Grand River Watershed: State of Water Resources

January 2020

Grand River Conservation Authority

Preface

The Grand River watershed is home to many vibrant growing communities. It is where some of the most productive agricultural lands are in Ontario and it is where close to 1 million people call home. Much of the river system is used and valued as it provides communities with their water supply but also receives their treated wastewater effluent. The groundwater resources in the watershed are some of the most complex systems in Canada yet they have been a sustainable supply for municipalities and rural domestic users for over 100 years.

The Grand River is a heavily managed river system due to the fundamentally altered landscape of the late 1800s. The use of large water management reservoirs are a vital component of the water system in the watershed to not only reduce flood damage potential to the communities downstream of the reservoirs but also to augment river flows for both supply and to help assimilate treated wastewater effluents. This close attention to the management of the water resource system will carry on so that communities in the watershed can continue to grow and prosper.

This report takes a snapshot of the state of the water resources in the watershed. This snapshot, combined with the status presented in the report: "2014 - 2018 Summary of Accomplishments" will help to inform whether the actions completed so far have helped to achieve the goals of the 2014 Water Management Plan update. Where possible, it will highlight successes that have been achieved or flag any potential issues.

The health of the Grand River and its tributaries has improved greatly due to a long-standing commitment to continuous improvement by GRCA staff and board of directors, municipalities, government agencies and residents of the watershed. Population growth, greenfield development and urbanization, agricultural production and a changing climate will continue to exert pressure on the water resources; however, with diligent and mindful care and attention, and a commitment to collaboration across boundaries, our collective efforts will continue to make this watershed a great place to live, work and play.

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Water Managers Working Group

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Highlights

Water is a shared and highly valued resource in the Grand River watershed local residents and the economy depend on it. People need water to live, work, play and prosper. Since water knows no boundaries in the watershed, municipal, provincial and federal water managers and First Nations partners came together to collaboratively plan and implement actions to improve water management in the basin. To measure progress, a report was prepared to summarize the actions implemented by partners (see the report 2014-2018 Summary of Accomplishments). Although a few actions put forward by partners in the plan have been deferred, many of the actions are now complete. This report provides a snapshot of the state of the water resources in the watershed to help determine whether the collective effort is meeting the goals of the Plan:

1. Improve water quality to improve river health and reduce the river's impact on Lake Erie;
2. Ensure water supplies for communities, economies and ecosystems;
3. Reduce flood damage potential;
4. Build resilience to deal with climate change.

Water is intricately associated with the landscape whether it runs off the land, is stored in a surface water feature such as a wetland or reservoir, or percolates through the soils of the rolling fields of the moraines. Most pressures on water resources are landscape and usage based however, climate change is fundamentally changing the water cycle and therefore the way water moves in the watershed.

This report highlights the land-based and usage pressures on the watershed's water resources, the current state of the water resources – including weather and climate, water management reservoirs, rivers and groundwater, and acknowledges the potential implications of a changing climate. Some highlights include:

Pressures on our water resources

- The watershed's population has grown to 1 million people and will grow to over 1.4 million by 2041. This will continue to put pressure on the quality and supply of water resources in the watershed. Some of the growth is projected to occur in smaller communities in sensitive areas of the watershed.
- More people generate more treated wastewater. This in-land river system receives the treated wastewater from 30 plants servicing over 837,000 people. A further 150,000 people rely on private on-site septic systems.
- People need water. An increasing population means continued pressure on aquifers and rivers to meet the demand for water of a quality appropriate for the various uses.
- Municipalities remain the largest permitted water taker in the watershed; municipalities service both residents and industry.
- About 861,000 people are on municipal drinking water systems. A further 130,000 people rely on private wells. While we remain heavily reliant on groundwater for drinking water, four communities draw drinking water from the Grand River; and three community rely on water from a Great Lake.

- Agriculture remains the largest land use in the watershed with 61% of the total watershed area; most of the cattle and dairy production in the Greater Golden Horseshoe resides in the Grand River watershed. The area to the northwest of the City of Waterloo is a hot spot in terms of livestock water use and manure production.
- While agricultural irrigation isn't a top water use at the watershed scale it is regionally important. Crop irrigation is the largest permitted water use in Whiteman's Creek and McKenzie Creek subwatersheds, reflecting the irrigated specialty crops grown on the Norfolk sand plain in the Brant-Oxford-Norfolk areas.
- Urban areas are growing at the expense of farmland and stormwater is an important pressure to manage regionally. A lot of the urban growth is on moraines, the source of drinking water for many communities.
- Wetlands and forested lands play a key role in maintaining a natural hydrologic cycle and in moderating impacts of land use change. Wetlands comprise only 9% of the total watershed area while forested lands occupy 14% of the total watershed area.
- With a growing population, the need for open, natural spaces for recreation increases. It is unknown what pressure this increased attention and resulting recreational use will put on the water resources of the watershed.

Weather and Climate

- Over the most recent 30-year period (1986-2016), the average annual temperature was 7.2 degrees and about 921mm of precipitation fell in the watershed. Precipitation varies across the watershed with the highest totals in the northern portion of the watershed and lowest in the Brantford area.
- Over the last five years, weather conditions varied widely, and ranged from wet and cool to warm and dry; 2016 was a moderate-to-severe low water year.
- Climate extremes occurred throughout the history of recording weather data in the watershed, with many of the highest rainfall events in recent years; Luther Dam climate station recorded the highest one-day total rainfall of 128.2 mm on June 23, 2017. The highest one-day rainfall total February occurred during a February 2018 event.
- The watershed is warming. There has been an increase in the annual mean temperature of approximately half a degree and an increase in the average winter temperature of approximately one degree from the earliest climate period (1961-1990) to the most recent (1981-2010).
- There were no strong trends in total precipitation; however, climate normal data showed a decrease in the annual snowfall and a decrease in the amount of water in the snowpack. The winter snowpack and spring rains are a source of water, which fill the large water management reservoirs. While the trend in annual snowpack accumulation and volume is decreasing, exceptions can occur. The snowpack in the winter of 2014 was the highest on record across the watershed.

Water Management Reservoirs

- The designed water storage in the multi-purpose water management reservoirs remains intact. On average, the water in the two largest reservoirs, Belwood and

Conestogo, is replaced 2-3 times per year. However the timing of when water is available is important, more frequent early winter melts make operating decisions of when to hold or release water more complex.

- During 2014 to 2018 reservoirs continue to be used to reduce peak flows in times of flooding by 20 – 80% depending on the time of year and location downstream of the reservoirs. They also continued to supply water to the river during dry periods.
- Downstream dikes complimented the ability to reduce flooding and the monitoring network allowed reservoir operations to be optimized to realize the greatest benefit both from a flood reduction and low flow operation perspective.
- All of the large water management reservoirs tend to be eutrophic and experience regular algal blooms. Surface runoff from the upstream, primarily agricultural catchments represents the primary nutrient source to the reservoirs, compared to other sources such as septic systems.
- On occasion, cyanobacteria or blue-green algae blooms have occurred in the Conestogo and Belwood reservoirs resulting in advisories being issued to protect public health.

Rivers and Streams

- River flows downstream of the large water management reservoirs are modified such that peak flows are reduced (reducing flood damages) and low flows are increased;
- The large water management reservoirs continue to provide sufficient storage for flood management and to supply water to downstream rivers during low flows; operational targets are met with greater than 95% reliability meaning that the reservoirs are operating as they were designed;
- In dry years, the flow in the Speed River is augmented up to 70% while the flow in the Grand River at Doon is augmented up to 85%.
- The Ministry of Natural Resources and Forestry's Low Water Response program was active 14 times in the last 19 years due to low-water conditions. Whitemans Creek, in Brant and Oxford counties, continues to have low water issues on an almost annual basis.
- Headwater rivers in Dufferin County, north-west Wellington County and Perth County drain areas of extensive farming and are not supplied with water from the large water management reservoirs. The streams tend to have very low flows during the summer and flashy high flows in the spring or following rainfall events. These rivers often have poor water quality as nutrients and sediment tend to be high.
- Similarly, urban streams are 'flashy' with very high and rapid peak flows and low summer flows. Urban streams often exhibit poor water quality with elevated chloride levels during snowmelt events representing one of the main water quality concerns. By association, chloride levels are steadily increasing in the Speed and Grand rivers downstream of major urban areas.
- High river flows have historically occurred because of snowmelt or rain-on-snow events in the spring. However, since the early 1990s, there seems to be a shift in peak flows occurring earlier during the winter or during the late spring and summer months.

- Using the federal Water Quality Index to help communicate the general status of nutrients and chloride levels, most of the 40 water quality monitoring sites in the basin scored ‘marginal’. Those sites that have ‘good’ scores for water quality are in rivers and streams that tend to be fed by groundwater.
- Dissolved oxygen in the Grand River at Blair has improved since the mid-2000s. The upgrades at the Kitchener wastewater treatment plant have contributed to higher daily minimum dissolved oxygen levels in the summer and much lower ammonia levels. Phosphorus levels remain high though.
- Nitrate levels were monitored continuously in the Grand River at Bridgeport. Levels have a seasonal cycle. Nitrate levels in the river tend to be the lowest during the active summer growing season as natural processes including algae growth, can use up much of the nitrate in the river. However, during the winter months, nitrate levels can increase and approach the drinking water quality guideline of 10 mg/L.
- Water temperatures regulate how much oxygen river water can hold while also influencing the health of aquatic organisms. Temperatures in the Grand River are highest downstream of the central urban area. A changing climate may push river water temperatures even higher in some areas. One threat from climate change is persistent warmer overnight air temperatures. These conditions have potential to maintain warmer water temperatures overnight when aquatic plants in the river consume oxygen increasing the potential for low oxygen levels in the river.

Regional Groundwater

- Groundwater accounts for about 82% of the municipal water supply in the Grand River watershed. In Brant and Oxford Counties, shallow groundwater resources are heavily relied upon for irrigation.
- Groundwater discharge from aquifers provides baseflow to cold-water streams and maintains many wetlands in the basin. The quantity of groundwater discharge can be significant such as in the reach between Cambridge and Brantford.
- Groundwater discharge helps moderate water temperatures in the river during the summer and helps moderate river ice during the winter.
- Water budget studies indicate that groundwater takings are sustainable in the watershed for our current and future uses. However, cumulative water takings should be considered in areas of potential conflict.
- Water management will be critical in three areas of potential conflict: Guelph/Guelph Eramosa, Brant, Centre Wellington, Oxford and Norfolk counties.
- Groundwater quality is impacted by nitrate in rural areas through fertilizer application, by chloride in urban areas through salt application, and from industrial/legacy contamination (i.e., TCE).
- Poor bedrock groundwater quality is present in portions of Haldimand County in proximity to Lake Erie to the point the bedrock groundwater quality is not useable as a domestic supply.

Grand River – Lake Erie Connection

- The Grand River is the largest tributary that discharges into the eastern basin of Lake Erie. It contributes 373 tonnes of total phosphorus to the eastern basin of Lake Erie which is about 54% of the total tributary loading to the eastern basin.

- Water quality conditions at the mouth of the Grand River is ranked as ‘marginal’ meaning that nutrients, chloride and metals exceed the guidelines frequently and by a lot.

Building Resilience

- Climate change will primarily be felt through the changing water cycle. These changes are putting additional stress on our water resources, water infrastructure and water managers.
- Gathering and supporting a network of water, wastewater, stormwater planning and emergency managers working in the basin provides a framework with which to continue to build and improve the resiliency of the watershed.
- Maintaining and improving the operations of the built infrastructure such as dams and dikes, wastewater and water treatment plants, and urban stormwater system is ongoing across the watershed.
- Characterizing, protecting and enhancing natural infrastructure, such as groundwater recharge areas, wetlands and hummocky topography continues through municipal and provincial planning. Protecting these areas into the future will become even more important.
- Lastly, investing in social learning and building the human capacity to learn and adapt to changing conditions will be important for water managers. The Water Managers Working Group enables continued dialogue, and information sharing for building capacity across the watershed.
- Investigating different opportunities or means of holding water on the landscape will an important adaptive measure to smooth out variations in the hydrologic cycle. New LiDAR topography information collected by OMAFARA holds a great potential to better analysis existing storage on the landscape and investigate potential opportunities to increase landscape water holding capacity. Rural storm management may be a more practical to investigate now that this information exists.

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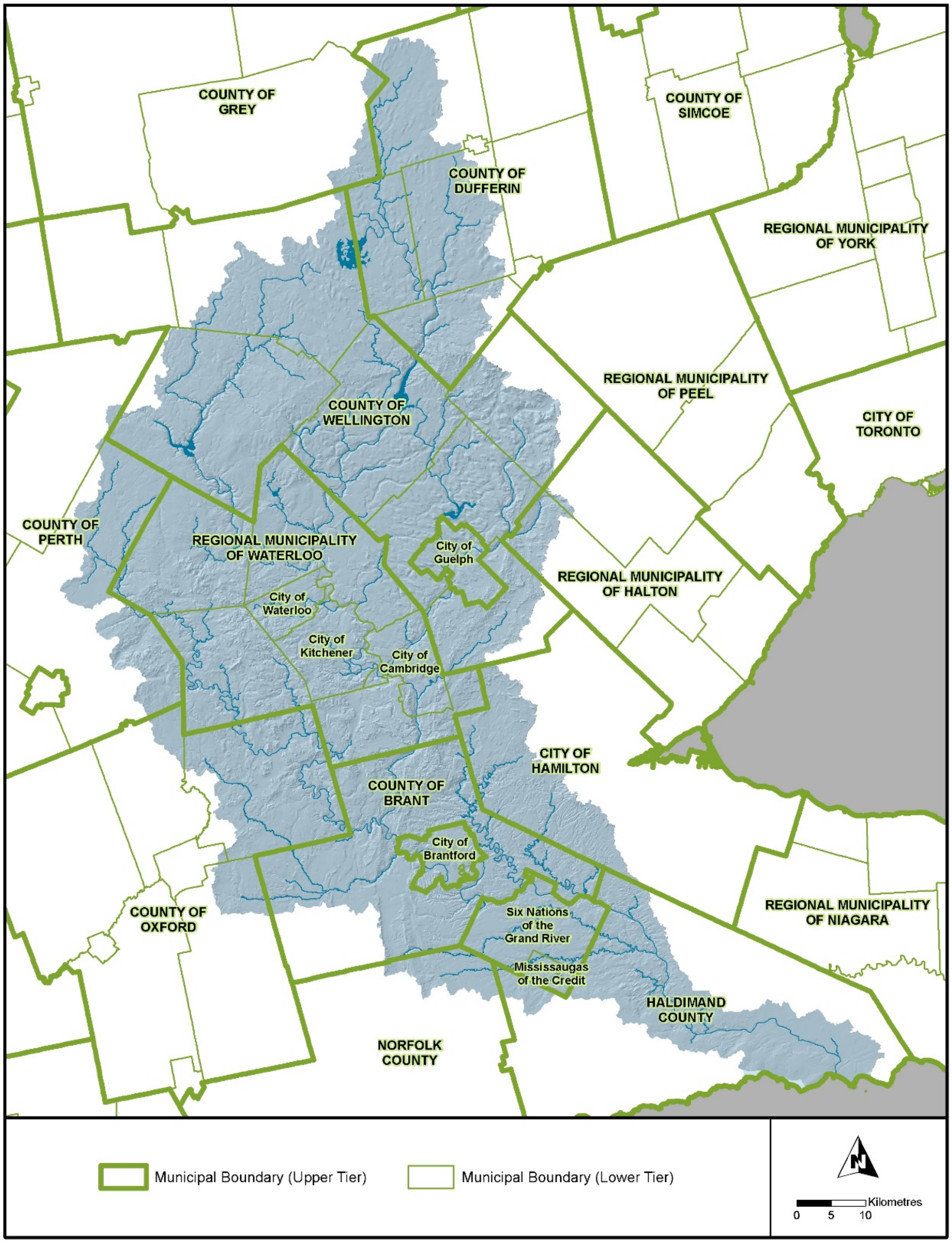

Figure 1. Municipalities connected by the Grand River and its tributaries. Area draining to the Grand River watershed in blue.

Introduction

The Grand River has a long history of water management and a rich culture of the First Nations peoples. It is important to all the people who live, work and play in the watershed. The Grand River and its tributaries connect 39 municipalities in southern Ontario and flow through the hearts of many communities (Figure 1). It is a significant part of the larger Greater Golden Horseshoe and just west of the Greenbelt (Figure 2). The river drains about 6,800 square kilometres and most (61%) of the land is devoted to agricultural production.

The watershed is home to five large cities – Guelph, Kitchener, Waterloo, Cambridge and Brantford where most of the 994,000 people live and the combined Gross Domestic Product from these cities amounts to the third largest in Ontario[1]. The watershed is also home to many species of fish, animals and birds.

Water resources are highly valued for a multitude of uses and considerations in the watershed. Most notable is the value of surface and ground water for municipal water supplies that supports the continued development of the many growing communities. Although most (73%) of the water supplying residents in Ontario comes from surface water such as a Great Lake, in the Grand River watershed, most (82%) municipal water supplies comes from groundwater. These same communities depend on the river system to receive treated wastewater effluent. As a whole the Grand River watershed has one of the largest populations in Ontario partially or solely dependant on an inland river or groundwater system for water supply and waste water disposal.

Some of the most productive agriculture in Ontario is in the watershed. Crop irrigation and livestock production in the watershed rely on secure water supplies. Other industries prosper in the region and the river system is becoming more and more valued as a place to enjoy and recreate.

The Water Management Plan focuses on surface and ground water resources in the Grand River watershed. This Plan links to, and complements, a broader watershed strategy that addresses the management of other natural resources such as forests, fisheries and municipal drinking water uses.

The strategy for the Grand River watershed includes a commitment from the GRCA to support integrated planning and management through regular meetings that facilitate discussion among municipal, provincial, federal agency staff and other stakeholders.

GRCA staff, water, wastewater and resource managers must continue to work together when evaluating actions that may impact people or the natural resources of the watershed.

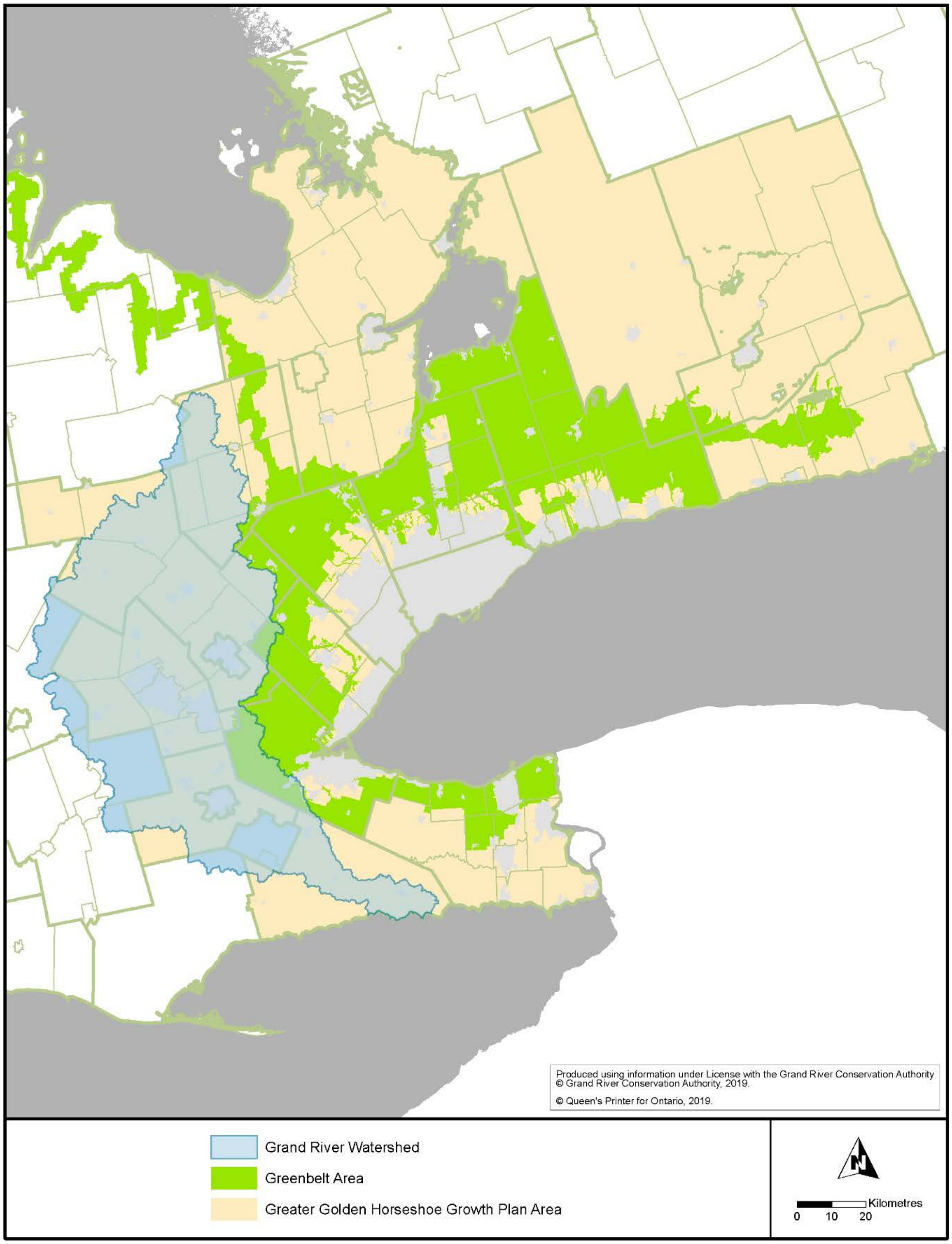

Figure 2. The Grand River lies in the Greater Golden Horseshoe and west of the Greenbelt in southern Ontario.

The boundary of a watershed is the logical physiographic landscape unit for natural resource management as it centres the processes of the water cycle locally. The watershed boundary, however does not align with municipal boundaries and therefore, a collaborative approach is needed to collectively understand the state of the water resources both within and beyond municipal boundaries.

The Grand River watershed has a long history of collaborative water and natural resource management to improve the health and well-being of residents and the natural environment. This report brings together information, studies, data analysis and the collective knowledge of water managers to determine the state of the water resources in the Grand River watershed. Through this synthesis, water managers can evaluate whether our collective efforts, as identified in the Water Management Plan (Plan) (2014), are achieving the four goals to support communities, economies and the environment:

- ensure water supplies for communities, economies and ecosystems;
- improve water quality to improve river health and reduce the river's impact on Lake Erie;
- reduce flood damage potential; and
- increase the resiliency of the watershed to deal with climate change.

Achieving the above four goals was founded on the guiding principle that best value solutions are sought to manage water issues in the watershed, thus balancing environmental, social and economical benefits. These best value solutions are often arrived upon through collaboration and cooperation of watershed partners.

The water cycle

The water cycle describes how water moves in our environment. In general, water vapour in the atmosphere falls on the landscape as rain or snow and is then captured and released through the three primary mechanisms of evapotranspiration, infiltration, and runoff. On average in a natural, undeveloped state, most (2/3) of the water is directed back to the atmosphere by evapotranspiration, which is a combination of evaporation from the soil and water bodies and transpiration from plants. That portion which is not evapotranspirated either percolates into the ground as infiltration, or directly runs off over the surface eventually into streams and rivers. Infiltrated water can stay shallow (close to the surface) and move horizontally until it re-emerges back at the surface as groundwater discharge or it can travel deeper and remain in groundwater reserves.

The geology and soils of the watershed play a predominant role in influencing the water cycle. In the northern portion of the watershed till plains dominate, this is where the soils tend to be tight and clay-rich, a relatively high proportion of water runs off the land. On the other hand, in the central region, where moraines, hummocky topography, and sand plains are located, much of the water tends to percolate through the soils down to the groundwater aquifers. The aquifers in this area are an important water resource to local municipalities and residents. The southern portion of the watershed consists of the extensive Haldimand clay plain, which facilitates water running off the land quickly into nearby ditches and streams. For more detailed information on the geology in the Grand

River watershed, see the Report: Geology of the Grand River watershed. An Overview of Bedrock and Quaternary Geological Interpretations in the Grand River watershed

The long history of human settlement and landscape change in southern Ontario has altered the natural water cycle. In the late 1800s, new settlers drained many of the wetlands, cleared much of the forested areas, and removed many small landscape depressions to make way for agriculture. Trees, wetlands, and depressions help keep water on the landscape. Their removal results in increased runoff volumes and peak rates directed to the receiving rivers much more quickly, resulting in both increased flooding in the springtime and following large rainfall events, and in droughts in drier periods. To a lesser, but also notable extent within our watershed, the urbanization of land from pervious soil to impervious asphalt, rooftops, and concrete significantly increases the runoff component of the water cycle, generating much higher volumes and at faster rates along local urban water courses.

To help counteract the negative impacts on the water cycle associated with land use change and human development, the Grand River watershed has a long history of undertaking active management strategies. Most notably, seven major reservoirs were purpose-built between the 1940s and 70s to help re-establish a more natural water cycle by holding water on the landscape in the spring and discharging the water back into the rivers over the drier summer periods. The reservoirs are operated as a system primarily to achieve the dual purposes of reducing flooding and providing water for water supplies and pollution abatement.

A report: The Grand River Watershed: Water Resource Systems compiles the best available information from numerous studies that have characterized and quantified the water cycle or ‘water budget’ of the watershed. This report highlights those areas of the watershed with high runoff or significant groundwater recharge.

Pressures on our water resources

An understanding of the pressures the watershed is experiencing is important to providing context on the state of the water resources. The three primary pressures affecting water resources, as identified in the Water Management Plan and described further in subsequent sections, include:

1. **people and population growth** and the need to ensure enough water supplies for communities and at the same time have the ability to release treated wastewater effluent with sufficient quality to local rivers so as to not harm the natural environment;
2. extensive **agricultural production** across much of the watershed. Water is needed for livestock production and irrigating crops. Runoff from agricultural landscapes can also affect water quality and quantity; and
3. **a changing climate** that is affecting the water cycle including shifts in the timing, amount, and type of precipitation and the resulting changes in snowpack, spring freshet, and low flow conditions.

These pressures continue today and their effects will continue to be felt into the future.

During the update to the Water Management Plan in 2014, water managers acknowledged that **urban development** in the central region of Kitchener, Waterloo, Cambridge and Guelph also is putting increasing pressure on local streams and potentially affecting the larger river systems.

An emerging pressure may also be the interest and desire to recreate on the rivers, and in the parks and natural areas of the watershed. The intensification of this use should be reviewed in the future.

People and population growth

People need water to live, work and play. People need drinking water and wastewater services, which can put pressure on both the quantity and quality of local water resources. The availability of a reliable quantity and quality of water is required to support healthy, prosperous communities and the local economy.

The Grand River watershed is home to many growing communities. Population growth has been steady since the 1800s when pioneers first settled the land. People continue to farm most of the watershed; however, the economy of the watershed has evolved from agrarian, to manufacturing and now to a largely mixed economy with a focus on the knowledge/tech industry, especially in the Region of Waterloo. This shift also influences the demand we place on the water resource in our communities.

There continues to be more people coming to live, work and play in the watershed. The watershed population increased by about 100,000 between 2006 and 2016, bringing the total to roughly 1 million. Most of these people reside in the five large cities and their municipalities supply their water and wastewater services. About 130,000 and 150,000 people rely on their own groundwater wells and septic systems for their drinking water and sewage treatment, respectively. Population density in 2016 ranges from a high of over 1,900 persons per square kilometre in the City of Waterloo to less than 10 in some of the northern Townships (e.g., Melanchthon).

Water supplies for people remain the largest use of surface and ground water in the Grand River watershed (see the report 'Water Use Inventory for the Grand River Watershed[2]) with about 86.26 Mm^3 used for total municipal supply annually (note that some of the municipal supplies also service industry). This represents about 62% of the total permitted water takings in the watershed (Figure 3). Other uses include rural industrial, commercial and institutional (21%), rural residential and agriculture (14%), and remediation (4%).

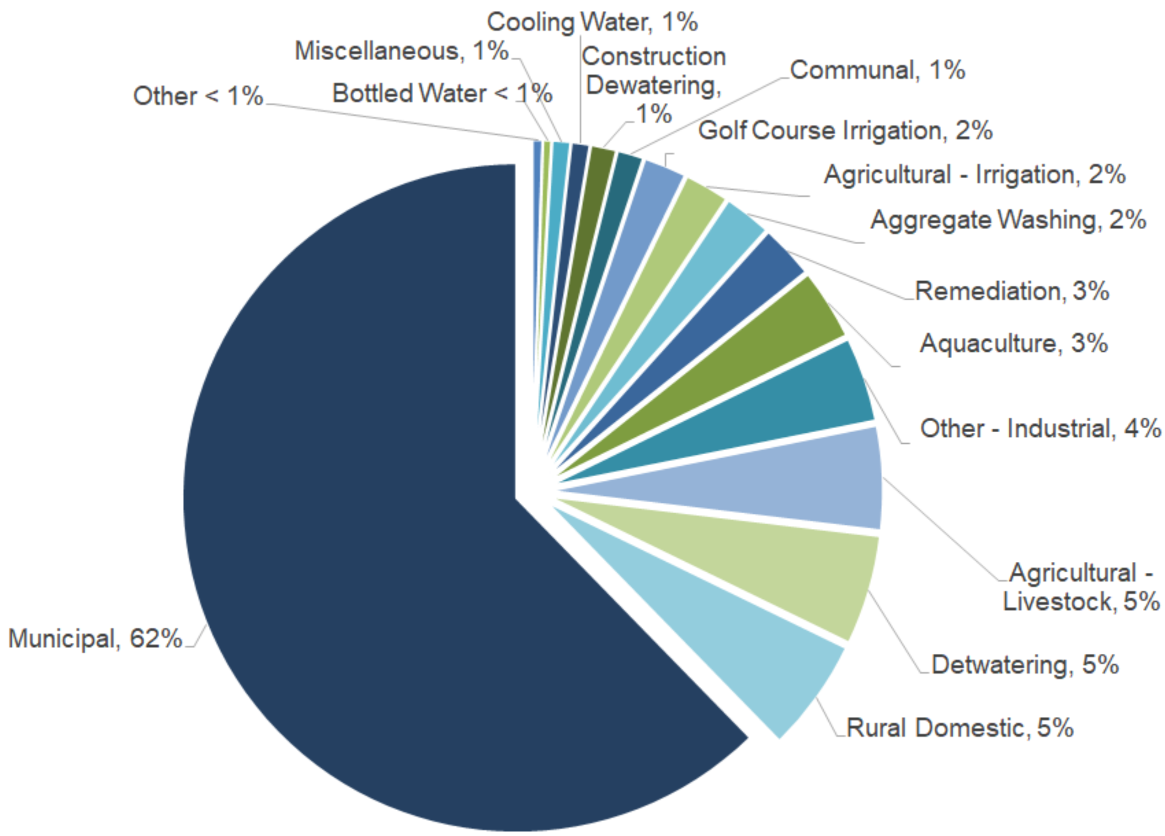

Figure 3. Percent total water taking by category for the Grand River watershed. Total water taking is 138 Mm3 in 2016. The total water taking in 2009 was 152 Mm3.

While population is increasing, per capita water demand is going down, resulting in a 23% reduction in total water use since 2009. On average the demand for water by municipalities is 274 L/pp/d which is down from 356 L/pp/d in 2009 (Figure 4) and is lower than the 2017 average of 355 l/pp/d for Ontario.

Rural, industrial, commercial and institutional takings represent the next highest category of water takings and represent about 21% of the total permitted takings (29 Mm^3). Rural residential and agriculture, both livestock and irrigation, represent about 14% and remediation, through pump-and-treat systems for contaminated groundwater, are about three percent of the total water takings in the watershed.

Irrigation in the Brant/Oxford area continues to be a high water use area putting seasonal pressure on local ground and surface waters.

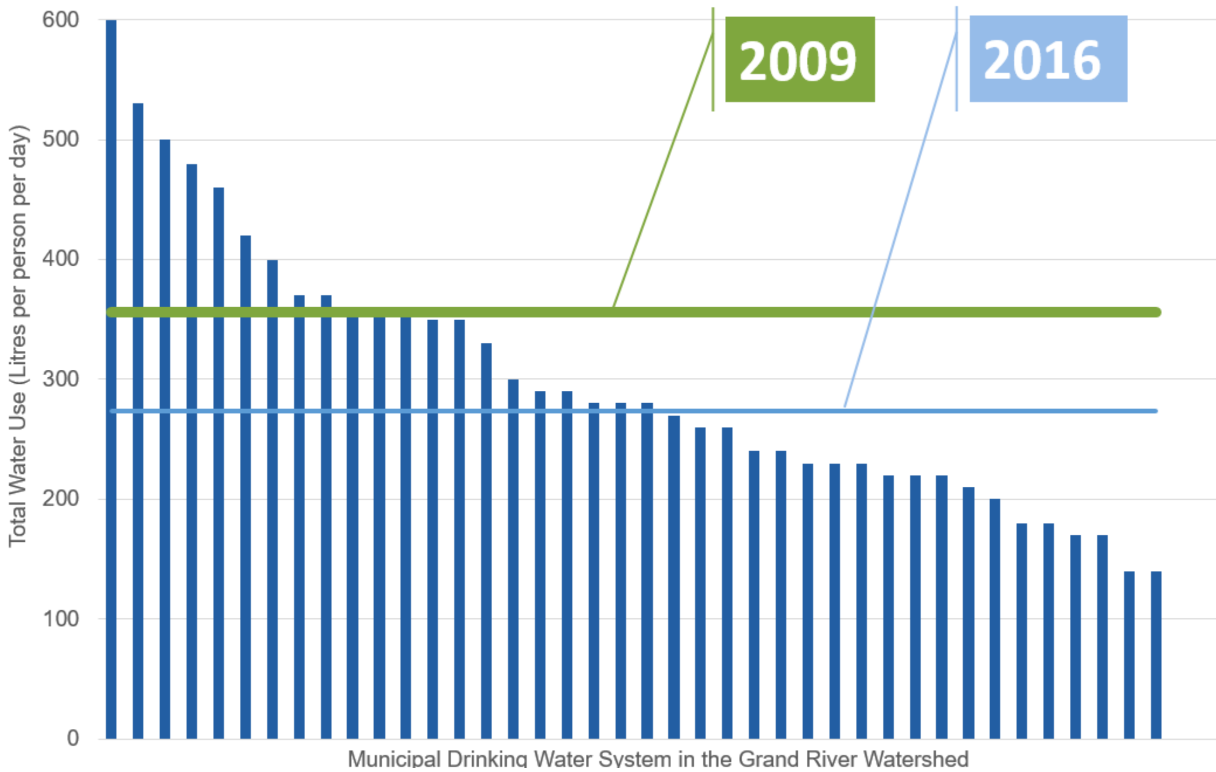

Figure 4. Per capita demand (2016) for the municipalities in the Grand River watershed. Green line shows the 2009 average total per capita demand in the watershed (356 l/pp/d); the blue line indicates the 2016 average total per capita demand (274 l/pp/d). Of note is that the 2017 average total per capita demand in Ontario is 355 l/pp/d.

There are 30 wastewater treatment plants in the watershed treating sewage from over 837,000 people as well as industrial/commercial wastewater. The treated sewage is discharged to inland river systems, which also provide drinking water supplies for four communities. Many of the sewage treatment plants have advanced (or tertiary) treatment, which includes advanced nitrogen and phosphorus removal, while some communities still operate lagoon systems and discharge effluent seasonally.

The population of the Grand River region is projected to grow. The provincial Growth Plan for the Greater Golden Horseshoe has provided direction to where and how municipalities are to grow their populations since 2006. The most recent update to the Growth Plan has refined population projections as well as incorporated several planning requirements for municipalities including intensification targets. The population of the watershed is forecast to grow to about 1.44 million residents by 2041 and to approximately 1.87 million by 2066, based on the most recent municipal growth plans from the watershed municipalities. The large urban centres of Waterloo, Kitchener, Cambridge, Guelph, and Brantford are most likely to experience the highest growth by 2041, with the Township of Centre Wellington also projecting a population increase of greater than 50,000 in the next 25 years.

Generally, more people require more water and they generate more wastewater. More urban development can increase surface runoff requiring more stormwater management. Managing the demand for more water, and treating more wastewater and stormwater will continue to be important for municipalities.

Land cover and use

Another source of pressure on the water resources of the watershed stems from the interaction water has with the land it falls on as either rain or snow. Natural land cover can hold onto and store water effectively. Removing natural cover and changing the landscape can affect how water moves. For instance, urban development can increase the proportion of areas that are impermeable to water and shift water movement from infiltrating into the ground to overland runoff. The following land uses in the watershed can affect the quantity and quality of water:

Agriculture

Some of the most agriculturally productive lands in Ontario are in the Grand River watershed. Agriculture is the largest land use in the watershed (61% of the land is used for agricultural production using land cover data from 2017 and cross referenced with Agriculture and Agri-Food Canada). In 2016, there were 5,641 farms, which is fewer than the 6,372 farms in 2001 (see the Technical Memo: Status of Agriculture in the Grand River watershed). The fewer farms that remain are getting slightly bigger in size; the average size of a farm increased from 71 hectares in 2001 to 76 hectares in 2016.

Livestock production requires accessible and available water of suitable quality. It is the fourth largest use of water in the watershed using about 6.97Mm^3/yr, or about 5.0% of the overall water takings. Most of the beef cattle (50%) and dairy cattle (58%) in the Greater Golden Horseshoe reside in the Grand River watershed. Although cattle numbers have been on a steady decline since 2001, dairy cattle remain steady at about 51,000 head. However, there are fewer dairy farms suggesting that the size of farm is getting bigger. Poultry, on the other hand is increasing significantly, up 36% since 2011, to over 12 million birds in 2016. Livestock generate manure, a valuable source of nutrients for crops. If manure is applied in excess of crop requirements, it can become a pollutant to surface and ground waters.

The area south and west of Brantford is an area that relies upon irrigation to support crop production. This area is the Norfolk Sand plain and the sandy soils cannot retain water long enough to sustain crop growth during the hot summers. Irrigation uses about 3.0 Mm^3 of water per year, a number that is small in comparison to the total takings in the watershed (~2%), but one that is locally significant.

The portion of the County of Brant west of Brantford tends to have the most water taking permits for agricultural irrigation, with about 230 permits split between surface and groundwater sources. This area, specifically the catchment for Whitemans Creek, can be an area of conflict and tension between irrigators and those who value the coldwater stream that sustains a local trout population.

Combining rural residential, livestock and irrigation water use, rural uses of water makes up about 14% of the total water takings (see the report Water Use Inventory for the Grand River Watershed). In contrast, rural businesses and industry (i.e., areas not serviced by a municipality), make up about 20% (28.7Mm^3/year) of the total water takings in the watershed.

Most (82%) of the farm land in the watershed is used for crop production, specifically corn, followed by soybeans, hay and grains. According to Agriculture and Agri-food Canada, most farms use crop rotations of corn-soybean; corn-soybean-wheat while relatively few farms just farm one crop continuously. Most of the specialty crops like fruit, tobacco and vegetables are grown on the Norfolk Sand Plain where they are typically irrigated.

During the growing season, water tends to stay where it falls and is actively used up by the crops except for significant rainfall events when the rainfall exceeds the capacity for the landscape to soak in the water. When this happens, water runs off carrying valuable soil and nutrients that can become pollutants in rivers and streams. During the spring, unless there are controls in place such as cover crops, the volume of runoff increases due to the melting of the snowpack. Snowmelt can carry pollutants that are left or spread on the fields.

Since 2001, there has been an increase in the use of winter cover throughout the watershed. In 2016, 34% of farms in the Grand River watershed reported using winter cover while only 12% of farms were using this practice in 2001. For more information, see the technical memo on Land Cover and Land Use in the Grand River Watershed.

A Nutrient Unit (NU) is a concept defined by the Ontario Ministry of Agriculture, Food and Rural Affairs and allows a direct comparison of the nutrient value of differing livestock manures. Based on the total number of livestock in the watershed, the total number of nutrient units is 319,805 NU. Most (68%) of the nutrient units (or animal manures) in the watershed are located upstream of the central urban area.

The nutrients from manure represent a valuable resource however. The estimated nutrient value of 319,805 NU equates to more than 14,394 tonnes of nitrogen and 17,589 tonnes of phosphorus. Although not all nitrogen and phosphorus are readily available, a conservative estimate suggests that the nitrogen and phosphorus in the manure may be valued at \$8.6M and \$40M[3], respectively.

Tile drainage is a method used to move water off the landscape to increase efficiency and productivity of croplands. Because of tile drainage, the hydrologic connectivity between agricultural fields and streams are altered and may affect the water quantity and quality. About 38% of the cultivated land in the watershed is tile drained. Most of this drainage coincides with the high runoff areas in the north-west region of Wellington County, Region of Waterloo and Perth County. Most (1,203 km^2) of the tile drainage in the watershed was installed prior to 1996 with an additional 360km^2 added to the total area since that time. About 23% (1,566 km^2) of the watershed is tile drained.

Urban development

Urban and built up areas, including roads are now about 14% (2017) of the total watershed area. This is up from an estimate of five percent in 1999; the difference in part can be attributed to different methods of capturing and classifying landscape imagery with the newer findings being a better reflection of actual conditions. . According to a 2016 Statistics Canada report[4], the increasing ‘footprint’ of the five major urban areas almost tripled in size in 40 years (between 1971 and 2011). This expansion of urban built up areas can impact local creeks and larger rivers if urban stormwater is not managed. Much of the old urban centres do not have stormwater management. For instance, about 75% of the City of Kitchener does not have stormwater controls in place[5]. Much of this development occurred before current stormwater management guidelines and practices were in place and required.

Urbanization in the watershed has typically replaced agricultural and natural/forested lands. Urban lands are compacted and paved, which increases the imperviousness. This results in higher and faster runoff from urban areas. In urban areas where there is no stormwater management in place, heavy rains can cause localized, and sometimes severe, urban flooding and stream erosion. In addition to altering the quantity of water, urbanization can affect water quality. Runoff from urban areas can carry dirt, debris, and other pollutants into local creeks. Areas under construction are most in need of proper erosion control and stormwater management as stabilizing topsoil and vegetation are removed, fundamentally altering how water and sediment moves.

Traditionally, water running off urban areas was directed to channels with the goal of draining water away as quickly as possible. By the 1980s, management of stormwater from newer urban areas began to be implemented with the focus being to collect and slowly release stormwater from ponds to reduce flooding downstream. By the 1990s, stormwater management started to address water quality and stream erosion.

During the 1990’s subwatershed planning began to be implemented for newly developing areas. It was recognized that an overall system design approach was needed achieve the goals of avoiding downstream flooding, erosion and water quality issues associated with post urban development.

Despite improved requirements for developing areas, the older urban cores of the cities and towns are largely without stormwater management, with resulting impacts on stream health and risks to infrastructure located along watercourses. Intensification and redevelopment in older urban areas may offer opportunities to improve stormwater management through retrofits to existing infrastructure and implementation of low impact development (LID) practices to redevelopment areas.

There are over 600 stormwater ponds and at least 700 devices to capture oil and sediments from stormwater in the watershed's urbanized areas. At least 40% of the ponds are over 20 years old and few have had the accumulated sediment removed thus causing poor performance for both managing water quantity and quality. Many municipalities have implemented asset management plans for stormwater assets. Several have or are in the process of investigating stormwater management utilities to manage these assets.

Urbanization of the central region coincides with the location of the Waterloo moraine. Attentive planning has helped to redirect development away from sensitive landscapes so that the landscape can continue to infiltrate water to the groundwater aquifers that supplies the communities with drinking water; however, some land has been lost. Most of the new urban development is on farmland. A Statistics Canada study quantified the type of land loss to urban development between 1971 and 2011 for the main urban centres in the watershed with most of it being arable lands[6] (Figure 5)

Since the 1990s, some stormwater facilities have been built to infiltrate clean runoff into the ground to maintain baseflows to streams and wetlands, support coldwater fish habitat, and ensure recharge of groundwater aquifers. There are over 350 infiltration galleries in the areas that drain to Strasburg and Blair creeks in Kitchener. Most of these have been installed since 2010 and they too will need to be maintained to ensure functionality. For more history of low impact development in the watershed, see the Technical Memo History of Low Impact Development in the Grand River Watershed.

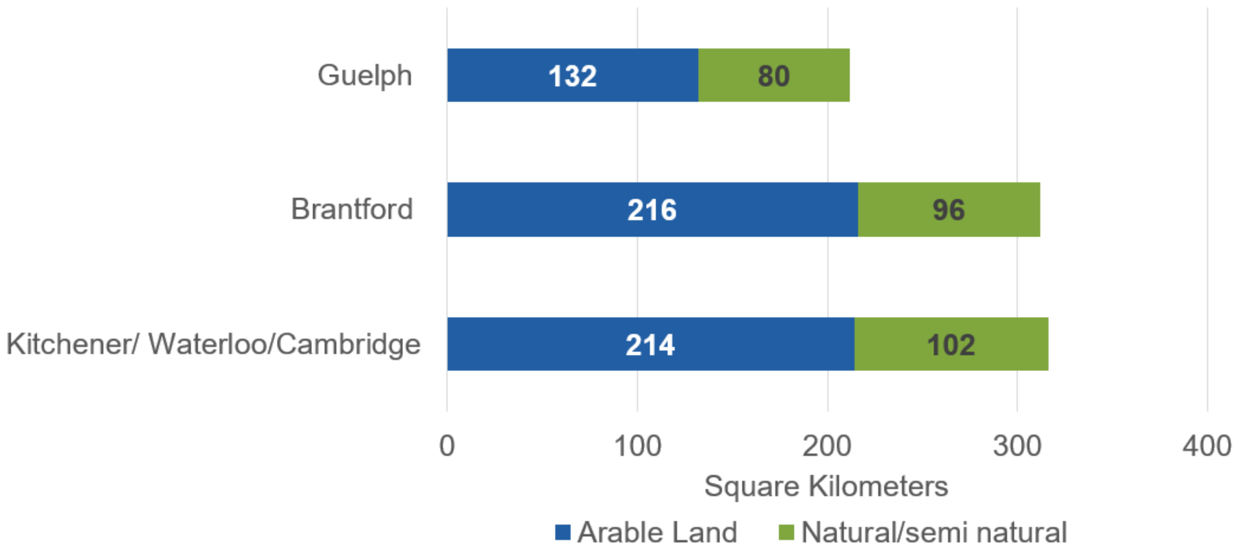

Figure 5. Land lost to urban develop between 1971 and 2011. Data from Statistics Canada (2016).

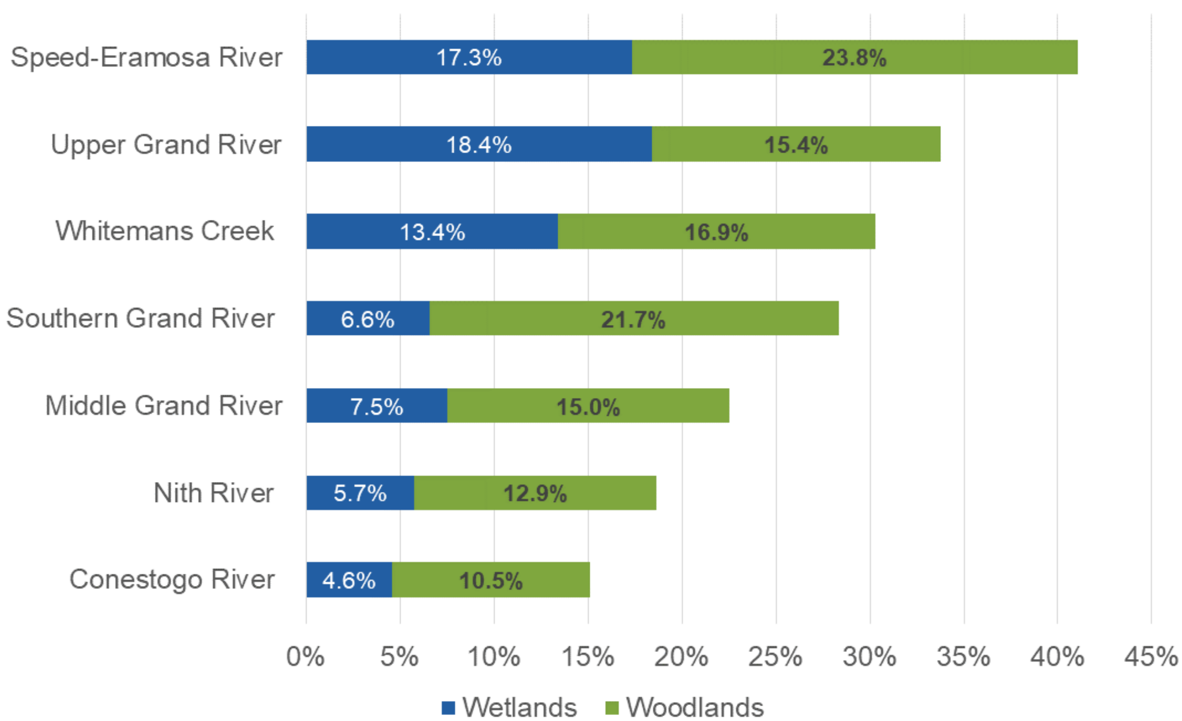

Figure 6. Wetlands and woodlands as a percent of total subbasin area.

Urban areas also tend to become warmer than surrounding rural areas due to the concentration of built infrastructure and paved surfaces, which retain more heat than open, natural areas. This heat can also influence the streams and rivers that flow through our communities. Consequently, a changing climate with more extreme temperatures may put more stress on our local waterways.

Loss of natural areas

Natural areas include wetlands and forests. Less than 10% (640 km^2) of the Grand River watershed is covered by wetlands while there is 14-16% (1,109 km^2) forest cover. All four major wetland types (marsh, swamp, bog, and fen) are represented within the watershed, with treed swamps being the most common and widespread wetland type (see Technical Memo Spatial Relationship between Natural Heritage and Hydrologic Features[6])

Environment Canada suggests for areas of up to 500 to 1,000 km^2, that a minimum of 30% forest cover helps to maintain ecological functions[7]. Woodland areas in the major subbasins range from about 10% (Conestogo River) to 24% (Speed/Eramosa) and 26% (McKenzie Creek) of the total subbasin area (Figure 6).

Although there are regulations to help protect existing provincially significant wetlands, any further loss in these areas can continue to undermine the natural water cycle. Natural areas such as forestlands, wetlands and native prairie grasslands are fundamental to maintain key processes of the water cycle like keeping water on the landscape, and allowing water to infiltrate to aquifers. Natural areas have intact soil structure that allows water to infiltrate to groundwater or keep water on the landscape to help mitigate downstream flooding. Natural areas also have significant benefits for maintaining habitat and biodiversity.

Wetlands are important for moderating the movement of water across the landscape as they absorb surface water runoff during wet periods and release that water slowly during dryer periods. In the Grand River watershed, it is estimated that 45% of the wetlands have been lost since pre-settlement (early 1800's)[8]. Pre-settlement wetland extent for the Grand River watershed was estimated to be about 114,299 ha which was about 16% of the total watershed area. According to the GRCA mapped wetland areas, about 64,000 ha or 640 km^2 remain and ranges from 4% of the subbasin area in the lower middle Grand River area to 18% of the total upper Grand River area (Figure 6). The province has evaluated only 77% of the mapped wetlands.

Riparian areas refer to those lands that are adjacent to streams and rivers and mark the transition between land and water. These areas are important for many surface and groundwater processes as riparian areas that have cover, either trees or shrubs, tend to maintain the integrity of both the river system and the adjacent lands. For instance, vegetation can slow down runoff and filter out sediment from upland areas. These areas can also help store water during high runoff periods, and release it during dryer periods. Intact riparian areas can also absorb and dissipate the energy in high flows and help prevent streambanks from eroding away.

Through the State of the Great Lakes reporting in 2017, Environment and Climate Change Canada show that much of the Grand River watershed has very low forest cover within riparian areas (30-50%) and low (10-20%) forest cover at the large tertiary watershed scale[9].

Locally significant land uses

Aggregate operations and golf courses are locally significant land uses. The central region of the watershed is rich in aggregate resources due to the moraine features that have a rich store of rock and gravel. Currently, there are 246 active aggregate pits or quarries in the watershed.

Aggregate mining is a land use that changes the landscape and has the potential to disrupt the existing movement of surface and ground water locally. Although local / site changes to water resources may occur, the land use is minor when evaluated on the scale of the Grand River watershed (total area of aggregate mining is 85 km^2 or 1.25% of the total land area).

Water needs for aggregate washing have also been declining as operations have moved from open loop water cycling to closed loop water cycling. New water is required only to top up the wash ponds to account for evaporation and infiltration from the wash pond and water trucked out on the aggregate.

There are 77 golf courses in the Grand River watershed that total about 32 km^2 (< 1% of the Grand River watershed). Many of these courses have permits to take water for irrigation during the summer. Fertilizer use may also impact local water courses.

Recreation

With increasing population, comes an increasing demand on outdoor space to recreate. As the communities in the watershed grew, so did the investment in best practices like wastewater treatment and rural and urban stormwater management. These investments have improved the health of the river system over time to a point where many people are turning back to the river to enjoy its natural beauty. This recognition culminated in the Grand River being designated as a Heritage River in 1994 as a river system that has outstanding human heritage values and excellent recreational opportunities along the rivers.

The pressure on the river and natural areas is illustrated by the doubling of attendance at the Elora Quarry between 2013 and 2017. Attendance went from 27,628 to 66,432 visits, respectively. In 2016, attendance reached a record high of 85,909 persons. This was the highest volume of day use visitations of any conservation area that year. Rising attendance levels has put increased pressure on staffing for maintenance, security and traffic control, has greater impact on the local environment and can negatively affect the visitor experience.

Another example is the growth in canoeing and rafting the Grand River with specific targets developed by Regional Tourism Organization 4 Inc.'s (RTO4) 2018 Business Plan[10] to increase the number and enhance existing river access points. Also included in RTO4's Business Plan is a target to promote the Grand River as a *provincially significant water trail.* It's unknown what this increased attention and resulting recreational use will put on the natural resources of the watershed.

Recreational pressures will continue with the projected population growth for the Greater Golden Horseshoe area. In 2018, the Ministry of Tourism, Culture and Sport specifically targeted the Grand River and the Fergus and Elora areas as tourism growth areas.

A changing climate

The climate in the Grand River watershed is changing. Weather stations in the watershed have shown rising mean annual air temperatures of about half a degree, with a rise of a full degree during the winter season, while total snowfall and the size of the snowpack is dropping (see report: Climate Trend Analysis). Numerous studies have predicted changes in temperature, precipitation, and snow accumulation and shifts in season (see Technical Memo: Climate Change Science Update).

A 2014 GRCA study[11] suggested that a warming climate could result in some changes to annual average precipitation and temperature conditions but there will be more substantive changes to seasonal and monthly conditions. Changes to the extent and timing of the snow pack, spring freshet, and summer low-flow conditions will have implications for water management. Similarly, a study by McDermid[12] *et al* (2015) highlighted the following for the Great Lakes region:

- increases in mean air temperature from between 1.5-7°C by the 2080s with an increase in the number of frost free days
- 20% increase in precipitation by 2080 however, less of the precipitation will fall as snow
- Changes in the frequency and magnitude of extreme weather including both flooding and droughts
- Shorter, warmer winters and longer and hotter summers;

Climate change science continues to evolve, with recent updates to greenhouse gas emissions scenarios, global and regional climate projections, and assessments of potential impacts to environmental and human systems. Improved Regional Climate Models and downscaling of projected conditions will allow for more refined assessments in the future.

Gaps in our knowledge remain. There is less consensus on the effects of climate change on the frequency of rain, ice, and windstorms; snow and ice dynamics (river and lake), water chemistry, coastal processes, and wetland hydrology.

Weather and climate

Weather is the physical conditions of our atmosphere over a short time period. Current weather conditions of the watershed are important for water managers to manage the daily operations of the dams and reservoirs. Climate is the longer-term weather patterns over a 30 year period, as recommended by the World Meteorological Organization. An understanding of climate is important for water managers since it provides the expected conditions that govern water availability such as precipitation and temperature. Understanding climate variability assists water managers to plan for and manage watershed water supplies. Climate is not static and is currently undergoing a period of accelerated change worldwide. For a full description of climate trends in the watershed, see the report Climate Trend Analysis.

Air temperatures, rain and snow are critical components of the water cycle. Collecting temperature and precipitation data are important for managing both current weather conditions and determining any changes in long-term climate patterns.

Over the most recent 30-year period (1986-2016), the Grand River watershed had an average annual temperature of 7.2 degrees. Average annual temperatures are coldest in the north portion of the watershed (6.1 °C) and then increase gradually towards the south (Byng Island, 9.0 °C), although extreme temperatures can occur anywhere in the watershed.

On average, the watershed has an annual precipitation of 921mm but it varies across the watershed. The highest annual precipitation is in the northern region, at the Conestogo and Luther Dams and is generally over 1000mm, while the lowest annual precipitation is in Brantford with 848mm. Over 80% of annual precipitation falls as rain with the remainder snow or mixed precipitation.

Over the last five years, weather conditions varied widely and ranged from wet and cool to warm and dry (Figure 7). In 2014, conditions were generally wetter and cooler than average and water levels were above average due to the wet conditions. 2015 was a year of weather extremes: February was the coldest month on record at 7.4 degrees below average temperatures; December 2015 was the warmest December on record. In the summer months, there was lower than average rainfall which resulted in low water conditions in many naturally flowing watercourses throughout the watershed.

In 2016, precipitation was low and evaporation was high but sufficient groundwater levels helped to add flow to the rivers. Reservoirs were used extensively to augment river flows in the summer considering the hot and dry conditions.

In 2017, all watershed climate stations recorded above the normal total annual precipitation and temperatures. In June 2017, over 240mm of rain fell at the Luther climate station because of an extreme weather event that covered the northwestern portion of the watershed resulting in very high flows on the Grand River, Conestogo River and Canagagigue Creek.

In 2018, an extremely cold January led to thick ice on the river. Periodic melts coupled with a large rain event resulted in ice jam flooding and a very high watershed wide flood event in the middle of February.

Climate extremes occurred throughout the period of record with many of the highest rainfall events in recent years. The highest one-day rainfall total was recorded at the

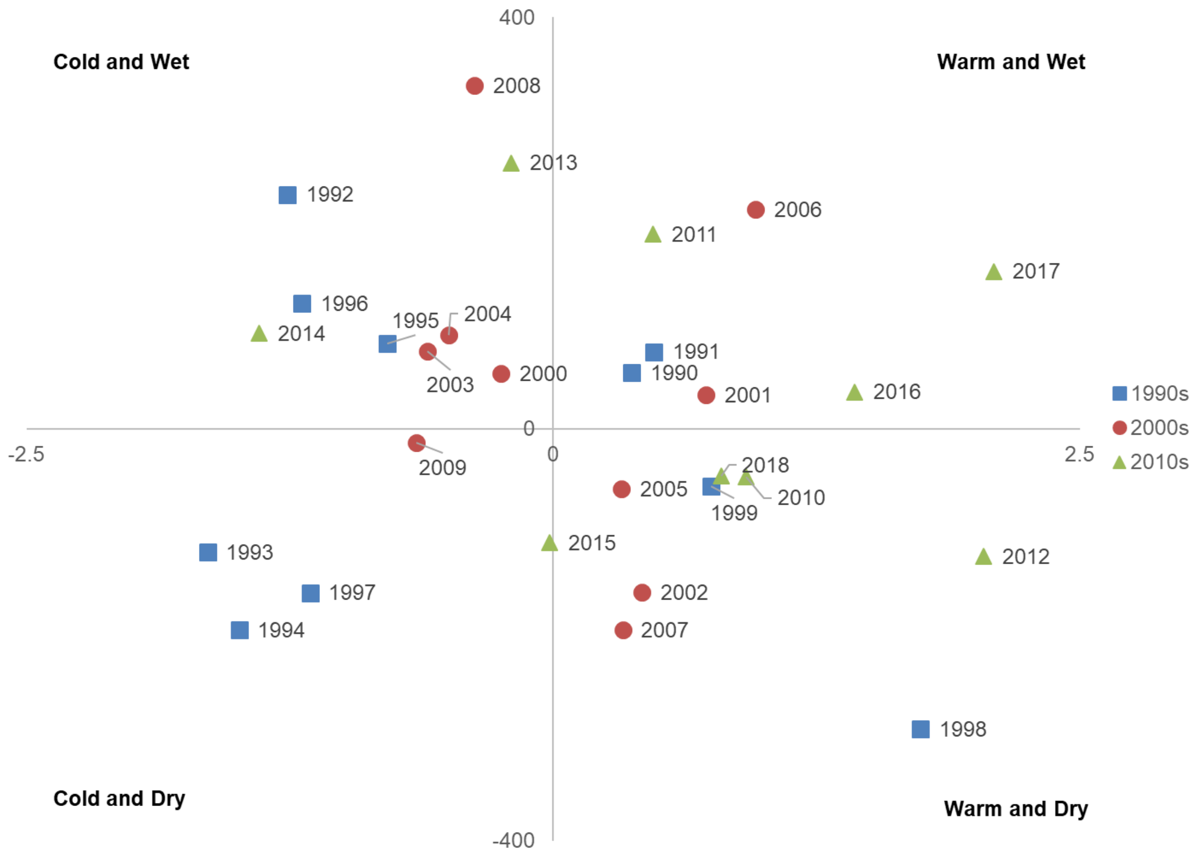

Figure 7. Deviation from annual average precipitation and annual average temperatures from 1990 to 2018 at the Shand Dam, near Fergus.

Luther Dam climate station on June 23, 2017 with a total of 128.2mm. September 1986 was the wettest month across the watershed with a watershed average of 256mm. The wettest year was 2008, which also had the highest snowfall. The driest years are more variable. Both 1963 and 1998 were very dry years across the watershed. Luther was driest in 1958, while 2007 was a very dry year through the south-central parts of the watershed.

The warmest year is also quite recent. 2012 was very warm across the watershed with a watershed average temperature of 10.6 degrees, which was 3.4 degrees above the long-term average. A very warm winter in 2012 contributed to the high average. The oldest years on record are generally still the coldest; however, recently there were some extreme cold events. For example, 2015 was one of the coldest winters on record. The coldest summer was 1992, which was mainly due to the eruption of Mt. Pinatubo the previous June, which affected global climate patterns.

Climate trends were determined for six stations across the watershed and over three time-periods (1961-1990, 1971-2000 and 1981-2010). Between the earliest and latest climate normal there has been an increase in the mean annual temperature of approximately half a degree and an increase in the average temperature during the winter season of approximately one degree. There were no strong trends in total precipitation however, climate normal data showed a decrease in the annual snowfall over time.

Snow survey data from six sites were used to study trends in the snowpack including the amount of water stored in the snowpack and the occurrence of mid-winter melts. A decrease in snowfall over time can indicate changes to winter hydrology. The winter snowpack represents a significant water reserve that allows the multipurpose reservoirs to fill in the spring. Changes to the snowpack are a very important consideration for managing water supplies into the future.

The snowpack represents an important reservoir of water on the land that fills the multipurpose reservoirs needed to augment river flows during dry periods.

The amount of water in the snowpack is decreasing over time. With a few exceptions, most sites are showing relatively similar decreases in the maximum annual and the mid-winter snowpack although patterns are not consistent across the watershed. The number of mid-season melts has increased over time, with the largest increases for small and medium melts, where 50% or less of the snowpack water content is lost. In the southern locations, large or very large melts are occurring almost every year, but in the north, they are still a relatively rare occurrence. The snowpack is light in about 1 in 7 years in the northern half of the watershed and 1 in 3 years in the southern half. A more detailed summary of the state of the winter snowpack is included in Climate Trend Analysis report. An exception to the trend explained in the above, was the winter of 2014. A record snowpack accumulated into 2014 as a result of no mid winter melts, a consistently cold winter and a delay spring freshet. The spring freshet in 2014 did not occur until near mid-April. The record snowpack set conditions for what could have resulted in a flood of record, however limited precipitation accompanied the freshet and the freshet was gradual over several days allowing a slow release of the snowpack water. Conditions experienced in 2014 is a reminder that climate is variable and there can be exceptions to trends, however the trend indicates the tendency is to smaller snow packs. For more information, See the Technical Brief Winter 2014's Significant Snowpack.

Water management reservoirs

Multipurpose water management reservoirs were built to assist water managers to re-establish more naturalized river flows. The reservoirs catch the spring melt thus reducing flood flows and then they slowly discharge water back into the river during low-flow periods. Originally, this *conservation plan* allowed for the dilution of treated and untreated sewage downstream of the reservoirs. Today, the water in these reservoirs still provides the additional flows needed for wastewater assimilation however, most of the wastewater treatment plants now have advanced treatment.

The water management reservoirs are important today just as much as they were when they were first built. Due to increasing population, the reservoirs continue to serve their purpose of supplying water to the river for downstream communities as well as for accommodating treated wastewater effluent. From a flooding perspective, the reservoirs are actively used to manage floods by storing water during high flows and releasing it slowly afterwards. Most peak flows are reduced by between 20 and 80% the 2014 to 2018 period for communities downstream of the large reservoirs.

Flood management

Flood management is one of the primary purposes of the water management reservoirs. Water is taken into storage in the reservoirs to reduce downstream peak flows and/or delay the timing of peak flows to reduce impacts.

The degree to which the water management reservoirs reduce flood impacts is dependent on the time of year of the flood event and the conditions which lead to flooding. There were a number of high flow events between 2014 and 2018 in which the reservoirs were used to manage downstream impacts. For example, the June 2017 event saw peak flows reduced by 20 to 40% downstream of the Shand, Conestogo and Woolwich reservoirs. In addition, the peak flow was delayed by a number of hours to provide a longer preparation time for response to the unexpected event. During the February 2018 event, downstream peak flows were reduced by 40 to 80% by reservoir operations. Downstream peak flows were reduced by a greater amount during the February 2018 event because it occurred when the reservoirs have their highest flood storage capacity. On average flood peaks in the Grand River through Cambridge and Brantford are reduced by 20% to 30% consistently. Weather forecasting, the monitoring network and the flood forecasting modeling all aid in optimizing use of reservoir storage to reduce flows and delay flood peaks downstream of the reservoirs.

Water storage

The designed water storage in the multi-purpose water management reservoirs remains intact. On average, the water in the two largest reservoirs, Belwood and Conestogo, is replaced 2-3 times per year[13].

The total amount of storage in the reservoirs is 170,993,000 m^3, which is equivalent to 50,000 Olympic-sized swimming pools. Most (93%) of that storage is provided by the four large reservoirs – Belwood, Conestogo, Guelph and Luther. The remaining storage is in the Woolwich, Shade's Mill, Laurel Creek and Damascus reservoirs. The smaller reservoirs were purpose built for local flood management and low flow augmentation to enhance summer water quality conditions and in the case of Shade Mills dam to induce infiltration/recharge for municipal water supply.

Water quality

Historic studies along with more research by the University of Waterloo and Wilfrid Laurier University suggest that all of the large water management reservoirs are eutrophic and experience regular algal blooms. High levels of phosphorus are available to generate algal blooms mid-to late summer with most of the nutrients coming from the upstream watershed[14]. Reservoir sediment studies have shown that the aquatic productivity in both Belwood and Conestogo has increased since the mid-1990s[15]. On occasion, cyanobacteria blooms have occurred in both reservoirs[16].

Due to the rapid flushing nature of the water management reservoirs, however, the effects of high nutrients in the reservoir is moderated as most of the water in the reservoirs is replaced, on average 2-3 times per year.

By their very nature of catching water during the spring freshet, reservoirs are sinks for nutrients that come from the upstream catchment. Similarly, the pool of nutrients in these reservoirs then become sources of nutrients as water is discharged downstream.

Although research at the University of Waterloo has shown that these reservoirs have always had algal blooms[15], with a changing climate and the possibility for more frequent and significant runoff events, implementing land management practices to reduce runoff and phosphorus losses in the upper catchments is more important than ever to help to maintain or improve in reservoir water quality

Water supply – low-flow augmentation

Low-flow augmentation of the Grand River – or adding water to the river during dry periods can be up to 90% of the flow on any given day, but averages about 50% of the total summer flow that passes through Kitchener year to year. Figure 8 illustrates the seven day minimum natural and augmented flows through Galt by year. Without the large water management reservoirs in the upstream watershed, the river flow would be very low. For the speed river, low-flow augmentation from Guelph reservoir can be as much as 70% of the daily flows during hot dry summers.

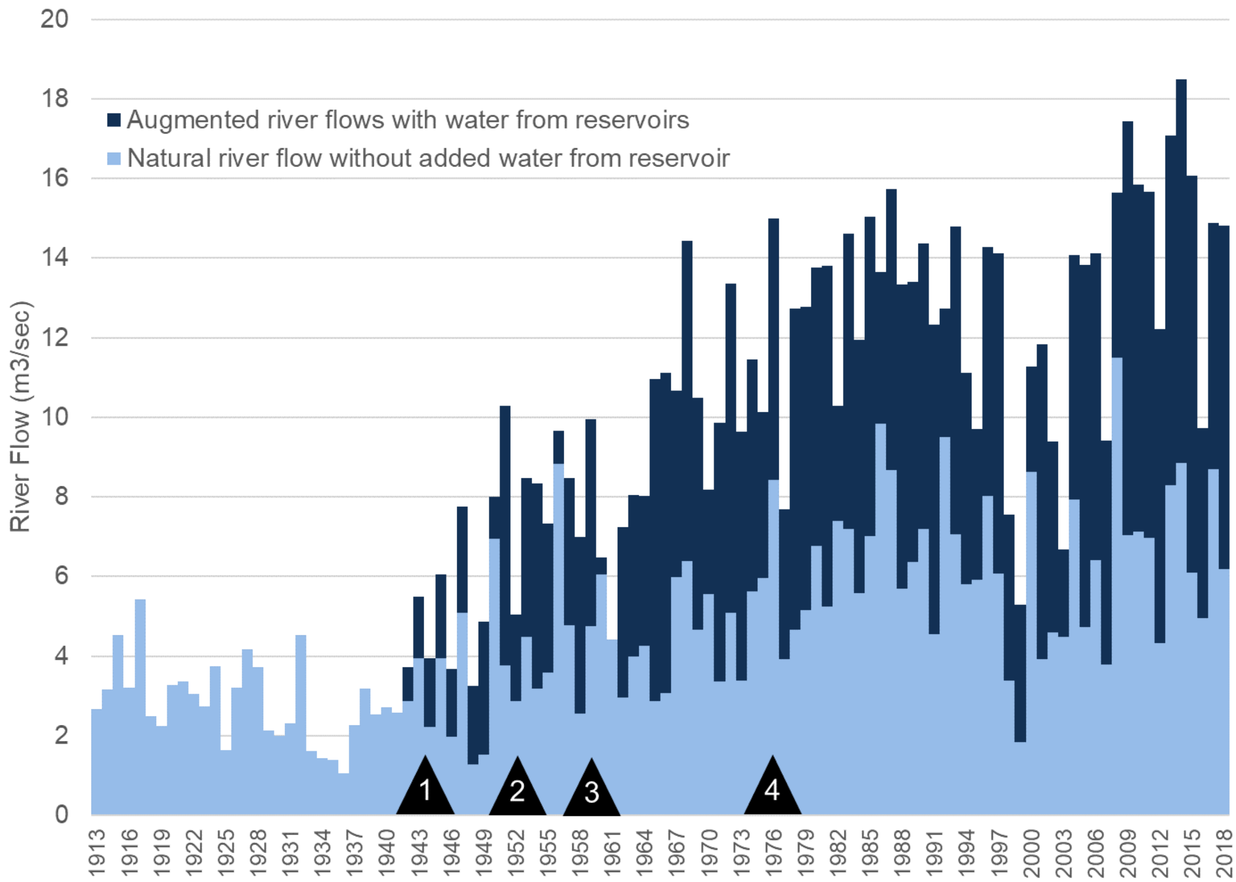

Figure 8. Summer low flows in the Grand River at Galt without the large water management reservoirs augmenting river flows (light blue). The reservoirs are used to augment water to the river (dark blue) to ensure downstream water supplies and that enough water is in the river to dilute treated wastewater effluent without harming the aquatic life in the river. The black triangles show when the large dams and reservoirs were built: 1- Shand Dam; 2 – Luther Dam; 3- Conestogo Dam; and 4- Guelph Dam. Note the exceptional dry period in 1998-99.

From 2014 to 2018, the water added to the Grand River by the Conestogo and Shand reservoirs amounted to between 40% and 75% through Kitchener and 20 and 35% at Brantford. On average, however, the reservoirs contribute about 60% of the flows in the Grand River through Kitchener and about 30 percent of the Grand River flows through Brantford. For the Speed River, the reservoirs add about 30% of the flows during an average year. In contrast, however, during a dry year, the reservoirs can add up to 85 and 50% of the flows through Kitchener and Brantford and 70% of the flows in the Speed River flowing through Guelph (Figure 9). The Grand River receives additional flow between Kitchener and Brantford from the Speed River, Nith River and Whitemans Creek. In addition, there is a sizable amount of groundwater that discharging into the Grand River between Paris and Brantford as the Paris-Galt moraine system intersects the river. The noted groundwater discharge additional downstream of Kitchener can equal the augmentation provided by the large reservoir in the Grand River through Brantford during extremely dry periods. The moraine and groundwater system act as a large natural reservoir, providing an important benefit to the river.

The Guelph reservoir added between 25 and 50% of the flow in the Speed River through the City of Guelph between 2014 and 2018.

Rivers and streams

There are about 9,900 km of rivers and streams draining the Grand River watershed. Most (82%) are low order, headwater streams while the remainder are the major rivers and large creeks, including the Conestogo, Speed/Eramosa, Nith, Whitemans, Fairchild, Boston/ McKenzie, that flow into the Grand River as it winds 311 km from Dundalk to Port Maitland.

Streamflow is a result of runoff from precipitation (rainfall or snowmelt), discharges from storage features (wetlands, ponds and reservoirs) and groundwater discharge. Streams that are primarily runoff fed tend to be flashy with quick transitions from high flood flows to low baseflow. Streams that are primarily groundwater fed tend to be slower to respond during a flood event and maintain high baseflow throughout the year.

Headwater streams in the Conestogo, Nith and Speed subwatersheds tend to be primarily surface runoff fed with minimal groundwater discharge. As a result, these streams have very low summer flows. Low river flows can limit the river's use downstream including the discharge of treated wastewater for assimilation. On the other hand, the flashy nature of these systems means that flows increase quickly following rain or snowmelt resulting in flash flooding and erosion.

The creeks and streams draining the moraine systems generally have good base flows, due to groundwater discharge, that help augment flows downstream and moderate stream temperatures. Most of the coldwater habitat in the watershed are in these small streams off the moraine or draining the sand plain in Brant and Oxford counties. The stream-groundwater connection is especially important in the moraine regions of the

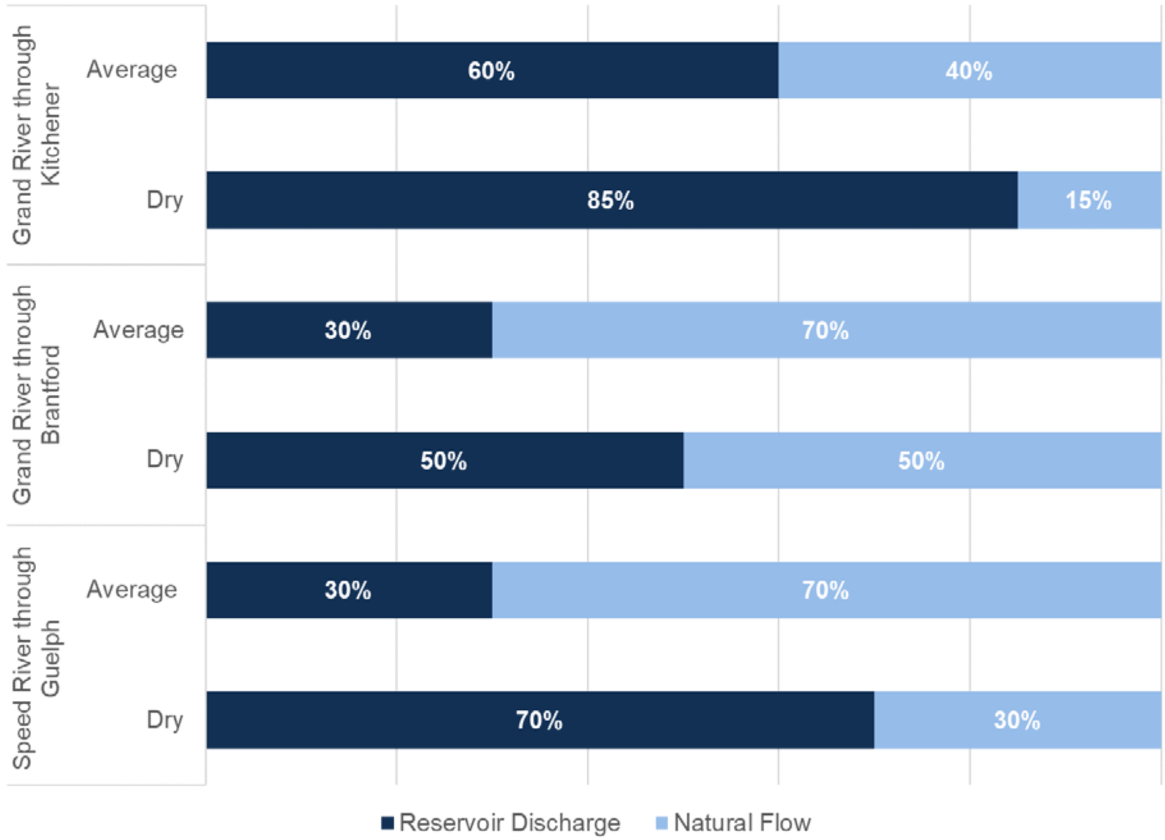

Figure 9. The natural river flows (light blue) and augmented river flows by adding water from the large water management reservoirs (dark blue) in the Grand and Speed Rivers during an average year and a dry year.

watershed including the Orangeville, Paris-Galt and Waterloo moraines. These watercourses are less prone to flooding.

A preliminary study using the Indicators of Hydrologic Alteration[17] to identify trends in base-flows in selected small groundwater fed creeks in the watershed showed mixed results[18]. In some areas, base flows had decreasing trends across a range of durations (e.g., 1-,3-,7-,30-, and 90- day minima) while others suggested an increasing trend. Seasonality was also apparent. Many creeks showed increasing base flows during the winter months (i.e., January and February) and two rivers showed a shift of the minimum daily flows to later in the year. Some creeks did not have sufficiently long data records to undertake analysis and, thus, a commitment to continued data collection on these creeks will support future trends resulting from a changing climate. Analysis that is more detailed is required to inspect the cause and effect of these trends over the long-term.

Trends in baseflow are affected by recent climate. The groundwater aquifers in the the Grand River watershed have different storage and connection characteristics. The shallower aquifers upstream of Kitchener start to lose their connection to the river system after two years of dry conditions. The aquifers still contain water but the groundwater levels drop and are not high enough to push groundwater in to the local streams and rivers. The larger moraine driven groundwater systems between Kitchener and Brantford and the Paris Moriane along the Eramosa River appear to reduce their contribution of groundwater to the river after 3 to 5 years of dry conditions. The shoulder seasons to the growing season are important net groundwater recharge periods, the spring after the ground thaws and before the growing season starts and the fall after the growing season ceases and before the ground freezes are important periods in the hydrologic cycle.

Operational river flow targets

The large water management reservoirs add water to the Grand, Conestogo and Speed rivers during low-flow periods. The reservoir operating policy identifies operational river flow targets at Leggatt, Doon and Brantford on the Grand River, and at the Below Guelph gauge on the Speed River, to ensure river flows are sufficient for downstream municipal water supply and waste water assimilation.

Operational river flow targets are specified river flows at select locations that result from reservoir discharges. Targets were determined based on how much water could be reliably supplied downstream, 95% of the time.

Between 2011 and 2017, reservoirs provided sufficient water to meet the operational river targets more than 95% of the time. Reliability of meeting flow targets has improved for all locations over the last decade. However, in 2012 and 2016, due to exceptionally dry conditions with little rain, flows were lower than the targets for short periods. The summer river flow target on the Speed River in Guelph continues to have the lowest percent reliability on an ongoing basis (about 95.3%).

The added water in the river system from the water management reservoirs is important for maintaining the aquatic ecosystem. When the operational flow targets are met there is sufficient water for aquatic organisms to move between different parts of the river system which is critical for ecosystem health during low flow conditions.

Low river flows and droughts

Water released from water management reservoirs helps to maintain flows in rivers downstream; however, naturally flowing streams can experience low water conditions due to low precipitation or low groundwater levels. In reaches downstream of the reservoirs, low river flows tend to happen later in the fall while in naturally flowing rivers, low flows tend to occur during the summer. Low flows in some of the naturally flowing watercourses appear to be trending down over time, but additional study is needed to confirm this trend.

The Low Water Response Program, administered by the Ministry of Natural Resources and Forestry, ensures provincial and local authorities are prepared in the event of low water conditions. The Low Water Response Program uses increasing levels to describe the conditions of the watershed and the voluntary response required from water users. Level 1 is for minor low water conditions where water users are asked to conserve water; Level 2 is for major low water conditions where water users are asked to reduce water use where possible; Level 3 is when water supplies are threatened or no longer available. The Grand River Low Water Response Team has coordinated the program in the watershed since 2001.

Areas prone to having low water are areas that are not regulated by large reservoirs and include the upper Grand River above Black Creek, upper Conestogo River, upper Speed River, Eramosa River, Nith River, Mill Creek, Whitemans Creek and McKenzie Creek. Since 2001, the Low Water Response program was used 14 times in these areas with the most frequent and sever low water conditions generally occurring in the upper Conestogo, McKenzie and Whitemans creek subwatersheds.

Conditions in 2012 were severe enough to prepare Level 3 request documentation for Whiteman’s Creek and the Eramosa River. The Low Water Response team requested that Whiteman’s Creek be declared in a Level 3 condition by the Ministry of Natural Resources and Forestry but no declaration was made and water levels recovered naturally. In the last five years, 2016 was the driest. Low reservoir levels resulted in a watershed wide Level 2 declaration continuing to January, 2017 and to Level 1 until April, 2017, when the reservoirs returned to normal levels.

Areas of potential conflict

Headwater streams tend to be flashy, have very high flows during spring runoff or intense summer rainfall events and yet they have very low flows during the summer. Many headwater streams in the Nith, Conestogo and upper Grand River region tend to experience this large range of flow annually. Very low water conditions in the summer contribute to limited support for the aquatic ecosystem and constraints for communities who wish to discharge treated wastewater effluent into these rivers.

Whitemans and McKenzie Creeks continue to have low water issues on an almost annual basis. These creeks support healthy aquatic ecosystems and coldwater fisheries as much of the baseflow come from shallow groundwater. Soils are sandy in this area and there is a high water demand to irrigate crops in the growing season. This high seasonal demand can conflict with the needs of the aquatic ecosystem. These creek systems were identified as having moderate potential for stress through the Tier 2 water budget process and a subsequent more detailed regional water budget study was undertaken in 2019.

Water levels in the Upper Speed and Eramosa rivers are naturally low in the summer because it depends on rainfall and surface water runoff for much of its flow. Flows are more consistent in the Eramosa River which is fed, in part, by groundwater. The City of Guelph takes water from the Eramosa River during the summer to supplement its municipal drinking water supplies. The Eramosa subwatershed was highlighted in the regional water budget as having moderate potential for stress for surface water quantity under the local water demand conditions[19] and was included in the Guelph/Guelph-Eramosa detailed Water Budget study.

A drought contingency plan is a plan that outlines what water users can do in the event of a low water conditions. The drought contingency plan for the Grand River watershed only identifies volunteer actions to conserve water.

High river flows and floods

High flows and riverine flooding in the Grand River watershed can occur any time of the year and result from one or more primary driving factors including rapid snowmelt, snowmelt combined with rainfall, wide spread heavy rainfall, or localized intense rainfall (urban and rural flash flooding). Areas adjacent the Lake Erie shoreline, including the Grand River reach up to the Dunnville Dam, can also experience surge flooding from wind and storm events on Lake Erie. Lastly, ice jams can occur almost anywhere in the watershed, though there are areas that are notably more prone to such occurrences.

In addition to the type and magnitude of a particular weather event as a driver of high flows, the state of the landscape at the time and location of an event plays a significant role in determining the potential for associated flooding. The underlying geology, for example, contributes to whether there is a tendency for water to runoff or to infiltrate. The till plains that dominate the headwater areas of the watershed and the clay plains of the southern Grand generate runoff much more quickly and at a higher volume per unit area than does the moraine systems that occupy the central watershed.

The runoff characteristics of an area can be significantly impacted by other natural or anthropogenic drivers as well. The landscape's capacity to retain water may be significantly reduced by virtue of their seasonal condition (e.g., frozen ground), extent of impervious coverage (e.g., pavement), through the removal of vegetation (reduced evapotranspiration), or through the completion of drainage 'improvements such as ditching or tiling to support agriculture. Large-scale or cumulative small-scale grading activities including the removal of depressions, for example, often reduce the volume of available storage on the landscape, creating more runoff volume and higher downstream peak flows. The anticident conditions prior to an event also contribute to runoff potential.

With reference to the previous section that outlined reservoir operations vis-à-vis flood management, the seasonality of an event as it relates to the volume of available engineered storage, can also play a significant role as well. The June 23, 2017 event, for example, occurred when the major reservoirs were essentially full, limiting the capacity to provide substantial storage. By contrast, the large flood event of February 2018 was significantly reduced through the availability and use of available reservoir storage at that time.

High river flows can become a public safety concern, but are also necessary to maintain the health of the river system. High flows move sediment and nutrients downstream and out onto the floodplain improving water quality and aquatic habitat. High flows for moving sediment, nutrient flushing and pushing nutrients out onto the floodplain are occurring with sufficient frequency throughout the watershed in both naturally flowing rivers and downstream of the water management reservoirs.

In the Grand River watershed, high river flows are caused by

- severe wide spread rain such as tropical storm remnants;
- extreme localized rain;
- moderate rainfall on saturated or frozen ground;
- snowmelt over a short period of time;
- combined rainfall and snowmelt;
- localized ice jam flooding; and
- surges from Lake Erie in the Dunnville, Port Maitland, and along the Lake Erie shoreline.

Flood frequency and maximum recorded flood flows

The flood frequency analysis for 37 locations across the Grand River watershed including eight locations with deregulated or naturalized flow and one Lake Erie water level location (see Technical Memo Flood Frequency Analysis). This analysis evaluates historic river flows across the watershed using the most recent five years of data.

The June 23, 2017 was a significant flood event in which extreme rainfall concentrated over the northern portion of the watershed. The one-day rainfall total at Luther Dam was the highest daily total rainfall recorded since 1950. Two characteristics made this storm very uncommon: High intensity rainfall – 126 mm of rainfall fell over a 3-4 hour period. This is a very large volume of rainfall in a short period of time; and the rainfall occurred over a large area – approximately 1/3 of the watershed.

For more details around this event, see the Technical Brief June 2017 Flood Event – Drayton, Grand Valley and West Montrose.

Ice jams can also cause flooding in the Grand River watershed, especially during rapid thaw and freeze events mid-winter. The winter of 2018 saw the conditions develop to risk flooding from an ice jam in the river. Very cold winter conditions over a prolonged period allowed for the formation of very strong ice to build up in the river. A warm front that emerged over the watershed generated 10-15 mm of rain on top of a significant snowpack that yielded 125-150 mm of runoff which significantly increased flows that pushed ice downstream creating ice jams at Cambridge and Brantford. Cold conditions set in again and more ice was formed in the river.

Another warm front came into the area on February 19th raising temperatures and dropping rain (40-60 mm). This rainfall was the highest two-day February rain event at the Shand Dam in 79 years. Ice and flood levels at Cambridge and Brantford began rapidly increasing until the ice jams broke sending a significant amount of water and debris downstream which set new flood level records in Brantford.

For more details around this event, see the Technical Brief February 2018 Ice Jam Event – Cambridge and Brantford.

Intense rainstorms over urban areas also contributed to record creek flows, although only a few of these watercourses have gauge stations that can record the flows. A particularly intense storm hit parts of Cambridge on August 25th 2016 in which 92mm of rain fell within a two-hour period. Intense, localized rainfall has also occurred in Brantford and Kitchener yet were not captured by existing gauge networks.

A recent Government of Canada report indicated that the seasonal timing of peak streamflow has shifted and it is due to warming air temperatures[20]. Warming air temperatures, warm the atmosphere and increase its capacity to hold water and therefore, the intensity of precipitation events is increasing[21]. This shift is seen in the Grand River watershed. A shift in the timing of the peak flood flows from the typical snowmelt driven flows in March-April to higher flows in January-February or even in the summer is evident. Maximum instantaneous river flows appear to be shifting away from occurring during the spring months of March and April and happening across the calendar year. Figure 10 shows the maximum instantaneous flows in the Grand River at Marsville. Since 1990, a number of high flow events were recorded outside the typical spring period.

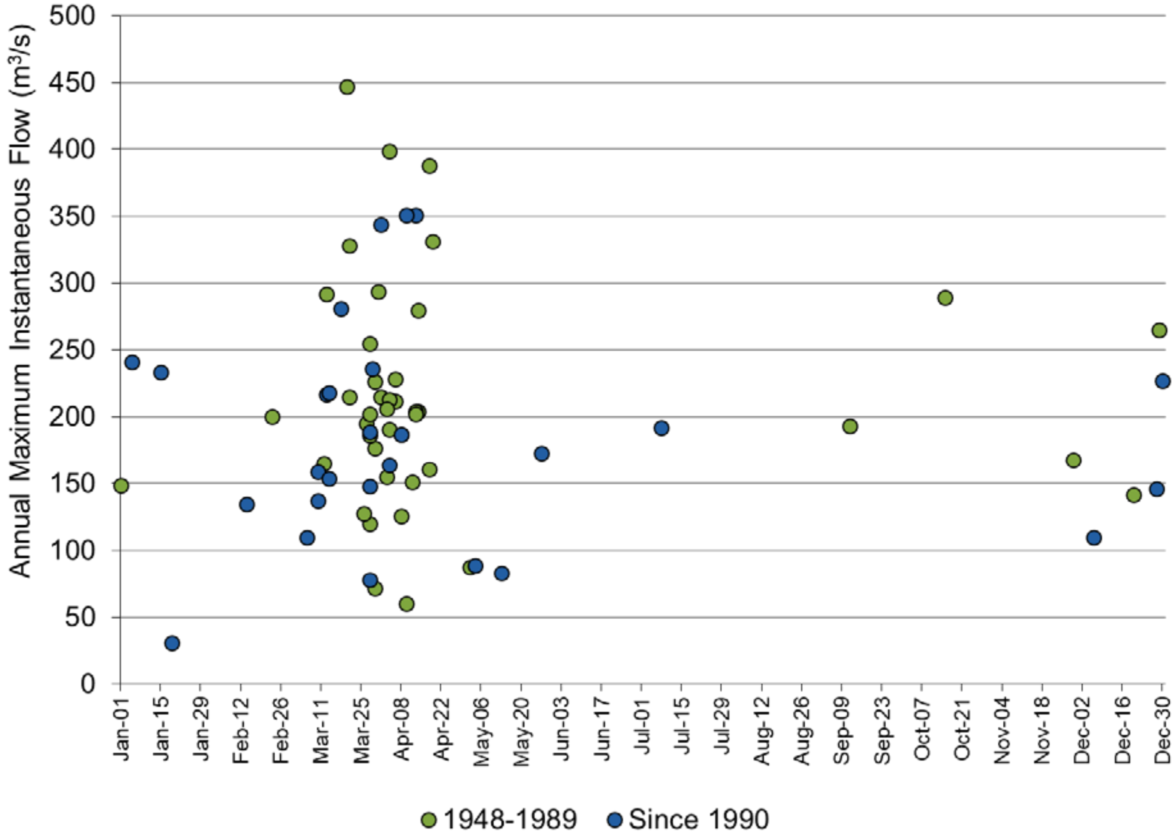

Figure 10. Annual maximum instantaneous flow (m^3/sec) of the Grand River at Marsville. Typical high flows have been in the spring months (March/April) when snowmelt dominated runoff generate high flows. Maximum instantaneous flows since 1990 appear to be shifting away from just occurring during the spring months.

Reducing the Impacts of Flooding

The GRCA's flood damage reduction program uses both structural and non-structural approaches and is based upon the three primary, overlapping, and complementary pillars of land use regulation or floodplain management, physical water management infrastructure such as dams and dykes, and a flood forecasting and warning program.

Land Use Regulation / Floodplain Management

Regulation of land use within the floodplain to limit new development and ensure that any redevelopments are protected to a higher degree than what was there previously is a particularly effective approach to limiting and reducing flood losses. The floodplain mapping and regulation component of the program is relatively mature, having been in place in some form for over 60 years. The GRCA works cooperatively with municipalities to insure that regulated areas are incorporated within planning documents minimizing the creation of new flood-related risks to life and property and, when redevelopment is contemplated, so that reductions in risk are achieved through structural or non-structural improvements.

As of 2019, approximately 60% of the 9,900 km of watercourses in the watershed have an associated floodplain mapped. Approximately 1,600 km of the larger systems have formal, engineered floodlines based upon hydraulic analysis and base mapping of an accuracy suitable for the task. The remaining 4,500 km of the flood-regulated areas, generally associated with smaller and/or rural watercourses remain in an estimated or approximated state. Recent large-scale capture of topographic and bathymetric data sets, combined with advancements in modeling and mapping technologies, is allowing the rapid advancement of the program to update existing hardcopy floodplain mapping to new digital floodplain mapping . Digital floodplain mapping will result in a range of new flood mapping products, including flood risk maps, safe access maps and flood zone maps to name a few. These new mapping products will improve the ability for municipalities to preplan and prepare for floods, will provide improved information to resource planner and will provide better information to the land owner in the hazard area.,

Flood Management Infrastructure

Physical flood management infrastructure in the watershed exists in two basic forms - flood management reservoirs and dykes/channel works. The multi-purpose functionality of the reservoirs and associated seasonal limitations on flood management were described in an earlier section.

There are ten full or partial dyke systems within the watershed at Bridgeport, Cambridge-Galt, Paris, Brantford, Caledonia, Dunnville, Drayton, Guelph, Hespeler and New Hamburg. With the exception of minor human intervention required to temporarily close engineered gaps (e.g., at road crossing), the dykes function as passive flood management structures.

As of 2019, the flood management infrastructure system is relatively stable with no new major works in the forecast. An operation and maintenance program is in place, ranging from day-to-day routine activities to much larger refurbishment / replacement works undertaken on an infrequent basis. A flood mitigation study is underway in the community of New Hamburg to investigate options to further mitigate flooding in that community. An ice management study has been completed through the dyke reach in the City of Brantford, this study documented the mechanisms of ice jams and mitigation options to reduce the potential for ice jam flooding in the future.

Flood Forecasting and Warning

The aim of the flood forecasting system is two-fold: to effectively operate reservoirs to reduce flood damages and to provide a flood warning in advance of a flood to municipal officials in the watershed

Monitoring network comprised of the following (Figure 11):

- 66 flow gauges
- 31 rain gauge / climate stations
- 12 snow courses
- Continual maintenance and upgrades to gauge and communication infrastructure
- Connectivity to neighbouring networks, an initiative taken following the June 2017 event so as to provide additional real-time early warning of incoming events (e.g., 7 rain gauges added in surrounding watersheds) and/or to provide for better estimation of hard-to-measure characteristics (e.g., 28 snow course survey locations in neighbouring watersheds)

The GRCA’s real-time hydrologic forecast model, the Grand River Integrated Flood Forecast System (GRIFFS) has been in place since the late 1970’s. This is a sophisticated deterministic model used to forecast snowmelt and/or rainfall related flood flow to support reservoir operations and flood warning. While the model has served its purpose well, current efforts include working with the US Army Corps of Engineers to update and improve their hydrologic model, Hydrologic Engineering Centre - Hydrologic Modeling System (HEC-HMS) for use in a modernized, hydrologic/hydraulic, real-time flood forecasting model for the watershed.

Creation of inundation mapping for more communities has been completed and is in place and in use currently in New Hamburg (8.1 km), Ayr (20 km), Drayton (1.5 km), Grand Valley / Waldemar (7.5 km), West Montrose (1.2 km), Conestogo (3.5 km), and the Haldimand Lakeshore (25 km), with more areas anticipated to come on-line shortly. Inundation mapping has become a critical part in helping reduce flooding impacts in these communities as it improves the understanding of relative risks for all stakeholders and improves the efficiencies and effectiveness of emergency management personnel in notifying and assisting affected residents. Inundation mapping allows preplanning of flood emergencies creating a foundation for municipality emergency response plans for flood emergencies. In 2016, municipality wide flood emergency mapping illustrating the extent of the regulatory floodplain, roads, building and critical infrastructure in the floodplain was prepared for municipalities. These maps provided a high-level visual flood risk assessment for the municipality. In 2019 as LiDAR topographic mapping

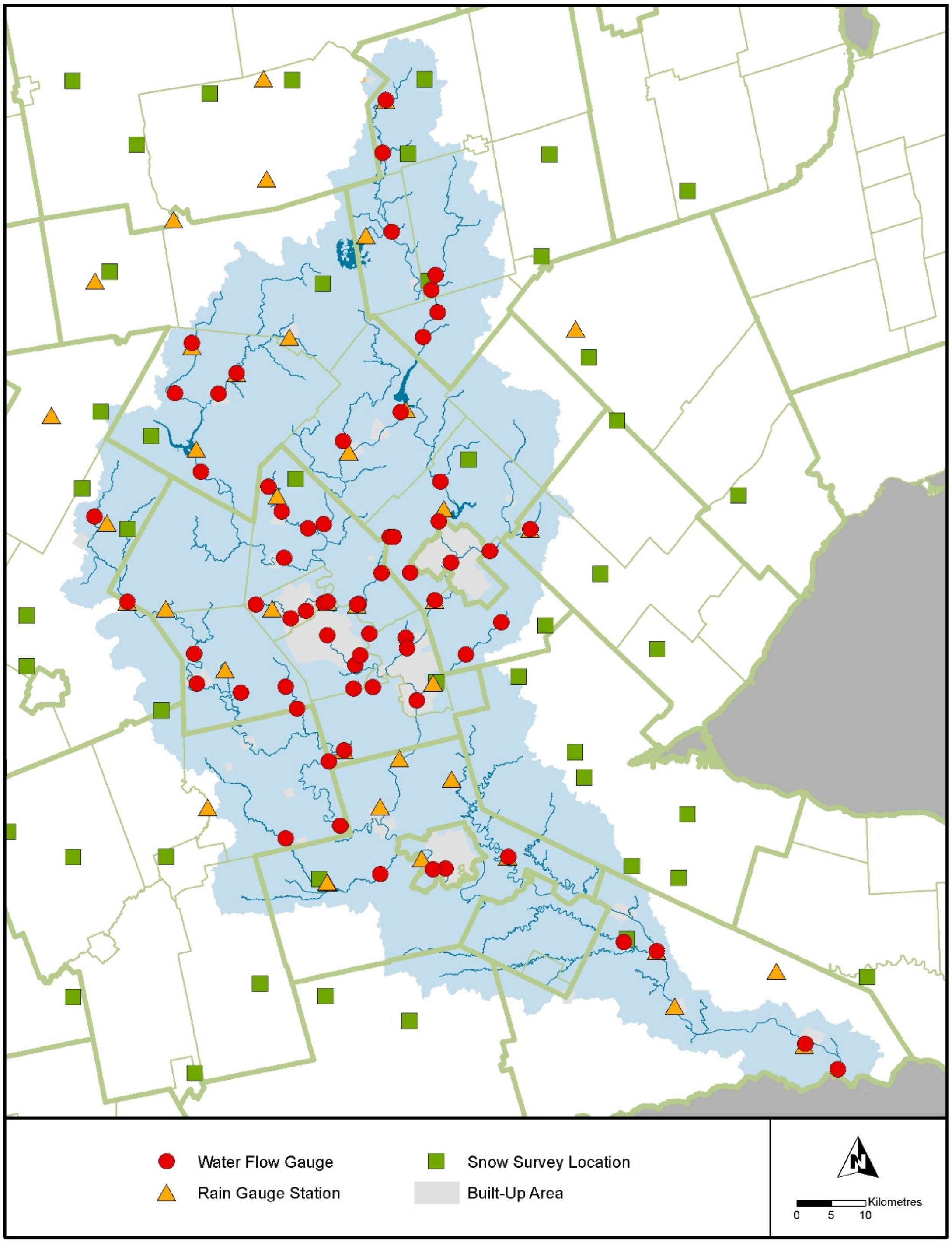

Figure 11. River flow gauge, rain gauge and snow survey location in the Grand River watershed

became available, reached based inundations mapping along the large river has been initiated and integrated with efforts to update the emergency preparedness plan for Conestogo Dam. Integrating municipal prepared for flood emergency with emergency preparedness for dam emergencies is now possible largely because of the availability of topographic LiDAR, this improves preparedness for the full range of floods from small flood to the very extreme floods that exceed the Regulatory flood used to map and regulate the flood hazard.

River water quality

River water quality can be described through chemical, physical or biological attributes. The well-established and long-standing water quality concerns in the Grand River watershed are dissolved oxygen and nutrients like phosphorus and nitrogen. Nutrients can cause nuisance algae to grow in the river impeding water flow and significantly influencing the dissolved oxygen regime. Therefore, total phosphorus, ammonia, dissolved oxygen and nitrate are important parameters to evaluate to help determine the general state of river water quality. More recently, chloride from road salt and water softeners is also increasing concern. Emerging contaminants such as pharmaceuticals or personal care products are discussed later in this section.

Many factors influence river water quality. Point sources, such as wastewater treatment plants influence the water quality, especially at low river flows. Land cover or use, either urbanization or agricultural uses, influences runoff that, in turn, influences river water quality. The amount and timing of precipitation, either snowmelt or rainfall, can also influence river water quality. Thus, to define the overall quality of a river system is challenging.

Although many agencies collect river samples to analyze the chemical and physical characteristics, two primary programs underpin the characterization of water quality at the watershed scale. Through a partnership with the Ministry of Environment, Conservation and Parks, the GRCA collects river samples at 37 sites that are part of the Provincial Water Quality Monitoring Network. This network has been in place since the 1960s and offers the best long-term record for temporal trends in river water quality. As part of long-term wastewater master planning, the GRCA also maintains and operates seven monitoring stations where continuous data for oxygen, pH, temperature and dissolved oxygen are collected. These data support the calibration of the Grand River Simulation Model for wastewater master planning. Further, municipal partners, including the Region of Waterloo, may also collect data either in response to Environmental Compliance Approvals or for their own long-term wastewater planning initiatives.

The Provincial Water Quality Monitoring Network (PWQMN) measures water quality in rivers and streams across Ontario.

The first samples in the Grand River watershed were taken on October 5th, 1964.

A water quality index is a mathematical tool that can summarize water quality data for consistent reporting purposes. The Canadian Council of Ministers of Environment's

(CCME) Water Quality Index is a simple and concise way to describe ambient water quality using a number of different parameters that are relevant to the river system. It provides a score from zero (poor) to 100 (excellent) on the overall quality of the water body. CCME's Index uses three statistics to evaluate the overall ambient 'score' of a river system: a measure of how many parameters exceed an objective; a measure of how often it is exceeded (frequency); and a measure of how much the objective is exceeded (magnitude).

Water quality data used in the index include phosphorus, nitrogen and chloride data collected between 2013 and 2017 from long-term provincial and project monitoring sites. The status of water quality of the streams and rivers in the watershed is presented in Figure 12.

Of the 40 sites evaluated, most (18) of the sites score as 'marginal' which mean many parameters exceed benchmarks, frequently and by a sizable amount. Many of these are streams draining urban and intensive agricultural areas. The four streams sites with 'good' water quality tend to be in the areas that have more woodlands, wetlands and strong groundwater fed baseflows. The Grand River below the Shand dam, the tail water region, also tends to have good water quality. The quality of the Grand River at Dunnville, close to Lake Erie is marginal which is consistent with the State of the Great Lakes reporting (2019).

Water quality is improving but some challenges remain

Several water quality benchmarks developed for the Water Management Plan anticipated water quality improvements resulting from the management actions in the Plan. Benchmarks were set for summer total phosphorus (Table 1), dissolved oxygen and un-ionized ammonia.

Two metrics were developed for dissolved oxygen to evaluate progress and ensure the river can provide a good environment to support aquatic life. The daily minimum dissolved oxygen levels should be above 4.0 mg/L 95 % of the time between June 1 and September 30th. The summer is the time when the water is the warmest, and the hardest time for oxygen to remain in the water. Further, the 30-day average minimum should be above 4.5 mg/L 95% of the time between June 1 and September 30th. Water managers anticipated these levels following the implementation of the actions in Plan. These benchmarks are similar to those set for the Basin Study in 1982.

A benchmark for un-ionized ammonia is the provincial water quality objective of 0.016 mg-N/L due to its toxic effects.

For a complete description of the assessment of whether our collective actions are improving water quality conditions in the river, see "Current water quality conditions in the Grand River watershed relative to the Water Management Plan benchmarks[22]"

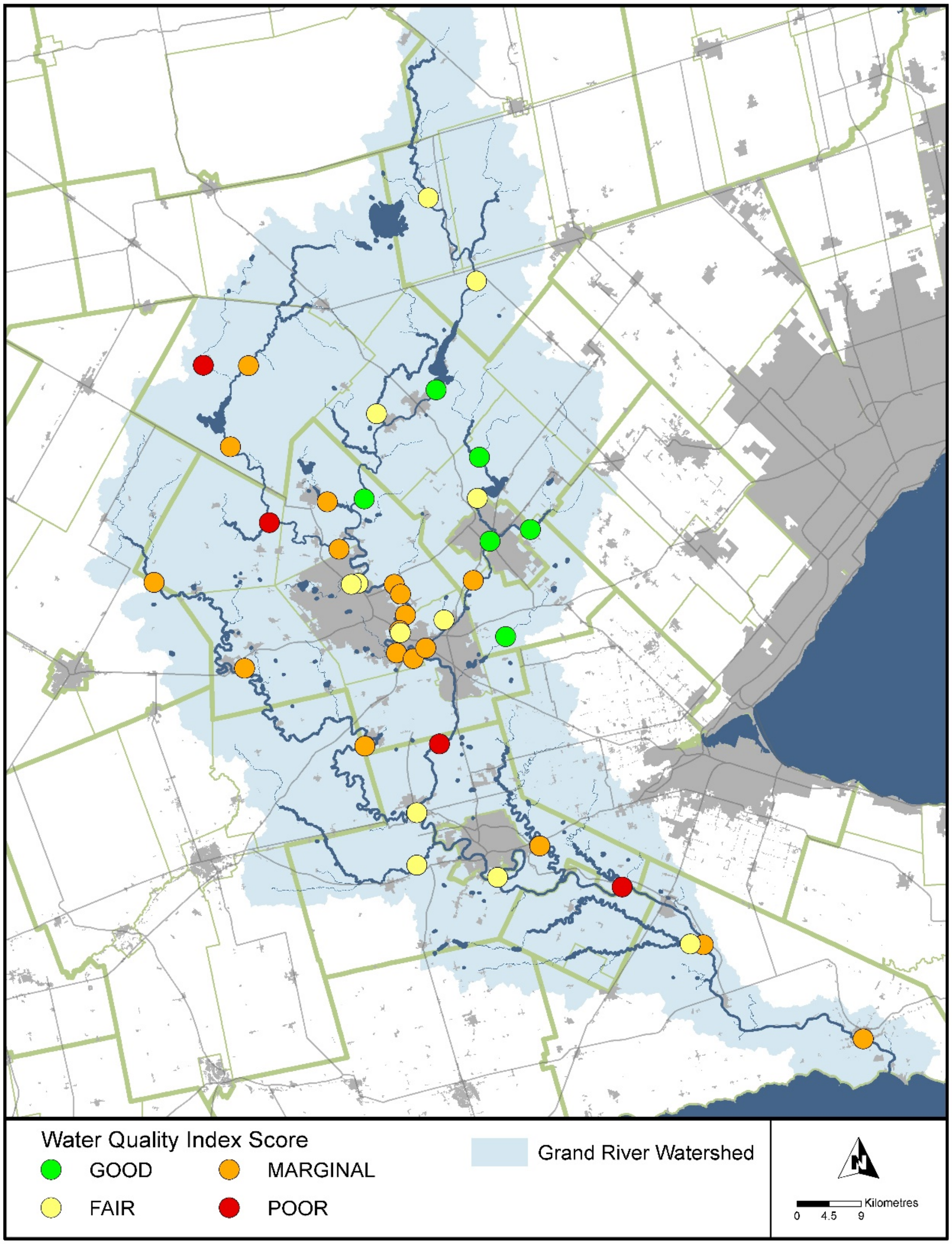

Figure 12. General water quality conditions, as depicted through the CCME water quality index for selected sites in the Grand River watershed.

Table 1. Total phosphorus summer benchmarks for locations on the Grand and Speed River.

River location	Median TP (mg/L)	75th percentile TP (mg/L)
Grand River at Bridgeport	< 0.027	< 0.029
Grand River at Blair	< 0.035	< 0.049
Grand River at Glen Morris	< 0.029	< 0.046
Speed River at Wellington Rd. 32	< 0.036	< 0.039

Dissolved oxygen in the Grand River at Blair has improved since the mid-2000s. Figure 13 shows the improved oxygen levels at Blair since 1975. Significant improvements occurred following the upgrade to the Kitchener wastewater treatment plant that commenced around 2011-12.

Total phosphorus concentrations have improved or remained stable over time, however the total phosphorus levels in the river still remain higher than the benchmarks therefore, this milestone has not been met. Work continues on upgrading wastewater treatment plants to remove additional phosphorus as well, significant reductions of total phosphorus has been seen through improved wastewater treatment plant performance. More work is required to help reduce non-point sources of total phosphorus including improving urban and rural stormwater management.

Un-ionized ammonia has also shown improvements over time and concentrations generally meet the benchmark. The largest improvements in un-ionized ammonia have been observed in the Grand River at the Blair, which is related to reduced total ammonia loading from the Kitchener Wastewater Treatment Plant since 2013 (see Figure 14) and improved process control at many wastewater treatment plants throughout the watershed as part of the wastewater optimization program (see the most recent wastewater treatment plant performance reports at www.grandriver.ca).

With five years of implementing the actions in the Plan, the partnership reached a milestone for reducing ammonia concentrations. Thanks to the commitment by watershed municipalities to upgrade their wastewater infrastructure and improve the performance of their treatment plants.

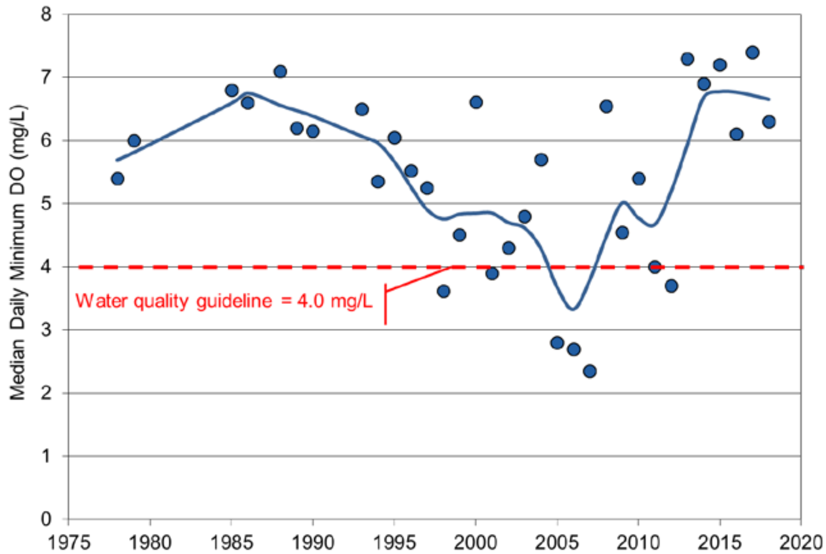

Figure 13. Median daily minimum summer (July/August) dissolved oxygen levels in the Grand River at Blair. Blue solid line shows the general trend of dissolved oxygen since the late 1970's. Recent upgrades to the Kitchener wastewater treatment plant has improved oxygen levels in the river since the mid-2000's**.**

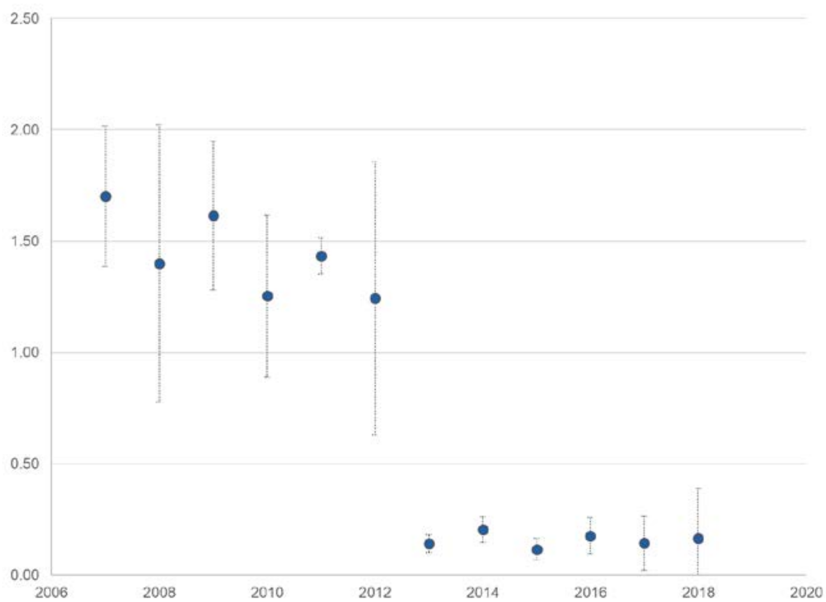

Figure 14. Yearly average summer total ammonia nitrogen concentrations (+/- standard deviation) in the Grand River downstream of the Kitchener Wastewater Treatment Plant between 2007 and 2018. Ammonia levels have decreased significantly in the river.

Celebrating good performance of wastewater treatment plants in the Grand River watershed.

Twenty-eight of the 30 plants are participating in the performance based wastewater treatment plant optimization program.

Six plants met the voluntary total phosphorus effluent quality target in 2018;

17 plants met the voluntary total ammonia nitrogen quality effluent targets.

The total phosphorus load is down 15 % to 30.6 tonnes/yr in 2018 compared to the average load between 2012 and 2016.

The total ammonia nitrogen loading is down significantly to 146 tonnes per year in 2018 compared to an average of 314 tonnes/yr. between 2012 and 2016.

Collectively, work is continuing to achieve a milestone for total phosphorus but reaching that milestone will take much more effort from not only our wastewater managers, but our stormwater managers, and agricultural communities. More actions and a collective effort is needed.

Rural Creeks

Nitrogen is a valuable nutrient for growing crops. However, having too much nitrogen from fertilizers or manures on a field can increase the risk of having the nitrogen carried away in runoff during a heavy rainfall event or with snowmelt. High levels of nitrogen, such as nitrate, can be harmful to aquatic life but if the levels are high enough (e.g. > 10 mg/L) in drinking water, can cause harm to humans.

Nitrate levels in the Grand River at Bridgeport have a seasonal cycle. Nitrate levels in the river tend to be the lowest during the summer growing season as natural processes including algae growth, can use up much of the nitrate in the river.

However, nitrate levels in the Grand River at Bridgeport can approach the drinking water guideline of 10 mg/L during the winter months. Winter nitrate concentrations average about 4.0 mg/L at Bridgeport but occasional peak levels have exceeded 10 mg/L. These levels are above the guideline for the protection of aquatic life of 3.0 mg-N/L.

Watershed sources of nitrate above Bridgeport are likely from fertilizers and manures that are not being incorporated into the soils or used up by crops. Recent research by the University of Waterloo in the Conestogo River area illustrated the high nitrate levels in tile drainage and that stream water is more influenced by water discharging from tile drains than that of local groundwater[23]. Heavily tiled catchments, including the Irvine, Canagagigue, and Conestogo rivers tend to have high nitrate levels in the winter (Figure 15).

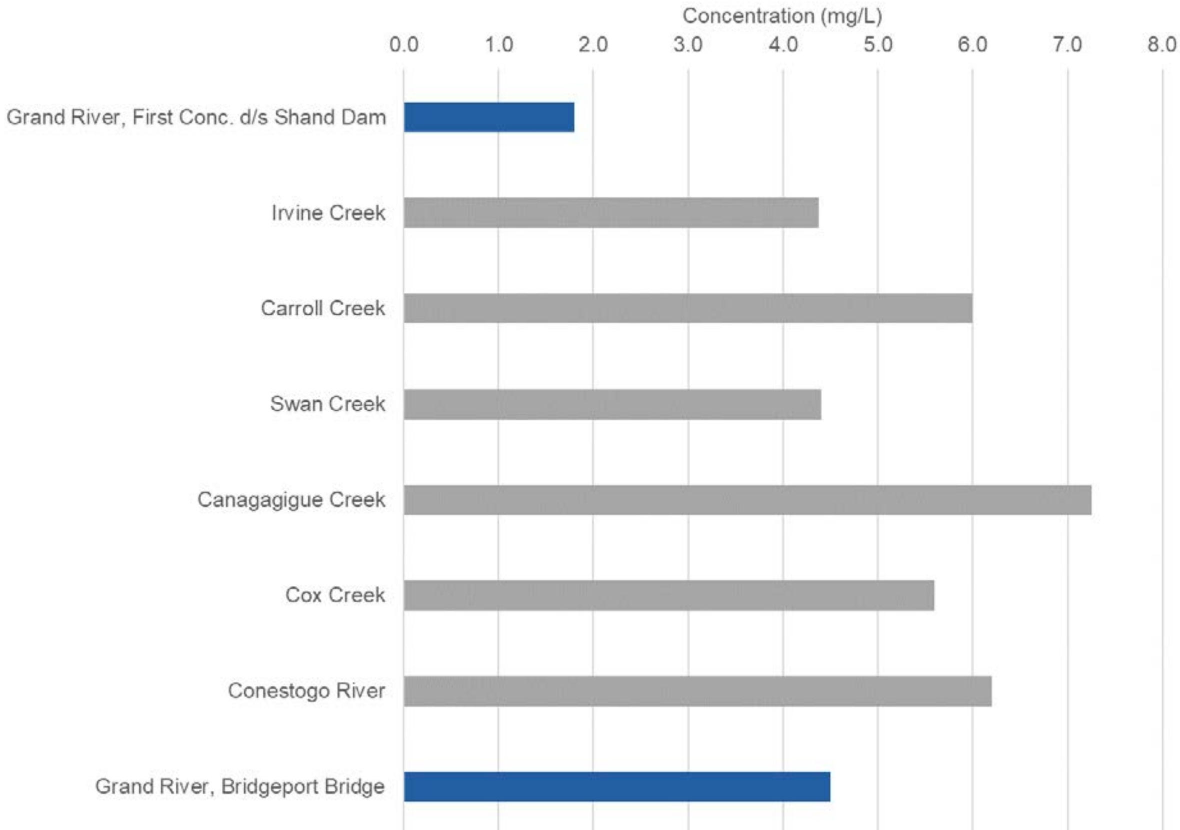

Figure 15. Nitrate concentrations (75th percentiles) in the Grand River below the Shand Dam (blue, top), at the outlet of major tributaries discharging to the Grand River and in the Grand River at Bridgeport (blue, bottom). The highest nitrate concentrations were recorded in the Canagagigue Creek in February 2011 at 11 mg/L. The federal guideline for the protection of aquatic health is 3.0 mg/L and the drinking water standard is 10.0 mg/L.

Phosphorus remains an issue in rural areas dominated by agricultural production, especially in the headwater region (Figure 16). Phosphorus levels are consistently above the provincial water quality objective of 0.030 mg/L in the upper Nith and Conestogo River basins. These areas drain till plains with tighter soils which facilitate snowmelt and rainfall to runoff overland. Coincidently, these areas are also heavily tile drained but research is not conclusive that tiles are a major pathway for phosphorus to reach streams[24] Phosphorus levels are highest during the spring melt and when there is significant rainfall causing runoff and high flows. The nonpoint source nature of the phosphorus in the Grand River and its tributaries will continue to be a challenge.

Urban creeks

Salt helps to make our roadways and sidewalks safe and help to soften our water for our household use. However, chloride can be carried away in runoff from our streets and sidewalks into our creeks and streams or released into our sewage treatment plants. Once salt dissolves in runoff, it can also percolate down to groundwater. Unfortunately chloride cannot evaporate or breakdown naturally in the environment. Once chloride is dissolved in water, it's very costly to remove it.

Extremely high concentrations of chloride are found in urban streams in the watershed. Some stream levels are in excess of 1,000 mg/L. The level to protect aquatic life is 120 mg/L for chronic, long-term exposure while levels above 640 mg/L would be acutely harmful.

Kitchener, Waterloo, Cambridge, Guelph and Brantford have been growing in size since the 1970s; a Statistics Canada showed how the urban 'footprint' for these cities has almost tripled in size since 1971[25]. With this growth, comes more roads, sidewalks, driveways and parking lots that require snow and ice management during winters.

Chloride levels are steadily increasing downstream of our urban areas since the 1970s. For example, the Speed River below the City of Guelph has high chloride levels due to the combined impact of road salt and high chlorides in wastewater discharges, likely from water softeners (Figure 17).

In addition to chloride, urban stormwater can carry nutrients and sediments from construction sites, roads and parking areas, lawns and gardens, and wastes from domestic animals and urban wildlife. It's thought to be an important nonpoint source of pollution in the central Grand River in the springtime and after large rainfall events. The Water Management Plan highlighted how little is known about the contribution of urban runoff to nutrient and sediment loading in the Grand River. A collaborative project was completed by the Region of Waterloo, cities of Waterloo and Kitchener, and the GRCA to explore whether current monitoring data can help to characterize urban stormwater in the larger river system. To see more information, check out the case study Urban Nonpoint Source Pollution in the Middle Grand River.

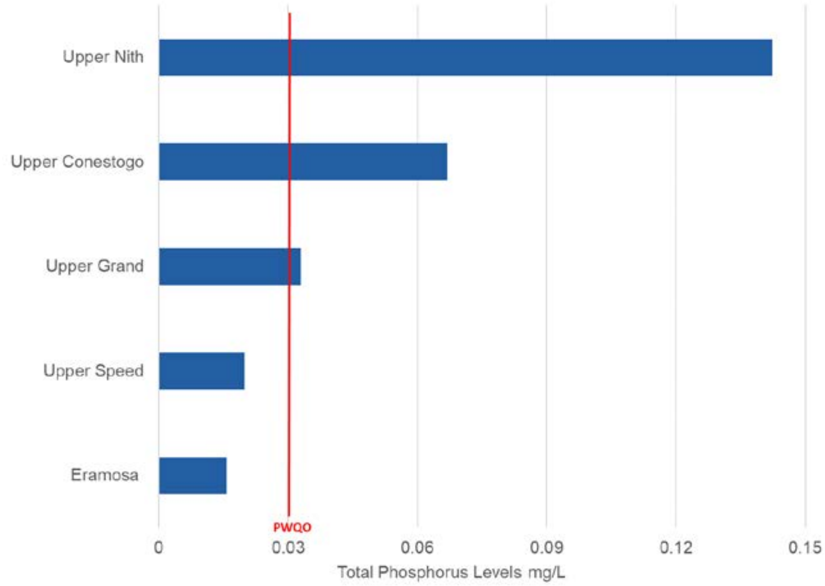

Figure 16. Total phosphorus concentrations (75th percentiles) from river sampling sites in the headwater region of the Grand River watershed. Pooled data from PWQMN sites, 2007-2018.

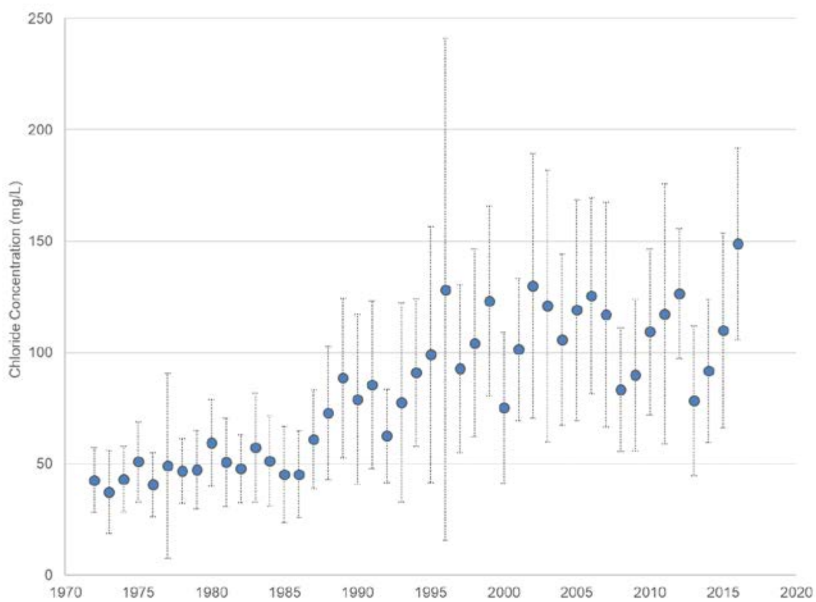

Figure 17. Annual average chloride concentrations (+/- standard deviation) in the Speed River at Wellington Road 32 since 1972. Chloride concentrations in the river appear to be increasing.

Additional insight can be gained from the case study on Blair Creek in which intensive monitoring over the last 10+ years was analyzed to determine if the urbanization of this catchment has been impacting the aquatic ecosystem. See Cumulative Effects Monitoring – Blair Creek Case Study.

Emerging contaminants

Pharmaceuticals and personal care products were identified as emerging contaminants of concern given the significant influence wastewater effluent has on the Grand River system. Research in the Grand River watershed showed increased concentrations of, for example, antiandrogenic personal care product triclosan, and pharmaceuticals such as Venlafaxine among others downstream of major wastewater treatment plants[26].

Research also showed that contaminants from wastewater treatment plants were found to produce endocrine disruptive effects that caused intersex in male fish[27]. The prevalence of intersex fish was quite high prior to the upgrades at the Kitchener wastewater treatment plant; however, following the major upgrades, the prevalence of intersex has declined[28].

Climate change

River water temperatures may also be at risk from a changing climate. Warmer air temperatures can lead to increasing water temperatures. Warming river temperatures can affect the thermal habitat of fish as temperature is a primary regulator of fish distribution. It also affects their metabolic rates and physiology. River temperatures also affect the dissolved oxygen levels in the river as warmer waters have less ability to hold oxygen. This may have implications to the assimilative capacity of the river system to receive additional wastewater effluent in the future. Increases in overnight water temperature in the river pose one of the greatest threats. Elevated overnight temperatures result in a reduced ability for the water to hold oxygen, the overnight period is when aquatic plants consume oxygen. The compounding effect of reduced ability for the water to retain oxygen and an over abundance of aquatic plants consuming oxygen can lead to overnight oxygen depletion or sags that impact the biological life in the river.

Preliminary analysis of continuous river temperature data at sites above, below and downstream of the central urban area of Waterloo, Kitchener and Cambridge show a heating effect on the Grand River. The greatest range and highest temperatures are downstream of the urban area at Glen Morris. Although temperatures are high (28°C) at Bridgeport, they reach an average maximum of 29.6 °C in Glen Morris and then fall back to average maximum of 27.7°C at the water quality station in Brant Park. Groundwater discharged through the exceptional waters reach between Paris and Brantford likely helps to mitigate the heating effects of the large urban area in the central part of the watershed. Groundwater discharge moderates river water temperatures over night and points of groundwater discharge can create important refuge areas for species that live in the river.

Moderating river water temperatures will become more important not only to the aquatic organisms living in the river system but also for the ability of the river to continue to assimilate wastewater effluents from the 30 wastewater treatment plants discharging into the river system.

About 10,000 km of rivers and streams are mapped within the watershed; about 50% are thermally classified by the Province. Only 17% of all classified streams are known to contain cold water fish species (e.g. brook trout, mottled sculpin) or have cold water restoration potential. With increasing air temperatures from a changing climate, there could be a shift in the thermal regimes of these streams. Protecting groundwater discharge functions and enhancing riparian vegetation along stream corridors becomes even more critical with a changing climate.

Regional groundwater

Aquifers

About 2.5 million people or 17% of Ontario residents rely on groundwater for their domestic water supply. In the Grand River watershed, groundwater usage is much greater, accounting for about 82% of the water supply and is the primary source of water for 37 municipal water systems. Largest population in Ontario reliant on an inland river system and groundwater for both water supply and waste water disposal.

Many different types of aquifers in the watershed provide water for both municipal and private water systems. Some aquifers are in overburden while others are in the bedrock. Overburden materials include sand, gravel and other unconsolidated sediment that is overtop of bedrock.

The Grand River watershed is home to three major moraine complexes which support overburden aquifers: the Orangeville Moraine in Dufferin and Wellington counties, the Waterloo Moraine in the western part of Waterloo Region, and the Paris-Galt Moraine in southern Wellington, eastern Waterloo and central Brant County.

An extensive overburden aquifer is located in the Norfolk Sand Plain, which occupies the western part of Brant County and the eastern part of Oxford County. The sand plain is an ancient river delta, made of material washed down the Grand River valley by melting glaciers. This aquifer is a source of water for many farms and homes in this part of the watershed.

The Gasport and Guelph Bedrock Formations in the eastern part of the watershed provide water used by the City of Guelph and other communities. The Salina Bedrock Formation, in the central and western portion of the watershed, is a source of water for the Regional Municipality of Waterloo.

Groundwater monitoring

Since 2002, the GRCA has maintained a regional groundwater monitoring program within the watershed. This program began in partnership with the Ministry of Environment, Conservation and Parks (MECP) as a part of the Provincial Groundwater Monitoring Network (PGMN), and has since expanded to include GRCA monitoring wells that are not a part of the provincial program.

The objective of long-term groundwater monitoring has been to monitor ambient groundwater levels and chemistry within the numerous aquifers across the watershed. Monitoring data produced from this network are baseline data used to support the Ontario Low Water Response Program, general condition reporting, climate change studies, source water protection studies, planning applications, and university research studies.

The GRCA maintains 56 regional monitoring wells in the watershed; 38 of which are part of the PMGN. Monitoring well locations are shown on **Figure 18**. For details regarding GRCA's groundwater monitoring, see the report: Regional Groundwater Monitoring within the Grand River Watershed.

Since 2000, the Ministry of Environment, Conservation and Parks has a long-term provincial groundwater monitoring network across the province.

GRCA partners with the Ministry to collect data from these wells.

Currently, there are 38 long-term groundwater monitoring wells in the watershed

Groundwater Recharge, Discharge, and Consumption

The flow of groundwater tends to follow surface topography, flowing from areas of higher elevation towards areas of lower elevation. Within areas of high elevation, surface waters tend to recharge the groundwater system, and in areas of low elevation, groundwater discharges to surface water features providing baseflow to streams and wetlands.

In the watershed, the majority of groundwater recharge occurs through surface water infiltration to the groundwater system. Significant amounts of recharge occur throughout the central portion of the watershed within the Waterloo, Orangeville, and Paris-Galt moraine complexes and the Norfolk sand plain to the southwest. Within the bedrock aquifers, in addition to surface water recharge, groundwater flows into the watershed from the north and flows to the south towards Lake Erie.

Groundwater discharge provides baseflow and cold water habitat to numerous streams and wetlands within the Eramosa subwatershed, Region of Waterloo, Brant County, and Oxford County. Many streams associated with moraines are groundwater- or spring-fed streams, which support sensitive aquatic species such as brook trout.

Groundwater, in addition to supporting natural heritage features, also supports a large percentage of water takings in the watershed. These takings provide water for municipal, domestic, agricultural, and industrial use. With an increase in population, changing climate, and more intense agricultural operations, this puts additional stress on the groundwater resources.

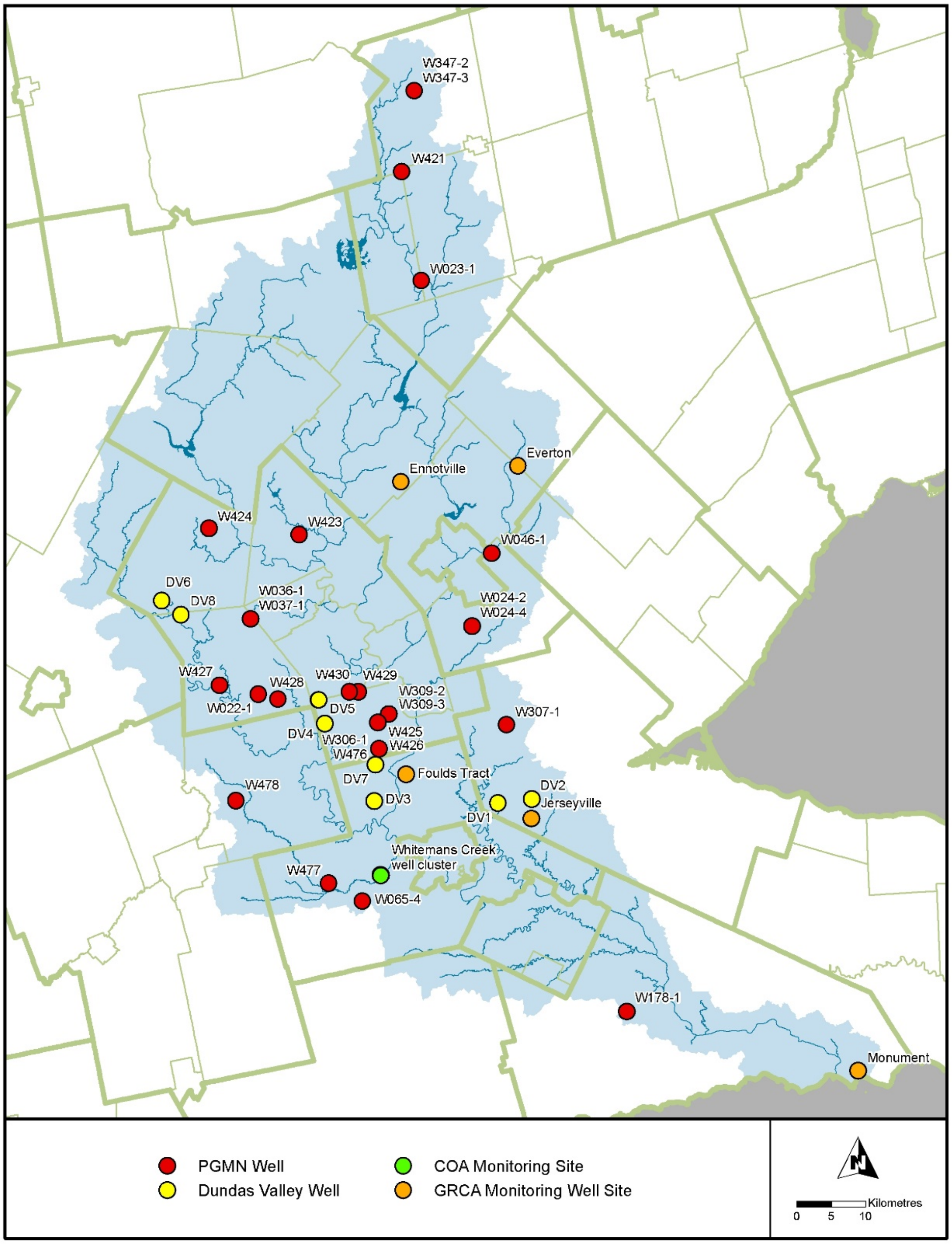

Figure 18. GRCA and PGMN monitoring well locations within the Grand River Watershed.

Conflicts in groundwater use exist within the City of Guelph and Township of Guelph-Eramosa, the Township of Centre Wellington, and County of Brant/ Oxford County areas because of competing needs for the resource.

Within the City of Guelph, Township of Guelph-Eramosa, and Township of Centre Wellington, groundwater is used for municipal supply and for industrial operations such as aggregate extraction, manufacturing, and food and beverage industries. Within the Counties of Brant and Oxford, extensive areas of agricultural land within the Norfolk Sand Plain are irrigated for crop production which competes with the groundwater needed to support the cold water brook trout population in Whitemans Creek. Increased tensions between municipalities, industries, and the farming community call for broader scale water management to help resolve local water use conflicts.

Source Protection Groundwater Studies

With the enactment of the *Clean Water Act*, 2006, numerous technical studies began in the Grand River Watershed to delineate quality and quantity-based Wellhead Protection Areas for municipal water supplies as a part of the Lake Erie Region Source Protection Program. This work included the development of detailed numerical groundwater flow and surface water models. In addition to the delineation of Wellhead Protection Areas for municipal wells, this work greatly increased the local understanding of groundwater recharge, flow, and availability in the watershed. Figure 19 shows the location of source protection numerical groundwater models in the watershed.

Since their development, a number of these models have been used as the basis for subwatershed studies and secondary plan assessments, and used in the development of water supply master plans in the Region of Waterloo, City of Guelph, and Township of Centre Wellington.

Water Budget Studies

A watershed-wide water budget study was completed for the Grand River Watershed in 2009 (AquaResource, 2009) through the Lake Erie Region Source Protection Program. The objective of this water budget study, also referred to as a Tier 2 water budget study, was to:

1. Evaluate current and future surface and groundwater takings within each subwatershed and groundwater assessment area; and
2. Classify each area as having low, moderate, or significant potential for stress related to water takings.

The study highlighted the need to evaluate the central Grand River region, Speed-Eramosa subwatershed area, and Whitemans Creek subwatershed as having potential water quantity stress.

These three areas moved onwards to complete local Tier 3 water budget studies. These were completed within the Region of Waterloo, City of Guelph and Township of Guelph-Eramosa, Centre Wellington, and County of Brant /Oxford County/ Whitemans Creek subwatershed.

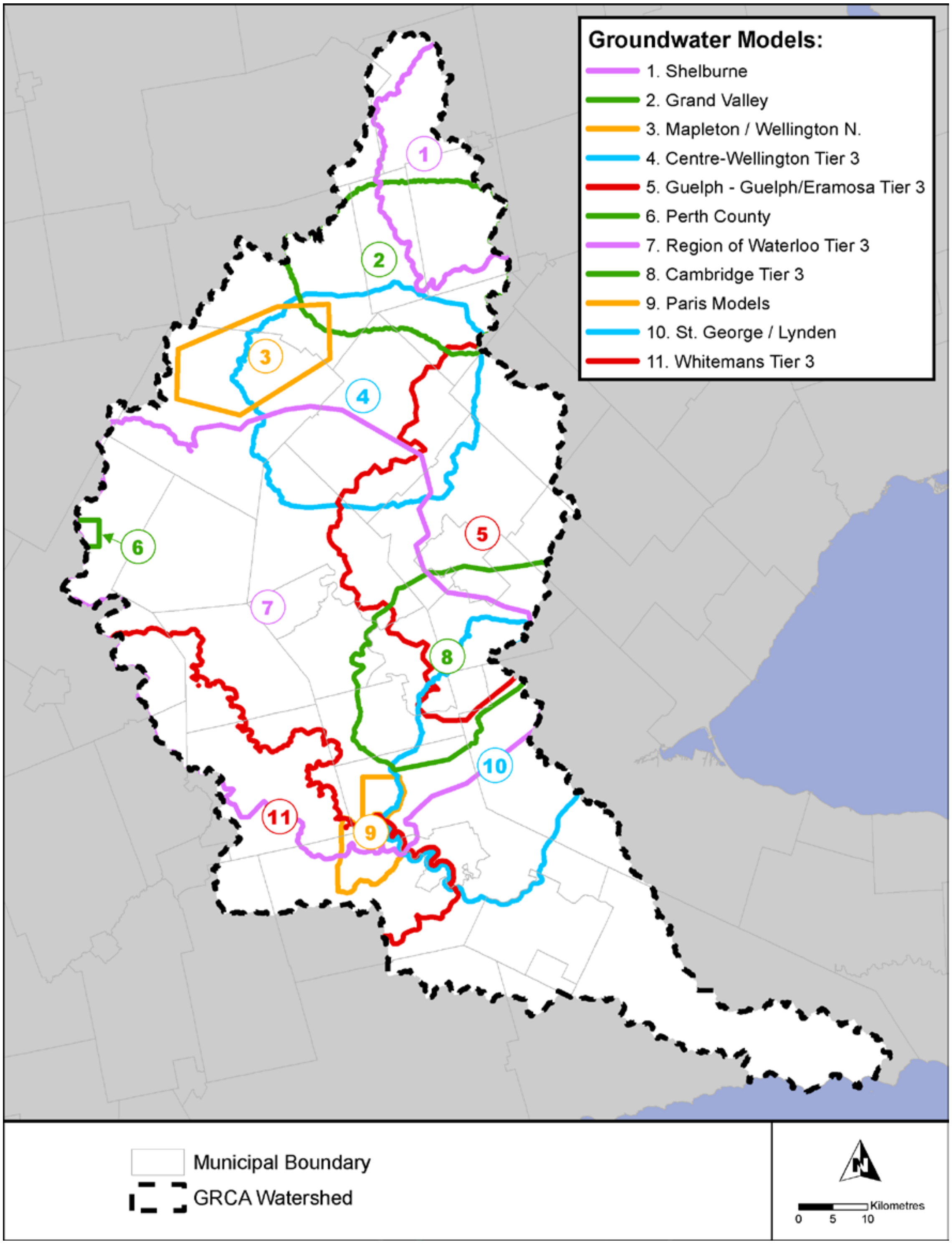

Figure 19. Model domains for numerical groundwater flow models completed as a part of the Lake Erie Region Source Protection Program within the Grand River Watershed.

Tier 3 Assessments evaluate whether a municipality is able to meet their current and future water demands. The assessments estimate the likelihood that a municipal system can sustain pumping at their future pumping rates, while accounting for the needs of other water uses such as cold-water streams, or other permitted water takers in the area. Tier 3 Assessments consider current and future municipal water demand, future land development, drought conditions, and other water uses as part of the evaluation.

For a more detailed summary of the Water Budget studies in the Grand River watershed, see the Technical Memo: Summary of Water Quantity Assessments in the Grand River Watershed.

The Tier 3 water budget studies indicate that municipal groundwater supplies are sustainable, provided there is effective water management.

In Tier 3 study areas, municipalities, residents and other water users will require proactive water conservation and efficiency, along with water demand and water supply management actions, local water management (subwatershed) plans and source protection policies to ensure sustainable future water supplies.

Groundwater quality

Naturally occurring parameters such as fluoride and arsenic can be elevated in some groundwater within the Grand River watershed. Other naturally occurring non-health related parameters such as hardness, iron, zinc, sulphate and manganese, which can influence taste or form deposits on pipes, can be elevated as well. Parameters such as these are reflective of the substrate the groundwater has flowed through and the relative residence time of the groundwater in the flow system.

Anthropogenic activities such as the use of road salt (chloride), septic systems, fertilizer (nitrate), and industrial or legacy contamination can also impact groundwater quality if not properly managed.

Groundwater quality is also affected by the local geology. There are areas in the watershed with high salt and sulphur content, such as in the Halidmand Clay plain area. These groundwater deposits are of poor quality.

Chloride

The application of road salt (sodium chloride) is a common activity across the watershed during the winter to mitigate icy road conditions. Chloride is soluble and highly mobile in water. If left unmanaged, chloride and sodium from road salt can easily infiltrate into the ground, and recharge into the groundwater flow system. Once in the groundwater, chloride is not easily removed through treatment. The Ontario Drinking Water Quality Aesthetic Objective for chloride is 250 mg/L.

Figure 20 shows chloride concentrations sampled from private domestic wells (Hamilton et al., 2015) and municipal wells where chloride was identified as a drinking water Issue through the Lake Erie Region Source Protection Program. The results indicate that elevated chloride concentrations are notably increasing within urban areas of the Region of Waterloo, the City of Guelph, and Township of Centre Wellington.

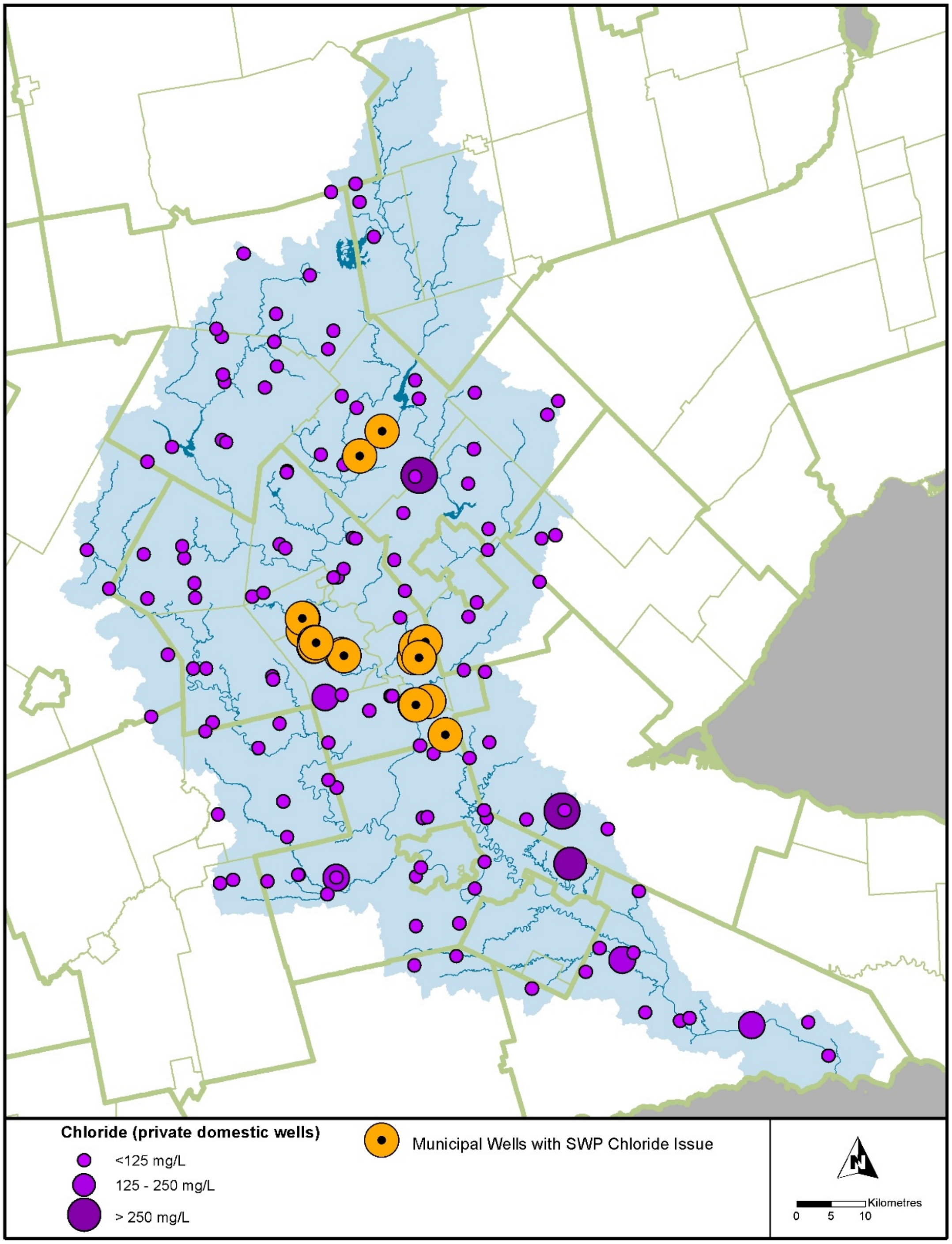

Figure 20. Chloride concentrations within private domestic wells, and municipal wells with a chloride issue identified through the Lake Erie Region Source Protection Program.

Nitrate

Approximately 62% of the Grand River watershed's landscape is in cropland. As such, nitrogen is applied directly to agricultural lands in the form of fertilizer. Excess nitrogen not removed from the soil by plants can either run off into surface water bodies, or infiltrate into the ground, eventually making its way to the groundwater system. The Ontario Drinking Water Quality Standard for nitrate is 10 mg/L.

Figure 21 shows nitrate concentrations sampled from private domestic wells (Hamilton et al., 2015) and municipal wells with an identified nitrate drinking water Issue through the Lake Erie Region Source Protection Program. These results highlight the rural nature of nitrate impacts to groundwater. In municipal wells, nitrate was identified as an issue within the rural areas of the Region of Waterloo, Guelph, and Brant County.

Generally, nitrate concentrations are quite low across the watershed especially in the deeper bedrock wells. However, localized impacts occur in agricultural areas with shallow unconfined aquifers where nitrogen is applied to the land and can be high in areas where septic systems are concentrated such as rural subdivisions,

Although nitrate can be removed from drinking water through treatment, it can be an expensive process and not always feasible.

Legacy contaminants

Legacy contamination continues in some localized areas of the watershed. It reflects the history of the region when much of the economy was driven by manufacturing. Contaminants include volatile organic carbon, phthalates, trichloroethylene, polychlorinated biphenyls, trichloroethylene, n-nitrosodimethylamine, chlorobenzene, ammonia and pesticides such as DDT and Lindane.

Identified contaminated sites have remedial plans with the Ministry of Environment, Conservation and Parks.

In the Grand River watershed, TCE has been identified as a Drinking Water Issue at 6 municipal wellfields across the Region of Waterloo, City of Guelph, and Township of Centre Wellington, as shown in Figure 22.

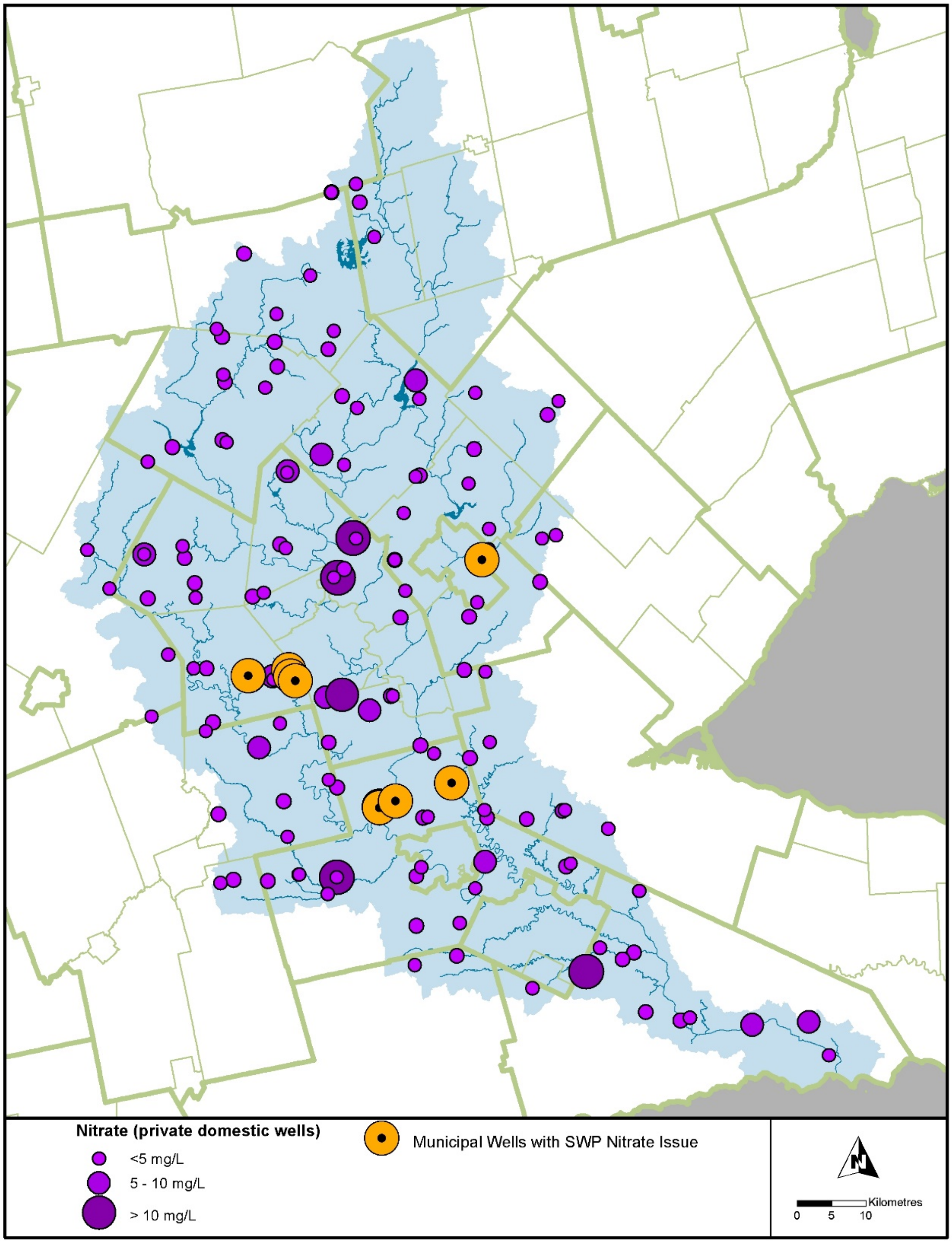

Figure 21. Nitrate concentrations within private domestic wells, and municipal wells with a nitrate issue identified through the Lake Erie Region Source Protection Program.

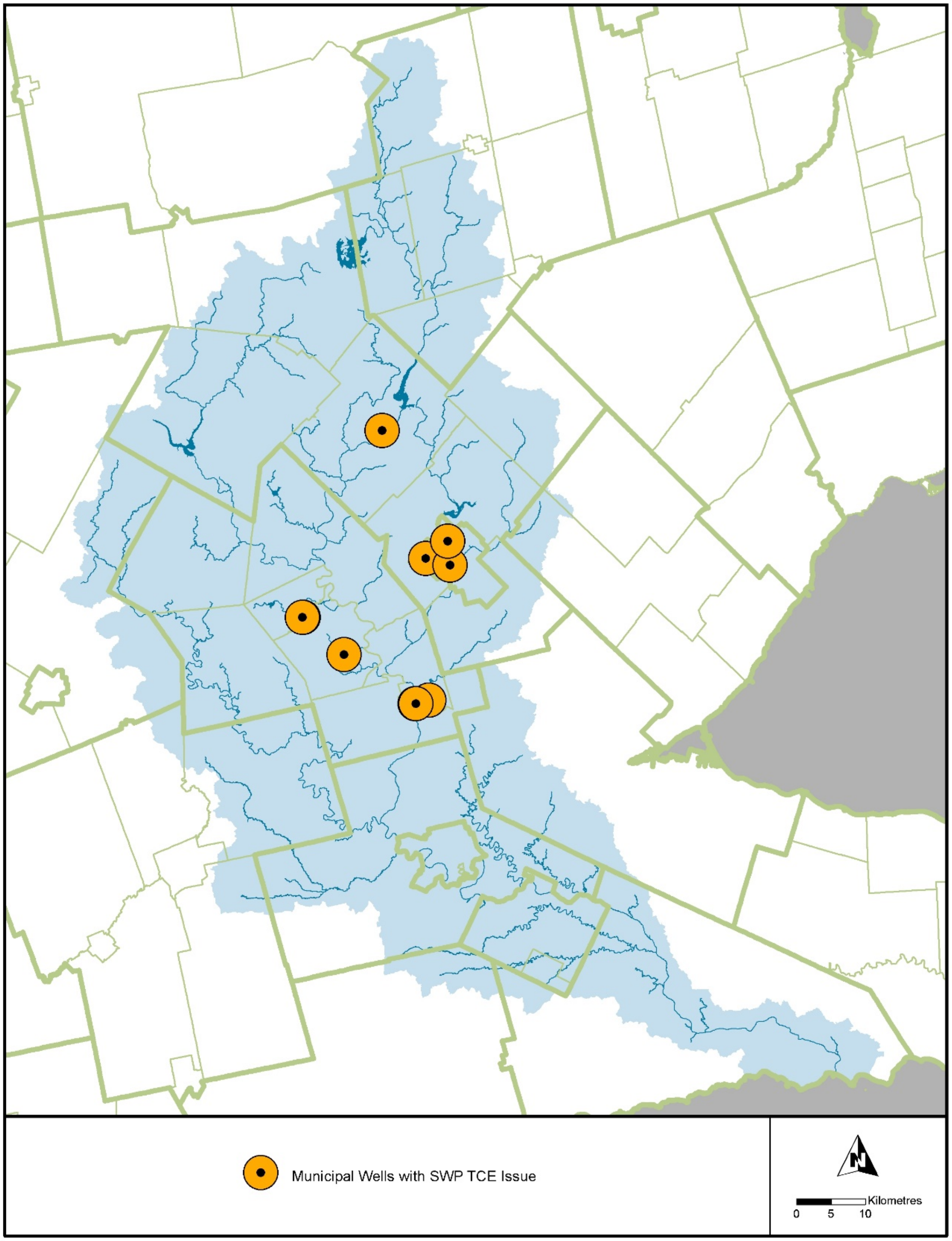

Figure 22. Municipal wells with a TCE issue identified through the Lake Erie Region Source Protection Program.

The Grand River - Lake Erie connection

The Grand River is the largest tributary that discharges into the eastern basin of Lake Erie. Recently, the Lake Erie Action Plan (2018) highlighted that the Grand River contributes 54% of the total phosphorus load to the eastern basin, which averages about 373 tonnes of total phosphorus annually.[29]

One study showed that there is a zone of influence of the Grand River on the nearshore area of the eastern basin of Lake Erie and tends to be east of the mouth due to the prevalence of eastward alongshore currents[30]. Other studies have shown that the concentration of total phosphorus in the river's plume can be as much as 10 times higher than in the offshore water concentrations of the eastern Lake Erie basin[31]. The high nutrients in the river plume is hypothesized to contribute to the nuisance Cladophora along the nearshore; however, scientists still are uncertain how invasive mussels in the nearshore and the off-shore lake phosphorus levels are contributing to the phosphorus cycling in the nearshore.

The Progress Report of the Parties (2019) on the status of actions to improve the Great Lakes indicated that the status of the algae *Cladophora* along the eastern basin of Lake Erie's north shore is poor [32] and phosphorus levels in and around the mouth of the Grand River as it empties into Lake Erie are high. Research is still on going in 2019 to determine the link between the Grand River's plume, the role of zebra and quagga mussels and the algae growing along the north shore[33] and as such, there is no phosphorus load reduction target developed for the Grand River.

The Grand River below the Dunnville Dam is a large river mouth. There are extensive riverine wetlands both above and below the dam and the quality of the wetlands are poor[34]. In addition to low diversity of the aquatic plants, *Phragmites*, an invasive species, covers 11% of the wetland area[29]. Further, only 1% of the river's 311km length connects to the lake due to the Dunnville Dam[35]. Studies have indicated that the dam has dramatically degraded the physical and biological processes that link the river and the lake.

Environment and Climate Change Canada reports regularly on a number of sustainability indicators, including freshwater quality. The long-term monitoring site on the Grand River at the mouth near Dunnville has been part of this national reporting program since 2002[36]. They use the CCME's Water Quality Index to show a relative comparison among sites in the various jurisdictions. For the Grand River, they primarily use nutrient data and chloride, similar to GRCA reporting for all of the monitoring sites in the watershed but also include metals such as Nickel, Chromium, and Zinc. Since 2004, the Grand River at the mouth is ranked as 'marginal' meaning that many of the guidelines for nutrients, chloride and metals have exceeded guidelines with a frequency and magnitude that warrants this score.

Lake Erie water levels are not regulated by a physical structure and therefore it experiences natural fluctuations[37]. The US Army Corps of Engineers has a record of Lake Erie lake levels since 1918 (see Figure 23). Lake Erie had extremely high water-level peaks in 1929, 1952, 1973, 1986, and 1997, as well as extreme lows bottoming out in 1926, 1934, 1964, and 2003[36]. There is large variability in lake levels over time yet there appears to be a cyclical pattern of highs and lows. New record highs have been set in Lake Erie in 2019.

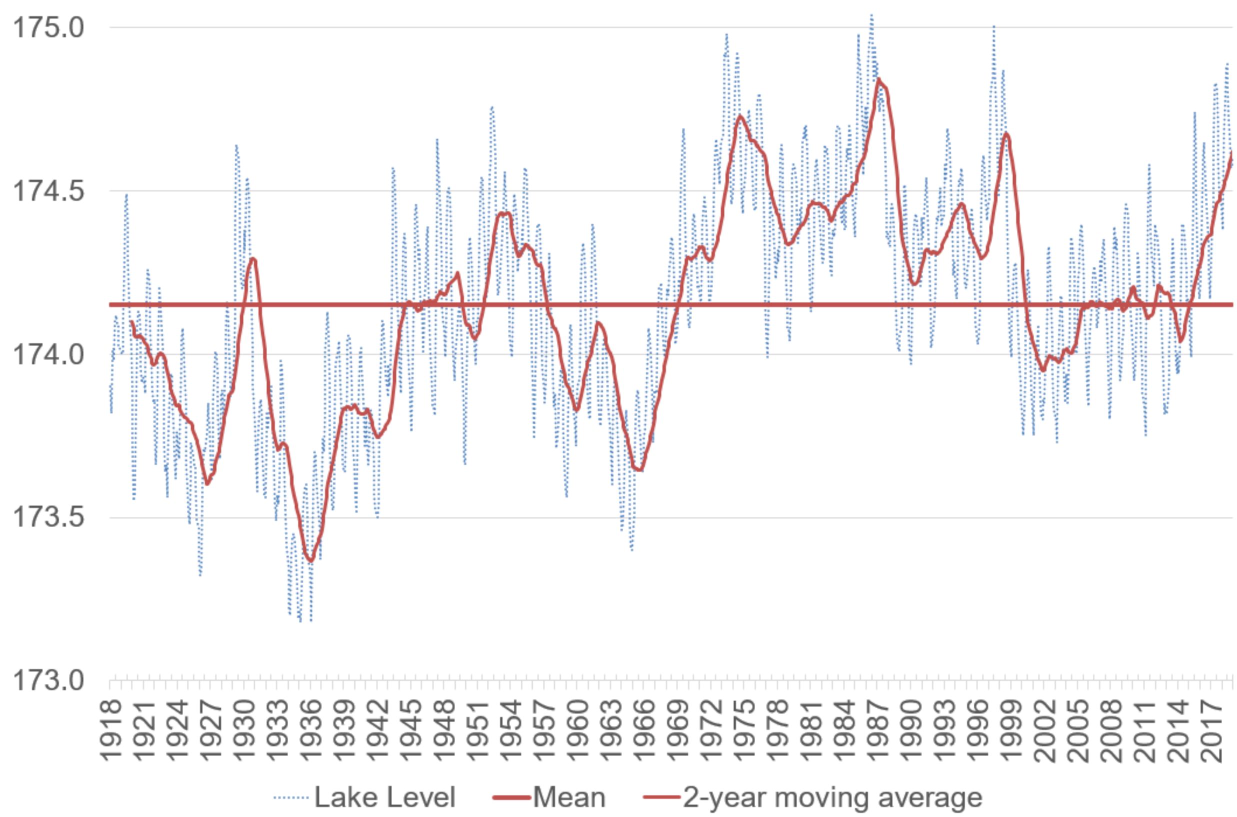

Figure 23. Long-term monthly mean lake-wide average water levels for Lake Erie. Data from US Army Corps of Engineers. https://www.lre.usace.army.mil/Missions/Great-Lakes-Information/Great-Lakes-Information-2/Water-Level-Data/

Building Resilience

Water is at the forefront of a changing climate. Warming temperatures affect the water cycle by evaporating and holding onto more water thus contributing to more intense rainstorm events. In addition, more evaporation also contributes to drier conditions resulting in droughts that can be more frequent. These changes in the water cycle require us to build resilience in our hard and soft infrastructure such as our built environment, our natural landscapes, and our collective capacity to learn and adapt to changing conditions.

The large multipurpose reservoirs were purpose-built for restoring a more naturalize hydrology in the Grand River watershed. This built infrastructure is a critical part of the form and function of the way water moves in the Grand River watershed. GRCA's commitment to the effective and efficient operation and maintenance of the dams and reservoirs in the watershed is a fundamental aspect of water management for the municipalities and ecosystems depending on the river system.

The natural infrastructure of the watershed is also a critical aspect that affects the water cycle. Landscape assets like moraine systems, hummocky topography and wetlands continue to keep water on the landscape and recharge groundwater aquifers. Maintaining and enhancing the natural infrastructure alongside the built infrastructure will help build resilience to deal with intense rainfall, and store valuable water in areas where people and nature need it.

For example, Figure 24 illustrates the range of flows generated per square kilometre (i.e. unit-area-flows) of select flood frequencies of some rivers in the watershed. Areas such as Blue Springs Creek and Eramosa have capacity to absorb water while Schneider's Creek, an urbanized system, and the upper Conestogo River have less capacity to absorb and keep water on the landscape. To build resiliency to deal with a changing climate, the areas with less capacity to absorb rainfall and snowmelt, should be a priority for restoration to regain a balance in the way water moves in the watershed.

Building and renewing landscapes that are more resilient is evident through many partner programs. Municipalities are improving stormwater management through targeted funding programs. Many of the watershed's older communities do not have infrastructure to manage rainfall and snowmelt. Investing in and retrofitting these areas is a start to rebuild resiliency in these areas. Moreover, stormwater managers are also recognizing and using natural infrastructure to optimize the management of storm water in our cities such a groundwater recharge areas and closed drainage areas for water storage.

Farmers and rural residents are building resilience into their land use practices by adopting cover crops and planting treed buffers along streams through programs such as the Rural Water Quality Program or Trees for Mapleton. According to data from Statistics Canada, the Grand River watershed outpaced the province with the number of farms adopting winter cover on fields[38]. Further, trees planted along rural creeks help stabilize banks and reduce erosion. This resiliency enables the streambanks to remain intact when storms deliver intense rainfall.

Shared learning is a key principle in resilience building[39]. Water is a shared resource that touches many agencies, and many managers within agencies. By working together and learning from one another, water managers can share best practices, which increases our collective capacity to deal with change. The Water Managers Working Group provides the network for the sharing of information and dialogue regarding water issues. Fundamental to this network is the support that GRCA provides to host and facilitate the peer-to-peer social learning. It provides the necessary support for regional collaboration.

Lastly, having a Water Management Plan for framing collective effort toward common goals helps to build resiliency in the water and land use planning communities. Since the 1970's, managers of water and wastewater utilities across the watershed have met to discuss water supply, water quality and flood damage reduction measures. This peer-to-peer network or *community of practice* enables the sharing of information and best practices. Moreover, the relationships forged through these meeting enables trust and understanding when issues cross municipal boundaries. Looking forward, a watershed Water Management Plan maintained and championed by the collective water, wastewater and land use planning managers across the watershed will continue to help build the capacity of the watershed to adapt to change.

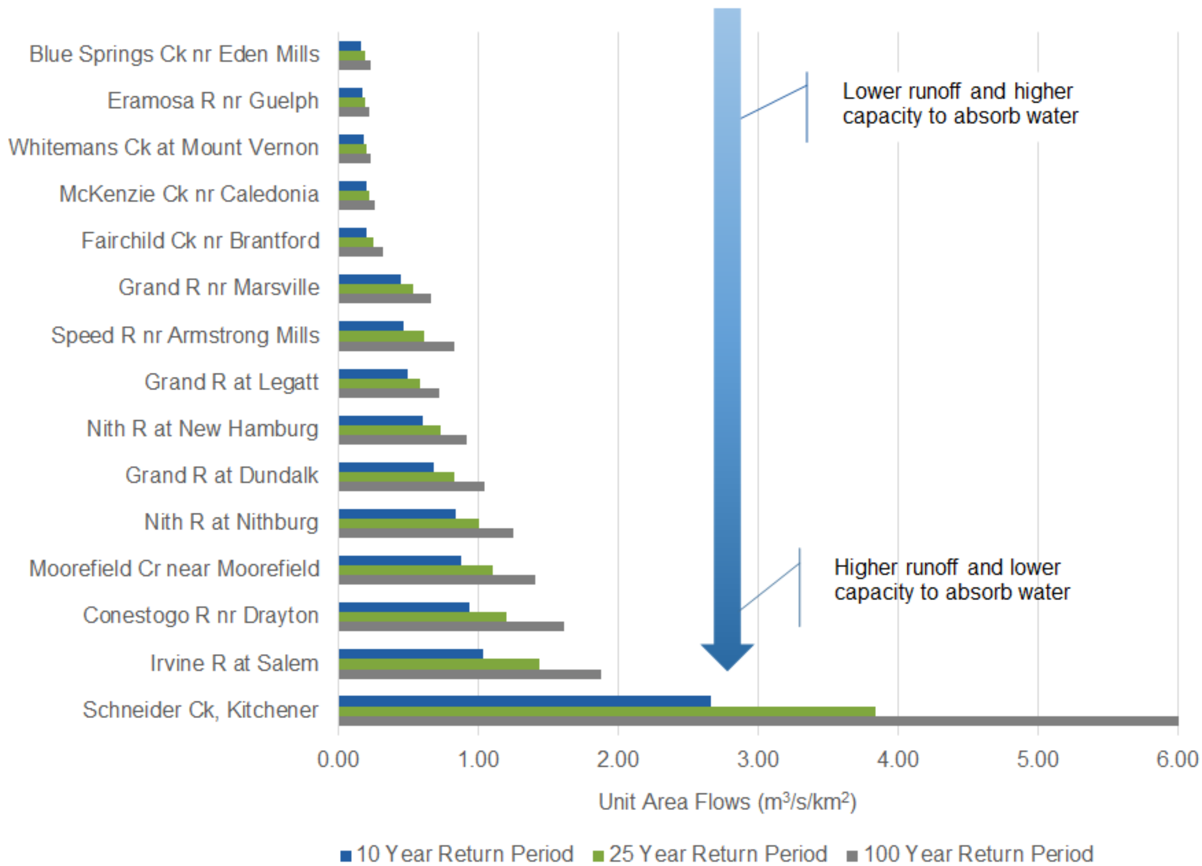

Figure 24. The range of unit-area-flows ($m^3/sec/km^2$) of select rivers in the Grand River watershed, which demonstrates the range of resiliency for keeping water on the landscape. Both the land cover and underlying geology contribute to the ability of the landscape to absorb water.

Supporting Reports

Supporting reports can be found at https://www.grandriver.ca/en/our-watershed/Studies-and-reports.aspx or by contacting the Grand River Conservation Authority at 519-621-2761

Report: The Grand River Watershed: Water Resource Systems

Report: Climate Trend Analysis

Report: Water Use Inventory for the Grand River Watershed, 2018

Report: 2014-2018 Summary of Accomplishments. https://www.grandriver.ca/en/our-watershed/resources/Documents/WMP/2019_06_18_IAP_FINAL.pdf

Report: Geology of the Grand River watershed. An Overview of Bedrock and Quaternary Geological Interpretations in the Grand River watershed https://www.grandriver.ca/en/our-watershed/resources/Documents/Groundwater/Watershed-Geology_March272019.pdf

Technical Memo: Climate Change Science Update. (draft)

Technical Memo: Summary of Population Statistics for the Grand River Watershed

Technical Memo: Spatial Relationship between Natural Heritage and Hydrologic Features

Technical Memo: Review of Flow Conditions – 2011 to 2017/8

Technical Memo: Flood Frequency Analysis.

Technical Memo: Land Cover and Land Use in the Grand River Watershed (DRAFT).

Technical Memo: Summary of the Status of Agriculture in the Grand River Watershed

Technical Memo: History of Low Impact Development in the Grand River Watershed

Technical Memo: Current water quality conditions in the Grand River watershed relative to the Water Management Plan benchmarks

Technical Brief: Winter 2014's Significant Snowpack. Grand River Conservation Authority.

Technical Brief: June 2017 Flood Event – Drayton, Grand Valley and West Montrose. Grand River Conservation Authority.

Technical Brief: February 2018 Ice Jam Event – Cambridge and Brantford. Grand River Conservation Authority.

Case Study: Urban Nonpoint Source Pollution in the Middle Grand River

Case Study: Cumulative Effects Monitoring – Blair Creek Case Study

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