GRAND RIVER WATERSHED
Water Management Plan

Grand River Watershed Water Management Plan

Sources of Nutrients and Sediments in the Grand River Watershed

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for the Water Quality Working Group

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Abbreviations

AAFC	Agriculture and Agri-Food Canada
EC	Environment Canada
GRCA	Grand River Conservation Authority
MNDM	(Ontario) Ministry of Northern Development and Mines
MOE	(Ontario) Ministry of the Environment
OMNR	Ontario Ministry of Natural Resources
OMAFRA	Ontario Ministry of Agriculture, Food & Rural Affairs
PLUARG	Pollution from Land Use Activities Reference Group
PWQMN	Provincial Water Quality Monitoring Network
PWQO	Provincial Water Quality Objective
TSS	Total suspended solids
WMP	Water Management Plan
WSC	Water Survey of Canada
WWTP	Wastewater treatment plant

Contents

Figures

Tables

Executive summary

Continued prosperity, growth and sustainability of the communities of the Grand River watershed depend on a healthy river system. Looking to the future, the Grand River Conservation Authority (GRCA) is championing an update of the Water Management Plan and working with its partners to identify the issues and the areas of opportunity for collaborative action. One of the goals of the plan is to "*Improve water quality to improve river health and reduce impact on the eastern basin of Lake Erie*". **To identify the most appropriate management actions to address the water quality issues on which the Water Management Plan is focused, it is important to have an understanding of the source, pathway and fate of contaminants which are transported into rivers and streams in the watershed.** Ultimately, understanding and adapting management practices to address the sources and mechanisms behind priority water quality issues will support more effective watershed water quality management.

This report provides a synthesis of information and discussions by the Water Quality Working Group in an effort to characterize sources of nutrients and sediments to surface waters in the watershed. The group was tasked with determining the relative importance of suspended solid and nutrient sources with respect to a set of key surface water quality issues:

- eutrophication of the river system (nuisance growth of plants and algae);
- sedimentation and turbidity in river reaches;
- phosphorus loading of the reservoirs and Lake Erie; and
- impairment of water uses by high nitrate concentrations.

These issues are particularly relevant to the Water Management Plan goals and objectives. Other water quality issues also exist in the watershed, but are not covered in this report.

Limited availability of data and information specific to the watershed prevented a full 'accounting' or 'budgeting' of nutrients and sediments from various areas and during specific times of the year. However, the weight of evidence from the various approaches synthesized in this report provides insight into the relative importance of the sources of nutrients and sediments in the watershed. It illustrated that **there is no single source that prevails as being the most important** in a large complex watershed such as the Grand River watershed since the contribution of source types and areas to water quality issues (identified above) varies both temporally and spatially.

The assessments of nutrient and suspended solid concentrations and relative loading rates were done at a coarse-scale, and were found to be consistent with the findings of other studies. There is a strong seasonal shift in the importance of sources that corresponds to the seasonality of water quality issues driven by hydrology and biological activity. **Point sources of phosphorus and nitrogen such as municipal wastewater treatment plants that directly discharge nutrients to the central Grand River region are very important nutrient sources during low flows in the summer; non-point sources dominate annual loads due to high contributions during spring high flows**. The relative importance of point sources increases during the summer since there is decreased potential for dilution of point sources in low flows and they contain nutrients that are in a form that is more readily used by plants and algae (e.g., dissolved phosphorus, ammonia). Similar issues associated with eutrophication in the reservoirs and slow-moving reaches of the southern Grand River are linked to re-suspension and recycling of accumulated nutrient loads from upstream sources.

Large spatial variations in the importance of non-point source areas reflect the combined effect of natural factors such as soil, slope and hydrologic response, as well as land use and management (e.g., cover type, hydrologic modifications, potential for land applied nutrients). Key non-point source areas for phosphorus include the Canagagigue, Conestogo and Nith subwatersheds as well as Fairchild Creek. Subwatersheds with high yields of suspended sediments include the Fairchild Creek, McKenzie Creek and Nith River. Key non-point source areas contributing to high nitrate concentrations in the river system included subwatersheds in the middle upper Grand (Irvine Creek, Canagagigue). Non-point source contributions from urban areas are significant in the context of local impacts such as episodic pulses of high suspended solids. The annual loading from urban areas is likely small in the context of the total load from the Grand River watershed (i.e., from the perspective of Lake Erie), but it may still be significant to regional impacts and is likely to become increasingly important with population growth.

It is important that gaps in data, information and scientific understanding be addressed in order to confirm the key source areas or more specifically identify the source types associated with each of the water quality issues described in this report. There is a high degree of uncertainty in the estimate of loads in the assessment on which this report was based. Despite this uncertainty and the coarse scale of the assessment, it enabled a weight of evidence approach that highlighted priority areas where more detailed investigation is needed. Strategic sampling to improve the spatial and temporal resolution of data in these priority areas during key delivery periods will provide further insight into transport mechanisms and the fate of nutrients and sediment. Improved or updated information about the distribution of specific land uses/management would also allow better or more specific identification of nutrient and sediment source types and allow for a better understanding of the relationships between land use or management and water quality. The relative importance of some pathways by which nutrients and sediments are transported from sources to the river system (e.g., by shallow groundwater or subsurface drainage) has not yet been determined due to a lack of data. Further work is needed to address the priority gaps in knowledge and information which are highlighted in this report.

The use of regional models can help to integrate information across scales (e.g., field to subwatershed) and enable a more strategic approach to nutrient and sediment management. There is a need to improve our understanding of the link between water quality impacts in the river and sources and transport processes of nutrients and sediment from the landscape. Of particular importance is the connection between the nutrient-dissolved oxygen relationship in the central Grand River and priority subwatersheds that influence this region. Both the Assimilative Capacity and the Water Quality Working Groups recommended the coupling of landscape nonpoint source models/monitoring with in-river nutrient-dissolved oxygen modelling to create a linked modelling platform from which to predict landscape changes in nutrient management in concert with point source management. **This point / nonpoint source decision support system would enable more strategic investments in stewardship practices as well as enable a more 'holistic' approach to nutrient management in the watershed.** Including economic considerations such as cost-benefit analyses within this framework would provide critical information to program managers who enable land owners to implement stewardship activities.

Preface

This report reflects the work of the Water Quality Working Group, convened to provide a synthesis of technical information in support of the update to the Water Management Plan for the Grand River watershed.

The focus of this report is to characterize sources of nutrient and sediment to surface waters in the Grand River watershed. Specific recommendations on solutions to address the causes and impacts of nutrient and sediment inputs are outside the scope of this report, but are addressed within the plan.

In addition to this report, a number of other documents have been produced by technical experts and other working groups. Of particular relevance to this report are the following documents:

Water Quality in the Grand River Watershed: Current Conditions & Trends (2003-2008)
This report summarizes the general chemical and physical characteristics of water quality in the six major subbasins of the Grand River watershed.

Broad Water Objectives for the Grand River Watershed
This report describes the process through which Water Management Plan partners compiled the implicitly and explicitly stated broad water objectives for the Grand River watershed.

A Framework for Identifying Indicators of Water Resource Conditions: Support of Ecological Health by Water Resources in the Grand River-Lake Erie Interface
This report describes a framework that was developed for the Lake Effect Zone to identify water resource condition indicators that describe conditions supportive of healthy aquatic ecosystems.

Water Quality Targets to Support Healthy and Resilient Aquatic Ecosystems in the Grand River Watershed
This report details the targets for the water resource condition indicators identified in the companion report (listed above). The targets give a quantitative measure that will be used to gauge whether water resource conditions are able to support the desired features of healthy and resilient aquatic ecosystems as stated in the broad water objectives now and into the future.

Environmental Flow Requirements in the Grand River Watershed
This report summarizes the findings of past work to identify environmental flow requirements in the Grand River watershed, including thresholds for maintaining healthy aquatic ecosystems in the Grand and Speed Rivers. Considerations included: channel maintenance and formation; nutrient management or biological functions; and low flow.

Assessment of Future Water Quality Conditions in the Grand and Speed Rivers
This report details the analysis of future river water quality conditions, based on modelled scenarios including wastewater treatment plant upgrades and optimization as well as rural / agricultural and urban nonpoint source load reductions.

Development of Water Quality Milestones for the Water Management Plan
This report outlines the milestones that quantify water quality conditions that are expected to be achieved when specific actions in the Water Management Plan are completed.

These documents provide additional background on the Water Management Plan and other technical information on which recommendations in the plan were based. A complete list of reports was not available at the time of drafting this report, but will be compiled within the Water Management Plan.

Introduction

1. The Water Management Plan for the Grand River watershed

Continued prosperity, growth and sustainability of the communities of the Grand River watershed depend on a healthy river system. Population growth, agricultural intensification and climate change all place stress on the health of the watershed. Addressing existing and emerging water management issues is critical for all who live, work and recreate in the watershed.

The 2013 update to the Water Management Plan for the Grand River watershed aspires to the following goals:

- Improve water quality to improve river health and reduce impact on the eastern basin of Lake Erie
- Ensure sustainable water supplies for communities, economies and ecosystems
- Reduce flood damage potential
- Increase resiliency to deal with climate change

Water is a shared resource and consequently, responsibility is shared for water management among many stakeholders and agencies. Looking to the future, the Grand River Conservation Authority (GRCA) is championing an update of the Water Management Plan and working with its partners to identify the issues and the areas of opportunity for collaborative action.

This characterization report focuses on the goal to improve water quality. The intent of the goal extends not only to rivers and streams, but also including other components of the river system, such as reservoirs. The goal to improve water quality in the river system also acknowledges that doing so has the potential to improve conditions in the eastern basin of Lake Erie. The broad scope of this goal is an important update to the existing Water Management Plan for the Grand River watershed.

2. Purpose and scope of the characterization

To identify the most appropriate management actions to address the water quality issues on which the Water Management Plan is focused, it is important to have an understanding of the source, pathway and fate of sediments and nutrients which are transported into rivers and streams in the watershed. Recent source water protection planning has helped to characterize the sources and transport mechanisms by which ground water quality can be impacted (LERSPC 2012); however, a more thorough characterization is required for issues affecting surface water. This report is focused on the sources and transport mechanisms that affect surface water quality issues.

Describing and characterizing water quality conditions are the first steps toward developing a better understanding of how the watershed is functioning. This information helps to identify potential sources and transport mechanisms that help to move nutrients and sediment into surface waters. Ultimately, understanding and adapting management practices to address the sources and mechanisms behind priority surface water quality issues will support more effective watershed water quality management.

The characterization of surface water quality issues is influenced by the choice of measures for water quality; what is considered to be 'good' water quality depends on the values or uses of the water body. For instance, the different aspects of water quality are important for the support of valued aquatic species (e.g., aquatic species that are at-risk, sport fish) or for the use of water for municipal drinking water supplies. Furthermore, different water quality issues occur in different types of waterbodies. In the Grand River watershed, there are small streams, large rivers, in-river dams/weirs, reservoirs, as well as Lake Erie to consider. This report is not intended to be a comprehensive analysis of all water quality issues. Instead, the characterization in this report is focused on nutrient and sediment inputs causing issues in surface waters. These issues are particularly relevant to the Water Management Plan goals, since nutrient and sediment inputs impact valued components and uses of surface water in the Grand River and are also of consequence to impacts on the eastern basin of Lake Erie.

The purpose of this report is to summarize the approaches taken by the Water Quality Working Group to characterize sources of nutrients and sediment in the watershed. Limited availability of data and information specific to the watershed prevents a full 'accounting' or 'budgeting' of nutrients and sediment from various areas and during specific times of the year. However, the weight of evidence from the various approaches synthesized in this report provides insight into the relative importance of the sources of nutrients and sediment in the watershed. This information helps to inform key management actions.

A variety of approaches are used by the scientific and research community to characterize watershed sources of nutrients and sediment. The approaches range from simple mass load calculations to sophisticated deterministic or statistical watershed models. More sophisticated approaches require large, detailed land use and/or water quality datasets from which to develop relationships or apply mathematical equations which describe specific processes (e.g., soil erosion). The Grand River Conservation Authority is the custodian for the Grand River Simulation Model (GRSM). It is an in-river dynamic water quality model that evaluates the cumulative effects of multiple nutrient sources (e.g., municipal wastewater treatment plants) on river water quality within the central region of the Grand River watershed. However, there are no existing models or decision support tools operational within GRCA that extend 'upland' from the river to include the specific watershed characteristics like land use or management practices. Watershed processes have been modelled by numerous researchers, but attempts specific to the Grand River watershed have been limited to the subwatershed scale (e.g., Laurel Creek, Winter and Duthie 2000; Canagagigue Creek, Liu et al. 2007; Fairchild Creek, Liu and Yang 2007). Furthermore, the data requirements to run many of these models are extensive and many of the datasets for the Grand River watershed (e.g., land cover, land management) do not exist or are lacking the detail that is required for a model at the scale of the watershed. Specialized technically skilled human resources must also be dedicated to the management of data and running of the models.

In light of these limitations, the Water Quality Working Group used a more simplistic approach to characterize nutrient and sediment sources in the watershed. The results of coarse scale analyses were combined with the findings of previous studies in a weight of evidence approach. The aim of the approach was to assess *relative* contributions of different sources types and areas (i.e., which were top contributors). To accomplish this it was not necessary to have a precise estimate of the magnitude of total accumulated inputs (i.e., watershed load); however it was important to ensure that errors did not introduce bias towards any particular source type or subwatershed area. The Working Group recognizes that to improve the certainty and precision of the assessment in this report, future work is needed to adopt or adapt watershed models for future water quality management decisions.

3. Source types and transport pathways

Watershed sources of contaminants can be described in a broad sense as either point or non-point sources. A point source is a discharge of contaminants that come from a specific location or facility: for example, wastewater effluent from a wastewater treatment plant outfall; drain outlet or reservoir discharges. Non-point sources of contaminants are those that accumulate in rivers and streams but they come from a large area with no defined outlet. For example, some non-point sources of nutrients or sediment include runoff from areas with agricultural production, forested lands, or urban development (e.g., stormwater or construction sites). A key difference between point and non-point sources is the timing of delivery of nutrients or sediment to surface waters. Point sources enter surface waters at approximately equal daily rates throughout the year. In contrast, the majority of contributions from nonpoint sources typically occur in pulses associated with runoff events from storms or snowmelt.

Sources of nutrients and sediment in the Grand River watershed along with the key transport mechanism responsible for delivery have been identified by the Water Quality Working Group and grouped into broad categories, which are listed in Table 1.

Table 1. Watershed source categories of nutrients and sediment and the key transport mechanism associated with moving nutrients / sediment from land to surface water.

Nutrient & Sediment Source Category			Issue	Key transport mechanisms
I	**II**	**III**		
Non Point Sources	Forested, wetland areas	Stormwater	Sediment Phosphorus	Runoff
	Rural (Non Agriculture)	Stormwater	Sediment, Phosphorus	Runoff
	Agriculture	Manure	Phosphorus Nitrogen	Runoff, infiltration
		Inorganic fertilizer	Phosphorus Nitrogen	
		Non Agricultural Source Materials (NASM)	Phosphorus Nitrogen	
		Soil Erosion	Sediment	Runoff
	Urban	Stormwater	Sediment, Phosphorus	Runoff
	In-River	Sediment	Sediment, Phosphorus	In-river flows; bank scouring; weirs/dams; internal cycling of nutrients
	Large Water Mgmt Reservoirs	Sediment	Phosphorus	Internal cycling of nutrients
	Septic Systems	Effluent	Nitrogen	Infiltration
Point Source	Wastewater Treatment Plants	Effluent	Phosphorus Nitrogen	Direct discharge
	Agriculture Washwaters		Phosphorus Nitrogen	Direct discharge

Sources on the landscape are important (in the context of this report) only if they are hydrologically connected to surface waters. Therefore, hydrologic connectivity must be acknowledged to identify key watershed sources that have the potential to impact conditions in surface waters. This underscores the need for better geospatial information that can be used to delineate hydrologically active areas in the watershed.

Hydrologic transport processes responsible for mobilizing nutrients and sediment are illustrated in Figure 1. The movement of sediment and phosphorus associated with sediment (i.e., particulate phosphorus) from the land to water is primarily achieved through water erosion and runoff processes. Erosion of the stream banks and bed material can serve as a transport mechanism as well as a potential source of sediment (and likely phosphorus). Another mechanism by which nutrients enter surface water from diffuse sources on the landscape is through the transport of dissolved forms (e.g., nitrate, phosphate) in surface runoff through overland flow. Dissolved forms may also enter groundwater as water infiltrates through the soil profile to shallow groundwater, which may then flow down gradient toward surface water (e.g., rivers and streams). Where dissolved nutrients percolate deeper (i.e., into aquifers), groundwater discharge may be an additional pathway that transports nutrients from the soil profile into surface water.

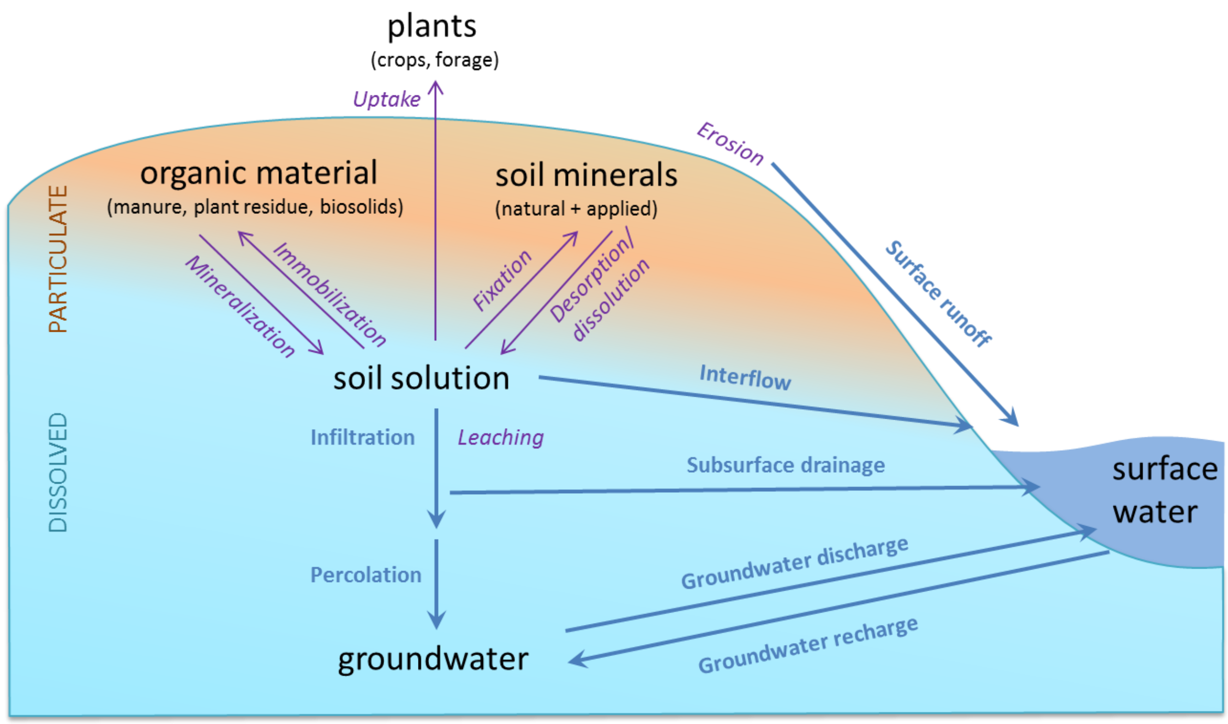


Figure 1. Simplified schematic of hydrologic processes (in blue) and nutrient cycling or export (in purple) from diffuse sources on the landscape. Hydrologic processes provide connectivity between surface water and soils, where nutrients cycle between dissolved and particulate states and organic and inorganic forms. Some transport processes (e.g., preferential flow) are not illustrated.

The likelihood for transport to occur by any of the hydrologic processes described above is influenced both by the natural characteristics of the landscape and by human activity. For example, the potential for rainfall to generate surface runoff or result in infiltration is influenced by soil porosity and texture as well as the intensity of subsurface tile drains and tillage practices. The risk that overland flow erodes and transports nutrients and sediment to surface water is related to slope length, gradient, surface texture and cover as well as land management activities such as the form, rate and placement (e.g., incorporation) of applied nutrients. Structures that affect the drainage of these landscapes, such as municipal drains and field tile drains, modify natural transport pathways, impacting the amount, form and timing of the delivery of nutrients or sediment from the land to the water (Fraser and Fleming 2001).

The transport mechanisms responsible for the delivery of nutrients and sediment from diffuse sources on the land to a watercourse, as well as any transport modifiers such as agricultural drains and tillage practices/compaction, are considerations that are fundamental to future water management options. They are particularly important to developing an understanding of the key areas for non-point source contributions of nutrients and sediment. Although the analysis within this report is not at a sufficient spatial or temporal scale to quantify contributions through the various transport mechanisms, it uses a weight of evidence approach to formulate hypotheses about their relative importance.

Background on water quality in the Grand River watershed

4. Introduction to the Grand River watershed

The Grand River watershed is complex. Water quality is affected by a wide range of natural and anthropogenic influences which vary among (and within) the major subwatersheds of the Grand River watershed, which are shown in Figure 2. Water quality in Grand River and its tributaries is a reflection of the geology; land use/land management practices; and seasonal weather conditions (e.g., rainfall, snowmelt) and resulting impact on watershed hydrology. Pressures that affect water quality and water quantity include agricultural land use, urbanization and point source discharges. These pressures and associated drivers vary temporally and spatially. Understanding and interpreting water quality in the watershed requires a firm understanding of the drivers and pressures in the watershed and their influence on water quality (and quantity).

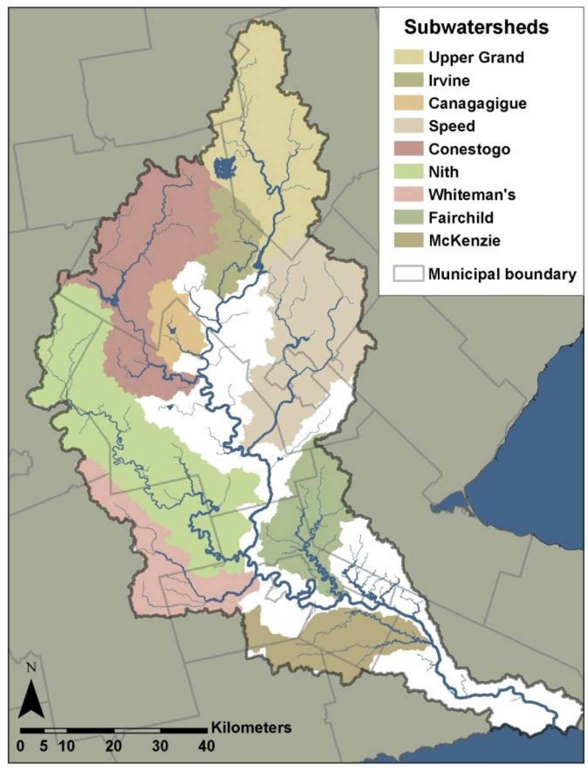


Figure 2. Major subwatersheds in the Grand River watershed on which this report is focused

4.1. Surficial geology/physiography/ hydrology

Watershed soil condition (e.g., impermeability, saturation etc.) combined with a significant amount of precipitation or snowmelt influences hydrologic processes such as overland runoff, rural soil erosion and stream bank erosion, which are the primary delivery mechanisms responsible for mobilizing particulate phosphorus and sediment from large diffuse areas. In contrast, highly permeable soils, such as coarse gravel and sands, can facilitate the movement of dissolved nutrients (e.g., nitrate) to shallow groundwater which can then migrate toward and get discharged to local streams and rivers. These mechanisms play a significant role in moving nutrients and sediment to the Grand River from diffuse or non-point sources.

The diverse geology and physiographic features in the Grand River watershed add to the complexity of the natural environment. There are three general physiographic regions in the watershed, each with a unique influence on the water quality of rivers and streams: the upper till plain; central gravel moraines; and lower clay plain. Figure 3 illustrates the three distinct geologic regions within the Grand River watershed and the variations in runoff that are characteristic of each region.

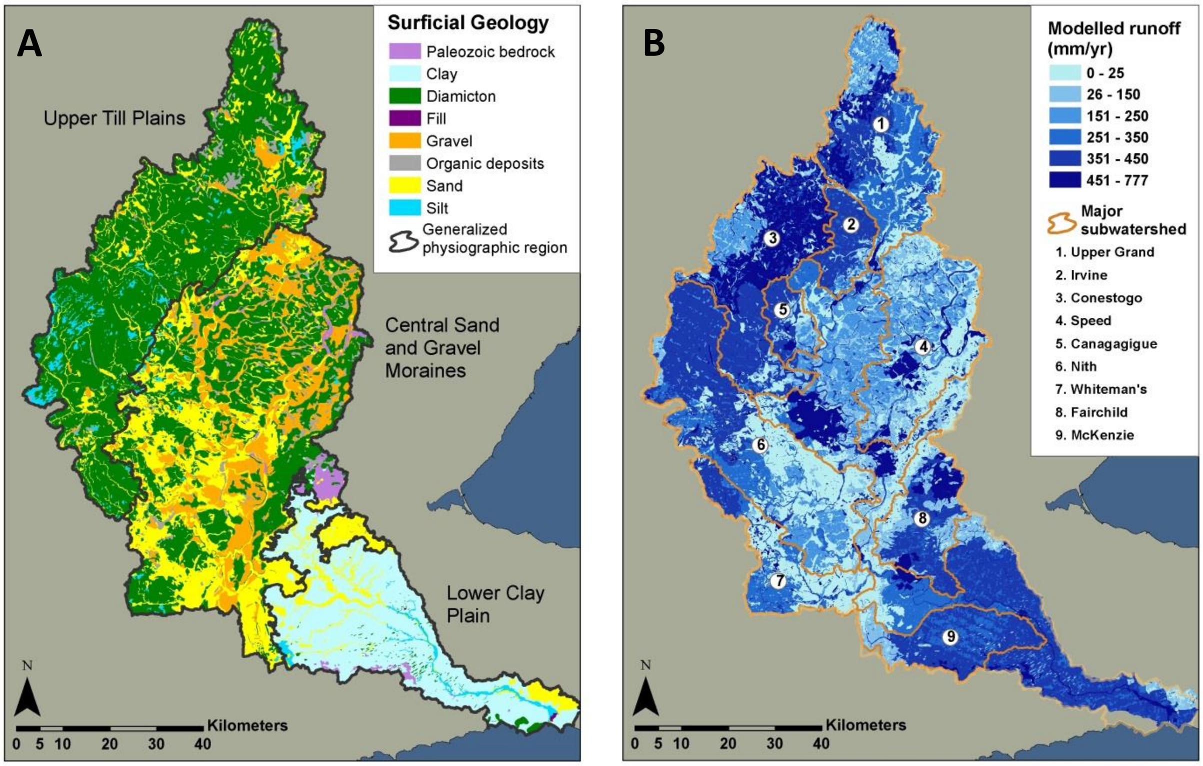


Figure 3. Surficial geology (A) and relative runoff (B) of the Grand River watershed. Surficial geology was provided by MNDM (OGS 2003). Runoff was determined by the continuous streamflow-generation model for the Grand River watershed (GRCA 2012).

The upper till plain spans most of the upper Nith and Conestogo subwatersheds (Figure 3). This geologic material facilitates the movement of water over the land surface, which increases the delivery of sediments and sediment-bound contaminants, such as phosphorus, to streams and rivers.

The gravel moraines and sand plains in the central region of the watershed are highly permeable and allow for a significant amount of water to recharge shallow groundwater aquifers. These aquifers, in turn, provide groundwater to streams and rivers within this region of the watershed. The added groundwater aids in the dilution of contaminants and enhances and facilitates nutrient cycling and other biogeochemical processes in the central region of the watershed.

The lower clay plain encompasses much of southern part of the watershed. This area tends to have high runoff (Figure 3) that carries fine particles and clay-bound materials, such as phosphorus. In reaches where clay particles are suspended in the water, the river takes on a cloudy or turbid coloration.

In some reaches, the hydrology of the watershed has been modified by large water control structures (Figure 4). These structures serve multiple purposes including flood damage reduction and low flow augmentation. Excess water is taken into storage during high flows thereby reducing peak flood levels and flood related damages. Water in storage is then released gradually during periods of low flow to add water to the river system to improve water quality and provide a consistent water supply. The hydrologic character of the reaches both above and below the reservoirs has changed as a result of flow management. Retention of water in the reservoirs has shifted some reaches above the control structures from riverine to lake-like conditions. Although water levels may drop significantly by the late fall, enough water is retained in the reservoirs to support healthy aquatic communities including populations of sport fish.

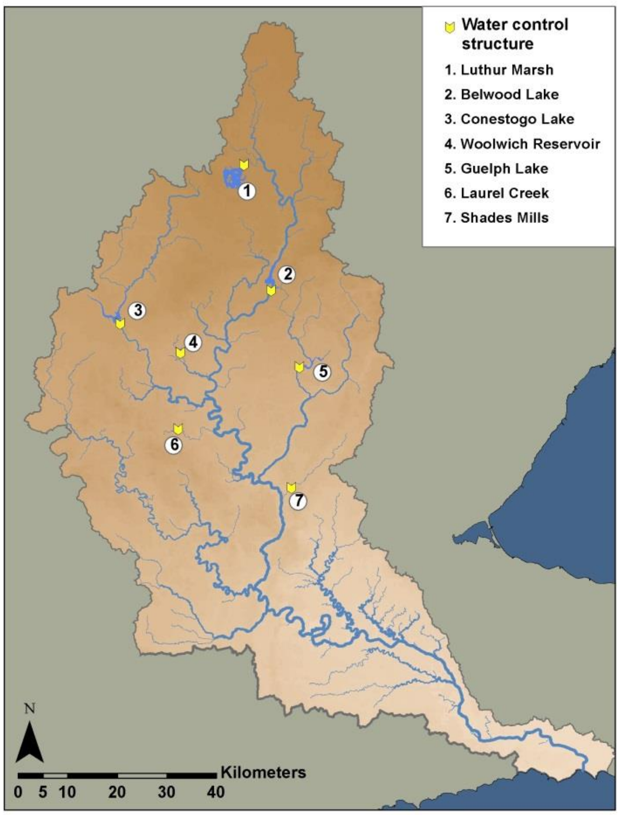


Figure 4. Location of the water control structures that provide flood control and low flow augmentation

4.2. Land use, land management practices

Human activities can impact the quality and quantity of surface (and ground) waters. Land *uses* describe a category of usage, such as urban areas, agriculture, forestlands, and wetlands. Land *management practices* describe specific activities such as the application of fertilizers to lawns, animal manures to agricultural fields and the paving of roads or parking lots.

The Grand River watershed is approximately 6,800 km^2. Land use in the Grand River watershed is dominated by agriculture. Approximately 71% of the total watershed area is in agricultural production. Figure 5 shows a clear shift in land use between the upper and central regions in the watershed. About 82% of land on the upper till plain (e.g., upper Nith and Conestogo subwatersheds) is in agricultural production while only 64% of the land within the central region is in agricultural production. The large urban areas are concentrated in the central region of the watershed but at the large watershed scale, only amount to 5-6% of the total watershed area. Forestlands and wetlands combined are about 20% of the total watershed area.

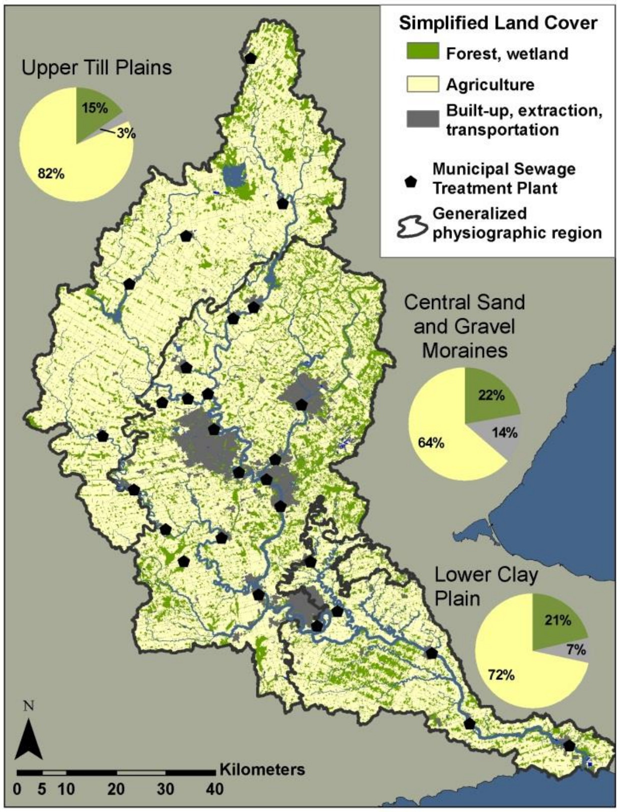


Figure 5. Land cover in the Grand River watershed, summarized by physiographic region. Land cover data produced using information from 2000-2002 and provided by the Ministry of Natural Resources (MNR 2008).

Some of the most intensive agricultural production in the watershed is on the upper till plain. This is illustrated by the regional distribution of nutrient production associated with the density of various types of livestock and incidence of fertilizer use, based on data from the 2006 Census of Agriculture (Lake Erie Source Protection Region Technical Team 2008). Livestock density suggests that there is the potential for relatively high (per unit area) production of nutrients associated with livestock in the Conestogo and Canagagigue subwatersheds and the upper portion of the Nith subwatershed (Figure 6A). According to the census data, fertilizer use is more common on parts of the upper till plain (Canagagigue, Irvine and Conestogo) relative to other areas (Figure 6B). If nutrient production/application in these areas is not balanced with nutrient removal (e.g., by crop harvest) , the risk that they may be lost to surface water or groundwater is increased.

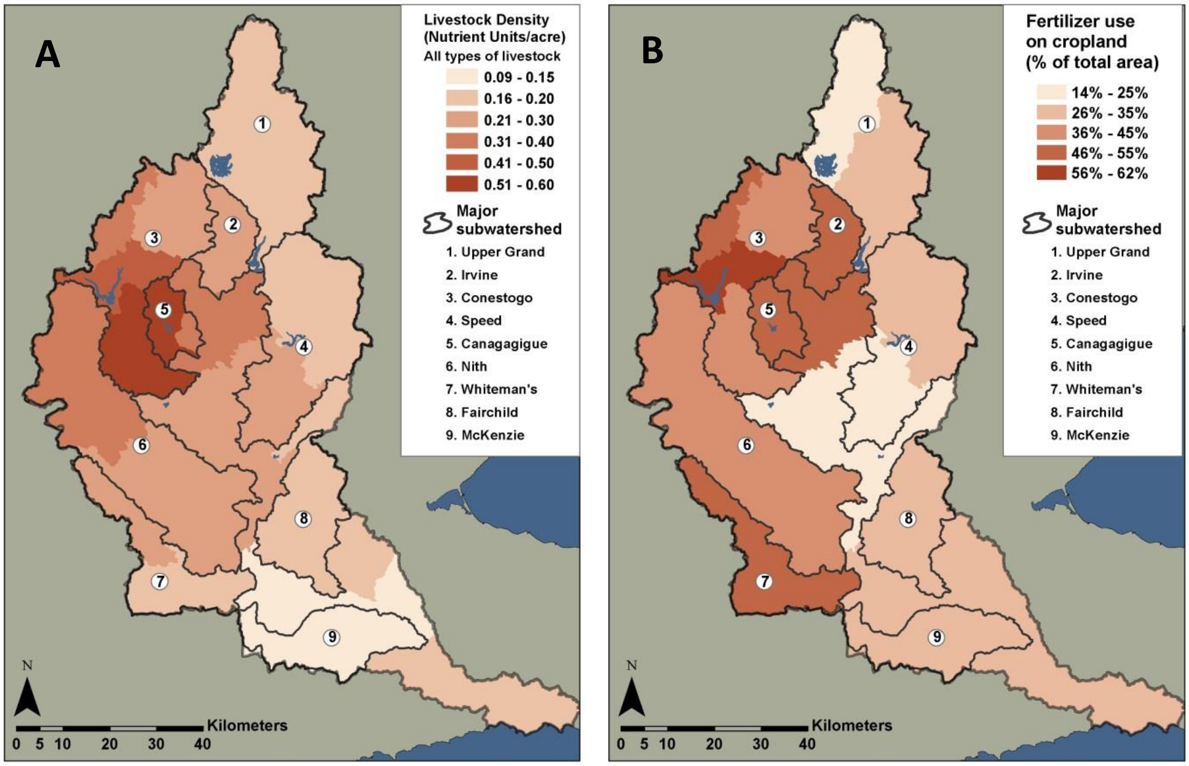
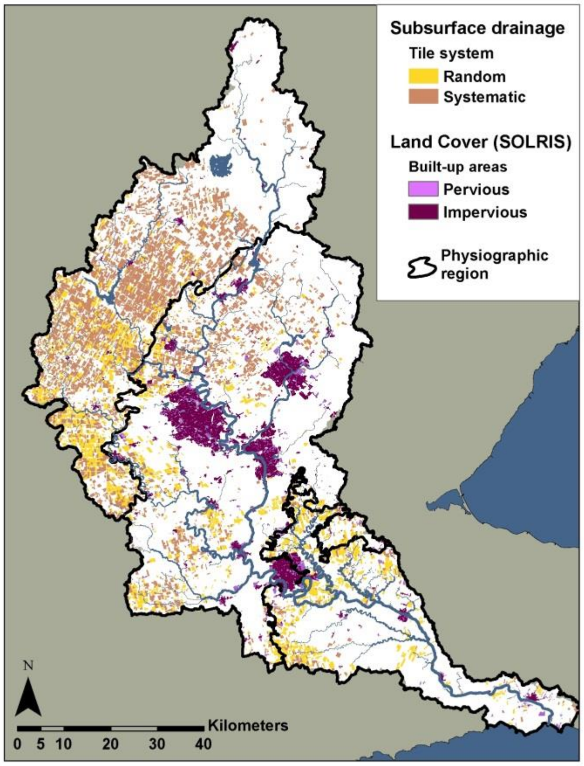


Figure 6. Density of nutrient production from all livestock types (nutrient units within the subwatershed area) (A) and proportion of subwatershed area on which there is agricultural use of fertilizer (B). Data from 2006 Census of Agriculture.

In the central gravel moraine region, urban development covers approximately 14% of the total area (Figure 5). A large impact of urban development is the resultant increase in stormwater. Impervious surfaces increase runoff which carries sediment and associated nutrients, as well as trace contaminants. The percentage of land that is urbanized is relatively low at a watershed scale, but at a regional scale, the urban land use is increasing. Much of the urban development in the watershed prior to 1980 does not have stormwater management control (e.g., AECOM 2011; AMEC 2012).

Urban areas are also associated with point source discharges, such as wastewater treatment plants. These point sources have an important influence on water quality. There are 30 wastewater treatment plants in the watershed (Figure 5). There are very few industrial discharges directed to the river; most industrial discharges are routed through municipal sanitary sewers and the effluent is treated at municipal wastewater treatment plants.

Both urban and rural land management can modify the hydrologic cycle. Whereas an increase in impervious surfaces associated with urban land cover can increase overland flow, modifications to rural or agricultural landscapes can have different effects. For instance, to improve agricultural productivity, hydrology is often altered to facilitate drainage of the landscape. The increased drainage is commonly accomplished by a network of subsurface drainpipes (tile drains). These systems collect excess water above field capacity that has infiltrated the soil and enable subsurface flow of water away from cropland and into surface water features (e.g., streams, municipal drains). A large portion of the upper till plain is covered by agricultural fields that have tile drainage (Figure 7).



Total subwatershed area (Ha)		Fields with tile drainage (Ha) ◊	(% by area)	
			Systematic	Random
Speed	78077	5465	6%	1%
Irvine	19647	7269	34%	3%
Canagagigue	14767	6793	36%	10%
Conestogo	81993	35257	34%	9%
Nith	112800	38352	21%	13%
Fairchild	40075	8015	6%	14%
Whitemans	40395	10099	15%	10%
McKenzie	36824	4787	4%	9%
Watershed	***503702***	***141037***	***18%***	***10%***

◊ This is the complete area of the field that contains drainage tiles; the actual catchment area of the tiles may be smaller.

Figure 7. The extent of agricultural fields with documented tile drainage and pervious or impervious urban cover in the Grand River watershed. Urban land cover data produced using information from 2000-2002 (MNR 2005); tile drain spatial data last updated by OMAFRA between 2005 and 2010 (MNR 2010).

5. Surface water quality issues linked to nutrients and sediments

As noted earlier (in section 2) the purpose and scope of this report is not comprehensive to all water quality issues. It will focused specifically on a few key water quality issues in the Grand River watershed caused by inputs of nutrients and sediments. These issues currently impact water uses or valued characteristics of water, such as the use of water for municipal drinking water supplies or the support of important aquatic species (e.g., species at risk, sport fish). The focus of the report is on the identification of the source types and areas that contribute nutrients and sediments, which can be transported long distances downstream to have impacts on locations far from where they originate. Understanding where nutrients and sediment are coming from in a watershed, their source and the mechanism that is facilitating their transport, will aid in the identification of management actions to minimize their impact.

5.1. Impacts of nutrients and suspended sediments on surface water

High concentrations of nutrients have long been recognized as an issue in rivers and streams in the Grand River watershed (Sandilands 1971; GRIC 1982; GRCA 1998) as well as downstream, in the Lake Erie ecosystem (Joosse and Baker 2011). Although the concentrations of nutrients, such as phosphorus, have decreased substantially since the 1970s as a result of legislation and various programs, they have not dropped to levels below which eutrophication (i.e., over-enrichment of nutrients) is less problematic

(Cooke 2006). Recent assessments of the ambient conditions in the Grand River watershed (Cooke 2006; Loomer and Cooke 2012) have illustrated the very high levels of phosphorus and nitrogen throughout the river system.

The water quality issues associated with eutrophication are largely the consequence of the prolific growth of aquatic primary producers (e.g., plants and algae) in the river system. Phosphorus is the limiting nutrient responsible for prolific growth of aquatic plants and algae in most freshwater ecosystems (Schindler 2012), although nitrogen can also play an important role (Dodds 2006).

If nutrient availability is high, aquatic primary producers are able to produce large amounts of biomass where adequate light conditions and substrate exist (Painter et al. 1976; Hood 2012). Studies in headwater streams of the Grand River watershed have suggested that total phosphorus concentrations above a threshold of 0.03 mg/L are conducive to the growth of common species of nuisance aquatic plants and algae (e.g., *Potamogeton* sp., *Cladophora* sp.)(Painter et al. 1976). Where these organisms grow abundantly, conditions in the river typically swing from oxygen super-saturated (from daytime photosynthesis) to oxygen-depleted (from overnight respiration). The overnight decrease in dissolved oxygen can result in conditions that are harmful or even lethal to sensitive organisms, such as fish. Similarly, low dissolved oxygen conditions can also be caused by the consumption of oxygen though decay of large amounts of plant and algal biomass. Key biochemical processes involving nutrients and oxygen in aquatic systems like the Grand River are illustrated in Figure 8.

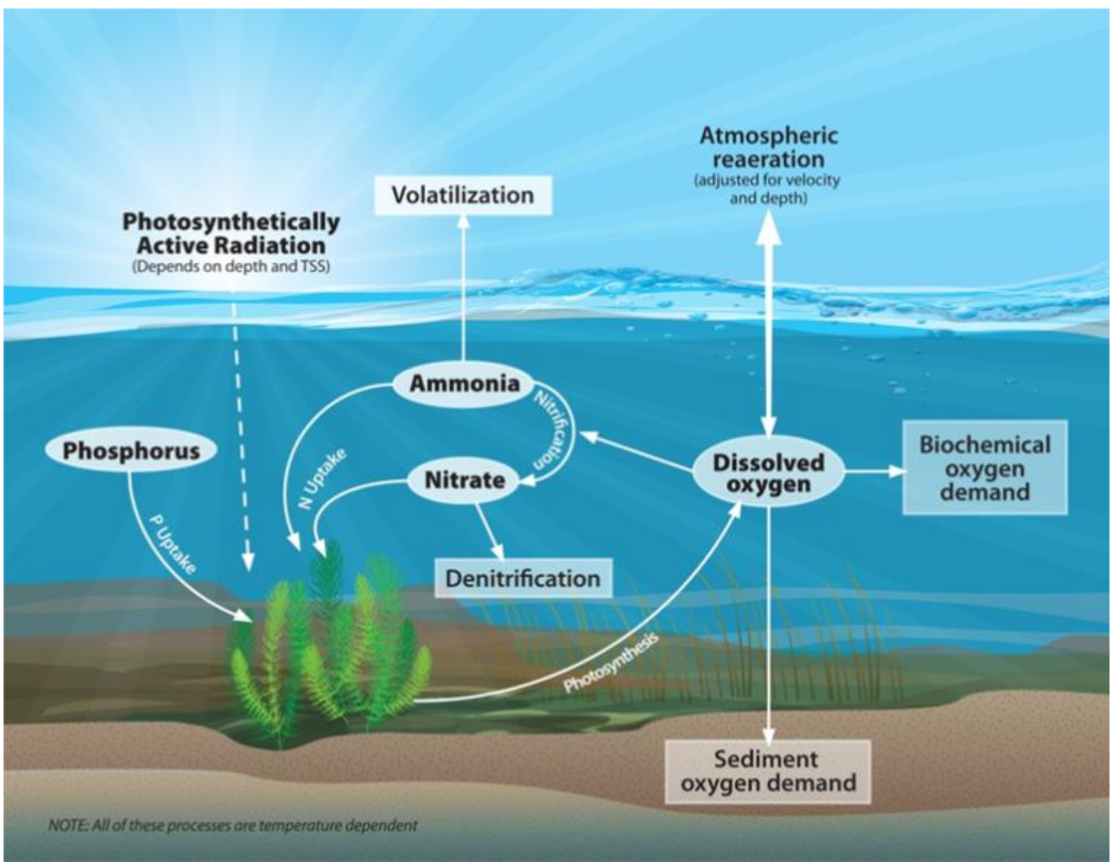


Figure 8. Illustration summarizing key biochemical processes in the Grand River system.

Similar to the effects in rivers, high nutrients can impact conditions in the reservoirs connected to the river system. High nutrient conditions can impact the structure, function and composition of the aquatic community in the reservoirs. For instance, elevated phosphorus availability concurrent with relatively low availability of nitrogen is sometimes linked to the proliferation of cyanobacteria, which have the potential to form toxic blooms in lakes and reservoirs (Orihel et al. 2012). Blooms of attached or planktonic algae can impact the aesthetics of the reservoirs, which are popular areas for water-based recreation. Other impacts of high nutrients in reservoirs can include changes to the food web structure and oxygen depletion in the bottom waters of the reservoir with the decay of organic matter created by the large nutrient-fueled blooms.

While nitrogen in the form of ammonia and nitrate is important to the growth of aquatic plants and algae, these forms can also have direct effects on aquatic organisms since they can be toxic at high concentrations (Camargo et al. 2005). Nitrate is also important in the context of the river as a source for drinking water supplies, since nitrate toxicity can cause human health concerns associated with the consumption of water with high nitrate concentrations (WHO 2007). Consequently, the treatment of water supplies can be impacted by high nitrate concentrations, particularly because the cost of nitrate removal is very high. In addition to the potential effects from toxicity, high levels of ammonia can cause conditions that are harmful to aquatic organisms since it acts as an oxygen scavenger and can reduce dissolved oxygen levels. The effects of ammonia tend to be located relatively close to the source of input, since it is rapidly converted to nitrate (nitrification; shown in Figure 8) in the presence of oxygen.

Sources that increase the transport of sediments into aquatic systems can have impacts on water uses in locations far downstream. The nutrients associated with sediment inputs (primarily with fine particles) may cause eutrophication in downstream locations. Where deposited sediments accumulate, there is the potential for sediment-associated phosphorus to be released in a dissolved form. Changes to the sediment flux at the scale of a reach or drainage basin may also change fluvial morphology and geomorphology, which may alter the ecology of a river. For instance, deposition of high sediment loads from flashy flows can result in the formation of raised river beds and braided channels (Rosgen 1998), which may have undesirable consequences such as decreased thermal stability (higher potential for warming), decreased habitat for valued fish species (e.g., loss of deep pools), and increased habitat for nuisance plant or algal species (e.g., *Cladophora*). Changes in size structure of the sediment load can impair critical biochemical processes that help to assimilate nutrients from upstream sources. For instance, the ability of organisms in the stream to act as natural “filters” by taking up nutrients is impaired by stream bank armouring, a process caused by the accumulation of fine sediments in the streambed.

High concentrations of suspended sediments can cause a range of impacts on aquatic organisms including suffocation, behavioural modifications, reduced reproduction success (e.g., smothering of eggs) and habitat degradation (Kerr 1995). The effects depend on the particle type/size, concentration, and duration of exposure. Suspended sediment can cause indirect effects by reducing water clarity. Elevated concentrations of particulate matter (e.g., suspended solids, phytoplankton) reduce light penetration and cause high turbidity. Turbidity levels that are high on an on-going (i.e., chronic) basis can impair aquatic systems by reducing light penetration, which then limits primary production and disrupts visually-mediated behaviours such as foraging (Kerr 1995).

5.2. Influence of seasonal weather conditions and hydrology

Water quality issues are influenced by factors that can vary with season, such as hydrologic processes (e.g., timing, amount of river flows). Characterizing the variability in nutrients and sediments by season and hydrologic regime (e.g., low or high river flows) is essential to identify and understand the drivers or mechanisms that contribute to water quality issues in the Grand River watershed, such as runoff from land or point source discharges. Palmer et al. (2005) recommends optimizing water quality management by identifying the flow situations when water quality variables become limiting to ecosystem processes.

High flows as well as low flows in rivers provide important hydrologic and ecological functions (Poff et al. 1997). Snowmelt and runoff from rain on frozen soil can generate particularly high flows during the spring (April – May). Even though high flows may be dampened in reaches below flood control structures (Figure 4), the highest flows in the Grand River system typically occur during the spring (Figure 9). High river flows mobilize and transport sediments and nutrients that are important to floodplains if the rivers remain connected (Junk et al. 1989). Other important ecological functions of high flows include the movement and redistribution of sediment within rivers (Junk et al. 1989). However, high flows can also increase suspended sediments which (as described above) can be harmful to aquatic organisms or limit primary production if conditions persist over extended periods of time (Kerr 1995; Newcombe 1998). Furthermore, because they represent a large proportion of flow by volume, high flows are likely to deliver the largest loads of nutrients or sediments to downstream receivers (Smith 2013). The impacts of the nutrient and sediment loads transported during high flows tend to be most significant to downstream water bodies where they may accumulate (e.g., lakes, reservoirs). Although the bulk of the nutrient load may be transported during the spring, ecological impacts may not occur until the start of the growing season when temperatures and biological productivity increase.

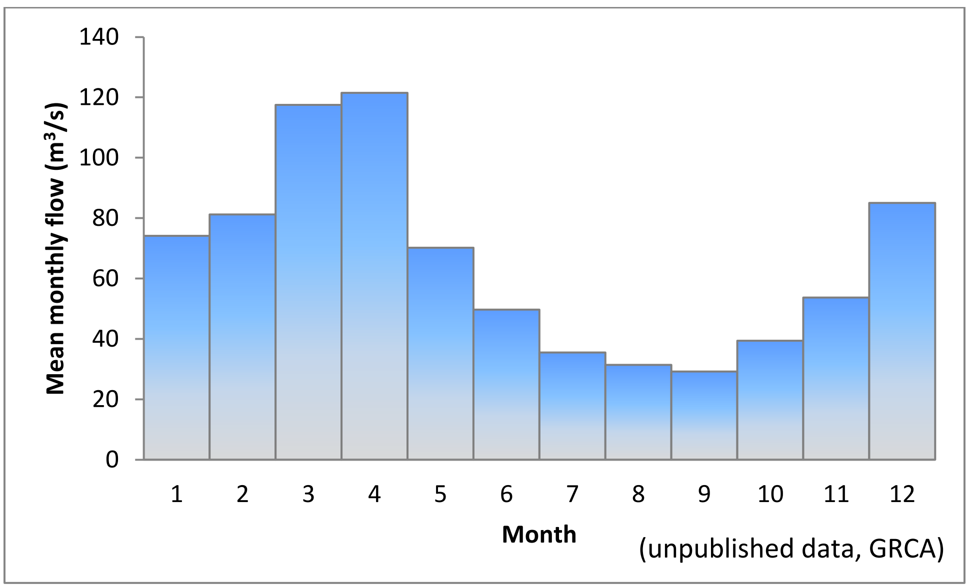


Figure 9. Average monthly flows (1974 to 2013) in the southern Grand River at York, Ontario.

In contrast, lower river flows typically occur during the summer or winter depending on whether the river is regulated by upstream dams. In the regulated river reaches, the lowest flows tend to occur during the winter. Periods of low flows present different water quality issues than high flow periods and are influenced by different sources (GRWMP 2013a). For instance, point source discharges tend to have a more profound effect on river water quality during low flows since there is minimal dilution of inputs. Water quality issues in summer low flow periods tend to focus on in-river biogeochemical processes of aquatic plants and algae.

Much of the long-term water quality dataset collected in the Grand River watershed has been collected in partnership with the Ministry of the Environment under the Provincial Water Quality Monitoring Network, which has been centred on open water ambient or low flow conditions. However, during the early 2000's the GRCA implemented changes to the sampling strategy of PWQMN sites in the watershed which improved characterization of high flow events and improving the ability to evaluate water quality issues in all seasons. A recent analysis of water quality in the Grand River watershed (Loomer and Cooke 2011) noted that further improvements to the sampling strategy (i.e., additional data collection during winter and spring) would provide additional insight into the full range of water quality conditions.

5.3. Key water quality issues in the Grand River, by season

Water quality issues in the Grand River vary with season, particularly those related to inputs of nutrients (Figure 10). These seasonal changes are also reflected in the relative importance of different types of sources (i.e., point and non-point). The following section will describe the factors contributing to seasonal changes in water quality by outlining the influence of seasonality in factors such as river flow (as described above) and biological processes (e.g., plant growth, microbial activity). Although not comprehensive in scope, it highlights some of the key water quality issues in the watershed associated with sources of nutrients and sediments.

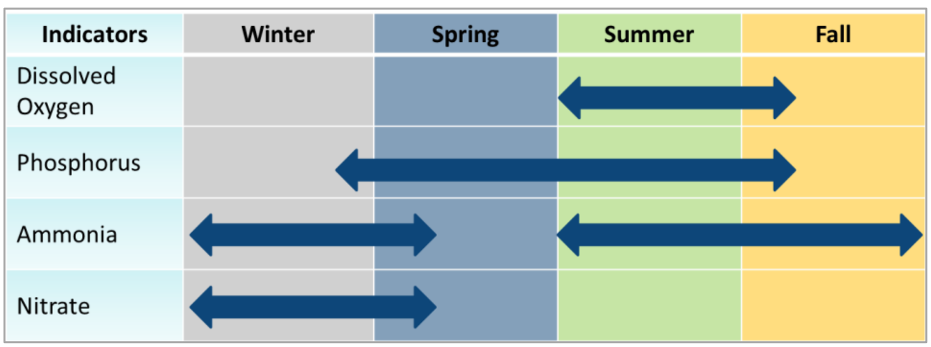


Figure 10. Water quality indicators related to nutrient inputs and the time of year (season) in which they present as issues in the Grand River watershed.

5.3.1. Winter and early spring – high nitrate concentrations

Winter conditions are typified by cold water temperatures, low biological productivity and ice cover on some sections of the river. Since there is relatively low surface runoff in the winter, groundwater contributes a relatively higher proportion of the baseflow than in other seasons. In the early spring, flows swell with the large volumes of water in the spring freshet and biological activity remains low, so there is minimal uptake of nutrients by in-stream processes. Elevated nitrate levels have been observed during these seasons, with particularly high concentrations in the Grand River between Shand Dam and Bridgeport. High levels of ammonia can also occur in localized reaches near point sources, and can persist where there is ice cover that limits oxygenation of the water (i.e., and conversion to nitrate through nitrification).

The Grand River system is used for municipal drinking water supplies. There are four communities which draw raw water from the river to service their communities. Nitrate is a parameter of concern in drinking water given its impact on human health. The Ontario Drinking Water Standards (ODWS) set a nitrate concentration of 10 mg N/L as the maximum allowable level for drinking water in Ontario. Since nitrate is in the dissolved form in water, it is very difficult and costly to remove.

Nitrate levels in the river system are increasing (Cooke 2006). Furthermore, monitoring of baseflows during winter conditions have shown periodically high levels (6 – 8 mg N/L) in the river at locations above drinking water intakes (GRCA, unpublished data). Given the increasing trend and the seasonally high levels in the river system, nitrate is a parameter of concern, particularly during the winter and early spring.

5.3.2. Spring high flows - phosphorus and sediment concentrations (and loads)

In contrast to the low flows during the winter, spring is characterized by high runoff events due to snow melt and heavy rain. These hydrologic processes lead to soil or stream bank erosion and high sediment delivery to the river from agricultural and urban areas. Many studies have documented the substantive mobilization of phosphorus and sediment that can occur during the spring freshet in rivers. Surface runoff and resulting high river flows from melting snow in the spring can contribute most of an annual phosphorus or sediment load (e.g., kilograms). The highest concentrations of total phosphorus (the sum of dissolved and particulate/solid forms) and suspended sediment are typically seen in the Grand River watershed during the spring freshet; recent measurements show total phosphorus in the spring to be two to five times higher than summer concentrations (Loomer and Cooke 2011). It is probable that the true range is higher since the sampling methods likely missed periods when concentrations would have peaked.

Although periods of elevated suspended sediments concentrations can cause a range of impacts during this season (described in section 5.1), water quality concerns in the spring are primarily related to the total loads of phosphorus and sediment delivered to the river system from non-point sources. As noted above, the endpoint for the loads transported during high flows tend to be on the downstream areas where the material settles out (e.g., downstream reservoirs, Lake Erie). The impacts of the load accumulated from the spring freshet may also not manifest as an issue until later in the season or in the summer (e.g., when prolific plant or algal growth can be fueled by the dissolution of nutrients from accumulated particulate material).

5.3.3. Summer low flows - phosphorus concentrations

During the summer period, water temperatures are high, river flows tend to be low and light availability increases. These conditions facilitate high biological productivity, including the growth of aquatic plants (as described in section 5.1). In addition, since low flows decrease the potential for dilution of point sources, high concentrations of ammonia can also cause toxic or low-oxygen conditions in some reaches or localized areas during the summer.

The amount of phosphorus in the river system during the summer growing season is a critical factor influencing biochemical processes, such as nutrient uptake and growth of aquatic plants and algae (Figure 8). Generally in the Grand River system, the concentration (i.e., availability) of nutrients is sufficiently high during this period that it does not limit the growth of aquatic plants and algae (Barlow-Busch 2006; Loomer and Cooke 2011; Hood 2012). In many river reaches where substrate, light and water levels are suitable, the high concentrations of nutrients allow prolific growth of aquatic plants and algae (Painter et al. 1976; Hood 2012). Respiration by these organisms during the summer growth period can cause dissolved oxygen levels to fall to a level that can cause stress or mortality of sensitive organisms, such as fish (Loomer and Cooke 2011; GRWMP 2013b). Similarly, excessive inputs of nutrients can fuel algal blooms in reservoirs, impacting both human uses and aquatic ecosystem health.

The form of phosphorus (i.e., particulate or dissolved) is particularly important during the summer growing season. Nutrients that are more biologically available can have a large effect on growth of aquatic plants and algae. The dissolved form of phosphorus tends to be more bioavailable so it can be readily taken up and used for growth (Withers and Jarvie 2008). The importance of point sources, such as wastewater effluent, becomes heightened during this period, since they tend to have a relatively high proportion of phosphorus in a form that is highly bioavailable (Hore and Ostry 1978; Jarvie et al. 2006). In addition, point sources are important during periods of low flow because they comprise a higher proportion of the river flow than in high flow periods.

5.3.4. Summer high flows - phosphorus and suspended sediment loads (and concentrations)

There is limited phosphorus and suspended sediment data available to thoroughly characterize the conditions that result from summer storm events on the Grand River system. Although data is sparse, event-based monitoring of suspended sediment and turbidity suggests that the sediment mobilized during summer storms can be significant to impacts from elevated concentrations. For instance, monitoring in the central Grand River region during a summer storm event in 2011 measured a large spike in turbidity (exceeding 200 NTU) that lasted >6 hours, suggesting a substantive load of sediment was delivered to the river system (GRCA, unpublished data). In reaches where particulates settle out, the increased sediment load can change the type or rate of sediment deposition, which in turn can impact physical shape or geomorphology of the river. The cumulative effect of increased sediment inputs from 'flashy' flows occurring over many years can cause the formation of the raised river beds and braided river channels (Rosgen 1996); this is reflected in the morphology of the central Grand River region, where the river receives flows from the urban areas. As noted above (section 5.1), the alteration of the river channel form and function in this reach likely also affects critical biochemical processes that help to assimilate nutrients from upstream sources. Deposition of the sediment-attached phosphorus that is mobilized during this period from land surfaces or through re-suspension may also contribute to a residual 'pool' of phosphorus that leads to degraded water quality (e.g., low dissolved oxygen) during the intervening low flow periods by fueling the nuisance growth of aquatic plants and algae.

In addition to the issues associated with the deposition of the sediment load mobilized during summer high flows, aquatic life can be harmed by exposure to the high concentrations of suspended sediments. The negative effects of high suspended sediment (described in section 5.1) are of particular consequence to the aquatic community, causing behavioural changes, impairment of growth, as well as mortality (Kerr 1995). Where summer high flows often result in high suspended sediment, prolonged or frequent sediment 'pulses' may result in the absence of species that are unable to escape or protect themselves (e.g., mussels).

Characterization of sources: a weight of evidence approach

6. Review: nutrient and sediment source studies in the Grand River watershed

6.1. Annual and seasonal loading: point and non-point sources

Over the past 40 years, the Grand River system has been the focus of many studies evaluating the effects of land use on river water quality. For example, starting in the 1970s, the Pollution from Land Use Activities Reference Group (PLUARG) undertook studies to evaluate the pollution from agriculture, forestry and other land use activities on Great Lakes water quality. This series of studies were implemented across the Great Lakes basin by the International Joint Commission which established the International Reference Group on Great Lakes in response to the 1972 Great Lakes Water Quality Agreement. As part of PLUARG, detailed surveys of water quality were conducted in several tributaries to the Great Lakes, including intensive water quality monitoring in the Grand River watershed.

One such study by Hore and Ostry (1978) used the Grand River as a pilot watershed to investigate the delivery of contaminants to the Great Lakes to determine the relative significance of sources of pollutants. Annual loads of contaminants (nutrients, sediments, etc.) contributed by various land uses have been determined from intensive monitoring of nutrients, sediment and other contaminants throughout the Grand River system. According to estimates of annual loads, agriculture, point-source discharges, and private-waste disposal systems were the dominant nutrient sources in the watershed.

The PLUARG study by Hore and Ostry (1978) indicated that the relative importance of different sources to the Grand River system varied seasonally and also with respect to the endpoint of the impact (e.g., eutrophication in rivers vs. phosphorus loading to Lake Erie). For example, the PLUARG study showed that non-point sources had a dominant influence on concentrations of phosphorus and sediment in spring runoff. Conversely, the influence of wastewater treatment plants on waste assimilation and water quality was shown to be greatest during low flow summer conditions when biological activity is at its peak.

Similar seasonal shifts in the concentrations and loading of nutrient and sediment have also been demonstrated by many recent studies in the Grand River watershed (Draper and Weatherbe 1994; Stantec 2010; Plawiuk 2011; MacDougall and Ryan 2013; MOE 2012). Seasonal loading from agricultural, urban and municipal sources of nutrient and suspended sediments in the Grand River as it flows into and out of the Waterloo Region (between West Montrose and Glen Morris) were estimated by Draper and Weatherbe (1994). More recently, seasonal loadings of nutrients between Bridgeport and the City of Brantford from point and non-point sources were also estimated as part of the Kitchener Assimilative Capacity Study (Stantec 2010), which will be discussed below.

6.2. Seasonal shift in the importance of point sources

Recent estimates of regional mass loading by point and non-point sources of nutrients and sediments in the Grand River system demonstrate that point sources are relatively more important than non-point sources in the context of regional eutrophication during summer low flows. For instance, the Kitchener Assimilative Capacity Study by Stantec (2010) indicated that the dominant sources of nutrients between Bridgeport and Brantford shift from non-point sources in the winter and spring to point sources (i.e., Kitchener and Waterloo wastewater treatment plants) in the summer and fall. Similarly, estimates of loads in the Grand River at Glen Morris by Draper and Weatherbe (1994) illustrated that point sources make a relatively small annual contribution to phosphorus loading on a large scale, but can be regionally significant in the summer. Their estimates showed that annual phosphorus discharges from the region's 11 WWTPs were regionally significant during the summer when the river is most sensitive to the impacts of phosphorus enrichment, but made a small contribution (approximately 10%) to the annual load.

The study by Draper and Weatherbe (1994) highlighted the importance of agricultural non-point sources and seasonal high flows to total annual loading. Winter and spring high flows contained the majority (approximately 80%) of the annual phosphorus and suspended sediment load at Glen Morris, which was estimated to come predominantly from rural landscapes. This illustrates how the relative importance of a source may vary with the spatial and temporal scale of the water quality issue under consideration.

In the context of eutrophication of river reaches, it is important to consider the timing and form of nutrient inputs in addition to the magnitude of annual loading. Due to the increased sensitivity of the aquatic ecosystem to eutrophication during the summer, there may be greater risk of ecological impacts from 'available' or soluble reactive phosphorus during this season. Consequently, inputs from wastewater treatment plants (WWTPs) which can be high 'available' or soluble reactive phosphorus (Jarvie et al. 2006) may represent a greater ecological risk than sediment-bound phosphorus from nonpoint sources on the landscape. During the 1970s Hore and Ostry (1978) highlighted the high proportion of dissolved phosphorus in point source discharges to the Grand River system, the majority of which was likely biologically available. It was postulated to have a large effect on downstream reaches. Since that time, wastewater treatment has advanced a great deal resulting in a greater capability to reduce loads of total phosphorus. There is considerable variability in discharge limits for total phosphorus, as defined in each WWTP certificate of approval, but all 30 WWTPs in the watershed have advanced phosphorus removal.

Recent monitoring of effluent from some of the largest WWTPs (Waterloo, Cambridge, Hespler, Guelph) indicates that the effluent contains a relatively high proportion of dissolved phosphorus (Region of Waterloo, unpublished operational data 2008-2012). In downstream reaches in recent summers, sharp increases in phosphorus, nitrogen and depressed dissolved oxygen concentrations continue to be observed, illustrating the strong influence of the large point sources in the central Grand River reach on aquatic plant growth and dissolved oxygen regimes (Loomer and Cooke 2011). This highlights the importance of point source discharges in the Grand River to such regional or localized impacts during summer low flows, a relationship that is likely heightened by the high proportion of dissolved phosphorus in the effluent.

6.3. Urban non-point sources of phosphorus and sediment

Based on loads of phosphorus from urban runoff estimated in the mid-1970s, Hore and Ostry (1978) suggested that urban runoff had a greater impact on the water quality in reaches of the Grand River than on the water quality of the Great Lakes. The study also noted that despite only accounting for 3% of the basin area, urban land use contributed 6% of the sediment load exported to Lake Erie. Unit area loads of suspended sediment were estimated to be double that from agricultural areas. The magnitude of the urban loads are likely to have increased substantially since this time, since urban land use in the watershed has doubled to about 6% of the total watershed area and much of it remains concentrated in the central Grand River region. Regardless, it stands to reason that urban runoff will have the highest importance to river health in the central portion of the watershed where the density of urban areas is highest.

In the 1970s O'Neill (1979) completed a detailed analysis of urban runoff from several urban areas in the Grand River watershed (including sites in Kitchener-Waterloo, Cambridge and Guelph). The study found that approximately 90% of the total phosphorus and 96% of the suspended sediment annual loads from urban areas were delivered during runoff events, with the largest proportion (50-60%) delivered during the spring melt period between February and April. The majority of the phosphorus load (>85%) was associated with the transport of suspended sediment. These patterns were confirmed more recently by Draper and Weatherbe (1994) whose data indicated that phosphorus and sediment export from the central region of the watershed occurs primarily during high flow conditions in winter and spring. The study indicated that urban runoff carries a high suspended sediment and phosphorus load. Their estimates suggested that urban runoff from the Region of Waterloo accounted for a similar proportion of the annual load of phosphorus as the Region's WWTPs. These studies indicate that although urban runoff may not contribute substantially to issues at the scale of the Grand River watershed, urban non-point sources of sediment are likely important to regional water quality issues during runoff events in the late winter and spring. At a regional scale, high concentrations of suspended sediment in urban runoff have the potential to contribute significantly to ecological impacts such as smothering or suffocation of aquatic life, excessive sedimentation, as well as nutrient loading in backwaters or reservoirs in downstream reaches of the river.

6.4. Export of sediment and phosphorus through erosion

Processes that transport sediments and particulate-associated phosphorus from the landscape into surface waters are important in the context of the total annual load to the watershed (and to the eastern basin of Lake Erie). For instance, Draper and Weatherbe (1994) reported that inputs from wastewater discharges were found to be very minor in comparison to the total annual suspended sediment load from other sources. Hydrology is a key driver of the transport processes that influence the export of sediment and phosphorus from non-point sources. The importance of high flow events to sediment yield was demonstrated particularly well in the Grand River watershed by Hore and Ostry (1978), who showed that spring high flows carried a disproportionately high proportion of the total annual suspended sediment load from the watershed (Figure 11). Their dataset also indicated that monthly flows from the Canagagigue subwatershed in the spring represented a high proportion of the annual flow (38-50%) and an exceptionally high proportion (79-81%) of the annual suspended sediment load from the subwatershed.

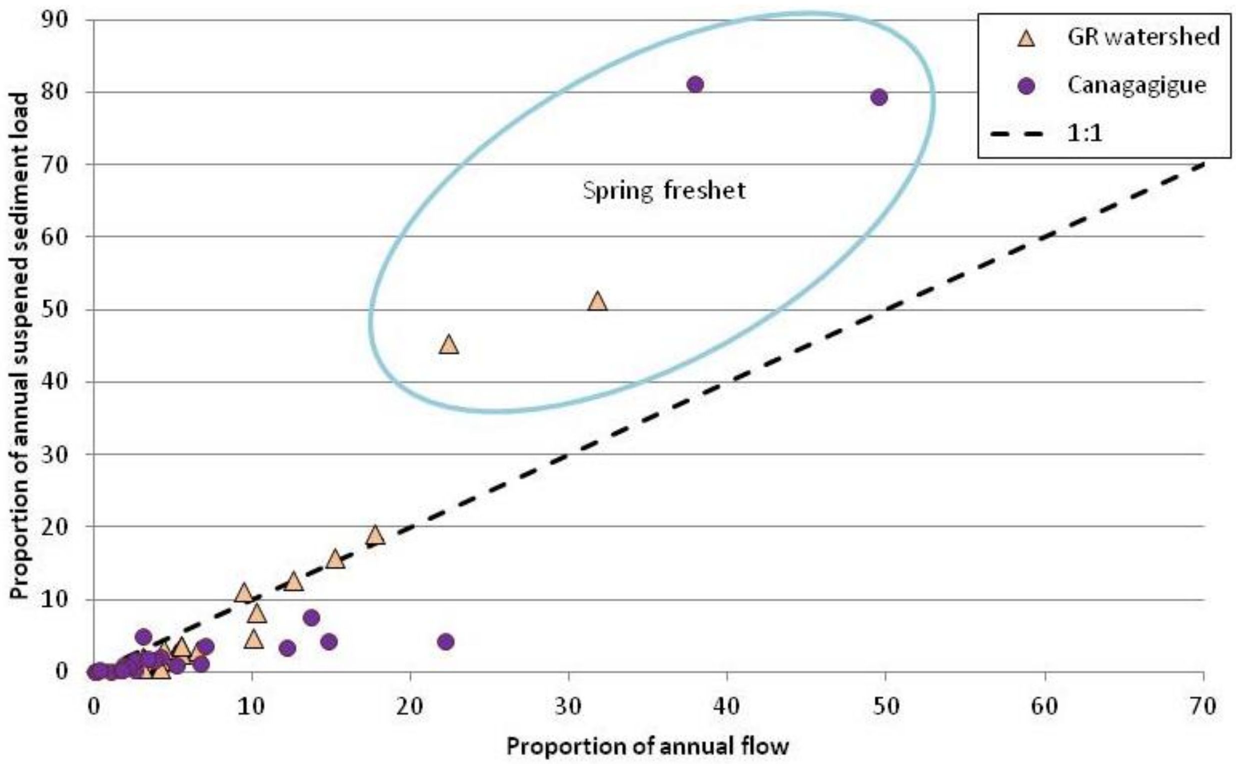


Figure 11. Contribution of monthly flows (1975 - 1976) to the total annual suspended sediment load exported from the Grand River watershed and Canagagigue subwatershed. (Data from Hore and Ostry 1978)

A more detailed assessment of the transport of particulate organic material from Canagagigue Creek was done by Hynes and Dance (1977). The report highlighted the importance of spring high flows to export of nutrients and suspended solids associated with particulate organic matter. Their study found that export of nitrogen and phosphorus in organic material was predominantly associated with fine organic particles (253 µm – 1 cm), the majority of which (95% of the annual load) was transported in the spring freshet. The data indicated that a significant proportion of the particles transported in high flows during the spring were associated with movement of the bedload, which was composed of organic detritus that was sourced from areas outside the stream as well as inorganic particles that had been churned up from the stream bed in the high flows. Although the study indicated that spring high flows are important for transport of organic forms of nutrients that are associated with fine particles, it did not investigate whether the mobilization of organic material into the stream originally occurred during preceding time periods. It is possible that a portion of the particles transported in spring high flows are 'flushed' from backwater or floodplain areas where eroded material has previously accumulated. It is unknown if the mobilization of particle-associated nutrients makes a substantial contribution to the total nutrient loading from subwatersheds in the Grand River watershed. Pathways which carry nutrients from the landscape to surface waters in a dissolved form may also be important to annual loading from some areas of the watershed; a possibility that will be discussed further in the following section of this report.

Where there is higher risk of erosion, particulate-associated phosphorus is likely to make a larger contribution to total phosphorus export on an annual basis. The risk of erosion can be affected by soil characteristics, hydrology and land cover. Draper and Weatherbe (1994) found that the sediment yield from areas in the upper Nith (above New Hamburg) was particularly high: the yield was ten times greater than areas in the Speed River subwatershed, which had the lowest sediment yield of subwatersheds in the study area. The upper Nith has greater potential for generating runoff compared to the Speed River subwatershed (Figure 3) and has a lower proportion of natural cover (Figure 5). The study by Draper and Weatherbe (1994) indicated that the Nith and Conestogo subwatersheds have similar phosphorus yield, despite comparatively lower (approximately 50% lower) sediment yield in the Conestogo subwatershed. This suggests that these areas contribute phosphorus by different pathways, with sediment-associated phosphorus contributing a higher proportion of the total phosphorus load in the Nith than in the Conestogo. These subwatersheds differ significantly in a number of respects including natural and managed factors affecting erosion or deposition of sediment (e.g., runoff potential, Figure 3; regulation of river flows, Figure 4) and potential sources of nutrients on the landscape (e.g., agricultural use of fertilizer and production of manure, Figure 6). Drainage from a large portion of the Conestogo subwatershed is captured in reservoir to control flows, whereas the Nith lacks a similar flow control structure. It is possible that deposition in the reservoir may account (at least in part) for the lower sediment yield from the Conestogo subwatershed in comparison to the Nith. The role of reservoirs in modifying sediment export from subwatersheds of the Grand River system has not yet been characterized, but is important to characterizing sediment sources at a subwatershed scale.

Many studies have not been able to assess the relative importance of in-stream sources of nutrients and sediments; quantitative estimates do exist, but vary widely. As noted above, a study by Hynes and Dance (1977) in Canagagigue Creek indicated that bedload transport was a significant mode of transport for particulates in spring high flows. However, they did not compare the proportion of material originally sourced from the landscape with material sourced from stream bed and bank erosion. Suspended sediment loading from stream bank erosion was estimated by Hore and Ostry (1978) to be similar to that from land that is undeveloped (i.e., wooded), but very small relative to urban and agricultural lands (4% and 7% of the yields, respectively).

In contrast to the findings of Hore and Ostry (1978), information from other areas suggest sediment loading from stream bank erosion may often be underestimated. A study by Tomer and Locke (2011) in the United States noted that in-stream processes are often a larger source of suspended sediments than previously thought. The study was part of an extensive effort by the US Department of Agriculture (USDA) to assess conservation practices in 14 agricultural watersheds that spanned a wide range of landscapes, climate, cropping systems and water quality issues. In some instances, sediment from channel and bank erosion surpassed the suspended sediment load that originated from soil erosion in fields. This source of suspended sediment is likely to be most important in reaches where the fluvial geomorphology is responding to hydrologic alterations caused by changes to the landscape (e.g., drainage). Tomer and Locke (2011) suggested that efforts to control sediment sources would be most effective if they focused on attenuating hydrologic discharge in addition to erosion control. It was not noted whether in-stream erosion of sediment also made significant contributions to the annual nutrient load, however this is likely to vary, depending on the composition of the stream bed and banks.

A recent study of suspended sediment transport in Fairchild Creek indicated that erosion from bare soil, streambeds and banks could be very large, but was moderated by vegetative cover. The study, by Stone (2004), found a wide variation in unit area loads of suspended sediment (values varied by three orders of magnitude) and total phosphorus (>50-fold difference). Suspended sediment loading was highest where there were little or no riparian buffers. The author postulated that vegetation (riparian and in-channel) provides in-channel storage (trapping sediment and acting as a sink for inputs), and stabilizes sediments, thus decreasing the potential for export of phosphorus and sediment from stream banks, beds and floodplain deposits through erosion.

6.5. Transport of land-applied nutrients

In addition to natural factors such as physiography and hydrology, the relative importance of source areas can be strongly affected by land use and land management practices. The risk for loss of nutrients from the landscape is increased where nutrients are present in excess of use or uptake (i.e., there is a net surplus in the nutrient balance). Since phosphorus is less mobile than forms of nitrogen and can accumulate in soils, legacy effects are particularly important for this nutrient (Kleinman et al. 2011). Increased hydrologic connectivity will also increase the risk that mobilized nutrients will be transported to surface waters.

At a coarse scale, data suggest the net phosphorus balance in Southern Ontario has been improving since the 1980s, when the GLWQA was signed (van Bochove et al. 2011). Within the Lake Erie basin, the same trend of declining P balance has been evident during the last 11 years, which Joosse and Baker (2011) attribute to increased removal of phosphorus, since crop yields have increased while total manure and fertilizer applications have remained relatively stable. Recently, an analysis using census data has focused on the phosphorus balance and cumulative phosphorus levels and distribution in the Grand River watershed (Feisthauer and Joosse 2013); it is highlighted in section 8 of this report.

Recent studies in other areas have indicated that, along with nutrient balance estimates, it is important to consider how land management activities affect the form and location of nutrients within fields. For instance, long-term shifts in agricultural practices on highly erodible soils in Ohio have been linked to an increase in the dissolved phosphorus load in tributaries to the western basin of Lake Erie (Joosse and Baker 2011). Since soil test phosphorus values and nutrient balance estimates cannot explain these increases in dissolved phosphorus loading, it is hypothesised that the mobility of dissolved phosphorus has increased. Mechanisms for this increase include alterations of phosphorus transport processes within the soil due to long term shifts in tillage practices (IPNI 2012). In some circumstances, this has altered the stratification of phosphorus in the soil, potentially leaving it more susceptible to loss from the field in surface runoff or through subsurface flow (Kleinman et al. 2011). It is unknown to what extent these findings from watersheds in the United States apply to agricultural lands within the Grand River watershed, which are different with respect to soils, crops, topography, practices and climatological factors. However, these studies illustrate one example of the way that land management practices have the potential to modify the processes by which nutrients are lost from the landscape.

Changes to the landscape that alter hydrologic processes (e.g., runoff, infiltration) have the potential to modify pathways by which nutrients are transported to surface water in particulate or dissolved forms. For example, by promoting infiltration tile drainage can reduce soil loss in surface runoff in some instances. Conversely, flow through tile drains can increase losses of both phosphorous and sediment from some catchments. If rapid drainage through tile drains contributes to a 'flashy' hydrograph, it can increase the erosion of streambed and banks in downstream areas. Tile drains can also act as a 'modifier' of transport from agricultural land, increasing the contributing area for nutrient export to surface water and reducing the opportunity for mitigation of sediment or phosphorus that is detached from the soil surface (Reid et al. 2012) . This impact is likely greatest following heavy rainfall on soils that have cracks, earthworm and root channels, particularly when the soil is wet. Other management practices, such as tillage, as well as the form, timing and distribution method of applied nutrients are likely to be equally (if not more) important in determining the dominant transport pathway for nutrient losses.

There are few recent studies in the Grand River watershed that quantitatively compare the pathways for nutrient transport in dissolved versus a particulate form. In the Grand River watershed, there are inadequate data to quantify the dissolved phosphorus contribution from non-point sources at a subwatershed scale. However, estimates could be produced for priority areas using strategic data collection in key areas during periods of active runoff. The findings of studies that are underway to characterize dissolved phosphorus transport processes in the watershed are essential for informing this type of data collection.

Sources and transport of dissolved forms of nutrients have been investigated at a limited scale in some areas of the Grand River watershed. For instance, a recent study of the Canagagigue subwatershed investigated changes that have occurred since the 1970s in the transport of dissolved nutrients (Plawiuk 2011). The study compared measurements of nitrate and soluble phosphorus in 2008 and 2009 with those previously determined as part of PLUARG studies in the same area. There was a large increase in the flow weighted mean (FWM) concentrations of nitrate and soluble phosphorus (88% and 92%, respectively) in the subwatershed since the 1970s. Loading estimates could only be produced for 2009, which was a relatively dry year; however, it was considered to be probable that the large increase in FWM concentrations in both years was associated with an increase in loadings. Data from 2009 and from an earlier study both suggested that the proportion of the annual phosphorus load contributed by soluble phosphorus was large: soluble phosphorus accounted for 41% of total phosphorus in 2009 (Plawiuk 2011), comparable to 37% in PLUARG studies from the 1970s (Coote et al. 1982). The increase in FWM concentrations of soluble phosphorus and nitrate since the 1970s was linked to a shift in a number of factors related to land management (e.g., a doubling in coverage by tile drains, increase in row crops, increased use of conservation tillage) (Plawiuk 2011). While there had only been minor changes in livestock production, there was a substantial increase in the proportion of agricultural fields that receive manure from an associated livestock operation. Agricultural lands associated with a livestock operation in the Canagagigue watershed jumped from 40% in 1977 to 100% in 2008-2009 (Plawiuk 2011). Although limited in spatial extent, this study highlights some of the agricultural land management practice changes that can affect the loss of nutrients from soils.

A recent study of agricultural non-point nutrient sources flagged the leaching of nitrate from land-applied livestock manure as a likely nitrate source in the upper Conestogo subwatershed (MOE 2012). The study collected data at 14 sites in southern Ontario agricultural watersheds, including one site in the Nith subwatershed and one site in the upper Conestogo (Stirton Creek) subwatershed. Of the 14 sites, manure production in upstream areas was highest for Stirton Creek. Correspondingly, Stirton Creek had relatively high winter/early spring concentrations of total nitrates (i.e., nitrate plus nitrite). Although loading estimates were not produced for the sites in the Nith and Conestogo subwatersheds, the study indicated that the majority of annual loads in other areas were dominated by nitrate delivered during the winter and early spring.

The mechanisms of soil profile nitrate leaching are relatively well understood, but the pathways by which nitrate is transported out of soils in source areas are not always clear. In most instances, it is likely that there is a delay between leaching from the source and loading to the river. Most nitrate movement out of the soil profile, either to surface or groundwater occurs outside the growing season when cooler temperatures slow plant and microbial nitrate uptake and denitrification. During this time precipitation exceeds evapotranspiration (evaporation and plant uptake of water). Pulses of melt/rain events "flush" nitrate out of the soils and into subsurface flow to surface water or groundwater (Figure 1). The increase in hydrologic transport during these periods can facilitate the loss of excess nitrate that has accumulated in soils during periods when soils were not hydrologically active (e.g., frozen or dry) and uptake was minimal or absent. A lag of longer duration may also occur between leaching of nitrate from soils and the discharge of shallow groundwater. A study of nitrate sources, including mass balance modelling of the Wilmot Centre municipal well field, suggested high concentrations of nitrate in shallow (i.e., uppermost) groundwater were linked to historical nutrient management practices in some areas

(WESA 2012). Although there have been other studies of nitrate transport within the watershed (e.g., Little et al. 2005; Samarajeewa et al. 2012), additional information about the timing and relative importance of different pathways from key source areas is needed to inform management of nitrate sources on the landscape.

6.6. Nutrient cycling in the river system

As noted previously in this report, the river system can act as a conduit for loads of nutrients, but can also contribute to the transformation between forms, or delay the transport to downstream areas, particularly in key areas where deposition or biological uptake is relatively high. Transport and subsequent deposition of particulate phosphorus may occur during the spring, with subsequent release or re-suspension during the summer. The spring flush can mobilize large loads of phosphorus from the landscape or upstream reaches to downstream areas. Where this load accumulates, the water quality issues may not manifest themselves until later in the season when biological activity increases.

The pathways involving nutrient cycling in the river system are likely significant to water quality issues in the southern portion of the Grand River and in the reservoirs on the Grand River system. For instance, the PLUARG study by Hore and Ostry (1978) highlighted that the southern Grand River likely had an important role in nutrient transformation and the transport of dissolved forms of nitrogen and phosphorus. Downstream from Brantford, they observed opposing longitudinal concentration gradients in dissolved and sediment-associated parameters, with an increase in the proportion of soluble forms of nitrogen and phosphorus in a downstream direction. In a more recent study on nutrient cycling in the southern Grand River, Kuntz (2008) proposed that this region is a significant transition zone for nutrients, particularly in the large impoundment created by the dam at Dunnville.

The southern Grand River was also the focus of detailed surveys of water quality, habitat and ecological condition as part of a southern Grand River restoration initiative that received support through the Canada Ontario Agreement respecting the Great Lakes Basins (MacDougall and Ryan 2012). Information in this report supports the importance of nutrient cycling, especially in the wetlands that fringe most of the river. The study also highlights the role of internal loading in the re-release of phosphorus from the sediments. The process of internal loading occurs as the result of a change in redox state that shifts phosphorus from a form that is retained in the sediments and bound to an iron complex to a form that can be released into the overlying water. The release of phosphorus into the water starts a positive-feedback loop in which the phosphorus feeds biological activity that heightens the change in redox state as the result of anoxic conditions at the sediment-water interface. A number of studies indicate that low oxygen or anoxic conditions are prevalent in some sections of the southern Grand River during the summer, likely resulting in internal loading (MacDougall and Ryan 2012; 2012 unpublished data, Howell, MOE). Although a high proportion of total phosphorus can be released as dissolved phosphorus through internal loading, it is difficult to quantify since phosphorus cycling is very rapid. In addition, studies in other areas indicate that sediments from different types of environments (e.g., macrophyte versus phytoplankton-dominated) have contrasting patterns of sensitivity to redox conditions (Kisand and Nõges 2003).

Physical processes causing re-suspension of sediment and associated phosphorus are important in the wide, slower flowing reaches of the southern Grand River. The report by MacDougall and Ryan (2012) indicated that re-suspension of particulate phosphorus from the sediments contributed significantly to the very high turbidity observed in the southern Grand River. The high turbidity in the southern Grand River is detrimental to the growth of submergent macrophytes, such that they are sparse or absent in many areas (Gilbert and Ryan 2007; Cvetkovic & Chow-Fraser 2012; MacDougall and Ryan 2012).

Macrophytes can modify nutrient and suspended sediment dynamics in the river: they take up nutrients for growth during the summer, can contribute to the immobilization of nutrients in the streambed sediments and can increase deposition and stabilization of particulates on the streambed (Reddy et al. 1999; Jones et al. 2011).

Reservoirs are locations where there is likely to be significant nutrient transformation. Since reservoirs are areas of slow moving or slack water where deposition can occur, they tend to accumulate particulate forms of nutrients that can be later released through biological and chemical processing. The development of thermal stratification within a reservoir can facilitate the development of anoxic sediments, which in turn can contribute to significant internal loading of phosphorus. A study to identify potential solutions that could be applied to prevent the formation of cyanobacteria blooms in the three large reservoirs (Belwood, Guelph Lake and Conestogo) proposed that internal loading of phosphorus is one of the mechanisms contributing to the onset of the blooms (Guildford 2006). Mechanisms also included the effect of low water levels on the potential for allowing nutrient-saturated bottom water to mix into well-lit upper layers, increasing the risk of a bloom. The extent to which the reservoirs act as net sources or sinks of nitrogen and phosphorus has not been quantified to date, but is the subject of ongoing studies by researchers at the University of Waterloo. While the processes controlling nutrient transformation within the reservoirs are unclear, it is reasonably certain that a reduction in external nutrient loading would be beneficial to both the reservoirs and downstream areas.

7. Water Quality Data Synthesis

To complement the findings of previous studies summarized above, analyses of more recent data specific to the Grand River system was used by the Water Quality Working Group to characterize nutrient and sediment sources. Data collected by the GRCA as part of the Provincial Water Quality Monitoring Network (PWQMN) was synthesized using both qualitative and semi-quantitative approaches to assess:

- longitudinal patterns of nutrient and sediment concentrations; and
- estimates of subwatershed and regional mass load/yield.

The longitudinal profiles and estimates of subwatershed loading characterize the areas in the watershed which are sources of nutrients and sediment in the Grand River. Both qualitative (e.g., longitudinal patterns of nutrient concentrations) and semi-quantitative (e.g., subwatershed loads/export) approaches were used to identify source areas. Combined, these approaches offer a weight of evidence that illustrates the major contaminant source areas in the watershed. To provide additional context with which to interpret this information, regional mass loads provide further detail for key source areas. This additional analysis estimates semi-quantitative mass loads from non-point and point sources (such as septic systems or wastewater treatment plants) to outline the relative importance of different types of sources. The synthesis will also highlight the key transport mechanisms for mobilizing nutrients and sediment from the land to surface (and ground) water.

Parallel to these approaches, an agronomic nutrient balance analysis has been undertaken by Agriculture and Agri-Food Canada, and is presented in a separate report (Feisthauer and Joosse 2013). The approach used for the nutrient balance and the utility of the information it yields will be described in section 8.

7.1. Data sources and limitations

The following synthesis was done at a watershed scale. Interpretation is at a coarse level, focused on the contributions by major drainage basins to the conditions in mainstem of the Grand River. Little data is available to characterize the spatial variations in conditions *within* some of the large tributaries of the Grand River (e.g., the Nith River). Understanding of the processes at a subwatershed scale that are contributing nutrients and suspended sediments can be inferred, to some extent, from conditions upstream and downstream of their confluence with the Grand River. More detailed monitoring within a subwatershed scale would help to generate a better understanding of the sources in the watershed, by better characterizing the spatial extent, timing and form of sediment and nutrient contributions within key subwatersheds.

The analyses presented herein use data collected in the Grand River watershed as part of the PWQMN. The data for this network is collected across the province as partnerships between watershed organizations (e.g., the GRCA) and the Ministry of Environment. Currently, there are 37 PWQMN sampling sites within the Grand River watershed. About 8-9 samples are collected by GRCA staff between February and November each year. Starting in 2002, GRCA modified the sampling strategy in an attempt to better characterize the full range of hydrologic conditions in the watershed including high spring flows, summer storm events and low summer flows; however, the number of samples collected each year remained the same. It is acknowledged that this sampling frequency is not suitable for calculating loads since it is likely to miss the peak of high flow events; therefore it is strongly recommended that these results be considered highly uncertain yet offer a relative comparison among areas at a coarse scale.

It is important to note that samples collected under the PWQMN are analysed for total suspended solids (TSS; also called non-filterable residue) rather than suspended sediment concentrations (SSC). TSS measurements often underestimate sand-sized material (Gray et al. 2000). In addition, PWQMN samples are collected from a single depth near the surface, whereas a true measure of suspended sediments is depth-integrated. TSS data has been synthesised in this report in order to make inferences about relative differences in contributions of sediment from different sources, with the recognition that it may represent only a portion of the total suspended sediment load. These results are cross-referenced with a more detailed analysis of sediment data collected using robust methodology under the Water Survey of Canada's Continuous/Miscellaneous Suspended Sediment Loading Program (1967-2012), detailed in a separate report (Smith 2013).

There is limited data available for recent years with which to characterize water quality issues associated with sediment and phosphorus in summer high flows. Although it was not feasible to apply the approaches described above to characterize summer high flow periods, examples will be drawn from available data to illustrate what is currently known about these seasonal events.

7.2. Longitudinal variations in concentrations

Longitudinal profiles of nutrient and sediment concentration have been plotted to develop a conceptual understanding of sources and sinks for nutrients and suspended sediments in the Grand River. Data was separated by season due to differences in the predominant hydrologic conditions (e.g., high spring runoff, summer low flow). This approach demonstrates qualitative changes in nutrient and sediment concentrations as the river moves downstream and helps to identify the subwatersheds that may be contributing disproportionately large amounts of nutrients and sediment.

Water quality data for nitrate, total phosphorus and TSS were compiled for several long-term sites along the Grand River (Table 2). The data was collected through the PWQMN between 2002 and 2011. The data were reviewed for data quality and grouped according to season. For the purposes of this analysis, winter was defined as December 1st to February 28th; spring as March 1st to April 30th; summer from May 1st to September 30th and fall from October 1st to November 30th.

Longitudinal water quality profiles of seasonal conditions in the Grand River were created by plotting the 25th percentile, median and 75th percentile for each parameter against distance upstream of Lake Erie. Summer high flows were not characterized, since an inadequate amount of data was available. The profiles provide an illustration of the typical range of values observed at each monitoring site and help to qualitatively identify changes in water quality from site to site. Each profile was examined to identify areas where substantial changes in nutrient and TSS concentrations occur.

Table 2. Provincial Water Quality Monitoring Network (PWQMN) sites used for illustrating the longitudinal profile of nutrients and TSS in the Grand River.

Site Description	PWQMN Site ID
First Conc. d/s of Belwood Lake	16018403702
Highway 86	16018410302
Bridgeport Bridge	16018401502
Blair Bridge	16018401202
Glen Morris Bridge	16018401002
Cockshutt Bridge, Brantford	16018402702
York Bridge	16018409202
Bridge at Dunnville	16018403502

Phosphorus

The longitudinal profile of total phosphorus from PWQMN sampling in the Grand River indicates that concentrations tend to increase as the river flows from the headwater region (e.g., Leggatt) to the mouth near Dunnville during both high (i.e., spring) and low (i.e., summer) river flows (Figure 12A, B). A profile has not been plotted for summer high flows since there were too few sampling events that occurred during these conditions.

Runoff from the headwaters drains the Dundalk till plain and much of the water on the landscape tends to move off the land quickly carrying sediment and phosphorus. Belwood Lake, a water management reservoir, receives the flows from the headwaters. During the spring, the reservoir likely acts as a sink of phosphorus and suspended sediment. Despite this, the relatively high phosphorus concentrations in the river below Belwood Lake (Figure 12 A) suggest a substantial amount of phosphorus is still transported downstream during the spring. As the river flows downstream into the central region of the watershed, it accumulates phosphorus in high flows from a few smaller tributaries and two large tributaries – the Canagagigue and Conestogo (shown on Figure 12 A as an increase in concentration above Bridgeport). The increasing trend in phosphorus concentrations in the spring continue through the central region of the Grand River, which receives runoff from the largest urban area as well as wastewater treatment plants. Total phosphorus concentrations peak in the urban centre of the watershed then decrease in the reaches above Brantford. As the Grand River flows toward its mouth near Dunnville and onto the clay plain, it receives water from the Nith River and Fairchild Creek and total phosphorus concentrations remain high.

In many of the reaches of the Grand River during high flows in the spring, total phosphorus levels almost always exceed the provincial interim guideline of 0.030 mg/L (Loomer and Cooke, 2011). Where concentrations exceed this threshold, there is more likely to be nuisance growth of aquatic plants or algae (Painter et al. 1976). In contrast to the total phosphorus concentrations seen in the river during the spring, summer phosphorus concentrations in the river are about two to ten times less (Figure 12 B). However, the concentrations in the river still tend to remain at or above the provincial interim guideline of 0.030 mg/L (Loomer and Cooke 2011). The concentration of phosphorus in the river is particularly important during the summer growing season since nuisance aquatic plant growth can impact the river's dissolved oxygen regime.

The concentration of phosphorus in water flowing out of Belwood Lake during the summer generally is above the provincial interim guideline for total phosphorus of 0.03 mg/L (Loomer and Cooke, 2011; Figure 12 B). In the summer, Belwood Lake likely switches from a sink to a source of nutrients within the river system. The high concentrations in the Lake may be due to the hypolimnetic conditions (i.e., low oxygen conditions at the bottom of the lake) that facilitate the release of phosphorus from the sediments. As the river flows through the major urban area in the summer, there is a substantial increase in phosphorus concentrations. This suggests that there is a strong influence of the large wastewater treatment plants that continuously discharge to the river in this region of the watershed. Phosphorus concentrations remain elevated but relatively stable as the river flows past Brantford (Cockshutt, Figure 12 B). However, as the river becomes more 'lake-like' near Dunnville, total phosphorus concentrations increase dramatically. The anoxic conditions in the lower river, possibly the result of high sediment oxygen demand (MacDougall and Ryan 2012), may create conditions that allow phosphorus to be released from the sediments in a dissolved form during the summer. Some of this phosphorus may be taken up and recycled by plants or algae during the growing season. Biological stores of phosphorus contributing to the high concentrations in the water include the large amount of phytoplankton (algae) in the river above Dunnville, which is characterized by high chlorophyll-a concentrations (Kuntz 2008; MacDougall and Ryan 2012).

Suspended solids

The longitudinal profile of TSS concentration in the Grand River as it flows from the headwater region to the mouth during high flows is shown in Figure 12 C. A profile has not been plotted for summer high flows since there were too few sampling events that occurred during these conditions. Data from monitoring that targeted a high flow event in a reach of the river flowing through the urban centre of the watershed will be presented later in section 7.4 to illustrate what is known about the dynamics of sediments in summer high flows.

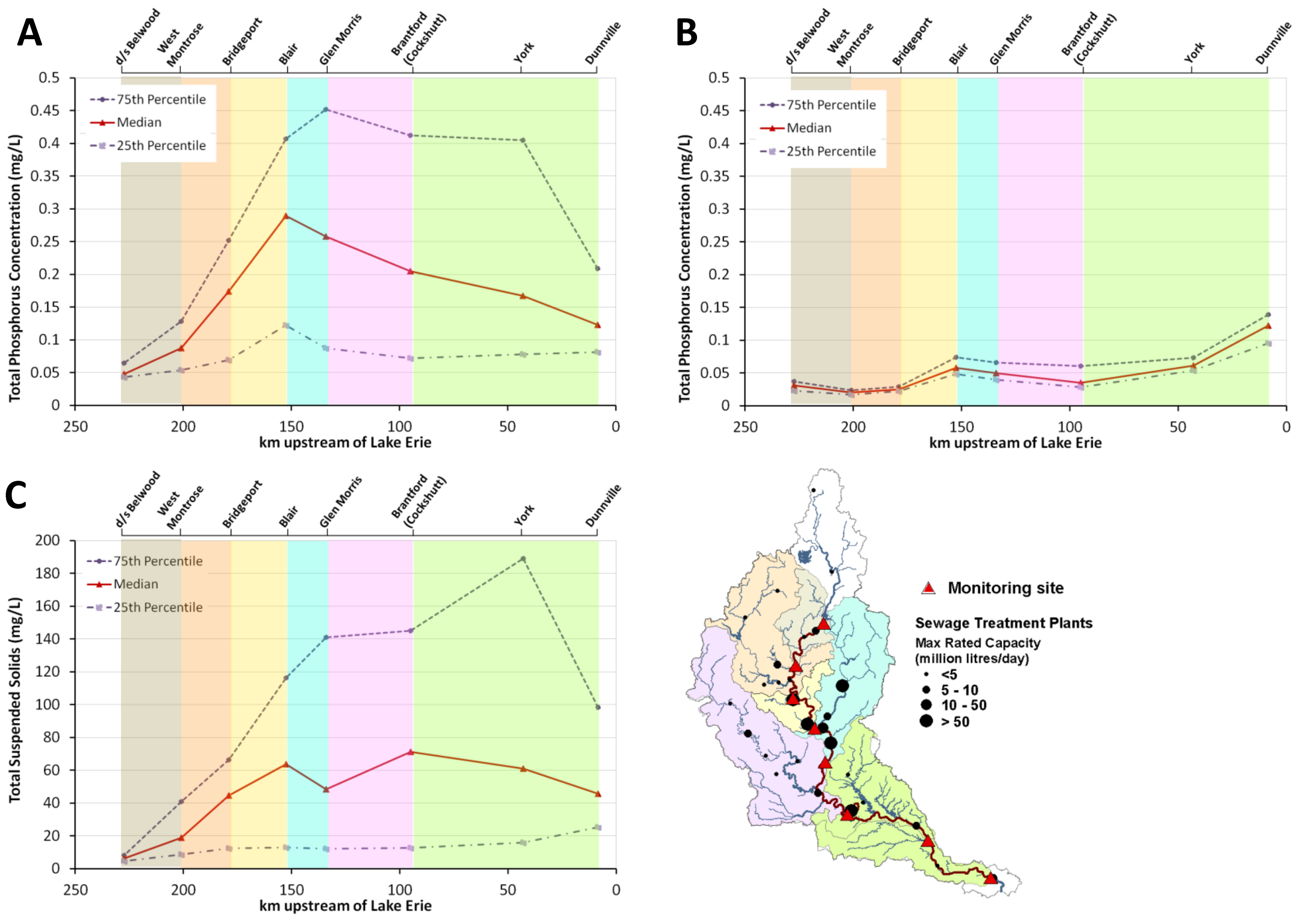


Figure 12. Longitudinal profiles of total phosphorus concentrations in the spring (A) and summer (B), and concentration of total suspended solids in the spring (C) between 2002 and 2011 at sites on the Grand River (shown lower right, in relation to the location of municipal sewage treatment plants).

Similar to the profile of phosphorus concentrations, TSS shows an increasing trend in concentration in a downstream direction (Figure 12 C). As with phosphorus, high flows from the headwaters likely carry a high load of suspended solids, some of which may be deposited in Belwood Lake during the spring. The longitudinal profiles of total phosphorus and TSS in the Grand River during the spring are generally similar (Figure 12 A). A notable exception to the similarity is that the highest concentrations of TSS are seen in the reaches *below* Glen Morris, whereas the highest total phosphorus concentrations are seen in reaches *above* Glen Morris. In contrast to the decrease in the upper range (75th percentile) of phosphorus concentrations between Glen Morris and York, there is an increase in the upper range of TSS values in this reach. The increase in the range of TSS concentrations is particularly pronounced in the reaches below the confluence of the Grand and Nith rivers, between Brantford (at Cockshutt bridge) and York. This stretch of river (i.e., downstream from Brantford) is a deeper, slower moving reach and receives flows from the Whitemans Creek and Fairchild Creek subwatersheds before it reaches the location where water quality samples are collected near York (just above the confluence with McKenzie Creek). As the river flows downstream from York towards Dunnville, there is a notable decrease in the upper range of TSS in the river, although the overall concentrations remain quite high.

Nitrate

The longitudinal profile of the concentration of total nitrates (nitrite + nitrate) in the Grand River as it flows from the headwater region to the mouth during the months of the winter low flow and the spring freshet (December to April) is illustrated in Figure 13. With the exception of the mixing zones below wastewater effluent discharges, nitrites comprise a very small proportion of total nitrates since they are rapidly transformed to nitrate in the presence of oxygen. For the sake of simplicity of communication, measurements of total nitrates will hereafter be referred to as nitrate.

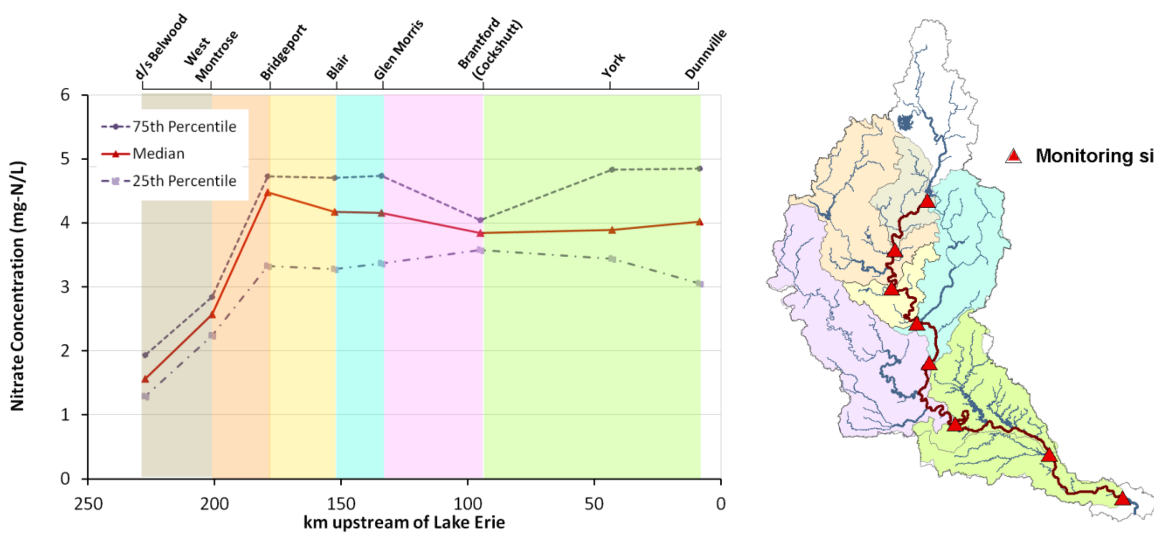


Figure 13. Longitudinal profile of concentrations of total nitrates (nitrate + nitrite) during the winter and spring (December - April) at sites in the Grand River (shown at right).

As the Grand River flows from the Shand Dam downstream to Bridgeport during the winter-early spring season, there is a dramatic increase in the concentration of nitrate. This reach receives flows from Irvine subwatershed (above West Montrose) in addition to the Conestogo and Canagagigue subwatersheds. As the river flows through the central urban region of the watershed and receives flows from several large wastewater treatment plants, the nitrate concentration in the river remains elevated, however no further increases are apparent. Continuing downstream toward the river mouth at

Dunnville, the concentration of nitrate remains elevated and relatively invariant. This suggests that inputs from subwatersheds have a similar (high) concentration of nitrate compared to that in the Grand River downstream from Bridgeport. During the summer, the range of concentrations in the river are much lower (GRCA, unpublished data), which is most likely due to the active biological uptake by plants and active microbial denitrification (reduction of nitrate).

7.3. Relative contributions from major subwatersheds

The relative tributary mass loads from the nine major subwatersheds shown in Figure 3 were originally estimated using the model FLUX (vers. 5.1; Walker 1996) as part of a water quality characterization by GRCA (Cooke 2006). The analysis by Cooke (2006) used grab sample concentration data (2000-2004) and continuous (e.g., average daily) flow records to estimate mass nutrient or TSS loads. Five algorithms were used in FLUX to generate estimates of mass loads. The method that produced the mass load estimate with the least variability (i.e., coefficient of variation <0.10) was used to determine the relative mass loads generated at each sampling site.

Table 3. The nine major subwatersheds in the Grand River watershed

Subwatershed	Approximate area (km2)
Canagagigue	148
Conestogo	820
Fairchild	401
Irvine	196
McKenzie	368
Nith	1128
Speed	781
Upper Grand	791
Whitemans	404

The mass load or transport, expressed as a unit of weight/unit of time, is the total amount of material that passes by a given location over a given time period. For watershed evaluations, mass loads are usually standardized for drainage basin areas, flow volumes and a time period (e.g., annual). To standardize mass load by drainage basin area, total mass loads were divided by drainage basin areas (mass unit/surface area unit; Table 3), which produced the total mass export per unit area (i.e., yield). This report will focus on the relative differences in the loading of total phosphorus, total nitrogen and TSS from the major subwatersheds, since the precision of the analysis is considered to be low.

In surface waters of the Grand River, nitrate accounts for a large proportion of the total nitrogen pool (Loomer and Cooke 2011). Other forms (e.g., ammonia, particulate nitrogen) comprise a relatively small proportion of the total nitrogen pool. Consequently, patterns in total nitrogen loading are likely to be indicative of nitrate loading.

The relative annual loads and unit area yields of total nitrogen from the nine major subwatersheds are illustrated in Figure 14 and Figure 15, respectively. Figure 14 indicates that the annual loads of total nitrogen from the Nith and Conestogo subwatersheds are very high relative to the contributions from other subwatersheds. However, estimates of total nitrogen yield (which take into account subwatershed size) suggest that contributions from other smaller subwatersheds on the upper till plain (Irvine and Canagagigue Creeks) make large contributions relative to their smaller size (Figure 15). As a result, the annual yield of nitrogen to the Grand River from Irvine and Canagagigue Creeks is likely to have significance for regional quality issues despite the relatively small magnitude of loads compared to other larger subwatersheds. Similarly, the yield of total nitrogen from the Whitemans Creek is comparable to the Conestogo subwatershed (Figure 15), which indicates there may be similar potential for impacts within the subwatershed due to high nitrate concentrations. Since these findings are based on a limited amount of data from key periods for nitrogen transport (the winter and early spring), they should be used with caution. It is recommended that these patterns be confirmed with a more detailed investigation in priority areas, which focuses on movement of nitrogen during key time periods.

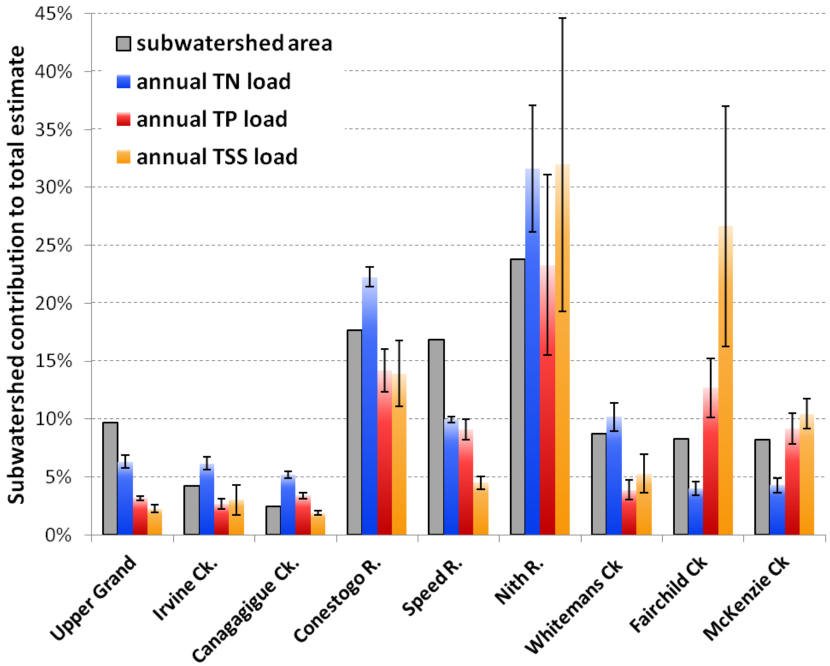


Figure 14. Comparison of area and mass loads for total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS) from major subwatersheds in the Grand River watershed. Estimates calculated from data collected from 2000-2004, as in Cooke (2006). Error bars (±1 standard deviation) indicate uncertainty of the load calculations, but do not take account uncertainty associated with sample collection.

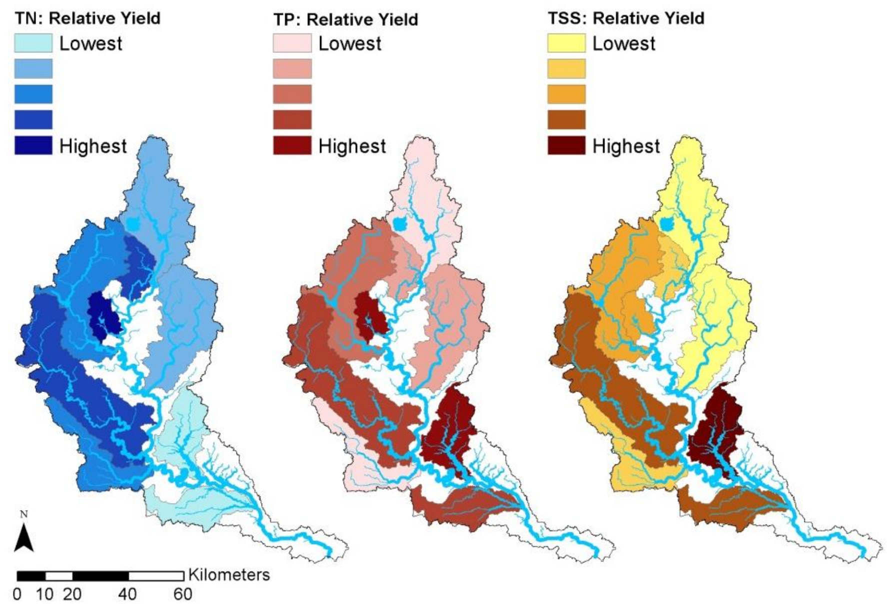


Figure 15. Relative yield (load generated per unit area) of total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS) from nine major subwatersheds in the Grand River watershed. Estimates calculated from data collected from 2000-2004, as in Cooke (2006).

The analysis of the annual subwatershed loading of total phosphorus to the Grand River is also illustrated in Figure 14. There are large differences among the nine major subwatersheds, with relatively large contributions by the Nith, Conestogo and Fairchild subwatersheds. Normalizing the loads to area (i.e., expressed as a yield), it is apparent that the contributions from the Canagagigue and lower clay plains (particularly Fairchild Creek subwatershed) are disproportionately high relative to their size (Figure 15).

The consistent increase in TSS concentration in the river during the spring high flow period (Figure 12 C) suggests that most of the watershed contributes particles during high flows, however the TSS loading estimates from Cooke (2006) suggest there are large differences in annual rates of loading between subwatersheds (Figure 14). The total annual loads of TSS from the Nith River and Fairchild Creek are very high relative to the contributions by the other subwatersheds for which estimates were produced. The load contributed by the Nith River is very large due to the combined effect of a large drainage area as well as relatively high TSS export. In comparison to the Nith, the subwatersheds on the lower clay plain contribute smaller total annual loads to the Grand River. Despite this, subwatersheds dominated by soil types that have a high potential for erosion, such as the lower clay plains have TSS yields comparable to the Nith (or higher in the case of Fairchild Creek).

It should be noted that these findings are based on a coarse approximation which is likely to have underestimated loading during transient events. The error bars on Figure 14 indicate that there was poor fit of some models, particularly in subwatersheds where concentrations are known to exhibit dramatic increases during hydrologic events (Nith River, Fairchild Creek). Since sampling does not often catch peak concentrations during these events, our estimates are most likely to underestimate loading in these drainage areas. These issues are most apparent with TSS and TP, since increases in these parameters can be driven by erosion and transport during hydrologic events. It is recommended that these patterns be confirmed with more a detailed investigation in key areas, which focuses on transport during hydrologic events.

7.4. Characterization of source types and transport mechanisms

The following sections outline a more detailed analysis of subwatersheds which are relatively important in the context of water quality issues or for which loads are relatively high in proportion to their area. These additional analyses provide additional context for the characterization of sources of nutrients and sediments, by determining the relative loads from key source areas or discharge types.

Calculation of regional mass loads

In addition to the longitudinal profile of nutrient concentrations and subwatershed export, additional analysis was conducted at a regional scale to semi-quantitatively estimate loadings from point sources, septic systems and diffuse sources in the areas where there was an obvious change in river nutrient or sediment concentrations. This approach was to provide an idea of the relative contributions from these areas during each season. It is a semi-quantitative approach due to the high degree of uncertainty and error associated with using the PWQMN data.

As previously mentioned, sampling carried out under the PWQMN is not sufficiently frequent nor does the sampling adequately characterize the full range of hydrologic conditions observed. Additional error may be associated with flow measurements which can be subject to significant interference from back water effects due to weeds in the summer and ice in the winter. Despite the inherent limitations of estimating loading rates, the sources of error are common to all sampling locations and therefore can be useful to identify relative differences between sites.

Seasonal loading from point sources was estimated using a combination of data from various sources as described in Table 4. In some cases, e.g., Fergus WWTP, monthly average concentrations and monthly average flows were used to estimate loadings whereas others, e.g., Kitchener WWTP, had more detailed information available. Effluent quality data was separated by season as defined above and seasonal average loads were estimated by averaging all available information.

Table 4. Wastewater effluent data sources used for analysis.

Wastewater treatment plant	Data source	Description
Elora WWTP	MOE records	Monthly average effluent concentrations and flows, 2006 to 2010
Fergus WWTP	MOE records	Monthly average effluent concentrations and flows, 2006 to 2010
Elmira WWTP	MOE records	Monthly average effluent concentrations and flows, 2008 to 2010
St. Jacobs WWTP	MOE records	Monthly average effluent concentrations and flows, 2008 to 2010
Conestogo WWTP	MOE records	Monthly average effluent concentrations and flows, 2008 to 2009
Waterloo WWTP	Region of Waterloo	bi-weekly effluent concentrations March 2003 to June 2007, weekly effluent concentrations July 2007 to May 2009 and daily average flows, March 2003 to May 2009
Kitchener WWTP	Region of Waterloo	Weekly effluent concentrations and daily average flows, March 2003 to May 2009

Loadings from septic systems were very conservatively estimated using per capita nitrogen and phosphorus loading rates from septic systems. Several literature sources were reviewed and reported nitrate-nitrogen loading rates from septic system were found to range from 4.4 to 17.7 g/capita/day (NJDEP 2001; Reay 2004; MOE 1996; MOE 2010; Maizel et al. 1997). To provide a highly conservative estimate of the nitrate loading from septic systems to the Grand River, the upper limit of reported per capita loading rates was used and no allowance was made for nitrate attenuation (i.e., it was assumed that all nitrate released from septic systems ended up in surface water). Similar assumptions were made for total phosphorus based on a per capita loading rate of 1.81 g/person/day (MOE 2010). The assumption that there is no attenuation of nitrate or phosphorus is highly conservative because there is likely to be significant attenuation in groundwater and sediments, particularly for phosphorus.

Per capita loading rates of nitrate and phosphorus were multiplied by the estimated unserviced population within specific drainage areas. The unserviced population for each subwatershed was determined by subtracting serviced population from the total population (Table 5). Serviced populations were taken from various sources (LERSPC 2012; Region of Waterloo 2012; Triton Engineering 2010). Total 2010 population in subwatersheds within the Grand River watershed was summarized using GIS tools. This analysis was done using Adjusted Census 2010 data, which is based on the 2006 census with annual data updates and estimate formulas to account for population growth.

Table 5. Estimated population in selected subwatersheds

Sub-watershed	Total population (adjusted 2010 census)	Serviced population	Unserviced population
Grand River above Shand Dam	13,277	Dundalk: 1,691 Grand Valley: 1,600	9,986
Grand River from Shand Dam to Bridgeport	26,017	Fergus: 12,893 Elora: 5,645 Conestogo: 269	7,210
Irvine Creek	3,591	---	3,591
Canagagigue Creek	11,756	Elmira: 9,725	2,031
Conestogo River	24,804	St. Jacobs: 1,791 Alt Heidelberg: 254 Drayton: 2,600 Arthur: 2,770	17,389

Seasonal loading rates were estimated using nutrient and TSS data from the PWQMN collected from 2002 to 2011 and flow data from GRCA or Water Survey of Canada (WSC) for selected locations along the Grand River and major tributaries. Where possible, WSC flow data was used because it is subject to quality assurance procedures and is corrected to account for back water effects from weeds in summer and ice cover in winter. Table 6 summarizes the data sources used in this analysis.

Table 6. Data sources used to estimate seasonal loading rates at selected PWQMN sites

Site Description	Site ID	Flow data source
Grand River, first concession downstream of Belwood Lake	16018403702	WSC: 2002 – 2010 GRCA: 2011 (provisional)
Grand River, Bridgeport	16018401502	GRCA: 2002 – 2011
Grand River, Fountain Street, Blair	16018401202	*see note
Irvine Creek	16018410402	WSC: 2002 – 2010 GRCA: 2011 (provisional)
Canagagigue Creek, downstream of Elmira WWTP	16018401602	WSC: 2002 – 2010 GRCA: 2011 (provisional)
Conestogo River, Waterloo County Rd 22	16018402902	GRCA: 2002 – 2011

**note: there is no flow gauge at this site, flow was estimated using the WSC gauge at Galt (WSC: 2002 -2009; GRCA: 2010 – 2011) and subtracting the flow from the Speed River using the WSC gauge at Beaverdale (WSC: 2003 – 2010; GRCA 2002 and 2011).*

Daily unit loads were calculated by pairing water quality measurements with average daily flows on the sampling date. The average loading rate was estimated by averaging the daily unit loads. This approach has a number of limitations, particularly for water quality parameters that are highly correlated to flow (e.g., total phosphorus and total suspended solids). The average loading rate calculated using this approach will underestimate the actual loading rate because a large portion of the load is delivered during high flow events that may not have been sampled.

Point source contributions

Longitudinal profiles of phosphorus (Figure 12) indicate large increases in total phosphorus concentration during the summer in the Grand River below some of the large wastewater treatment plants in the centre of the watershed. Regional mass loads suggest that the effluent from these wastewater treatment plants is a significant source of phosphorus to the central Grand River during the summer (Figure 16).

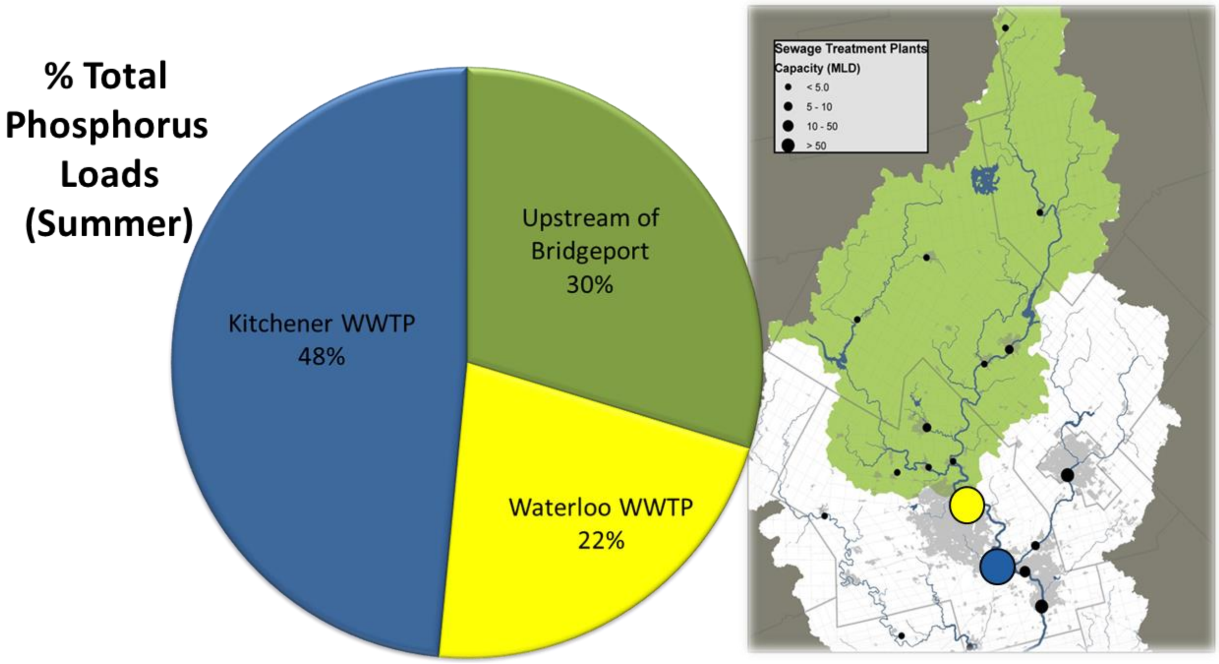


Figure 16. Total phosphorus loads in the upper-middle Grand River region during summer low flows.

Phosphorus concentrations during the summer are a key determinant of biological activity (i.e., growth and respiration by plants and algae) in the river, which is critical to the health of the aquatic ecosystem. Excessive biological activity can harm other aquatic life and significantly impair the use of aquatic resources by humans. The largest wastewater treatment plants are located within the central region of the watershed, where the dominant water quality issue is related to phosphorous inputs during the summer low flow period. The Waterloo and Kitchener wastewater treatment plants combined contribute about 70% of the total load of phosphorus to the Grand River at Blair while the remaining load comes from the cumulative inputs from the upstream tributaries and discharge from the Shand Dam (Figure 16).

Although nitrate can also be generated from point sources, the longitudinal profile (p. 34) indicates that point sources (e.g., large wastewater treatment plants) are not associated with large increases in nitrate concentration in the Grand River during the spring/winter. This suggest that the issue of high concentrations of nitrate in the Grand River during the winter is associated largely with non-point sources. Likewise, the longitudinal pattern of TSS during spring high flows (Figure 12) shows large increases downstream from areas where non-point sources (e.g., stream bank erosion, rural soil erosion and urban wash-off) predominate and point sources are absent, suggesting that the role of point sources is relatively minor.

Non-point source contributions

While point sources are relatively important to water quality issues linked to high concentrations of phosphorus in the summer low flow period, non-point sources are important contributors to the high load of phosphorus in spring high flows. Figure 17 illustrates the regional mass loads during the spring of total phosphorus from the tributary outlets for the upper middle Grand River region between the Shand Dam and Blair. The mass loads indicate that during the spring, much (94%) of the phosphorus being carried in the river system is from the diffuse areas draining to the tributary outlets. Point sources (such as sewage treatment plant discharges) account for only 3 percent of the total load in the Grand River at Blair during the spring. The estimates also indicate that the contribution by urban areas above Blair during spring high flows is relatively large (30% of the total load in the Grand River at Blair).

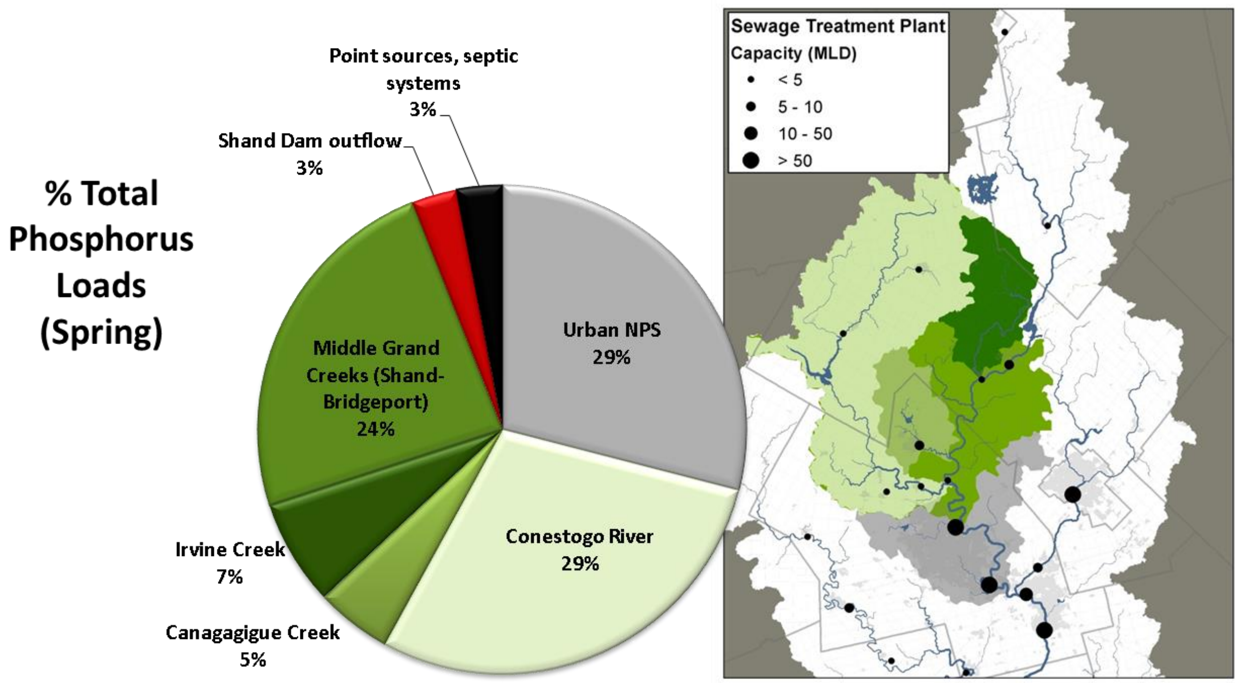


Figure 17. Total phosphorus loads in the upper-middle Grand River region (above Blair) during spring high flows.

Regional mass loads for TSS are not presented here due to high uncertainty in the estimates that resulted from the large amount of variability in the data. However, given the correspondence between total phosphorus and TSS in the river during spring high flows (e.g., Figure 12), it is hypothesized that TSS and phosphorus in the upper middle Grand River region have similar source areas during the spring.

Regional mass loads of total nitrate (the sum of nitrate and nitrite) during the winter/early spring season suggest that most (90%) of the load is coming from the cumulative inputs from the subwatersheds draining major tributaries (Figure 18). Specifically, the Conestogo River contributes the greatest relative load (41%). Point sources contribute very little to the total nitrate load in the Grand River at Bridgeport (about 2%) between December and April. During this season, biological processes that remove excess nitrate from soils through uptake transformation are limited. In addition, the potential for subsurface movement of nitrate through infiltration is enhanced. The discharge of shallow groundwater (that contains high nitrate concentrations) to surface water is hypothesised to have a significant role in delivering the nitrate to the river. Concentrations decline slightly during the spring thaw in March-April (GRCA, unpublished data), potentially due to increased biological uptake. Even with a slightly reduced concentration relative to late winter, the spring thaw is likely to be a period when loading is relatively high due to increased river discharge (i.e. volume of water).

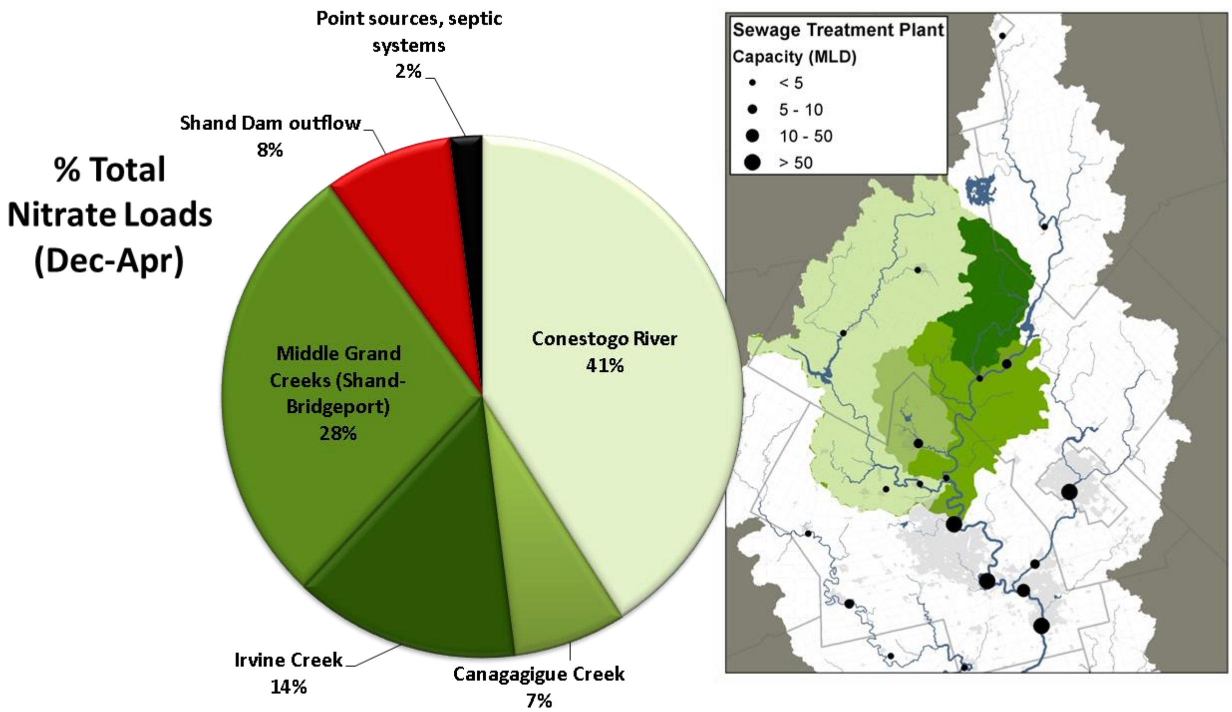


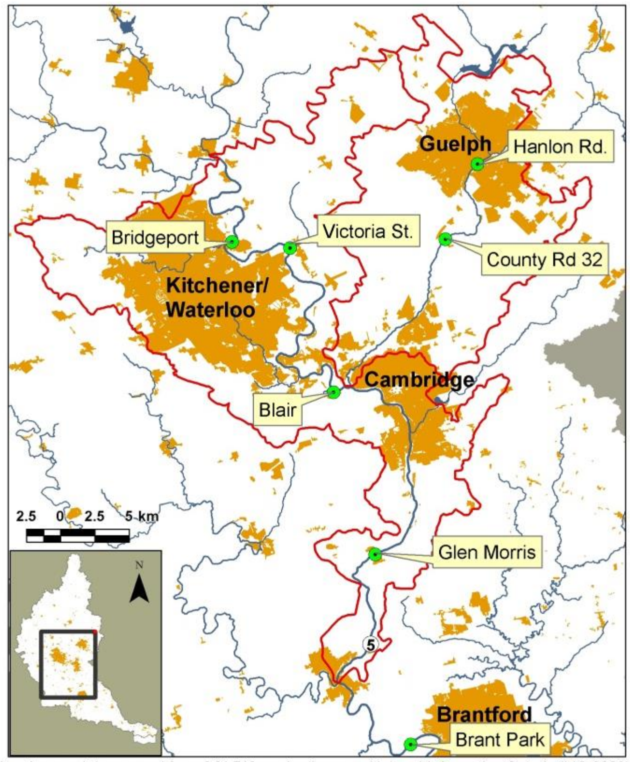
Figure 18. Total nitrate (nitrate + nitrite) loads in the upper-middle Grand River region (above Bridgeport) during the winter/early spring (December-April).

Transport mechanisms from non-point sources

The estimates of regional mass loads are useful to distinguish contributions from point and non-point sources, but are less informative about transport pathways acting on diffuse sources. Other information in this report may offer insight about the predominant mechanisms associated with contributions from diffuse sources at a coarse scale. For example, the similarity of longitudinal patterns in total phosphorus and TSS concentrations in the upper portion of the watershed (i.e., drainage areas above) during the spring (Figure 12) suggests a large portion of phosphorus load in the spring is associated with the transport of particles. As mentioned in section 3 of this report, the primary delivery mechanisms responsible for mobilizing particles from large diffuse areas are overland runoff, rural soil erosion and stream bank erosion (Table 1).

The processes that mobilize particles on the landscape are influenced by soil condition (e.g., permeability, saturation etc.), leading to seasonal and spatial variations in contributions of sediment and sediment-associated phosphorus from non-point sources. For instance, transport of particles in surface runoff by erosion is likely to play a larger role on soils of the clay plain in the southern portion of the watershed than on the central sand and gravel moraines (shown in Figure 3). Conversely, highly permeable soils, such as the coarse gravel and sands that dominate in the central portion of the watershed (shown in Figure 3), support the mobilization of nutrients from diffuse sources in a dissolved form (e.g., as nitrate). In regions with permeable soils, dissolved nutrients can be transported from sources on the landscape to surface water in interflow, subsurface drainage or shallow groundwater, as discussed in section 6.5. These transport mechanisms are variable temporally and spatially since they are influenced by hydrologic conditions, seasonal factors (e.g., biological activity, temperature) and with the physiography of the watershed. In addition to natural factors, the proportion of nutrients and sediments contributed by transport mechanisms is affected by land cover and land management, as discussed earlier in this report (e.g., section 6.5).

In urban landscapes, overland runoff is likely the dominant transport pathway due to the prevalence of impervious surfaces. Urban areas can generate large volumes of stormwater during runoff events as it runs off from roads, parking lots, roofs and other hard surfaces. If the flow of stormwater is uncontrolled, it can rapidly increase flows in streams draining urban areas, picking up and carrying sediments and other pollutants. Untreated urban stormwater typically contains high concentrations of suspended sediments, nutrients and other pollutants, particularly during episodic high flow events (Yu and Stone 2010; City of Kitchener 2011). Urban areas account for a relatively small proportion of land cover in the Grand River watershed, but are concentrated in the areas draining into the central portion along the Grand and Speed rivers (Figure 19). Land cover associated with transportation or built-up areas accounts for approximately 30% of the drainage area in the central portion of the watershed (outlined in red on Figure 19). The clustering of urban inputs in this area may cause localized water quality impacts from transient peaks in concentrations of nutrients and sediments. The relative importance of these inputs likely decreases downstream as the river receives flows from other areas and the urban areas account for a decreasing proportion of the flow.



Land cover data sourced from SOLRIS, under license with Land Information Ontario (LIO 2003).

Figure 19. Urban areas in the central Grand River watershed, showing GRCA continuous water quality monitoring stations. Built-up areas account for ~30% of the subwatersheds outlined in red.

The following paragraphs present additional water quality data collected by GRCA that provides detail about some of the mechanisms transporting nutrients and sediments from non-point sources.

Regional mass loads of TSS have not been presented in this report due to low confidence in the estimates. Continuous water quality monitoring in the Grand River can be used to illustrate the transport of suspended solids in the river due to rainfall, runoff and high stream flows, particularly in the spring. The turbidity of the river is used as a surrogate measure of suspended sediment and is monitored continuously at several locations in the Grand River both upstream and downstream from urban areas (Figure 19). Data from continuous monitoring is complementary to the longitudinal profiles of the Grand River (Figure 12). Although somewhat limited in spatial extent, it gives a more complete temporal characterization of suspended sediment concentrations than intermittent sampling, since it captures the highly dynamic nature of transport during hydrologic events. For example, Figure 20 shows that large increases in turbidity occurred in the Grand River following a rainfall event associated with high river flows. This demonstrates the effect of transient high flow events, that carries sediment from both urban and rural landscapes. Turbidity levels in the river respond quickly and dramatically to rain and high flow resulting in significant washoff of sediment from both agricultural and urban areas. Flows that drain the predominantly rural and agricultural areas above Bridgeport had very high turbidity, which increased as the river passed through urban areas (as shown in at Victoria St, Kitchener). Turbidity measurements at Brant Park above Brantford show two distinct peaks. The first peak is suspected to be sediment coming from the upper portions of the watershed, upstream from Paris. Based on travel time estimates, the second peak is suspected to be sediments delivered from the Nith River subwatershed to the Grand River. The figure illustrates that these intermittent events are of short duration, but can have a large magnitude. High concentrations of sediments in these events have the potential for significant effects on aquatic life (e.g., and river uses (municipal water intakes), as outlined in section 5.1 of this report.

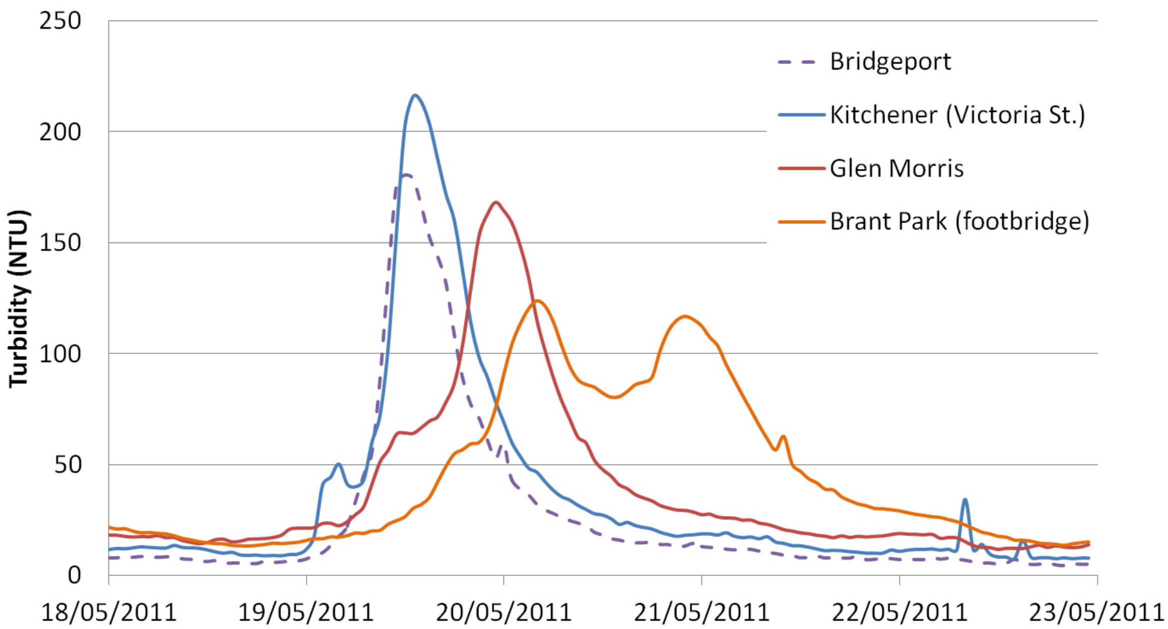


Figure 20. River turbidity (NTU) levels at continuous monitoring stations in the Grand River above (Bridgeport) and below (Glen Morris) urban areas during a significant rainfall event across the watershed.

A second example of continuous turbidity measurements (Figure 21) shows the large peak in turbidity in the Grand River after a storm event with a high amount of rainfall centred on the urban area of the watershed. Downstream from where the Grand River receives runoff from this urban area (i.e., between Bridgeport and Blair) there was a five-fold increase in turbidity. This figure illustrates that the sediment mobilized by urban runoff in large storm events can result in large increases in suspended sediment concentration in the Grand River. Data is currently inadequate to provide a quantitative estimate of suspended sediment concentrations from these turbidity measurements. However, a small number of water samples were collected during this event, which demonstrated increases in TSS at Blair as high as 150 mg/L (GRCA, unpublished data). With additional collection of samples during similar events it would be possible to generate estimates of the changes in suspended sediment concentration in spring high flows and summer storm events. Additional benefit would be derived by cross-calibration of turbidity with measurements of sediment transport collected using more detailed methodology (e.g., as in Smith 2013); this would enable the quantification of sediment (and associated phosphorus) inputs from spring high flows and summer storm events.

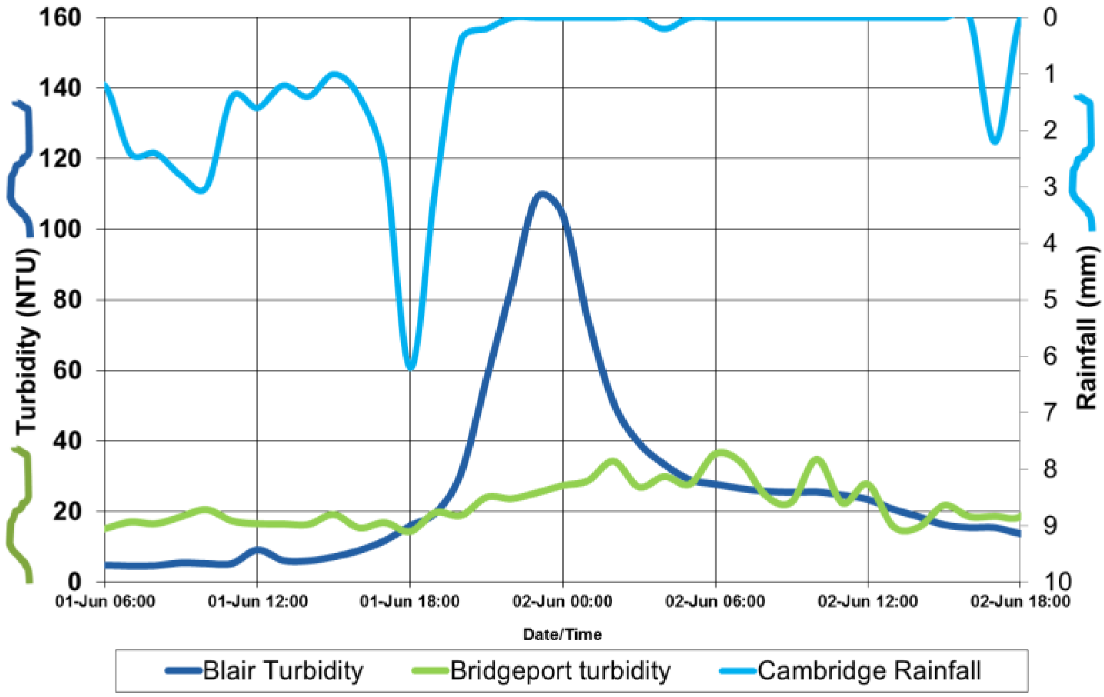


Figure 21. Turbidity in the Grand River at locations upstream (Bridgeport; green), and downstream (Blair; dark blue) of a large urban area during a rain storm event in June, 2012. Rainfall (light blue) was centered on the urban area of the watershed.

Issues of elevated nitrate in the upper-middle Grand River in the late winter reflect high concentrations in tributaries, most of which do not have point source inputs. The dramatic increase in winter nitrate levels between the Shand Dam and Bridgeport on the Grand River illustrated in Figure 13 suggests that the area of the watershed draining to the river between these two points contributes a significant amount of nitrate to the Grand River during a typical winter. Intensive data collection by GRCA in February and March of 2013 focused on this reach and is included in this report to further characterize the transport of nitrate into the upper-middle Grand River during the winter. In February, weekly sampling indicated that nitrate concentrations in the tributaries to the Grand River (shown in Figure 22) were consistently higher than concentrations in the Grand River below Belwood lake (2.4 mg-N/L on average). Nitrate concentrations were exceptionally high (5.3 to 9.2 mg-N/L) in the Canagagigue, Conestogo, Carroll and Cox Creeks. The distribution and range of nitrate concentrations are similar to data collected during other winters (2009, 2010 and 2011; unpublished data, GRCA) and by other programs in adjacent areas (MOE 2012). It is possible that the combined inputs from these tributaries (and others which were not monitored) resulted in the large increase in nitrate concentration in the Grand River between the Shand Dam and Bridgeport illustrated in the longitudinal profile shown earlier in this report (Figure 13).

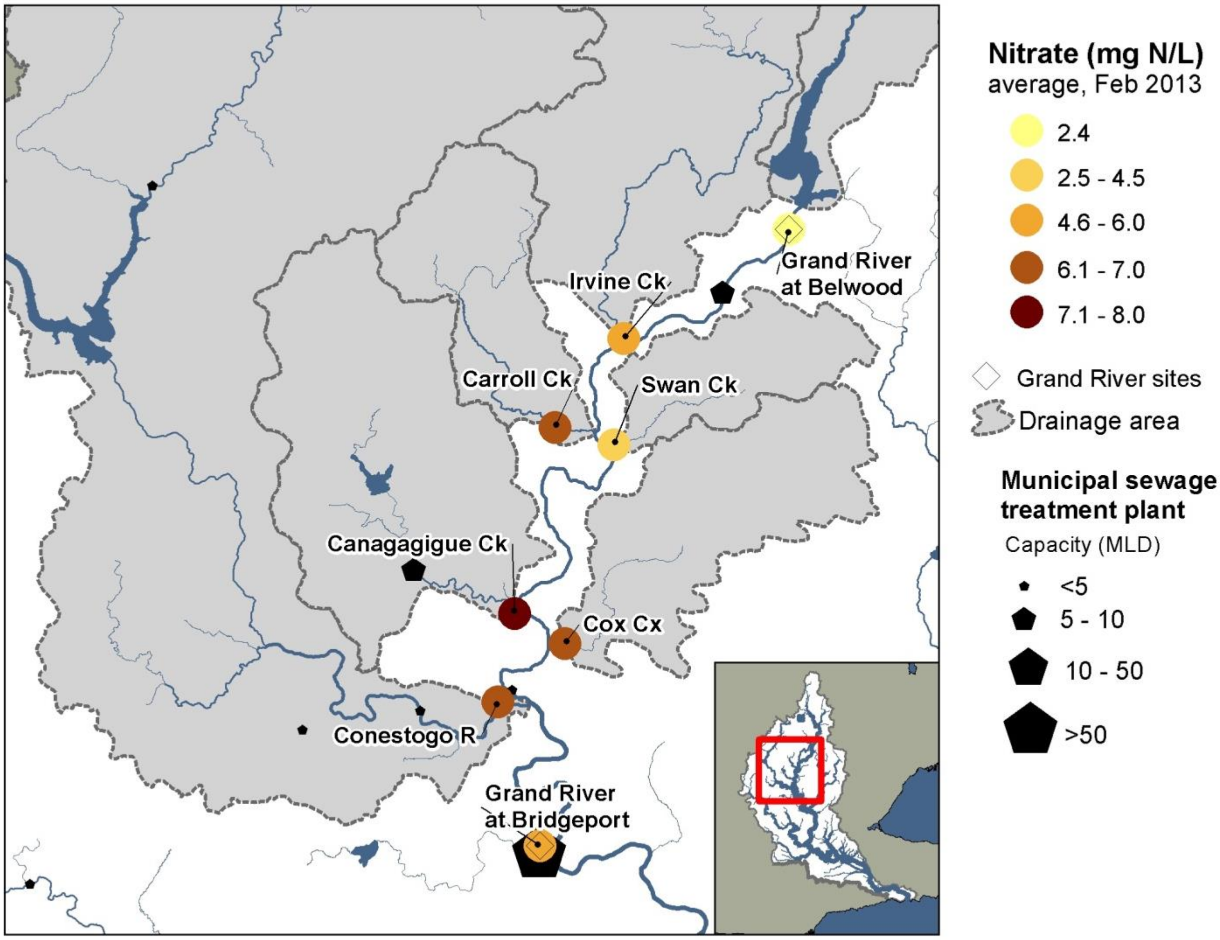


Figure 22. Average concentration of nitrate from weekly samples collected in the Grand River and tributaries between the Shand Dam (below Belwood Lake) and Bridgeport during February 2013. (unpublished data, GRCA)

Since many of these tributaries do not have point sources, it is likely that the increased nitrate concentrations were derived from non-point sources. The tributaries in Figure 22 drain rural landscapes with highly permeable soils (Figure 3), suggesting that infiltration and leaching may be more important and runoff may be less important than in areas with tight soils (e.g., clay plains). The predominant land use is agriculture (Figure 5) with a relatively high livestock density and a higher incidence of fertilizer use on crops (Figure 6) than in other areas. If rates of nutrient removal are not balanced with these potential sources, it increases the risk of nutrient loss to surface or ground water from agricultural sources. Hydrologic processes that could transport nutrients from these potential sources (Figure 1) are affected by structures that modify the drainage of these landscapes, such as municipal and tile drains. These structures impact the amount, form and timing of the delivery of nutrients (and sediment) from the land to the water (Fraser and Fleming 2001). It is not possible based on the data in this report to estimate the dominant pathway by which dissolved nutrients, such as nitrate, are transported to surface waters in the Grand River. However, this report has highlighted some of the factors that should be considered in future investigations of the transport mechanisms of dissolved nutrients in the Grand River watershed.

8. Agronomic nutrient balance analysis

In conjunction with Water Quality Working Group participation, Agriculture and Agri-Food Canada (Guelph) undertook a study to evaluate agricultural nutrient balances in the Grand River watershed. In contrast to a (sub)watershed *nutrient budget* which is based on coupling nutrient (and sediment) concentrations with stream flow to calculate total load (mass) for a given area or watershed, a *nutrient balance* is an agronomic approach for evaluating the nutrient requirement or excess on the land. A nutrient balance is calculated from the total nutrients available to a crop minus the nutrients removed from the field when a crop is harvested. While typically calculated for a field, a nutrient balance for a (sub) watershed or other spatial unit provides insight into where there may be a surplus of nutrients. Where these areas intersect with portions of the landscape that have active runoff, erosion or leaching processes, there will be a greater risk of excess nutrients being transported off the land. This information is useful to identify where enhanced adoption of best practices may be beneficial and the type of practices that may be required (i.e., preventative actions to avoid nutrient surpluses in the first place vs. erosion mitigating practices).

The findings of the nutrient balance by Agriculture and Agri-Food Canada are summarized in the report "*Characterization and Assessment of Sources and Pathways of Nitrogen, Phosphorus, and Sediment from Agricultural Activities in the Grand River Watershed."* (Feisthauer and Joosse 2013). The analysis showed that the N balance, P balance and cumulative P parameters, along with assessments incorporating primary loss pathways, had levels and distribution generally aligned with the analysis and locations of concern identified in this report.

9. Long term monitoring of suspended sediments

A long-term dataset that includes measurements of suspended sediment in the Grand River system has been collected under the Sediment Survey Program, which was initiated by the Water Survey of Canada (WSC) (unpublished data, provided by Barry Smith, Environment Canada (retired)). The data, which was collected between 1967 and 2012 can be used to examine the suspended sediment contributions from some of the major subwatersheds in the Grand River watershed. The data was collected using rigorous methodology that produces accurate measurements of suspended sediment concentrations. Measurements are collected in conjunction with stream flow calculations such that loads can be estimated with much greater precision and accuracy than the data presented earlier in section 7 of this report. Interpretation of the data and recommendations to inform future suspended sediment monitoring in the watershed were shared with the authors of this report (B. Smith, *pers. com.*). A portion of this information is described below.

The estimated yield of suspended sediment by the WSC data showed comparable differences among major subwatersheds to the TSS loads presented in section 7.3 of this report. One major exception was the relative magnitude of suspended sediment yield from Fairchild Creek: the estimates presented earlier in this report indicated the yield of TSS in the Fairchild Creek subwatershed was exceptionally large relative to other subwatersheds. This pattern was not substantiated by the SSP data, which showed it to have yield of suspended sediment which was similar to the Nith subwatershed. According to the WSC data, the highest yield of suspended sediment was from the MacKenzie Creek subwatershed, which was approximately 60% higher than the yield from the Nith. Both information sources indicated that the Nith subwatershed was a major contributor of suspended sediment loads because of the large drainage area, but also due to relatively high loading per unit area (i.e., yield).

Estimates of loading generated by the WSC data indicated that subwatersheds on the lower clay plain make a large contribution to the total load of suspended sediments from the watershed. The estimates of annual loads from the Grand River watershed and the McKenzie and Fairchild subwatersheds, compiled by between 1972 and 2010 are shown in Figure 23. The McKenzie and Fairchild subwatersheds account for 7% and 8% of the watershed area respectively, but contributed >20% of the watershed load of suspended sediment in some years. The high degree of inter-annual variability is likely indicative of years with different hydrologic drivers. For instance, in 2008 there were a number of large storm events which missed the lower portion of the watershed, which may have resulted in the relatively small contribution by the subwatersheds in comparison to the very large loads exported from the rest of the Grand River watershed that year.

River

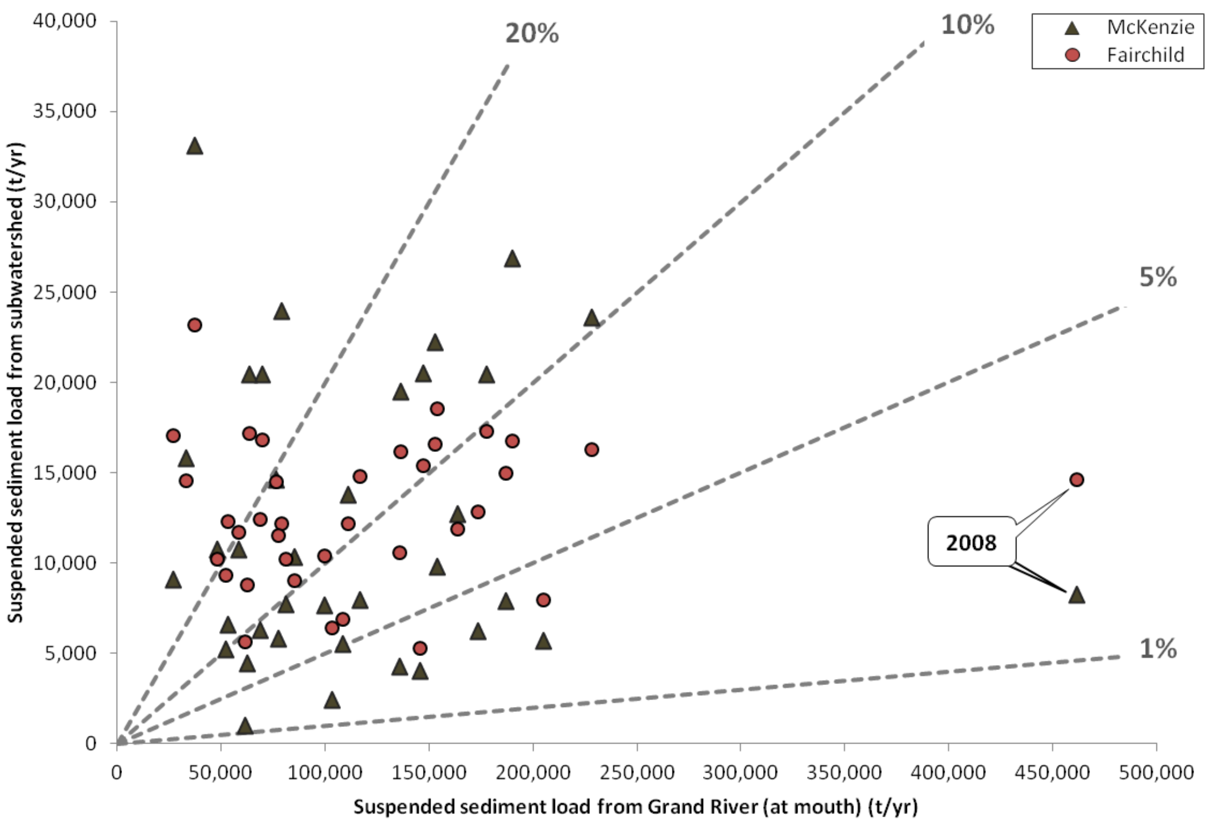


Figure 23. Comparison of estimated annual suspended sediment loads from the McKenzie and Fairchild subwatersheds to estimates of total loads from the Grand River watershed (1972-2010). Dashed lines indicate the proportion of the total load from the Grand River. Estimates are from unpublished data, provided by Barry Smith.

Data collected from several sites in the Canagagigue subwatershed by the WSC program highlighted some of the important sources of suspended sediment in this area. There was particularly high loading of silt clay suspended sediment from an area where there was severe bank erosion with little to no vegetative cover (B. Smith, *pers. com.*). Frequent disturbance of the streambed and bank by livestock were also observed upstream from the monitoring location. Suspended sediment yield from this area was among the highest of all estimates in the watershed, at 77 t/km^2. Since there is an impoundment downstream from this location (at Floradale), it was speculated that a portion of this load would be trapped and would have little influence on suspended sediment concentrations in the Grand River (B. Smith, *pers. com.*).

High yields of suspended sediment were also estimated for a site on the Conestogo River above Drayton. Loadings were particularly high during the early winter (November – December), often accounting for as much as 49% of the annual load. Several possible sources were suggested based on observations in the area: erosion from fields which lacked crop cover or re-suspended sediment in natural sinks (previously deposited by summer storms) (B. Smith, *pers. com.*). The area sits between till plain and sand and gravel moraine deposits.

In addition to the influence of land cover and surficial geology, the suspended sediment yields from the WSC data highlighted the large influence of hydrology. The large contributions of sediments and high proportion of coarse material from the Nith subwatershed has been linked to absence of a large water control structure on the Nith River (B. Smith, *pers. com.*). Higher flows than other major tributaries were also suggested to increase the potential for entrainment of bed material and increased transport of suspended sediments, particularly during the spring. The WSC data indicated there was a very large amount of variability in suspended sediment loading between years at most locations. Many of these patterns could be explained by hydrologic events that resulted in high discharge that carried a high proportion of the annual suspended sediment load.

Synthesis

The overall intent of the Water Management Plan is to identify the most cost-effective, and practical water management solutions to maintain or improve the quality of water resources in the watershed in to the future. One of the plan's goals is to "*improve water quality to improve river health and reduce the Grand River's impact on the eastern basin of Lake Erie*". To achieve this goal, an understanding of nutrient/sediment sources in a watershed, their source areas, and their relative importance or magnitude is needed to inform decisions around priority actions required for improved water management.

This synthesis will discuss sources of nutrients and sediments for each of the key water quality issues relevant to the Grand River watershed. The purpose is to improve the understanding of where and how nutrients and sediments are transported to surface waters to cause these issues. This information can then be used to determine the most appropriate management actions. Recommendations regarding management actions to address sources of nutrients and sediments are not included in this report, but be found in other components of the Water Management Plan. Recommendations in this report focus on the improvement of knowledge and information, such that decisions can be made about management actions with greater certainty within an adaptive management framework.

Very limited datasets (e.g., water quality, land use/cover) precluded the quantification of a true nutrient or sediment source allocation for the watershed. However, multiple lines of qualitative and semi-quantitative evidence have been used in this report to characterize watershed sources of nutrients and sediment. Although specific sources of nutrients or sediment have not been definitively identified, expert judgement by the Water Quality Working Group provided insight into the relative importance of source areas as well as general watershed source categories such as 'point' and 'non-point' sources of nutrients or sediment.

10. Relative importance of sources and transport mechanisms

The importance of a source can be judged by the magnitude and duration of the inputs as well as the potential for the inputs to cause impacts of some severity. In the context of their impact, the relative importance of a source is affected by the character of the receiving aquatic ecosystem (e.g., reservoir, river or lake) and the time of year (e.g., active summer aquatic plant growing season vs. winter). The choice of management actions to address the source is also informed by the key transport mechanisms and pathways responsible for mobilizing the contaminants into aquatic systems (e.g., direct discharges or runoff / erosion processes etc.; Table 1).

10.1. Eutrophication of the river system

In the context of nutrient and sediment sources, the primary water quality issue in many reaches of the Grand River during summer low flows is driven by the availability of phosphorus for uptake by organisms such as aquatic plants and algae (described on page 18). Impacts associated with high phosphorus availability in the summer growing season are widespread in many of the larger reaches of the Grand River and its tributaries, but are particularly severe in central reaches of the Grand River, the Canagagigue and in the reaches of the Grand River near the mouth of Lake Erie. Eutrophication is less severe in the 'recovery reach' of the Grand River between Glen Morris and Brantford, where groundwater input likely dilutes high phosphorus concentrations and facilitates nutrient processing. Effects from eutrophication (e.g., blooms of cyanobacteria and algae; low dissolved oxygen) also impair the conditions in many of the reservoirs (Guildford 2006). The nutrient enriched water which flows out of the turbid reaches of the Southern Grand River during the growing season may also fuel plant growth along the shores of the river mouth in Lake Erie (GRWMP 2012). As demonstrated in the longitudinal profile of total phosphorus in the summer (Figure 12), the highest concentrations occur in the southern reaches of the Grand River near Lake Erie. Despite this, impacts associated with eutrophication in this reach are moderated, to some extent, by low water clarity that limits biological uptake of nutrients (i.e., for plant or algal growth)(GRWMP 2012).

The timing of the delivery of nutrients or sediment is an important consideration in determining the relative importance of sources to the issue of eutrophication. Pathways that increase the amount of phosphorus that is bioavailable during the summer are most important in the context of eutrophication, since they have the greatest potential to cause an impact. Summer is the active growing season for aquatic plants and algae that can impact the dissolved oxygen levels though their prolific growth. Plant and algal growth is strongly influenced by the form (i.e., particulate or dissolved) of phosphorus inputs since the dissolved form of phosphorus tends to be more bioavailable (Withers and Jarvie 2008). Consequently, inputs of dissolved phosphorus during the summer season are very important to the impacts associated with eutrophication of the river system.

Phosphorus loads associated with sediments and particulate organic material that has previously been deposited upstream (e.g., in reservoirs, areas of slack water) can also be relevant. These deposits have the potential to become a source of dissolved phosphorus in the summer as the result of internal loading and release through microbial activity (Jarvie et al. 2005). Therefore, in addition to the effect of phosphorus inputs during the growing season that increase concentrations of bioavailable phosphorus, it is important to consider the contributions from upstream phosphorus stores in the river system.

The chief concern from the perspective of eutrophication in the river system are inputs during the growing season that increase the *concentration* of phosphorus in the water column. As a result, an assessment of annual *loading* may not provide sufficient information to determine the importance of a source to the impacts in the river associated with eutrophication. Only a portion of the annual loads affect concentrations during the growing season; in most reaches, a large portion of the phosphorus load passes through the reach before nutrient cycling or biological uptake takes place. While some reaches serve as a 'conduit' for loads of phosphorus, reaches or endpoints where the loads accumulate are more likely to experience the effects of eutrophication. In the Grand River watershed, the reservoirs and the wide reaches in the southern Grand River are more likely to function as stores of phosphorus since they are large areas of still or slow moving water. Key pathways for phosphorus loading of these stores differ in spatial and temporal scale from those pathways which are key to eutrophication of the river system so they will be discussed separately below (in section 10.3).

Point sources of nutrients, such as municipal wastewater treatment plants that directly discharge phosphorus, nitrate and ammonia to the central Grand River region, are very important contributors of phosphorus during low flows in the summer. Estimates of regional mass loads in the central Grand River indicate that point sources, such as wastewater discharges, become more important during periods of low flow (Figure 16) than in spring high flows (Figure 17). As reviewed in section 6, many seasonal loading estimates illustrate this pattern (Hore and Ostry 1978; Draper and Weatherbe 1994; Stantec 2010).

This seasonal shift is unlikely to reflect seasonality of WWTP inputs: when compared to the very large seasonal shift in the total loading of all sources the river, variations in WWTP inputs are minor. It is more likely that the change reflects a shift in the proportional contribution to flow; the reduction in river flow during the summer increases the relative proportion of flow attributed to wastewater discharges.

The strong influence of wastewater discharges on phosphorus concentrations in the river system is demonstrated by the relatively large increase in the reach between Bridgeport and Blair that receives effluent from some of the watersheds largest cities (Figure 12). Although an assessment was not made on the other wastewater treatment plants discharging to the Grand River or its tributaries, the case could be made to infer the importance of nutrients from directly discharged wastewater effluent locally, if not regionally.

The importance of wastewater discharges becomes heightened during the summer growing period compared to the remainder of the year due to increased biological activity. Treated effluent may pose a relatively high risk of eutrophication in nearby reaches compared to other sources because it tends have a high proportion of phosphorus in a form that is highly bioavailable (Hore and Ostry 1978; Jarvie et al. 2006; Region of Waterloo, unpublished operational data 2008-2012). The potential for impacts from eutrophication may also increase near these point sources since they typically contain other substances (e.g., ammonia) that scavenge oxygen from the water, compounding the low oxygen conditions caused by high plant or algal respiration.

It is difficult to determine the contribution of non-point sources to eutrophication in river reaches since the pathway is much less direct than with point sources: as previously described, there can be a large offset spatially and temporally between source and impact. Currently, there is a limited understanding of the pathway in the Grand River watershed by which nutrients can be transported or 'stored' in a form that is unavailable to plants and algae (e.g., associated with sediments), and later released in an available form. Similarly, since the pool of dissolved phosphorus is poorly characterized in the Grand River system, the pathway by which phosphorus is transported from the landscape in a dissolved form cannot currently be quantified. Other studies both in and outside the watershed have addressed this topic and were discussed in section 6.5 of this report.

Despite the lack of a precise estimate, regional mass loads (Figure 16) suggest that in the central Grand River where the impacts from eutrophication can be severe, non-point sources comprise a smaller proportion of phosphorus during the summer than point sources. Regional mass loads suggest that urban stormwater likely comprises an important component of the load from non-point sources in this area. The total estimated load from non-point sources to this area in the summer also includes the load of phosphorus from re-suspended or re-released phosphorus from the upstream reservoir (i.e., Belwood Lake). This suggests the reservoir plays a minor role in eutrophication of downstream reaches relative to point sources. It is possible that a large portion of the nutrients released in Belwood Lake during the growing season are retained in biomass, either as organic deposits or in the food web. Consequently, although non-point sources may be a minor contributor to eutrophication in the reaches of the central Grand River below Belwood Lake, they could potentially have a large importance to eutrophication in the reservoir itself. To quantify the importance of the reservoirs as sources or sinks for nutrients, it is recommended that reservoir conditions be investigated in the context of external and internal loading.

The profile of total phosphorus concentrations in the summer (Figure 12) indicates that concentrations rise downstream from Brantford, towards the slow moving reaches of the southern Grand River. Regional mass loads were not estimated for this reach, so it is not possible to judge the relative importance of summer inputs from different sources or source areas (e.g., Brantford and smaller WWTPs, Nith River and Whitemans Creek subwatersheds) to eutrophication. Despite this, a weight of evidence approach suggests there is complex nutrient cycling in this region, including a heightened role of phosphorus release from accumulated stores. Phosphorus concentrations are particularly high in the lake-like reaches closest to Lake Erie, despite the lack of large point sources (Figure 12). Anoxic conditions are known to develop in large portions of these reaches during the summer and late fall (MacDougall and Ryan 2012), potentially allowing for the release of phosphorus from the sediments in a dissolved form. Rooted emergent vegetation (e.g., cattails) along the river banks may act as a biological sink for a portion of the nutrients that enter these reaches, but the high turbidity of the river as it flows across the clay plain likely inhibits the growth of submergent vegetation or benthic algae in most areas. High chlorophyll concentrations indicate that phytoplankton blooms may incorporate some of the available nutrients into biomass (Kuntz 2008; MacDougall and Ryan 2012); however, as the biomass decays, it switches from a sink to a source of phosphorus. In balance, the evidence suggests that there is significant internal cycling of phosphorus that may increase the influence of non-point sources (both within and draining into the river system) on endpoints in the southern Grand River. Therefore, the annual load of nutrients from non-point sources is likely no less important to eutrophication in this region than point source inputs of nutrients during the growing season. To determine the relative importance of upstream nutrient sources to endpoints in the southern Grand River, additional data and synthesis would be required.

10.2. Sedimentation and turbidity in river reaches

Suspended sediment has been highlighted as a long-standing water quality issue in the Grand River watershed (Sandilands 1971; GRCA 1998; Loomer and Cooke 2011). The primary issues associated with inputs of suspended sediment in the Grand River watershed are increased erosion/re-suspension of sediments during high flows and turbidity that is high on a chronic basis (i.e., irrespective of flow conditions). In addition to these issues, there can be a high load of phosphorus associated with the suspended sediment; this will be discussed in greater detail in the next section.

Impacts from increased suspended sediment inputs are particularly problematic in some areas of the watershed and during certain periods (e.g., spring runoff, or severe rainfall events). For instance, flashy flows from urban areas that have a low proportion of stormwater control can have high concentrations of high suspended sediment (Yu and Stone 2010; City of Kitchener 2011). River reaches receiving such flows, such as the central region of the Grand River, experience prolonged or frequent sediment 'pulses' (such as those illustrated in Figure 20 and Figure 21) that can result in the absence of species which are unable to escape or protect themselves (e.g., mussels). This effect is compounded by the changes to the composition of bed sediments (i.e., increased accumulation of fines/organic content) that impair nutrient cycling and may facilitate the nuisance growth of plants or algae which have the potential to impact dissolved oxygen levels. The accumulation of suspended sediment in this region of the Grand River has been facilitated by changes to channel morphology that have occurred over many years, likely as the result of river regulation and flashy flows from urban streams.

Ecological condition and water quality in the slow flowing, wide reaches of the southern Grand River are also currently impaired by the effects of suspended sediments (Cvetkovic and Chow-Fraser 2012; MacDougall and Ryan 2012). These reaches are naturally turbid since they overlie the clay plain. However, changes over many years that are associated with human settlement in the region have altered sediment dynamics such that the deposition and re-suspension of fine sediments as well as chronic turbidity now cause a wide range of negative effects on human uses and ecological condition (Gilbert and Ryan 2007; GRWMP 2012; MacDougall and Ryan 2012).

Energy is required to mobilize and keep sediments in suspension, so the pathway associated with transport of sediments is largely linked with high flow events. Despite this, due to their small size, clay particles are easily mobilized and tend to stay in suspension even during relatively low flows. Inputs of fine sediments, such as clay particles, are particularly detrimental to water quality because they can be transported long distances, such that turbidity and siltation may impair reaches far downstream from source areas. Point sources typically do not discharge effluent that is high in sediments, so sources are more likely to come from diffuse sources (Table 1).

Sediment loss can occur from both urban and rural landscapes. Soils can be eroded from the rural landscape and transported in overland flow. In urban landscapes, particles are washed off impermeable surfaces (e.g., pavement) into stormwater systems that may discharge to surface water. Upstream river reaches or riparian areas can also be sources if high flow results in channel scouring or stream bank erosion. Vegetation in river channels and riparian areas plays an important role in modifying many of these pathways by increasing entrapment or deposition and stabilizing sediments (Stone 2004; Jones et al. 2011). In the case of aquatic vegetation, the relationship is complex: increased turbidity can reduce the growth or extent of coverage by submergent (subsurface) macrophytes, causing a negative-feedback loop of increasing turbidity. The dynamics and the resulting effects depend on the ratio between re-suspension/erosion and deposition as well as the nature (i.e., particle size and composition) of the sediments.

The longitudinal profile of TSS concentrations in the spring (Figure 12) showed a consistent increase as the Grand River flows downstream, suggesting that most of the watershed contributes sediment during spring high flows. The relative unit area yield of TSS from the nine major subwatersheds (Figure 15) supports this observation, but also indicates that some subwatersheds have a greater potential for contributing sediments to surface waters. These differences were explored in greater detail using data from the WSC Sediment Survey Program, which was summarized in section 9 of this report. The discussion of this data highlighted some of the underlying factors including land cover, physiography and hydrology.

The TSS mass load estimates (presented in section 7.3) and the WSC suspended sediment data (presented in section 9 of this report) demonstrate that areas with natural characteristics that result in a high potential for generating overland runoff (i.e., the upper Conestogo, Canagagigue, Irvine, Nith, Fairchild and McKenzie subwatersheds) have relatively high yields of suspended sediment. Of these areas, those on the lower clay plain (e.g., Fairchild and McKenzie subwatersheds), which have low relief but erodible soils and parent materials, have some of the highest yields. It is unclear what proportion of the annual loading from source areas occurs through each process (i.e., transport of sediments in overland runoff, in-river or bank scouring processes). To identify the major source/mechanisms responsible for mobilizing sediments from the landscape in the Grand River watershed, additional studies are needed. These studies should seek to build on the work that has previously been undertaken (e.g., the WSC long term suspended sediment dataset).

This report has a limited characterization of urban sources, but it suggests that sediments in urban runoff are of importance in some areas, particularly in river reaches that receive a high cumulative input from urban areas (e.g., the central reaches of the Grand River; Figure 19). It was not possible to estimate loading rates of sediment from urban sources; however, anecdotal evidence (Figure 20, Figure 21) and previous studies (e.g., O'Neill 1979; Draper and Weatherbe 1994; City of Kitchener 2011) suggests that in the context of local impacts, it is important to consider inputs of suspended sediments from urban areas during storm events. The magnitude of suspended sediment inputs during these events is poorly characterized, because intermittent sampling may miss peaks in concentration. Continuous measurement of turbidity holds promise as a tool to measure transient peaks in concentration, but the use of turbidity as a proxy for suspended sediment is currently limited by data availability. This highlights an important gap in our current understanding of the cumulative impact (regionally if not locally) of sediments from urban stormwater. To generate information supporting such an assessment, it is necessary to increase the temporal and spatial scale of data. This could be accomplished, for example, by sampling with better temporal resolution and inter-calibration of turbidity, suspended sediments and flow.

10.3. Phosphorus loading of Lake Erie and water management reservoirs

Regardless of their distance from the mouth of the Grand River, all sources of phosphorus to the Grand River system have the potential to eventually end up in Lake Erie as the result of nutrient cycling. Phosphorus from sources in the Grand River watershed are particularly important to the eastern basin of Lake Erie; estimates suggest the Grand River is a relatively large component of the tributary loads of phosphorus to the eastern basin of the lake (unpublished data 2004, D. Dolan, U. Wisconsin). Although nutrient dynamics in the nearshore are poorly understood, phosphorus fuels the nuisance growth of algae (i.e., *Cladophora*) on hard substrate in the nearshore, fouling extensive areas of shoreline on the eastern basin of Lake Erie (GRWMP 2012). It is unclear how the timing and form of phosphorus inputs affect the growth of *Cladophora*, but it is generally accepted that a reduction in total basin loads of phosphorus is a mechanism by which nuisance algal growth in the nearshore may be reduced (Lake Erie Nutrient Science Task Group 2010). There is also consensus that to restore the health of the Lake Erie ecosystem, basin loads of total phosphorus should (at a minimum) not be allowed to increase (Lake Erie Nutrient Science Task Group 2010). Parallel efforts to reduce phosphorus loadings are also focused on the western and central basins of Lake Erie, where high phosphorus availability has contributed to large and frequent harmful algal blooms (i.e., cyanobacteria) that have the potential to produce toxins and anoxic conditions (Lake Erie Millennium Network 2011).

Deposition of phosphorus associated with sediments, or sequestration in organic matter (e.g., algal blooms) can delay the transit time of the phosphorus load to Lake Erie, but may also result in impacts where the load accumulates in the river system. For instance, increases in the annual load of phosphorus delivered to the reservoirs on the river system (e.g., Belwood, Conestogo, and Woolwich) have likely contributed to water quality issues associated with nutrient loading (e.g., proliferation of cyanobacteria blooms, increase in the extent or duration of anoxic conditions)(Guildford 2006). It is less clear however, the extent to which the issues are caused by an increase in loads from upstream areas, since other causal factors (e.g., dynamics of water levels) are also important. Phosphorus loading of the slow moving, lake-like reaches of the Southern Grand has also contributed to a range of impacts as a result of degraded water quality (Gilbert and Ryan 2007; MacDougall and Ryan 2012).

Phosphorus can enter surface water in a dissolved form or associated with sediment or other particles through several pathways (Figure 1). The similarity between phosphorus and TSS concentration profiles and TSS yield estimates presented in section 7 of this report suggests that in many areas, hydrologic processes that transport particulate matter are important for transport of phosphorus. The discrepancies in this similarity may suggest, however, that transport of phosphorus in a dissolved form is more important from some source areas. For instance, the Canagagigue subwatershed has one of the highest phosphorus yields of the subwatershed areas investigated, but has a relatively moderate yield of suspended sediment. The Canagagigue subwatershed also has the highest yield of nitrate. A possible explanation for these patterns could be the deposition of suspended sediment and particulate organics in the reservoir, which may trap particulate matter but allow export of dissolved nutrients. Although a portion of the phosphorus loading from all source areas can be in a dissolved form, data is insufficient to characterize how the relative proportions vary among source areas and with season.

Key source areas of phosphorus that are important to annual phosphorus loading at a watershed scale are similar to those highlighted as important for regional impacts from suspended sediments. Estimations of total phosphorus loading indicate that the largest proportion of the annual load comes from the Nith subwatershed, but that contributions from the Conestogo and Fairchild subwatersheds are also relatively large. While the magnitude of annual total phosphorus contributions from the Canagagigue subwatershed are relatively small in comparison, they are likely important to regional loads since they are disproportionately high relative to the size of the subwatershed.

Overland runoff can be a key non-point source contaminant delivery mechanism in the physiographic regions of the watershed that have high runoff, such as the upper Nith, Canagagigue, Conestogo, Fairchild and MacKenzie subwatersheds. The generally impermeable soils and inherent geology of the upper till plain and the lower clay plain generate greater runoff than the central gravel moraines and Norfolk sand plain (Figure 3). As with sources of suspended sediment, it is unknown to what extent bank erosion and channel scour acts as a source of phosphorus to downstream areas in the Grand River watershed. In addition to the export of particulate phosphorus from areas on the clay plains (e.g., Fairchild subwatershed) that have soils which are more easily eroded, there is a substantial contribution (per unit area) from areas on the upper till plain, where livestock nutrient production is relatively high and there is higher coverage by cropland that is fertilized (e.g., Canagagigue, Conestogo, upper Nith; Figure 6). In these areas, there is a higher potential that excess nutrients on the landscape could be exported to surface waters. The high coverage by tile drainage in these areas also increases the spatial extent of fields that are hydrologically connected to surface waters. Despite this, the effect of tile drainage on the mobility of nutrients in the vadose zone (below the soil surface) is undetermined.

Point sources of phosphorus in the Grand River watershed are important in context of local loading causing eutrophication during the summer (Figure 16), but point source inputs are less dominant during high flows (Figure 17) when a large portion of the annual phosphorus load is delivered. These patterns have been illustrated in many previous studies of the Grand River system (e.g., Hore and Ostry 1978; Draper and Weatherbe 1994; Stantec 2010). Point sources are less than 3% of the load in the central region of the watershed during spring high flows. Winter and spring high flows have been estimated to carry the majority of the annual phosphorus and suspended sediment load in the Grand River at Glen Morris (Draper and Weatherbe 1994). It is unknown how summer storm events compare, but since increases in loading from point sources during hydrologic events are minor compared to changes in non-point source loading, it is probable that summer periods of high flow are also dominated by loading from non-point sources. Annually, the load of phosphorus associated with particles that are delivered in high flows from non-point sources is likely to dwarf the point source contribution. In the context of annual phosphorus loads at the watershed scale, point sources are less important than non-point sources. However, due to the complexities of phosphorus cycling in the river system and the lake, as well as uncertainties about factors affecting the ecology of the Lake Erie nearshore, the mechanisms driving the relationship between annual phosphorus loading and impacts in the river system, reservoir and nearshore of Lake Erie need further investigation.

10.4. Impairment of surface water uses by high nitrate concentration

High concentrations of nitrate in surface water can contribute to the impairment of ecosystems (Camargo and Alonso 2006) are also a concern for the provision of drinking water. Nitrate can be toxic to aquatic life and is also a parameter of concern for the provision of drinking water supplies for municipalities that draw source water from the river system (e.g., Eramosa river, City of Guelph; Grand River near Freeport, Region of Waterloo; Grand River near Wilkes dam, City of Brantford; Grand River near Ohsweken Six Nations). Although nitrate can be removed from water, the costs are prohibitive. Many sensitive aquatic species are affected at levels below those which have the potential to impact human health (Camargo et al. 2005). For instance, some of the more common sensitive species include mayflies, which are benthic invertebrates that are important to aquatic food webs and sustain key sport fish. In the Grand River watershed, elevated nitrate levels have been observed during the winter and early spring seasons, with particularly large increases in concentrations in the Grand River between Shand Dam and Bridgeport.

Nitrogen (chiefly in the form of nitrate) may also contribute to eutrophication in some areas of the watershed, although it is not clear how this relates to the influence of phosphorus on plant and algal growth (Carr et al. 2003; Hood 2012; MacDougall and Ryan 2012). The extent to which nitrogen plays a role in eutrophication is currently being investigated by researchers working in several areas of the Grand River watershed. Recent assessments of conditions in Lake Erie suggest that the influence of nitrogen on ecological health is minor in comparison to phosphorus (Lake Erie LaMP 2011). Consequently, lake management efforts have not previously focused on reductions of nitrogen loads to the lake. Nevertheless, the Lakewide Management Plan (LaMP) for Lake Erie recommends that the collection of data continue to follow nitrogen inputs to the lake, since loads (and thus ecological significance) appear to be increasing.

Elevated nitrate concentrations caused by natural sources are a relatively rare occurrence in Canadian river systems (CCME 2012), so are unlikely to result in elevated nitrate concentrations in the Grand River watershed. Nitrate that is present in soils is highly mobile. As a result, it can be readily transported in subsurface flow. Possible pathways to surface water include discharge from point sources (e.g., WWTP effluent), and entrainment in runoff and subsurface drainage from diffuse areas that have excess land applied nutrients (e.g., fertilizers, manure, biosolids). The pathway from the soils into surface water can occur either by overland runoff or by subsurface transport pathways (e.g., through the soil profile to deep drainage or to tile drains), including leaching through the soil profile into shallow groundwater which discharges into surface water (interflow) (Figure 1). The relative importance of these pathways is seasonally dynamic, affected by factors such as biological (plant) removal on the landscape, riparian zone and in the river; soil moisture content; evapotranspiration rates; and freeze/thaw cycling. In the winter and spring when biological uptake, volatilization and denitrification are minimal, more nitrogen is available for transport. However, there is little movement of nitrogen on the surface or subsurface of soils until they thaw. High nitrate concentrations observed in the winter when soils are frozen are most likely the result of nitrate sources that leached into shallow groundwater during previous time periods. The discharge of shallow groundwater sources contaminated by nitrate is more likely to affect surface water nitrate concentrations during periods of low flow since groundwater comprises a larger proportion of the total flow. In spring, groundwater contributions may be diluted, but meltwater can flush nitrates from the soils and into surface waters.

The profile of nitrate (Figure 13) during the winter and early spring (December to April) indicates that there are significant inputs of nitrate from the drainage areas above Bridgeport (including the Irvine, Canagagigue and Conestogo subwatersheds) that cause a dramatic rise in nitrate concentration as the river flows downstream from Belwood Lake. The largest point sources of nitrate (i.e., the large wastewater treatment plants) in this area are located downstream from Bridgeport in the central region of the Grand River, so it suggests that contributions are largely from non-point sources in this reach. Although data availability is limited, sampling from tributaries to this reach confirms that concentrations of nitrate in the Irvine, Canagagigue and Conestogo subwatersheds (as well as other smaller tributaries) can be particularly high during the late winter/early spring (Figure 22). This is also consistent with the distribution of areas with relatively high total nitrogen yield (Figure 15), which shows high unit area loading of nitrogen from subwatersheds on the upper till plain and particularly high yields of total nitrogen in the Canagagigue and Irvine Creek subwatersheds. In contrast, areas with less productive soils (upper Grand, Speed/Eramosa) and subwatersheds on the clay plain have relatively low total nitrogen yields. During the winter/spring period the cumulative inputs into the reaches of the Grand

River below Bridgeport are likely of similar concentration as the river since a high but relatively invariant concentration of nitrate is sustained in the river (Figure 13).

Based on estimates of annual total nitrogen yield, priority source areas for nitrate include the Irvine, Conestogo, Canagagigue, Nith and Whitemans Creek subwatersheds. Due to differences in physiography and land management /cover of these key source areas, the contribution by different pathways may vary regionally. For instance, in the Whitemans Creek subwatershed, discharge of shallow groundwater is likely to be an important pathway for the transport of nitrate since it accounts for a relatively high proportion of flow (Wong 2012). By comparison, tile drains hydrologically connect a relatively large proportion of the upper till plain where the less permeable soils facilitate runoff (Figure 7). In both of these areas, there is relatively high level of applied nutrients (e.g., fertilizer, manure) and potential for residual nitrogen to be available for leaching when the soils are hydrologically active. It is particularly important in these areas that removal rates of nutrients (e.g., in crops) are balanced with application and that loss during critical periods (e.g., early spring, late winter) is minimized. Agricultural census data (Figure 6) may provide an indication of the regional differences in the nitrogen source types. Based on the distribution of livestock density, manure is more likely to be a source of nitrogen on the upper till plain (e.g., Conestogo and Canagagigue) than in the Whitemans Creek subwatershed. Commercial fertilizer is likely to be a more important source than manure in Whitemans Creek subwatershed. It should be noted, however, that it is important to confirm these patterns with more current data, since factors such as weather and economic pressures can cause land management activities to change rapidly.

11. Future Directions

There is a need to link landscape or nonpoint source nutrients and sediment transport processes, particularly for priority subwatersheds influencing the central Grand River region, to in-river nutrient-dissolved oxygen processes. Both the Assimilative Capacity and the Water Quality Working Groups recommended the coupling of landscape nonpoint source models/monitoring with in-river nutrient dissolved oxygen modelling to create a linked modelling platform from which to predict landscape changes in nutrient management in concert with point source management. This point / nonpoint source decision support system would enable more strategic investments in stewardship practices as well as enable a more 'holistic' approach to nutrient management in the watershed. Including economic considerations such as cost-benefit analyses within this framework would provide critical information to program managers who enable land owners to implement stewardship activities.

Nitrate has been highlighted as an important nutrient of concern into the future by both the assimilative capacity and water quality working groups. Characterization of nitrate within the watershed, suggests that nitrate is coming from diffuse areas above the Region of Waterloo and that point sources play a minor role in contributing to the overall levels seen in the river. It is hypothesized that the nitrate is coming from priority subwatersheds like the Conestogo and Canagagigue but may also be coming from shallow groundwater within the upper middle region of the watershed (e.g., the Grand River between Shand Dam and Bridgeport). Strategic characterization of this region, such as the research carried out by the University of Waterloo (Schiff and others) characterizing the major rivers and creeks in this region plus a regional groundwater-surface water model will assist with evaluating land/nutrient management scenarios for enhanced stewardship practices.

The work compiled in this report by the water quality working group as well as the Grand River – Lake Erie working group (GRWMP 2012) highlighted the importance of the lake-like conditions in the southern Grand River to nutrient cycling in the river during the summer, when biological activity peaks.

Future work should focus on determining mechanisms to shift nutrient cycling within the region to a healthier state and to better understand the relationship between water levels and eutrophication within this reach.

Summary and recommendations

In summary, this report describes the relative importance of nutrient and sediment sources in the Grand River watershed. The importance of a source was assessed relative to its contribution to key water quality issues caused by excess inputs of suspended sediment and nutrients:

- eutrophication of the river system (nuisance growth of plants and algae);
- sedimentation and turbidity in river reaches;
- phosphorus loading of the reservoirs and Lake Erie; and
- impairment of water uses by high nitrate concentrations.

Since the contribution of source types and areas to these issues varies temporally and spatially, there is no single source of nutrients or sediment that prevails as being the most important in a large complex watershed such as the Grand River watershed.

POINT AND NON-POINT SOURCE IMPORTANCE

The assessments of nutrient and suspended sediment concentrations and relative rates of loading were done at a coarse-scale, but were consistent with the findings of other studies. There is a strong seasonal shift in the importance of sources that corresponds to the seasonality of water quality issues driven by hydrology and biological activity. The export of low-solubility parameters (suspended sediment/solids, total phosphorus) is driven largely by non-point sources during hydrologic events; concentrations peak in high flows during the spring. It is estimated that less than 3% of the total loads in the central Grand River during spring high flows were from point sources (i.e., WWTPs and septic systems).

Almost all of the phosphorus and suspended sediment load in spring high flows is estimated to come from rural and urban diffuse/nonpoint sources in the watershed.

Both point and non-point sources can contribute nutrients in a dissolved form (nitrate, ammonia, dissolved phosphorus) through a broad variety of pathways, many of which are not well understood. In particular, the processes by which dissolved phosphorus enters aquatic systems either directly, or through regeneration from particulate forms, are lacking in characterization due to a scarcity of data. Recent efforts have been made to characterize nitrate concentrations central Grand River, which experiences especially high concentrations in the winter and early spring.

Regional estimates suggest that winter/early spring concentrations of nitrate in the river system are dominated by contributions from non-point sources.

Point sources of phosphorus and nitrogen such as municipal wastewater treatment plants that directly discharge nutrients to the central Grand River region are very important nutrient sources during low flows in the summer.

Prolific aquatic plant growth that impacts dissolved oxygen levels is a significant water quality issue in many parts of the watershed, but particularly in the central Grand River region. Point sources from wastewater treatment plants contribute nearly three-quarters of the phosphorus in this section of the river during low flows. High phosphorus concentrations (hyper-eutrophic conditions), combined with available habitat and light facilitate the growth of many aquatic plants and algae. The relative importance of point sources increases during the summer since there is decreased potential for dilution of point sources in low flows and they contain nutrients that are in a form that is more readily used by producers (e.g., dissolved phosphorus, ammonia). Similar issues associated with eutrophication in the reservoirs and slow-moving reaches of the southern Grand River are linked to re-suspension and recycling of accumulated nutrient loads from upstream sources. The impacts are likely worsened by internal loading of phosphorus in the lake-like conditions above the on-line dams, but the relative importance of this pathway warrants further investigation .

Urban areas are significant non-point sources in the context of local impacts.

Urban runoff is an important contributor to episodic pulses of turbid water during summer high flow events, which can have a variety of adverse effects on aquatic life. Washoff from urban areas typically contains high concentrations of sediment and phosphorus. Our assessment suggests that inputs from urban areas are minor contributors to annual loading of phosphorus from the Grand River watershed (i.e., from the perspective of Lake Erie). However, urban inputs may still be significant to regional impacts from high concentrations of suspended sediments and phosphorus loading during periods of high flow. Further monitoring is required to fully characterize the impact urban stormwater may have regionally. Given the population growth that is anticipated in the watershed, urban non-point sources are likely to become increasingly important locally if not in the context of regional effects on the larger river system.

KEY SOURCE AREAS

Spatial variations in the importance of non-point source areas reflect the combined effect of natural factors such as soil, slope and hydrologic response, as well as land use and land management (e.g., cover type, hydrologic modifications, potential for excess land applied nutrients).

The Canagagigue, Nith and Conestogo subwatersheds contain key source areas for phosphorus and nitrate with a high potential for loss of land-applied nutrients.

Subwatersheds in which there is a high potential for generating runoff or subsurface drainage (i.e., Canagagigue, Nith, Conestogo) were important source areas for phosphorus and nitrate. These subwatersheds also have higher incidence of land-applied nutrients in the form of livestock manure and fertilizers than other subwatersheds. The Canagagigue subwatershed was a notable exception to the close correspondence between patterns of sediment and phosphorus export, suggesting dissolved phosphorus may account for a greater proportion of the exported phosphorus from this subwatershed than from others. Although the load of phosphorus from the Canagagigue is smaller than other subwatersheds, it is significant relative to the small size of the subwatershed.

The lower clay plains and the Nith subwatershed key areas for loading of suspended sediment and phosphorus.

Subwatersheds on the lower clay plains (including Fairchild and McKenzie Creek) are important source areas for sediment and associated phosphorus. Erosion through overland runoff as well as erosion of streambanks and channels are likely important processes contributing to sediment and phosphorus loading in these subwatersheds. Due in part to the large size of the drainage area, the Nith contributes a large load of suspended sediment to the Grand River system.

The Irvine and Whitemans Creek subwatersheds contain key source areas for nitrate.

Irvine and Whitemans Creek subwatersheds are important source areas in the context of nitrate, but phosphorus export from these areas is low relative to other subwatersheds. The high concentrations of nitrate that occur during the later winter and early spring in these areas are most likely linked to rural non-point sources. Additional information is needed to determine the pathway by which nitrogen is lost from the landscape in these areas and the role of land management practices.

The capacity of natural nutrient and sediment 'sinks' could be increased.

Parts of the river system, such as the wetlands that fringe the southern Grand River, have beneficial roles as nutrient and sediment sinks, but are currently impaired (Gilbert and Ryan 2007). By returning key ecological processes and functions to key areas (e.g., with riparian and channel restoration), it may be possible to increase the capacity these areas to process nutrients and improve water quality.

RECCOMENDATIONS

Motivation to address the key sources of nutrients and sediments highlighted in this report is based on the many valued features or functions of a variety of endpoints including: the use of rivers and streams by humans and aquatic species of ecological, cultural and economic importance; the use of reservoirs as important areas for recreation; and the health of the Lake Erie ecosystem, which is important to a broad range of aquatic species as well as the prosperity of the region. Since these endpoints may be affected by different sources via different pathways, a multi-pronged approach is required to address the diversity of the issues.

Management actions to reduce inputs of phosphorus, nitrogen and suspended sediments should be targeted to critical source areas and tailored appropriately to source types and transport pathways.

Targeting limited restoration and management resources most effectively requires an understanding of the spatial distribution and relative magnitude of nutrient and suspended sediment sources. A comprehensive understanding of the sources, fate and transport of suspended sediment and nutrients in the watershed is required, which is available only through regional models that can integrate information across spatial and temporal scales. To accomplish this, there is a need to improve our knowledge over a range of spatial scales (field-reach-region-subwatershed), specifically in priority subwatersheds such as the Conestogo, Nith and Canagagigue.

Targeted action in priority subwatersheds is best directed through regional models that integrate information across spatial scales from field to subwatershed.

To improve the integration of information across spatial and temporal scales, a better understanding of processes/pathways for transport of nutrients and suspended sediments from sources to the river system is needed. Some process or pathways by which nutrients and suspended sediments are transported from sources to the river system are poorly understood. Specifically, some of the priority gaps include:

- High flows in spring and summer are not well characterized or quantified, particularly in priority subwatersheds or in urban areas;
- Dissolved phosphorus conditions are not characterized
- Nitrate source types are not well characterized and pathways are poorly understood
- The relative importance of sediment and nutrients from in-stream sources (bank, riverbed erosion) is unknown
- Sediment transport mechanisms (sedimentation, re-suspension) are poorly characterized in most of the river system
- nutrient cycling and internal loading of phosphorus from sediments is largely unquantified

It is important that gaps in data, information and science be addressed in order to confirm the key source areas or more specifically identify the source types tied to each of the water quality issues described in this report. There was a high degree of uncertainty in the estimation of loading in the assessment on which this report was based. To increase the confidence in the results of this assessment, it is necessary to collect additional data during key periods and at priority locations.

Water quality parameters are inherently variable, so more frequent sample collection (particularly to describe the variability due to the hydrology and season) would enable improved characterization. The current spatial distribution of sampling sites is only sufficient for a coarse 'macro' level assessment (i.e., watershed-wide); collection of data at a finer scale could yield important information for key source areas and provide further insight into transport mechanisms and the fate of nutrients and sediment at multiple scales. Improved or updated information about the distribution of specific land uses/management would also allow better or more specific identification of nutrient and suspended sediment source types and allow for a better understanding of the relationships between land use or management and water quality.

Key steps to provide sufficient data for improved characterization of sources include:

- **more frequent monitoring, particularly during high flow events;**
- **more detailed information on land use and land management; and**
- **collection of data at a finer spatial scale in key source areas.**

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