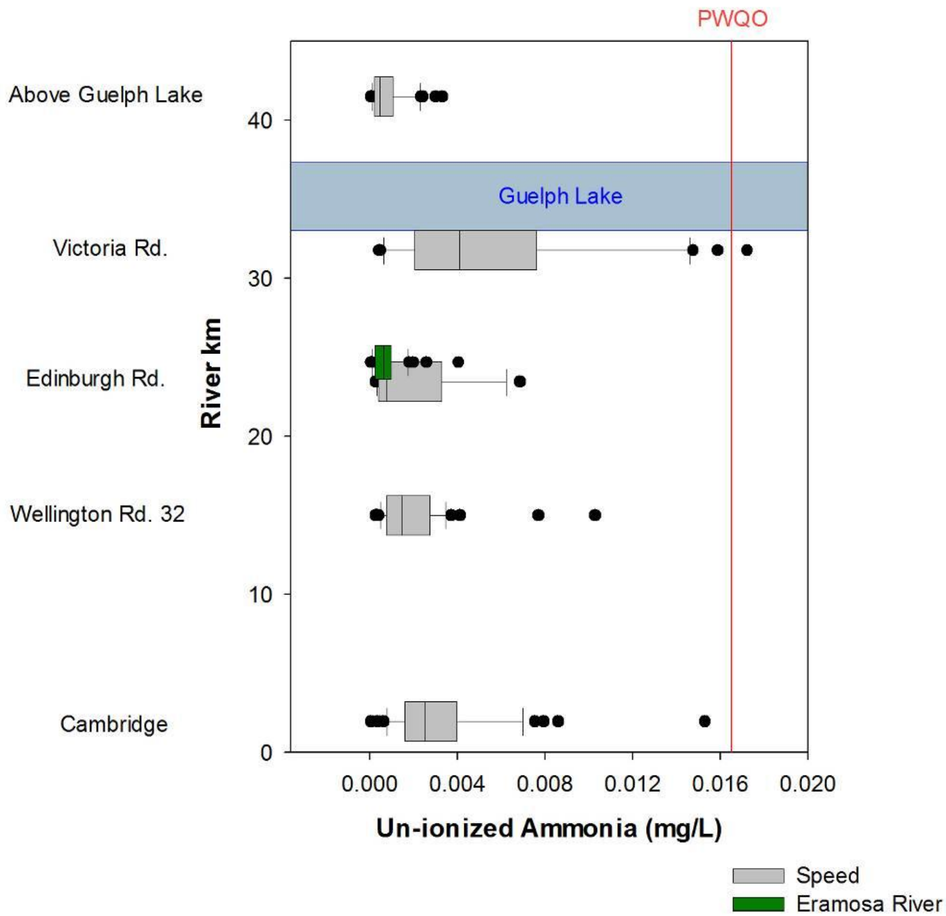


Figure 4-10: Box and whisker plots illustrating the range of un-ionized ammonia concentrations (mg/L) at monitoring sites in the Speed River subbasin

Grab samples collected at Victoria Rd. and York Rd. on the Speed River exceeded the un-ionized ammonia concentrations during low flow summer conditions. Concentrations were also elevated in Marden Creek due to a high stream pH value.

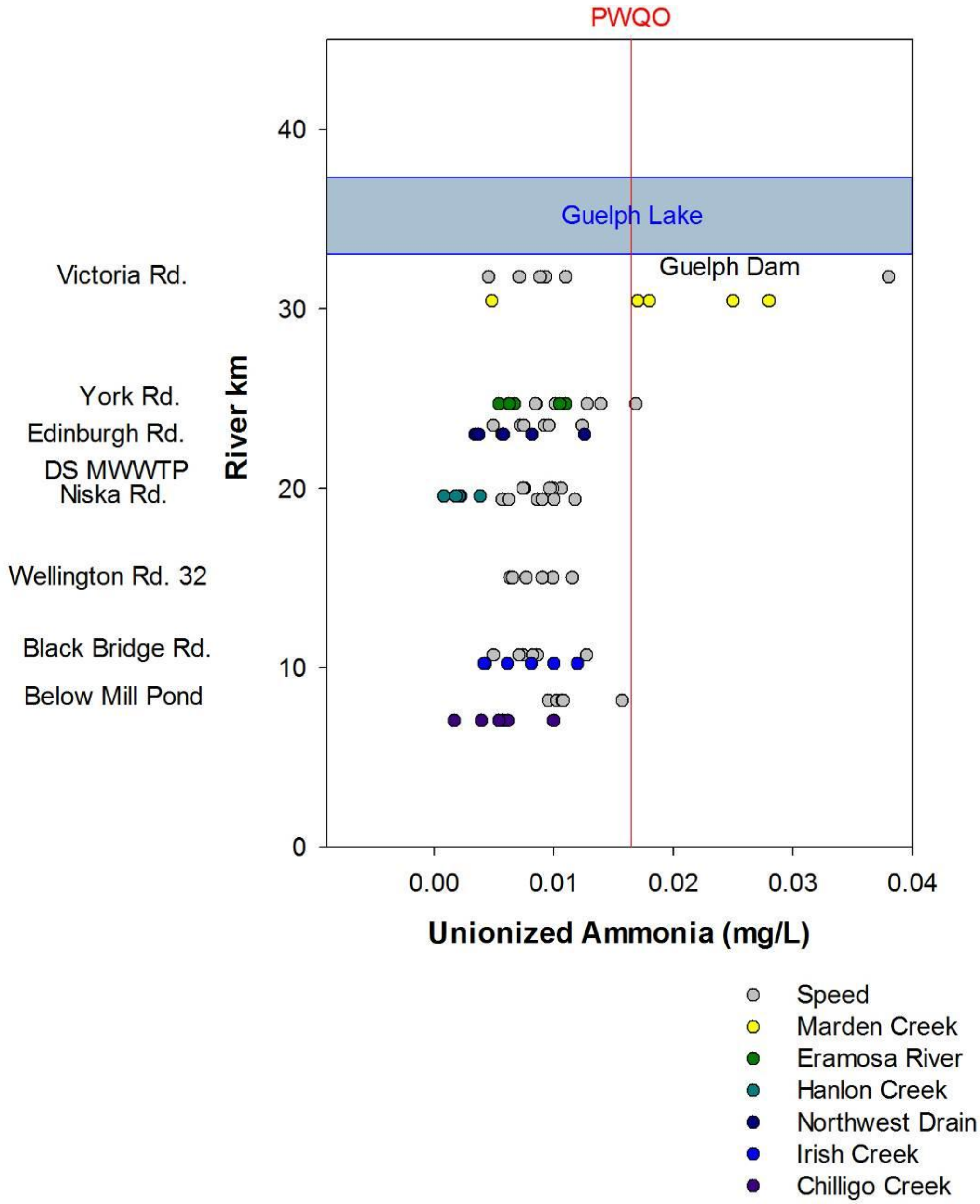


Figure 4-11: Un-ionized ammonia concentrations (mg/L) in the Speed River and select tributaries during summer low flows between July and August 2008

Total Nitrates

Total nitrate concentrations were below the federal environmental quality guideline above Guelph Lake, at Victoria Rd., and Edinburgh Rd. on the Speed River and in the Eramosa River (Figure 4-12). Total nitrate concentrations were significantly higher at Wellington Road 32 when compared to all upstream sites. More than 50% of the samples were above the guideline at Wellington Road 32 and in Cambridge.

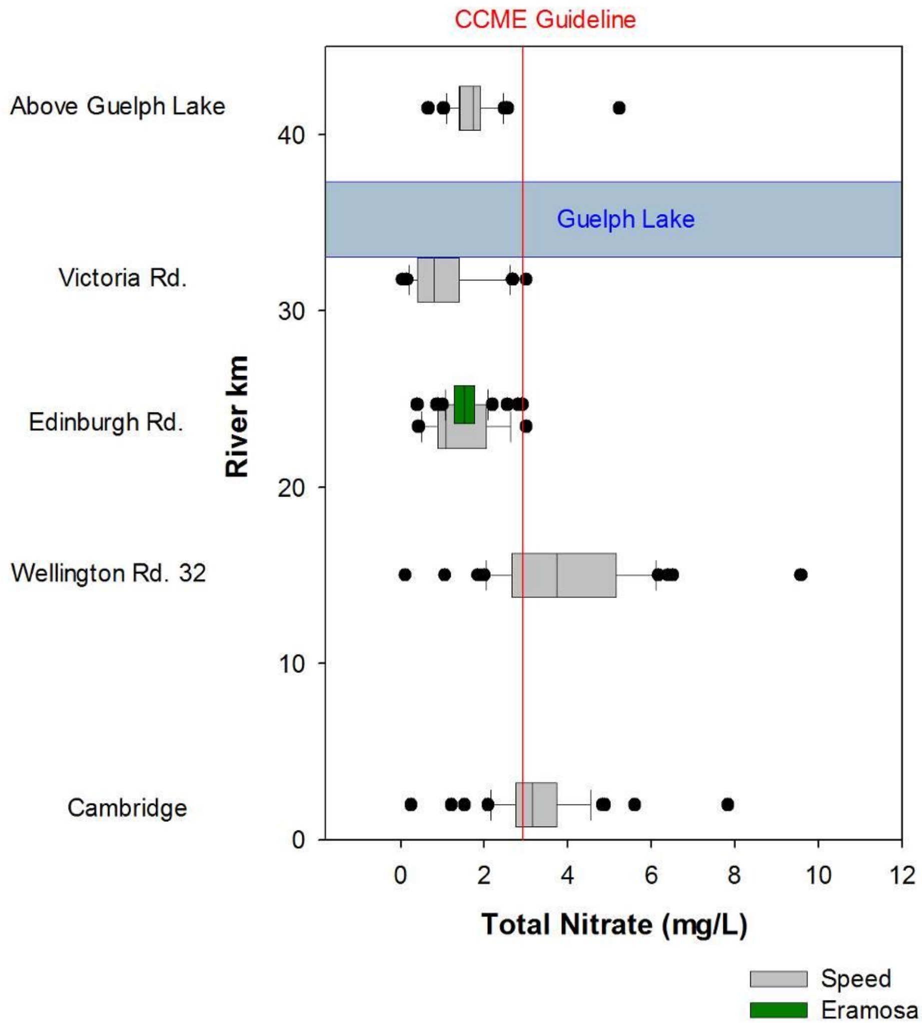


Figure 4-12: Box and whisker plots illustrating the range of total nitrate concentrations (mg/L) in the Speed River subbasin.

Nitrate concentrations at Wellington Rd. 32 and Cambridge were negatively correlated with flow ($p < 0.0001$, < 0.0005) but were not correlated with temperature ($p = 0.8448$ & 0.2286). Peak concentrations often occurred during winter and summer low flows (Figure 4-13).

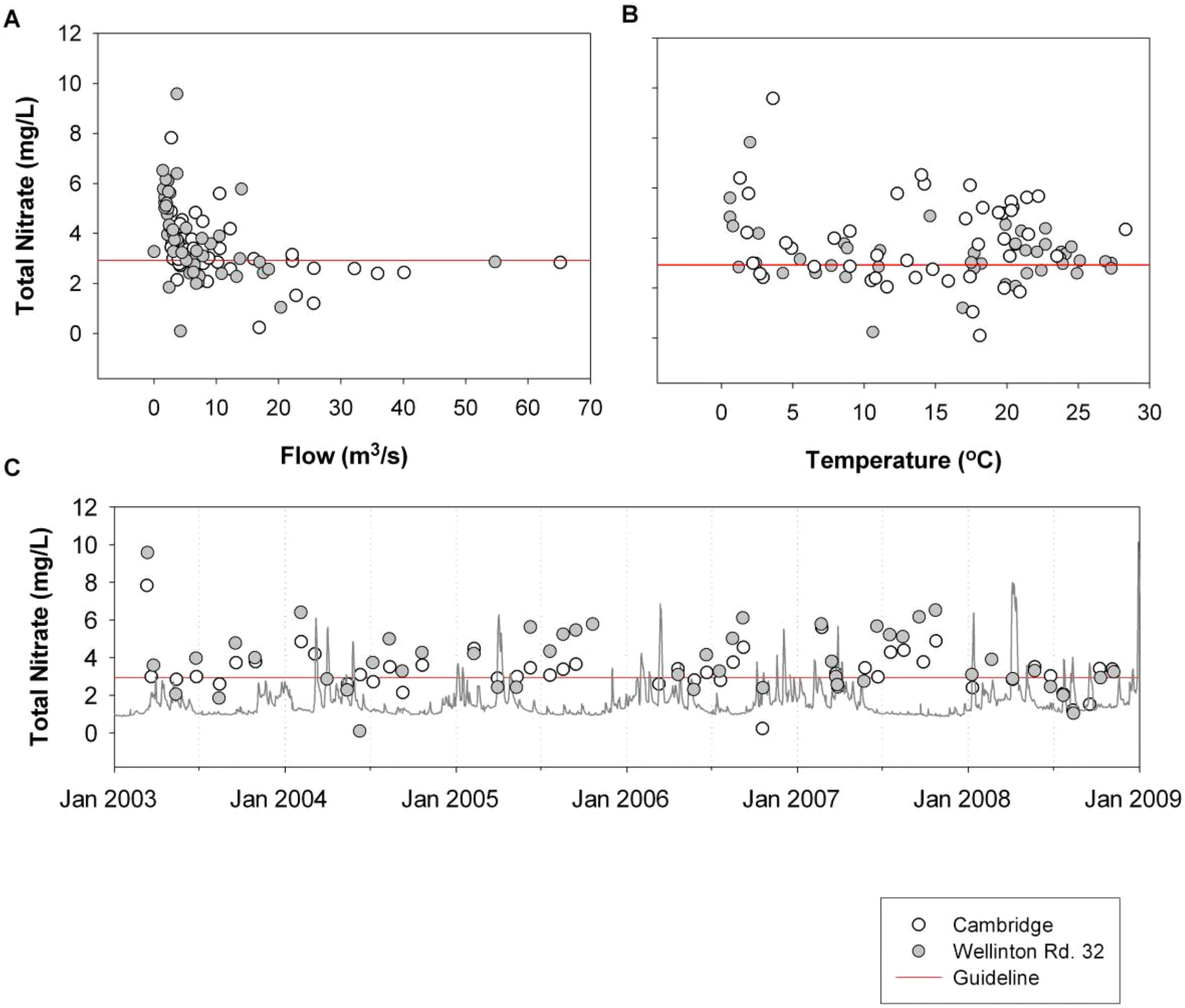


Figure 4-13: Total nitrate concentrations (mg/L) at Wellington Rd. 32 and Cambridge in the Speed River relative to sampled flow (A), field temperature (B), and time (C).

Intensive sampling during summer low also confirmed that total nitrates were consistently higher than the environmental quality guideline of 2.93 mg/L downstream of the wastewater treatment plant; however, concentrations tend to decrease with distance downstream (Figure 4-14). Chilligo Creek was the only tributary with total nitrate concentrations exceeding the guideline.

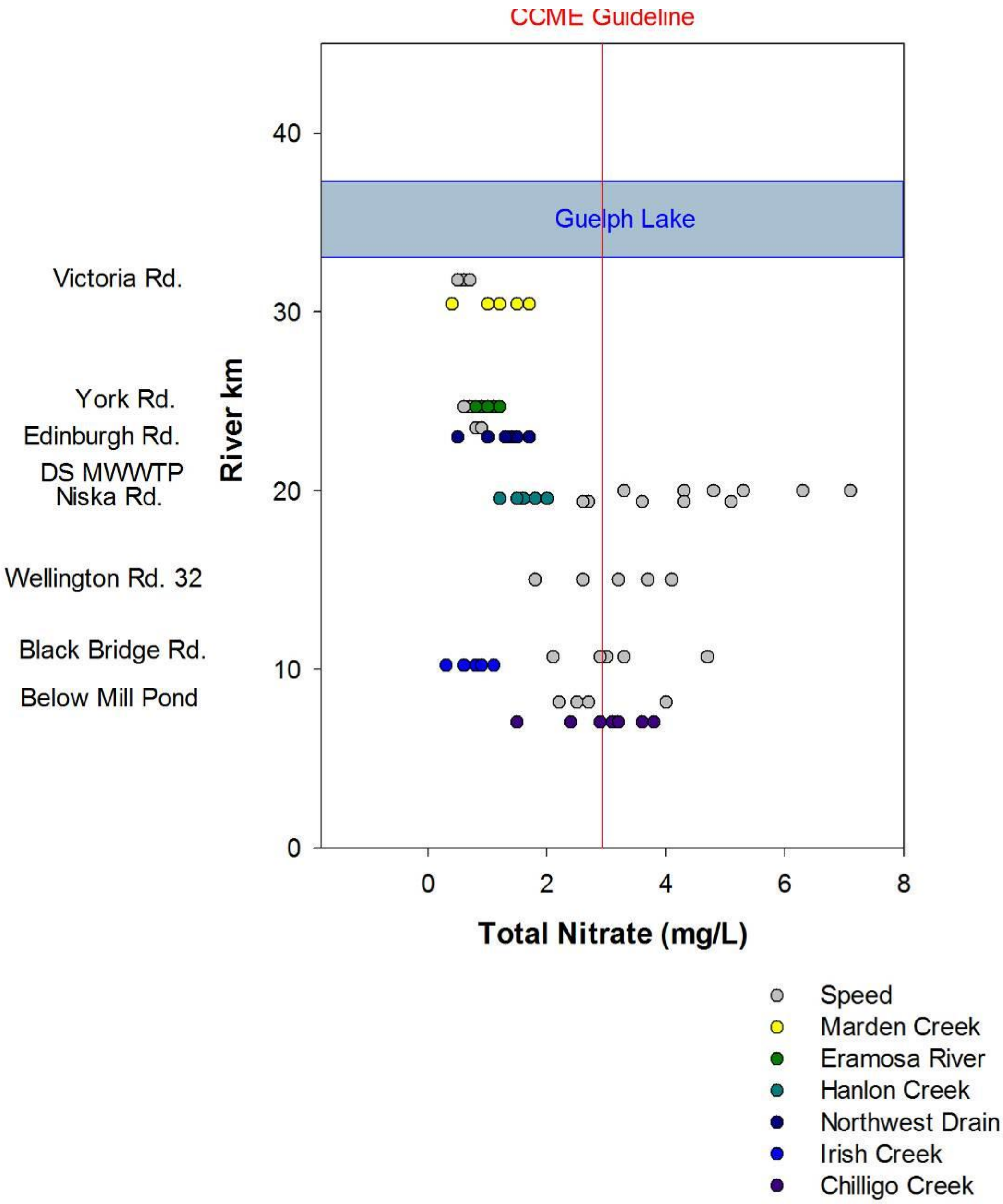


Figure 4-14: Total nitrate concentrations (mg/L) in the Speed River and select tributaries during summer low flows between July and August 2008

Total Phosphorus

Total phosphorus concentrations are similar above Guelph Lake, at Victoria Rd., and at Edinburgh Rd (p = 0.4259 - 4.1672). At these sites only, 25% of the phosphorus data were above the provincial water quality objective (Figure 4-15). The concentrations in the Eramosa River were slightly lower than above Guelph Lake and Edinburgh Rd. ($p < 0.05$, $p < 0.01$) and only ~5% of the samples were above the PWQO. The highest concentrations were observed at Wellington Rd. 32 and Cambridge which were significantly higher than at the other sites ($p < 0.0001$, $p < 0.05$, respectively) but not from each other (p = 0.5543). At these sites, most (~95%) of the phosphorus concentrations were above the PWQO (Figure 4-15).

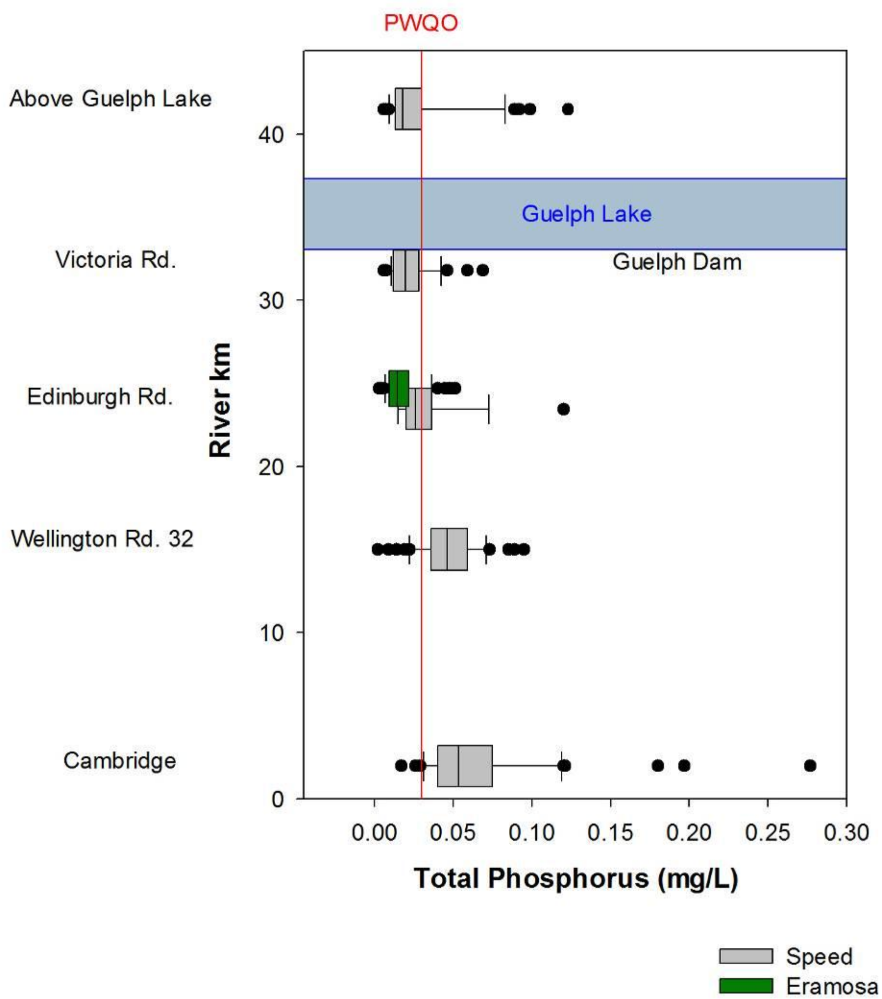


Figure 4-15: Box and whisker plots illustrating the range of total phosphorus concentrations (mg/L) in the Speed River subbasin.

Total phosphorus at Wellington Rd. 32 was negatively correlated with sampled flows ($p < 0.05$) but not with field temperature (p = 0.2812). At Cambridge, sampled flows and temperature were not significantly correlated with total phosphorus concentrations (p = 0.8670 & 0.8755). Visual inspection of time series plots does not reveal any seasonal trends in total phosphorus concentrations at these two sites.

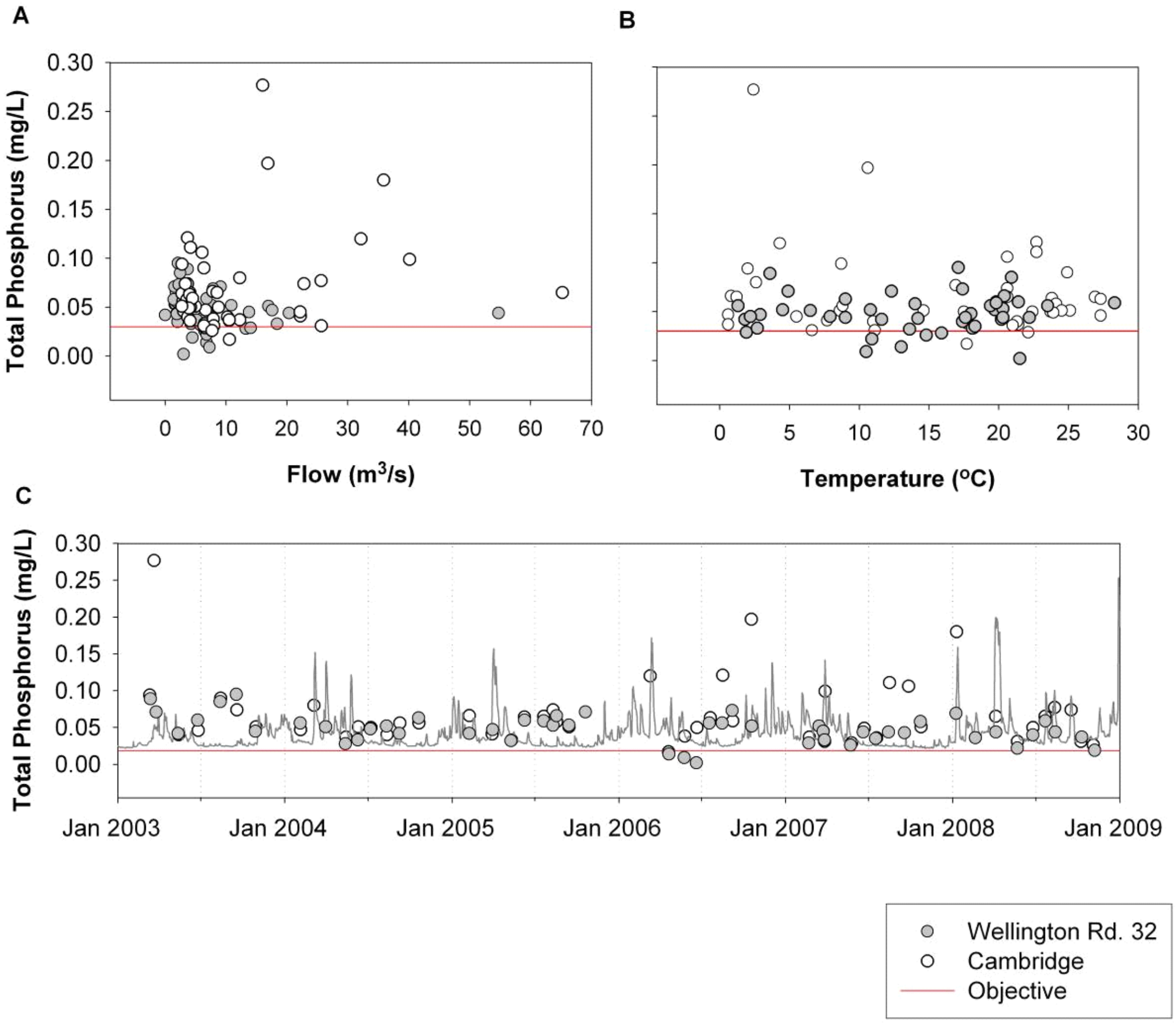


Figure 4-16: Total phosphorus concentrations (mg/L) at Wellington Rd. 32 and Cambridge in the Speed River subbasin relative to sampled flow (A), stream temperature (B), and time (C).

Total phosphorus concentrations increased downstream and exceeded the water quality objective frequently at sites downstream of the Guelph municipal waste water discharge (Figure 4-17). Marden Creek, Northwest Drain, Irish Creek, and Chilliga Creek all showed total phosphorus concentrations periodically exceeding the water quality objective.

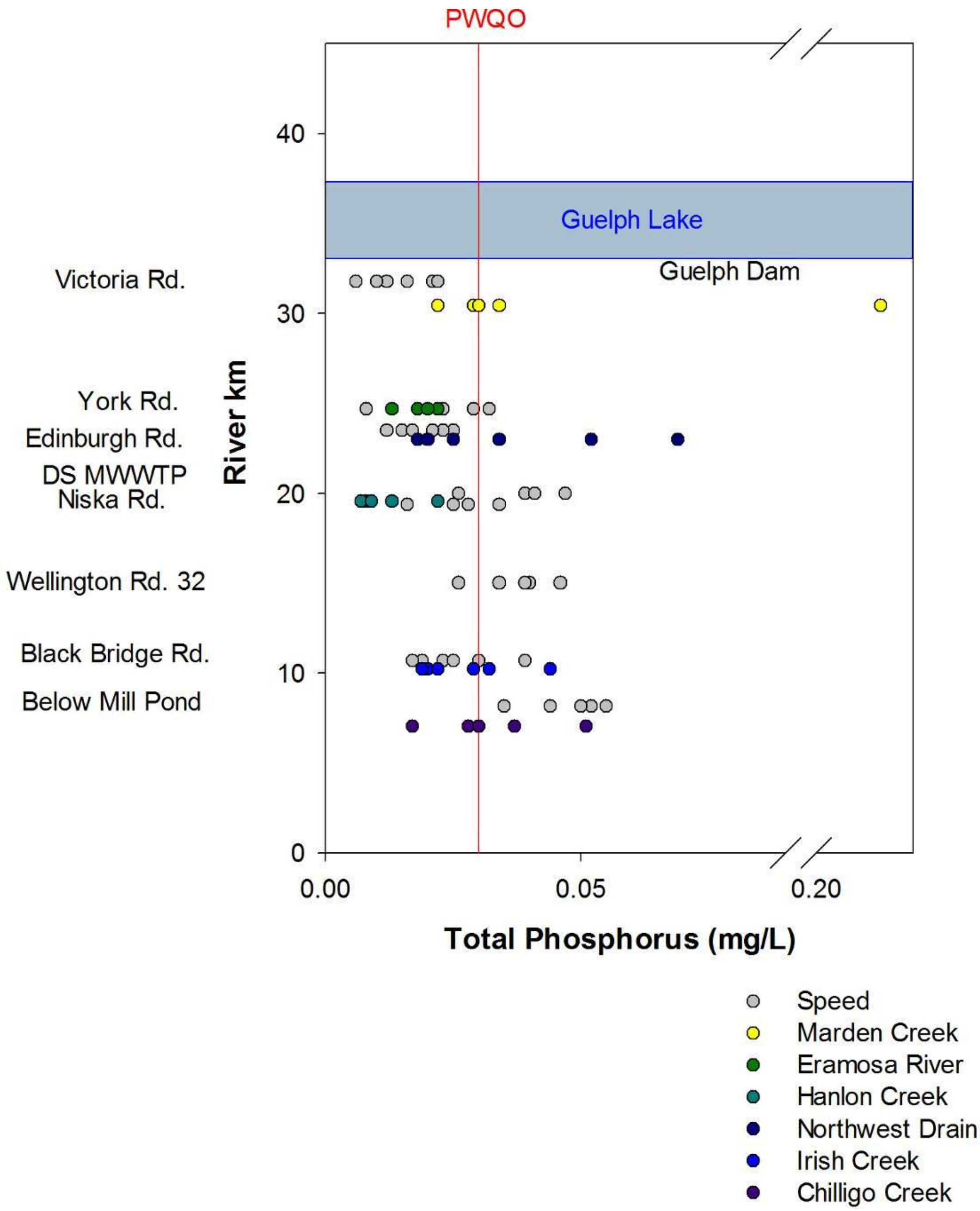


Figure 4-17: Total phosphorus concentrations (mg/L) in the Speed River and select tributaries during summer low flows between July and August 2008

Relationships between variables

Total phosphorus concentrations were positively correlated with suspended solid concentrations in Cambridge ($p < 0.0001$) and Edinburgh Rd. ($p < 0.0001$) but not Wellington Rd. 32 ($p = 0.0891$). Phosphate concentrations was not correlated with suspended solid concentrations at Cambridge, Edinburgh Rd. or Wellington Rd. 32 ($p = 0.0629 – 0.4053$). Total nitrate and chloride concentrations were positively correlated in Wellington Rd. 32 ($p < 0.0001$) and Cambridge ($p < 0.0001$). Phosphate concentrations were positively correlated with chloride at Wellington Rd. 32 ($p < 0.0001$) but not at Cambridge ($p = 0.1174$).

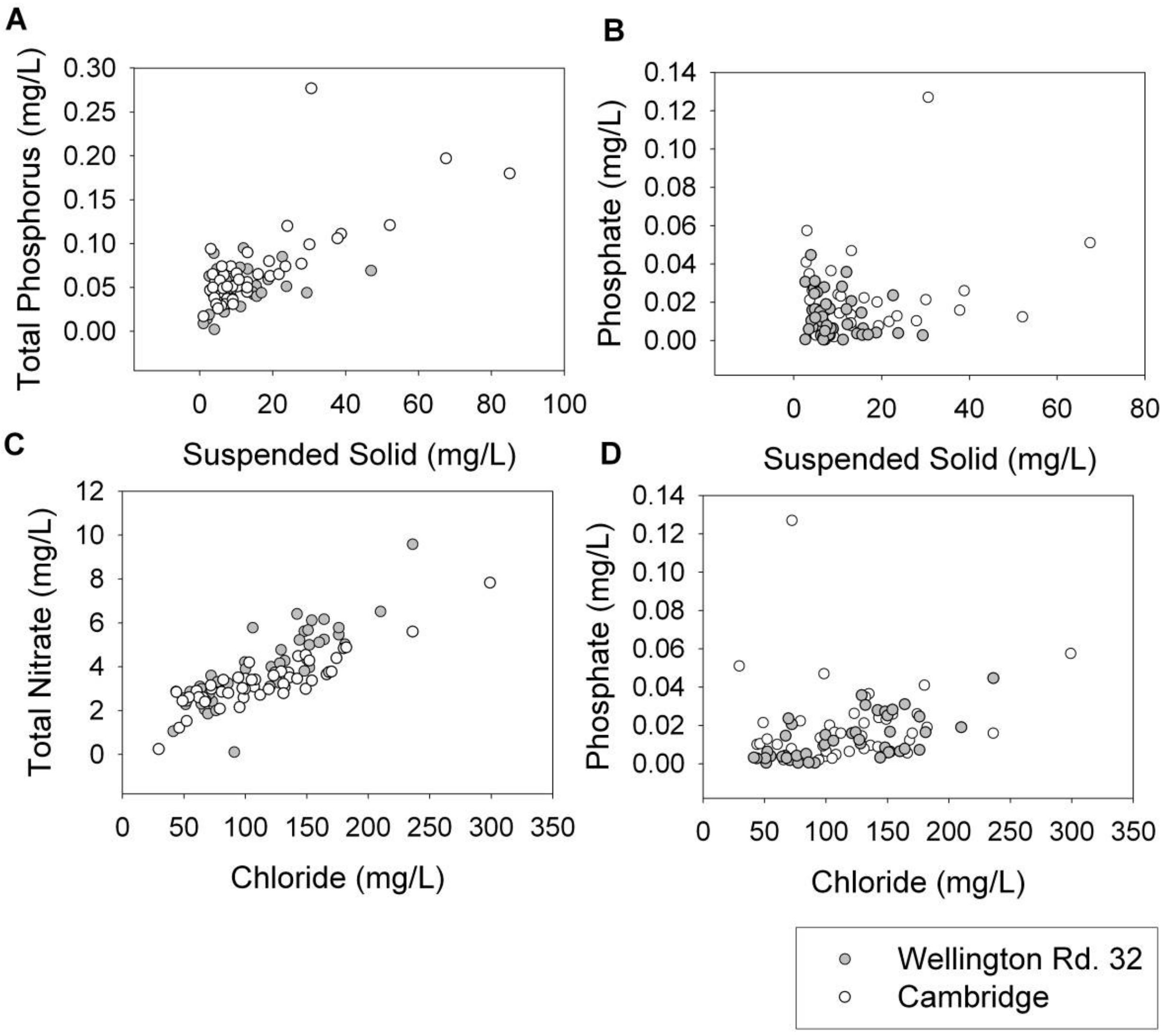


Figure 4-18: Total phosphorus (A) and phosphate (B) concentrations relative to suspended solid concentrations and total nitrate (C) and phosphate (D) concentrations relative to chloride concentrations at Wellington Rd. and Cambridge in the Speed River subbasin.

Metals

The only metal for which concentrations exceeded the water quality objective was zinc in the Eramosa River and at all Speed River sites downstream of the Eramosa River. Zinc concentrations exceeded water quality objectives in greater than 50% of the samples collected from Edinburgh Rd. and Cambridge and in all samples from Eramosa (Figure 4-19). Zinc concentrations in the Eramosa River were significantly higher than all other sites ($p < 0.0001$ – < 0.01). Edinburgh Rd, Wellington Rd. 32, and Cambridge were all significantly higher than the Speed River above Guelph Lake (which is above the confluence with Eramosa River, $p < 0.0001$).

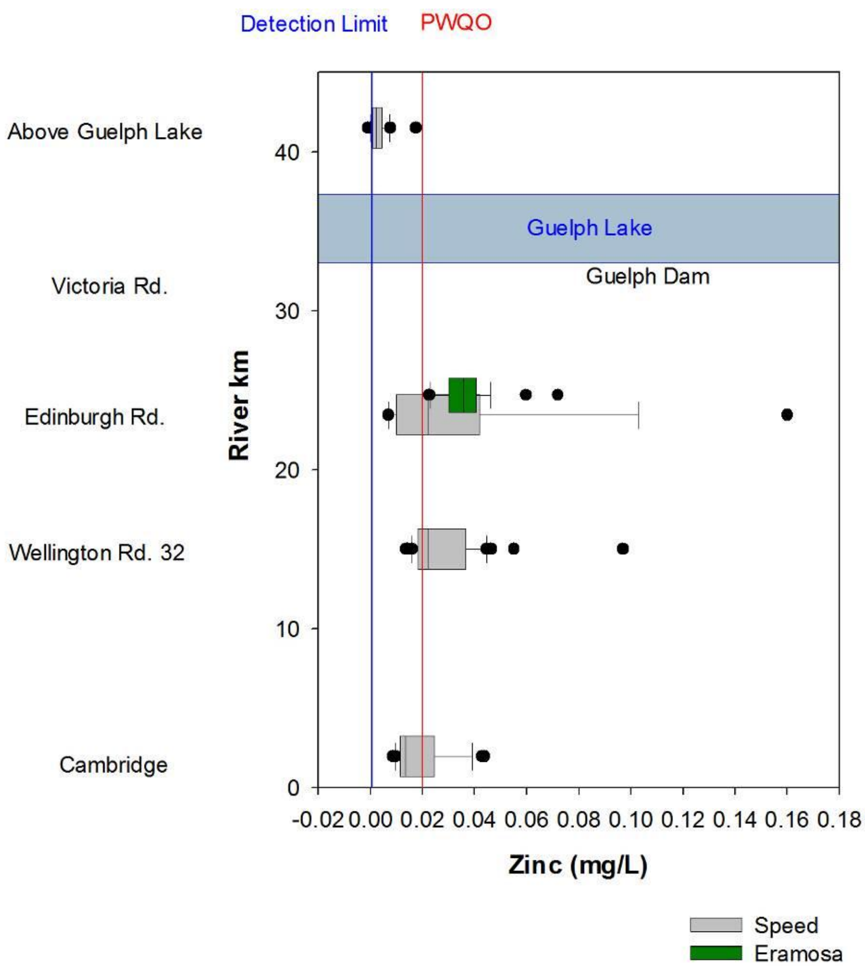


Figure 4-19: Box and whisker plots showing the range of zinc concentrations (mg/L) in the Speed River subbasin

Zinc concentrations were positively correlated with flow ($p < 0.0001$ – $p < 0.01$) and negatively correlated with sampled temperature ($p < 0.0001$ – $p < 0.01$) across all sites except in the

Eramosa River where correlations with flow and temperature were not significant (0.1095 & 0.3843, respectively; Figure 4-20).

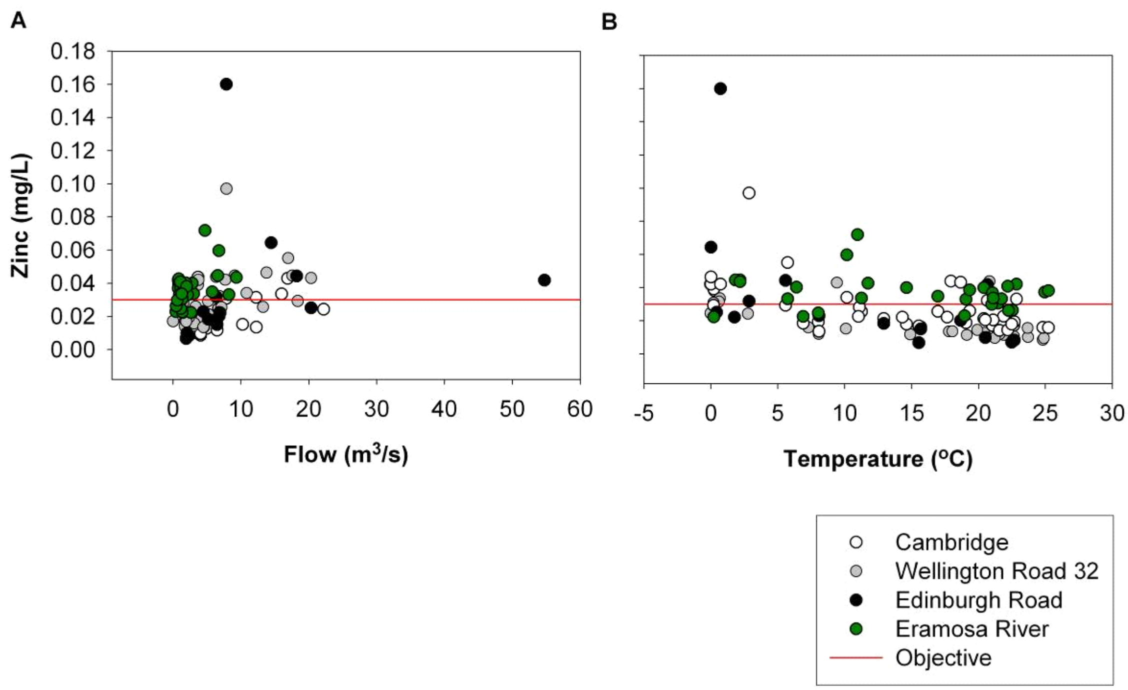


Figure 4-20: Zinc concentrations (mg/L) in the Eramosa River and in the Speed River at Edinburgh Rd, Wellington Rd. 32, and Cambridge sites relative to sampled flow (A) and stream temperature (B).

Discussion

Water quality in the upper Speed River and Eramosa River is of relatively high quality; however, below the City of Guelph, water quality tends to be impaired due to elevated levels of phosphorus, nitrates and chloride. Chloride and total nitrate concentrations are inversely related to flow and are strongly correlated at the two downstream sites. The inverse relationship with flow has previously been observed at sites heavily influenced by point sources (Jarvie, 2006) and likely reflects the discharge from the City of Guelph's wastewater treatment plant. During low flows, the variation in phosphorus at the two downstream sites is similar. However, Cambridge appears to be more strongly influenced by run-off during higher flows as indicated by higher total phosphorus and suspended solid concentrations associated with high flow events.

Low flow sampling in the summer of 2008 within the lower Speed River highlighted water quality concerns in two creeks: Marden Creek and the Northwest Drain. In Marden Creek, elevated un-ionized ammonia concentrations were observed as a result of high pH and temperatures. The Northwest Drain showed high chloride concentrations reflecting the drainage of urban areas.

Dissolved nutrient concentrations (ammonia, nitrate, and phosphate) are different above and below the Guelph Lake reservoir. These changes may reflect transformation and retention of nutrients in the reservoir (reviewed in (Jarvie, Neal et al. 2006; Bosch 2008)). Further investigation of the Guelph Lake reservoirs' influence on downstream water quality and nutrient loading would provide insight into management options.

Conclusions & Recommendations

- Water quality in the Speed River is of good quality above the City of Guelph but is impaired by increased nutrient and chloride concentrations in the lower reach.

- Water quality conditions are of greatest concern during the summer because of municipal waste water discharges, especially from the Guelph wastewater treatment plant. However, non-point source loading from agricultural areas also appears to influence water quality between Guelph and Cambridge.

- Two tributaries: Marden Creek and the North West Drain, showed impaired water quality during focused low-flow sampling and should be investigated further.

- Zinc concentrations are exceptionally high in the Eramosa River. These high levels are likely from groundwater. The high levels in the Eramosa influence zinc levels in the lower Speed River where the water quality objective is exceeded in more than 50% of the samples collected from Edinburgh Rd. and in Cambridge.

- There are very few data characterizing the water quality in the Guelph reservoir. The limnology of Guelph Lake reservoir should be further investigated to gain insight into management options that would improve downstream water quality.

- The current dataset is biased toward summer and spring sampling. To fully characterize seasonal differences in water quality, it is recommended that additional sampling be completed through the fall, winter and early spring time periods.

5. Nith River

Introduction

Watershed Characteristics

The Nith River subbasin drains an area of 1130 km^2 located in the western region of the Grand River Watershed (Figure 1-4). This region is characterized by two geological regions: the upper Nith River draining the tavistock tills and the lower Nith River which receives significant groundwater discharges from both the Waterloo and Paris-Galt moraines (Grand River Fisheries Management Plan Implementation Committee, 2005) (Figure 5-1; Figure 1-3).

About 80 percent of the subbasin is devoted to agricultural production (Table 5-1). Soybeans is the predominant (37%) crop in the subbasin followed by grains, corn, and fruit (18-22%; Figure 1-11) (Statistics Canada 2009). The different nature of soils between the two regions is likely responsible for the different amount of tile drainage used in the upper reaches (51%) relative to the lower reaches (18%; Figure 1-12, Figure 1-13). Livestock densities are just slightly lower than observed in the Conestogo subbasin with 18, 1.5, and 0.6 animals/ha for poultry, swine, and cattle, respectively (Figure 1-10).

Urban development covers the smallest portion of the watershed with a slightly higher portion and population density occurring in the lower region of the Nith River (5% & 42 people/km^2) relative to the upper region (3% & 29 people/km^2 Table 5-1 & Figure 1-14). Five municipal wastewater treatment plants are found in the Nith River subbasin (Table 1-1).

Relative to the other subbasins, treed land cover is similar but wetland cover is one of the lowest among all subbasins in the Grand River watershed (Table 5-1).

Table 5-1: The percentage of land cover devoted to agricultural activities, urban development, treed land, and wetlands in the upper and lower Nith River watershed.

Region	Land Cover (%)			
	Agriculture	Urban	Treed Land	Wetland
Upper Nith River *(Headwaters to New Hamburg)*	84	4	6	6
Lower Nith River *(New Hamburg to the Grand)*	76	6	9	9
Total	80	5	7	8

Watershed Uses & Values

Tributaries vary within the subbasin supporting cold, mixed, and warm water communities. In the main stem of the Nith River warm water and migratory cold water fisheries are supported (Figure 1-15) (Grand River Fisheries Management Plan Implementation Committee. 2005).

Five communities in the subbasin use the river to assimilate their wastewater.

Subbasin Specific Monitoring

There are four active monitoring sites in the Nith River subbasin (Figure 5-1, Figure 5-2, Table 5-2). New Hamburg and Paris have a long term monitoring record while the sampling of the Nith River at Nithburg and Ayr began in 2004 and 2007, respectively. Alder Creek was discontinued in 2007 due to the fact that a local industry was no longer discharging into Alder Creek.

Flow gauges across the subbasin correspond with water quality monitoring sites at New Hamburg, Ayr, and Paris. The Nithburg flow record was used for the Nithburg and Alder Creek sites.

Table 5-2: The river course sampled, site description, site number, and report short name for samples collected in the Nith River subbasin.

Stream	Site Description	Site number	Report Short Name
Nith	Perth Rd 9, North of Shakespeare at Nithburg	16018407402	Nithburg
	First Conc. d/s from Wellesley	16018404502	Wellesley
	First Bridge d/s from Ayr	16018403302	Ayr
	First Bridge d/s from New Hamburg	16018403202	New Hamburg
	Highway 24A, Paris	16018400902	Paris
Alder Creek	Mannheim Bridge	16018402602	n/a
	First Conc. South of New Dundee	16018403802	Alder Creek
Baden Creek	Bleams Rd. d/s from Baden STP	16018409802	n/a

Figure 5-1: Water quality sampling sites, flow gauge locations, and municipal wastewater treatment plants in the Nith River subbasin.

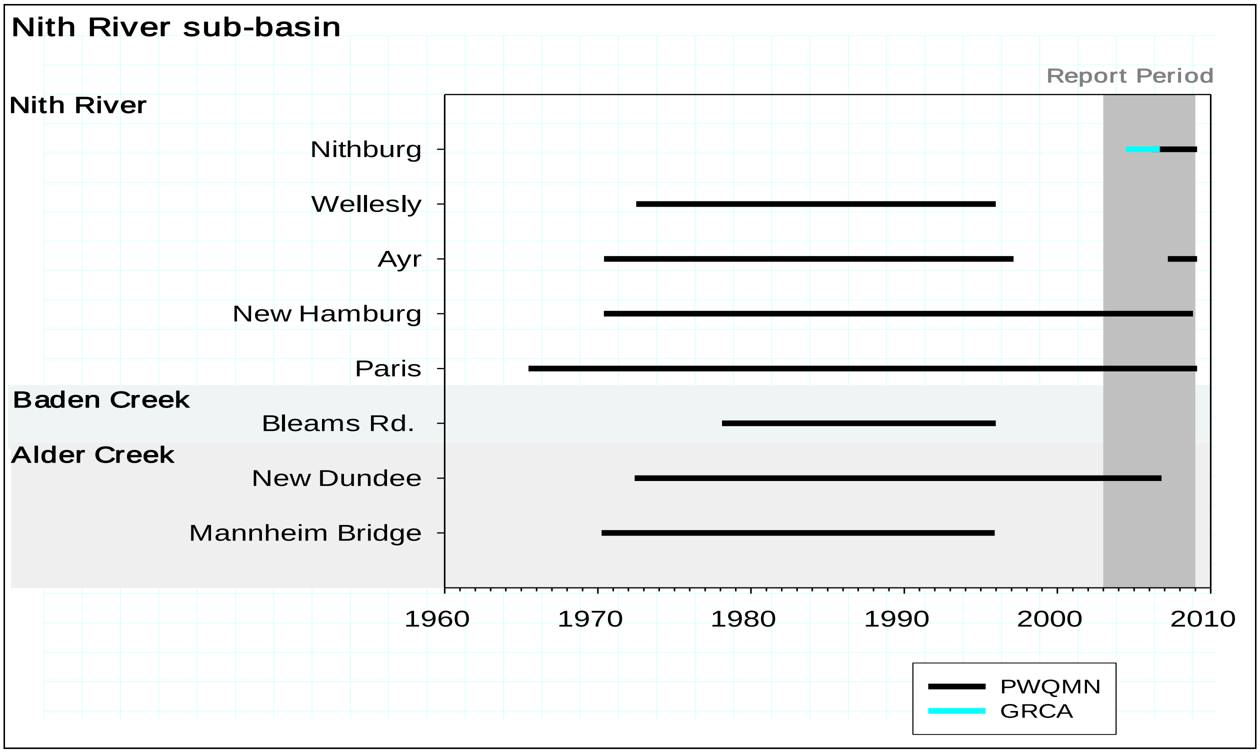


Figure 5-2: Sampling record for GRCA and Provincial Water Quality Monitoring Network sites in the Nith River subbasin.

Results

Dataset Description

The seasonal distribution of the monitoring data is similar between sites. All datasets are biased toward summer and spring with very few samples (0-8 %) in the dataset being collected in the winter (Table 5-3).

Table 5-3: Seasonal composition of water quality data in the Speed River Watershed.

Site	% of Samples Collected			
	Winter	Spring	Summer	Fall
Alder Creek	6	28	53	13
Nithburg	0	25	61	14
New Hamburg	4	30	51	15
Ayr	0	39	44	17
Paris	8	29	50	13

The sampled flow record was not significantly different between sites or from the observed record across sites (p = 0.1287). The sampled temperature was not different between sites but was significantly warmer than the temperature record at all sites ($p < 0.0001$) except Ayr, which was not significantly different.

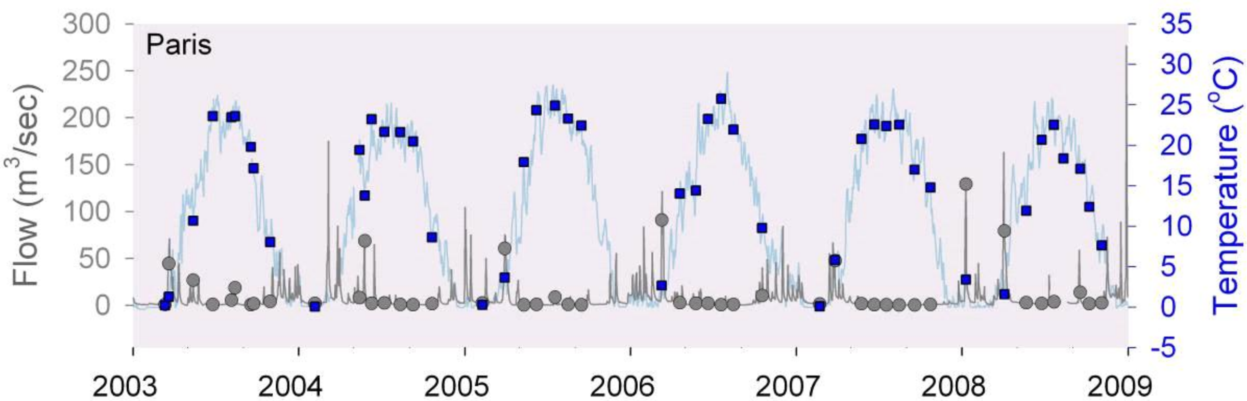


Figure 5-3: Daily average flow (grey line) and temperature (blue boxes) sampled at Paris relative to the flow timeseries of the New Hamburg flow gauge and Bridgeport temperature monitoring site between 2003 and 2008.

A similar percentage of the flow and temperature record were sampled across sites (Table 5-4, Figure 5-3). The highest peaks in the flow record were not sampled; however, greater than 75% of the temperature range was sampled.

Table 5-4: The percent of the flow and temperature record sampled at each site in the Nith River subbasin

Site	**% Sampled**	
	Flow	Temp
Alder Creek	25	88
Nithburg	36	85
New Hamburg	36	88
Ayr	36	74
Paris	47	88

Summer Water Temperature

Median summer temperatures fell within the range required for a cold water fishery at Ayr (

Total Nitrates

Nitrate concentrations exceeded the water quality objective in 50 – 95% of the samples across sites in the Nith River subbasin (Figure 5-5). No significant difference was observed between sites (p = 0.3311)

Nitrate concentrations tended to negatively correlate with temperatures ($p = 0.0002$ - 0.0261) and positively with flows ($p < 0.0001$ – 0.05). However, at the Nithburg and Ayr sites there was no relationship with temperature ($p = 0.3060$) or flow ($p = 0.4100$), respectively. Nitrate concentrations tended to decrease during the growing season at all sites (Figure 5-6).

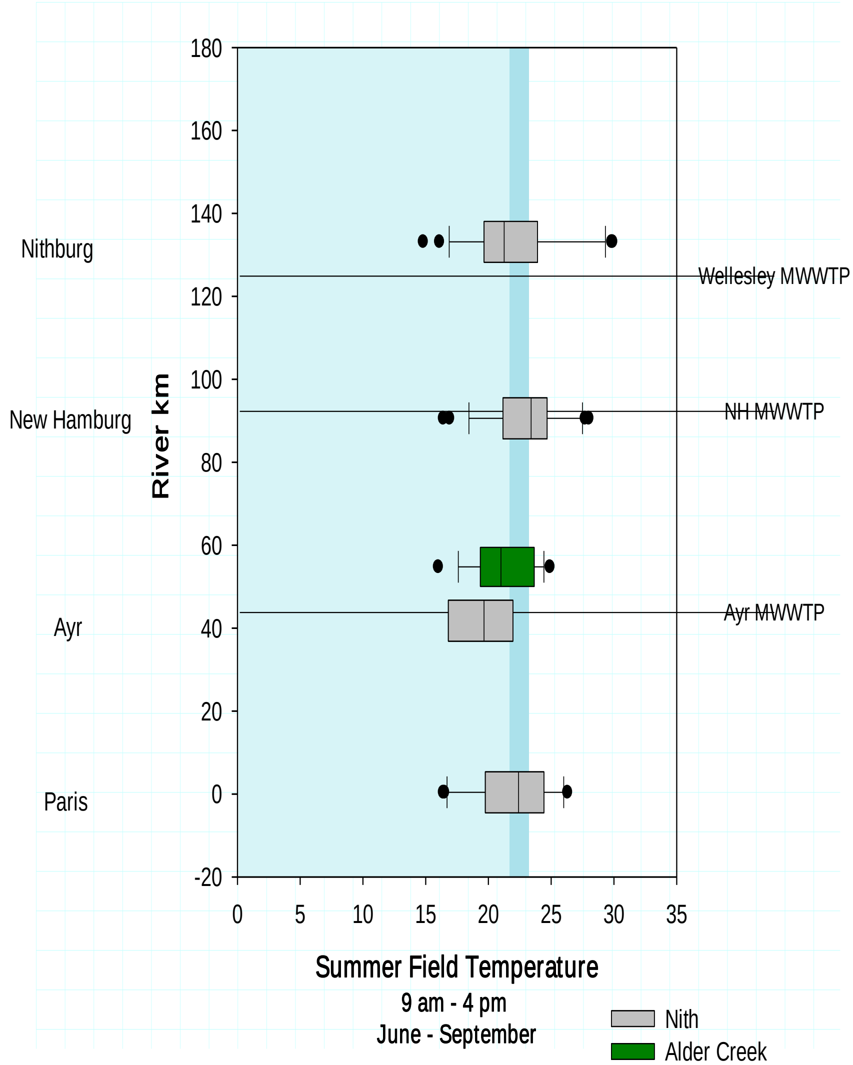


Figure 5-4: Box and whisker plots illustrating the range of summer (June – September) daytime (9 am - 4 pm) field temperatures in the Nith River Watershed

). However, temperatures at the Ayr site were not significantly different from other Nith River sites. Alder Creek was significantly lower than all other sites on the Nith ($p < 0.0001 – < 0.05$), except the Ayr site ($p = 7.5488$).

Total Nitrates

Nitrate concentrations exceeded the water quality objective in 50 – 95% of the samples across sites in the Nith River subbasin (Figure 5-5). No significant difference was observed between sites (p = 0.3311)

Nitrate concentrations tended to negatively correlate with temperatures (p = 0.0002 - 0.0261) and positively with flows (p < 0.0001 – 0.05). However, at the Nithburg and Ayr sites there was no relationship with temperature (p = 0.3060) or flow (p = 0.4100), respectively. Nitrate concentrations tended to decrease during the growing season at all sites (Figure 5-6).

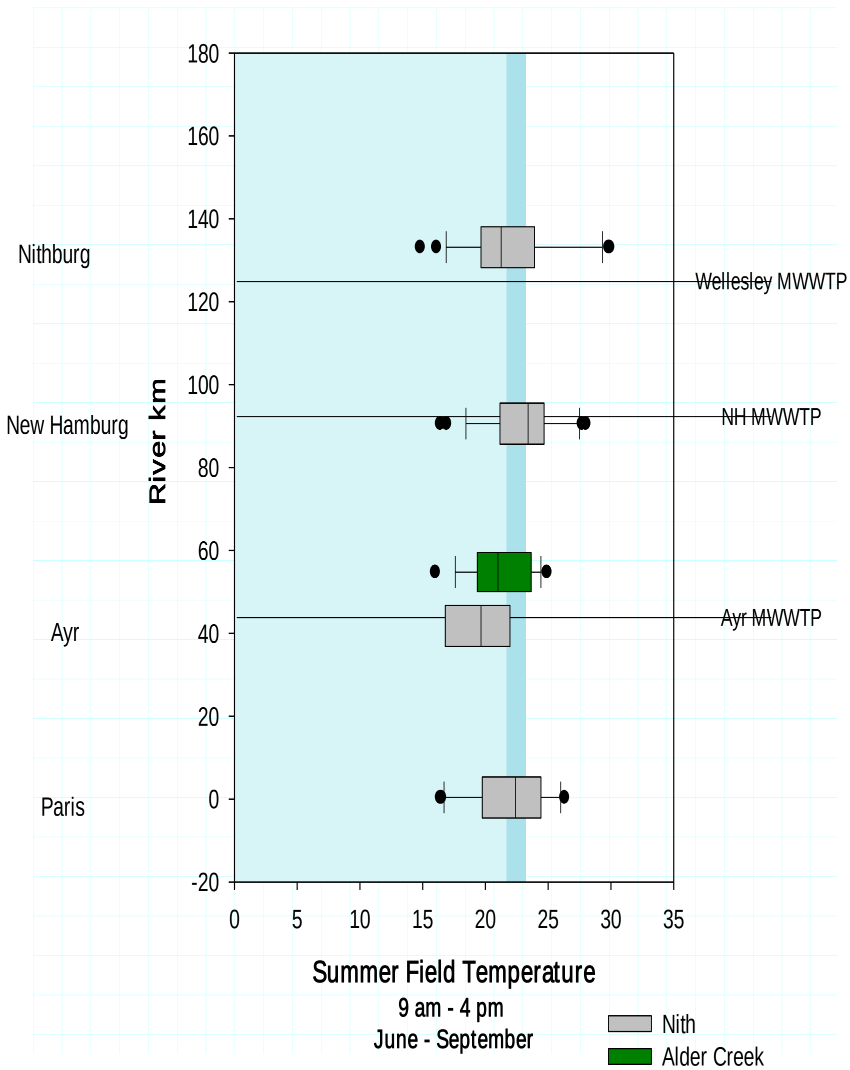


Figure 5-4: Box and whisker plots illustrating the range of summer (June – September) daytime (9 am - 4 pm) field temperatures in the Nith River Watershed

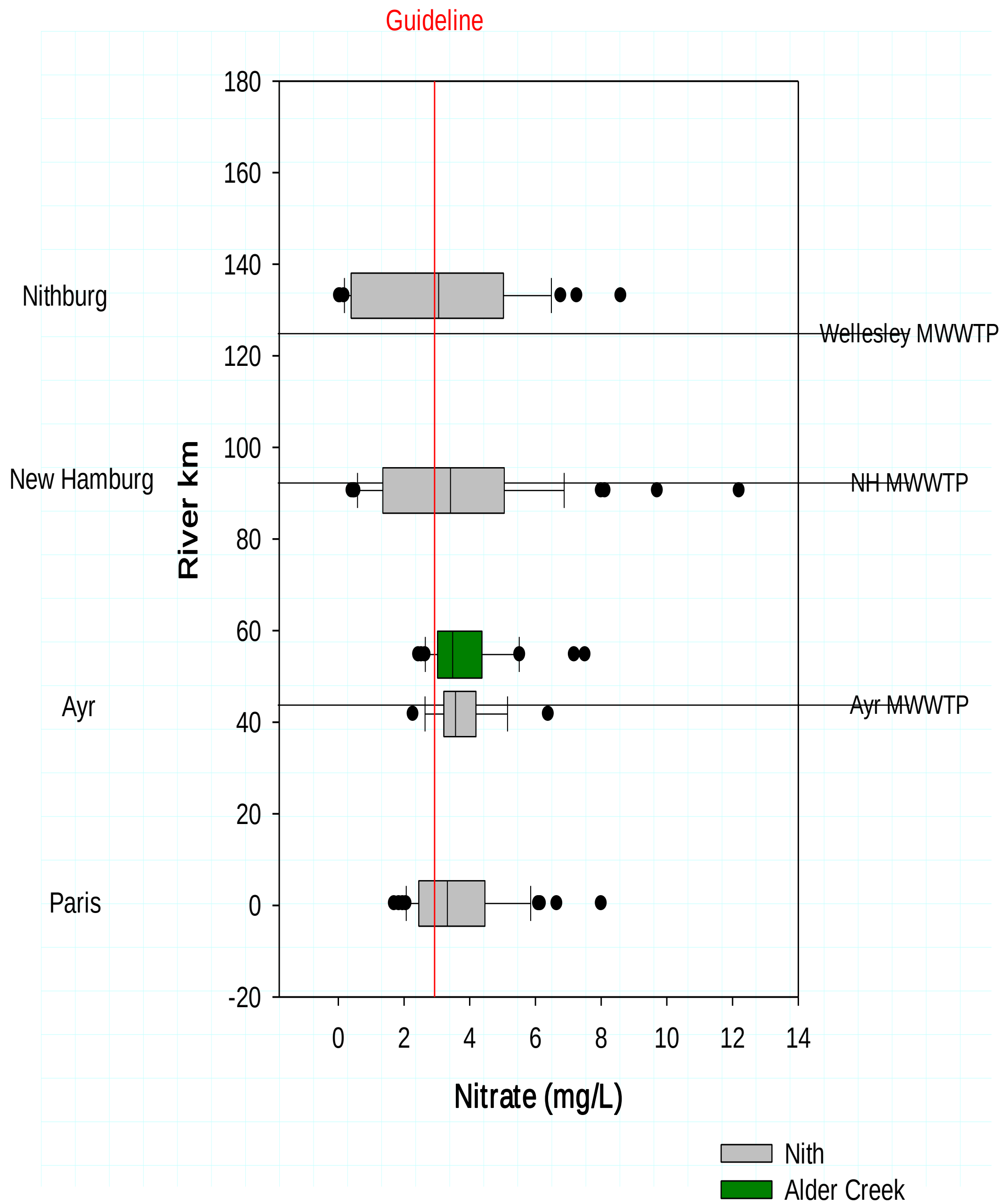


Figure 5-5: Box and whisker plots illustrating the range of total nitrate concentrations (mg/L) at water quality monitoring sites in the Nith River subbasin between 2003 and 2008.

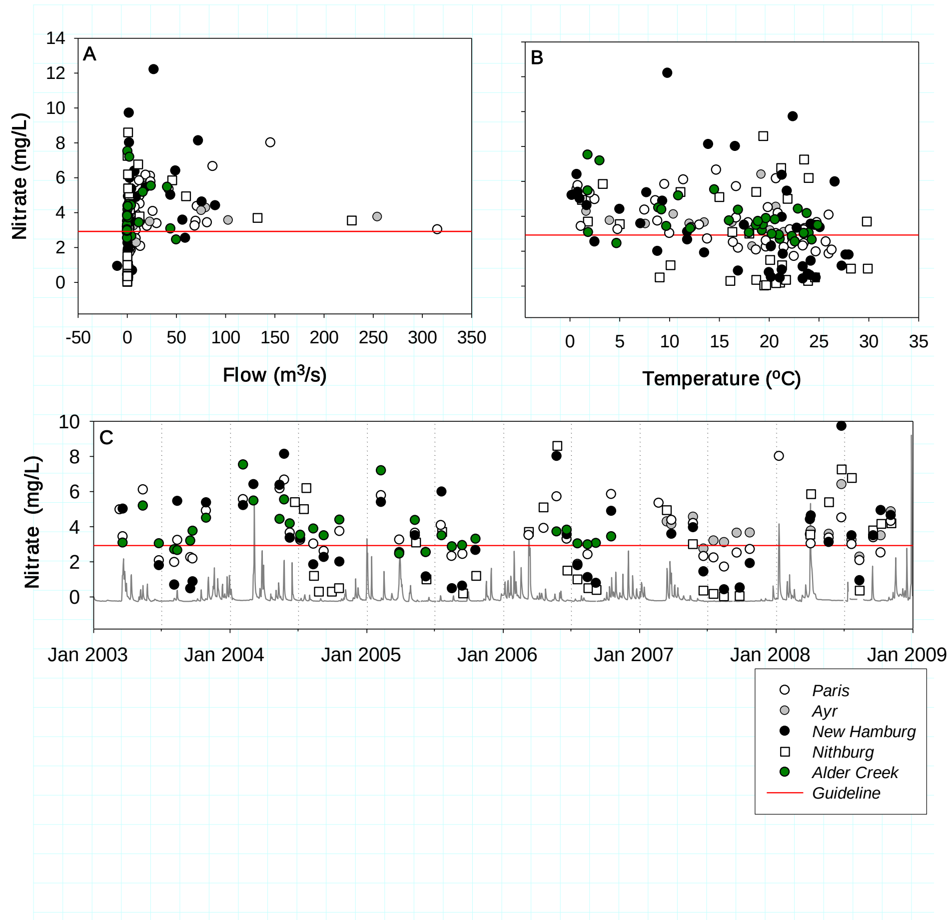


Figure 5-6: Total nitrate concentrations (mg/L) at water quality monitoring sites in the Nith River subbasin relative to flow (A), stream temperature (B), the time (C).

Total Phosphorus

Total phosphorus exceeds the water quality objective in approximately 95% of the samples in the upper reaches of the watershed but only in 50% of the samples in the lower reaches (Figure 5-7). These trends are reflected by significantly lower total phosphorus concentrations in the Nith River in Paris relative to Nithburg ($p < 0.05$), New Hamburg ($p < 0.0001$), and Alder Creek ($p < 0.01$).

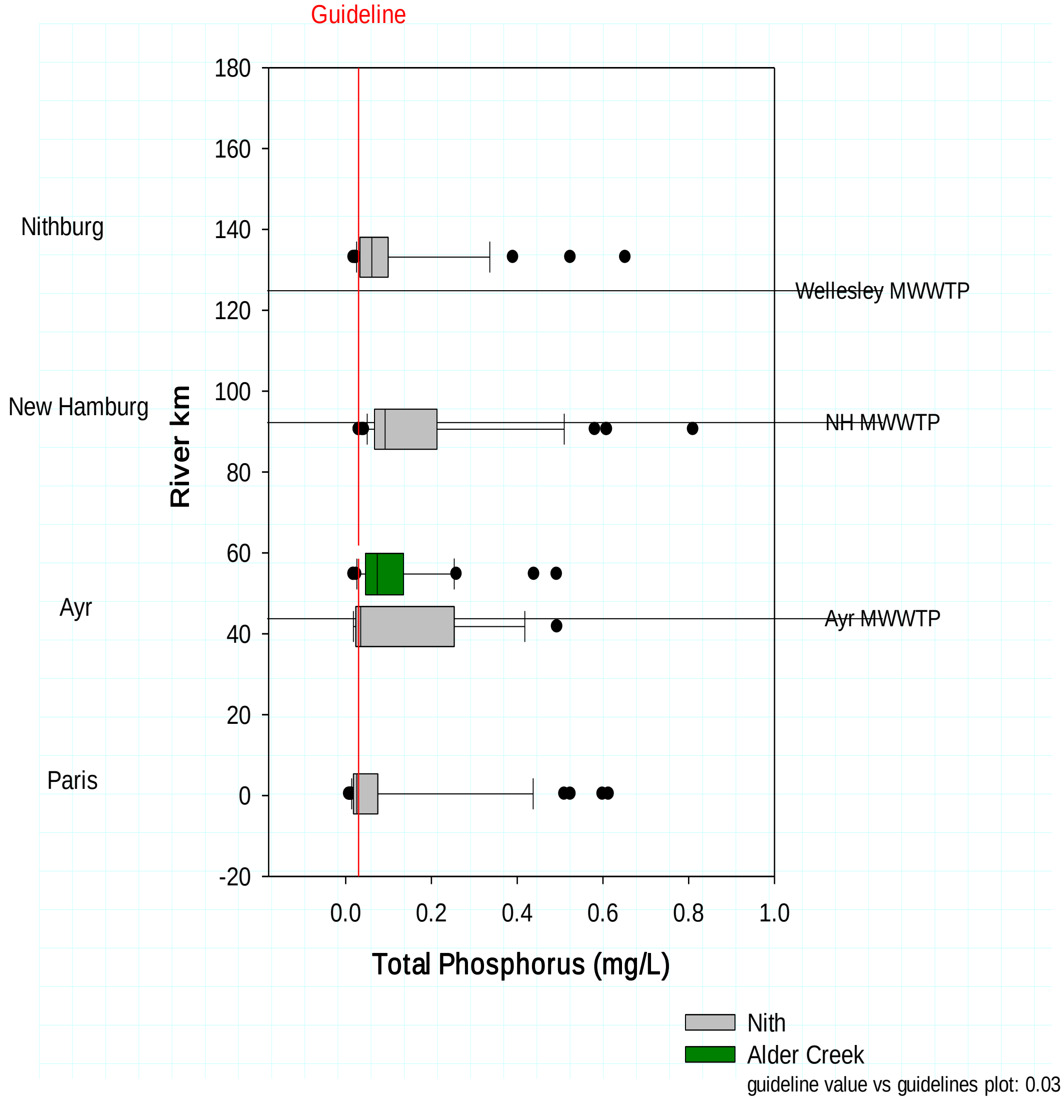
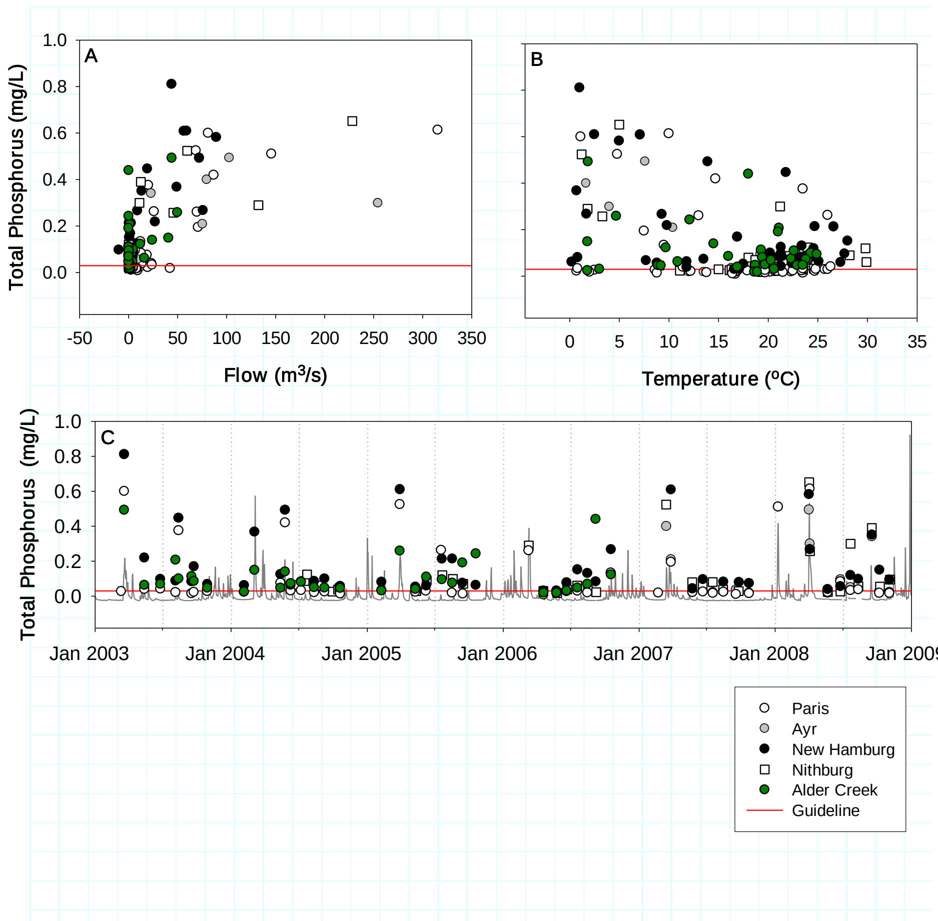


Figure 5-7: Box and whisker plots illustrating the range of total phosphorus concentrations (mg/L) at water quality monitoring sites in the Nith River subbasin between 2003 and 2008.

Figure 5-8). Total phosphorus concentrations were positively correlated with flow in the Nith River (p <0.0001 – 0.01) but not at the Alder Creek site (p = 0.9353). None of the sites were correlated with temperature. Total phosphorus concentrations were strongly correlated with suspended solids concentrations across sites (p < 0.0001, for all correlations).



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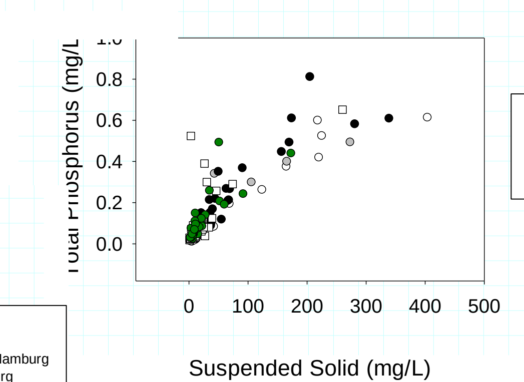

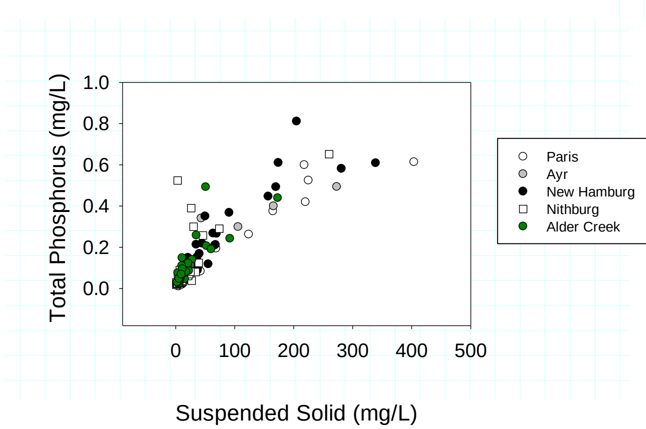

Figure 5-8: Total phosphorus concentrations in the Nith River Watershed relative to sampled flow (A), field temperature (B), and time (C).

Figure 5-9: Total phosphorus (mg/L) relative to suspended solids (mg/L) in the Nith River subbasin

Discussion

Although the water quality sample record does not characterize the flow regime adequately as most of the samples were taken during summer, low flow periods, water quality characterization using the current dataset suggests eutrophic conditions with high nitrate and total phosphorus concentrations throughout the watershed but more specifically in the upper Nith River region. Spatially, it appears that water quality, specifically total phosphorus concentrations, tends to improve as the Nith River flows from Wellesley to Paris although total nitrate levels tend to increase. This is likely a result of the significant influence of groundwater in the lower Nith River.

The hydrology of the lower Nith River subbasin is significantly influenced by groundwater from the Waterloo and Paris-Galt moraines (AquaResources 2009). The influence of groundwater on the lower Nith River is supported by the fact that the summer field temperatures at Ayr appear to be cooler than at any other site along the river; however, it should be noted that further monitoring is needed to confirm this. Across sites, total phosphorus and total ammonia concentrations were significantly lower at the mouth of the river relative to sites in the upper region indicating a slight improvement in water quality as the river flows from the headwaters to the mouth.

Total phosphorus concentrations are typically highest in late winter/early spring and correspond to high streamflow events although total nitrate concentrations varied more strongly with stream temperatures and tended to be highest during cold, low flow periods. While total nitrate concentrations are high during the winter they fall well below objectives during the summer. In contrast, total phosphorus did not show any decrease with temperature. However, total phosphorus was strongly correlated with suspended solids concentrations and with flows. All these trends reflect the loading of nutrients from nonpoint sources.

Conclusions & Recommendations

- Elevated nutrient concentrations associated with non-point source loading from agricultural regions are the major water quality concern in the Nith River subbasin.

- Limited seasonal sampling exists for the Nith River subbasin. Additional monitoring during the winter and spring is required to fully characterize the flow regime and consequently the water quality.

- Water quality appears to improve slightly in the lower half of the subbasin. Increased discharge of ground water to the river in the area of the Waterloo Moraine may explain this slight increase in water quality. Further investigation of the role of groundwater in the Nith River subbasin is recommended.

6. Central Grand River

Introduction

Watershed Characteristics

The central Grand River region flows from the Shand Dam, below Belwood Lake to Paris (Figure 1-4). The area drains about 1225 km^2 notwithstanding the major tributaries and upper Grand that contribute to this area.

Through the central Grand River region, the river traverses diamicton tills, gravel and sand spillways and moraines (Lake Erie Source Protection Region Technical Team 2008). Irvine Creek drains a portion of the tavistock tills where there tends to be high surface runoff. The remaining area in the central Grand River region drain various moraine complexes - Elmira, Waterloo and the Galt/Paris moraines, which tend to be permeable which facilitates high groundwater recharge ((Lake Erie Source Protection Region Technical Team 2008; Aquaresource Inc. 2009)). Groundwater discharge in this subbasin feed many cold water creeks in the region and contributes significantly to flows in the Grand River between Waterloo and Paris (Figure 1-6, Figure 1-8).

As the Grand River flows from the Shand Dam to Bridgeport, the river flows down the steepest slopes in the entire watershed (Figure 1-7). This allows the river to have good pool and riffle sections that help to maintain the tailwater fishery in this area. The change in elevation through the Region of Waterloo (Bridgeport to Cambridge) is also quite steep however, as the river flows past Cambridge and down toward Paris, it traverses the second steepest section in the watershed. Again, this helps the river to re-oxygenate as it flows over many riffle sections. It also collects a substantial amount of groundwater through this reach as well.

Land use across the region (Figure 6-1, Table 6-1) is primarily agriculture (63%) however, the highest percentage of urban land use in the Grand River watershed is found in this region (17%). More specifically, the percentage of urban lands draining to the Grand River is greatest between the Conestogo River and Paris (34%) and supports the highest population densities across the Grand River watershed (728.2 people/km^2). As a result, the largest wastewater treatment plants are located in the central Grand River region (Table 1-1). Population densities in the upper region of the subbasin between the Shand Dam and the Conestogo River and in Canagagigue

Creek were elevated (67 & 83 people/km^2) relative to other agriculturally dominated areas in the Grand River Watershed such as Irvine Creek (25.5 people/km^2; Figure 1-14).

A high percentage of the agricultural lands in the upper or more northern region has tile drainage (27- 49%) relative to the lower region (0.2 & 6%; Figure 1-12). Corn is the dominant crop produced across the subbasin (33%) followed by grains (23%), other field crops (22%), and soy (19%; Figure 1-11). Livestock densities of 16.7, 0.97, and 0.57 animals/ha for poultry, swine, and cattle, respectively are similar or slightly lower than those observed in the Nith River subbasin (Figure 1-10).

Tree and wetland cover in the subbasin is not distinctive relative to other subbasins in the watershed. However, in Mill Creek tree and wetland areas make up a large portion of the land area (16 & 26%, respectively) making this a unique region within the Grand River watershed (Figure 1-2, Table 6-1).

Table 6-1: The percentage of land cover devoted to agriculture, urban development, treed land, and wetlands in the central Grand River subbasin.

Region	**Land Cover (%)**			
	Agriculture	Urban	Treed Land	Wetland
Central Grand: Below Shand Dam-Conestogo R.	77	7	5	10
Irvine Creek	84	3	3	10
Canagagigue Creek	80	8	5	7
Central Grand: Conestogo R. - Paris	45	34	9	11
Mill Creek	47	8	16	27
Total	63	17	7	11

Watershed Uses & Values

The tail waters from the Shand Dam provide cold water to the Grand River which supports a world class brown trout fishery (Figure 1-15). This fishery is a destination for fly-fishermen and has an estimated economic value of over 1 million dollars per season (Plummer, Kulczychi et al. in progress). Warm water fish communities are supported between Bridgeport and Park Hill dam in Cambridge as well as downstream to Brantford. Between Paris and Brantford, the Grand River is known as the “exceptional waters reach” and supports a healthy warmwarter and seasonally cool water sport fishery; it is enjoyed by many residents that canoe or hike in the area ((Scott and Imhof 2005)). Additionally, the small tributaries to the central Grand River are diverse and are capable of supporting a range of cold, mixed, and warm water fish communities (GRFMPIC 1998).

The Grand River is an important source of municipal drinking water supply for the Region of Waterloo. It is used as part of an integrated urban system along with many local sources of groundwater. The central Grand River region also receives the municipal wastewaters from nine facilities serving approximately 550,000 people (Table 1-1). Consequently, the river is an important natural heritage feature which services the communities in this region.

Subbasin Specific Monitoring

In the central Grand River subbasin there are 13 active water quality monitoring sites (Figure 6-1, Figure 6-2, Table 6-2). The Grand River sites below the Shand Dam, at West Montrose, Bridgeport, Blair, and Glen Morris are long term sites and sampling at the Freeport site started in 2007. Seven tributaries to the Grand River are monitored in this subbasin: the Irvine River, Carroll Creek, Canagagigue Creek, Cox Creek, Laurel Creek, Schneider Creek, and Mill Creek. Irvine River, 2 sites on Canagagigue Creek, and Mill Creek all have long term monitoring records while sampling on the upper Canagagigue Creek, Laurel Creek, and Schneider Creek only started recently (e.g. in 2004 or 2007). Carroll Creek was monitored briefly between 2004 and 2007.

Corresponding flow gauges are available for below Shand Dam, West Montrose, Bridgeport, and Glen Morris sites on the Grand River. The flow record from the Doon gauge was used for the Freeport and Blair sites. Flow records in the Irvine River, Canagagigue Creek, Laurel Creek, and Mill Creek all correspond with monitoring sites. For Carroll Creek and Schneider Creek, the flow records from the Irvine River and Laurel Creek, respectively, were used to estimate sampled flows.

In addition to routine grab sampling for chemical parameters, the Grand River Conservation Authority monitors dissolved oxygen, conductivity, pH and temperatures continuously at four stations in the central Grand River region: below Shand Dam; Bridgeport; Blair; and Glen Morris. These stations collect readings from YSI™ multiparameter datasondes and posts this information to the website hourly: www.grandriver.ca. Dissolved oxygen is an indicator parameter for the river and as such, data are collected continuously due to the dynamic nature of dissolved oxygen in a eutrophic river system.

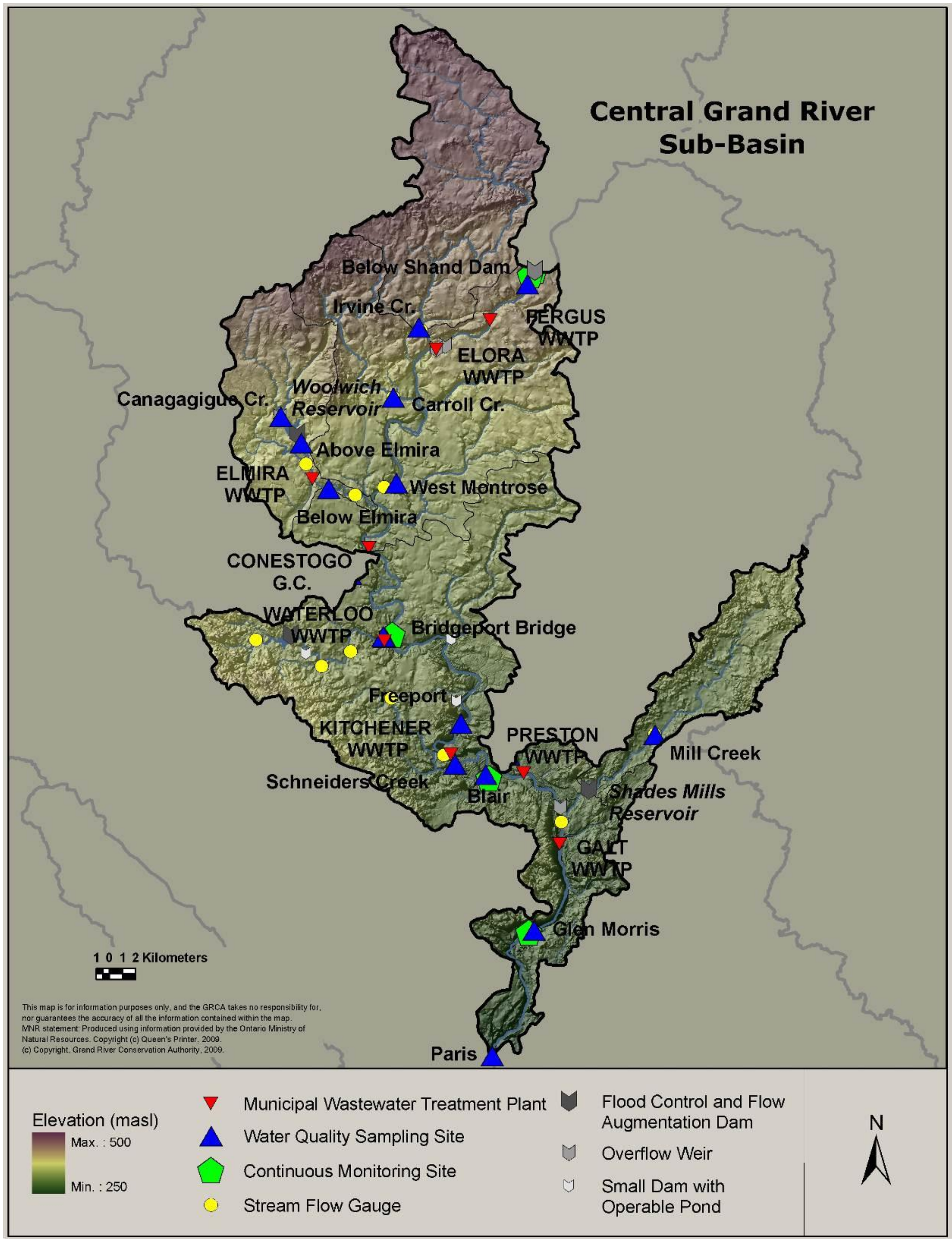

Figure 6-1: The water quality sampling sites, flow gauge locations, and municipal wastewater treatment plants in the central Grand River subbasin.

Table 6-2: The river course sampled, site description, site number, and report short name for samples collected in the Central Grand River subbasin.

Stream	Site Description	Site number	Report Short Name
Grand	First Conc. d/s of Belwood Lake	16018403702	Below Shand Dam
	Highway 86	16018410302	West Montrose
	Bridgeport Bridge	16018401502	Bridgeport
	Highway 7, Breslau	16018402802	n/a
	Old Hwy. 8, Freeport	16018404102	Freeport
	Blair Bridge	16018401202	Blair
	Glen Morris Bridge	16018401002	Glen Morris
Carroll Creek	Middlebrook Rd, Pilkington 5-6	16477604102	Carroll Creek
Irvine Creek	William St., Salem	16018410402	Irvine Creek
Canagagigue Creek	County Rd. 19, Floradale	16018405202	Above Reservoir
	First Conc. North of Elmira	16018405102	Below Reservoir
	First Bridge d/s of Elmira STP	16018401602	Below Elmira
Cox Creek	Highway 86	16018410502	n/a
Laurel Creek	At mouth, Bridgeport	16018403002	Laurel Creek
Schneider Creek	Old Mill Rd, Kitchener	16018411702	Schneider Creek
Mill Creek	Sideroad 10, Puslinch Township, S of Hwy 401	16018413102	Mill Creek

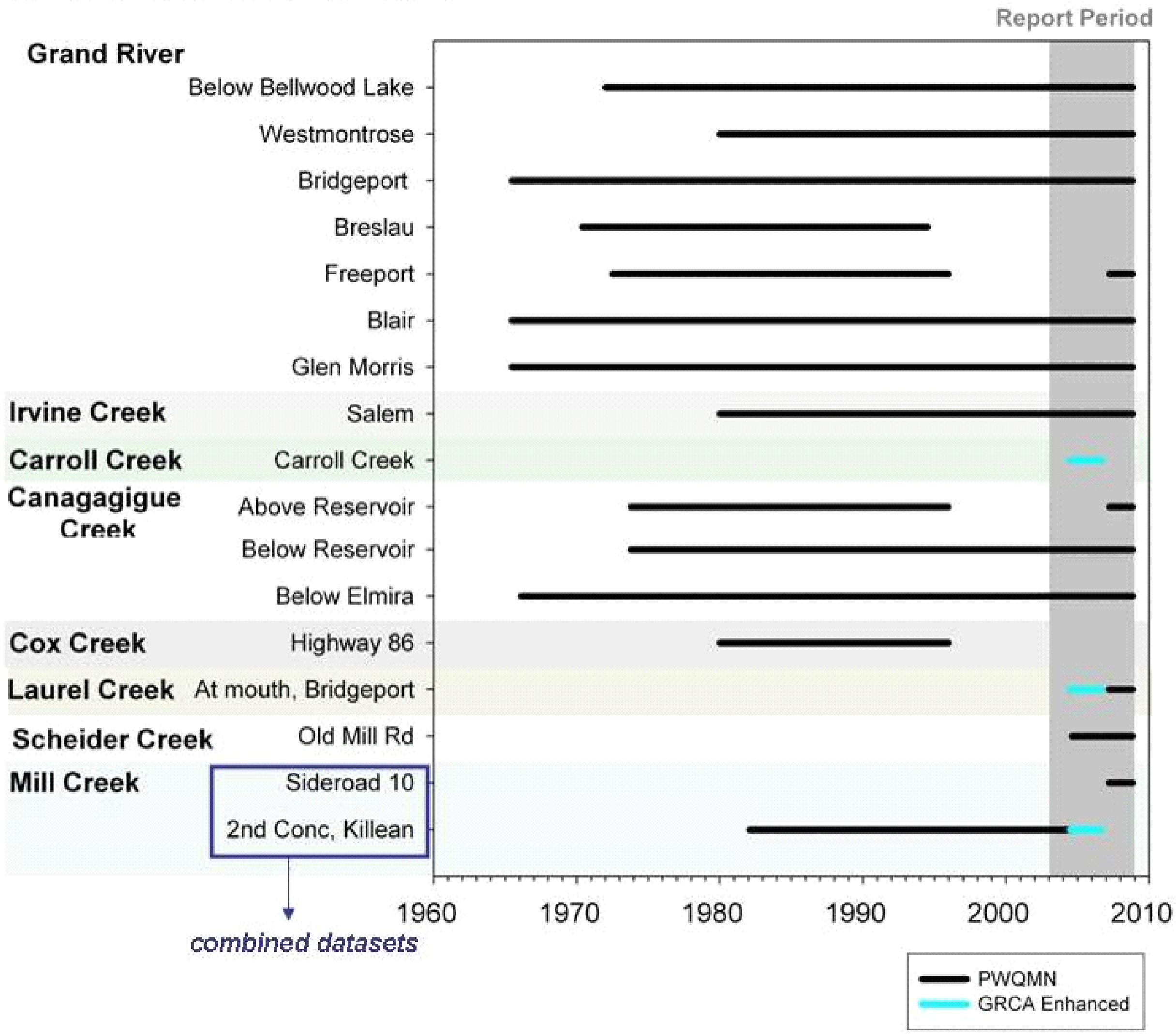

Figure 6-2: Sampling record for GRCA and Provincial Water Quality Monitoring Network sites in the central Grand River region.

Results

Dataset Description

The seasonal distribution of the monitoring data is similar between sites. All datasets are biased toward summer and spring with very few samples (0-8%) taken during the winter. Spring samples comprised 20–30 %, summer 45–70 %, and fall 0–20 (Table 6-3).

Table 6-3: Seasonal composition of water quality data in the Central Grand River subbasin.

Site	% of Samples Collected			
	Winter	Spring	Summer	Fall
Below Shand Dam	6	30	49	15
Carroll Creek	0	21	64	14
Irvine Creek	4	31	47	18
West Montrose	2	28	52	17
Canagagigue Creek:				
- *Above Woolwich*	0	30	70	0
- *Above Elmira*	0	27	59	15
- *Below Elmira (mouth)*	8	33	45	14
Conestogo River	7	35	48	11
Bridgeport	8	30	46	16
Laurel Creek	0	25	60	15
Freeport	0	27	53	20
Schneider Creek	0	31	54	14
Blair	8	31	47	14
Speed River	9	35	48	9
Mill Creek	0	26	55	18
Glen Morris	8	31	46	15
Nith River	8	29	50	13

The percent of flow sampled relative to the flow record ranged from 13 to 52 % with most sites being greater than 37% (Table 6-4). Comparisons between the sampled flows and the flow record showed no significant differences between sites or against the flow record (p = 0.0755 – 102.5034).

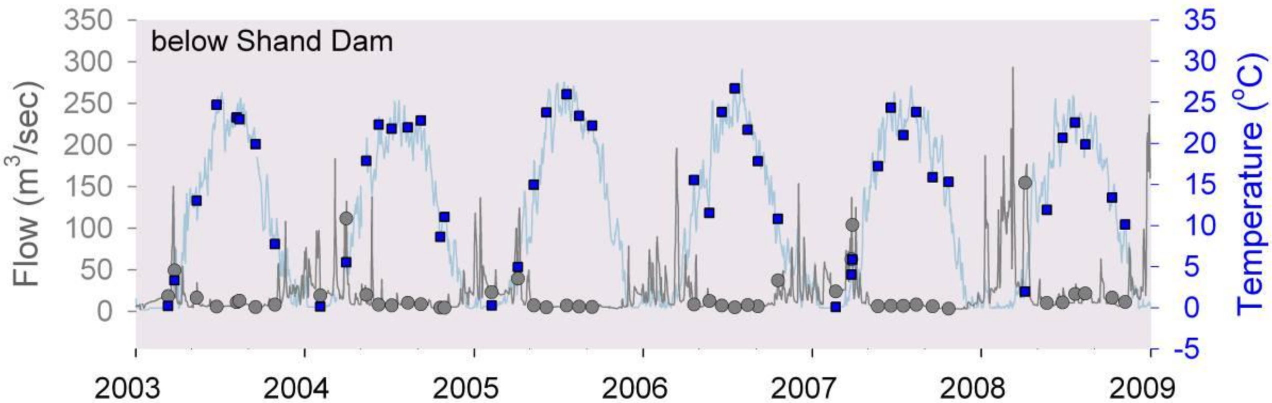

Figure 6-3: Daily average flow (grey line) and temperature (blue boxes) sampled below Shand Dam relative to the flow timeseries of the West Montrose flow gauge and Bridgeport temperature monitoring site between 2003 and 2008.

Greater than 70% of the temperature range was sampled across sites (Figure 6-3, Table 6-4). When compared against the temperature record, significantly warmer temperatures were sampled at Irvine Creek, above Elmira, West Montrose, Laurel Creek, Schneider Creek, Mill Creek (p = < 0.001 - < 0.05). Between sites, no differences were observed.

Table 6-4: The percent of the flow and temperature record sampled at each site in the Central Grand River Watershed.

Site	**% Sampled**	
	Flow	Temp
Below Shand Dam	52	91
Carroll Creek	22	83
Irvine Creek	52	91
West Montrose	37	87
Canagagigue Creek:		
- *Above Woolwich*	13	72
- *Above Elmira*	37	84
- *Below Elmira (mouth)*	52	91
Conestogo River	33	91
Bridgeport	38	91
Laurel Creek	38	84
Freeport	38	72
Schneider Creek	37	81
Blair	46	88
Speed River	98	89
Mill Creek	46	88
Glen Morris	46	88
Nith River	47	88

Summer Water Temperature

Three creeks discharging to the Grand River (Mill Creek, Carroll Creek, and Irvine Creek) and one site on the Grand River (below Shand Dam) showed summer water temperatures capable of supporting cold water fisheries (Figure 6-4). In Mill Creek, water temperatures appeared the lowest but was not significantly different from Carroll Creek (p = 2.3513) or Below Shand Dam (p = 1.1562). Higher temperatures tended to be observed at Blair but they were not significantly different from the other Grand River sites (p = 1.2318 - 68.1983) or many of the larger tributaries (p = 26.8712 – 52.3752).

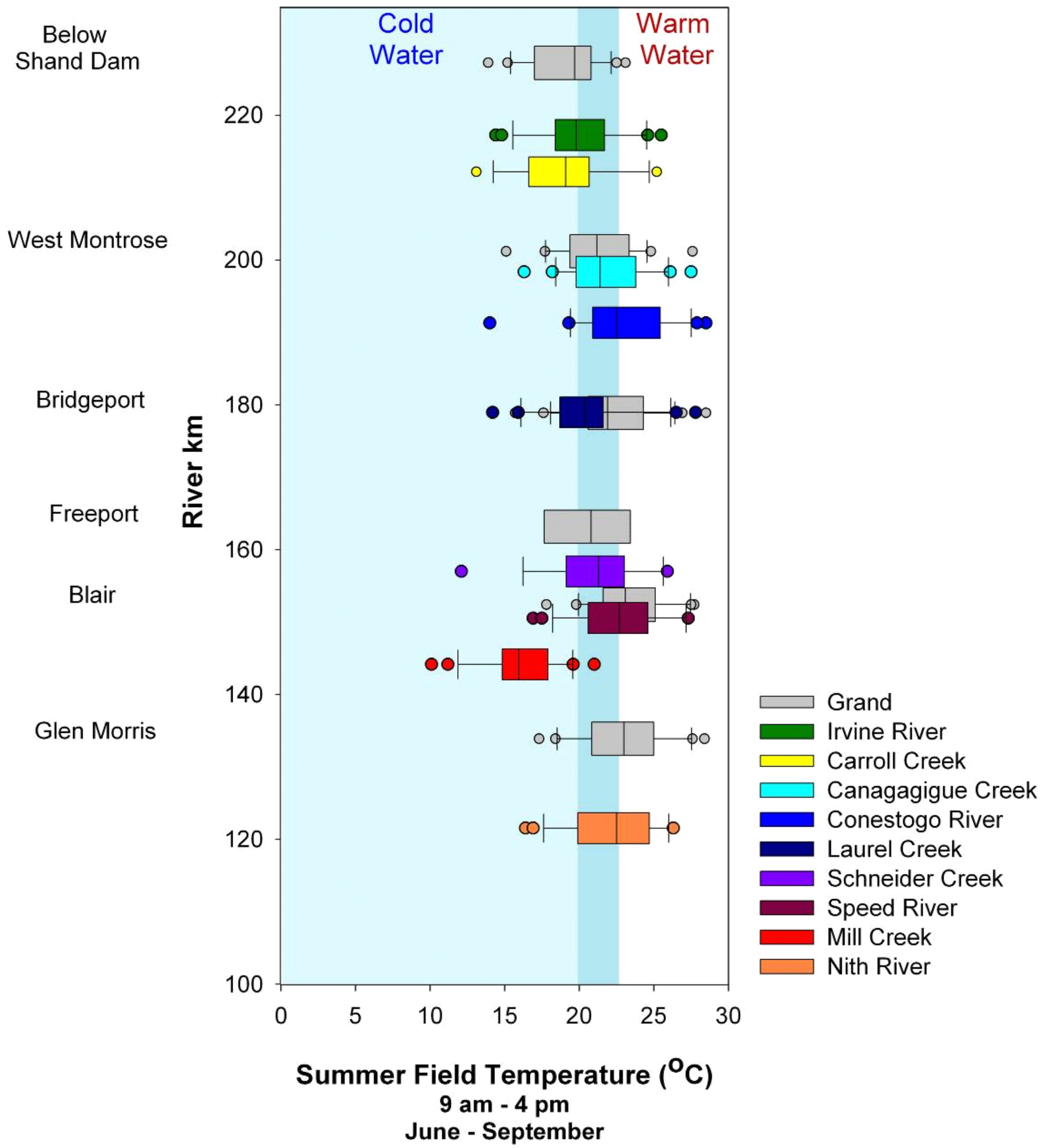

Figure 6-4: Box and whisker plots illustrating the range of summer (June – September) daytime (9 am - 4 pm) field temperatures in the central Grand River subbasin.

Canagagigue Creek

Temperatures at one site in the Canagagigue Creek subwatershed (above Woolwich) appeared to be able to support a cool water fishery. A comparison among sites showed that it was significantly lower than the sites above and below Elmira (p = 0.001 $p < 0.01$, respectively; Figure 6-5); however, it may be an artefact of the small dataset. Further monitoring is required to confirm this.

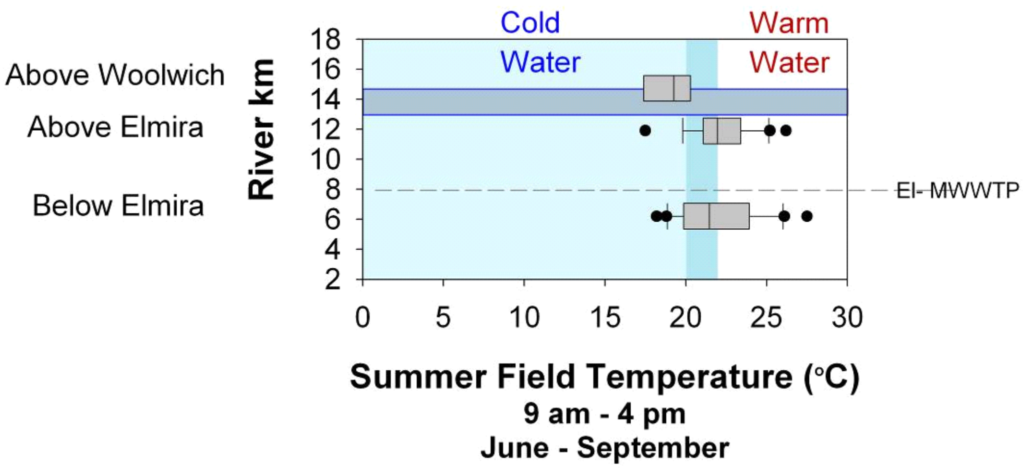

Figure 6-5: Box and whisker plots illustrating the range of summer field daytime temperature on Canagagigue Creek, in the central Grand River subbasin.

Dissolved Oxygen

The daily minimal dissolved oxygen concentrations at Bridgeport, Blair, and Glen Morris (2003-2008) vary seasonally and, as expected, the lowest concentrations occur during the summer and the highest in winter and early spring (Figure 6-6). At Bridgeport and Glen Morris, the summer daily minimal dissolved oxygen concentrations approach the water quality objective. At Blair, half of the days in July and August fall below the objective in addition to approximately 25 - 30% of the days in June and September.

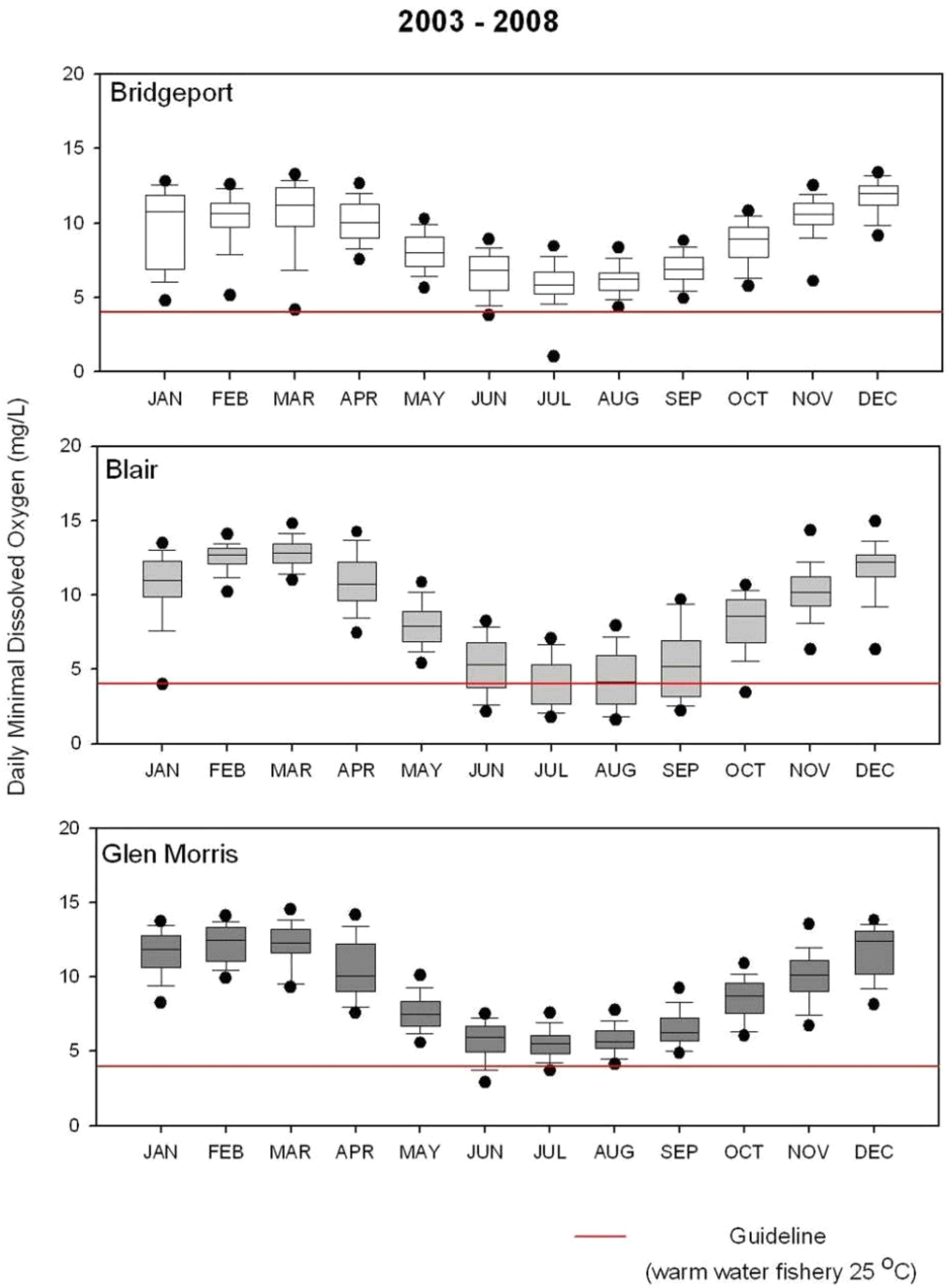

Figure 6-6: Box and whisker plots illustrating the range of the daily minimum dissolved oxygen concentrations by month from the continuous monitoring records at Bridgeport (top), Blair (middle), and Glen Morris (bottom). The red line represents the PWQO of 4 mg/L for warm water fish.

Dissolved oxygen concentrations at Blair and Glen Morris follow a similar diurnal cycle; however, lower dissolved oxygen concentrations were observed at Blair (Figure 6-7). The diurnal trend at Bridgeport is less distinctive; the diurnal fluctuations appear to not be as extreme as the other two sites with overall lower daily maximum and higher daily minimum concentrations (Figure 6-7). At Bridgeport, dissolved oxygen tends to be the lowest between 3 to 9 am with the highest concentrations observed between 3 and 8 pm. At Blair, however, dissolved oxygen concentrations were the lowest between 11 pm and 7 am while the highest concentrations were observed between 1 and 5 pm with the period of high concentrations lasting 1 hour shorter than at Bridgeport or Glen Morris. At Glen Morris, the period where dissolved oxygen levels were the lowest occurred between 2 and 7 am while the period with the highest concentrations where observed between 1 and 6 pm.

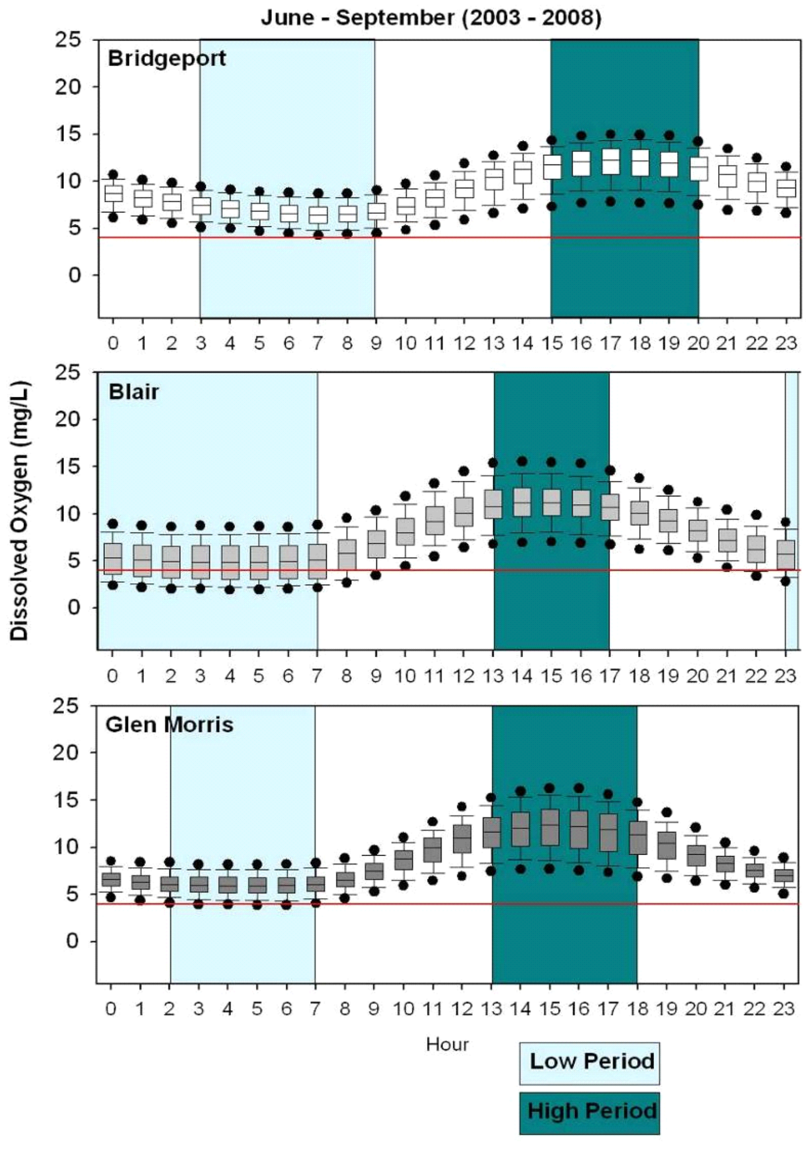

Figure 6-7: Box and whisker plots illustrating the range of the hourly dissolve oxygen concentrations (mg/L) at Bridgeport (top), Blair (middle), and Glen Morris (bottom) between June and September. The red line represents the PWQO of 4 mg/L.

The spatial extent of hypoxia at the Blair site was investigated in more detail by measuring dissolved oxygen concentrations along the river reach during the period of day in which levels tend to be at their lowest on August, 24, 2005 (Figure 6-8). The concentration ranged from a high dissolved oxygen concentration of above 9 mg/L to a low of 1.2 mg/L at the downstream location.

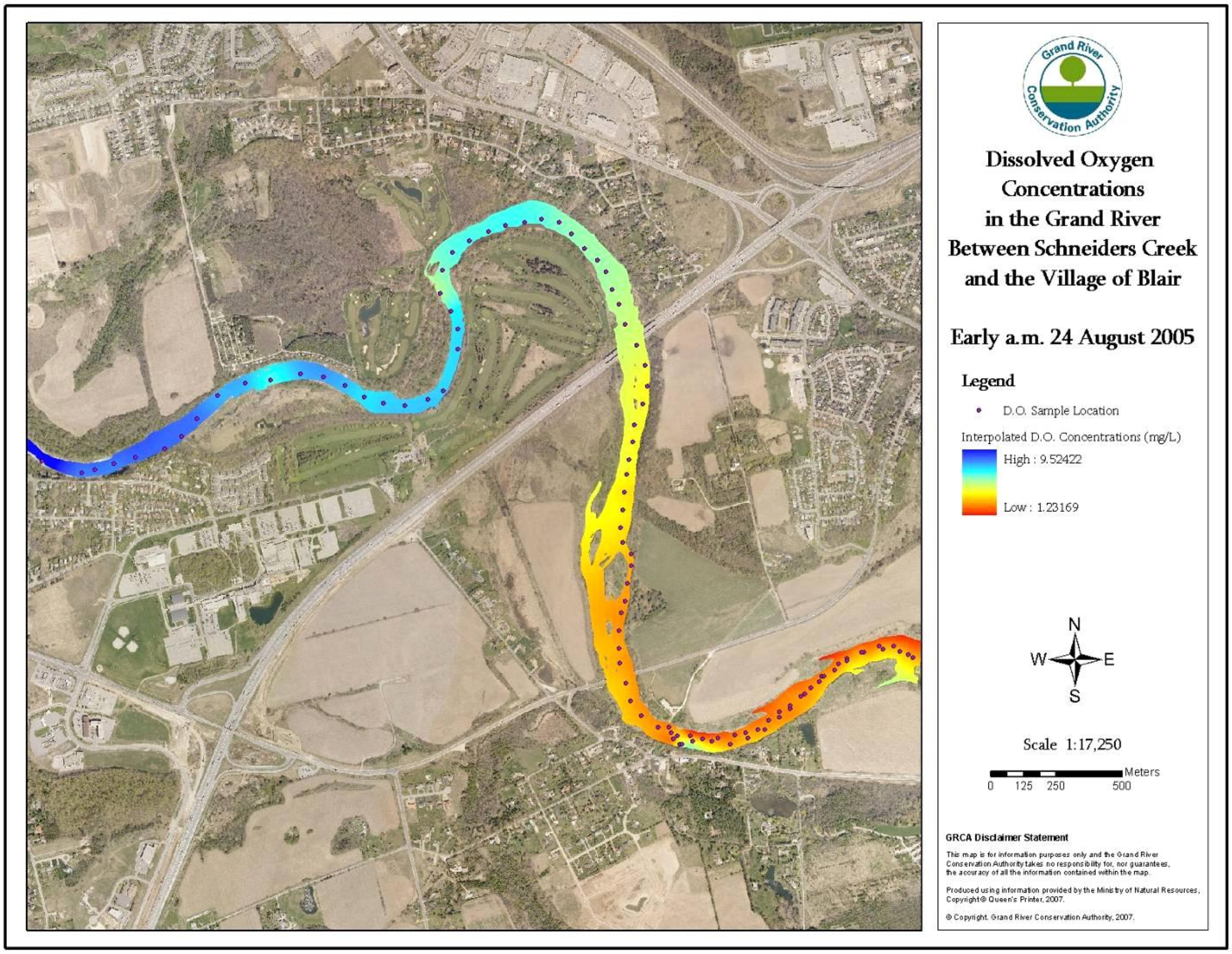

Figure 6-8: Observed dissolved oxygen concentrations between Schneider Creek and Blair on the Grand River between 6 and 8 am on August 24th, 2005.

Chloride

Chloride concentrations increase with distance downstream on the main stem of the Grand River such that significant differences were observed between adjacent sites (p <0.0001 – 0.001) with the exception of Blair and Glen Morris (p = 4.9911; Figure 6-9). The tributaries to the Grand River with the highest chloride concentrations were Canagagigue Creek, Laurel Creek, Schneider Creek, and the Speed River. Chloride concentration in Laurel Creek and Schneider Creek were often above the water quality objective.

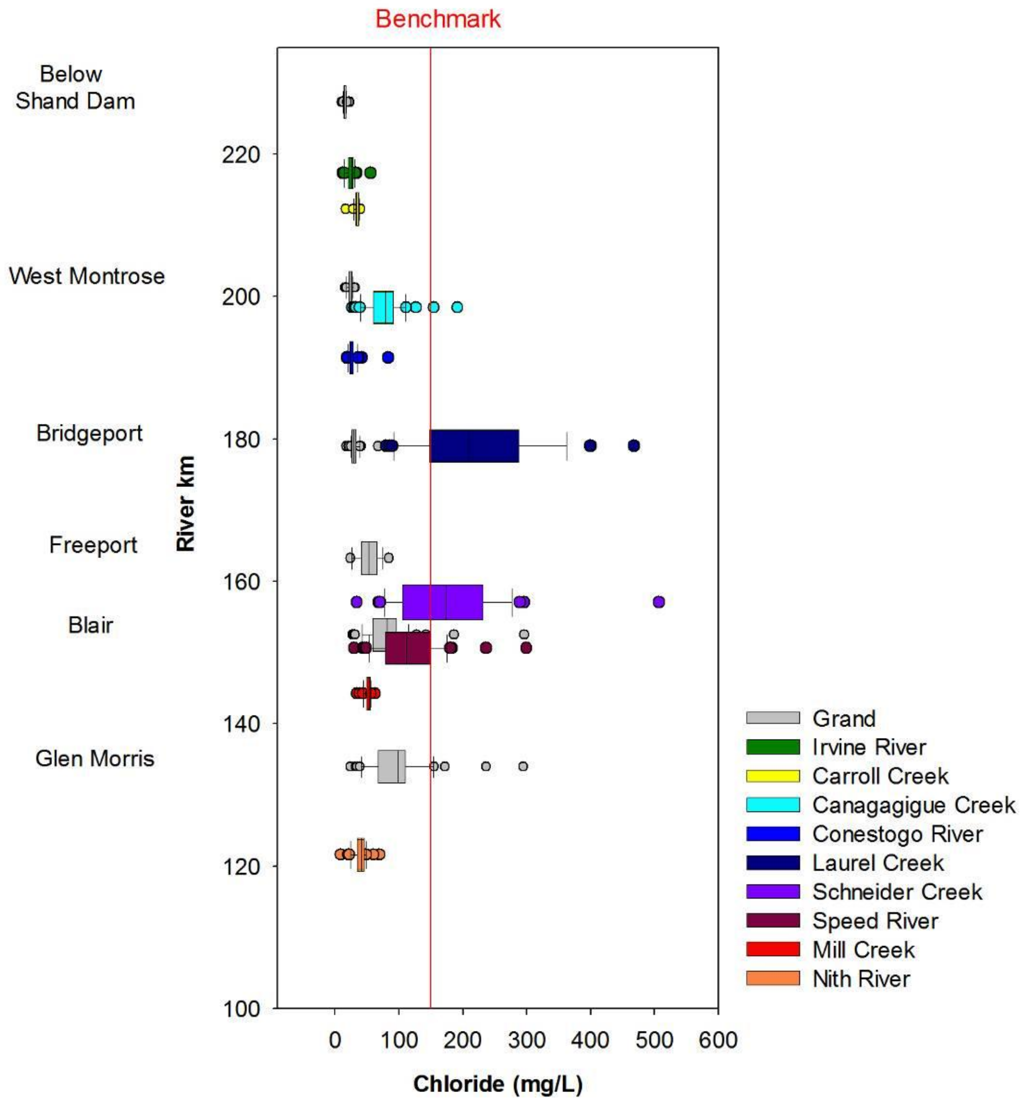

Figure 6-9: Box and whisker plots illustrating the range of chloride concentrations (mg/L) observed at water quality monitoring sites in the central Grand River subbasin.

Chloride concentration in Laurel Creek and Schneider Creek were not significantly correlated with sampled flow or temperature (p > 0.05; Figure 6-10).

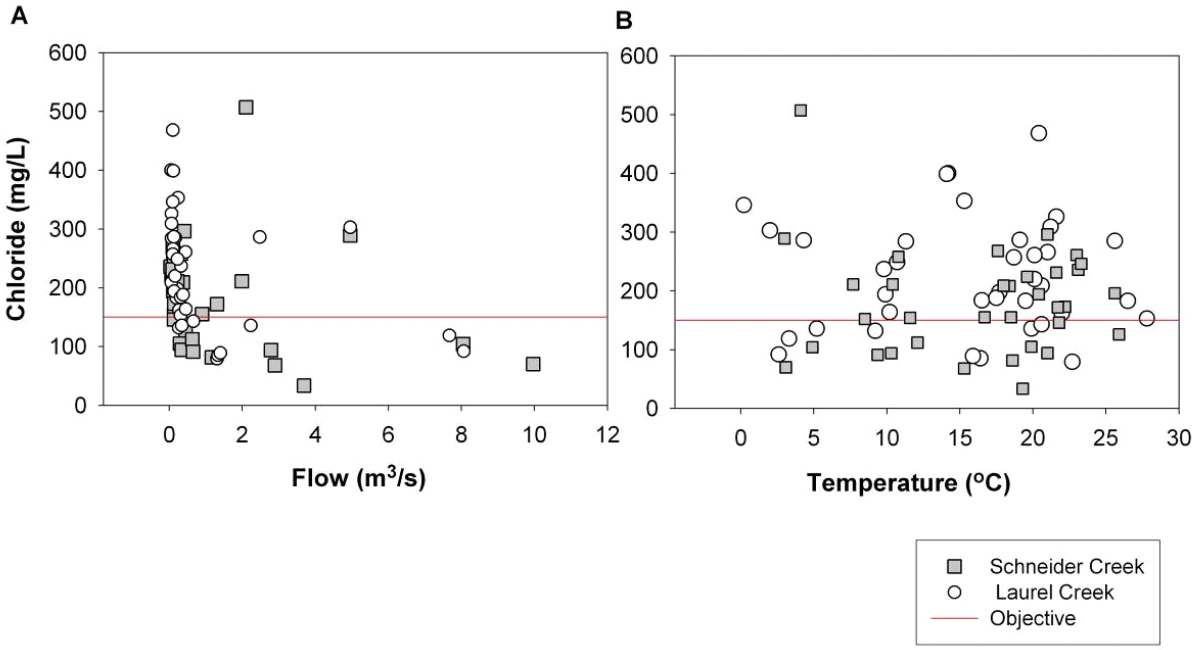

Figure 6-10: Chloride concentrations (mg/L) in Schneider Creek and Laurel Creek relative to sampled flow (A) and temperature (B).

Chloride loading in Schneider Creek and Laurel Creek is elevated during spring melt periods (Figure 6-11).

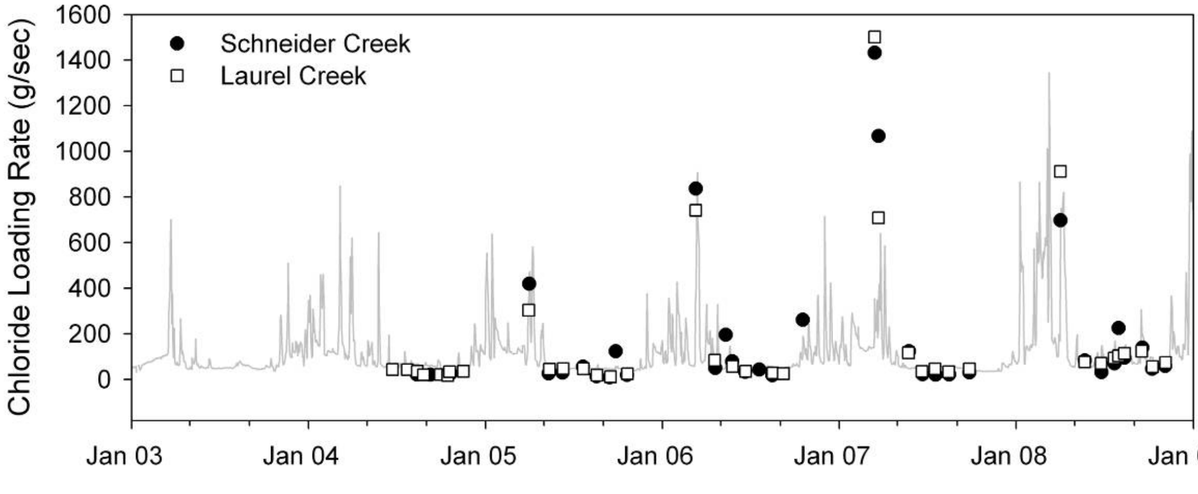

Figure 6-11: The chloride loading (g/sec) rate in Schneider Creek and Laurel Creek in comparison with the hydrograph

Canagagigue Creek

Significantly higher chloride concentrations occurred below Elmira relative to the two upstream sites ($p < 0.0001$; Figure 6-12) however most concentrations remained below the objective.

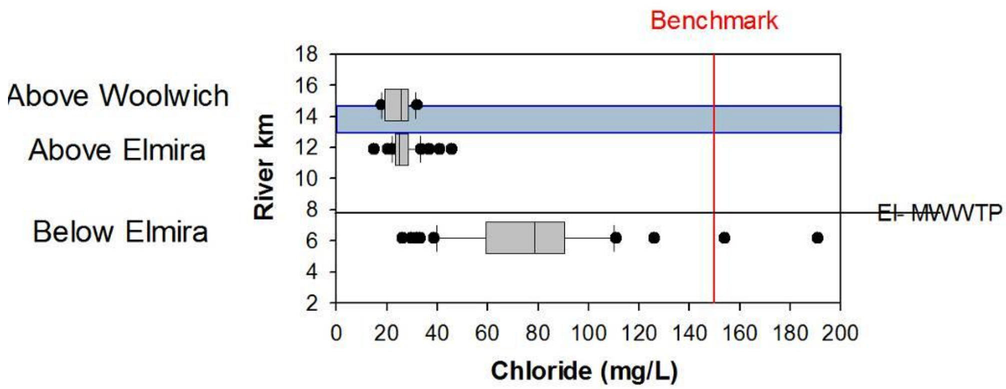

Figure 6-12: Box and whisker plots illustrating the range of chloride concentrations (mg/L) in Canagagigue Creek in the central Grand River subbasin.

Ammonia

Un-ionized ammonia concentrations were below the water quality objective at most sites. At Blair, about half of the dataset exceeded the PWQO while at Glen Morris only about 5% of the data were above the objective. Blair was significantly higher than all other sites in the study reach ($p < 0.0001$ – < 0.01), except for Glen Morris ($p = 0.4311$).

The total ammonia concentrations at Blair were significantly higher than at any of the sampling sites in the central Grand River subbasin (p <0.0001 – 0.051). High total ammonia concentrations were observed at the mouth of Canagagigue Creek (below Elmira) and at Glen Morris. The elevated total ammonia concentrations at these sites correspond to elevated un-ionized ammonia concentrations. Both total and un-ionized ammonia concentrations were lowest in Mill Creek.

Un-ionized ammonia concentrations were not significantly correlated with flow ($p = 0.9858$) or temperature ($p = 0.5049$). In contrast, total ammonia concentrations were positively correlated with flow ($p < 0.05$) and negatively correlated with temperature ($p < 0.0001$; Figure 6-14).

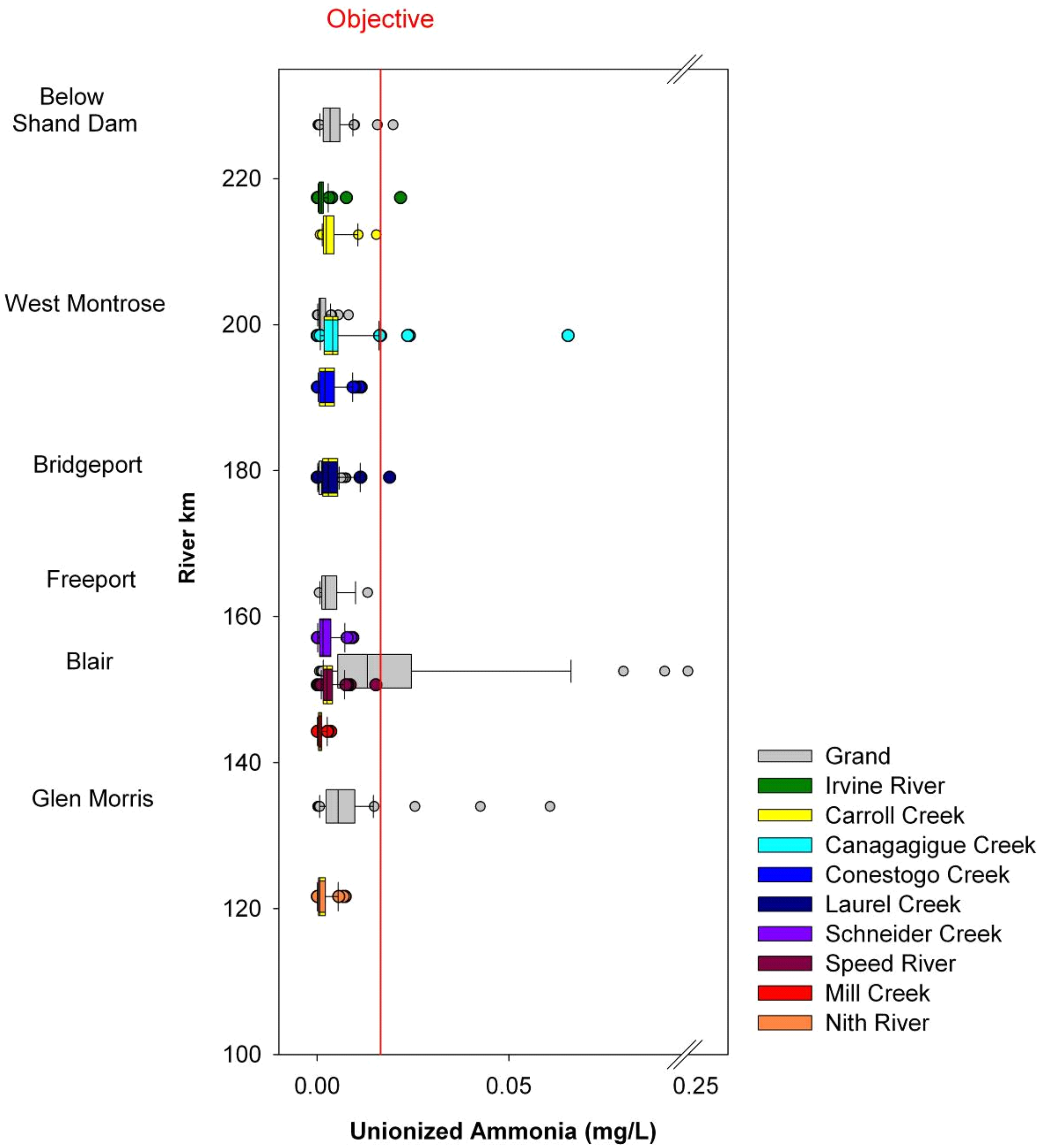

Figure 6-13: Box and whisker plots illustrating the range of un-ionized ammonia concentrations (mg/L) between June and September in the central Grand River subbasin.

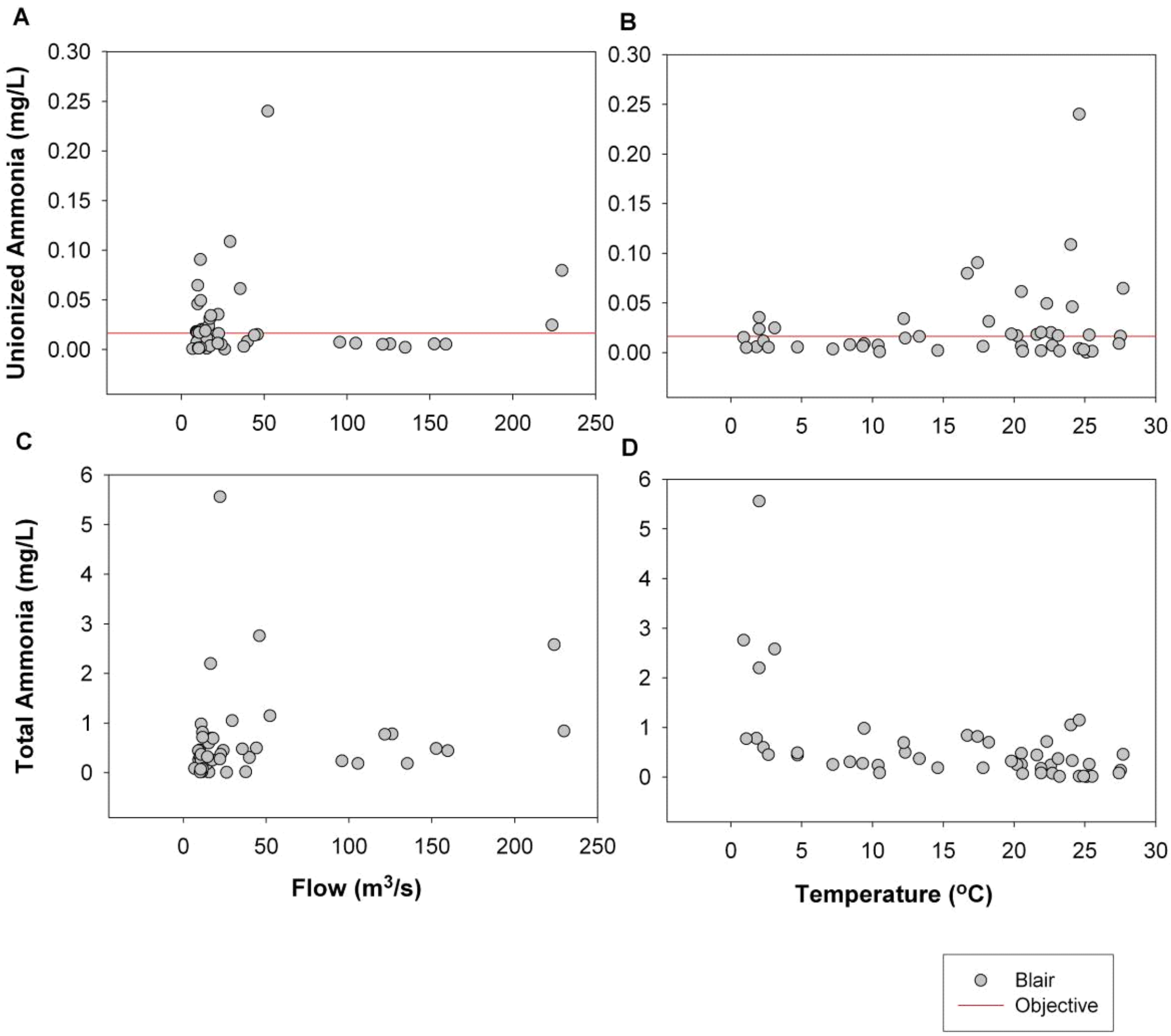

Figure 6-14: Un-ionized ammonia (A) relative to flow (A) and temperature (B) and total ammonia concentrations relative to flow (C) and temperature (D) at Blair.

Canagagigue Creek

Calculated un-ionized ammonia concentrations were above the PWQO in about 50% of the samples at the site located above Elmira. The concentrations were significantly higher than those found at the monitoring site below Elmira ($p < 0.0001$) but not higher than the site located above the Woolwich reservoir ($p = 2.0385$; Figure 6-15).

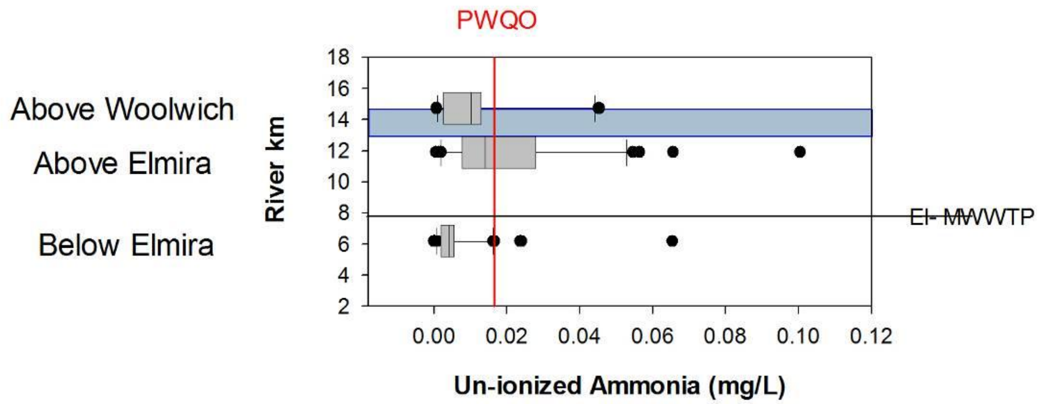

Figure 6-15: Box and whisker plots illustrating the range of un-ionized ammonia (mg/L) in Canagagigue Creek in the central Grand River subbasin.

Total Nitrates

Total nitrate concentrations on the main stem of the Grand River increases as the Grand River flows from the Shand Dam to Paris. The federal environmental quality guideline of 2.93 mg/L was exceeded in more than 25% of the samples at Bridgeport and rose to 75% at Glen Morris (Figure 6-16). Nitrate levels in the Grand River below the Shand Dam were significantly lower than at West Montrose ($p < 0.01$) and levels in the Grand River at West Montrose were significantly less than at Bridgeport ($p < 0.01$). The remaining 3 sites (Freeport, Blair, and Glen Morris) were not significantly different from each other although there appears to be an increasing trend.

At least half of samples collected in six tributaries (Irvine, Carroll, Speed, Canagagigue, Conestogo and Nith) to the central Grand River subbasin had total nitrate concentrations that exceeded the guideline (Figure 6-16). However, in Laurel Creek, Schneider Creek, and Mill Creek, total nitrate concentrations were below the water quality objective. Carroll Creek and Canagagigue Creek were significantly higher than the three Grand River sites in the northern region of the central Grand River subbasin (below Shand Dam, West Montrose and Bridgeport; $p < 0.0001$ for all contrasts). Although nitrate levels tended to be high in the Irvine River, they were significantly lower than both Carroll Creek ($p < 0.0001$) and Canagagigue Creek ($p = 0.0016$) and higher than total nitrate levels in the Grand River below the Shand Dam ($p < 0.0001$) and West Montrose ($p < 0.0001$). Nitrate concentrations in the Conestogo River were significantly higher than in the Grand River at West Montrose ($p < 0.0001$) but not at Bridgeport ($p = 0.9455$). Nitrate levels in the Speed, Nith, Conestogo rivers and at two sites on the Grand River (Blair and Glen Morris) were not significantly different ($p = 9.1293 – 99.8571$).

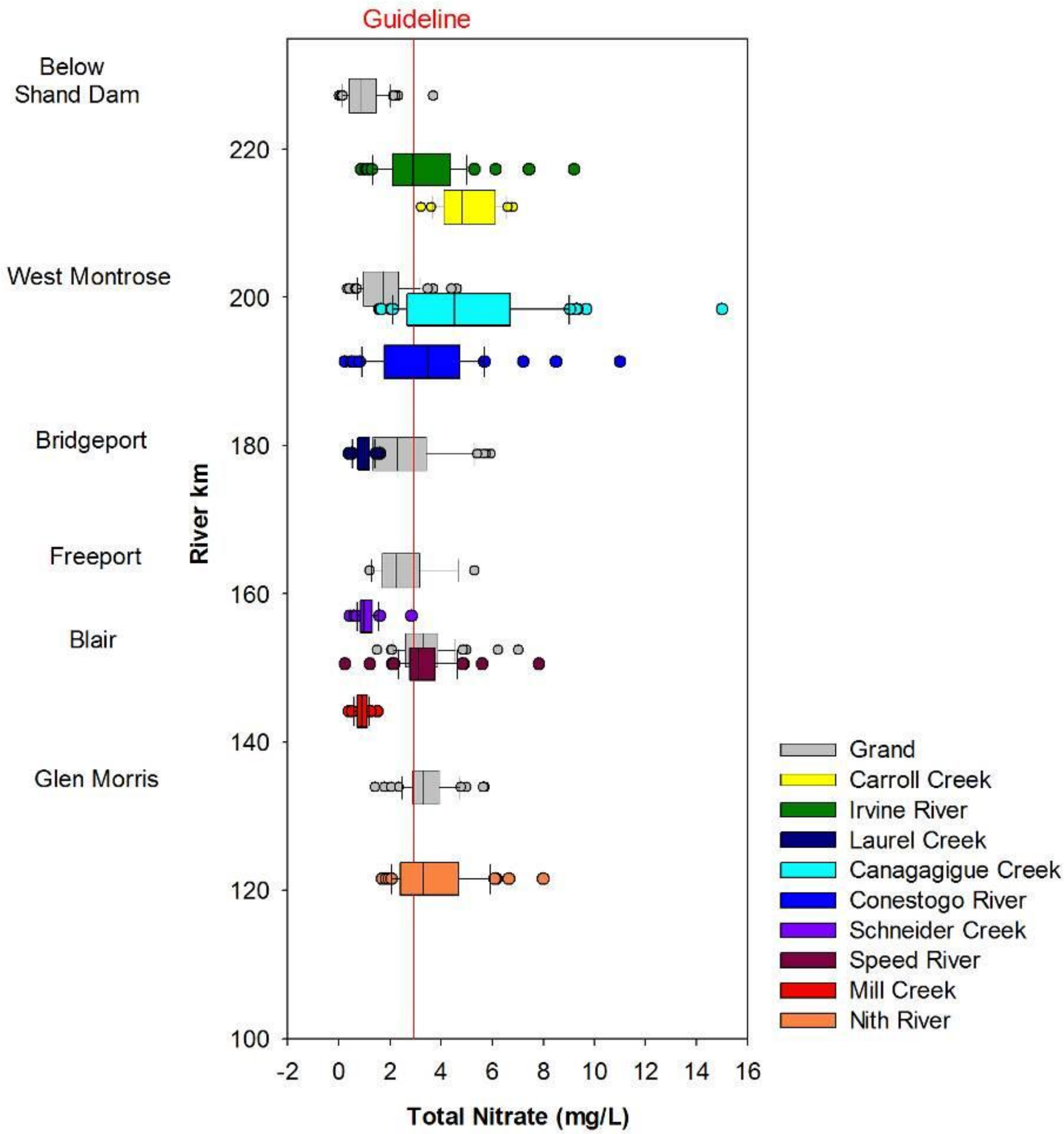

Figure 6-16: Box and whisker plots illustrating the range of total nitrate concentrations (mg/L) in the central Grand River subbasin (2003 – 2008).

Nitrate levels at Bridgeport, Freeport, Blair, and Glen Morris were negatively correlation with temperature ($p < 0.0001 - < 0.05$; Figure 6-17). No observed correlation was seen for total nitrate levels and flow at these sites except at Blair where nitrate levels were positively correlated with flow ($p < 0.01$).

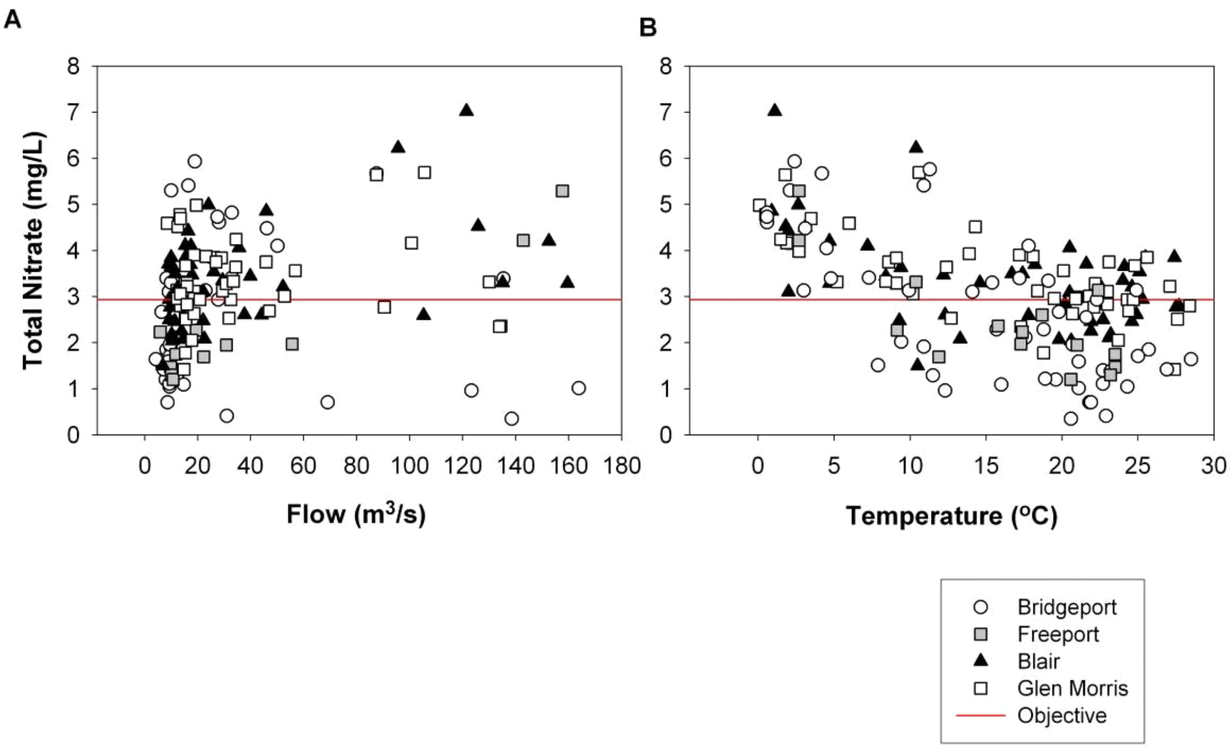

Figure 6-17: Total nitrate concentrations (mg/L) in the Grand River in the central Grand River subbasin relative to sampled flow (A) and temperature (B).

Total nitrate concentrations at the mouth of the Speed River are negatively correlated with flow while concentrations at the mouth of the Conestogo and Nith rivers were positively correlated with flow. Although there was no relationship between total nitrate concentrations and temperature at the sampling site near the mouth of the Speed River, there was a positive relationship between total nitrate concentrations and temperature at the sampling sites located near the mouth of the Nith and Conestogo rivers.

In Carroll Creek, total nitrate concentrations varied neither with sampled flows ($p = 0.5784$) nor temperatures ($p = 0.1750$; Figure 6-18) however, nitrate concentrations in the Irvine River were significantly and positively correlated to flow ($p < 0.0001$) and negatively correlated to temperature ($p < 0.0001$).

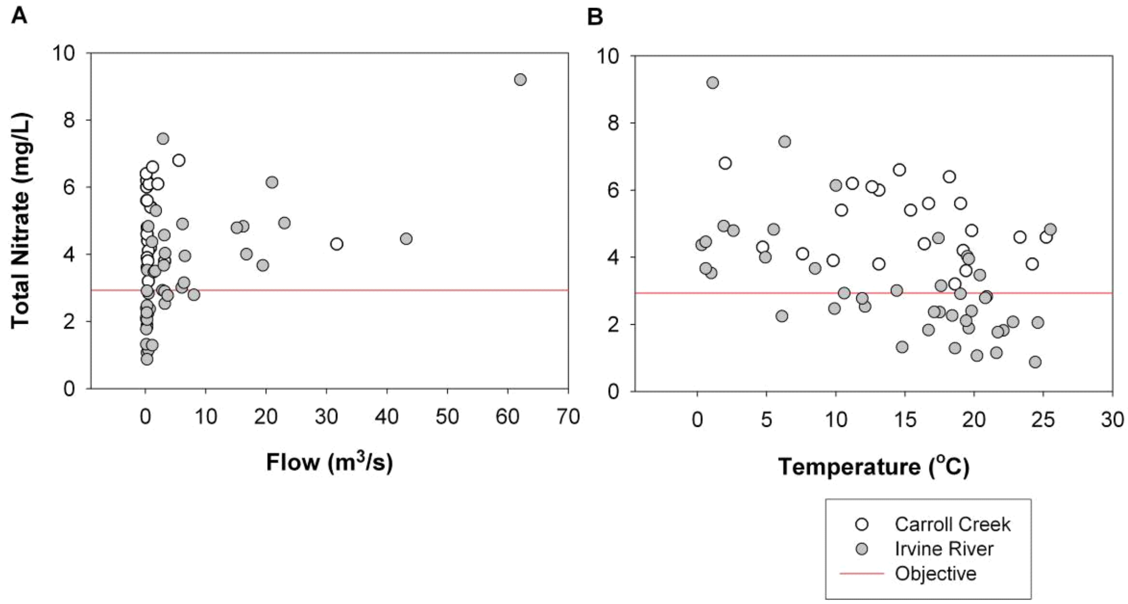

Figure 6-18: Total nitrate concentrations (mg/L) in Carroll Creek and Irvine River in the central Grand River subbasin relative to sampled flow (A) and temperature (B).

Canagagigue Creek

Nitrate concentrations in the Canagagigue Creek were significantly higher at the sampling site below Elmira relative to the site above Elmira ($p < 0.01$); however, they were not significantly different from the concentrations found at the site above the Woolwich reservoir ($p = 2.5657$, Figure 6-19). There was no significant difference in nitrate concentrations at the sites above Woolwich and above Elmira ($p = 0.1844$).

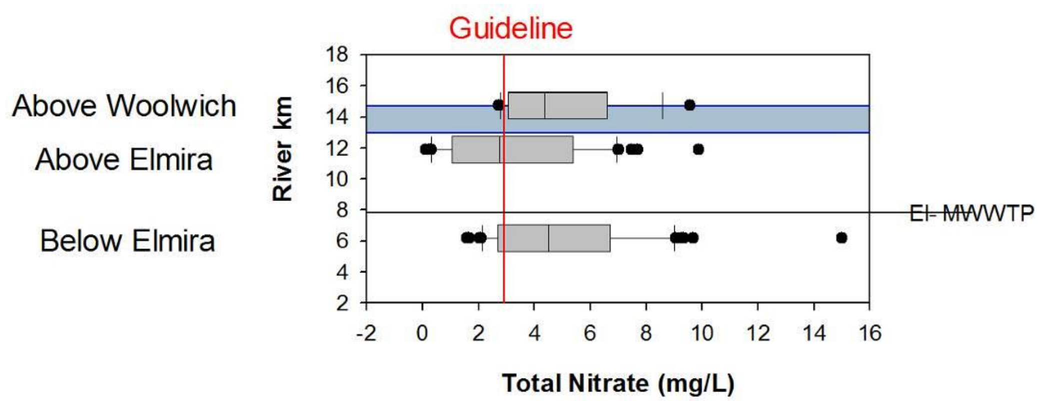

Figure 6-19: Box and whisker plots illustrating the range of total nitrate concentrations (mg/L) (2003 – 2008) in the Canagagigue Creek, located in the central Grand River subbasin.

At all three sites on the Canagagigue Creek, total nitrate concentrations were negatively correlated with temperatures ($p < 0.0001 – 0.05$), but were not correlated with flows ($p = 0.4653 – 0.8327$, Figure 6-20).

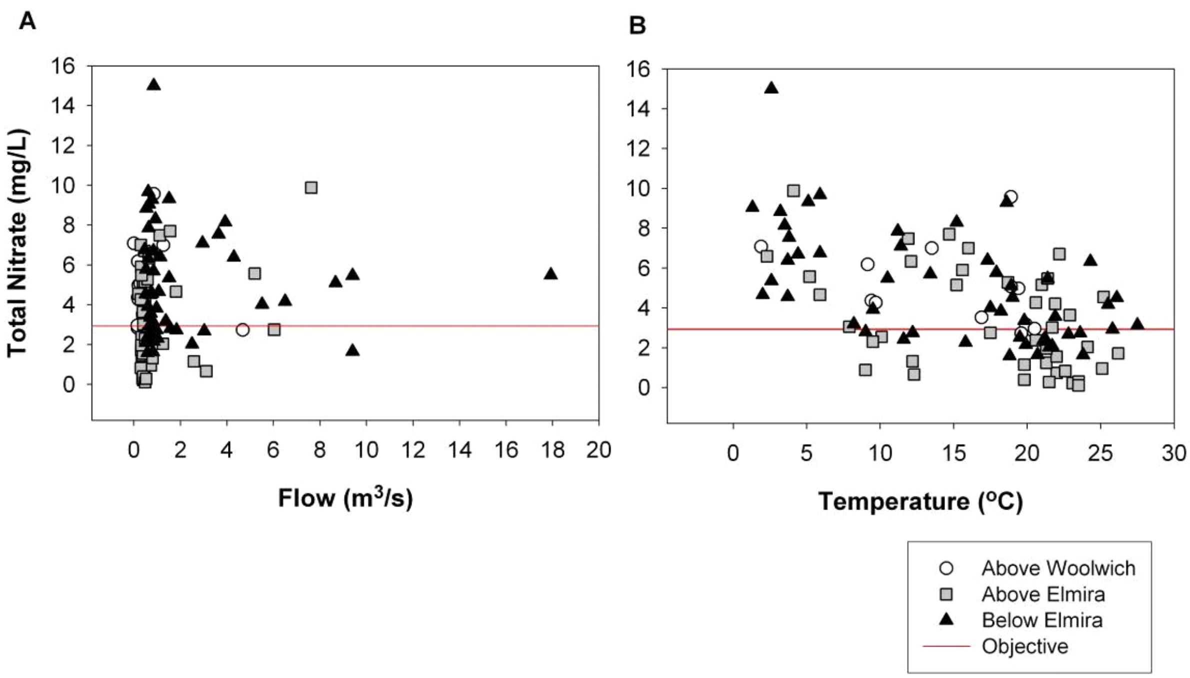

Figure 6-20: Total nitrate concentrations (mg/L) in Canagagigue Creek in the central Grand River subbasin relative to sampled flow (A) and temperature (B).

Total Phosphorus

Total phosphorus concentrations exceeded the water quality objective in at least 25% of the samples at all sites except Mill Creek (Figure 6-21). Total phosphorus concentrations at the three upstream sites on the Grand River (Below Shand Dam, West Montrose, and Bridgeport) are significantly lower than concentrations at the two downstream sites (Blair and Glen Morris; $p < 0.0001$ - < 0.001), while the concentrations at Freeport are not significantly different from either group ($p = 0.5909 – 25.3323$).

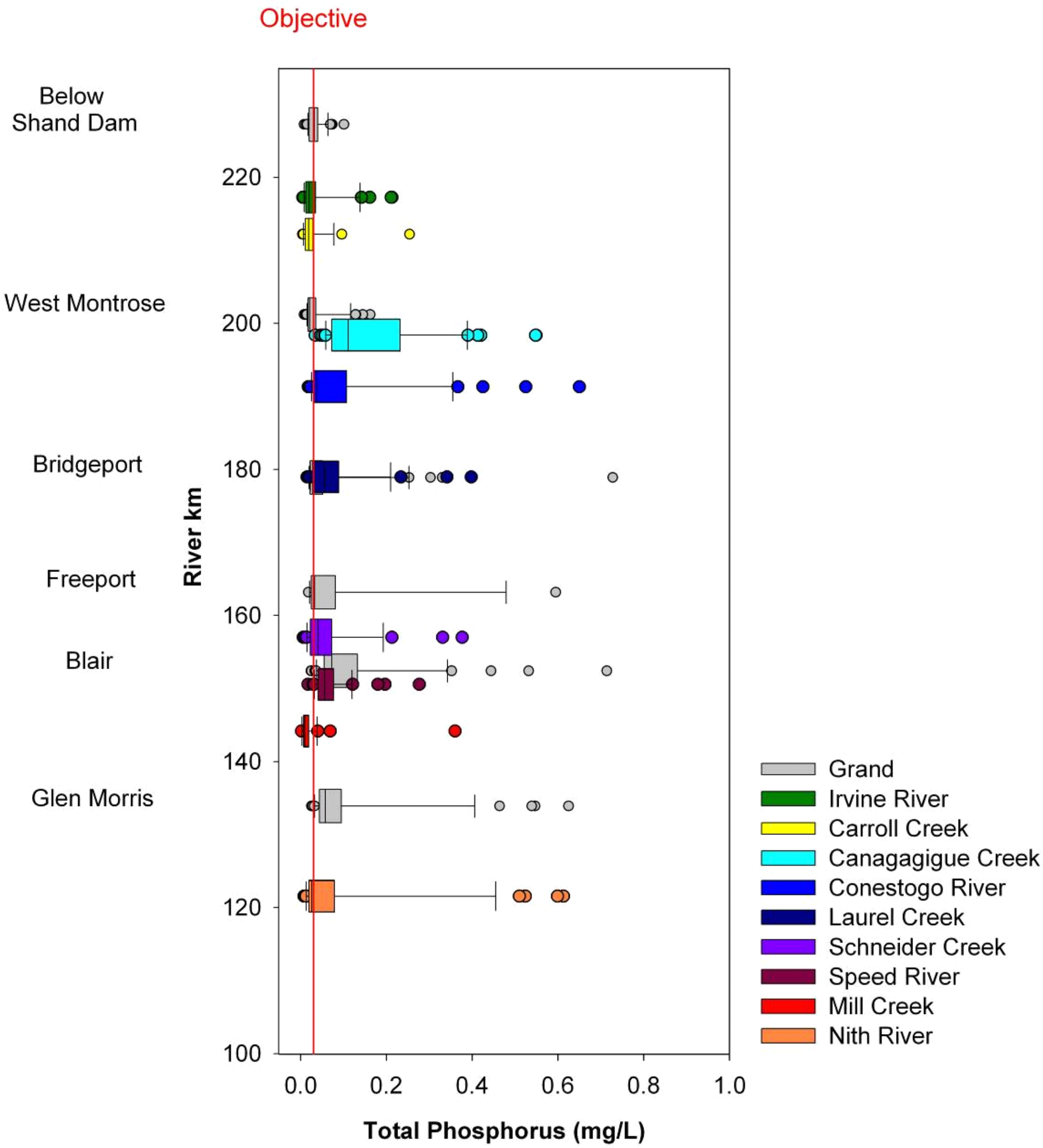

Figure 6-21: Box and whisker plots illustrating the range of total phosphorus concentrations (mg/L) in the central Grand River subbasin.

Total phosphorus concentrations in six of the nine tributaries to the central Grand River subbasin exceeded water quality objectives in more than 50% of the samples. Canagagigue Creek had significantly higher total phosphorus concentrations relative to the other tributaries ($p < 0.0001$), while Carroll Creek, Irvine Creek, and Mill Creek had significantly lower concentrations which did not exceed the PWQO for total phosphorus (0.03 mg/L).

Significant correlations between total phosphorus concentrations and flow were not observed at Blair ($p = 0.0801$) or Glen Morris ($p = 0.1277$) but were observed at Freeport ($p < 0.01$, Figure 6-22). Neither Freeport nor Glen Morris showed significant correlations with temperature (p = 0.6911 & 0.1232), however a negative correlation was observed at Blair ($p < 0.05$).

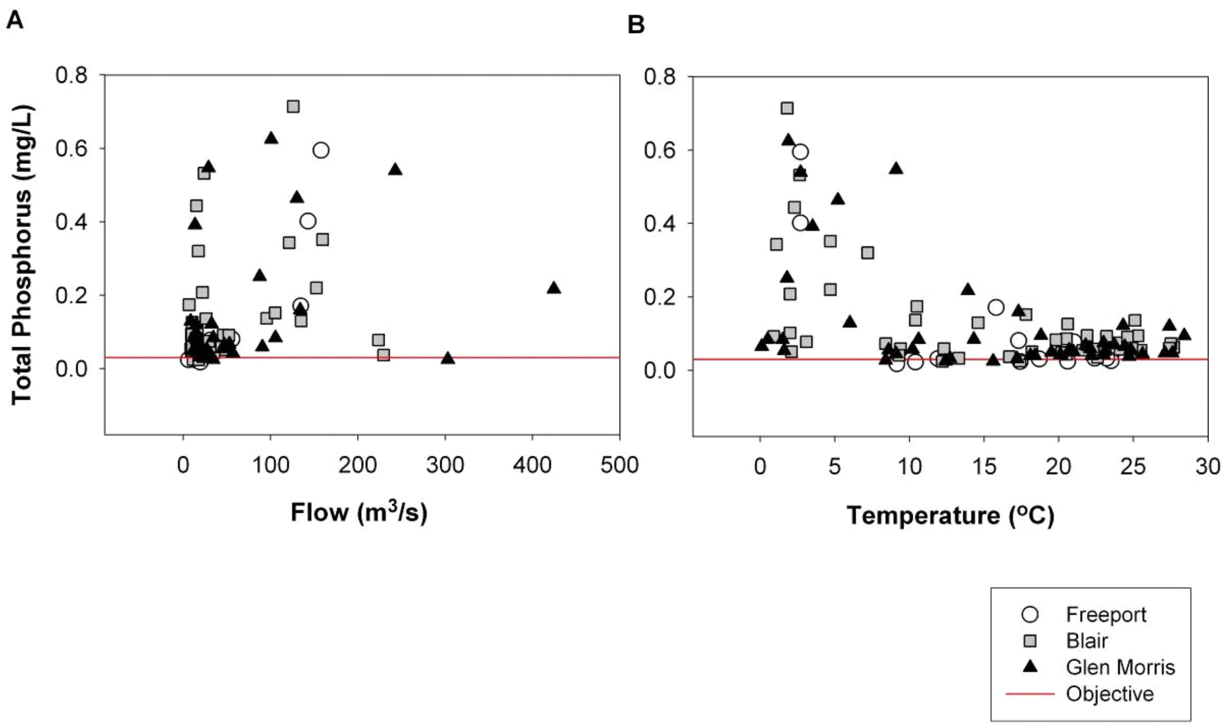

Figure 6-22: Total phosphorus concentrations (mg/L) in the Grand River in the central Grand River subbasin relative to sampled flow (A) and temperature (B), 2003-2008.

The total phosphorus concentrations at the mouths of the Conestogo and Nith rivers were positively related with flow but not in the Speed River (see Subbasin Chapters). Only at the mouth of the Conestogo River was total phosphorus concentrations correlated with sampled stream temperatures.

Canagagigue Creek

Total phosphorus concentrations in the Canagagigue Creek were well above the water quality objective at all sampling sites. No differences in total phosphorus concentrations was observed between sites ($p = 0.9556$; Figure 6-23).

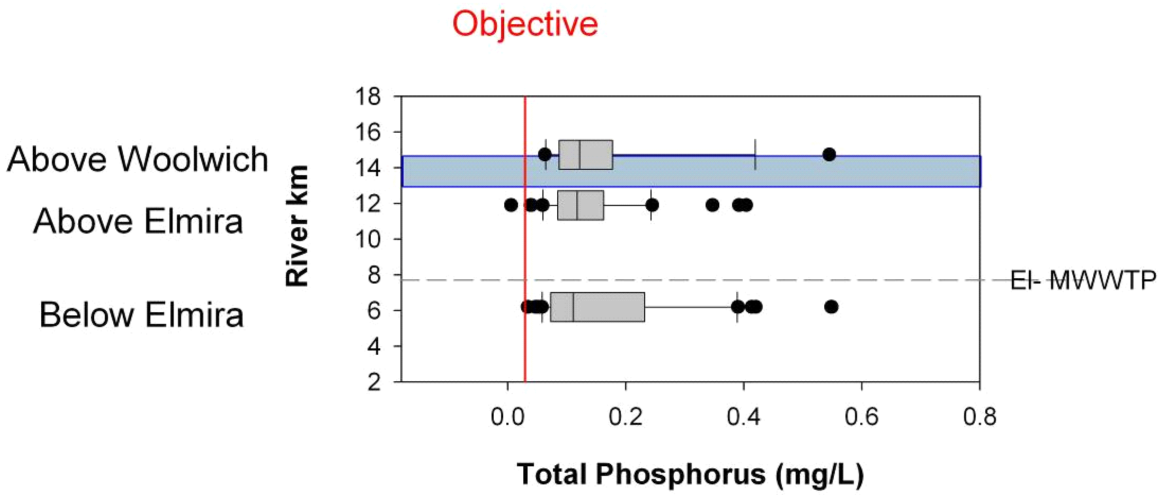

Figure 6-23: Box and whisker plots illustrating the range of total phosphorus concentrations (mg/L) in Canagagigue Creek (2003 – 2008), in the central Grand River subbasin.

Total phosphorus concentrations were observed to be correlated with flow only at one site: above Elmira (p < 0.05, p < 0.01, Figure 6-24). No relationship was observed between total phosphorus concentrations and sampled stream temperatures.

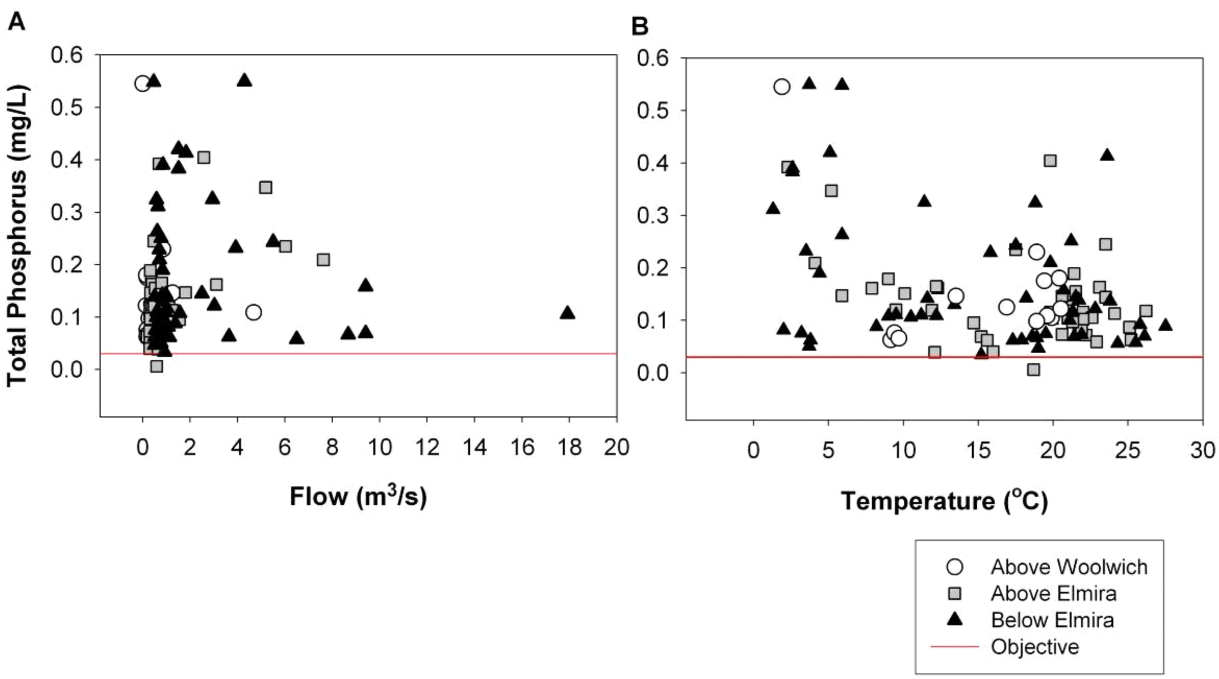

Figure 6-24: Total phosphorus concentrations (mg/L) in Canagagigue Creek (2003 – 2008) in the central Grand River subbasin relative to sampled flow (A) and temperature (B).

Relationships between variables

Grand River

Significant correlations were observed between suspended solids and total phosphorus concentrations at all sampling sites on the Grand River ($p < 0.0001$ across sites; Figure 6-25).

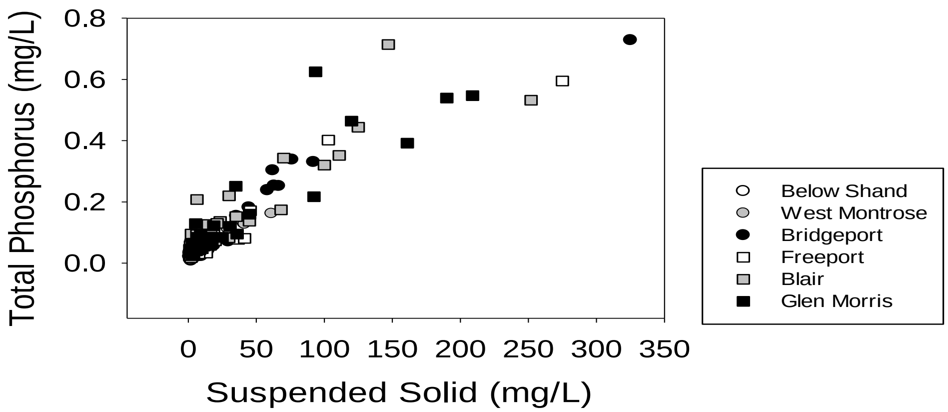

Figure 6-25: Total phosphorus concentrations relative to suspended solids concentrations at sampling sites in the central Grand River subbasin.

Tributaries

Very strong positive correlations were observed between suspended solids and total phosphorus concentrations in the Irvine River, Laurel Creek, and Schneider Creek ($p < 0.0001$ – <0.001) but not in Carroll Creek ($p = 0.1668$).

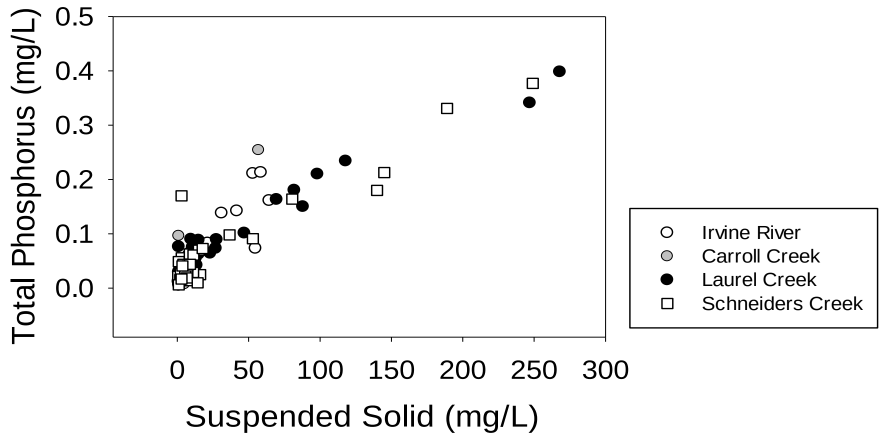

Figure 6-26: Total phosphorus concentrations relative to suspended solids in tributaries in the Central Grand River subbasin.

Canagagigue Creek

In the Canagagigue Creek, total phosphorus concentrations at monitoring sites above and below Elmira were positively correlated with suspended solid (p < 0.0001 – < 0.01; Figure 6-27) but were not significant at the monitoring site above the Woolwich reservoir (p = 0.1431 & 0.7142, respectively).

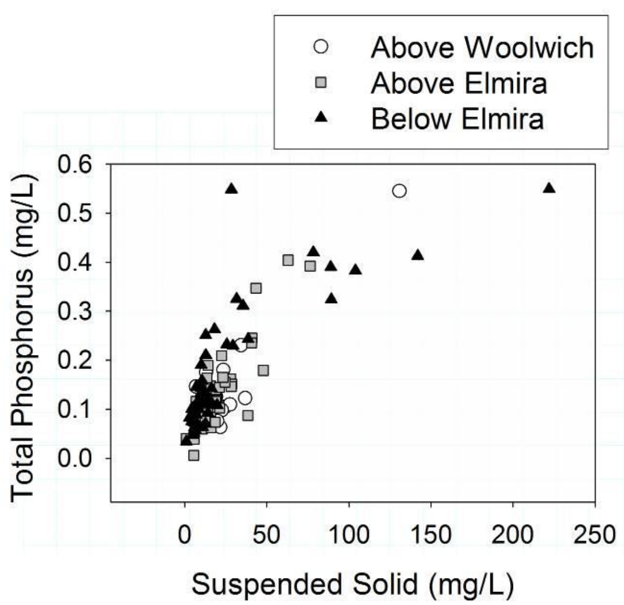

Figure 6-27: Total phosphorus concentrations relative to suspended solids in Canagagigue Creek in the central Grand River subbasin

Discussion

Grand River

Although the current sampling dataset does not fully characterize the flow regime nor seasonal differences, it does highlight the differences among sampling sites on the Grand River. Generally, total nitrate, total phosphorus, and chloride concentrations increase as the Grand River flows from the Shand Dam to Glen Morris with many samples exceeding water quality objectives or guidelines.

The highest observed total nitrate and phosphorus concentrations occurred exclusively during cooler temperatures and often during higher flows suggesting that the greatest flux of nitrogen and phosphorus is likely during spring runoff. This finding is supported by (Draper and Weatherbe 1994) who illustrated that a large percentage of the annual load was a result of the significant nonpoint source contributions from upstream the Region of Waterloo and that most of the loading occurs during the spring. Although it is assumed that most of the nutrient flux in the spring would likely be transported downstream into Lake Erie, it is unclear as to how much of the spring contributions contribute to an in-river supply of nutrients available for aquatic plants during the active growing season. More research is needed to better understand the implications of high spring-time concentrations to both the river and Lake Erie.

Aside from springtime, high levels of nitrogen, specifically total ammonia and un-ionized ammonia and total phosphorus are seen during the summer in the Grand River through the Region of Waterloo. The impact of a series of point sources through this reach of river is evident. High nutrient concentrations facilitates prolific aquatic plant and macoalgae growth (e.g. *Cladophora sp.*) in the river, specifically in the Grand River at Blair, which results in substantial diurnal variation in dissolved oxygen concentrations. Therefore, single point-in-time measures of dissolved oxygen in rivers is generally meaningless (Huggins and Anderson 2005) and as a result, dissolved oxygen levels are monitored continuously at specific locations in the central Grand River region. During warm, low flow conditions, daily minimum concentrations in the Grand River at Blair fall below the provincial objective while dissolved oxygen levels generally remain above the provincial objective in the Grand River at Bridgeport. The low dissolved oxygen levels at Blair likely have an impact on the local aquatic communities however; there is no routine monitoring of the aquatic communities (e.g. benthic macroinvertebrates and fish) in this area. Two recent studies, (Loomer 2008) and (Brown 2010), however, showed that there is a negative impact to local fish communities below the wastewater treatment plant outfalls but further research and monitoring is recommend. Planned upgrades to the Kitchener wastewater treatment plant will likely have a substantive positive effect on the nutrient and dissolved oxygen levels in the river.

Chloride concentrations observed in the central Grand River reflect the loading from both urban point and non-point sources. The central Grand River region has a dense road network and most intense urban development of the entire watershed. The use of road salt in the winter and the year-round use of water softeners that contribute chloride to the urban wastewater collection system likely have a significant impact on the chloride concentrations seen in the Grand River through this region. Although chloride levels don’t tend to exceed water quality benchmarks in the Grand River, extremely high levels, some samples were approaching 500 mg/L, were found in the two creeks draining the urban areas in the cities of Kitchener and Waterloo: Schneider's and Laurel creeks. With increasing urbanization in the watershed, continued monitoring and load reduction efforts are recommended.

Tributaries to the Grand

Much of the water within the central Grand River region is inherited from the upper Grand, Conestogo, Speed and Nith rivers. Although the dataset consists of mostly summer and late spring samples, the general trend in water quality at the mouths of the large tributaries is characterized by variable but high nutrient concentrations across all seasons. Trends in total nitrate and total phosphorus concentrations relative to sampled temperatures and flows in the Conestogo and Nith River were similar to those observed in the central Grand River and showed higher concentrations in winter and spring, which is characteristic for non-point source loading. Agriculture predominates the landscape in the Conestogo and Nith rivers and is likely the land-use that influences the high nutrient levels seen in these rivers. In contrast, trends in the Speed River show higher concentrations during the summer which is characteristic of point source pollution (Jarvie, Neal et al. 2006). Many of the smaller tributaries draining agricultural regions exhibited elevated nutrient concentrations and followed similar seasonal trends as those in the larger tributaries.

The datasets for the smaller urban creeks – Laurel and Schneider's, are generally limited to summer conditions as it is extremely difficult to adequately characterize high flows. These creeks are 'flashy' and experience peak streamflows an order of magnitude greater than baseflow conditions. Chlorides tend to be the water quality concern for these creeks with the highest levels approaching 500 mg/L. Further characterization of storm flows is required to fully characterize the water quality in these streams and get a better understanding of their contributions to the central Grand River.

Other tributaries showing elevated chloride concentrations were the Speed River and Canagagigue Creek. Although these subbasins have significant urban development, seasonal patterns of chloride levels found in these tributaries are more indicative of point source discharges.

Canagagigue Creek subbasin supports some of the most intensive agricultural production in the watershed. As a result, the water quality in the upper Canagagigue Creek, above Woolwich reservoir, has some of the highest levels of total nitrate and total phosphorus concentrations in the watershed. The lack of a significant relationship between total phosphorus and suspended sediment may suggest a shift in the phosphorus delivery within this watershed and more research is required to investigate this phenomenon. Un-ionized ammonia concentrations below the reservoir are elevated during warmer conditions, probably due to the discharge of hypoxic water from the bottom of the reservoir. Total nitrates and chloride concentrations are increased below the Town of Elmira and the discharge from the wastewater treatment plant (Figure 6-12, Figure 6-20). Chloride concentrations do not exceed the water quality objective and are not a current concern.

In contrast to Canagagigue Creek, water quality in Mill Creek is good. Mill Creek is a groundwater dominated system, collecting its flow from the Paris-Galt moraine complexes (Lake Erie Source Protection Technical Team 2008). The substantial influx of groundwater into this creek moderates temperatures, nutrients and chloride levels seen in the creek. The subwatershed also has some of the most wetlands and treed areas in the watershed outside of the Upper Grand region. Mill Creek also has a dedicated program to help rehabilitate the creek – the Mill Creek Rangers, which likely has had positive effects on the creek's water quality.

Conclusions & Recommendations

- The current dataset is biased toward summer and spring sampling. To fully characterize seasonal differences in water quality, it is recommended that additional sampling be completed through the fall, winter and early spring time periods.

- A downstream degradation in water quality characterized by increasing total nitrates, total phosphorus, and chloride concentrations is observed in the central Grand River subbasin.

- A significant increase in total nitrate concentrations between the Shand Dam and Bridgeport was observed with this dataset. Further monitoring and investigation across all seasons is needed to fully characterize this issue.

- Elevated total and un-ionized ammonia concentrations and critically low dissolved oxygen concentrations occur in the Grand River at Blair during the summer months. Diurnal observations indicate that the poorest water quality happens during the early morning hours. Proposed upgrades to the Kitchener wastewater treatment plant by the Region of Waterloo will likely improve water quality at this site in the future.

- The larger tributaries and some of the small tributaries that predominantly drain agricultural regions have elevated nutrient concentrations. Those tributaries draining urban areas or influenced by point source inputs show elevated chloride concentrations in addition to elevated nutrient concentrations.

- The highest water quality across the central Grand River region is observed in Mill Creek reflecting the natural and anthropogenic features as well as stewardship and rehabilitation efforts to improve the creek.

7. Southern Grand River

Introduction

Watershed Characteristics

The Southern Grand River region covers a 2,059 km^2 area and extends from north-west of the City of Brantford to Port Maitland where it discharges to Lake Erie (Figure 1-4). Most of this area is drained by several large tributaries that discharge to the Grand River, notably Whiteman's, Fairchild's, Boston-McKenzie and Big creeks. By the time the Grand River reaches the southern Grand River region, it is a large seventh-order river.

As the Grand River flows from Paris, the river collects flow from Whiteman's Creek. Whiteman's Creek drains the Norfolk sand plain and is strongly influenced by shallow groundwater. As the river winds its way through Brantford, it flows onto the Haldimand Clay plain and starts to become more turbid as clay particles are picked up and carried in suspension (Figure 1-3). The geology of this region facilitates runoff as there is little ability for the soils to absorb excess water. The change in elevation of the river through Brantford and south toward Port Maitland is extremely gentle when compared to the steep change in elevation between Cambridge and Paris (Figure 1-7).

Fairchild's Creek is a significant tributary to the southern Grand River. The upper section of the creek drains the eastern portion of the Paris-Galt moraine and flows off outcroppings of bedrock. The creek is highly dendritic, likely a result of the unique geological features of this subbasin.

Boston-McKenzie creeks discharge to the Grand River near York. This subbasin drains a good portion of the Haldimand Clay plain. Although you would expect the stream flows to be somewhat flashy, much of the landscape is treed as much of this area belongs to the Six Nations of the Grand River.

Agriculture is the primary land use in the Southern Grand River region (Table 7-1). It covers between 64 -76 % of the land base in this subbasin. Soy is the dominant crop produced in the region (35%) followed by other field crops (27%) while lower proportions of grains (17%) and corn (16%) are produced (Figure 1-11). The geology and agricultural profile of Whiteman's Creek is unique in that the upper region has a similar agricultural profile and surficial geology as observed in the Nith and Conestogo River subbasins which supports a high density of livestock production (16.93, 1.59, and 9.37 animals/ ha for poultry, swine, and cattle, Figure 1-10). The proportion of land that is tile drained is roughly 31% (Figure 1-13). The Southern region of Whiteman's Creek, in contrast, drains a portion of the Norfolk sand plain and is heavily influenced by shallow groundwater discharges. The efficient drainage in this region allows for the production of specialty crops (root crops) and requires irrigation to support production.

The largest municipality in this region is the City of Brantford (Figure 1-14). Accordingly, urban development and human densities are highest along the Grand River between Paris and York (14% and 193 people/km^2, respectively) and in Fairchild Creek (11 % and 130 people/km^2, respectively) yet, when compared to the central Grand River region, population density is less intense. In addition, the small municipalities of Caledonia, Cayuga, and Dunnville are situated on the banks of the Grand River. Other smaller community developments are located throughout the subbasin. Municipal wastewater from five plants is discharged to either the Grand River or Fairchild Creek (Table 1-1).

Trees and wetlands combine to cover 17 to 30% of the drainage area. The lowest percentage is observed between Paris and York along the Grand River and the highest percentage in McKenzie Creek which drains the Six Nations of the Grand River reserve (Figure 1-2,Table 7-1).

Table 7-1: The percentage of land cover devoted to agricultural activities, urban development, treed land, and wetlands in Southern Grand River region.

Region	**Land Cover (%)**			
	Agriculture	Urban	Treed Land	Wetland
Grand River from Paris-York	67	14	9	8
upper-Whiteman's Creek	77	3	5	15
lower-Whiteman's Creek	76	5	4	16
Fairchild Creek	66	11	11	13
Big Creek	76	7	10	8
Grand River from York- Dunnville	68	6	8	17
Boston Creek	73	3	11	13
McKenzie Creek	65	5	13	17
Total	70	8	9	13

Watershed Uses & Values

Surface water intakes drawing more than 9,000 and 600-2000 m^3 daily from the Grand River provide raw drinking water supplies to the City of Brantford and Six Nations, respectively. The municipality of Dunnville is also served by a surface water intake that takes water from Lake Erie.

The southern Grand River region has an inherent connection with Lake Erie both geographically and through the movement of significant valued fish stocks. The Grand River is vital to the Lake Erie walleye fishery as it provides for ideal habitat for the reproduction of walleye. However, the walleye stock in the river is under-producing (T. MacDougall, Ministry of Natural Resources, pers.com.). The southern Grand River provides for spawning and nursery habitats as well as a seasonal cold water migratory route for many lake-based salmonids and walleye (GRFMP 1998a.) (Figure 1-15).

The Southern Grand River region is also a haven for river-based recreation. Due to the presence of the Dunnville and Caledonia dams, water levels are generally much higher than if the river was free-flowing. This provides for adequate water depths for motorized boats and watercraft of all types.

Subbasin Specific Monitoring

Within the Southern Grand River subbasin there are currently seven active monitoring sites (Figure 7-1, Figure 7-2, Table 7-2). York and Dunnville on the Grand River and the mouths of Whiteman's Creek and Fairchild Creek all have long term monitoring records. The Brantford site was sampled in 2003 and from 2007 to present while the Newport site was sampled between 2004 and 2007. The site at the mouth of McKenzie Creek was sampled from 2007 to present.

Flow gauges correspond with water quality monitoring sites at Brantford and York. The Brantford flow record was used for the Newport site and the York flow record was used to model flows at Dunnville. The flow gauge on McKenzie Creek was used to determine the sampled flow record at McKenzie Creek, Big Creek, Fairchild Creek, and Whiteman's Creek.

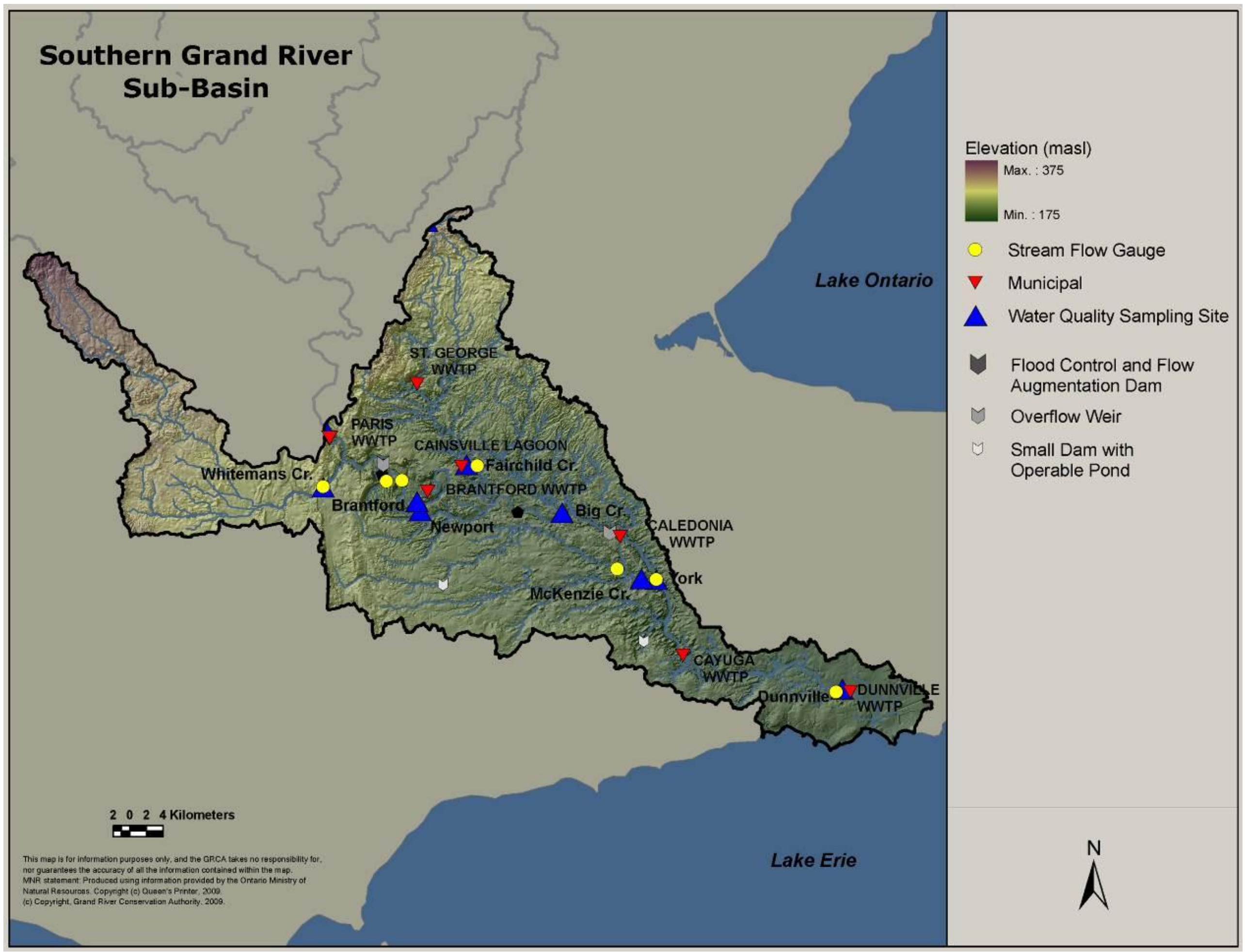

Figure 7-1: The water quality sampling sites, flow gauge locations, and point source inputs within the southern Grand River subbasin between 2003 and 2008.

Table 7-2: The river, site description, site number, and report short name for samples collected in the southern Grand River subbasin.

River	Site Description	Site number	Report Short Name
Grand	Cockshutts Bridge, Brantford	16018402702	Brantford
	Blossom Ave. Bridge, Newport	16018402402	Newport
	York Bridge	16018409202	York
	Bridge at Dunnville	16018403502	Dunnville
Whitemans Creek	First Conc. West of Hwy 24A	16018410602	Whiteman's Creek
Fairchild Creek	First Conc. d/s St. George	16018404402	n/a
	Lot G, South of Hamilton Rd.	16018409302	Fairchild Creek
McKenzie Creek	First Conc. East of Hwy 6	16018409602	n/a
	at River Rd upstream of Grand River confluence	16018412902	McKenzie Creek
Boston Creek	First Conc. East of Hwy 6	16018409502	n/a
Big Creek	at Highway 54	16018412802	Big Creek

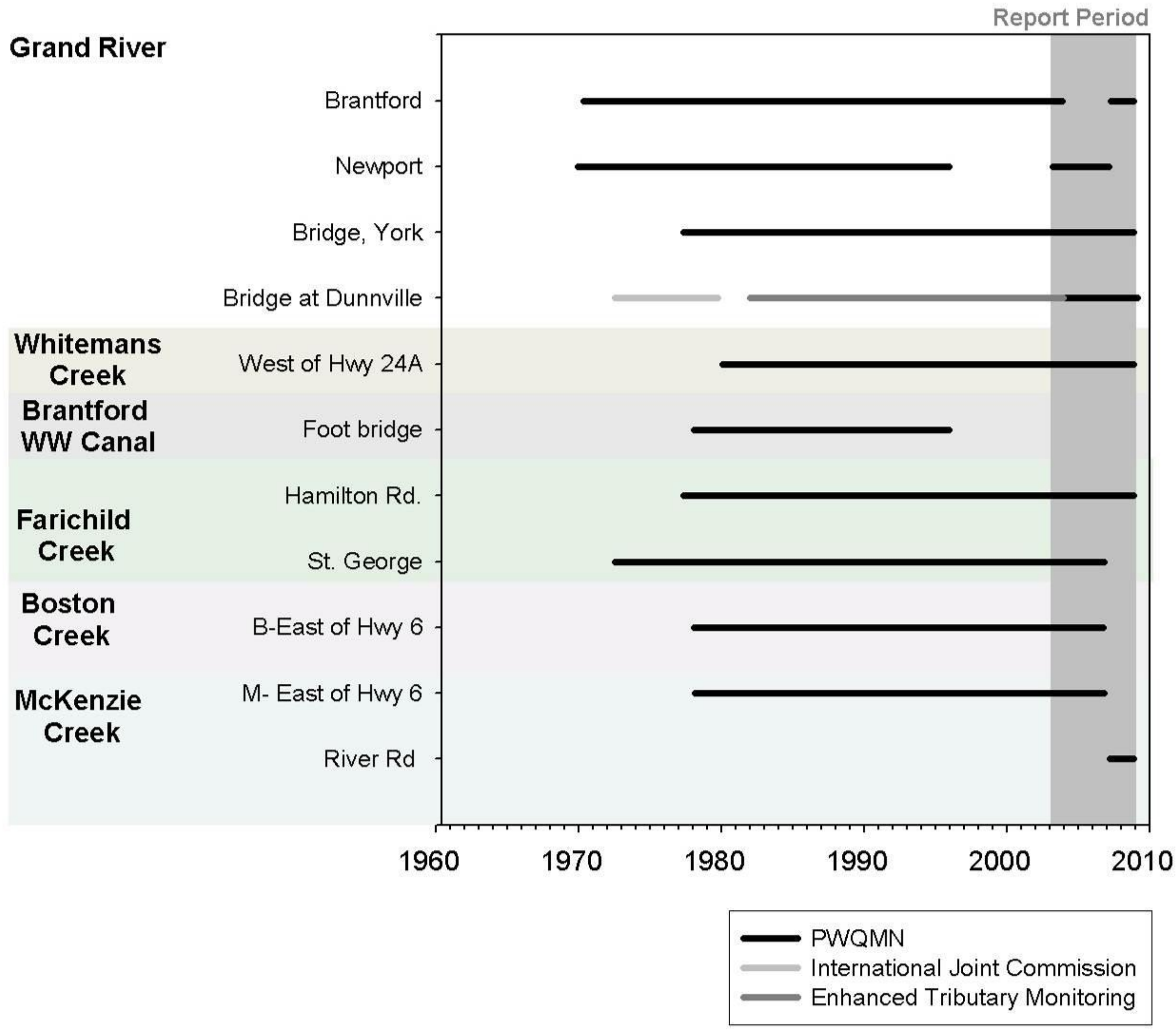

Figure 7-2: Sampling record for the Provincial Water Quality Monitoring Network, Ministry of the Environment (International Joint Commission) and Enhanced Tributary monitoring sites in the southern Grand River subbasin.

Results

Dataset Description

The seasonal distribution of samples collected in the southern Grand River subbasin showed a similar dataset across sites. Datasets were more heavily weighted toward the summer and spring conditions, although winter and fall conditions were also captured at some sites (Table 7-3).

Table 7-3: Seasonal composition of water quality data in the Southern Grand River subbasin.

Site	% of Samples Collected			
	Winter	Spring	Summer	Fall
Whiteman's Creek	7.7	30.8	48.1	13.5
Brantford	4.0	28.0	52.0	16.0
Newport	14.3	28.6	46.4	10.7
Fairchild Creek	4.1	30.6	51.0	14.3
Big Creek	6.3	31.3	50.0	12.5
York	10.6	31.9	42.6	14.9
Mackenzie Creek	5.3	36.8	42.1	15.8
Dunnville Bridge	16.7	29.2	36.5	17.7

The sampled flow and temperature were not significantly different between sites nor across sites (p = 0.9112 & 0.0028, respectively). The range of flow and temperature sampled between 2003 and 2008 was well captured across most sites. At Whiteman's Creek and the Grand River at Newport the range in flow sampled was less than at other sites.

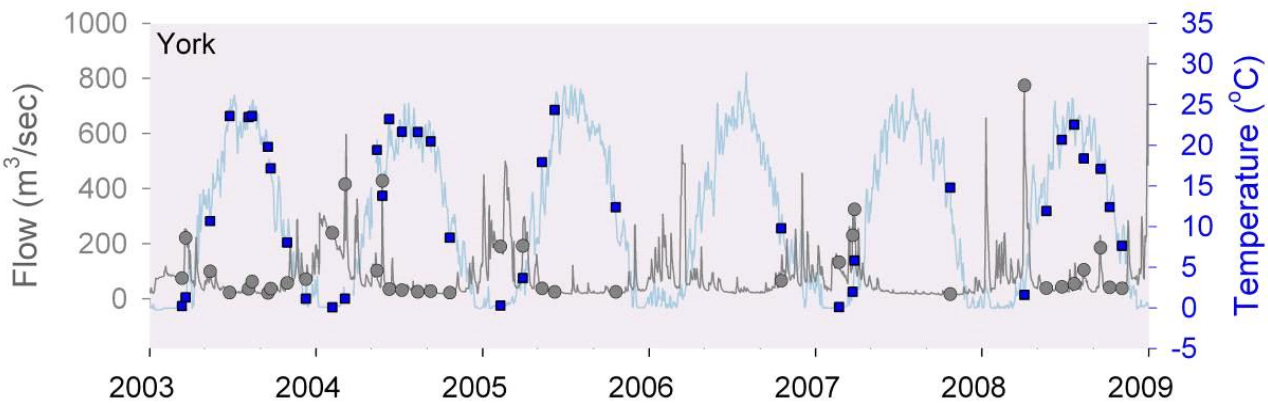

Figure 7-3: Daily average flow (grey line) and temperature (blue boxes) sampled at York relative to the timeseries of the Brantford flow gauge and Bridgeport temperature site between 2003 and 2008..

The datasets for sites in the southern Grand River subbasin appear relatively similar and characterize environmental conditions reasonably well although slightly biased toward summer and spring conditions (Figure 7-3, Table 7-4).

Table 7-4: The percent of the flow and temperature record sampled at each site in the Southern Grand River subbasin

Site	% Sampled	
	Flow	Temp
Whiteman's Creek	47	83
Brantford	87	76
Newport	47	88
Fairchild Creek	87	80
Big Creek	87	72
York	87	83
McKenzie Creek	87	72
Dunnville Bridge	77	94

Summer Water Temperature

Summer temperatures in the southern Grand River subbasin were within the range required for a cold water fishery in Whiteman's Creek (Figure 7-4). Temperatures within the other tributaries fell into a warmer temperature classification, although they were not significantly different from Whiteman's Creek (p = 0.8479 – 10.5982). Whiteman Creek was significantly cooler than the Grand River at Newport, York, and Dunnville (p < 0.0001 - < 0.001).

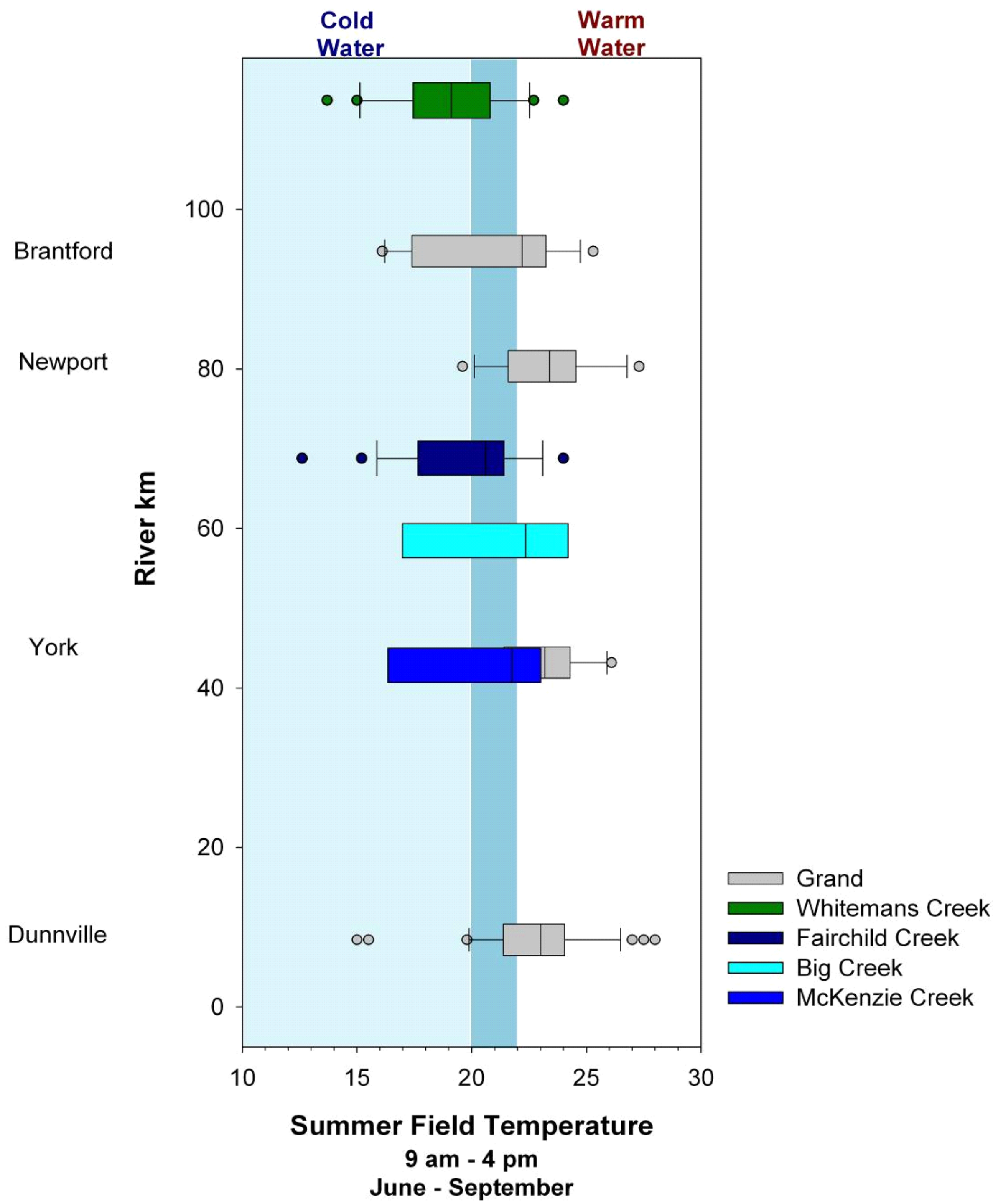

Figure 7-4: Box and whisker plots illustrating the range of summer (June – September) daytime (9 am - 4 pm) field temperatures in the Southern Grand River subbasin

Chloride

Chloride concentration in this subbasin is summarized in Chapter 8 and Figure 8-1.

Total Nitrate

Total nitrate concentrations exceeded the objective in approximately 50% of the samples. Concentrations were not significantly different between the Grand River sites (p = 0.7585 – 17.3794, Figure 7-5). Fairchild Creek, Big Creek, and Mackenzie Creek showed concentrations below the water quality objective and were not significantly different from each other (p = 0.3053 – 11.8255), although they were different from the Grand River and Whiteman's Creek sites (p < 0.0001 – < 0.01). Whiteman's Creek had the highest total nitrate concentrations and were significantly higher than at all Grand River sites (p < 0.0001 - < 0.05) except Newport (p = 1.7758).

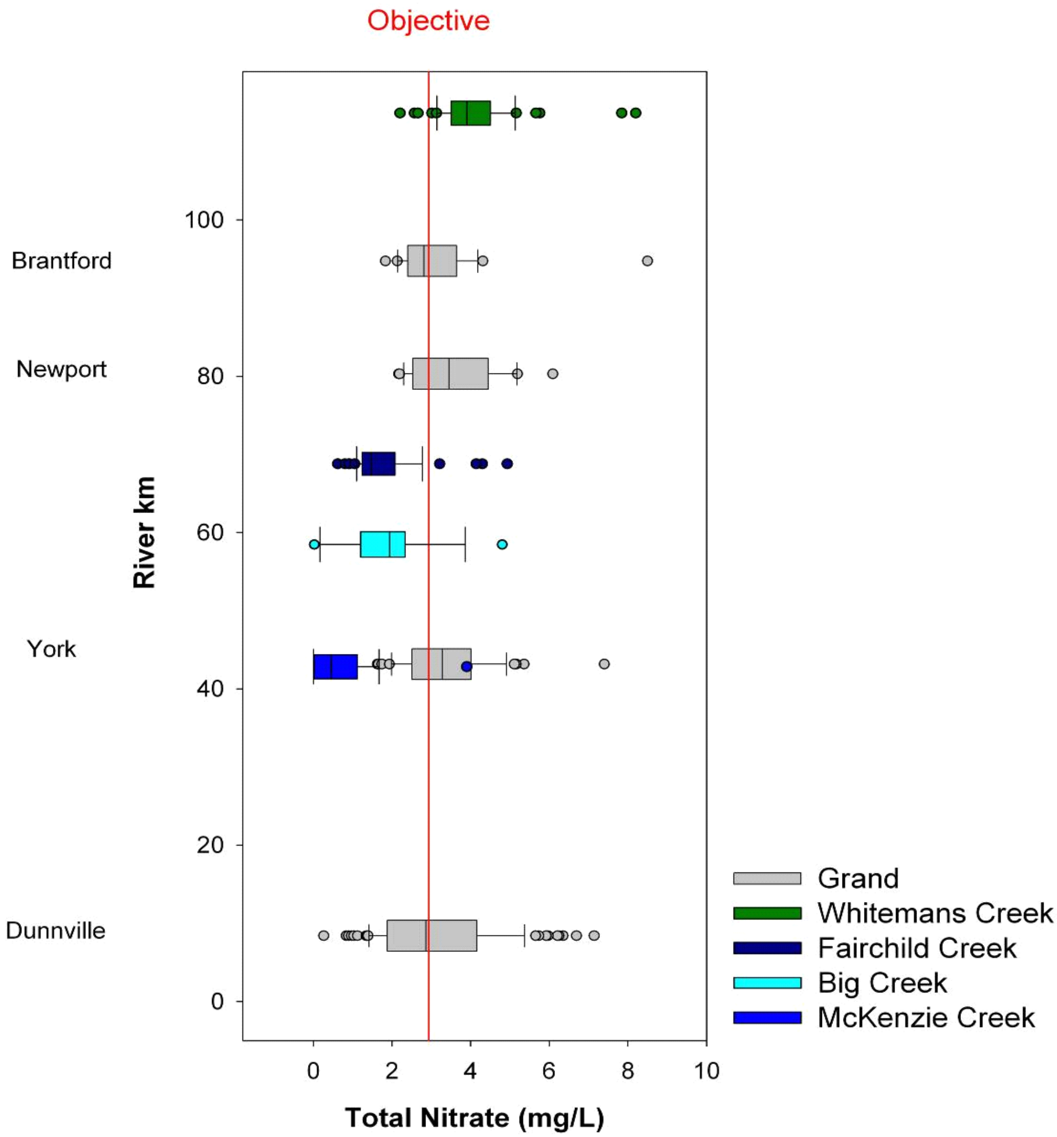

Figure 7-5: Box and whisker plots illustrating the range of summer (June – September) total nitrate concentrations in the southern Grand River subbasin.

Positive correlations between total nitrate concentrations and flow (p < 0.0001 – < 0.01) and negative correlations between total nitrate concentrations and temperatures (p < 0.0001) were observed in the Grand River sites (Figure 7-6). No significant correlations with flow and temperature were observed in Whitemans Creek (p = 0.3558 & 0.0839, respectively).

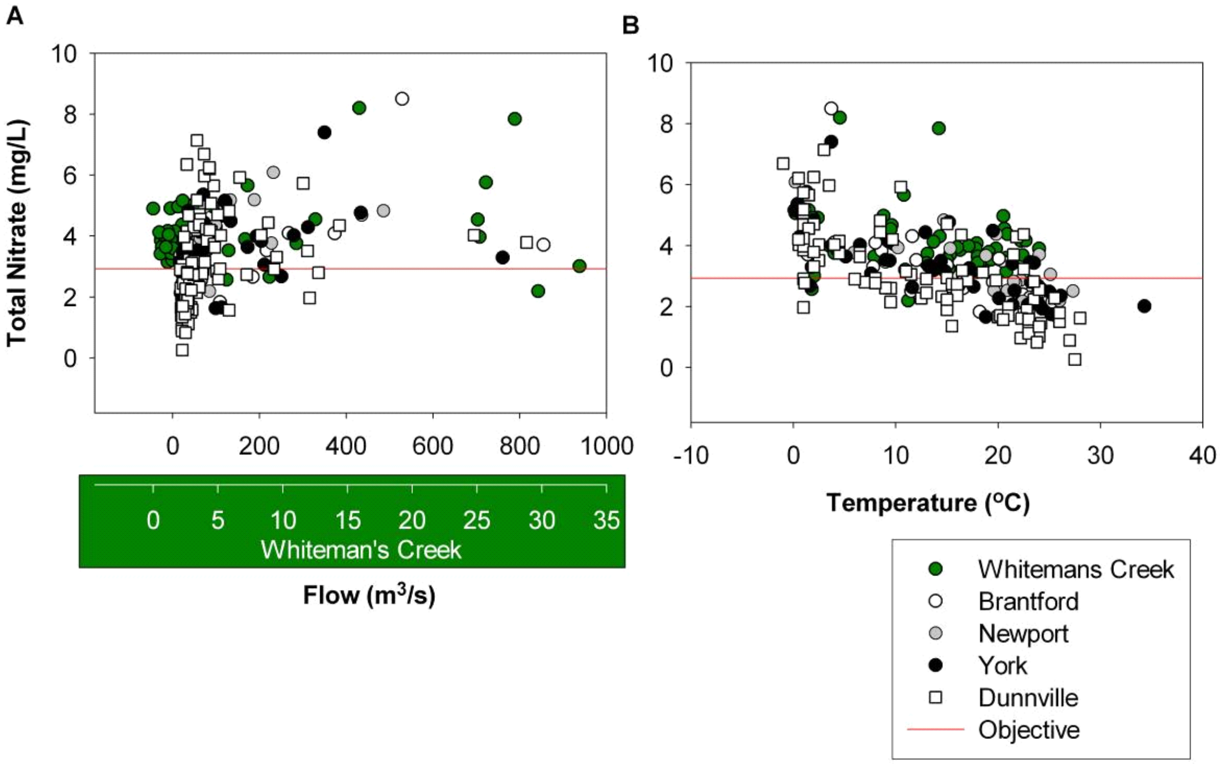

Figure 7-6: Total nitrate concentrations in the Grand River and Whiteman's Creek relative to sampled flow (A) & field temperature (B)

Total Phosphorus

Total phosphorus concentrations exceeded the water quality objective in approximately 95% of the samples at all sites except Whiteman's Creek, where concentrations exceeded the objective in only 50% of the samples (Figure 7-7). Concentrations tended to be higher in Fairchild Creek and were significantly higher than in Whiteman's Creek ($p < 0.0001$) and at Brantford ($p < 0.05$), Newport ($p < 0.0001$), and York ($p < 0.05$) on the Grand River.

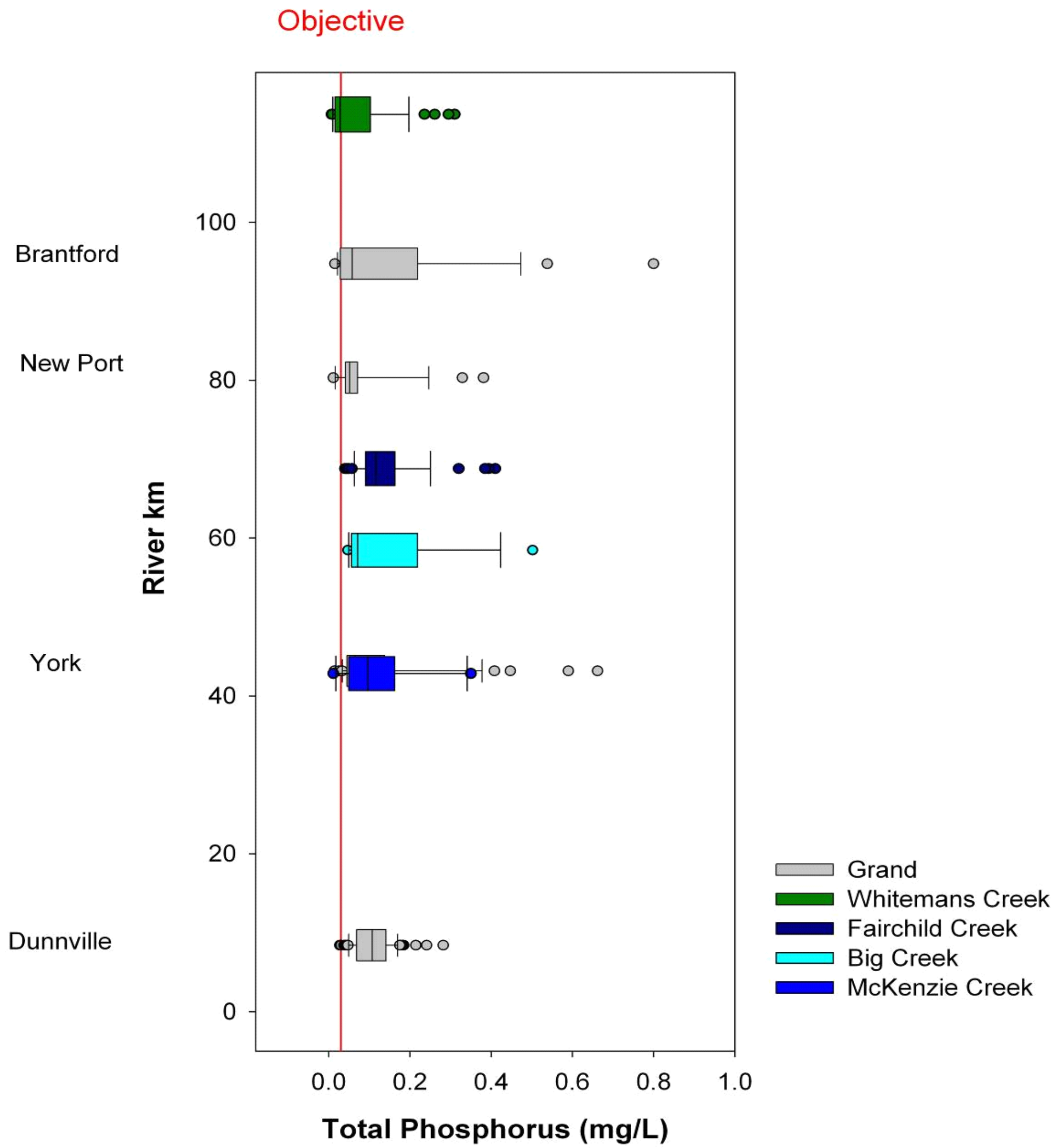

Figure 7-7: Box and whisker plots illustrating the range of summer (June-September) total phosphorus concentrations at water quality monitoring sites in the southern Grand River subbasin.

Total phosphorus was positively correlated with sampled flows at Brantford ($p < 0.0001$), Newport ($p < 0.01$), and York ($p < 0.0001$) on the Grand River (Figure 7-8). Total phosphorus was not correlated with sampled temperature at these sites (p = 0.1609, 0.7228, & 0.4045, respectively). At Dunnville, total phosphorus was not correlated with flows ($p = 0.6947$) but with temperature ($p < 0.0001$). In contrast, total phosphorus concentrations in the tributaries of the southern Grand River subbasin were positively correlated with flow but not with temperature (p = 0.1497 - 0.8683, Figure 7-9).

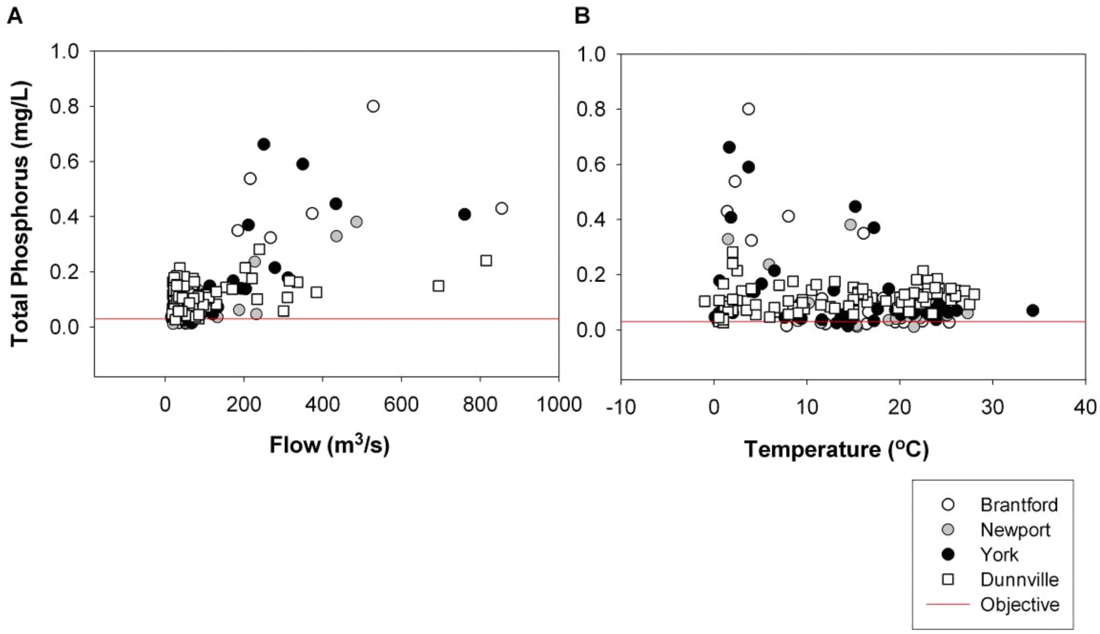

Figure 7-8: Total phosphorus concentrations in the southern Grand River subbasin relative to sampled flow (A) and field temperature (B).

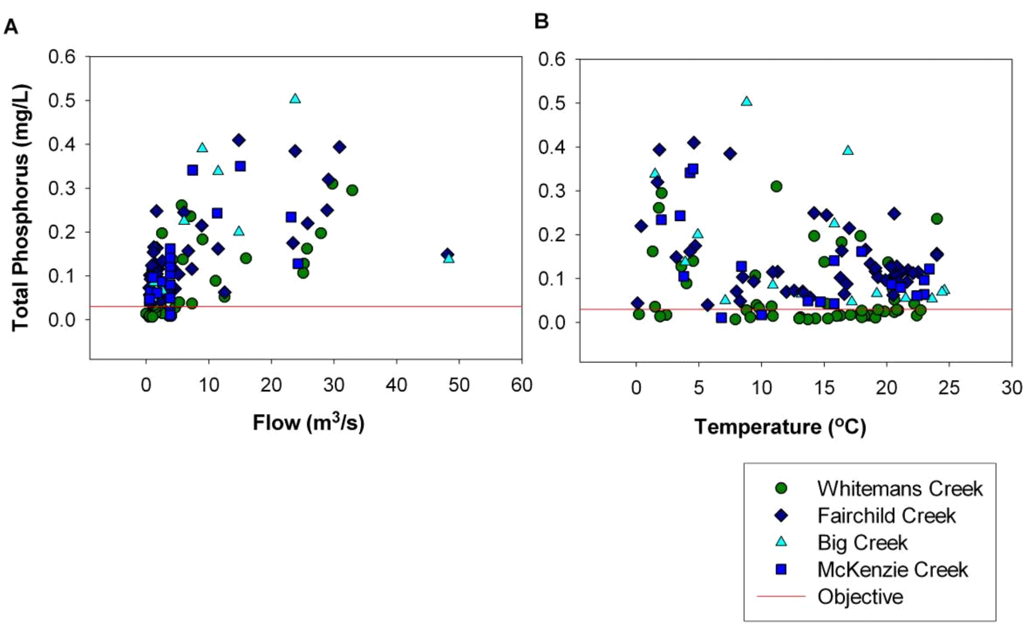

Figure 7-9: Total phosphorus in major tributaries in the southern Grand River subbasin relative to sampled flow (A) and field temperature (B).

Suspended Sediments

Total suspended sediment concentrations increase as the Grand River flows from Brantford to Dunnville. Concentrations tended to be highest in Fairchild Creek and were significantly higher than in Whiteman's Creek ($p < 0.0001$) and at Brantford ($p < 0.05$), Newport ($p < 0.0001$), and York ($p < 0.05$) on the Grand River.

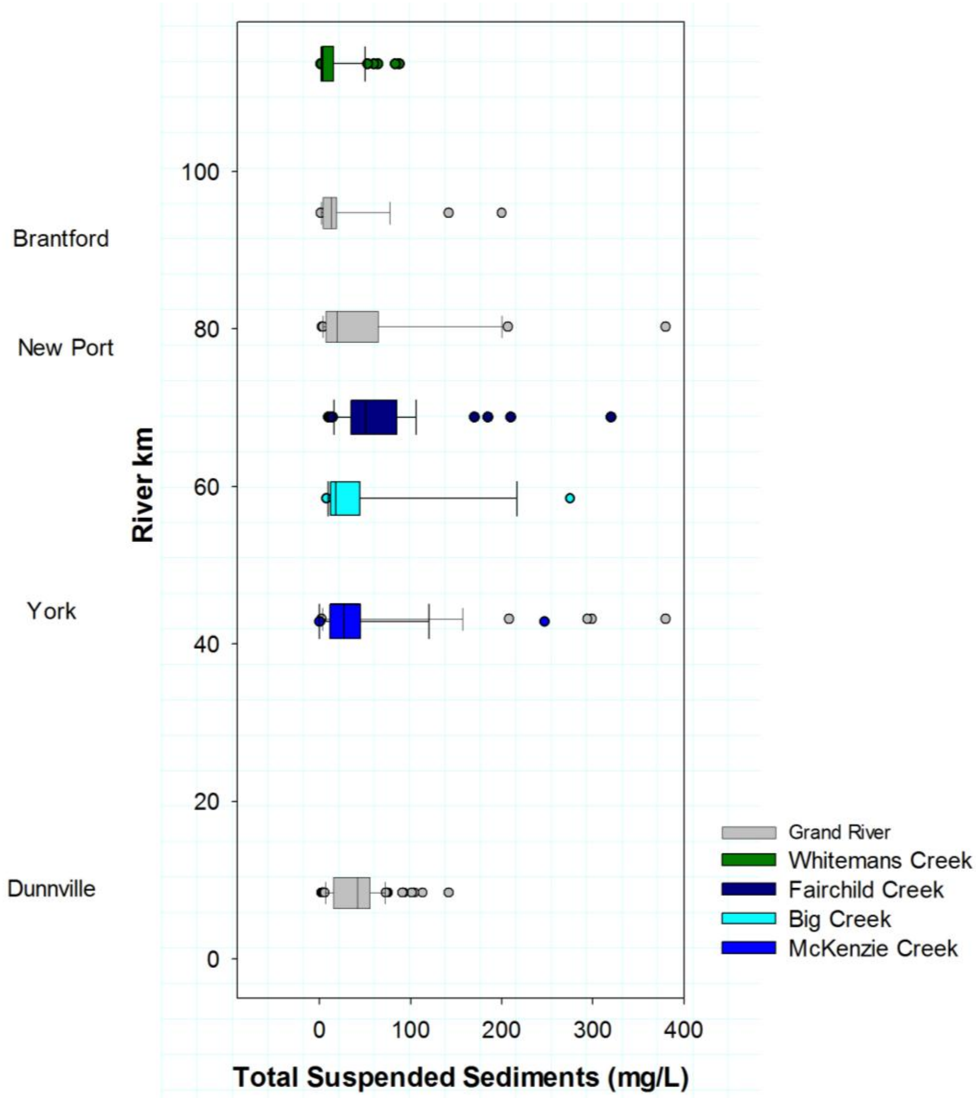

Figure 7- 10. Box and whisker plots illustrating the range of summer (June-September) total suspended sediment concentrations at water quality monitoring sites in the southern Grand River subbasin.

Relationships between variables

Total phosphorus was positively correlated with suspended solids across all Grand River sites ($p < 0.0001 – < 0.01$) ($p < 0.01$, Figure 7-10) and tributary sites ($p < 0.0001$, Figure 7-11).

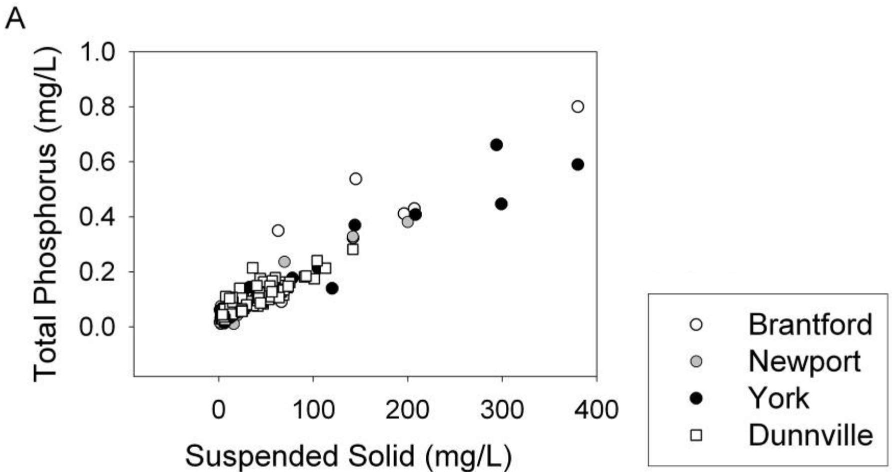

Figure 7-10: Total phosphorus concentrations relative to suspended solids concentrations at Grand River sites in the southern Grand River subbasin.

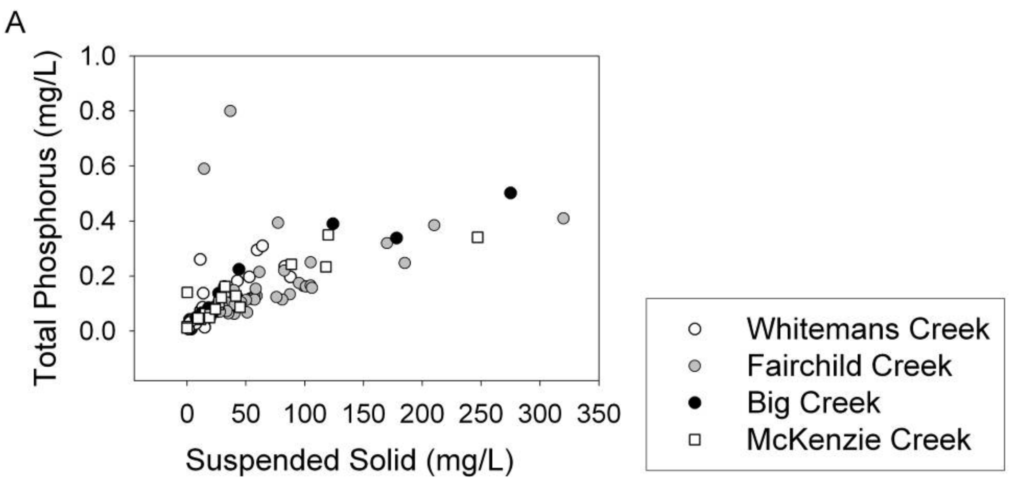

Figure 7-11: Total phosphorus concentrations relative to suspended solids concentrations at tributary sites in the southern Grand River subbasin.

Seasonal trends on nutrient discharge to Lake Erie

Total nitrate concentrations were lowest during the summer months, but increased in late fall, winter, and spring (Figure 7-12). Loading rates were less variable but included elevated loads throughout the winter and during the spring melt, in March and April. Total phosphorus concentrations are higher between April and September relative to the cooler months (Figure 7-13). The highest total phosphorus loading rates were observed during the spring melt in March and April.

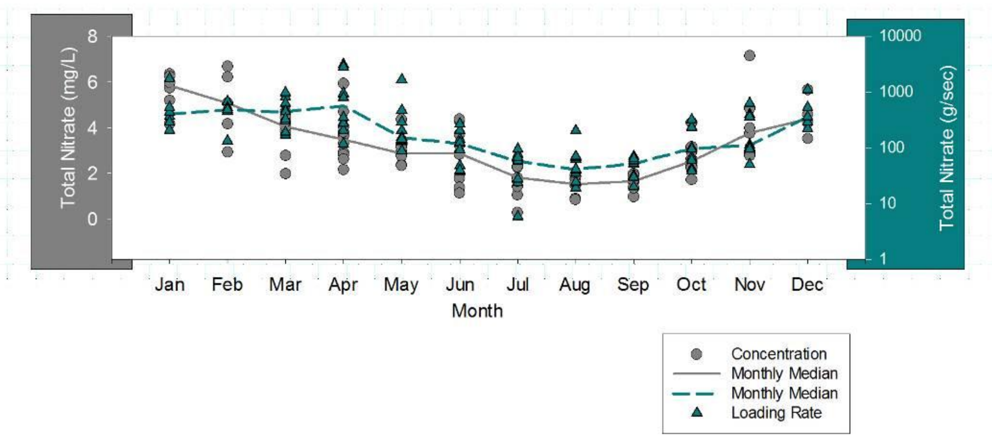

Figure 7-12: Monthly total nitrate concentrations and loading rates at Dunnville, 2003-2008.

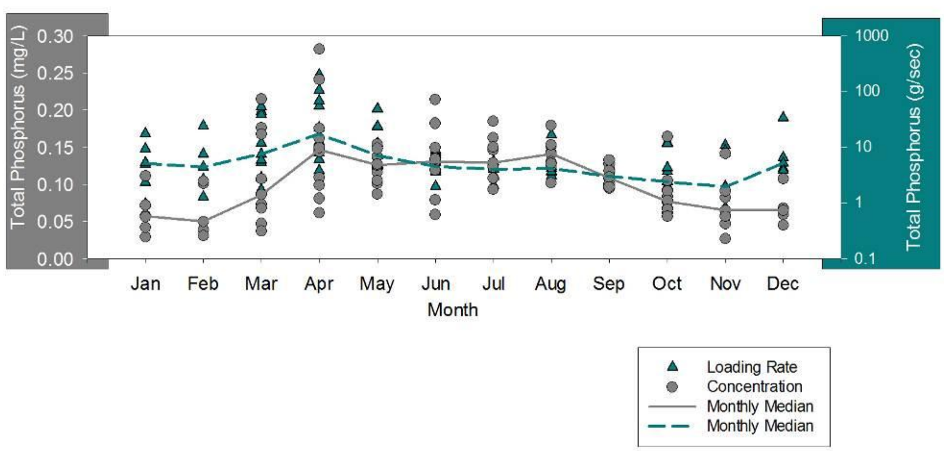

Figure 7-13: Monthly total phosphorus concentrations and loading rates at Dunnville, 2003-2008.

Discussion

High nutrient (phosphorus and nitrogen) concentrations are the major water quality concerns for all sites in the southern Grand River subbasin. Concentrations total phosphorus in the southern

Grand River tended to be some of the highest found within the entire watershed. Seasonal trends in total nitrate and total phosphorus in the southern Grand River region are similar to those observed upstream in the central Grand River, the Conestogo River, and the Nith River subbasins. The high total suspended sediment concentrations found in the southern Grand River are likely a result of the inherent geology of the region.

While total phosphorus concentrations showed similar trends in the tributaries, nitrate concentrations in Whiteman's Creek were distinctly different. The shallow groundwater of the Norfolk sand plain likely influences and contributes to the elevated nitrate levels seen in Whiteman's Creek.

Studies hypothesized that nutrient cycling may be different between York and Dunnville compared to upstream sites given the lake-like nature of this reach of the Grand River ((Cooke 2004); (Kuntz 2008)). In this assessment, distinct trends in the nutrient loading, concentrations, and proportions at Dunnville were observed relative to the other upstream sites (York, Brantford, and Glen Morris). Further study is required to fully understand the in-river nutrient cycling and total loading to and effects on Lake Erie. Clarification of this issue may be important for future management of the river and discharge into Lake Erie.

With two drinking water intakes in the southern Grand River, the elevated nitrate concentrations in the Grand River require attention. While the highest concentrations do not reach the drinking water objective, previous assessment of long term trends indicates a slight increasing trend in nitrate concentrations over time at the Brantford site (Cooke 2006). Continued monitoring is recommended to track trends over time. Effort should be made to reduce nitrate levels in the Grand River and its tributaries.

Conclusions & Recommendations

- The current dataset is biased toward summer and spring sampling with the exception of the Dunnville site where there is more effort given to sampling year-round. To fully characterize seasonal differences in water quality, it is recommended that additional sampling be completed through the fall, winter and early spring time periods.

- Elevated nitrates and total phosphorus concentrations are the major water quality concern in the southern Grand River subbasin

- Total phosphorus levels in the Grand River at Dunnville far exceed the provincial objective of 0.030 mg/L; tend to be highly correlated with total suspended sediments and generally are highest during significant runoff events (e.g. spring runoff).

- Total phosphorus concentrations are similar in concentration and variation across tributaries, except total nitrate concentrations are significantly higher in Whiteman's Creek.

- Continued long-term monitoring of nitrate is recommended in the vicinity of the drinking water intakes.

8. Water Quality: Watershed Trends

Introduction

The water quality in the Grand River and its tributaries are not only important to local residents but is also important to those living downstream. Generally, the water quality in the southern Grand River and its' discharge to Lake Erie is heavily influenced by the cumulative upstream inputs (chapter 7) and generally supports the observation by Alexander et al. (Alexander, Boyer et al. 2007) that headwater areas have a profound influence on downstream water quality.

The Grand River also has a strong influence on the eastern basin of Lake Erie and the nearshore region where the plume of the river can be tracked along either the western or eastern shoreline depending on prevailing currents and extends a distance out into the eastern basin (T. Howell, Ministry of the Environment, pers. com.).

In this chapter, longitudinal water quality trends in the Grand River are summarized based on Chapters 2 to 7 of the individual subbasins. In particular, the following sections are presented:

1. The progression of concentration and loading of chloride and nutrients in the Grand River from the headwaters to the mouth;
2. Relationships of nutrients with temperature and suspended solids; and
3. Overall summary of water quality using the Nutrient Water Quality Index

Longitudinal Trends in River Water Quality

Chloride

Chloride concentrations in the headwater region of the Grand River increase marginally from Leggatt to Bridgeport. Once the river flows through the major urban area of the Region of Waterloo and receives the flows from the Speed River which is strongly influenced by the cities of Guelph and Hespeler, chloride concentrations increase dramatically and concentrations peak at Glen Morris. Levels remain high until the Grand River flows through Dunnville.

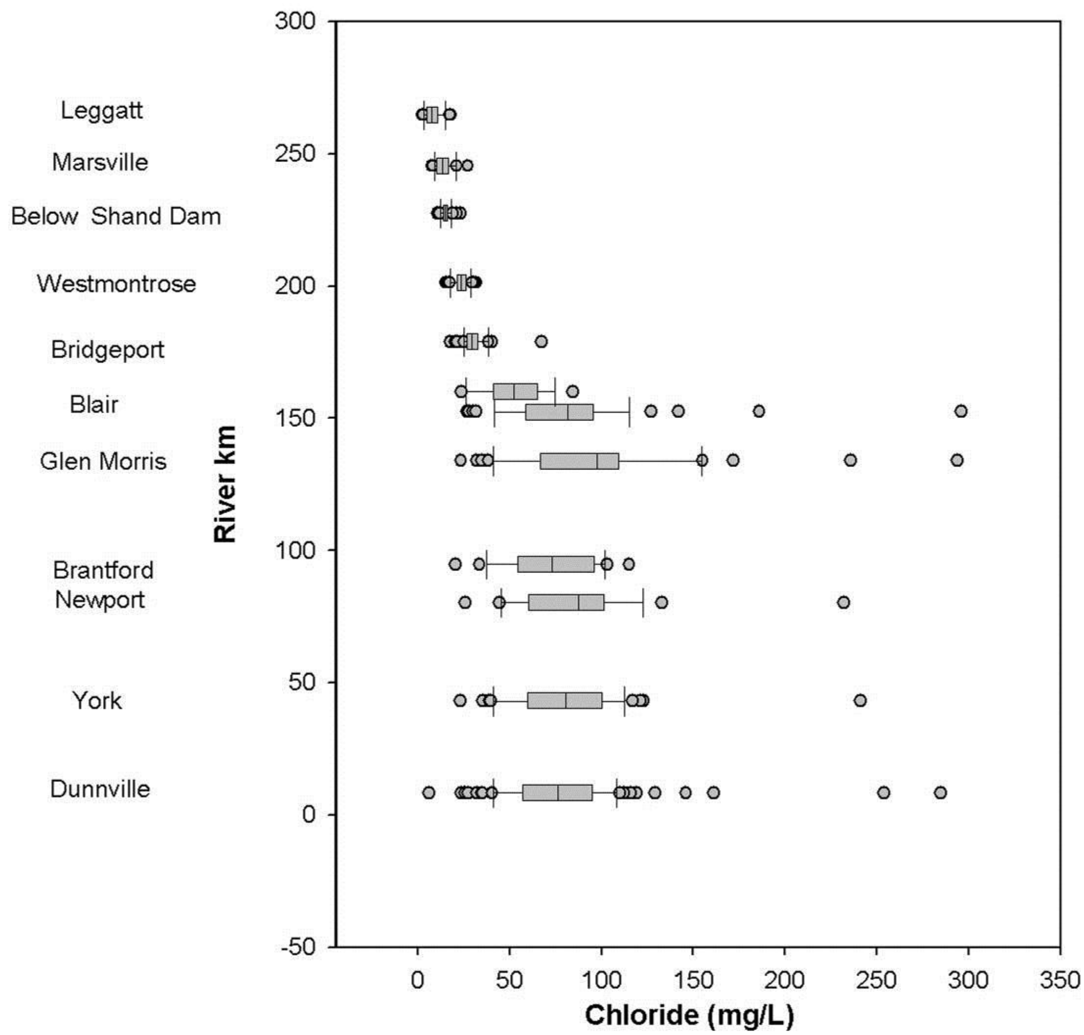

Figure 8-1: Box and whisker plots illustrating the range of chloride concentrations at sampling sites along the Grand River from the headwaters near Leggatt to Dunnville, near the mouth (2003-2008).

Total Nitrate

Total nitrate concentrations increase quite rapidly as the Grand River flows from the Shand Dam to Bridgeport. They peak at Blair, where they level off and remain high until the Grand River flows to Dunnville (Figure 8-2).

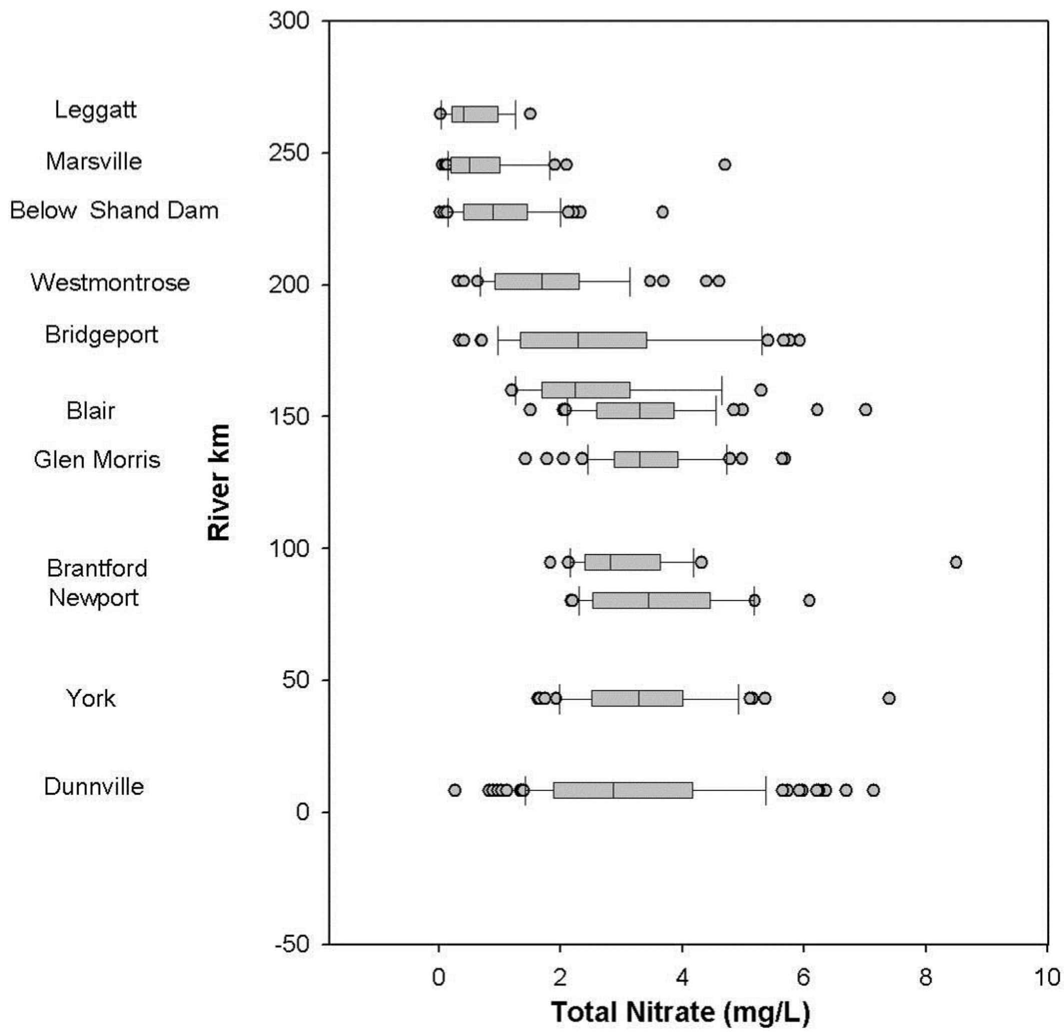

Figure 8-2: Box and whisker plots illustrating the range of total nitrate concentrations at sampling sites along the Grand River from the headwaters near Leggatt to Dunnville, near the mouth (2003-2008).

Total Phosphorus

Total phosphorus concentrations increase downstream (Figure 8-3). Total phosphorus concentrations at Dunnville tend to be less variable compared to upstream sites such as York or Brantford which may be a result of increased sampling effort at the Dunnville site by the Ministry of the Environment.

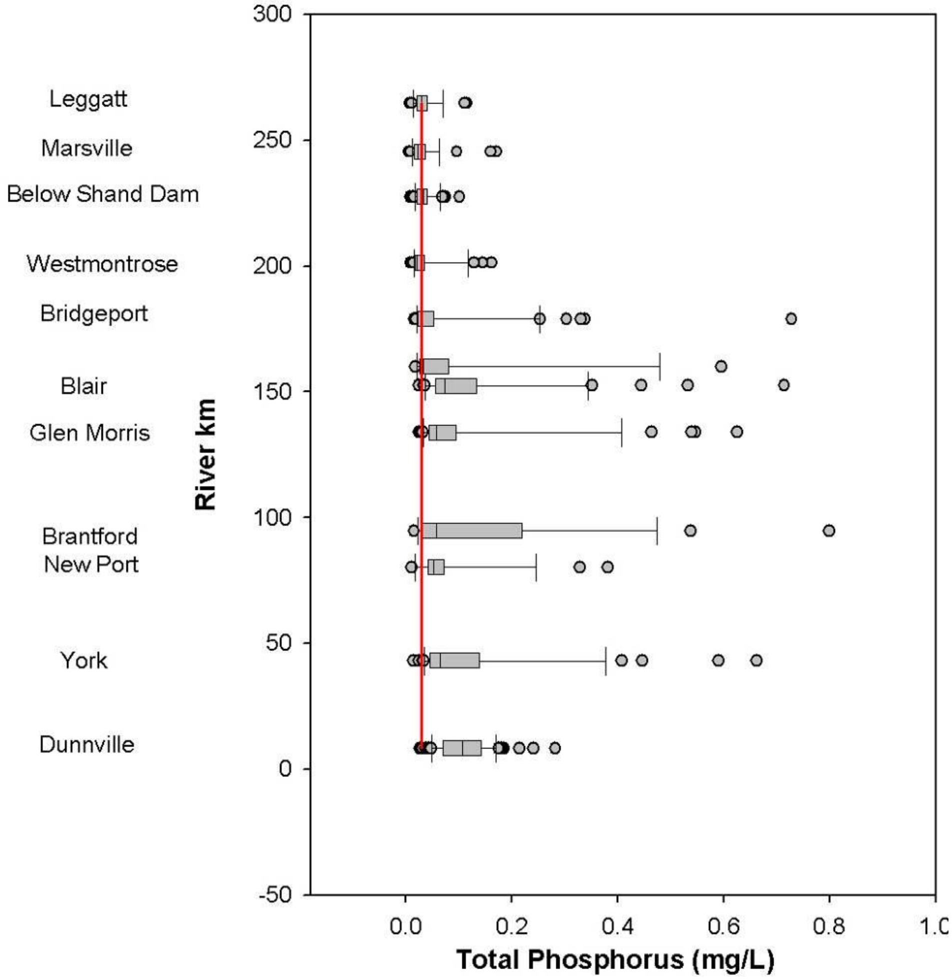

Figure 8-3: Box and whisker plots illustrating the range of total phosphorus concentrations at sampling sites along the Grand River from the headwaters near Leggatt to Dunnville (2003-2008).

To explore the proportion of phosphorus that is more biologically available, phosphate concentrations (as measured as soluble reactive phosphorus) were compared to the 'residual' phosphorus (total phosphorus – soluble reactive phosphorus) levels to evaluate whether there was a difference in phosphorus dynamics along the Grand River. In general, the proportion of phosphate at all sites was highest in the late fall, winter, and early spring (when sampling occurred) but lowest during the summer, which coincides with the time aquatic plant growth predominates (Figure 8-4). Interestingly, however, was the gradual predominance of phosphate relative to the residual phosphorus pool during the fall and winter months at sites further downstream relative to upstream sites. A more in-depth description of phosphorus delivery in the Grand River watershed is summarized in Appendix B.

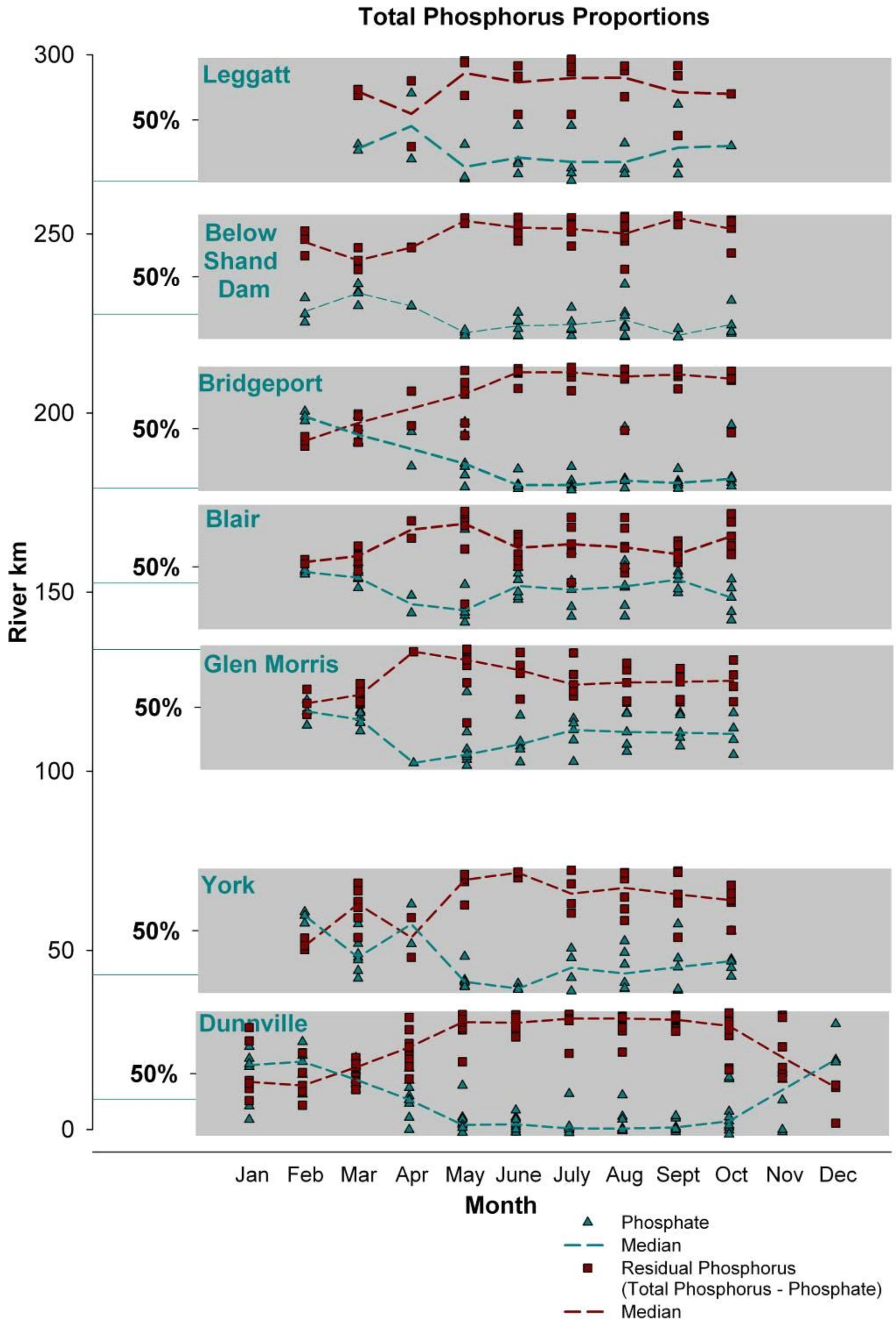

Figure 8-4: Percentage of phosphate, as measured as soluble reactive phosphorus, and residual phosphorus at seven sampling sites along the Grand River.

Using a Water Quality Index for Reporting on the State of Water Quality

The Canadian Council for Environment Minister's Water Quality Index (WQI) is a communications tool to provide consistent procedures for Canadian jurisdictions to report on water quality information (CCME 2001). The WQI compares observed water quality of various input parameters with defined objectives or benchmarks and generates a single summarized 'score'. This approach allows for a relative comparison within a watershed or area of study. Sites within a watershed can be ranked according to this score and spatial trends in water quality can be described. Temporal changes in water quality can be summarized by comparing the time periods used to calculate the index. Specific water quality categories (e.g. Nutrient Index) can be summarized and test parameters can be defined by the user.

The predominant water quality concern in the Grand River is nutrients. High levels of phosphorus and nitrogen cause concern with respect to the health of the aquatic system but also for municipal surface water supplies. Consequently, a 'Grand River Specific Nutrient Water Quality Index' was developed for the Grand River to illustrate relative differences among sampling sites. Given that the index was scoped to only include nutrients, the index metric was modified so that only the F2 (Frequency of excursions from benchmark) and F3 (Amplitude of the excursion) factors of the index formula. This was done as the F1 factor (Scope – number of variables whose benchmarks are not met) would routinely saturate (i.e. all five variables would exceed benchmarks) and mask the relative differences among sampling sites. The formula used for the modified WQI for nutrients is shown in Table 8-1.

The Grand River-specific Nutrient WQI has been effectively used to summarize the relative differences in water quality among sites in the watershed and is the communication tool used to report on water quality to the Grand River Conservation Authority Board (Cooke 2006). That study also determined that metals did not appear to be a water quality concern in the Grand River watershed. Therefore, the index is computed only for nutrients to cover the study period of 2003 – 2008.

For comparison with the Grand River-specific WQI, the CCME-Index was calculated as well. This CCME Index was based on the same province- and country-wide water quality objectives as were used for the assessment of each subbasin in this report. The scores from these two indices were highly linearly correlated (Figure 8-5). Values calculated by the CCME-Index are approximately 10 units lower on average than the GR-specific index as indicated by the regression equation. As a result, fewer sites are separated into different water quality categories and most sites fall into the poor or marginal category. Although the CCME-index therefore provides a more consistent approach across jurisdictions, the Grand River-specific WQI provides a better way to communicate water quality across the watershed, because it allows for higher resolution and differentiation. Both indices were calculated for the whole data set without special attention to seasonal distributions.

Table 8-1: A summary of the two water quality indexes calculated in the Grand River Watershed

Water Quality Index	Water Quality Variable	Criteria (mg/L)	Index Equation
Nutrient Objective Specific Index *uses provincial and federal water quality objectives*	Un-ionized Ammonia	0.0165	$= 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right)$
	Total nitrate	2.93	
	Nitrite	0.06	
	Total Phosphorus	0.030	
Grand River Specific Nutrient Index *comparable with 2000-2004 index result* *uses 1978-82 water quality benchmarks*	Total Ammonia	0.0435	$= 100 - \left(\frac{\sqrt{F_2^2 + F_3^2}}{1.414} \right)$
	Total nitrate	2.043	
	Total Kjeldahl Nitrogen	0.78	
	Total Phosphorus	0.078	
	Phosphate	0.021	

Note: Scores range between 0-100, with 0 representing poor and 100 ideal water quality.
F1 – Scope, i.e., number of variables whose benchmarks are not met
F2 - Frequency of excursions from benchmark
F3 - Amplitude of the excursion

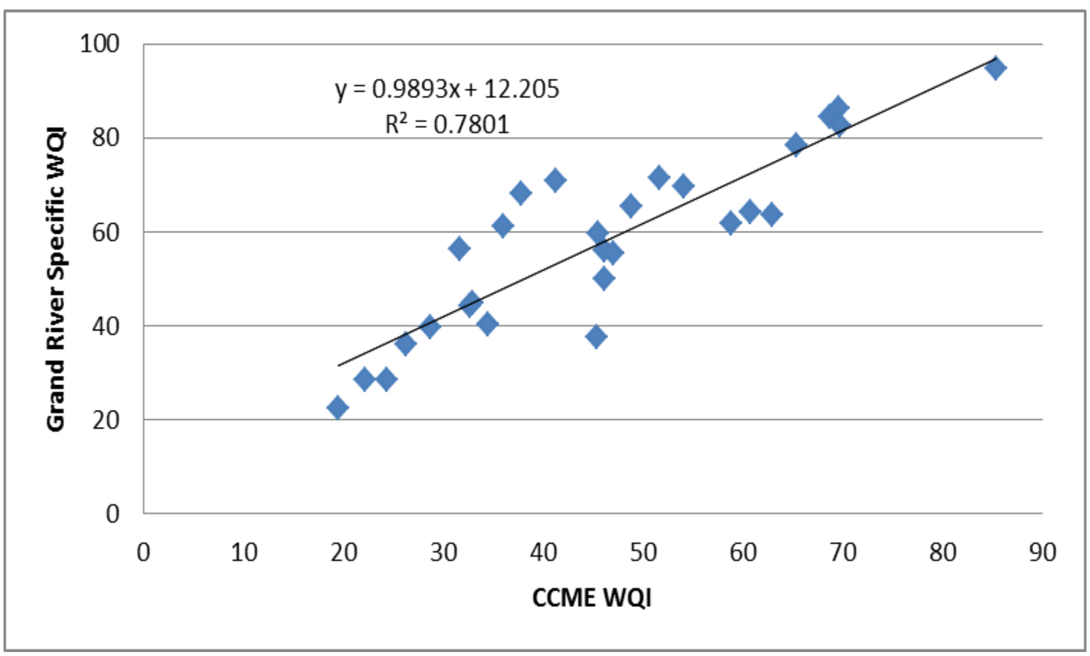

Figure 8-5: The relationship between the Grand-River specific WQI using benchmarks specific to the Grand River and the CCME Nutrient WQI using provincial objectives.

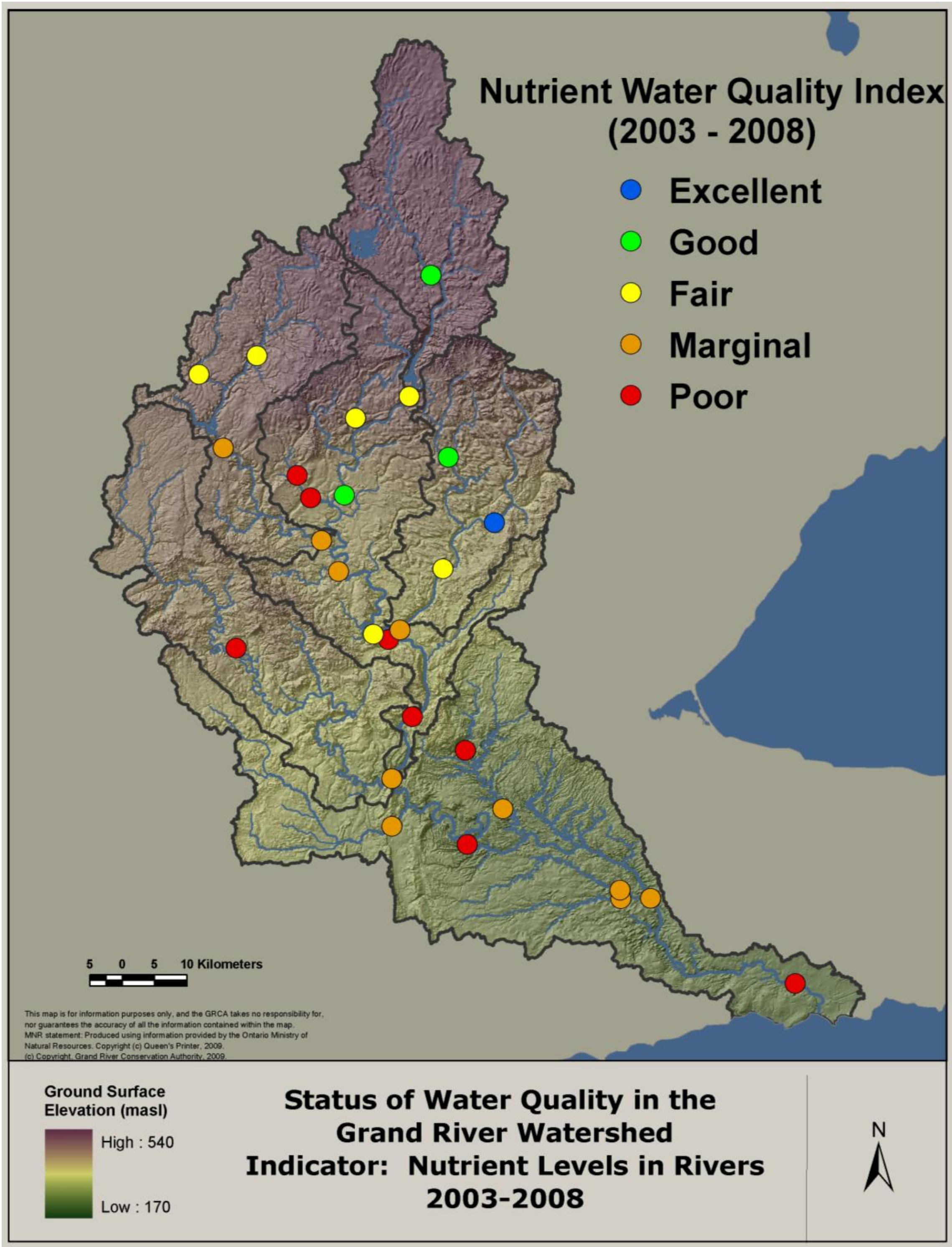

Figure 8-6: The Grand River specific WQI for Nutrients for data between 2003-2008.

To provide a relative ranking of the GR-specific nutrient index scores calculated for each site within the watershed, scores were grouped into categories based on those derived by CCME (2001) (e.g. excellent, good, fair, marginal & poor). However, due to the nature of the index it is not possible to determine if a calculated score is as a result of one very high excursion or frequent small excursions away from the benchmark. Therefore, it is always recommended to only apply the index after a full exploration of the data (see chapters 2-7) to fully understand what is driving the results. For example, high levels of phosphorus are the driver behind the poor score in the upper Nith River watershed while the marginal score in Whiteman's creek is driven by very high nitrate levels.

The sites within each of the categories for the GR-specific nutrient water quality index for 2003-2008 highlight the variability of the water quality across the watershed (Figure 8-6). In particular, it reveals poorer water quality in the western and lower reaches of the watershed which is consistent with the very high levels of both phosphorus and nitrogen seen at those sites. The poorer water quality corresponds with areas of high agricultural intensity in regions with high run-off volume, as well as below urban areas. Higher quality water scores are in the head water areas of the Speed / Eramosa Rivers and Upper Grand River subbasin.

Discussion

The Provincial Water Quality Monitoring Network is a vitally important long term water quality monitoring network for Ontario. It enables the evaluation of the state of the water quality for surface waters so that areas of concern can be identified and actions to improve water quality can be focused. However, financial cutbacks by the province over the last decade compromise the utility of the data. For example, estimating mass loads, completing thorough trend analysis and characterizing the full range of seasonal variability in chemical and physical water quality of streams and rivers in Ontario is significantly limited by the number of samples taken each year and the timing at which samples are taken. Nonetheless, the data provide a preliminary assessment of the conditions and trends that may be occurring in stream water quality.

Water quality in the Grand River watershed

Generally, nutrient concentrations in the Grand River tend to be high likely as a result of the underlying geology, intensive agricultural production and growing urban development in the watershed. Accordingly, the Grand River ranks third of 30 Ontario rivers with respect to total phosphorus concentration, after the Don and Thames Rivers (2001-2006, (Ministry of Environment 2009)). Chloride and nutrient concentrations are elevated throughout the watershed and increase downstream so that they are most elevated at Dunnville Dam, the last monitoring site before the Grand River discharges into Lake Erie.

The middle reach of the Grand River, including the major tributaries draining into this reach such as the Canagagigue Creek, Conestogo River and lower Speed River shows generally the lowest water quality. Land use including intensive agricultural production, urban development and wastewater treatment plant effluents in this area likely contribute to the degradation in water quality. In contrast, much of the nutrient enrichment and high suspended solid concentrations within the lower reaches of the Grand River are influenced by the cumulative impact from the upstream watershed and the underlying geology. Future stressors to the watershed (agricultural intensification, urban growth, and climate change) are unlikely to improve the current state. Maintenance and improvement of current watershed uses and values will require innovative approaches to manage river water quality.

By evaluating and inspecting the seasonal trends in nitrogen and phosphorus, the different sources (e.g. point and nonpoint sources) that influence their in-river concentrations can be identified (Bowes, Smith et al. 2008). Within this watershed, sites predominantly influenced by non-point source loading from agriculture (e.g., the Conestogo and Upper Nith River subbasins) were different from ones strongly influenced by point source inputs in urban areas (e.g., the central Grand River and Speed River subbasins). In particular, a correlation between total phosphorus and suspended solids, and decreasing trends of nitrate concentration between spring and fall indicate agricultural inputs. High nitrate concentration in the summer indicates WWTP effluents, while high ammonia and phosphate concentrations are indicative of an upstream reservoir outlet. Urban point sources are characterized by elevated chloride concentrations (e.g., downstream of Elmira or Guelph).

Loading and flow-adjusted concentrations

A more thorough and detailed loading analysis for all monitoring sites would indicate potential sources of nutrients and would help to identify areas for remediation. Such analysis of more than 20 sites of the neighbouring Upper Thames river quantified agricultural and WWTP phosphorus loads, and their response to the effect of climate, seasons, and helped identify long-term trends (Nürnberg and LaZerte 2005; Nürnberg and LaZerte 2006). In particular, flow-adjusted concentrations and total loads should be reported separately to provide a nutrient *fingerprint* along the Grand River and its tributaries. This analysis would involve the matching of daily flow estimates to daily estimated TP concentrations that are interpolated from the monthly samples at the water quality stations to arrive at daily loads. Summation of these daily estimates would yield monthly loads, from which annual and summer loads can be computed. These load estimates can be divided by the corresponding flows to arrive at annual and summer flow adjusted (volumetric) total phosphorous concentrations.

Impoundment effect

The effect of dams on river water quality can be pronounced (Thornton, Kimmel et al. 1990). Downstream monitoring sites exist at most of the reservoirs of the Grand River and its tributaries. Cursory inspection of the data presented in this report indicates that the water quality is commonly decreased down-stream of the dams. In particular, elevated total phosphorus, soluble reactive phosphorus (i.e. phosphate) and ammonia-nitrogen levels as well as low oxygen levels is apparent. Monitoring data of Belwood, Conestogo and Guelph reservoirs (Guildford 2006) confirm that the water bodies are thermally stratified in the summer and fall which creates oxygen depletion above the bottom sediment that subsequently releases phosphorus to the bottom waters of the reservoir. Because these reservoirs have bottom and mid-depth outlets, such accumulated substances are flushed downstream. Upon mixing events the internal phosphorus load fertilizes the photogenic zones leading to cyanobacterial or blue-green algae blooms in the reservoirs (Guildford 2006) and possibly the downstream river sections. Similarly, a study in the southern Grand River observed that algal biomass increase upon impounding and that sediment oxygen demand is high throughout the this reach (Kuntz 2008). Consequently, the effect of reservoirs can probably explain several of the water quality issues in the downstream river sections and should be evaluated in more detail.

Biological Assessment of Surface Waters

While the provincial water quality monitoring network allows for both temporal and spatial assessment of trends in water chemistry, the lack of watershed-scale monitoring of biological indicators such as benthic macroinvertebrates or fish communities limits the assessment in this report of the overall ecological state or health of the river system. In many cases, benthic macroinvertebrates are used to assess stream condition as they are seen as integrators of environmental condition as their lifecycles tend to be limited to a small geographical area (Borisko, Kilgore et al. 2006). Therefore, monitoring the biological communities and the application of biological indices can assist with establishing relationships between chemical water quality and biological conditions. Further, establishing relationships between biological and/or chemical indicators with key stressors, like land use, can help provide insight into what the appropriate thresholds or targets may be for improving aquatic health.

Recent biological assessment of ideal conditions in Ontario agricultural watersheds identified ideal performance standard (IPS) concentrations for total nitrogen, phosphorus, and suspended solids based on aquatic community indicators of watershed health (Chambers, Guy et al. 2009; Culp, Benoy et al. 2009). IPS concentrations for agricultural watersheds proposed by Chambers *et al.* are lower than the current benchmarks used in this report for evaluating the state of water quality (Table 1-4). Concentrations of nitrogen and phosphorus found at most sampling sites draining agricultural areas in the Grand River watershed were well above the IPS concentrations proposed by the authors. Therefore, in the absence of biological monitoring data for the watershed, it is likely, based on the work completed by Chambers et al. (2009) that the aquatic health could be poor in many regions; however, monitoring and a more complete assessment of the aquatic communities is recommended to understand the aquatic health of the watershed.

Recommendations

To improve our understanding of the water quality conditions of the Grand River and its tributaries, the following recommendations are made:

Data analysis

1. A more in-depth analysis of the relationships between watershed stressors such as land use and water quality should be evaluated to better understand the mechanisms contributing to the improvement or degradation in water quality.

2. A more thorough and detailed loading analysis for all monitoring sites would indicate potential sources of nutrients and facilitate targeted remediation. Separate loads from point and nonpoint sources as well as reservoir outflows could be distinguished on a seasonal basis.

3. The influence of the Grand River on Lake Erie should be further investigated and nutrient export quantified.

4. A limnological investigation of all impoundments would provide improved information and guide management decisions with the goal to improve their water quality as well as their effect on downstream river reaches.

Sampling Regime

5. At a minimum, 12 samples per year should be taken at each long term monitoring site to characterize ambient water quality conditions throughout the year so that seasonal variability can be more adequately characterized.

6. Additional high flow sampling should be targeted during spring runoff and summer rainfall events. This will characterize the range of environmental conditions that exist in the watershed.

Monitoring

7. There is no long-term monitoring program focused on biological parameters in the Grand River watershed. Identify appropriate biological indicators and initiate biological monitoring that best integrates with the chemical and physical monitoring programs that best describes the health of the Grand River system.

8. Long-term monitoring is required for the multipurpose reservoirs. In particular, basic limnological characteristics and food web interactions of the main reservoirs should be determined, besides information on nutrients (nitrate, depth profiles of TP, phosphate), temperature and dissolved oxygen throughout the summer and algal biomass.

Reporting

9. Aside from nutrients, identify additional long-term indicators that can be used for progress measurement. Review monitoring activities so that these indicators will be collected annually.

10. Continue with annual high-level reporting of current conditions to report on progress to the Grand River Conservation Authority Board.

11. Every five years, prepare an in-depth technical report.

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Appendix A: Comparison of Analysis by Maxxam and MOE Laboratories

Differences between the laboratories of the Ontario MOE and the commercial lab, Maxxam, were assessed. Following analyses were conducted by both laboratories: chloride, ammonia, total Kjeldahl nitrogen, nitrite, total nitrates, total phosphorus, reactive phosphate, and total suspended solid or residual particulate.

Between 2006 and 2008, 27 samples were run in duplicate by the two laboratories and differences were assessed in three ways, by graphical presentation, paired T-tests, and linear regressions.

Table A-1: The location, date, and corresponding stream flow for sample pairs analyzed for dissolved nutrients, particulates, and chloride by Maxxam and MOE laboratories.

Sample #	Site	Date	Daily Average Flows at Brantford (m^3/sec)
1	16018410202	5-Sept-06	553.94
2	16018403902	5-Sept-06	553.94
3	16018410402	5-Sept-06	553.94
4	16018401602	5-Sept-06	553.94
5	16018402902	5-Sept-06	553.94
6	16018411702	6-Sept-06	547.68
7	16018401202	6-Sept-06	547.68
8	16018400902	6-Sept-06	547.68
9	16018410602	6-Sept-06	547.68
10	16018409302	6-Sept-06	547.68
11	16018409202	6-Sept-06	547.68
12	16018403002	1-Apr-08	6593.81
13	16018401202	1-Apr-08	6593.81
14	16018401202	3-Apr-08	18585.66
15	16018401502	1-Apr-08	6593.81
16	16018401502	3-Apr-08	18585.66
17	16018403302	1-Apr-08	6593.81
18	16018403202	1-Apr-08	6593.81
19	16018401002	1-Apr-08	6593.81
20	16018404102	1-Apr-08	6593.81
21	16018404102	3-Apr-08	18585.66
22	16018411702	1-Apr-08	6593.81
23	16018407402	1-Apr-08	6593.81
24	16018401202	03-Nov-08	897.32
25	16018401502	04-Nov-08	965.93
26	16018411702	03-Nov-08	897.32
27	16018403002	04-Nov-08	965.93

Graphical Analysis

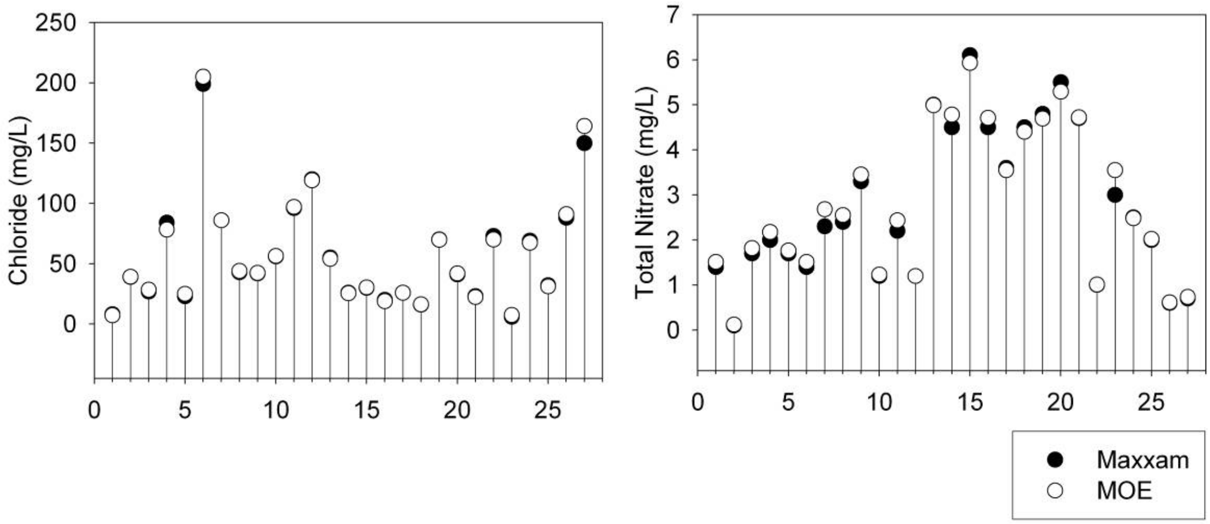

Figure A-1: Chloride and total nitrate concentrations analyzed by Maxxam (closed circles) and MOE (open circles) in 27 duplicate water samples.

Samples analyzed for chloride and total nitrate showed consistent overlap in sample values between the two laboratories across parameter concentrations.

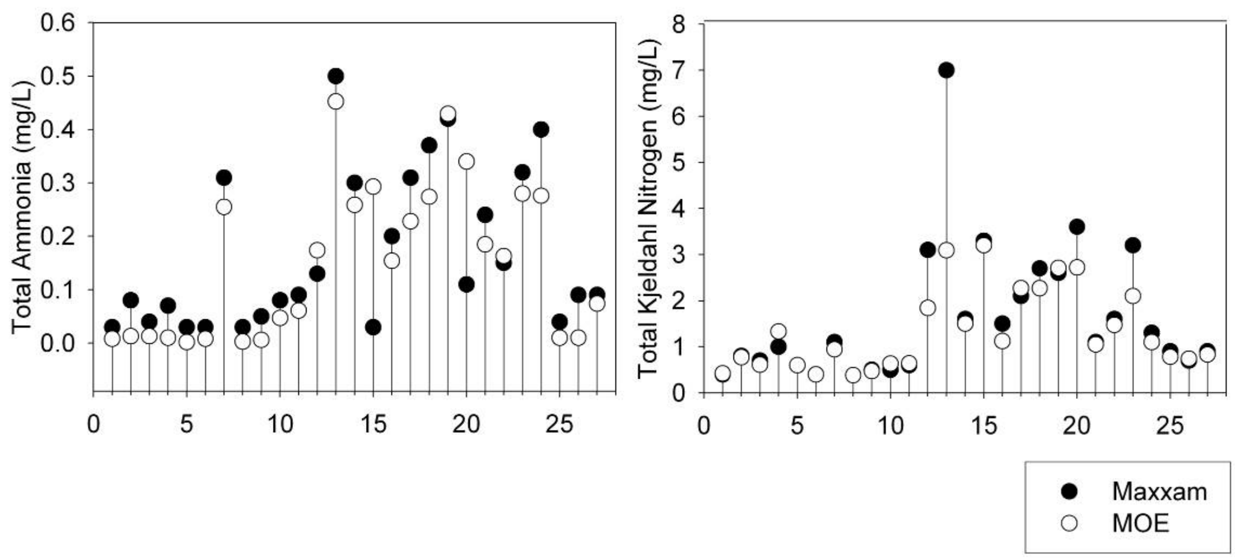

Figure A-2: Total ammonia and total Kjeldahl nitrogen concentrations analyzed by Maxxam (closed circles) and MOE (open circles) in 27 duplicate water samples.

Total ammonia concentrations differed slightly between labs with relatively higher total ammonia concentrations typically reported by the Maxxam lab. Several samples showed large differences between samples. Total Kjeldahl nitrogen samples showed relatively good agreement between labs except for several samples.

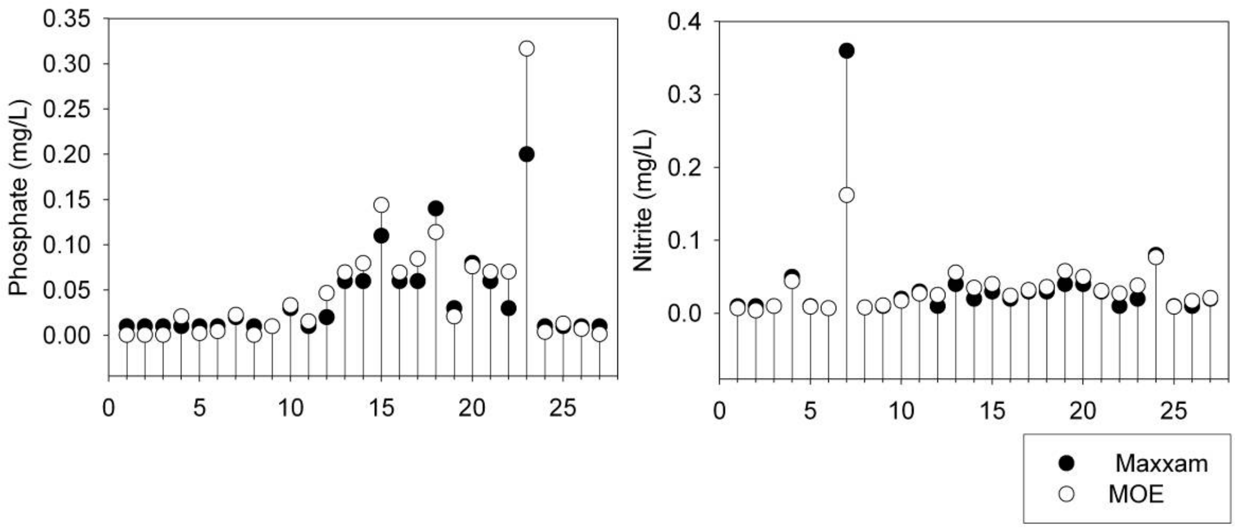

Figure A-3: Phosphate and nitrite concentrations analyzed by Maxxam (closed circles) and MOE (open circles) in 27 duplicate water samples.

Relatively good agreement between labs was observed for phosphate and nitrite with one sample with relatively high concentrations reported by both labs differing.

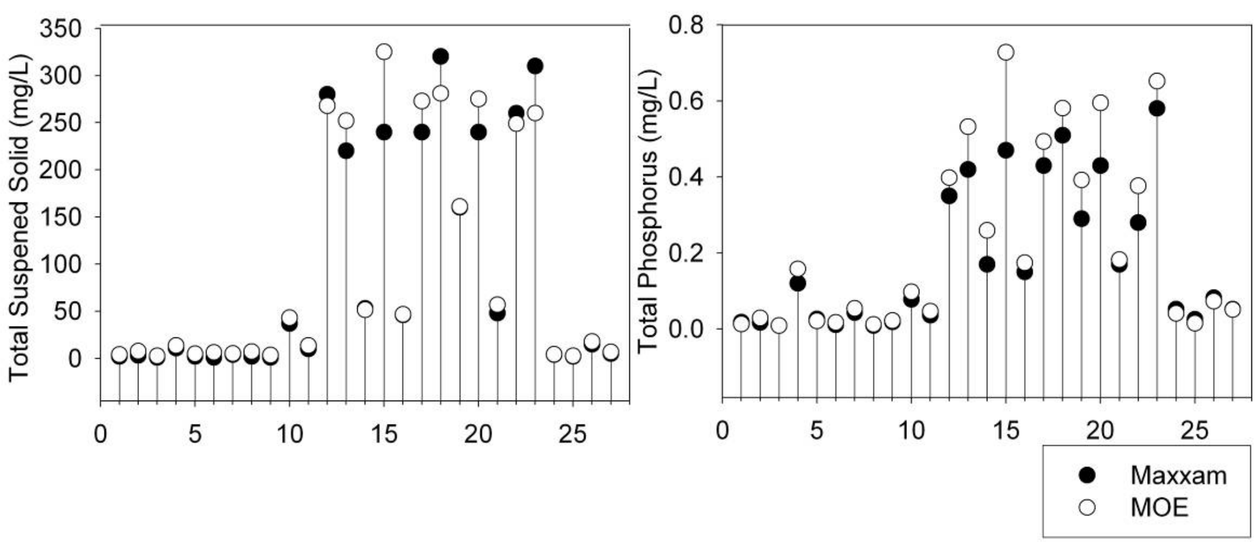

Figure A-4: Total suspended solid and total phosphorus concentrations analyzed by Maxxam (closed circles) and MOE (open circles) in 27 duplicate water samples.

Total suspended solid (TSS) and total phosphorus (TP) concentrations agreed well at low concentrations but differed at higher concentrations, where the MOE lab reported lower TSS, but higher TP concentrations.

Statistical Analysis

Samples which showed large differences in results reported by the two laboratories were identified as outliers for each dataset.

Table A-2: The sample numbers with large differences in laboratory results

Parameter	Outlier Sample #
Total Ammonia	15 & 20
Total Kjeldahl Nitrogen	13
Nitrite	7
Phosphate	23

Paired T-Tests

Paired t-tests including the outliers revealed significant differences between laboratories for total nitrate, phosphate, and total phosphorus. When outliers were removed, significant differences between laboratories was observed for total ammonia, total Kjeldahl nitrogen, and nitrite.

Table A-3: Paired t-test statistics on differences

Parameter	Paired T-Test		Paired T-Test: Outliers Removed	
	p value	mean difference	*p* value	Mean difference
Chloride	n.s.	-0.6 ± 0.64		
Total nitrates	<0.05	-0.07 ± 0.031		
Total Ammonia	n.s.	0.019 ± 0.016	<0.0001	0.040 ± 0.0070
TKN	0.06	0.32 ±0.161	<0.05	0.17 ±0.076
Nitrite	n.s.	0.003 ± 0.0083	<0.01	-0.005 ± 0.0017
Phosphate	<0.05	-0.0146 ±0.006	n.s.	-0.004 ±0.003
TP	<0.01	-0.043 ±0.012		
TSS	n.s.	-4.6 ±4.55		

Linear Regressions

Highly significant linear relationships with slopes of 1 were observed for chloride and total nitrate concentrations. Highly significant linear relationships with slopes of 1 were also observed for suspended solid and total phosphorus concentrations but the variance was unequally distributed in the dataset and the assumptions of the test are violated. When identified outliers were removed from total ammonia and total Kjeldahl nitrogen datasets, significant linear relationships with slopes less than 1 were observed but these data also violated the equality of variance assumption. Nitrite and phosphate datasets showed a linear relationship with a slope approaching 1 when identified outliers were removed.

Table A-4: Statistical results for linear regressions performed between water quality parameters measured by the MOE and Maxxam laboratories.

Parameter	Linear Regression (MOE by MAXXAM)		Linear Regression: Outliers Removed	
	R^2 value	Slope	R^2 value	Slope
Chloride	0.9960	1.035		
Total nitrates	0.9907	0.9771		
Total Ammonia	0.68	0.8185	0.94 *	0.92
TKN	0.7742	0.5196	0.88*	0.74
Nitrite	0.8533	0.4290	0.80	0.97
Phosphate	0.90	1.356	0.8575	1.07
TP	0.9712*	1.259		
TSS	0.9615*	0.9968		

* Variance was unequally distributed across the dataset. Regression line equation is skewed, often by a few elevated concentrations.

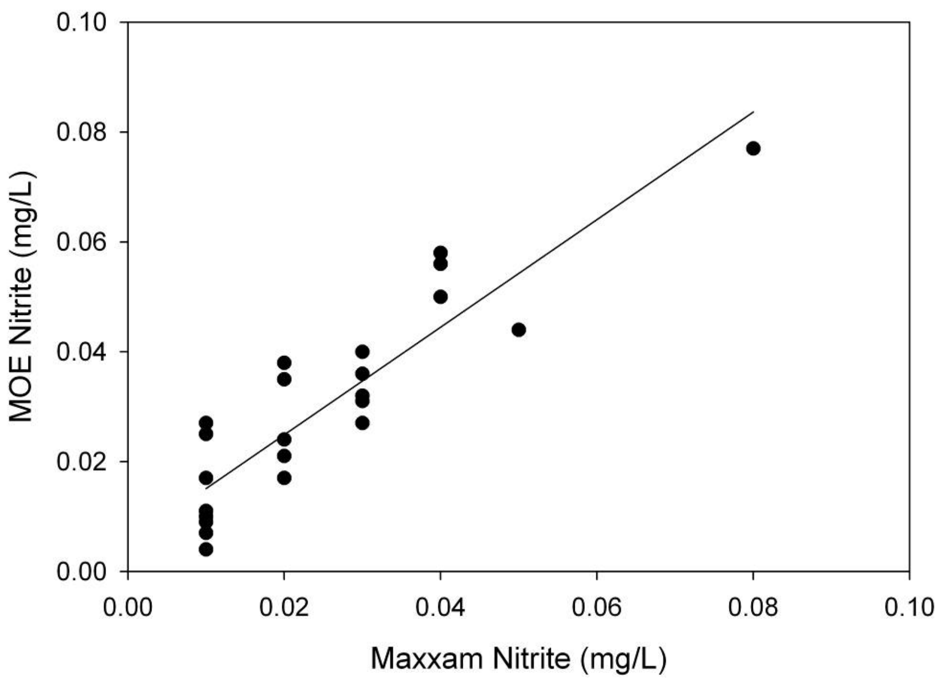

Figure A-5: The nitrite concentration measured by the MOW laboratory plotted against the concentration measured by the Maxxam laboratory.

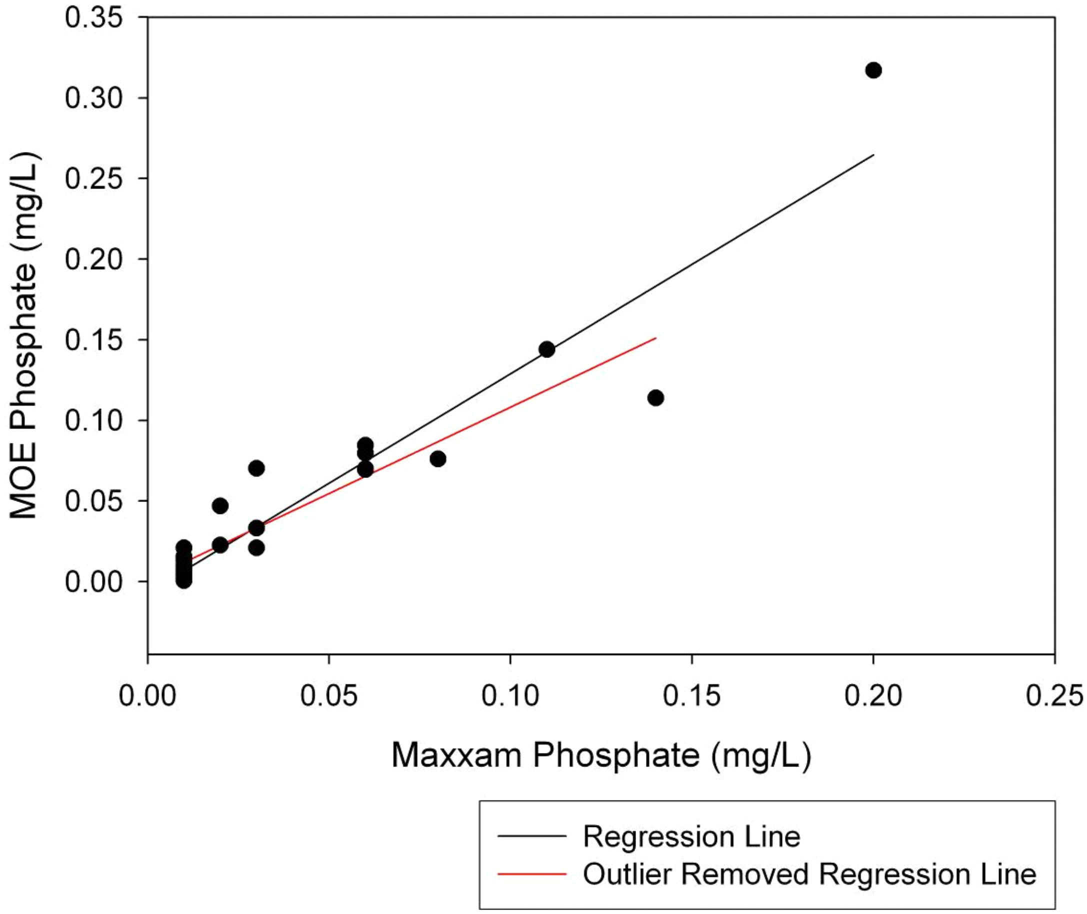

Figure A-6: The phosphate concentration measured by the MOE laboratory plotted against the phosphate concentration measured by the Maxxam laboratory.

Proportion of samples analyzed by the two laboratories across sites

Table A-5: The number of samples within each site dataset and the proportion of samples analyzed by the MOE and Maxxam Laboratories in the upper Grand River subbasin.

Site	N	% Samples	
		MOE	MAX
Leggatt	30	50	50
Grand Valley	28	68	32
Marsville	40	40	60

Table A-6: The number of samples within each site dataset and the proportion of samples analyzed by the MOE and Maxxam Laboratories in the Conestogo River subbasin.

Site	N	% Samples	
		MOE	MAX
Wellington Rd. 7	28	64	36
Moorefield Creek	41	79	21
Drayton	15	100	0
Glen Allen	39	75	25
Boomer Creek	40	31	69
St. Jacobs	49	76	23

Table A-7: The number of samples within each site dataset and the proportion of samples analyzed by the MOE and Maxxam Laboratories in the Speed River subbasin.

Site	N	% Samples	
		MOE	MAX
Eramosa	48	78	22
Above Guelph Lake	45	81	19
Victoria Rd.	39	32	68
Edinburgh Rd.	17	80	20
Wellington Rd. 32	50	75	25
Cambridge	50	78	22

Table A-8: The number of samples within each site dataset and the proportion of samples analyzed by the MOE and Maxxam Laboratories in the Nith River subbasin.

Site	N	% Samples	
		MOE	MAX
Alder Creek	32	72	28
Nithburg	42	58	42
New Hamburg	47	83	17
Ayr	17	94	6
Paris	48	77	23

Table A-9: The number of samples within each site dataset and the proportion of samples analyzed by the MOE and Maxxam Laboratories in the central Grand River subbasin.

Site		% Samples	
	N	MOE	MAX
Below Shand Dam	47	84	16
Carroll Creek	24	0	100
Irvine Creek	47	78	22
West Montrose	46	81	19
Canagagigue Creek			
Above Reservoir	10	100	0
Above Elmira	41	78	22
Below Elmira (mouth)	51	75	25
Conestogo River			
Bridgeport	50	77	23
Laurel Creek	40	32	68
Freeport	15	100	0
Schneider Creek	35	66	34
Blair	49	80	20
Speed River			
Mill Creek	40	30	70
Glen Morris	48	82	18
Nith River		77	23

Table A-10: The number of samples within each site dataset and the proportion of samples analyzed by the MOE and Maxxam Laboratories in the Southern Grand River subbasin.

Site	N	% Samples	
		MOE	MAX
Whiteman's Creek	52	82	18
Brantford	25	95	5
New Port	28	71	29
Fairchild Creek	49	76	24
Big Creek	16	86	14
York	47	77	23
Mackenzie Creek	19	88	12
Dunnville Bridge	96	100	0

Discussion & Conclusions

All variables showed a strong agreement between laboratories. When the mean difference was compared to the dataset it was typically 1-2 orders of magnitude less than the concentrations observed in the samples. This difference on laboratory results would not affect the interpretation of site water quality and it can be concluded that the combination of water quality datasets analyzed by two separate labs will not compromise the assessment of site water quality.

The samples with large differences between laboratories were identified as outliers. These outliers would not have been identified in the dataset had duplicate samples not be run. It is likely that within the total ammonia, total Kjeldahl nitrogen, nitrite, and phosphate datasets a portion (~3-4%) of the datasets analyzed contains errors. The assessment of trends in datasets with known sources of variation such as flow or season helps understand such variation reducing the influence of potential errors on conclusions.

Appendix B: A Conceptual Understanding of Phosphorus Delivery in the Grand River Watershed

Report No.:	*WMPSC-2011-06-01*	***Date:***	*June 7, 2011*
To:	*Grand River Water Management Plan Steering Committee*		
From:	*Water Quality Working Group*		
Subject:	*Conceptual Understanding of Phosphorus Delivery in the Grand River Watershed*		

Introduction

The most significant water quality issue in the Grand River Watershed is the eutrophication of the river from both anthropogenic and natural sources. Eutrophication is a term used to describe the addition of nutrients, specifically nitrogen, phosphorus and/or carbon to freshwaters and the resulting increased growth of freshwater plants and algae. Nutrients are essential for plant and animal growth but their overabundance in freshwater systems can cause a number of adverse ecological effects (USGS 2009).

The Province of Ontario sets an objective of 0.030 mg Total Phosphorus / L as a threshold to limit the growth of aquatic plants and algae in rivers (Ministry of the Environment, 1999); however, this is only an interim guideline as the science behind phosphorus plant growth mechanisms and bioavailability is complex. Generally, phosphorus levels in the Grand River system tend to exceed the Provincial Objective (Figure B - 1). It is generally understood that phosphorus is the limiting nutrient in the Grand River system (Barlow-Busch 2006) and it's excess tends to facilitate the prolific growth of aquatic weeds and algae in some reaches.

Total phosphorus dynamics in rivers tends to be influenced by river flow (Doyle 2005) In general, higher phosphorus levels are seen in the river during high flows when overland runoff from snowmelt or significant rainfall events move a lot of water and soil off the land and into smaller streams, and then larger rivers. This tends to be true for the Grand River system. Figure B-2 illustrates relatively strong relationships between phosphorus concentrations and flow at select monitoring sites within the Grand River system. Conversely, phosphorus levels tend to be lower during low flows such as summer when there is very little surface runoff and there is significant biological uptake by aquatic plants and/or algae (Figure B - 1)

The purpose of this technical paper is to describe the conceptual understanding of phosphorus dynamics in the Grand River system, characterize some of the mechanisms that drive phosphorus delivery / transport in surface waters and identify possible significant phosphorus contributing areas. To achieve this, phosphorus levels in the river will be illustrated from the headwaters, near Leggatt to Dunnville near the mouth of the Grand River during different hydrologic regimes which typically occur during different seasons. Understanding phosphorus dynamics in the river during different seasons and under different hydrologic regimes is important as there are different mechanisms contributing phosphorus to the river (point source discharges versus nonpoint source runoff) and water quality issues (e.g. prolific aquatic plant growth and subsequent large fluctuations in dissolved oxygen) depending on the season.

As a first attempt to qualitatively assess the phosphorus dynamics in the Grand River system, the most recent five year dataset (2006-2010) from the Provincial Water Quality Monitoring Network (PWQMN) was explored in the context of the hydrologic regime (e.g. high flows and low flows). Since 2004, effort has been made to collect PWQMN samples that characterize the hydrologic regime (high and low flows) across open water seasons (March through November). The highest river flows typically occur during spring runoff which typically occurs during the months of March and April (see Figure B - 3). In contrast, low flows are typically observed during the summer months of June, July, August and September (see ***Error! Reference source not found.****Figure B - 3). River phosphorus dynamics during the winter months cannot be explored for this paper as the Provincial Water Quality Monitoring Network is limited to sample collection from March until November.*

Total phosphorus and phosphate data from the PWQMN dataset were queried and the median statistic (50^{th} percentile) was calculated for the spring (March, April) and summer (June, July, August, September) for those sampling sites on the Grand River between Leggatt and Dunnville (Figure B - 5). The median statistic provided the best representation of 'typical' conditions; it describes neither the maximum nor the minimum values yet it was used to hypothesize the mechanisms driving phosphorus levels in the Grand River. These data were plotted in figures to spatially depict the dynamics in phosphorus concentrations as the river flows from the headwaters near Leggatt to Dunnville near the mouth of the Grand River.

The following sections describe the conceptual understanding of phosphorus dynamics in the watershed under both high and low flow regimes. Although this approach is qualitative, it is a start toward conceptually understanding phosphorus dynamics in a large river system. A more quantitative assessment of loads is required to fully describe those areas contributing greater amount of phosphorus to the Grand River (and therefore target those areas for phosphorus reduction strategies). In addition, detailed research is required, some of which is currently being undertaken by researchers from the University of Waterloo, to describe the detailed mechanisms behind phosphorus and aquatic plant/algae growth and transport into Lake Erie.

Conceptual Understanding of River Phosphorus Levels during High Flows

Generally, high river flows likely have a more significant impact on a downstream receiver. Although some sediment and nutrients are deposited in the river or taken up in aquatic biota through scouring and deposition, most of the load, or mass of sediment or nutrients transported by the river is likely transferred to a downstream receiver or end point. Further, there is little biological activity or processing in the river when high flows typically occur, due to cold temperatures; therefore, the high nutrient levels seen in the river are likely not as much a concern as they are during the summer low flows when biological activity is high. In the Grand River System, the downstream receivers are, generally, the large flood control reservoirs and Lake Erie. Therefore, during high spring flows, the endpoints of concern are generally these waterbodies.

In general, total phosphorus concentrations in the Grand River tend to increase in concentration from the headwaters to the mouth (Figure B - 5). During high flows in the spring, total phosphorus levels in the Grand River near Leggatt already tend to exceed the provincial guideline of 0.030 mg/L. Runoff from the headwater area drains the Dundalk till plain and much of the water on the landscape tends to move off the land quickly carrying sediment and phosphorus. Concentrations gradually increase as the river flows toward Belwood Lake, which is a reservoir that is operated to control peak flows and hold water back before releasing more controlled flows downstream. The buildup of phosphorus in the reservoir is released downstream as indicated by a marked increase in phosphorus between the sites upstream and downstream of Shand Dam. Between the Shand Dam and West Montrose phosphorus levels don't tend to increase significantly, since the river collects flows from smaller tributaries with relatively low phosphorus and there are only two smaller point source discharges.

Phosphorus levels in the Grand River more than double after receiving flows from the Conestogo River. This is evident by a significant jump in median total phosphorus level seen in the Grand River at Bridgeport. The geology of the upper Conestogo River basin and the land use - some of the most intensive agricultural production in the watershed, likely influences the phosphorus levels in the Grand River as it flows into the Region of Waterloo.

It is hypothesized that urban stormwater runoff during the spring, combined with multiple point source discharges nearly doubles the phosphorus levels in the Grand River through the Region of Waterloo; however, the urban stormwater contribution to the river is not well characterized. The limited dataset and/or the Mannheim weir likely play a role in the phosphorus dynamics in the river at Freeport.

As the Grand River flows out of the large urban area toward Glen Morris, it receives the flow from the entire Speed/Eramosa catchment. The phosphorus levels tend to decrease but are still well above the provincial objective of 0.030 mg/L. Although there is a significant urban area within the Speed River subbasin, it also drains the Eramosa system which has some of the lowest river phosphorus concentrations in the watershed.

Therefore, the Speed Eramosa River system likely helps to reduce the total phosphorus levels in the Grand River.

The Nith River and Whitemans Creek, both of which are unregulated rivers with extensive agricultural production, join the Grand River upstream of the City of Brantford. Spring high flows from the Nith River are significant and are about 24 percent of the Grand River (D. Boyd, pers. comm.). Median phosphorus levels in the Nith during high flows are relatively high at 0.113 yet levels can reach as high as 1.66 mg/L (maximum concentration sampled March 2007) during springtime. In contrast, phosphorus is not as high in Whitemans Creek as the median concentration for spring runoff is 0.089 mg/L and maximum levels are five times less than they are in the Nith River. The high levels seen in the Nith River during spring runoff conditions likely contribute to the doubling of total phosphorus levels in the Grand River in Brantford when compared to the levels seen at Glen Morris. The Grand River appears to be heavily influenced by the Nith River but also likely local urban runoff from the City of Brantford as well; however, there are no data describing the urban stormwater contributions through the City of Brantford.

As the Grand River flows out of Brantford toward York and Dunnville, it flows onto the Haldimand Clay plain. The transition onto the clay plain is significant with respect to phosphorus and sediment dynamics as clay particles are easily suspended in the water column giving the river a 'dirty' look. Phosphorus binds tightly to clay due to the adsorption properties of clay and therefore, phosphorus levels in the river would naturally increase throughout this region due to the influence of the geology. However, land use likely exacerbates the levels seen in the river.

Phosphorus levels tend to recede somewhat but the levels still remain well above the provincial objective. The dams in Caledonia and Dunnville likely play a significant role in the phosphorus dynamics in the river as they alter the fundamental hydraulic character of the river. The median total phosphorus levels during high spring flows at Dunnville (0.128 mg/L) are about four times the provincial objective but the maximum concentrations seen can be as high as 12 times the objective (0.360 mg/L). These very high levels are discharged to the eastern basin of Lake Erie and likely have a significant impact along the nearshore region of the lake (T. Howell, pers. comm.).

Conceptual Understanding of River Phosphorus Levels during Low Flows

Low flows typically occur in the Grand River during the hot summer months of June, July, August and September (see Figure B - 6). This is the time period in which significant biological activity (e.g. photosynthesis and respiration) occurs and there is significant aquatic plant and algae growth in the river. Phosphorus is the key limiting nutrient in the Grand River and generally drives the aquatic plant growth; consequently, the more phosphorus in the river, the higher the productivity of these waters.

Unlike spring runoff in which there is a strong flushing effect and the endpoints of concern are the reservoirs or Lake Erie, river hydrology during the summer is not as dynamic. Except for large rainfall events, river flows in the summer and the biological activity in the river tend to be heavily influenced by local inputs like point source discharges. Therefore, the endpoint of concern within the Grand River system during the summer is likely more localized river reaches. It must be acknowledged, however, that the effects of high flows cannot be completely separated from the resulting biological activity of the river during the summer due to the spiralling or deposition of sediment and phosphorus in river reaches from upstream areas. Although the following may be an over simplified conceptualization of phosphorus dynamics during low river flows, it is a start at understanding the mechanisms driving phosphorus dynamics and the resulting biological effects which contribute to summer water quality issues in the river.

*Median summer total phosphorus levels in the headwater region of the Grand River system tend to be at or slightly below the provincial objective of 0.030 mg/L (**Error! Reference source not found.**). Flows in the summer in the upper Grand River region are sustained by discharges from the Luther Marsh in addition to some minor groundwater inputs from the Orangeville moraine. These sources of water to the river likely influence the low phosphorus levels found in the river.*

In the hot summer months, Belwood Lake becomes thermally stratified which results in elevated phosphorus levels in the bottom waters due to hypoxic conditions. This phosphorus-rich water is discharged from the bottom valve of the Shand Dam to the tailwater region of the Grand. This effectively makes Belwood Lake a source of nutrients to the central Grand River.

The Grand River between the Shand Dam and the confluence of the Conestogo River collects flows from small groundwater fed streams (e.g. Carroll, Cox, Swan, Irvine). There are only two small point source discharges (e.g. Fergus and Elora), so the phosphorus in this reach tends to be assimilated without significant negative effects on the water quality. This results in a general decrease in phosphorus levels in the river as it flows from the Shand Dam to West Montrose.

Phosphorus levels in the Grand River tend to steadily climb once it receives the flow from the Conestogo River and then flows into the Region of Waterloo. The river receives the inputs from two substantive point source discharges – the Waterloo and Kitchener wastewater treatment plants and a number of smaller ones (Hespeler, Preston and Galt) which service a population of over 485,000 (2011) (Region of Waterloo, 2011). Given the low river flows in this reach, these inputs heavily influence the phosphorus levels and resulting biological activity in the river. The median total phosphorus level in the Grand River at Blair is twice the provincial objective and is likely one of the mechanisms driving the prolific aquatic plant/algae growth in this reach. Hood et al, (2009) at the University of Waterloo have determined that aquatic plants and algae in the central Grand River are a significant sink of phosphorus in the summer. Of particular note is the significant increase in phosphate (i.e. soluble reactive phosphorus) *levels in the river at this point as well. Phosphate is considered to be the more biologically available form of phosphorus. The significant increase in phosphate at Blair is likely sourced from the upstream wastewater treatment plants, as it is acknowledged that wastewater effluent tends to have disproportionately high soluble phosphorus (Jarvie et al. 2006).*

As the Grand River flows out of the central urban region, phosphorus levels tend to decrease or be assimilated by the biological processes in the river. The Speed River may also play a role in decreasing the total phosphorus levels in the river as well as total phosphorus levels tend to be much lower than in the Grand. Since there are few smaller point source discharges to the river between Cambridge and Brantford, the river tends to be able to assimilate phosphorus with limited impacts to the physiochemical regime of the river. For example, the fluctuations of dissolved oxygen in the river at Glen Morris, although quite dramatic, only occasionally fall below the provincial objective. Total phosphorus levels tend to continue to decrease as the river flows into Brantford. The Nith River and Whitemans Creek also tend to influence the decrease in phosphorus levels seen in the river, as phosphorus levels from these river systems are generally low (i.e. below the provincial objective) in the summer due to the significant discharge of groundwater that heavily influences the stream flows and stream chemistry in these systems.

Once the river flows out of Brantford and onto the Haldimand Clay plain, it is strongly influenced by the geology as the point sources tend to be relatively minor when compared to the flow in the river. The phosphorus levels in the Grand River increase dramatically as it flows from Brantford toward York and then Dunnville likely due to the clay particles in suspension which have a natural affinity for adsorbing phosphorus.

*On-line dams in Caledonia and Dunnville also play a role in the phosphorus dynamics in the river. More detailed assessment of the southern Grand for a Canada-Ontario Agreement (COA) sponsored project in 2004 illustrated the influence of the dams in which phosphorus levels tended to 'spike' just above the dams (**Error! Reference source not found.**Figure B - 7)(Cooke, 2005). A build up of phosphorus-rich sediment; the lake-like behaviour of the river behind these dams; and localized biogeochemical processes likely contributes to the increased phosphorus levels found in the lower river reaches. Researchers at the University of Waterloo (Kuntz, Smith, Schiff et al.) have also documented the increasing total phosphorus levels and contrasting draw-down of biologically available phosphorus in the southern Grand River during in the summer months. Of particular note and interest is the corresponding increase in soluble reactive phosphorus at Dunnville, also likely influenced by the on-line dams and the lake-like behaviour of the river in this reach. The high levels of biologically available phosphorus in Dunnville (Figure B - 5), however, likely have significance to aquatic plant and algae growth along the nearshore of Lake Erie. Further research is required to fully characterize the phosphorus dynamics in the southern Grand River and its connection with the eastern basin of Lake Erie.*

Summary

Our conceptual understanding of phosphorus dynamics in the Grand River system is limited to current river water quality monitoring activities, most notable the Provincial Water Quality Monitoring Network. Over the last 5 to 8 years, there has been a substantive research effort in characterizing phosphorus and nitrogen dynamics in the river; the predominant biological processes influencing river phosphorus concentrations; and aquatic biomass that we are only starting to synthesize and learn from (e.g. Schiff, Taylor, Smith et al). Our conceptual understanding allows water managers to highlight areas of focus for management and identify gaps in the collective understanding of phosphorus dynamics in the Grand River system. For example, agricultural best management practices should be targeted to those areas in the Conestogo and Nith rivers, as these are contributing areas during high flow events when the mechanism of phosphorus transport is overland runoff and the end points are reservoirs and Lake Erie. Alternatively, In addition, during low summer flows the mechanism contributing to elevated phosphorus levels is point source discharges; consequently attention must be made to reduce phosphorus levels in sewage effluent where those inputs of phosphorus to the river cannot be assimilated.

Furthering our understanding of phosphorus dynamics, as well as nitrogen, in the Grand River system will require a commitment to long term monitoring and additional research during all seasons, since different water quality issues can be seen during different times of the year. Further, more intensive monitoring is required to fully characterize and quantify phosphorus loads from contaminant source areas so that, in a progressive fashion, hot spots can be identified and appropriate land management actions can be adopted. Lastly, the sustainability of the Grand River system will require all agencies to do their part, so that the cumulative effects of phosphorus from the headwaters to the mouth can be reduced not only for the Grand River itself, but also for Lake Erie.

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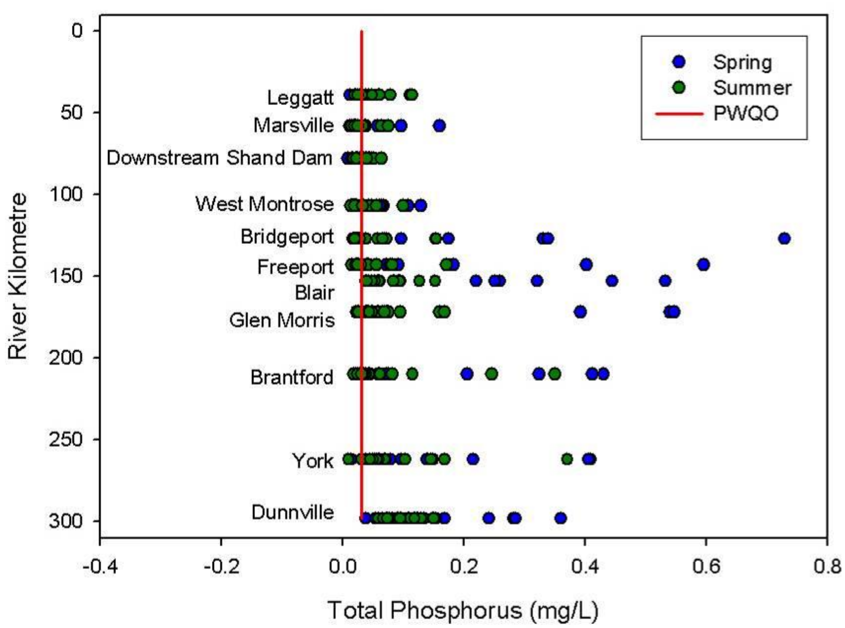

Figure B - 1. Total phosphorus concentrations at monitoring sites from the headwater region (e.g. Leggatt) to Dunnville on the Grand River for Spring high flows (blue dots) and summer low flows (green dots). The red line is the Provincial Water Quality Objective. Data from the Provincial Water Quality Monitoring Network (2006-2010).

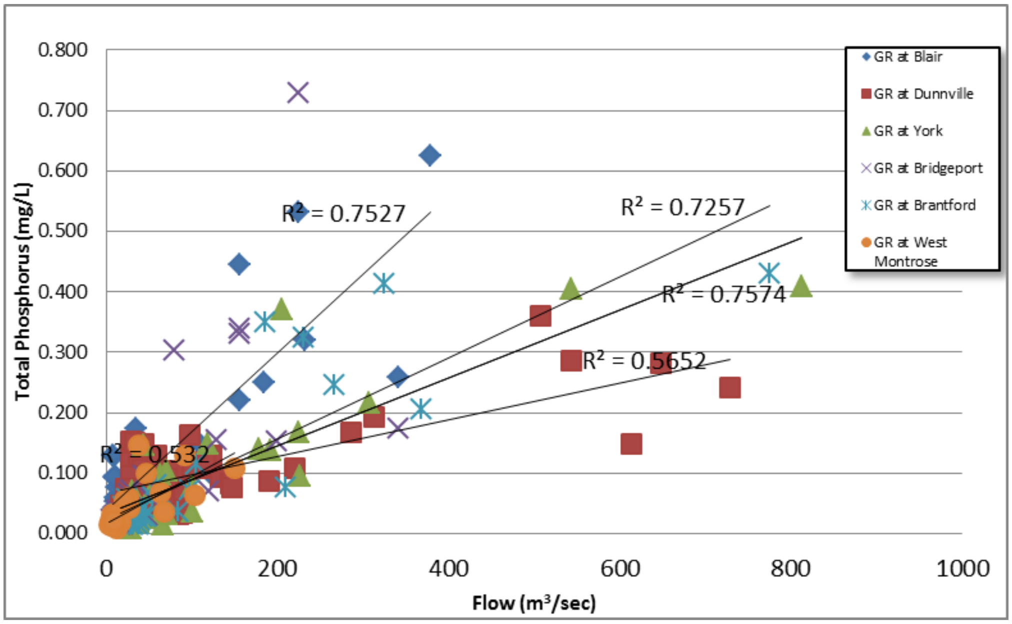

Figure B - 2. Relationship between total phosphorus (mg/L) and river flow (m^3/sec) at select locations on the Grand River. In general, the R^2 values illustrates a stronger relationship between total phosphorus concentrations and flow.

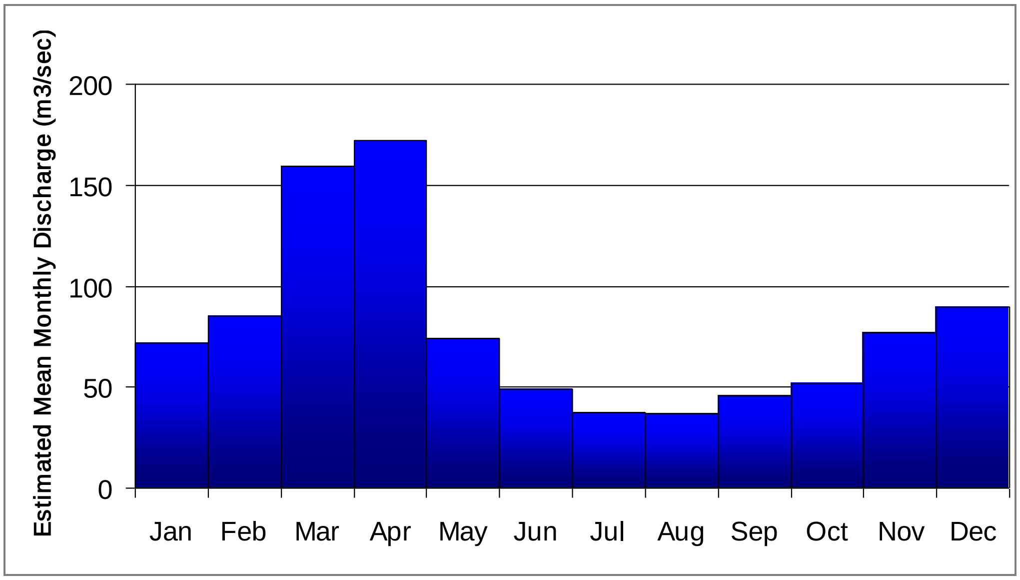

Figure B - 3. Mean monthly discharge at Port Maitland.

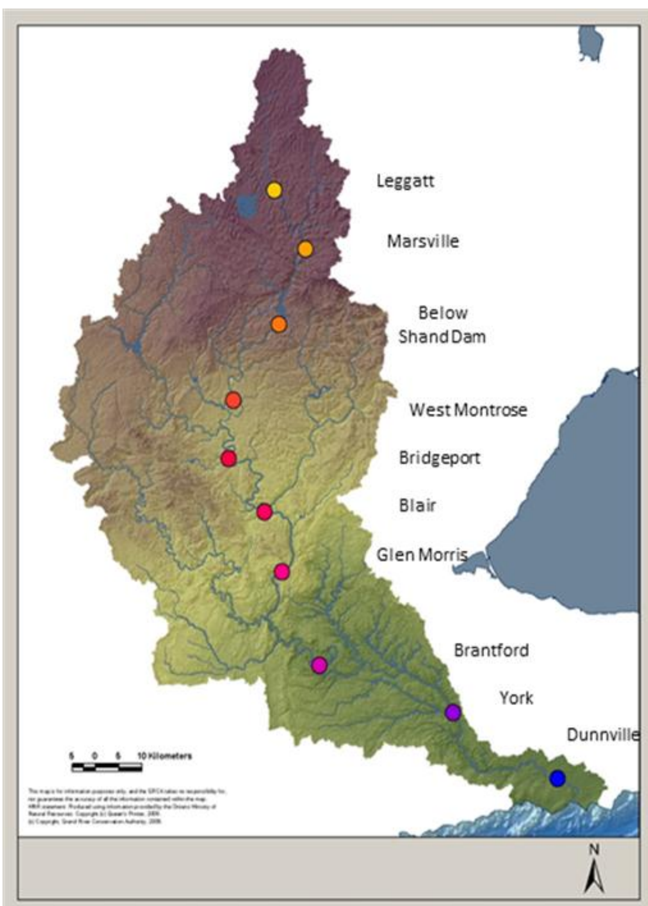

Figure B - 4. The Grand River watershed illustrating the Provincial Water Quality Monitoring network sampling sites along the Grand River

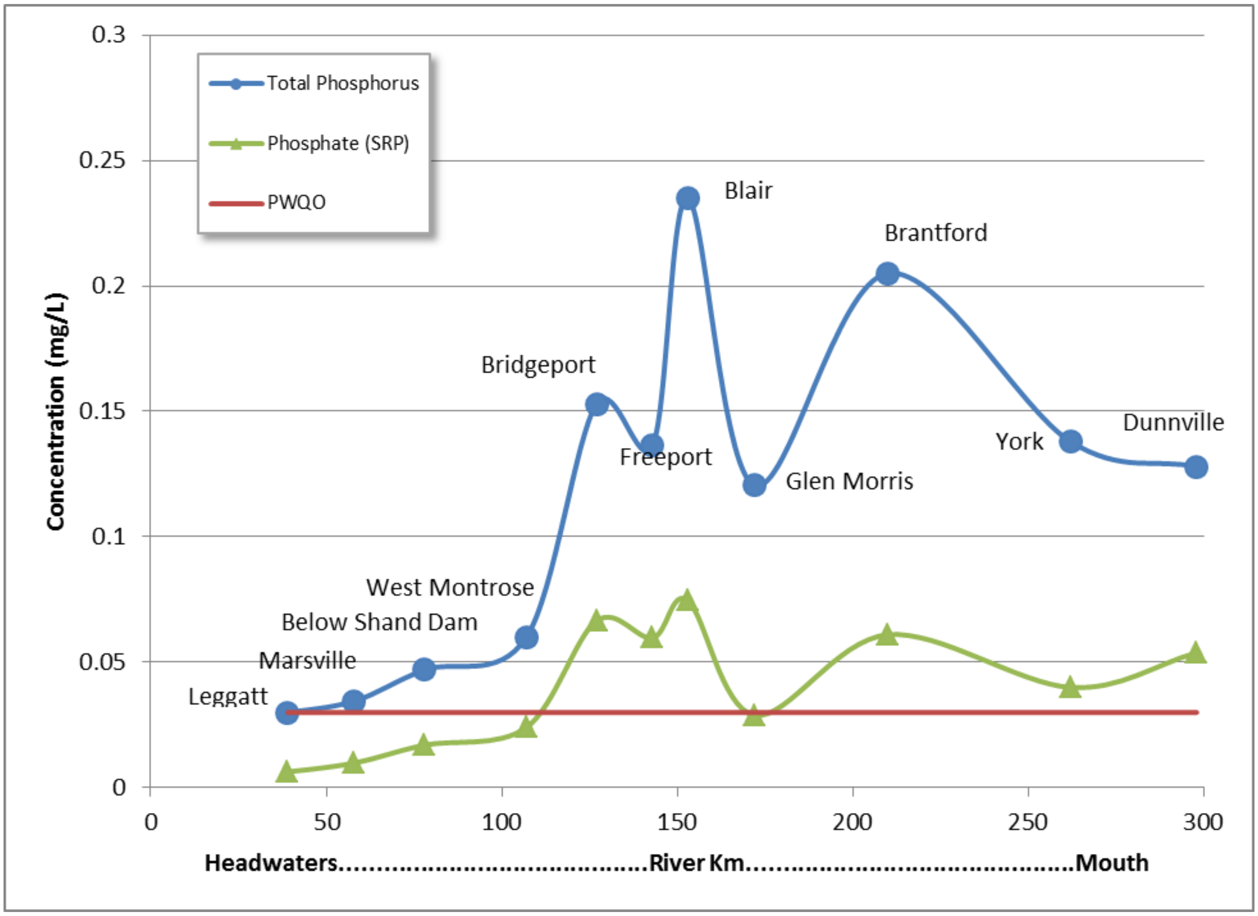

Figure B - 5. Representative total phosphorus and soluble reactive phosphorus (a measure of biologically available phosphorus or phosphate) concentrations along the Grand River from the headwaters (Leggatt) to the mouth of the Grand River near Dunnville during spring (e.g. March/April) high flow conditions. The red line is the Provincial Water Quality Objective of 0.030 mg/L.

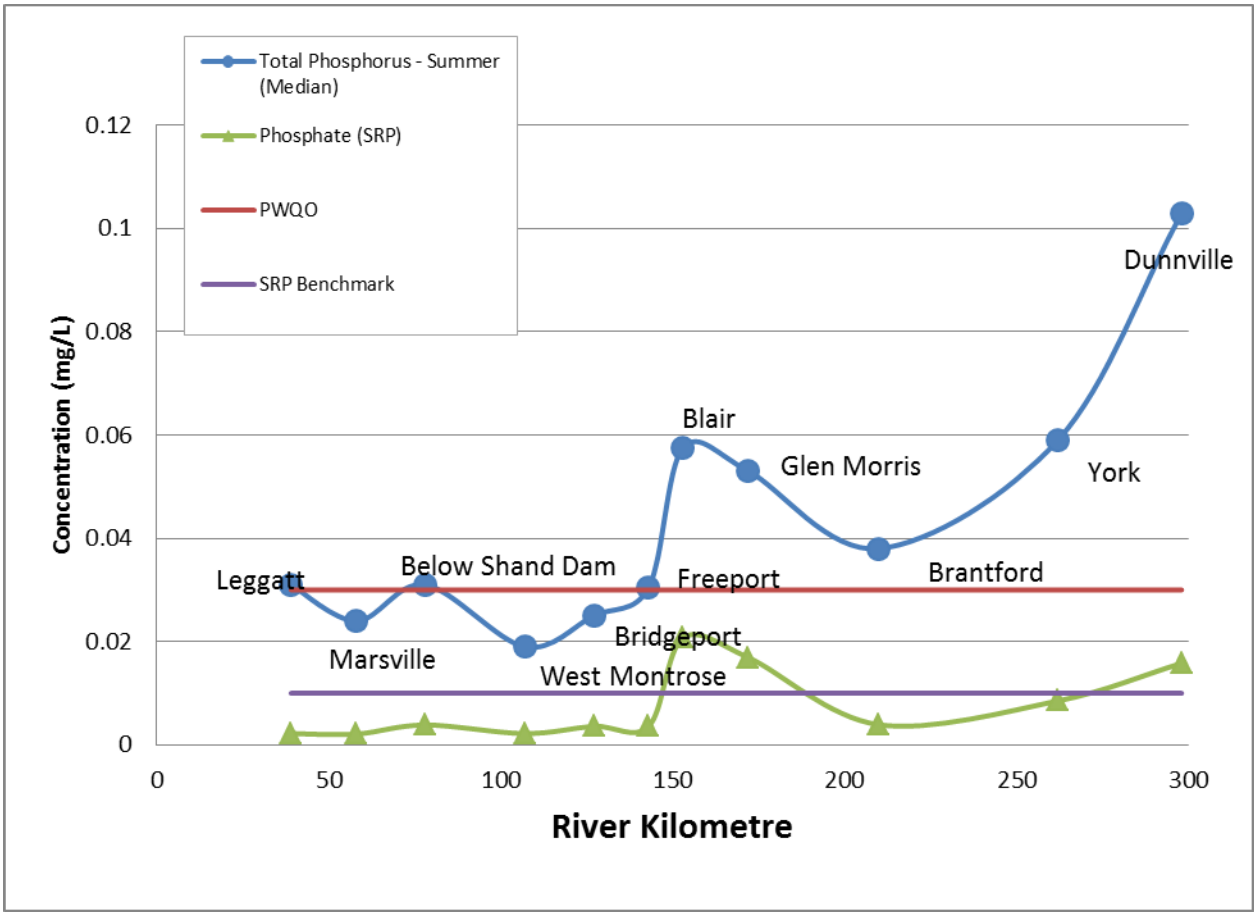

Figure B - 6. Representative total phosphorus and soluble reactive phosphorus (a measure of biologically available phosphorus or phosphate) concentrations along the Grand River from the headwaters (Leggatt) to the mouth of the Grand River near Dunnville during low flow conditions (e.g. June – September). The red line is the Provincial Water Quality Objective of 0.030 mg/L.

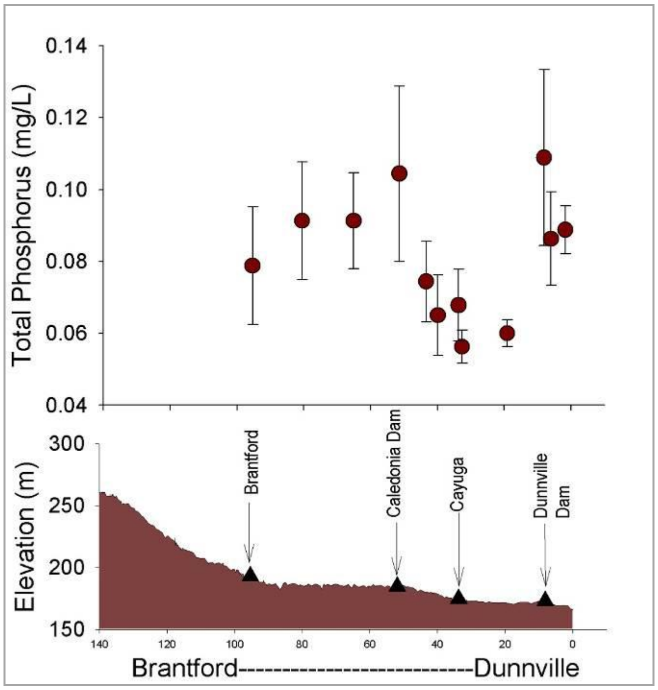

Figure B - 7 The average summer phosphorus levels (dot) and range (maximum and minimum) in the Grand River between Brantford and the Dunnville Dam. The bottom figure illustrates the elevation profile of the southern Grand River with the locations of on-line dams.

Prepared by:

Sandra Cooke
Senior Water Quality Supervisor

Approved by:

Lorrie Minshall
Water Management Plan Director