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2.0 WATERSHED CHARACTERIZATION

Understanding the human and physical characteristics of the watershed is important to protecting and managing water. Interactions between surface water, groundwater and potential sources of contamination require an understanding of the physical characteristics of the bedrock and surficial geology, physiographic regions, climate and significant natural features within the watershed. Additionally, how the people of the watershed interact with these physical characteristics plays an ever-increasing role in determining overall health of the ecosystem. The following sections are intended to provide information on the physical and human characteristics of the Grand River watershed.

2.1 Lake Erie Source Protection Region

In an effort to share knowledge and resources for the purposes of developing source protection plans, a partnership was formed in 2004 between the Grand River, Long Point Region, Catfish Creek and Kettle Creek Conservation Authorities to form the Lake Erie Source Protection Region. The partnership was formalized in 2007 by Ontario Regulation 284/07 (Source Protection Areas and Regions) under the *Clean Water Act, 2006*. The Grand River Conservation Authority, referred to in the regulation as the Grand River Source Protection Authority, acts as the lead source protection authority for the region.

Map 2-1 shows the territory covered by the Lake Erie Region, including municipal boundaries, and main rivers and tributaries. The four Source Protection Authorities agreed to jointly undertake research, public education, and watershed planning and management for the advancement of drinking water source protection for the respective watersheds. The watersheds have a long history of partnership and cooperation, and also have a natural association by containing the majority of inland rivers and streams flowing from Ontario directly into Lake Erie.

Combined, the Source Protection Region represents a diverse area, ranging from intense agricultural production to large, and rapidly expanding urban areas. The region spans an area from the City of St. Thomas in the west, to Halton Hills on the east, and as far north as Dundalk. The area includes, in whole or in part, 39 upper, lower and single tier municipalities, as well as two First Nations communities (Glauser et al., 2008).

2.2 Grand River Source Protection Area

The Grand River watershed covers an area of approximately 6,800 square kilometres in south-central Ontario, and contains 39 upper-, lower- and single-tier municipalities, as listed in **Table 2-1**, and two First Nations bands, as listed in **Table 2-2**. The watershed contributes about ten percent of the drainage to Lake Erie. The length of the Grand River itself is 300 kilometres, while the average width of the watershed is 36 kilometres. **Map 2-2** shows the boundaries of the Grand River watershed, along with subwatersheds (**Map 2-3**) and the municipalities it contains.

Surface elevation in the watershed ranges from 173 metres above sea level at the mouth of the Grand River on Lake Erie, to 535 metres above sea level in the northern headwaters. The major tributaries of the Grand River include: the Conestogo and Nith, draining the western half of the watershed; and the Speed, which drains the north-east. Several smaller tributaries drain the southern half of the watershed. The largest of these include the Fairchild, Whitemans and McKenzie creeks.

The Grand River watershed has a long history of settlement that has drastically altered the landscape and impacted surface water and groundwater quality and quantity. Settlement areas of the Grand River watershed are shown in **Map 2-4.**

Table 2-1: Municipalities in the Grand River Source Protection Area

Upper/Single Tier Municipality	Lower Tier Municipality
Grey County	Township of Southgate
Dufferin County	Township of Melancthon
	Township of Amaranth
	The Town of Grand Valley
	Township of East Garafraxa
Wellington County	Township of Wellington North
	Township of Mapleton
	Township of Centre Wellington
	Township of Guelph-Eramosa
	Town of Erin
	Township of Puslinch
City of Guelph	
Region of Waterloo	Township of Woolwich
	Township of Wellesley
	Township of Wilmot
	City of Waterloo
	City of Kitchener
	City of Cambridge
	Township of North Dumfries
Region of Halton	Town of Milton
	Town of Halton Hills
County of Perth	Township of North Perth
	Township of Perth East
County of Oxford	Township of East Zorra-Tavistock
	Township of Blandford-Blenheim
	City of Woodstock
	Township of Norwich
City of Hamilton	
County of Brant	
City of Brantford	
County of Norfolk	
County of Haldimand	

Table 2-2: First Nations Reserves in the Grand River Source Protection Area

First Nation	Reserve
Six Nations of the Grand River Territory	Reserve No. 40
Mississaugas of the New Credit First Nation	Reserve No. 40A

2.3 Population, Population Density and Future Projections

According to the 2016 Statistics Canada Census, the Grand River Source Protection Area had a population of approximately 994,000 people. **Table 2-3** shows the breakdown of the population in each municipality for the area that falls within the Grand River Source Protection Area boundaries. The Counties of Grey, Dufferin, Wellington, Perth, Oxford, and the Regions of Halton and Waterloo have been left off of this table because the populations are broken down into the lower tiers. **Table 2-3** also summarizes the 2041 and 2066 population projections by municipality. The 2041 projections are based on municipal population projection estimates from municipal official plans, master servicing plans or other municipal documents, where applicable. The same growth rates and assumptions used for the

2041 projections were applied for the period up to 2066 to estimate the 2066 projections. Where updated projections were not available, the growth rate from the 2010 Population Forecasts report (GSP, 2010) were applied to the 2016 population and extrapolated to the years 2041 and 2066. A detailed summary of population and population projections in the Grand River Source Protection Area is provided in the technical memorandum entitled *Summary of Population Statistics for the Grand River Watershed, August 2018*.

Table 2-3: Population and Population Projections in the Grand River Source Protection Area

Municipality/First Nation	2016 Population*	2041 Projection*	2066 Projection*
Township of Southgate	1,754	4,078	6,453
Township of Melancthon	1,306	1,493	1,718
Township of Amaranth	3,058	4,860	5,610
Town of Grand Valley	3,045	7,694	**7,694
Township of East Garafraxa	1,833	2,194	2,594
Township of Wellington North	5,294	7,118	8,148
Township of Mapleton	10,518	13,710	16,960
Township of Centre Wellington	29,037	52,310	74,735
Township of Guelph-Eramosa	13,240	14,575	15,750
Township of Puslinch	6,041	7,724	9,574
Town of Erin	4,033	*4,801	5,569
City of Guelph	135,748	193,733	255,683
Township of Woolwich	25,756	43,060	59,460
Township of Wilmot	21,120	32,820	43,620
City of Waterloo	126,083	155,320	193,620
City of Kitchener	240,219	361,500	466,500
City of Cambridge	133,818	196,840	248,940
Township of Wellesley	11,598	13,460	15,860
Township of North Dumfries	10,521	18,720	25,520
Town of Halton Hills	280	*467	467
Town of Milton	1,383	*1,423	1,423
Township of North Perth	73	*71	71
Township of Perth East	5,762	*6,554	7,346
Township of East Zorra-Tavistock	265	275	315
Township of Blandford-Blenheim	7,020	7,889	8,694
Township of Norwich	1,060	1,385	1,647
City of Woodstock	595	*683	788
City of Hamilton	16,605	*16,946	17,771
County of Brant	35,387	*46,381	58,406
City of Brantford	100,421	158,786	220,086
Six Nations of the Grand River / Mississaugas of the New Credit	13,687	*15,363	17,438
Norfolk County	1,781	*2,164	2,547
Haldimand County	28,254	41,520	68,846
Total	994,000	1,435,917	1,869,853

Source: Statistics Canada Census, 2016; Summary of Population Statistics for Grand River Watershed, GRCA, August 2018.
*where Municipal plans have not been updated, growth rate from the previous report was applied to the 2016 population to estimate 2041 population
** no growth estimates beyond current capacity of water supply system

Map 2-5 and **Table 2-4** illustrate the population density by Municipality/First Nation within the Grand River watershed area. The Counties of Grey, Dufferin, Wellington, Perth, Oxford, and the Regions of Halton and Waterloo have been left off of this table because the population densities are broken down into the lower tiers. As indicated, the central portion of the watershed is the most densely populated area with the Cities of Waterloo, Kitchener, Cambridge, Guelph and Brantford. The remaining areas in the watershed are mainly rural agricultural areas, and, as such, have lower population density.

Table 2-4: Population Density in the Grand River Source Protection Area

Municipality/First Nation	2016 Population Density (people/km^2)*	2041 Projected Population Density (people /km^2)*
Township of Southgate	38.31	89.06
Township of Melancthon	7.64	8.73
Township of Amaranth	14.01	22.26
Town of Grand Valley	18.71	47.29
Township of East Garafraxa	13.06	15.62
Township of Wellington North	15.97	21.47
Township of Mapleton	20.47	26.69
Township of Centre Wellington	69.83	125.79
Township of Guelph-Eramosa	44.68	49.19
Township of Puslinch	35.22	45.04
Town of Erin	24.82	29.54
City of Guelph	1543.99	2203.51
Township of Woolwich	78.21	130.76
Township of Wilmot	79.35	123.31
City of Waterloo	1932.02	2380.02
City of Kitchener	1736.94	2613.88
City of Cambridge	1156.49	1701.15
Township of Wellesley	41.64	48.33
Township of North Dumfries	55.43	98.62
Town of Halton Hills	53.57	89.29
Town of Milton	24.36	25.06
Township of North Perth	10.52	10.22
Township of Perth East	19.13	21.76
Township of East Zorra-Tavistock	9.09	9.44
Township of Blandford-Blenheim	20.13	22.62
Township of Norwich	19.79	25.86
City of Woodstock	143.46	164.58
City of Hamilton	55.39	56.53
County of Brant	51.64	67.68
City of Brantford	980.00	1549.59
Six Nations of the Grand River / Mississaugas of the New Credit	64.14	71.99
Norfolk County	22.66	27.54
Haldimand County	54.00	79.35

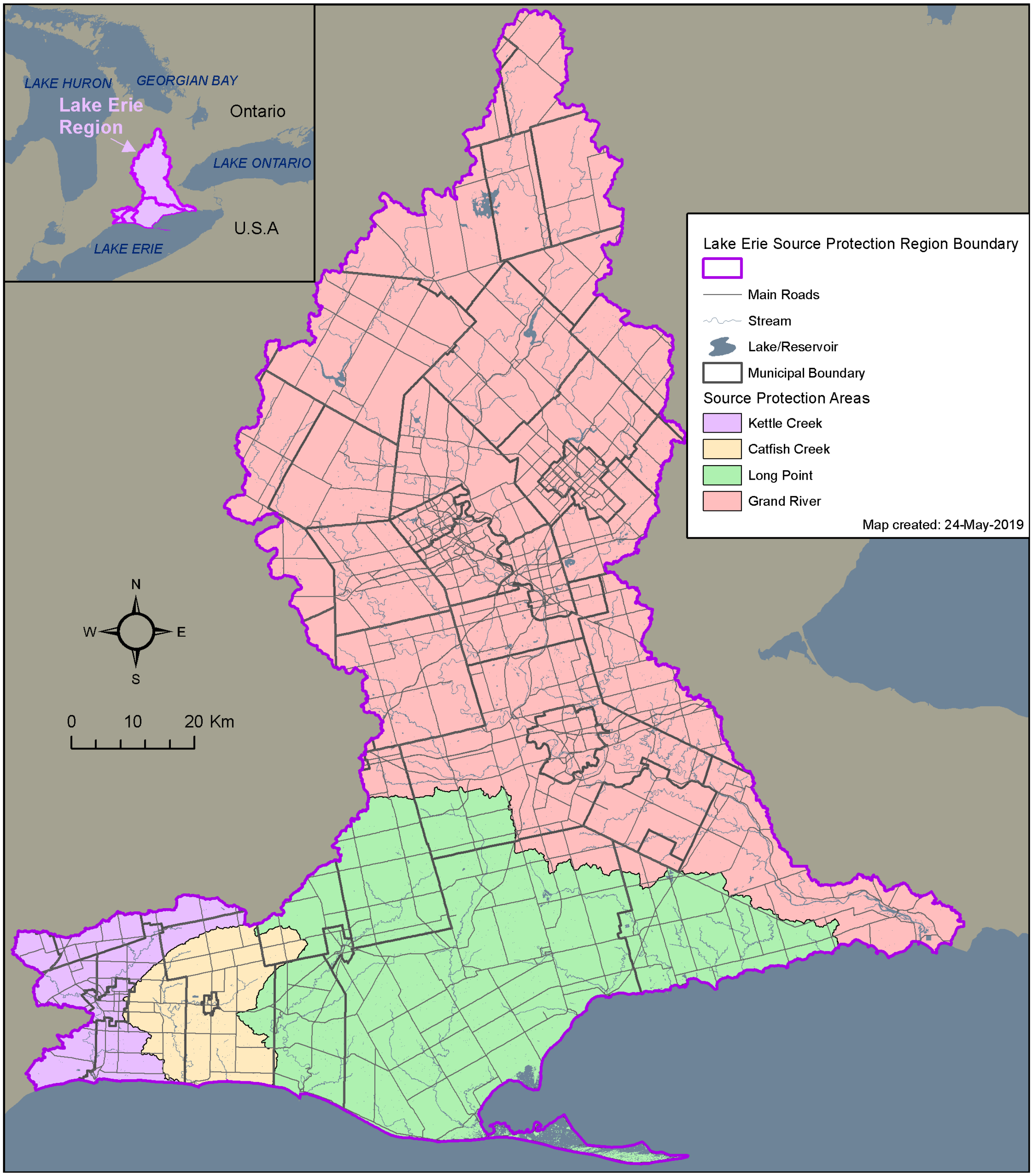
Source: Statistics Canada Census, 2016; Summary of Population Statistics for Grand River Watershed, GRCA, August 2018.
*Prorated to the area of the municipality that falls within the Grand River watershed.

The population of the watershed that receives municipal water supplies is 865,538. All groundwater and surface water municipal and First Nation supply systems are shown on **Map 2-6. Table 2-5** provides a breakdown of the serviced population by Municipality/First Nation for 2016. As indicated, approximately 87 percent of the total population in the watershed is serviced by municipal water supplies.

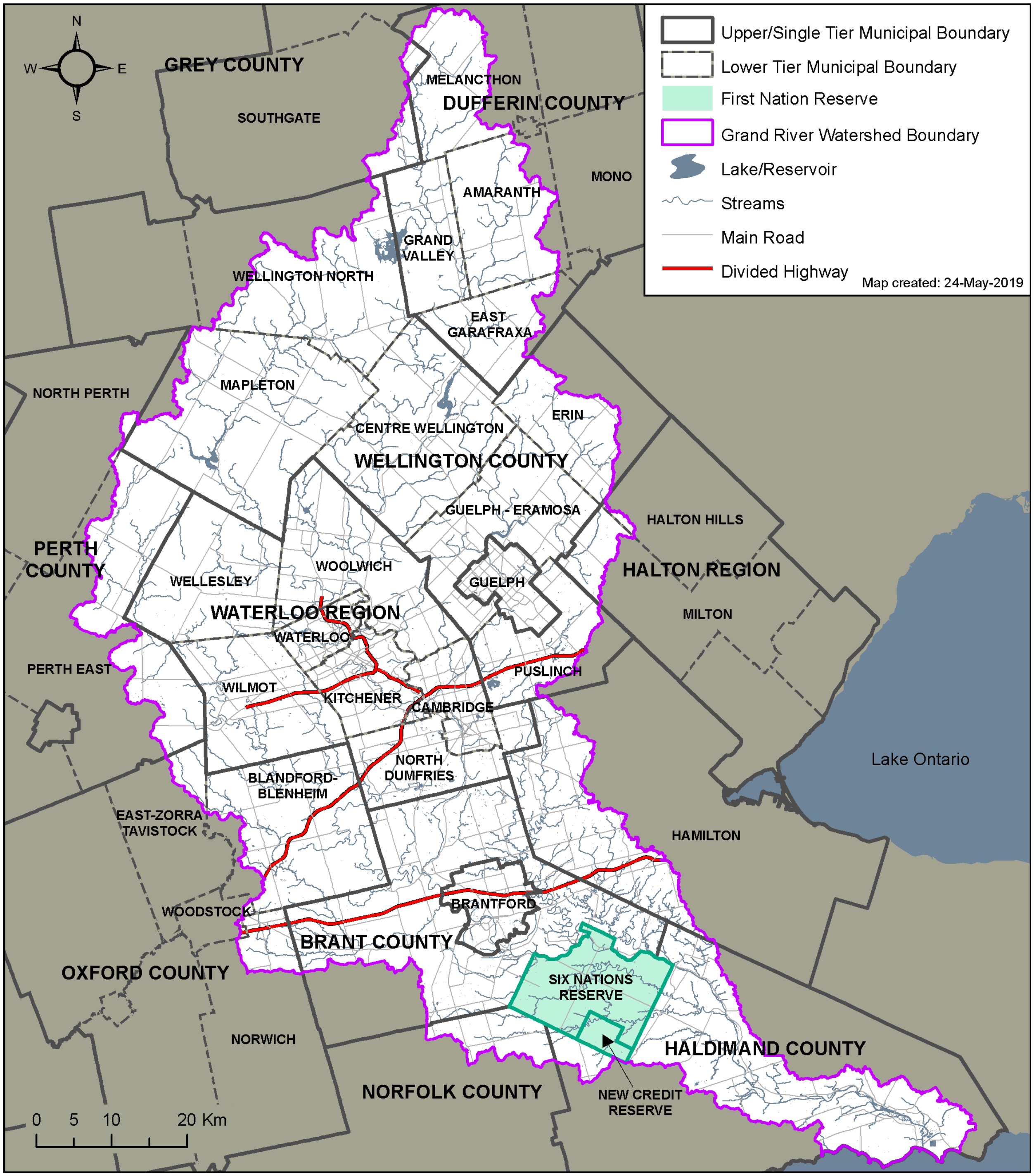
Table 2-5: 2016 Serviced Population by Municipality/First Nation in the Grand River Source Protection Area

Municipality/First Nation	2016 Population*
Township of Southgate	1,794
Township of Melancthon	0
Township of Amaranth	536
Township of East Luther-Grand Valley	2,228
Township of East Garafraxa	93
Township of Wellington North	2,333
Township of Mapleton	2,430
Township of Centre Wellington	19,300
Township of Guelph-Eramosa	4,561
Township of Puslinch	0
Town of Erin	0
City of Guelph	132,000
Township of Woolwich	14,798
Township of Wilmot	15,096
City of Waterloo	138,464
City of Kitchener	240,669
City of Cambridge	134,403
Township of Wellesley	5,451
Township of North Dumfries	5,598
Town of Halton Hills	0
Town of Milton	0
Township of North Perth	0
Township of Perth East	1,872
Township of East Zorra-Tavistock	0
Township of Blandford-Blenheim	3,482
Township of Norwich	0
City of Woodstock	0
City of Hamilton	**8,234
County of Brant	18,763
City of Brantford	96,000
Six Nations of the Grand River / Mississaugas of the New Credit	2,000
Norfolk County	0
Haldimand County	15,433
Total	865,538

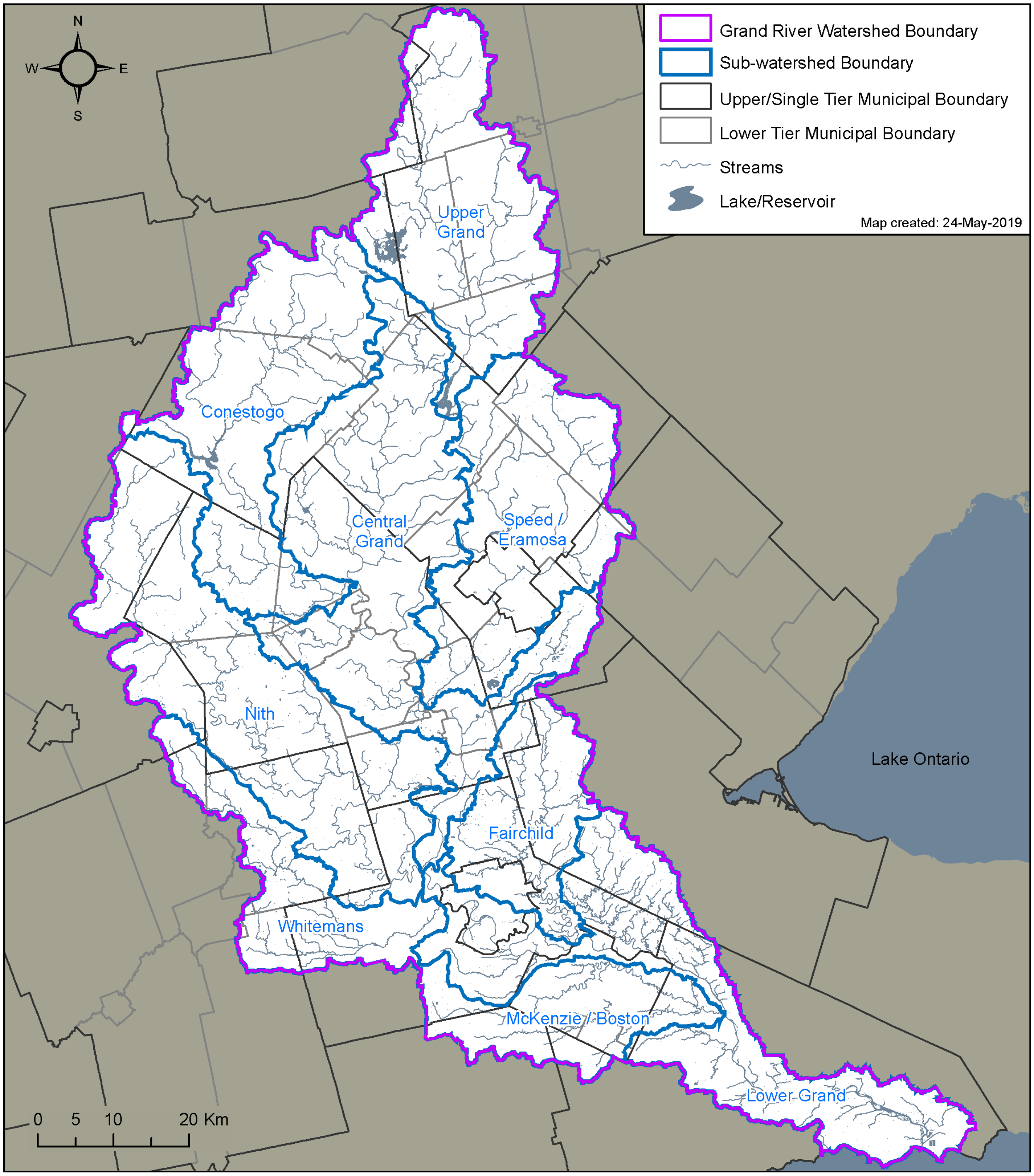
Map 2-1: Lake Erie Source Protection Region Boundary



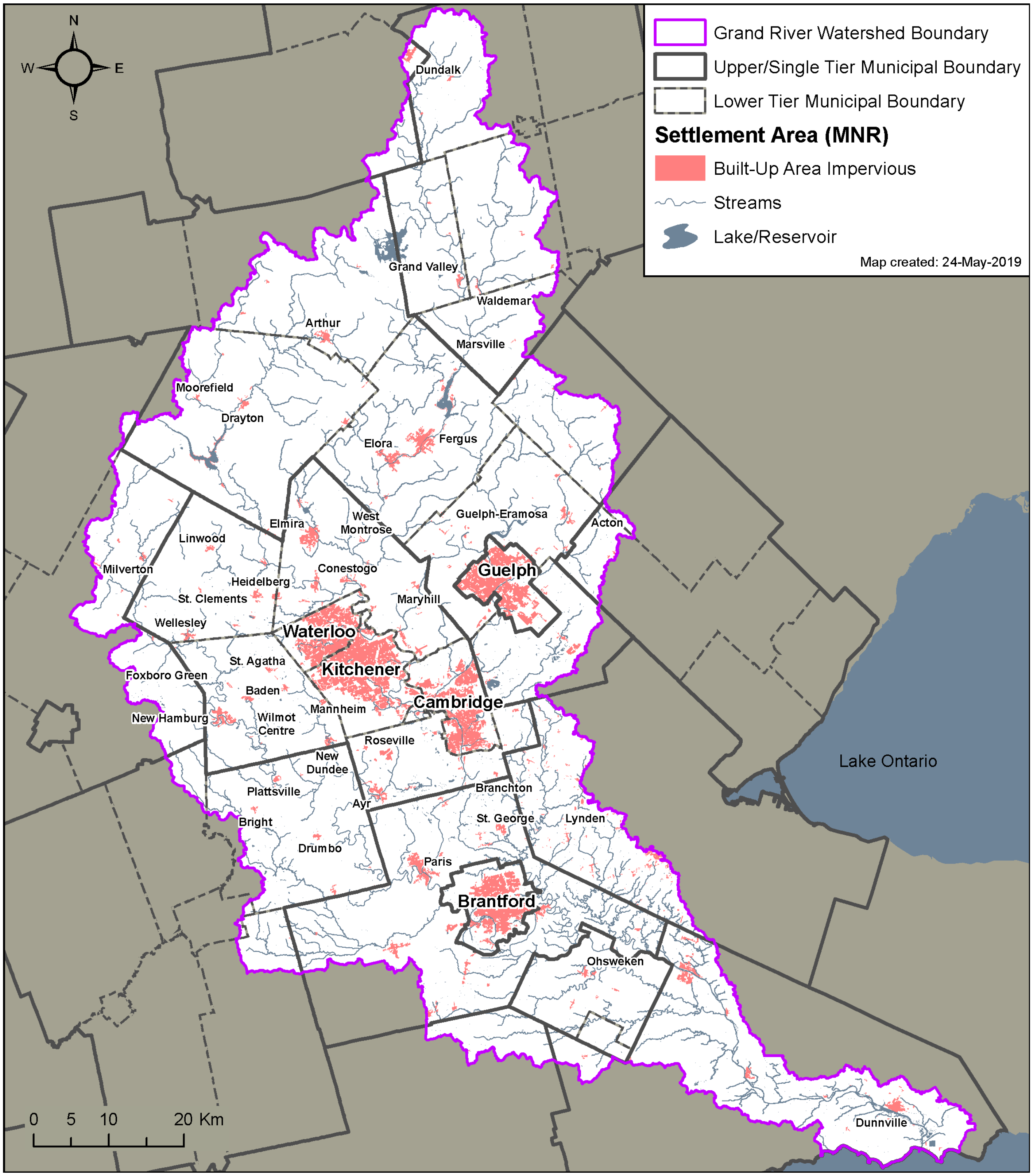
Map 2-2: Grand River Watershed Boundary



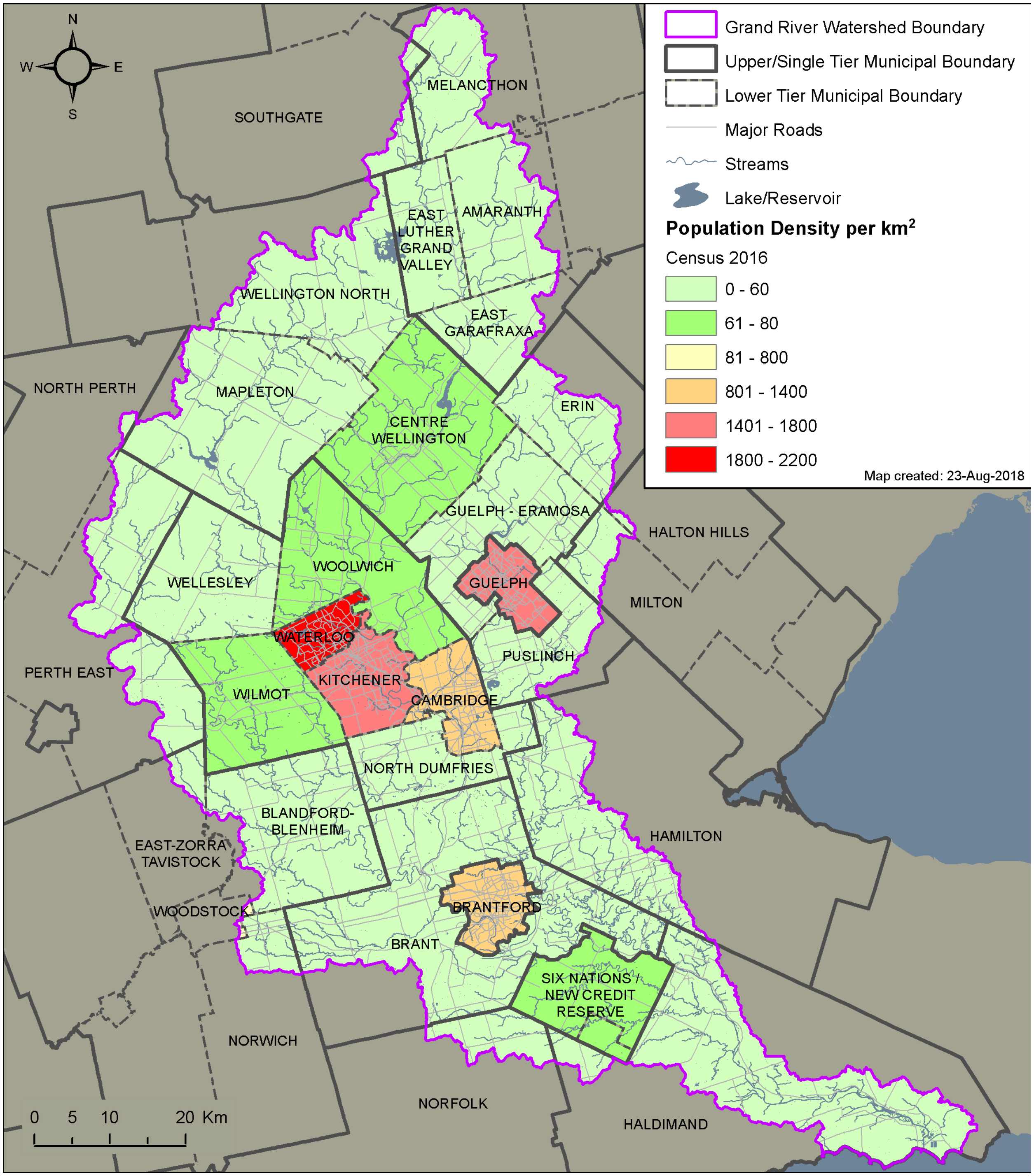
Map 2-3: Grand River Subwatershed Boundaries



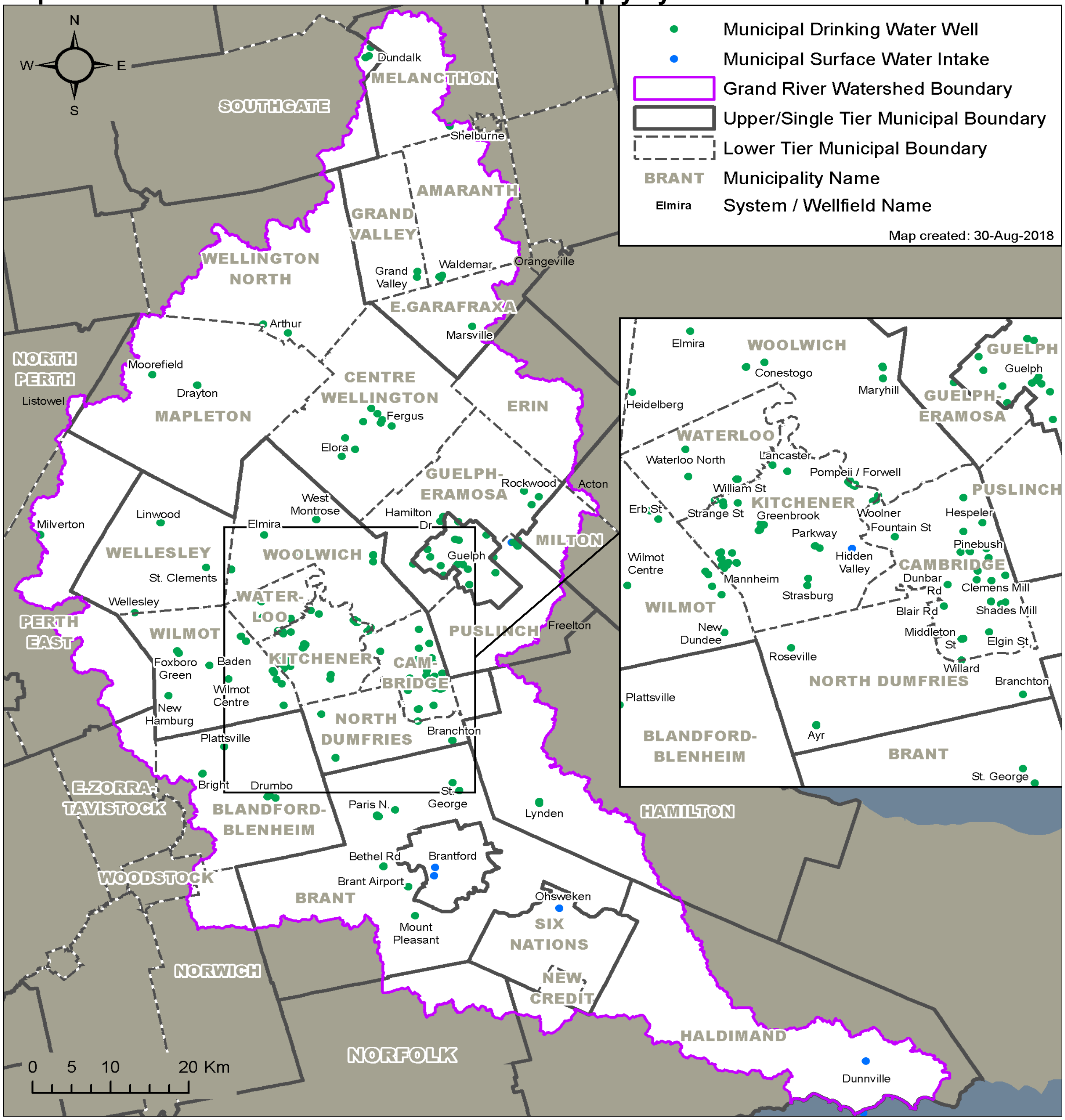
Map 2-4: Grand River Watershed Areas of Settlement



Map 2-5: Population and Population Density in Watershed by Municipality and Reserve in the Grand River Watershed



Map 2-6: Groundwater and Surface Water Supply Systems in the Grand River Watershed



2.4 Physiography

Physiography plays an important role in the hydrologic and hydrogeologic systems within the Grand River watershed. In total, there are 11 physiographic regions within the Grand River watershed, which are described by Chapman and Putnam (1984). The regions are described below, from north to south, and shown in **Map 2-7.**

2.4.1 Dundalk Till Plain

The Dundalk Till Plain, generally located north of County Road 109, is a major headwater area for the Grand and Conestogo Rivers. It includes most of Dufferin County and portions of the Townships of Wellington North and Mapleton.

The till plain is gently undulating and consists of a mix of clay, gravel, and boulders deposited by retreating glaciers. Elevations within the till plain range from 425 metres above sea level (m asl) to 530 m asl.

The till plain supports extensive wetland complexes, wet meadows, and agricultural land in four major source areas: Dundalk, Melancthon, Amaranth, and Keldon. An extensive network of agricultural drains and small watercourses which link the numerous wetlands drain the till plain.

Two large eskers and a series of small drumlins, which are located at the northwest boundary of the watershed, add considerable diversity to the habitat of the till plain. The western esker runs through the Keldon Swamp southeasterly to the north bog at Luther Marsh Wildlife Management Area.

Luther Marsh is a 5,679 ha complex of bog, marsh, mixed deciduous-coniferous swamp, upland deciduous forest, plantation, meadow and agricultural fields. The Luther Dam has created a lake-wetland area of about 2,000 ha.

The well-vegetated Horseshoe Moraine and Niagara Escarpment physiographic regions border the till plain on its east side. There is a noticeable transition from scarce natural vegetative cover along the west side of the till plain to extensive cover in the east.

2.4.2 Stratford Till Plain

The Stratford Till Plain is located to the south of the Dundalk Till Plain and includes parts of Dufferin County, Wellington County, Waterloo Region, and Perth County. This flat clay plain is wedge-shaped with its broadest sector in the west, between New Hamburg, Millbank, and County Road 109. The point is in the east, between Belwood and County Road 109. The terrain, which is generally level and often poorly drained, is characterized by silty, clay-rich soils. Artificial drainage has made this a rich and productive agricultural region and, as a consequence, only a small portion of the land remains in woodlot, marsh, or rough pasture.

Natural vegetative cover is more extensive in the east. The valleys of the Conestogo, Irvine, and Grand Rivers are deeply cut through the till plain. The headwater area of the Nith River, in the western sector, is very open and there is little wildlife habitat. Slightly better, covered drainage ditches and small watercourses are located to the east, in the northerly source area for the Speed River.

Conestogo Lake and the river’s valley lands in the Drayton area have the most extensive habitat. Between Glen Allen and Wallenstein, along the Conestogo River, there is a diverse valley forest accompanied by floodplain meadows.

2.4.3 Hillsburg Sandhills

In the Township of East Garafraxa and the Town of Erin, the Hillsburg Sandhills form a natural boundary on the southeastern flank of the Dundalk and Stratford Till Plains. The sandhills have a minimum elevation of 425 masl with some ridges reaching elevations of 490 masl.

This region is characterized by rough topography, sandy soils and swampy valleys. Agricultural use is limited due to topographical and drainage factors. The region is approximately 30% forested and much of the forest is composed of provincially significant swamps located in the valleys between the hills.

2.4.4 Guelph Drumlin Field

The watersheds of the Speed and Eramosa Rivers lie within the Guelph Drumlin Field which also includes the City of Guelph and parts of Wellington County and Waterloo Region. In this region there are approximately 300 drumlins, which are characterized as broad, oval shaped hills with low slopes.

The general landform pattern in the Guelph Drumlin Field consists of drumlins or groups of drumlins fringed by gravel terraces and separated by swampy valleys. Tributaries of the Grand River flow through these valleys. The dominant soil materials are the stony tills of the drumlins and deep gravel terraces.

This region has the most extensive network of forest habitat in the watershed. Large forests typically cover the valleys between the numerous hills and drumlins. The areas of lowest elevation are swamp and floodplain.

At the northwest corner of the drumlin field, in the Lutteral Creek watershed, there is swamp-upland forest known as the Speedside Forest. The Ariss woods are located on a significant esker and have importance due to size and botanical features. The Eramosa River Valley follows a lengthy glacial spillway from Brisbane to Guelph. The Brisbane Swamp, which is a major headwater area for the river, and the upper river valley, above Ospringe, are within the drumlin field. From Ospringe, the Eramosa River flows through the Horseshoe Moraine physiographic region to its confluence with the Speed River.

2.4.5 Horseshoe Moraines

As the name suggests, the Horseshoe Moraines region consists of a series of moraines surrounding much of southwestern Ontario. The “toe” of the horseshoe is at the north, near Georgian Bay. The moraines run roughly parallel to the Lake Huron shoreline on the west, Georgian Bay along the north, and the Niagara Escarpment to the east.

The eastern leg of the horseshoe runs along the eastern boundary and through the central part of the Grand River Watershed, from the Town of Erin in the north, past Guelph and Cambridge to Paris and Brantford in the south.

Some of this region is very hilly, often with steep irregular slopes and small enclosed basins which contain water in the spring and early summer, often referred to as kettles.

Two large moraines dominate the Horseshoe Moraines region: the Paris and Galt moraines (**Map 2-8**).

The Paris Moraine runs from Erin to Paris and then through the southwestern part of Brant County. South of Paris, the surface is sandy and to the north it consists of loose bouldery loam. Broad gravel terraces, often at one or more levels, with swampy stretches in the lowest one, can be traced along the length of the Paris Moraine. For part of its length, the moraine provides a channel for the Eramosa River.

The Galt Moraine runs parallel to and east of the Paris Moraine, never more than a few kilometres away and touching it in some places, such as near the City of Guelph. The soils are quite similar to the Paris Moraine as well: sandier in the region south of Brantford, and loose loamy till north of Brantford.

The Horseshoe Moraines region of the Grand River watershed has large sand and gravel deposits with many extraction operations in southern Wellington County, southern Waterloo Region, and northern Brant County.

The Horseshoe Moraines region is a very dynamic area and provides extensive habitat, including 5,000 ha of wetlands. Approximately 30% of the moraine region is forested, field sizes are slightly smaller, and fencerow vegetation is often very well developed. The region hosts a number of cold-water watercourses, including the Eramosa River and Mill Creek, which receive groundwater discharge. Groundwater discharge also feeds the Grand River itself, between Cambridge and Paris, providing a significant portion of its flow during summer months.

Groundwater discharge also affects soil formation and initiates wetland development on steep slopes.

2.4.6 Waterloo Hills

The Waterloo Hills region is located within the centre of the watershed, mostly within the Regional Municipality of Waterloo. This area is characterized by sand hills, gravel terraces, and many swampy valleys. The soils of the hilly areas are rich and well drained.

Water from precipitation infiltrates in the sand hills and discharges as groundwater to the headwater wetlands and source areas of the streams, creating fens, bogs, kettle lakes, swamps, marshes, and baseflow in streams.

The Grand River has cut its valley in a north-south direction through the eastern half of the region, and two of its major tributaries, the Conestogo and Speed, converge on the Grand in this area.

2.4.7 Flamborough Plain

The western side of the former Township of Beverly (now part of the City of Hamilton) lies within the Flamborough Plain. Shallow soils over bedrock in the Sheffield-Rockton area create areas of swamps, marshes, and bedrock outcrops. Soils are either wet or stony and shallow. The west end of the Beverly Swamp and the headwater area of Fairchild Creek are located in this region.

The 2000 ha Beverly Swamp is the third largest remaining interior wetland in Southern Ontario. There are relatively flat exposed bedrock plains in the Kirkwall-Rockton area.

2.4.8 Norfolk Sand Plain

The portion of the Norfolk Sand Plain in the Grand River watershed covers parts of Brant and Oxford Counties. The sands and silts of this region were deposited as a delta of the ancient Grand River when water from melting glaciers made its way south.

There are two parts in this plain region, one being west of the southern Horseshoe Moraine region, the other to the east.

The western portion covers the watershed from Ayr to Princeton and southerly to the watershed boundary in the vicinity of Scotland and Oakland. The western leg of the sand plain is drained by Whitemans Creek, which joins the Grand River near Brantford. There are also large wetlands near Falkland, Oakland and Burford. The headwaters of McKenzie Creek and Boston Creek are in this region.

Fairchild Creek and Big Creek drain the eastern portion of the Norfolk Sand Plain region, in the Peter's Corners, Ancaster, and Cainsville area. Wetlands in the Fairchild Creek watershed complex are important to this region. Most natural areas are small, fragmented, and narrowly sinuous along streams and steep slopes.

2.4.9 Oxford Till Plain

The Oxford Till Plain is located in the Plattsville, Drumbo, Princeton, and Woodstock area and is a source area for Black Creek and Whiteman-Horner Creek.

All of the blocks of natural habitat of any significant size are wetlands in this region. The Black Creek complex drains to the Nith River. The upper Whitemans Creek complex has a number of wetlands within it which are provincially significant. They include Chesney Bog, Pine Pond, Lockart Pond, Buchanan Lake, and Benwall Swamp. Soils and drainage in this region are considered to be good.

2.4.10 Mount Elgin Ridges

The Kenny Creek watershed is located in this northeastern tip of the Mount Elgin Ridges region which covers parts of Oxford and Brant Counties within the Grand River Watershed. The landscape is dominated by a succession of ridges composed of imperfectly drained clay or silty clay and hollows supporting alluvial swamps, along with deposits of sand and silt. The wetlands of the Kenny Creek watershed, which are mainly riparian swamps, are provincially significant and the creek supports a warm water fishery.

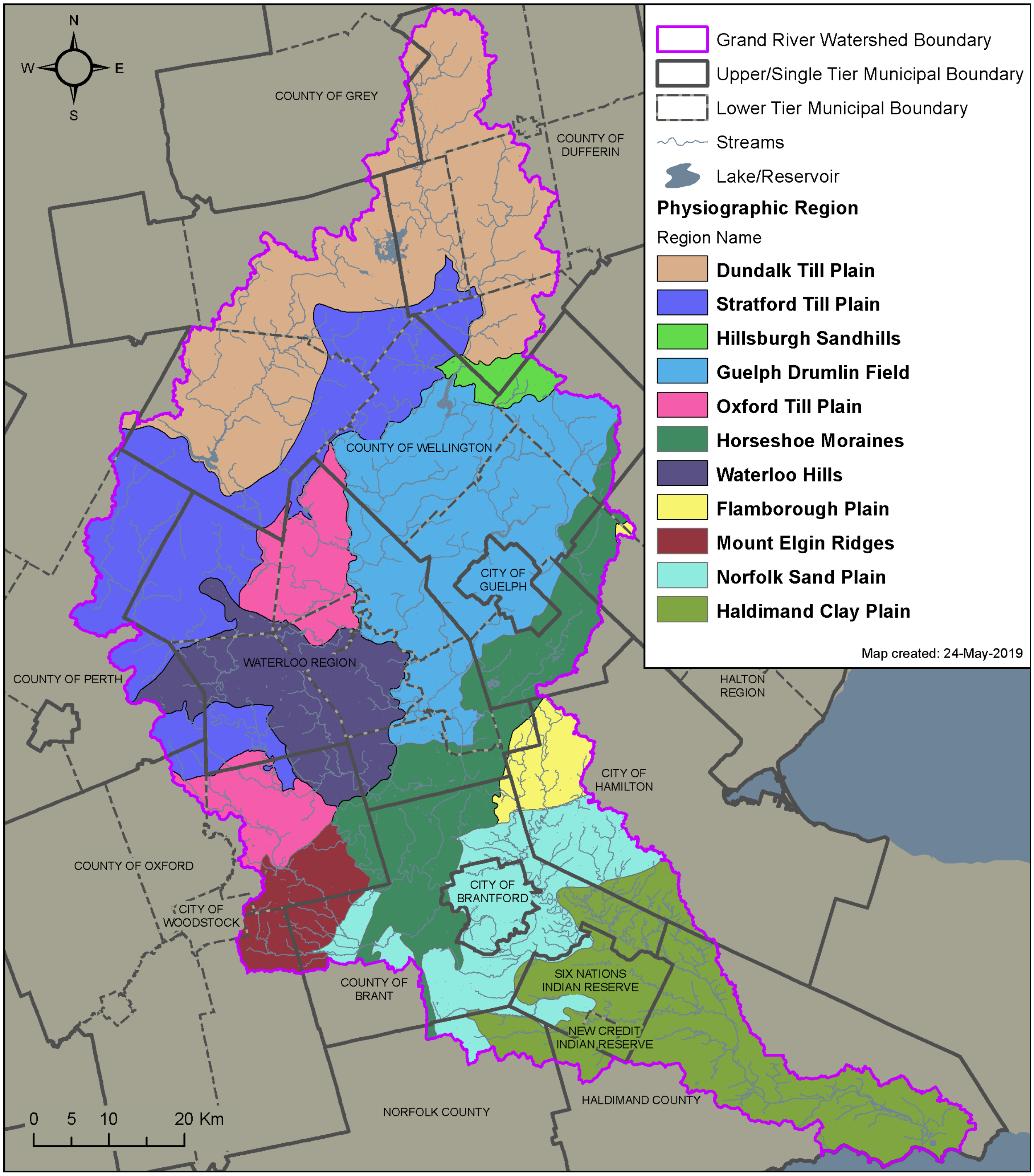
2.4.11 Haldimand Clay Plain

The lower Grand River watershed, southeast of a line through Alberton, Onondaga, and Bealton, is within the Haldimand Clay Plain region. The Grand River has cut a deep valley into the clay and silt below Brantford. Soils tend to be clay-rich and are poorly drained in places. There are however, some siltier and better drained soils in the Caledonia area and south of the Grand River.

The river corridor is well developed with extensive marshes, floodplain meadows, oak savannahs, woodlands, and willow lined riverbanks, between the roads that parallel the river.

The Six Nations and New Credit Reserves have almost 50% forest cover. Other large forested areas of importance are the North Cayuga slough forest, the Oriskany Sandstone woodland and Dry Lake wetland complex, the Taquanyah wetland complex, the lower Grand River marshes, the Dunnville northwest woodland and wetland complex, and the Mount Healy woods.

Map 2-7: Physiography of Grand River Watershed



2.5 Ground Surface Topography

Map 2-9 shows the topography of the Grand River watershed. The ground surface elevation ranges from a high of more than 500 m above sea level (asl) near Dundalk to a low of approximately 175 m asl at the Lake Erie shoreline. Significant topographic features within the watershed include the moraine features, clay/till plains, drumlin fields, and incised river valleys. The moraine features shown on **Map 2-8** (Waterloo, Orangeville, etc.) create topographic ridges on the landscape as formed through the last glaciation. Clay and till plains (Haldimand Clay Plain and Stratford Till Plain) result in large flat regions which are particularly prevalent throughout the southern and western extents of the watershed. Drumlin fields create a series of elongated hills on the landscape, with the elongation in the direction of glacial ice movement. The river valleys throughout the watershed are also dominant features on the landscape and have created well-recognized features such as the Elora Gorge.

2.5.1 Bedrock Surface

The bedrock surface is displayed in **Map 2-10** using information from the Ontario Geological Survey (OGS) (Gao *et al*., 2006).

The highest elevation in the Grand River watershed is the northern extent coincident with the 'Dundalk Dome' at approximately 525 masl, which is also one of the highest elevations in southern Ontario. The bedrock slopes uniformly to the south where it dips beneath Lake Erie at approximately 173 masl. The lowest bedrock elevation within the Grand River watershed is found within the Dundas Buried Valley near Copetown. A 198 m deep borehole was drilled here by the City of Hamilton during an investigation of the sediments filling the Dundas Buried Valley. Bedrock was not intersected, but drilling reached 30 masl which is 44 m below the surface of nearby Lake Ontario (Bajc *et al*, 2017). Additionally, a borehole was drilled on the Burlington Bar, to the east, that reached a depth of 195 m without intercepting bedrock suggesting this valley reaches depths of at least 120 m below sea level, which is 193 m below the surface of Lake Ontario (Burt, 2017).

Bedrock valleys within the Grand River watershed include the Dundas, Rockwood, and Elora Buried Valleys, along with several other buried and re-entrant valleys surrounding the watershed. The origin of the buried valleys in the Grand River watershed have been interpreted by Gao (2011) as being formed through glacial and subglacial drainage carving out the underlying bedrock prior to the deposition of sediments, while Marich *et al*. (2011) argues for a polygenetic origin where deglacial meltwaters reoccupied previously carved nonglacial fluvial channels prior to the deposition of sediments.

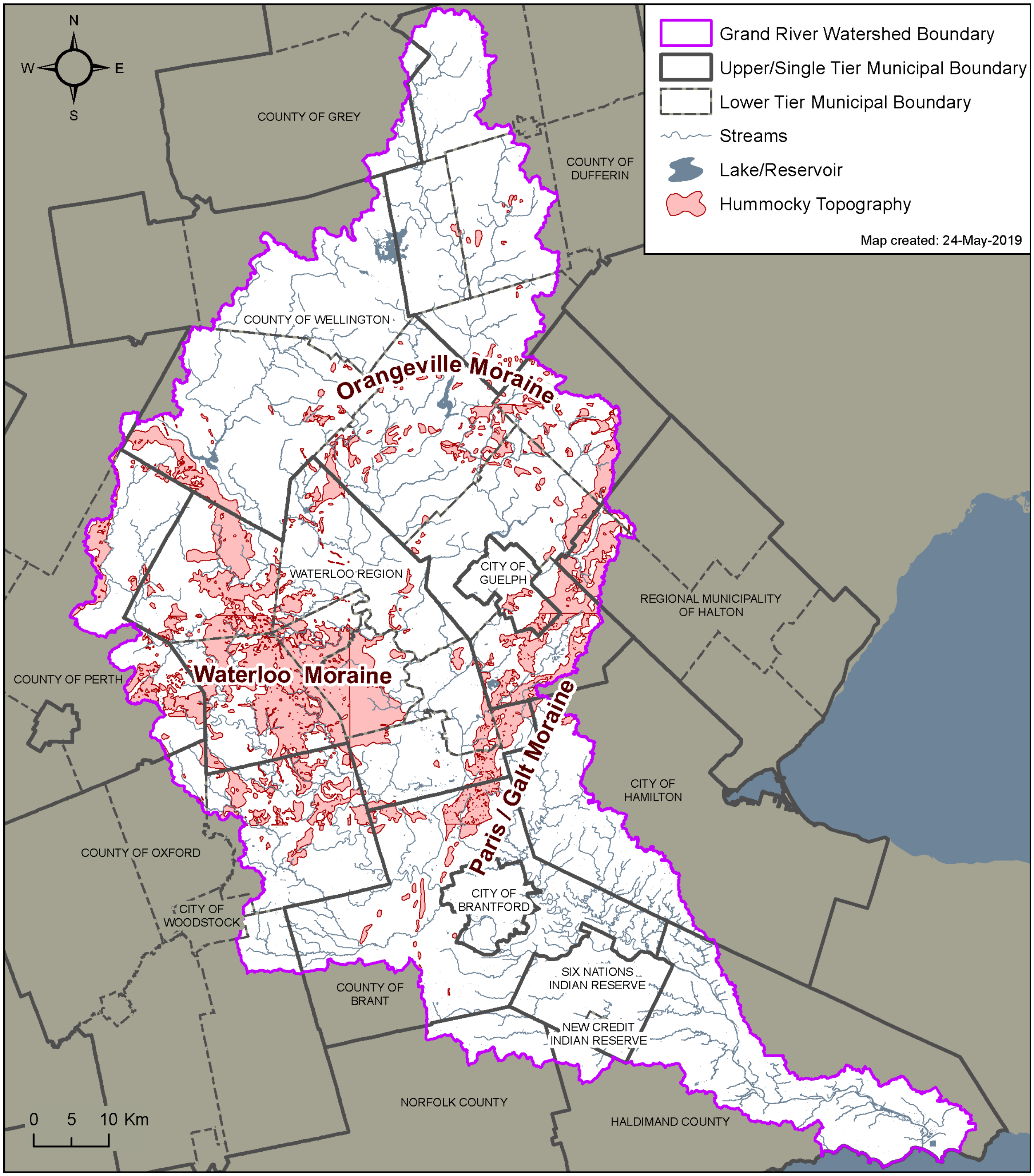
The Dundas Valley, aside from having the lowest bedrock surface elevation in the watershed, is a buried bedrock valley with little to no surface expression as it has been infilled with glacially-derived sediments. The valley is the deepest at Copetown because it is thought to be a knickpoint (a sudden drop in the slope of a river) for the drainage system, creating a deeply incised, narrow channel below a large waterfall, very much like Niagara Falls today (Marich *et al*., 2011). From Copetown, the channel trends west and northwest within the Guelph and Salina Formations, displaying a dendritic drainage network with limited valley incision that is controlled by the elevation of the knickpoint (Marich *et al*., 2011). The channel then continues northwest through Wellesley and the Onondaga Escarpment as it once again returns to a linear, deeply incised, bedrock depression known as the Milverton Buried Valley (Marich *et al*., 2011).

The Rockwood Valley is also a buried bedrock valley system with no surface expression which trends southwest to northeast from the Rockwood area past the town of Erin bisecting the Niagara Escarpment at the Credit River Valley (Burt *et al*., 2011).

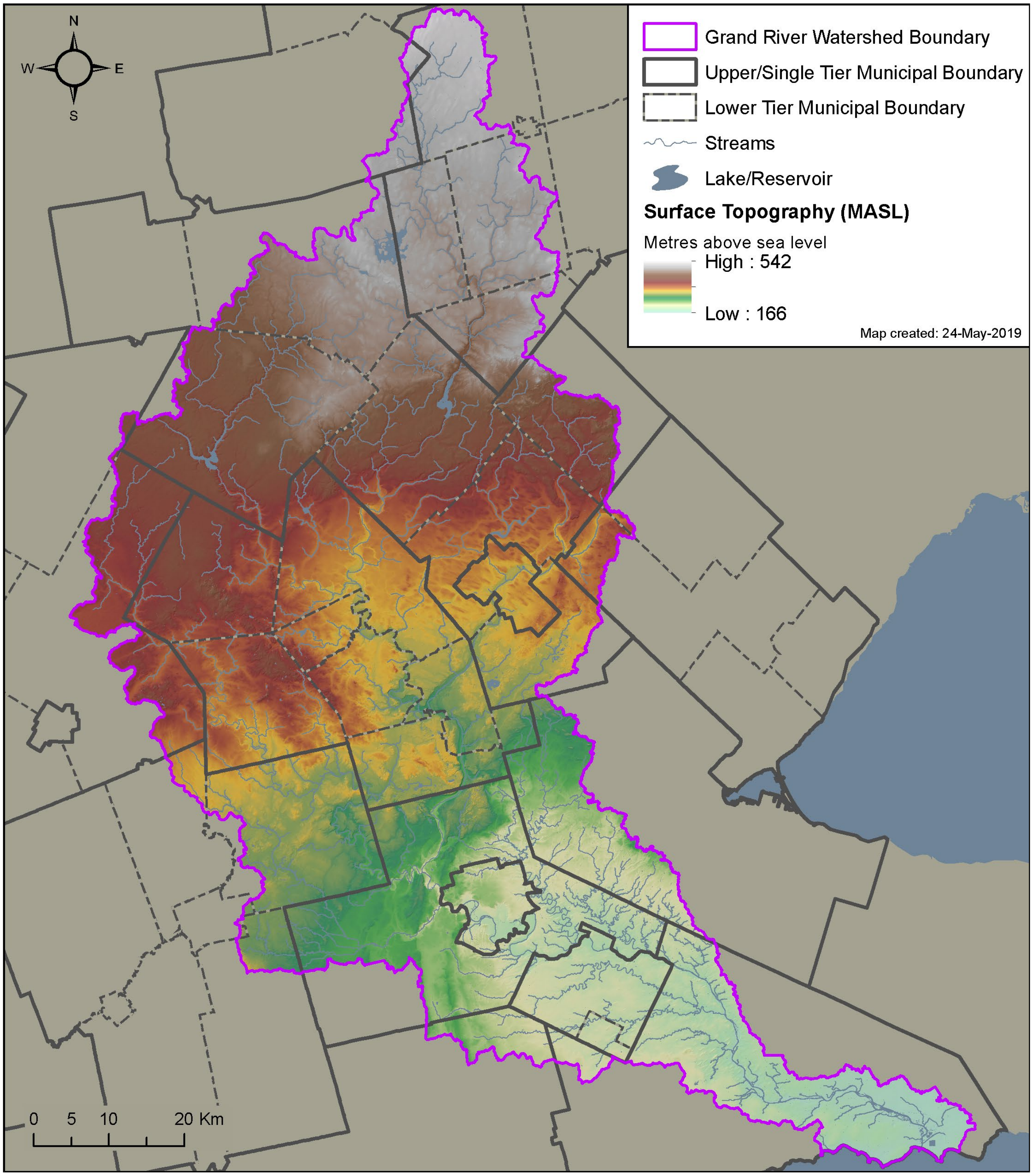
The Elora Buried Valley is a discontinuous feature. The valley originates to the north of Fergus, trends toward the south, and east of Belwood Lake, then disappears for several kilometers before re-appearing on the west side of Belwood Lake suggesting that water flowed in an underground conduit, as is a common occurrence in karst landscapes (Burt *et al*., 2011; Burt and Dodge, 2016). It should be noted that these interpretations have been inferred through water well and geophysical records and have not been confirmed through drilling.

Additional buried valleys within the Grand River watershed include the Woodstock, Mitchell, Wingham, and Mount Forest Buried Valleys, as well as the Waterdown, Black Creek, Alton, Mono, and Hockley re-entrant valleys (partially filled valleys along the Niagara Escarpment).

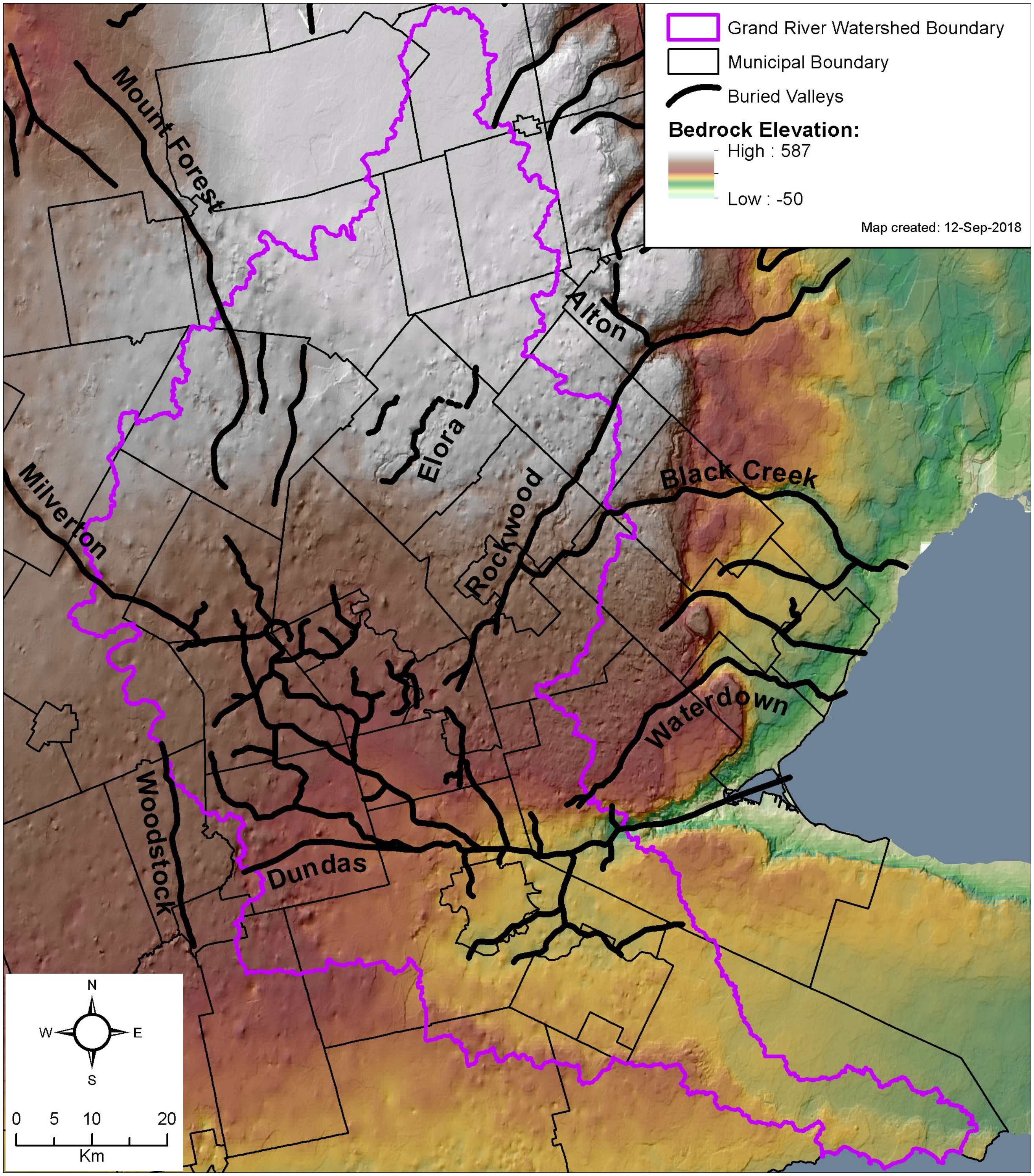
Map 2-8: Hummocky Topography in the Grand River Watershed



Map 2-9: Ground Surface Topography in the Grand River Watershed



Map 2-10: Bedrock Topography in the Grand River Watershed



2.6 Geology

The geology of the Grand River watershed, both bedrock and surficial sediment, forms the foundation of the Grand River watershed. The Grand River watershed is bounded on the northeast and southwest by two bedrock escarpments and to the northwest by an ancient bedrock arch. Bedrock, and the glacial deposits blanketing much of the bedrock in this region of Ontario, host significant aggregate and groundwater resources.

In a general sense, the geology of the watershed is separated into two events that shaped the landforms as we know them today: the formation of the Paleozoic sedimentary bedrock sequences followed by the North American Quaternary glacial events. The Paleozoic sedimentary bedrock is primarily composed of shales, sandstones, dolostones, and limestones. The North American Quaternary glaciations then altered the expression of the top of bedrock and draped the underlying bedrock with unconsolidated sediments composed of primarily gravel, sand, silt, clay, and diamicton.

2.6.1 Bedrock Geology

The sediments that formed the bedrock within the Grand River watershed were deposited as a result of the rise and fall of global sea levels. Sea water inundated all of southern Ontario depositing different types of sediments relative to the depth of the sea along with marine Animalia that lived and died within the sea (Westgate *et al*., 1999). This has allowed researchers to piece together a history of the biotic life and the settings in which they were deposited during this time period.

The bedrock underlying the Grand River watershed consists largely of marine sediments deposited in shallow seas that periodically covered eastern North America during the Paleozoic Era. These seas were occasionally centered on depressions of the lithosphere, also referred to as sedimentary basins, which were separated by structural highs, or arches. The Grand River watershed is located in the northern Appalachian Basin, on the southern flank of the Algonquin Arch as shown on **Map 2-11.**

Three bedrock features, shown in **Map 2-11,** underlie the Grand River watershed and help define the shape of the watershed:

- the Algonquin Arch forebulge
- the Niagara Escarpment cuesta
- the Onondaga Escarpment cuesta

Algonquin Arch

The Alleghanian orogeny, a mountain building event caused by tectonic plate movement, occurred approximately 325 million to 260 million years ago to the east of Southern Ontario. This orogenic event was responsible for the development of the arch and basin bedrock expression found in Southern Ontario (Root and Onasch, 1999). Mountains are created through the collision of tectonic plates. The area behind the newly formed mountain range is folded and faulted creating a network of bedrock highs (arches) and basinal foreland lows, such as the Algonquin arch to the west of the Grand River watershed and the associated bedrock lows of the Michigan basin to the west of the Algonquin arch and the Appalachian foreland basin to the east.

The Algonquin Arch is a northeast to southwest trending forebulge zone separating the Michigan and Appalachian Basins. A forebulge is a flexural bulge in the lithosphere (earth's crust) caused by a load (e.g. mountains created by an orogeny) depressing a tectonic plate. Forebulges are developed on the inland side of a foreland basin. The Algonquin Arch trends from the Chatham area, through Dundalk and continues to the northeast. The western edge of the Grand River watershed divide appears to follow this trend from the Woodstock area, where the Onondaga Escarpment meets the Algonquin Arch, and follows it to the northeast where it meets Dundalk. The interpreted bedrock structures are shown in **Map 2-11** and display the importance of bedrock structures in shaping the Grand River watershed.

The Grand River watershed is situated adjacent to the southeastern edge of the Algonquin Arch, within the westernmost part of the Appalachian foreland basin. Bedrock formations within the Grand River watershed consists of upper Ordovician, Silurian, and lower Devonian aged mainly marine sediments that straddle the broad northeastern oriented basement high of the Algonquin Arch.

Paleozoic sedimentary rocks were deposited in the Grand River watershed area between 458 to 393 Ma (Thurston *et al*., 1992; Armstrong and Carter, 2010; Sun, 2018). The sedimentary bedrock contains shales, sandstones, limestones, dolostones, and evaporites with varying degrees of disconformable (erosion has removed a part of the sedimentary record due to low sea levels) and conformable (continuous deposition of sediments) surfaces. The type of sedimentary rock is highly dependent on the geologic setting that existed during deposition. The rise and fall of sea levels determined the type and characteristics of the rock deposited. The bedrock formations generally subcrop (beneath Quaternary drift) in long parallel bands of varying width generally aligned in a north-west to south-east direction that is parallel to the outline of the Appalachian basin in this area.

Bedrock Cuestas

A cuesta is defined as a ridge that contains a gentle slope on one side and a scarp on the other. Cuestas typically form in response to erosional undercutting of resistant bedrock units and trend parallel to the basin margin with the bedrock units dipping towards the basin center.

The Niagara Escarpment cuesta is located to the east and is nearly parallel, at a distance of approximately 10 to 20 km, to the eastern boundary of the Grand River watershed from Dundalk, south to Hamilton. There are multiple re-entrant bedrock valleys that cut perpendicular through the rock face and many areas above the Niagara Escarpment that have been subjected to karstification (Cowell and Ford, 1983; Ford and Williams, 2007; Brunton *et al*., 2012; Burt, 2017).

The Onondaga Escarpment cuesta trends east-west near the Lake Erie shoreline from the Niagara Region to South Cayuga before turning northwest to the Woodstock area, then trending approximately south-north to the County of Bruce. The Grand River cuts through the Onondaga escarpment at its terminus at Port Maitland on Lake Erie but the southern and southwestern boundary of the watershed trend along this escarpment from South Cayuga, northwest, to the area east of Listowel.

Queenston Formation

The Queenston Formation, commonly known as the Queenston Shale, was formed during the Upper Ordovician period, 458 to 443 Ma, and is the oldest Paleozoic bedrock formation within the watershed. It underlies all of southwestern Ontario and outcrops, within the Grand River watershed along the Niagara Escarpment in a small area of the Dundas Valley, in the vicinity of Copetown. It is a noncalcareaous to calcareaous red (maroon) shale with subordinate amounts of green shale, siltstone, sandstone, and limestone (Armstrong and Carter, 2010). The thickness ranges from 275 m beneath Lake Erie to 50 m in the Bruce Peninsula (Sanford, 1961).

Clinton–Cataract Group

The Clinton-Cataract Group is represented by a narrow band on Map 2-11 that overlies the Queenston Formation. The Clinton-Cataract Group subcrops in the Dundas Valley area of the Grand River Watershed, and is comprised of several different bedrock formations, including the Whirlpool, Manitoulin, Cabot Head, Merritton, Rockway, and Irondequoit Formations. These formations however have not been differentiated on Map 2-11 and are mapped as the Clinton-Cataract Group. This group, which is exposed along the face of the Niagara Escarpment, was deposited during the Lower to Middle Silurian period, 444 to 430 Ma, and generally consists of grey to dark grey shale, sandstone, limestone and dolostone (Telford, 1979). Additional information on the individual formations is found in Janzen (2018).

Gasport Formation

The Gasport Formation consists of thick- to massive-bedded, fine- to coarse-grained, blue-grey to white to pinkish grey dolostone and dolomitic limestone (Armstrong and Carter, 2010). There are two members to the Gasport Formation; the basal Gothic Hill member and the upper Pekin member. The basal Gothic hill member is a light pinkish-grey, cross-bedded grainstone to packstone containing microbial–crinoidal reef mound lithofacies changing upward to rhynchonellid brachiopod–bryozoan–bivalve coquinas (Brett *et al.*, 1995; Brunton, 2009). The upper Pekin member is a dark olive-gray, argillaceous, fine- to medium-grained, thin- to medium-bedded dolomicrite with coral-stromatoporoid framestone bioherms up to 6 m high and dark grey, coarse, rubbly dolorudite representing biohermal flank debris (Brett *et al.*, 1995; Brunton, 2009). Bioherms extend from the top of the Gothic Hill member grainstones into the Pekin member and occasionally into the overlying Goat Island Formation.

The Gasport Formation outcrops in the Grand River watershed at three points along the eastern boundary of the watershed: i) in Amaranth Township near Laurel; ii) in a relatively large area surrounding the town of Rockwood; and, iii) in a band surrounding the Dundas Valley.

The thickness of the Gasport Formation changes due to an increase in accommodation space during deposition. This results in thicker development of the microbial–crinoidal–bryozoan–coral reef mound complexes of the lower Gothic Hill member (Brunton, 2009). In some areas, the reef mounds form multiple stacked cycles that range in thickness from 25 m to more than 70 m (Brunton, 2009). The relative thickness of the Gothic Hill member of the Gasport Formation controls the relationship with the overlying strata. This results in the upper Pekin member being absent north of Hamilton, from Guelph to the southern Bruce Peninsula. Furthermore, if the Gasport Formation lithofacies is thicker, then the stratigraphic unit that rests disconformably on the sequence boundary will be younger. For example, when the younger Guelph Formation rests disconformably on a sufficiently thick Gasport Formation, the Goat Island and Eramosa Formations (which stratigraphically overlie the Gasport Formation but underlie the Guelph Formation) are absent. Additionally, there is no evidence to suggest that the Goat Island and Eramosa Formations were ever deposited at these locations prior to the deposition of the Guelph Formation (Brunton, 2009). The upper contact of the Gasport Formation is typically characterized by a sharp disconformable contact that can be stylolitic and is erosional in many places (Brett *et al.*, 1995). The Gasport Formation is also susceptible to karstification where the Gothic Hill member reef mounds are overlain by the Guelph Formation lithofacies (Brunton, 2009). There are large cavernous pores created by karstification of the subterranean Gasport Formation beneath the city of Guelph (Cole *et al.*, 2009). The Gothic Hill member reef mounds make up the key hydrogeologic units in the Guelph–Cambridge region (Brunton, 2009).

Goat Island Formation

The basal contact of the Goat Island Formation with the underlying Gasport Formation is truncated by the variable thickness of the Gasport Formation reef mounds (Brett *et al*., 1995). The Goat Island Formation is not always present due to the variably thick lower Gasport Formation.

The Goat Island Formation consists of the lower Niagara Falls member and the upper Ancaster member. The Niagara Falls member is a crinoidal grainstone (brachiopod bearing) that contains a distinctive pin-striped appearance, is finely crystalline, tight, and cross laminated with incipient small reef mounds (Brunton, 2009). This member can be distinguished from the underlying encrinitic Gasport Formation by the finer grained and thinner bedded nature of the Niagara Falls member (Brett *et al*., 1995; Armstrong and Carter, 2010). The upper Ancaster member is a chert-rich, finely crystalline dolostone that is medium to ash grey in colour, thin to medium bedded and bioturbated (Brunton, 2009). Near Hamilton and among various other locales, it contains abundant chert nodules and lenses within the basal beds. These are informally referred to as the Ancaster chert beds (Armstrong and Carter, 2010). There is also a shaly interval near the top of the member east of Hamilton (Bolton, 1957; Armstrong and Carter, 2010). This is the cap rock of much of the Niagara Escarpment between Hamilton and Niagara Falls but due to the variably thick Gasport Formation north of Hamilton, the Niagara Falls and Ancaster members of the Goat Island Formation become an interfingered hybrid rock unit (Brunton, 2009). North of Hamilton, the hybridized members of the Goat Island Formation occur when the Gasport Formation is 30 to 50 m thick. The Goat Island Formation may even be absent if the Gasport is sufficiently thick (*i.e*. where significant relief is caused by Gasport Formation reef mounds) (Brunton, 2009). Where the Gasport Formation is less than 20 to 25 m thick, the Niagara Falls member may be up to 10 m thick and the Ancaster member up to 6 m thick (Brunton, 2009).

Eramosa Formation

The Eramosa Formation is comprised of three members; the basal Vinemount member, the middle Reformatory Quarry member, and the upper Stone Road member.

The basal Vinemount member is a black (fresh) to light grey (weathered), thinly bedded, fine-crystalline, and cyclic horizontally bioturbated dolostone with interbedded partially silicified brachiopods and digitate tabulate corals, and has a distinctive petroliferous odour when broken (Brunton, 2009). It is most shaly west of Hamilton becoming less shaly to the north.

The middle and upper Reformatory Quarry and Stone Road members are lithologically similar units. The Reformatory Quarry member is a light brown to cream coloured thick bedded, coarsely crystalline and coral-stromatoporoid biostromal lithofacies dolomite (Brunton, 2009). It also contains a strongly deformed pseudonodular interval, interpreted as a seismite (earthquake-deformed) bed, that varies in thickness from <30 cm to 1.6 m regionally (Brunton, 2009).

The Stone Road member is the upper cream-coloured pseudonodular facies dolomite of the Eramosa Formation (Brunton *et al*., 2012).

Guelph Formation

The Guelph Formation is the uppermost bedrock stratum for a large portion of the watershed, stretching in a 30 km wide swath from Dundalk to the Hamilton International Airport. This formation is a platformal and reefal dolostone with biostromal and biohermal reef complexes (Armstrong and Carter, 2010; Brintnell, 2012). There are two members of the Guelph Formation; the basal Wellington member and the upper Hanlon member.

The Wellington member is a carbonate reef mound-bearing and open-marine medium to thickly bedded, cross-stratified, crinoidal grainstone to wackestone-dominated facies (Brunton, 2009; Brunton *et al.*, 2012). The Hanlon member is a mid-shelf, open marine to lagoonal dolostone that is a thinly-bedded megalodont–gastropod-dominated wackestone and packstone facies (Brunton, 2009; Brunton *et al.*, 2012).

The Guelph Formation is typically 15 to 22 m thick in the Cambridge through Guelph area and thickens to more than 100 m in the Luther Lake region (Brunton, 2009; Brintnell, 2012; Brunton *et al*., 2012). Areas with exposed sections of the Guelph Formation include the Guelph Dolime Quarry (approximately 16 m of strata) and the Irvine Gorge in Elora (Brunton *et al*., 2012).

There are large, interconnected, cavernous, karstic pores associated with the Guelph Formation, located at an average depth of ~60 m, which have been identified using downhole geophysical logs, video logs, and hydraulic testing (Cole *et al*., 2009). The karst in the Guelph Formation is extremely important to the hydraulic characteristics of the watershed.

Salina Group

The Salina Group overlays the Guelph Formation and, similar to the Guelph Formation, it also underlies a large portion of the Grand River Watershed, stretching from Drayton to Dunnville. The group, which was deposited during the Upper Silurian period, approximately 420 million years ago, is comprised of several sub-members, four of which can be found in the watershed. From east to west, these sub-members are labelled A, C, E, and F. Similar to the main geological formations, the sub-members are aligned in long parallel bands, with the geology of each sub-member differing slightly. The A sub-member of the Salina abuts the Guelph Formation and consists of tan dolomite and grey mudstone. Immediately west is the C member, consisting of grey and olive green shale containing lenses of anhydrite and gypsum. The E member generally consists of tan dolomite with lenses of anhydrite or gypsum. Finally, the westernmost F member is made up of grey and red shale containing lenses of anhydrite or gypsum (Sanford, 1969). The gypsum mines present in the Caledonia area are set within the Salina Group. Generally, the Salina Group has poor water quality, forcing many municipal systems in the western portion of the watershed to rely on overburden aquifers for drinking water supplies.

Bertie - Bass Islands Formation

The Bass Island and Bertie Formations are considered to be laterally equivalent. The Bertie Formation is considered an Appalachian basin Formation in the Niagara Peninsula and the Bass Island Formation is considered a Michigan basin Formation (Johnson *et al*., 1992; Armstrong and Carter, 2010).

The Bertie Formation consists of cyclic successions of dark brown to light grey-tan, very fine- to fine-crystalline, variably laminated and massive, argillaceous or bituminous dolostones and minor shales (Armstrong and Carter, 2010; Sun, 2018).

The Bass Island Formation contains a 2-cm thick shale layer at its base, overlying the Bertie Formation (Sun, 2018). The formation is a dark brown to light grey, variably laminated, mottled, argillaceous or bituminous, very fine- to fine-crystalline and sucrosic dolostone. Intraclastic breccias, evaporite interbeds, and blue-grey mottling are common (Armstrong and Carter, 2010; Sun, 2018).

The Bertie and Bass Island formations may comprise a succession from 10 to 90 m thick with local intervals up to 150 m; however, in the Grand River watershed the Bass Island Formation is 5 m thick and overlies the 16 to 18 m thick Bertie Formation (Sanford, 1969; Armstrong and Carter, 2010; Sun, 2018).

Bois Blanc Formation

The Bois Blanc Formation unconformably overlies the Bass Islands-Bertie Formation to the west. The formation subcrops in a band roughly paralleling the western boundary of the watershed from approximately Conestogo Lake south. This unit was deposited during the Lower Devonian period, 418 to 394 million years before present, and primarily consists of grey and grayish-brown dolomite, limestone and nodular chert (Sanford, 1969).

Oriskany Formation

In the Grand River watershed, the Oriskany Formation overlies the Bass Island Formation by a sharp and irregular erosional surface (Sun, 2018). The Oriskany Formation is the oldest Devonian deposit in southwestern Ontario and has been assigned a Pragian age of 410 to 407 Ma (Sun, 2018). The Oriskany Formation consists of grey to yellowish white, well-rounded to sub-angular, well-sorted, medium to coarse grained, loosely cemented, thick- to massive-bedded, calcareous quartzose sandstone with fossiliferous horizons (Armstrong and Carter, 2010; Sun, 2018).

In Southern Ontario, the Oriskany Formation is discontinuous, thins from east to west, and eventually pinches out west of the Hagarsville area (Sun, 2018). In the Grand River watershed, the Oriskany Formation underlies an area of roughly 6 km^2.

Onondaga – Amherstburg Formation

The Onondaga-Amherstburg Formation is the youngest and westernmost bedrock formation which is present in the watershed at two locations: in the County of Perth and along the western boundary of the watershed west of Dunnville. The Onondaga-Amherstburg Formation was deposited during the Middle Devonian period, 394 to 382 million years ago. The formation is primarily composed of fossiliferous limestone, which is variably cherty and includes some shale (Telford and Tarrant, 1975).

2.6.3 Quaternary Geology

The understanding and interpretation of the Quaternary geology of the Grand River watershed is largely confined to the Late Wisconsinan time period, which began around 25,000 years ago. Prior to this time the geological record within the watershed is vague; however, it is known that Early and Middle Wisconsinan sediments and even pre-Wisconsinan sediments might underlie parts of the watershed.

The most recent glacial history of southern Ontario can be summarized as three episodes of glaciation, the Nissouri, Port Bruce, and Port Huron Stadial events, separated by three ice-free periods, the Erie, Mackinaw and the current interstadial events. Numerous surficial landforms were deposited within the Grand River Watershed with each stadial and interstadial event.

The first widely recognized Late Wisconsinan event is associated with the Nissouri Stadial ice advance about 20,000 years ago (Karrow, 1993). Catfish Creek Till, which is believed to generally underlie the entire Grand River Watershed, is representative of the Nissouri Stadial. It is often used as a stratigraphic marker bed as a result of its overall consistency in composition (Barnett, 1992). During the Nissouri Stadial, thick ice spread over the entire southwestern Ontario area and into the northern United States as far south as Ohio. The ice advance was quite strong and was believed to have progressed unimpeded by any of the subtle topographical features in southern Ontario. Approximately 18,000 years ago, the ice began to retreat from Ohio, and 16,000 years ago the glacier covering southern Ontario was believed to have split along a line from the Kitchener-Waterloo area to northeast of Orangeville (Sibul et al., 1980). Where the ice lobes broke apart, the low areas between the separating ice lobes became the focus for sediment-laden meltwaters. Over time, as the meltwaters flowed into these low areas, large deposits of sands and gravels built up and subsequently formed interlobate moraines. Upon full retreat of the ice, these deposits remained behind as topographical highs. Initial deposition of the Waterloo and Orangeville interlobate moraine complexes were thought to have taken place at this time (Sibul et al., 1980). As the ice retreated, meltwaters flowed across the area, resulting in extensive glaciofluvial deposits and numerous small lakes and ponds were formed on the surface of the Catfish Creek till.

Within the Grand River watershed, subsequent glaciation and the resulting sediment deposition occurred as a result of the advance of three ice lobes: the Georgian Bay lobe, the Huron lobe, and the Lake Erie-Ontario lobe. The lobes were centered in the lows provided by the Great Lake basins and advanced out of, and retreated back into these basins. A strong re-advancement of ice during the Port Bruce Stadial, about 15, 000 years ago, resulted in the deposition of the Maryhill Till and later the Port Stanley Till by the Erie-Ontario lobe which advanced from the south. The Guelph Drumlin field was also formed at this time. At the same time, the Huron-Georgian Bay lobe advanced from the north and deposited the Stirton Till followed by the Tavistock Till. Local short-lived re-advancements of the retreating Huron and Georgian Bay lobes resulted in the deposition of the Mornington Till, the Stratford Till, and the Wartburg Till. A stronger re-advancement about 14,500 years ago, resulted in the deposition of the Elma Till (Sibul et al., 1980).

Retreat of the ice during the late Port Bruce Stadial resulted in extensive kame and outwash deposits throughout the central parts of the watershed. The Waterloo, Elmira, Easthope and Orangeville Moraine complexes were either further built upon or created at this time. Meltwaters flowing to the south created a complex of outwash channels, now occupied by many present day streams. These channels are commonly filled with coarser grained sediments. A series of terminal moraines (and associated kame and outwash deposits) are found to the southwest of Brantford marking the retreat of the Lake Ontario/Erie ice lobe. At the time of the Mackinaw Interstadial, about 13,300 years ago, the entire Grand River Watershed was ice free.

The Port Huron Stadial, which began approximately 13,000 years ago, marked an advancement of ice back into the Grand River Watershed, however at this time, ice only advanced from the Lake Ontario/Erie lobe. The Wentworth Till was deposited at this time as the ice advanced to the Paris Moraine. During the recession of the Port Huron ice, ice contact sediments were again laid down, further building the Paris and Galt Moraine systems.

With the final retreat of ice from the Grand River Watershed, Lake Whittlesey was created. A series of large glacial lakes continued to occupy the Lake Erie basin until about 12,000 years ago, when the present day drainage system was created. In the Brantford and Paris areas, shallow water deltaic sediments were deposited closer to the shoreline of Lake Whittlesey. In contrast, the deep water clay and silt sediments south and east of Brantford, were deposited in the basin at the time of the deeper Lake Warren II. At this time, Halton ice advanced out of the Lake Ontario basin (east of the watershed) thus preventing the escape of meltwaters from the Lake Erie basin.

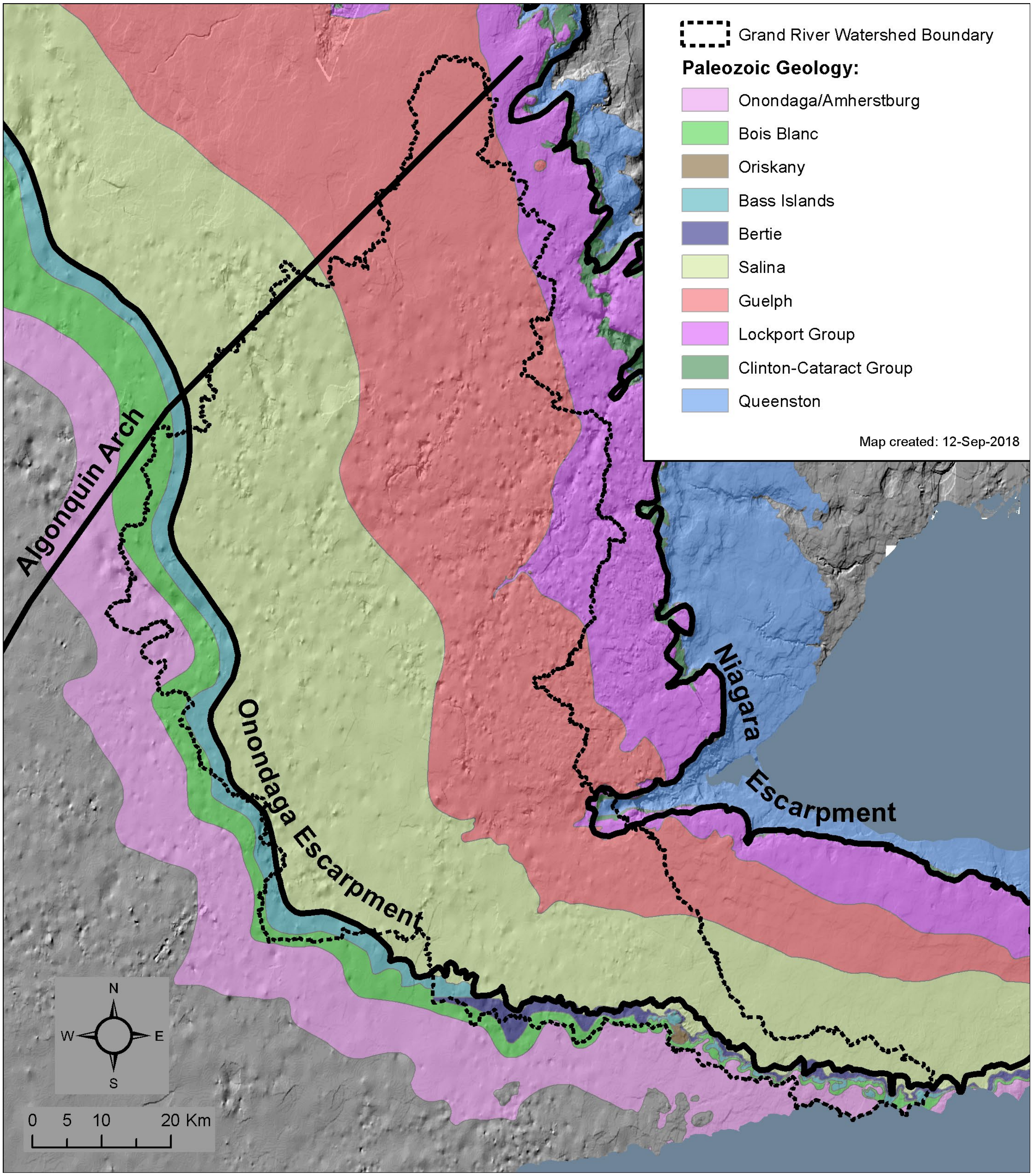
Since the final glacial retreat from southwestern Ontario, the present day stream system has eroded through the pre-existing surficial geology to create the current landscape. The retreat also resulted in the formation of major moraines within the Grand River Watershed.

Map 2-12 shows the Quaternary geology of the watershed. Although the Quaternary geology of the watershed is relatively complex, it can be generally divided into three broad areas:

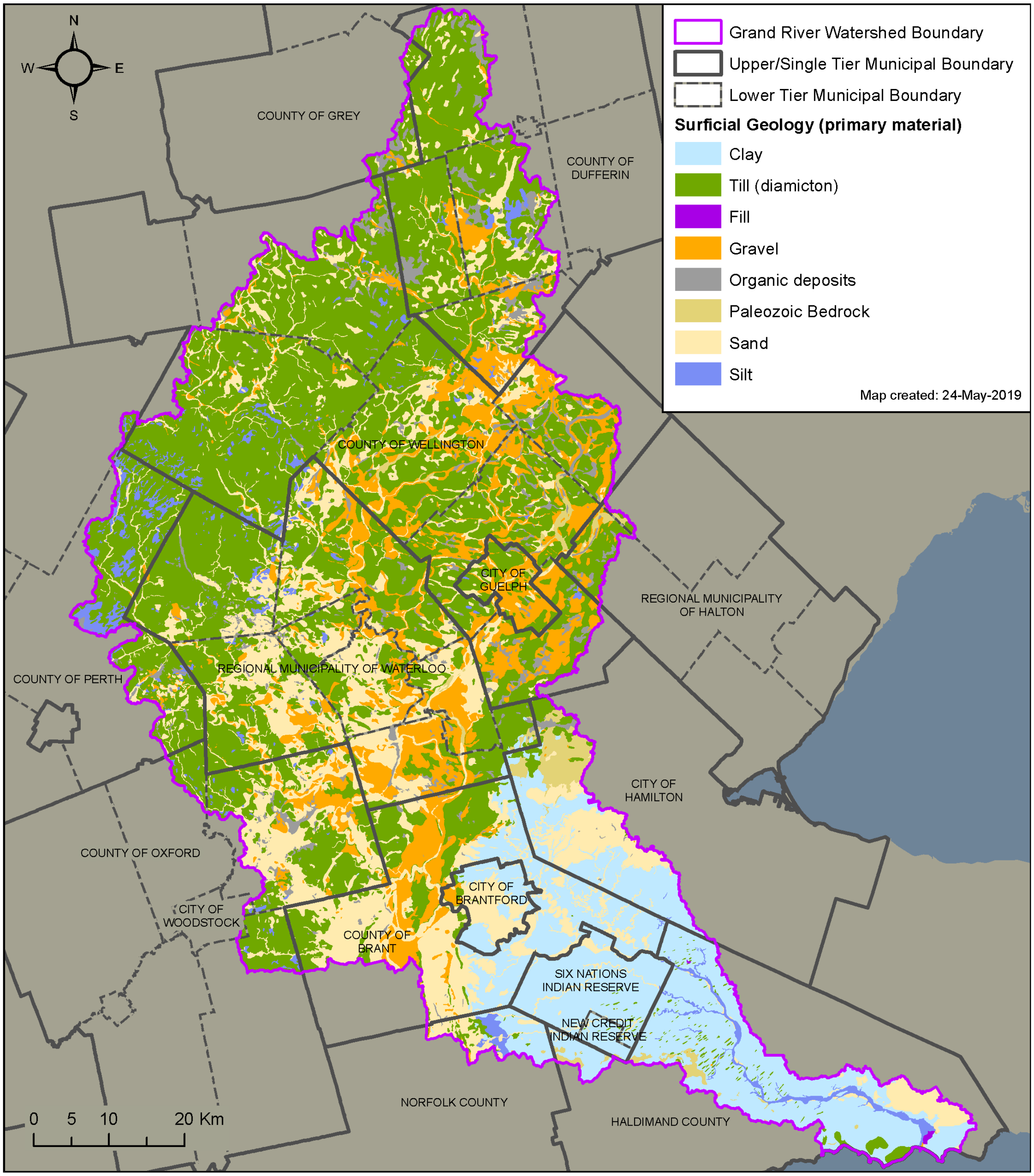
- The northern till plains, with varying relief and lower permeability;
- The central sand and gravel kame moraines and recessional moraines, with moderately high relief and higher permeability;
- The southern lacustrine clay plains, with lower permeability and low relief.

Map 2-13 shows the Overburden Thickness of the watershed.

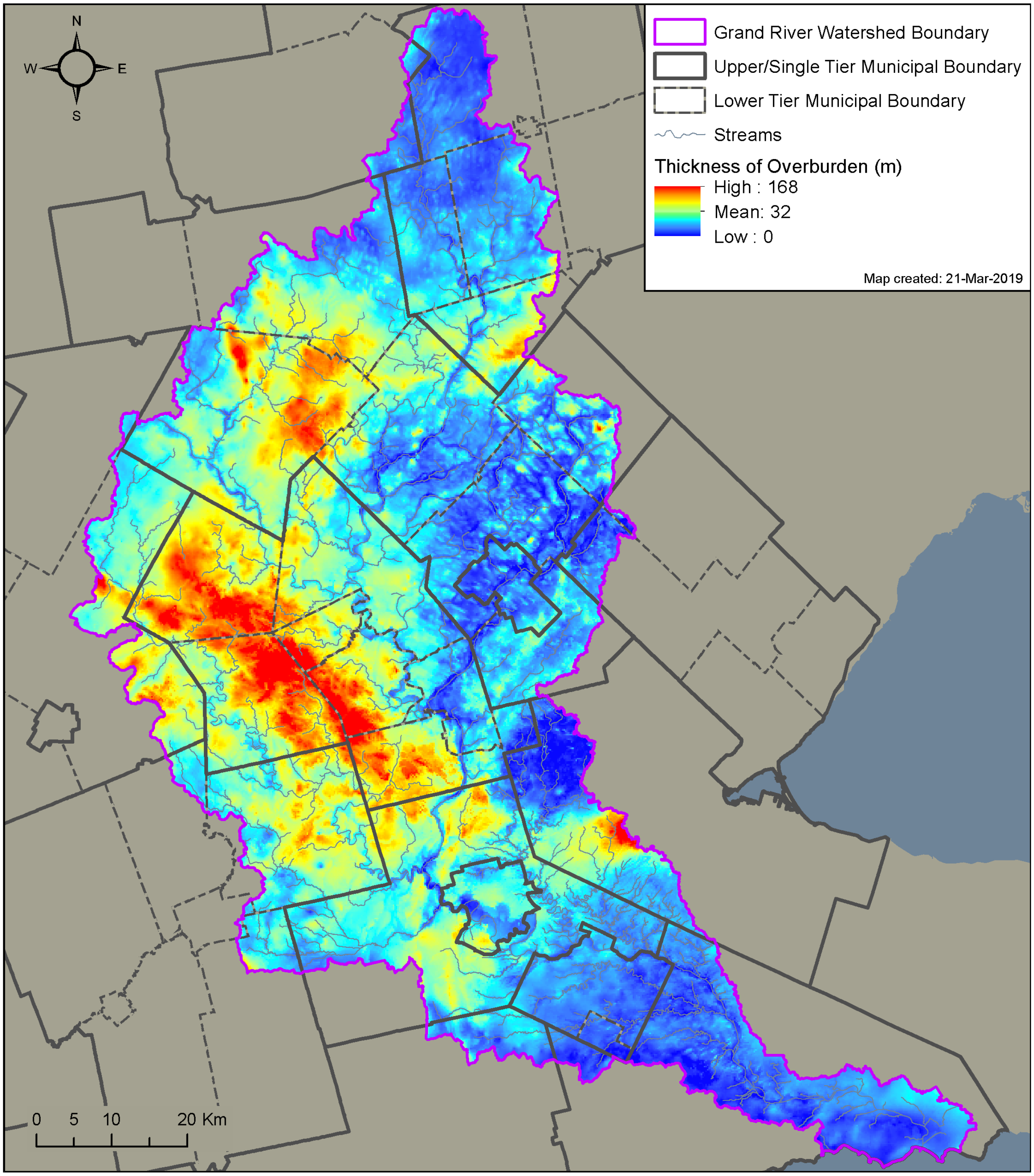
Map 2-11: Bedrock Geology in the Grand River Watershed



Map 2-12: Quaternary (Surficial) Geology in the Grand River Watershed



Map 2-13: Overburden Thickness in the Grand River Watershed



2.7 Groundwater

2.7.1 Hydrogeology

The majority of the population of the Grand River watershed relies on groundwater as a clean, safe, drinking water supply. In addition to providing a safe source of drinking water, groundwater is used in agriculture, commercial, and industrial applications. Groundwater also plays a pivotal role in sustaining sensitive natural features and aquatic habitats such as streams and wetlands. It has long been recognized that groundwater has a vital role in the hydrologic function of the watershed. Groundwater provides critical baseflow to many parts of the watershed, thereby supporting aquatic and wetland ecosystems.

Numerous municipalities and communities within the watershed are dependent on groundwater as their principal drinking water source. Groundwater resources are found within both bedrock and overburden aquifers as summarized in the following sections. In areas where rivers, streams or wetlands intersect the water table, groundwater discharges into the stream or river and contributes baseflow to the surface water feature. Understanding the movement of groundwater through the subsurface, and through interactions with surface water features requires an understanding of the location and extent of the watershed's aquifers (water bearing units) and aquitards (confining units) as well as the location of significant recharge areas.

The most recent regional characterization and quantification of groundwater resources in the Grand River watershed has been through the completion of the Grand River Tier 2 Integrated Water Budget (AquaResource, 2009). Since the completion of the Tier 2 water budget, areas of the watershed have been locally refined and further characterized through Tier 3 water budgets. To date, Tier 3 studies have been initiated within the Region of Waterloo, the City of Guelph / Township of Guelph Eramosa, the Whitemans Creek subwatershed, and the Township of Centre Wellington. Summaries of these water budget studies are included in this assessment report.

Regional Aquifers

The Grand River watershed contains extensive aquifers within its bedrock formations and overburden deposits. Groundwater within the aquifers provides for municipal and private water takings, and also supports cold water surface water features through the provision of baseflow from groundwater discharge.

The northern portion of the watershed contains primarily till deposits, which do not to contain extensive or significant aquifer units. Communities such as Dundalk, Grand Valley, Waldemar, Marsville, Fergus, Elora, Guelph-Eramosa, and the City of Guelph rely on groundwater obtained from the Guelph, Goat Island, and Gasport Formations for municipal supply. Communities in Wellington North, such as Arthur, Moorefield, and Drayton obtain municipal water from aquifer units located in the overburden.

Several major moraine systems which support aquifers within the overburden are found in the Grand River Watershed. These include the Orangeville and Waterloo interlobate moraines, and the Paris and Galt recessional moraines. These moraines, made up of extensive sand and gravel units, provide significant amounts of groundwater for municipal and private use across the watershed. **Map 2-8** shows the location of moraines in the watershed.

The Orangeville interlobate moraine, located in the northern portion of the Grand River Watershed, is situated on the east side of Belwood Lake, and extends up to the west side of Orangeville. A high water table elevation is generally associated with the feature. A portion of the groundwater within the moraine tends to flow to the northwest towards the Grand River, while the remainder flows to the southwest towards the Credit River Watershed. Although not used for municipal supply within the Grand River watershed, the Orangeville Moraine is a highly permeable feature and has been identified as an area of significant recharge (AquaResource, 2009a, AquaResource, 2011).

Located to the south of the Orangeville Moraine, the Waterloo Moraine is one of the largest moraines within the Grand River watershed. A number of aquifers situated within the moraine are used by the Region of Waterloo for drinking water supply. The moraine is situated within the west-central part of Waterloo Region in the central portion of the watershed. There are three major overburden aquifer units found within the Waterloo Moraine and they supply 50% of the municipal groundwater supplies for the Region of Waterloo (AquaResource, 2009a). Groundwater discharge from aquifers within the moraine also provides baseflow to numerous surface water features located on the flanks of the moraine.

In the St. George area, just north of Brantford, the Galt Moraine yields two local aquifers; a deeper aquifer which consists of 3 to 5 m of gravel deposits and a shallow sand and gravel aquifer (AquaResource, 2009a).

Located in the southwest portion of the watershed, the Norfolk Sand Plain is a significant source of groundwater within the overburden sediments. The sand plain is comprised of coarse-grained glaciolacustrine sand and silt deposits laid down as a delta in glacial Lakes Whittlesey and Warren (Waterloo Hydrogeologic, 2003b). The deposits consist of fine- to medium-grained, cross-bedded sand up to 25 m thick. The permeable sand and gravel deposits associated with the Norfolk Sand Plain yield good water supplies; however, they are particularly vulnerable to impacts from land use activities. Groundwater from the aquifers located within the sand plain is used as a drinking water resource, and also relied heavily upon for crop irrigation and to meet agricultural water needs. Groundwater from these shallow aquifers also provides critical baseflow to Whitemans Creek which supports cold-water fisheries.

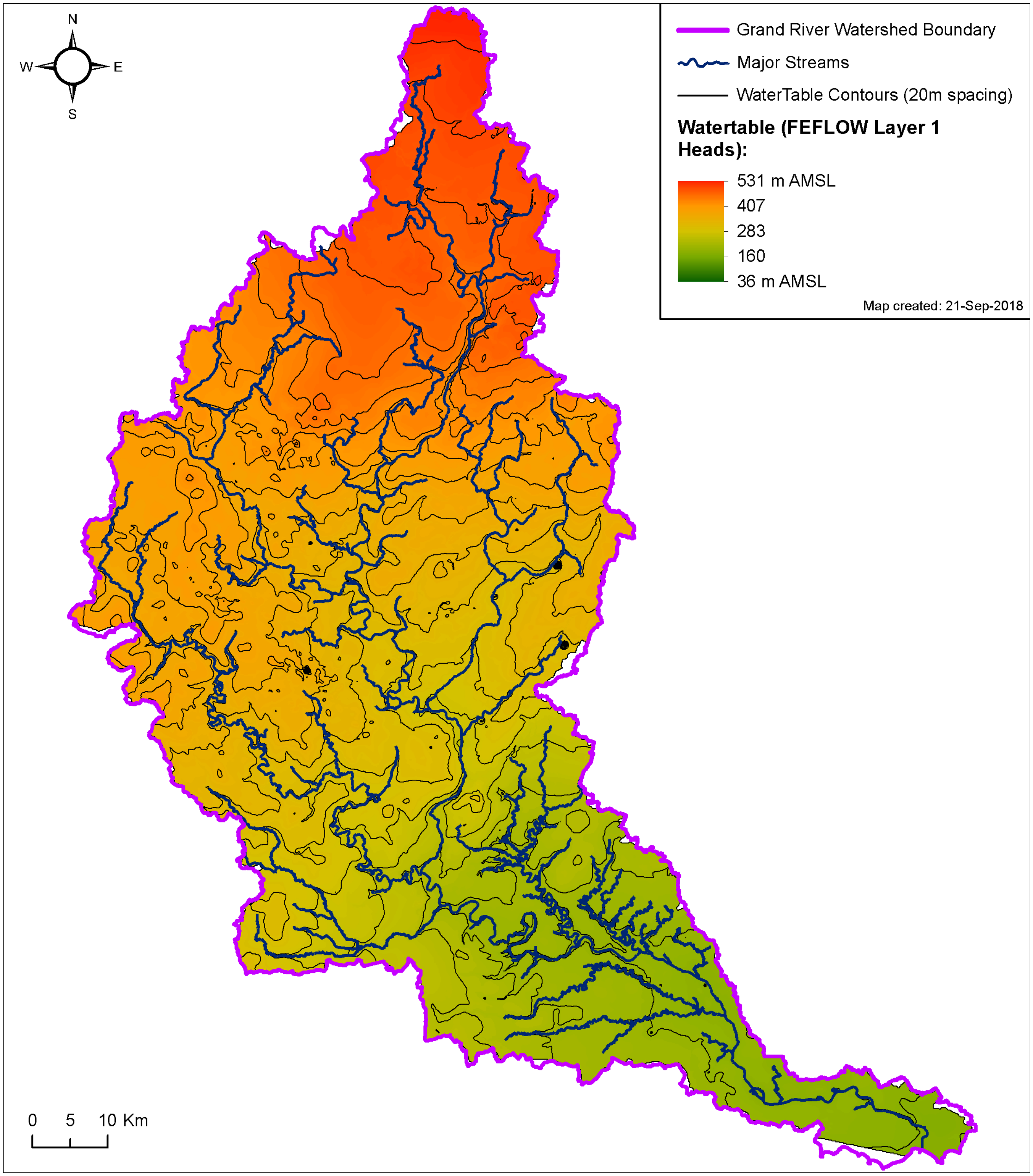
2.7.2 Regional Groundwater Flow Directions

As a part of the regional Tier 2 water budget study, hydraulic heads were simulated for the water table and contact zone (weathered bedrock) across the Grand River watershed (AquaResource, 2009). **Map 2-14** and **Map 2-15** show the hydraulic head distribution throughout the watershed for the water table and contact zone aquifer. These maps were based on a regional numerical groundwater flow model developed for the entire Grand River watershed that was completed as a part of the Tier 2 study.

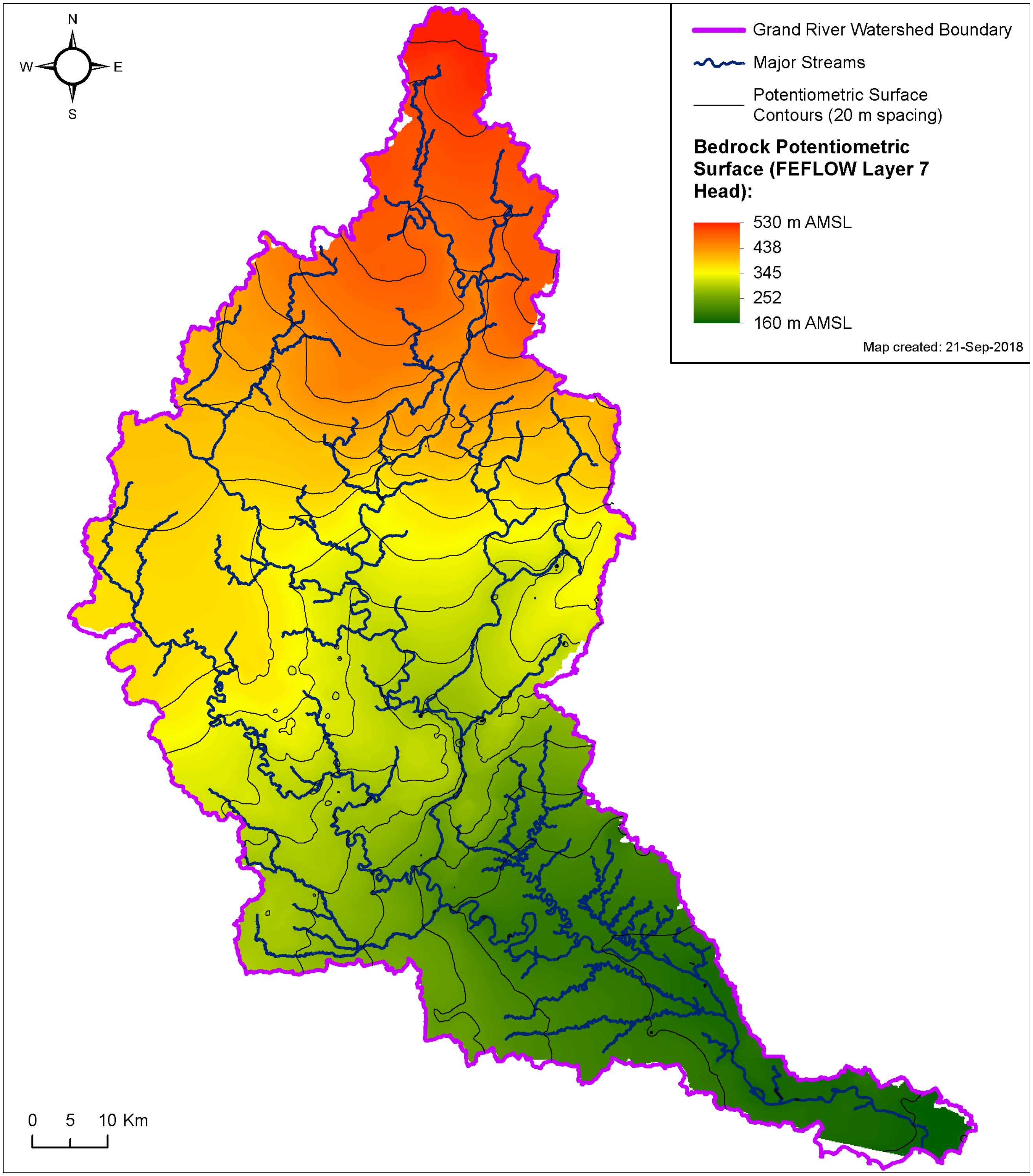
Both maps illustrate the flow from the upper reaches of the watershed where there is a topographic high, to the south toward Lake Erie. The maps also exhibit the influence of primary surface water features; this influence is greater on the water table than on deeper groundwater. The irregularity of the water table shown on **Map 2-14** reflects both the heterogeneity of the hydraulic conductivity values applied to the overburden layers within the groundwater flow model, and the strong local influences of the surface water features.

In contrast, the hydraulic conductivity within the contact zone aquifer is relatively uniform, resulting in a smoother contour distribution. Additionally, the direct influence of surface water features decreases for deeper hydrogeologic units.

Map 2-14: Calibrated Water Table for the Grand River Watershed



Map 2-15: Calibrated Potentiometric Surface (Contact Zone) for the Grand River Watershed



2.7.3 Major Groundwater Recharge Areas

The recharge of surface water to the groundwater system occurs throughout the Grand River watershed. The rate of recharge is dependent on slope of the ground surface, soil moisture, grain size, and stratification.

Significant Groundwater Recharge Areas (SGRAs) are defined as a specific type of vulnerable area that may be protected under the *Clean Water Act*, 2006. The role of SGRAs is to support the protection of drinking water across the broader landscape.

Map 2-16 shows the SGRAs mapped with isolated areas of less than 1 km^2 removed. All of the SGRAs mapped within the Grand River Source Protection Area are considered hydrologically connected to groundwater sources used for drinking water because of the extensive cover of domestic overburden wells in the watershed.

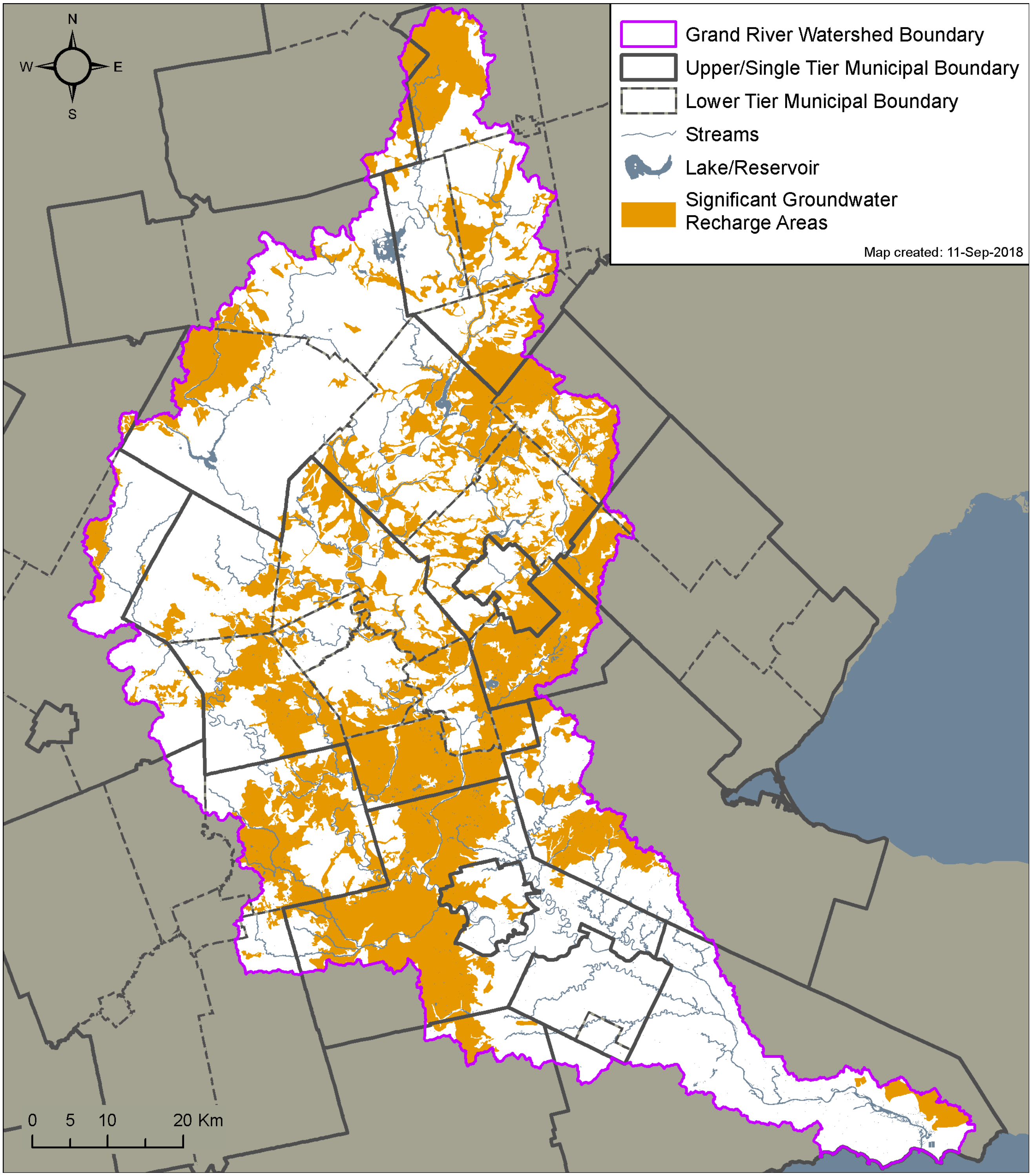
The areas of highest recharge tend to coincide with the moraine features within the watershed (shown on **Map 2-7** and **Map 2-8**). These include the Galt, Paris, and Waterloo Moraines in the central portion of the watershed and the Orangeville Moraine located in the northern portion of the watershed. These moraines are commonly comprised of permeable, coarse-grained deposits and hummocky topography (disconnected drainage), allowing for extensive infiltration and recharge. These moraine areas represent very significant recharge zones for the watershed's major aquifers.

Where recharge in the areas of the Galt, Paris, and Waterloo Moraines contributes to the groundwater system in the overburden deposits, the Orangeville Moraine is a major recharge area that contributes to the bedrock aquifers in the region. In addition to the moraine features, areas within the Upper Grand watershed contain isolated, interspersed pockets of coarse-grained glaciofluvial outwash deposits which allow for high recharge rates.

To the southwest, the Norfolk Sand Plain is an area characterized by thick deposits of highly permeable, coarse-grained sands. High recharge supports an extensive unconfined overburden aquifer throughout the Norfolk Sand Plain.

The northern portions of the watershed, including the Upper Conestogo River, Upper Nith River, and the Irvine River, generally consist of consolidated till deposits with low permeability that inhibit water movement through to the subsurface. Towards the south of the watershed, the fine-grained clay-rich deposits characteristic of the Halidmand Clay Plain inhibit recharge in this area.

Map 2-16: Significant Groundwater Recharge Areas

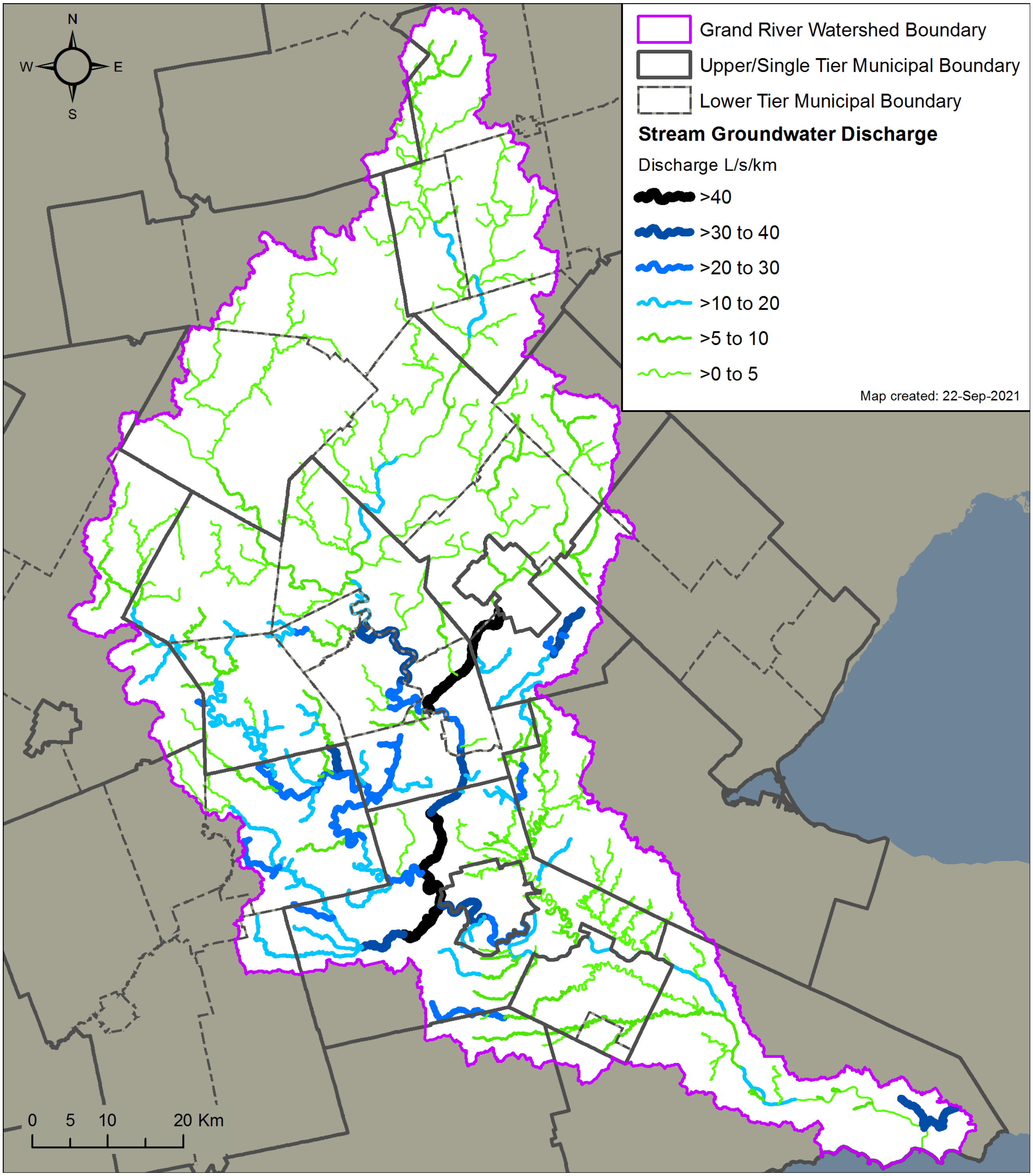


2.7.4 Major Groundwater Discharge Areas

Major discharge areas within the Grand River watershed are associated with the major river corridors, especially along the lower Nith River and the Grand River south of Cambridge. In addition, Luther Marsh, Belwood Lake and the Orangeville Reservoir are examples of significant wetland areas that are indicated as being groundwater discharge areas. Groundwater discharge areas within the watershed have resulted in significant ecological habitat for numerous cold water aquatic species. Particularly, the stretch of the main Grand River from Paris to Brantford is known for significant groundwater discharge, and has spurred resurgence in trout populations within the last decade as water quality has improved.

Simulated groundwater discharge at a watershed scale is shown on **Map 2-17** (AquaResource, 2009). This information is presented as groundwater discharge per kilometer of stream. Groundwater discharge was calculated by delineating stream reaches into shorter lengths (i.e. 2-5 km), calculating total amount of groundwater discharge into each reach, and then dividing the total groundwater discharge by the length of the reach. On the figure, reaches of highest groundwater discharge are shown as thicker dark blue lines. Thin light blue lines indicate that the headwater regions primarily receive smaller discharge volumes. The highest groundwater discharge rates occur in major stream reaches in low lying areas, such as between Cambridge and Paris. These results provide an initial regional-scale visualization of groundwater / surface water interactions.

Map 2-17: Simulated Groundwater Discharge



2.7.5 Surface and Groundwater Interactions

Interactions between groundwater and surface water systems in the Grand River watershed are critical to the maintenance of the water cycle within the watershed. Groundwater discharge sustains many watercourses through dry periods resulting in significant ecological habitat and improved water quality. On the other hand, recharge from surface waters supports groundwater aquifers which are a significant source of drinking water in the watershed.

Within the Grand River Watershed, groundwater recharge occurs over much of the landscape. However the rate at which recharge occurs is dependent on the nature of the overburden material, where highest rates of recharge occur on coarse-grained deposits and areas with disconnected drainage. Groundwater discharge occurs in many of the watercourses in the watershed where stream beds intersect the water table or upward hydrologic gradients drive water through permeable material. This is shown by sustained baseflows in many watercourses and the abundance of cold water aquatic ecosystems. Areas that have been identified with high rates of groundwater discharge include the middle portions of the Grand River, in particular the reach between Cambridge and Brantford, the Nith River below New Hamburg, the Lower Eramosa River including Blue Springs Creek, the Speed River below Guelph, and Whitemans Creek.

Major areas of potential discharge to the Grand River include the reach between Legatt and Shand Dam, the reach below Elora through Kitchener, and the reach from Cambridge to Brantford (AquaResource, 2009a). The massive discharge zone downstream of Cambridge is most likely produced from a combination of the Galt Moraine to the east and the presence of large overburden aquifers to the west. Discharge in this area adds as much flow to the river as either the Shand or Conestogo dams, allowing water quality to recover after large urban influences upstream.

The lower Nith River and some of its tributaries including Cedar Creek receive large quantities of groundwater discharge from moraines and other coarse-grained deposits. This area of the Nith River subwatershed is characterized by thick deposits of coarse-grained sand and gravel which support extensive overburden aquifers. Both local and regional groundwater flow systems may contribute to groundwater discharges through this subwatershed.

The lower Eramosa River including Blue Springs Creek and the Speed River below Guelph pass though areas receiving groundwater discharge. The Lower Eramosa River receives discharge from both bedrock aquifers and overburden sediments (Gartner Lee, 2004). Unconfined aquifers are located along much of the river's length in this area. Groundwater discharge contributes to healthy cold water aquatic ecosystems in this subwatershed.

Whitemans Creek flows through a large groundwater discharge zone. Springs and seeps can be found along parts of the creek, which also supports a cold water fishery. Whitemans Creek flows through the upper part of the Norfolk Sand Plain, an area characterized by thick deposits of coarse-grained and highly permeable sand. High recharge in this subwatershed supports an unconfined overburden aquifer, which in turn discharges to the creek.

There are also areas with little groundwater - surface water interaction. These areas often are characterized by fine-grained, silt- and clay-rich surficial deposits which results in a decreased permeability that inhibits water movement between the surface and sub-surface systems. Areas within the Grand River Watershed with these characteristics include the Haldimand Clay Plain in the south and tight, consolidated tills in the north.

2.8 Groundwater Quality Across the Watershed

Groundwater within the Grand River watershed is used extensively as a drinking water source for both municipal and private supplies. As such, monitoring and managing the quality of the groundwater supply is of critical importance.

The chemical characteristics of groundwater within the Grand River watershed are derived from two sources: (1) the ambient chemistry, where the composition of the groundwater reflects its relative residence time in the aquifer and the nature of the substrate through which it flows, and (2) anthropogenic impacts to the quality of the groundwater through various land use activities such as road salting, fertilizer and manure applications to agricultural fields, and industrial chemical use.

In some groundwater, parameters such as fluoride and arsenic can be elevated to greater than the maximum allowable concentration (MAC) as specified in the Ontario Drinking Water Quality Standards (ODWQS). Other non-health related parameters such as hardness, iron, 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. Recently recharged groundwater tends to be less mineralized and more bicarbonate-rich. As groundwater moves through the flow system, and depending on the nature of material (i.e., bedrock versus sands or gravel) it comes in contact with, the water becomes increasingly mineralized along its flow path.

The second class of controls which influence the quality of groundwater are related to land use activities. In the Grand River watershed, three distinctive land use activities have impacted groundwater quality: road salting, the application of manures/fertilizer, and the use of industrial chemicals.

Road Salt

The application of road salt (sodium chloride) is a common activity across the watershed given winter road conditions. Chloride is soluble and highly mobile in water. It can impair the taste of drinking water, and at high concentrations can be toxic to aquatic vegetation and species. Sodium can be a health concern for people on low sodium diets. If left unmanaged, chloride and sodium from road salt can infiltrate into the ground, and potentially recharge into the groundwater flow system. Once in the groundwater, chloride is not readily removed through treatment.

Through the source protection program, elevated concentrations of chloride have been identified and classified as drinking water issues for 11 municipal wellfields in the Grand River watershed. Four municipal wellfields have had sodium identified as a drinking water issue. To mitigate the impact of road salt to the groundwater system a number of measures can be applied. Road salt storage and application can be managed through: source protection plan policies within WHPAs, municipal programs such as the Region of Waterloo's Smart About Salt program, and public outreach and education.

Nitrate

Approximately 70% of the Grand River watershed's land use is classified as rural agricultural. As such, nitrate is applied directly to agricultural lands in the form of fertilizer. Excess nitrate 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. Elevated concentrations of nitrate in drinking water can be harmful to young infants or young livestock. Excessive nitrate in the body can result in the restriction of oxygen transport in the bloodstream. Infants under the age of 4 months lack the enzyme necessary to correct this condition; this is referred to as ‘blue baby syndrome’.

Nitrate has been identified as a drinking water issue through the source protection program at 11 municipal wellfields, where nitrate has been monitored at concentrations greater than 5 mg/L or one half of the nitrate MAC (10 mg/L). Although nitrate can be removed from drinking water through treatment, it can be an expensive process and not always feasible. Similar to road salt, nitrate application and the storage and handling of manure and fertilizer can be managed through source protection policies within WHPAs, in addition to public education and outreach strategies.

Industrial Chemicals

The use of industrial chemicals, such as trichloroethylene (TCE), is prevalent in the watershed. Chemicals such as TCE are classified as dense non-aqueous phase liquids, or DNAPLs. When these compounds enter the groundwater system, they are only slightly soluble in water, and therefore persist in aquifers, forming pools and plumes. DNAPLs, even at low levels, can present human health and ecological risks. When present in groundwater, DNAPLs are removed from the aquifer using such technologies as pump-and-treat; however, these can be lengthy treatment processes due to the complexity and migration of the DNAPL plume. In the Grand River watershed, TCE has been identified as a drinking water issue at 6 municipal wellfields.

2.9 Climate in the Grand River Watershed

The climate of the Grand River watershed is reflective of its position at the heart of southwestern Ontario. The watershed covers a large area where proximity to different Great Lakes and topographic relief result in a variable climate across the watershed. Climate is changing worldwide. Both the historic and recent climate is important in the understanding of water movement and availability in the Grand River watershed.

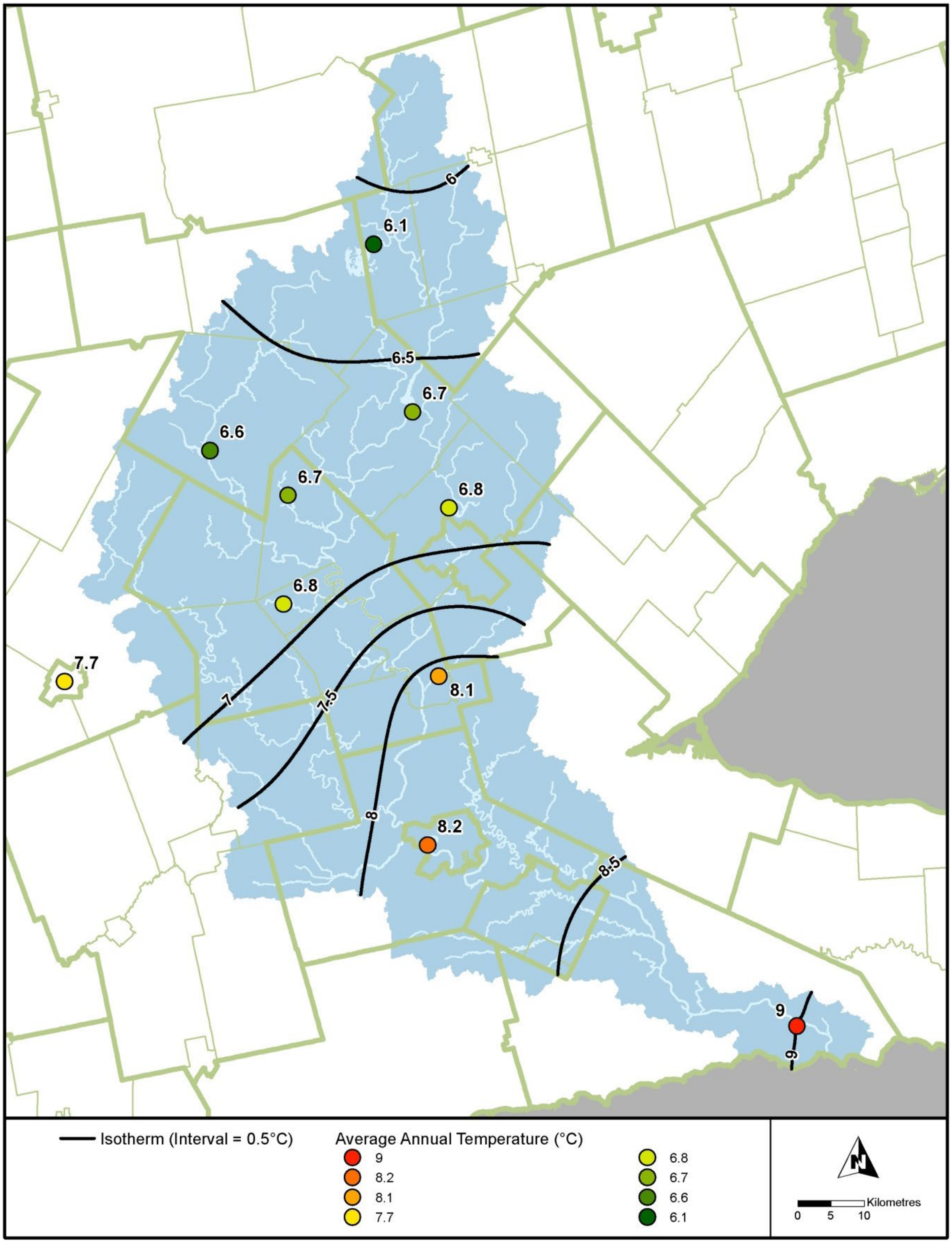
Precipitation and temperature averages were calculated from observed data collected at Grand River Conservation Authority (GRCA) manual weather stations and from Environment and Climate Change Canada (ECCC) climate stations across the watershed. A thirty year average period, 1986 to 2016, was used to calculate average precipitation and temperature on an annual and monthly basis. This length of time was recommended by the World Meteorological Organization to be long enough to filter out year to year variability, but short enough to observe changes with time.

Over the 30 year period, the Grand River watershed had an average temperature of 7.2 degrees. **Map 2-18** shows the annual average temperature across the watershed. Temperatures follow an increasing trend from north to south. The warmest temperatures were in the south with an average of 9.0 degrees near Lake Erie. The coolest temperatures were in the north with an average of 6.1 degrees near Grand Valley. Observed data shows an increase in average temperatures of about 0.5 degrees over the last half century with the winter months having the highest increase at approximately 1.0 degrees.

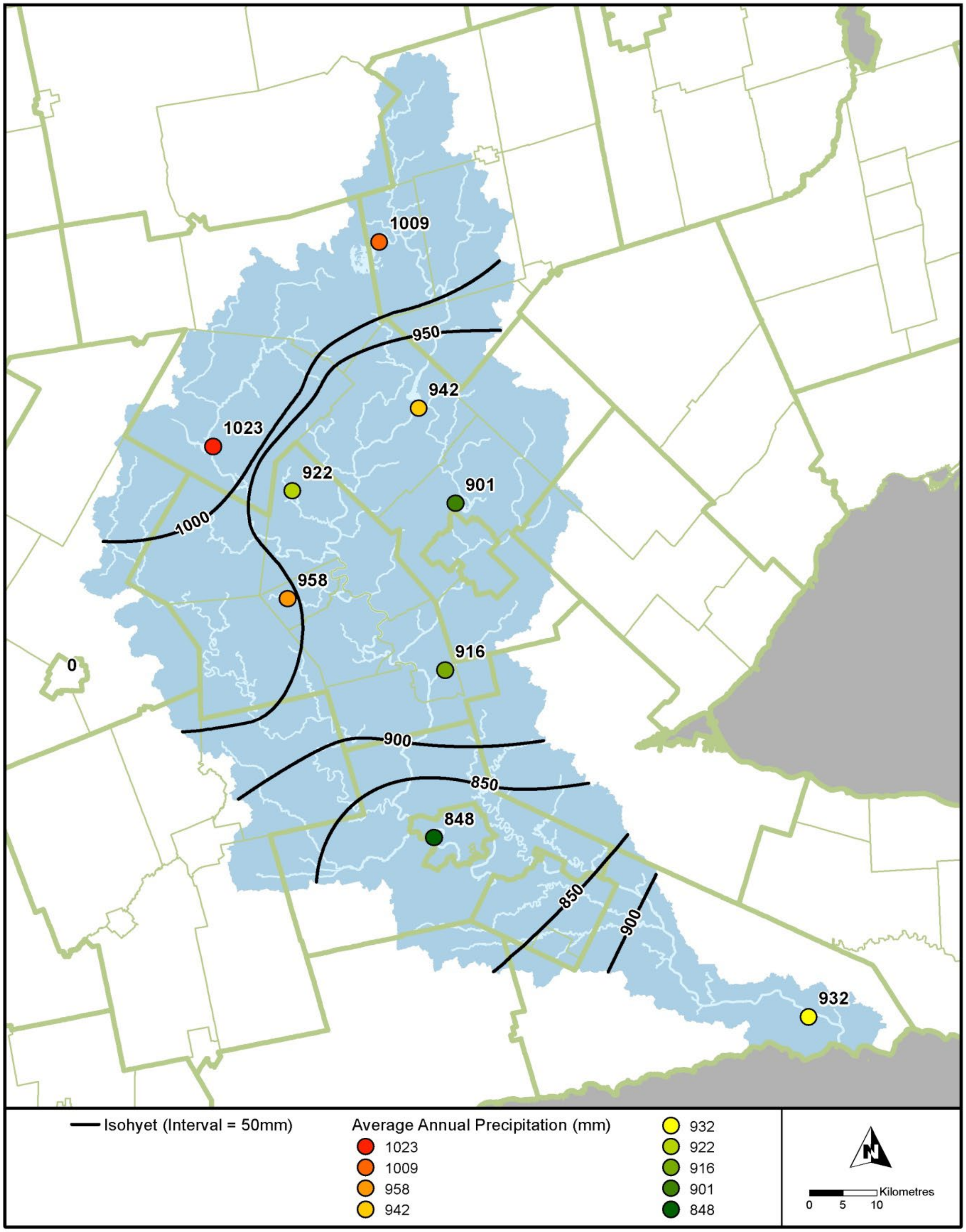
The watershed has an average annual precipitation of 921 mm with 16% of total precipitation falling as snow. Precipitation is highly variable within the watershed, **Map 2-19**. The northern part of the watershed had the highest annual precipitation at over 1000 mm, while the lowest annual precipitation occurred near Brantford at 850 mm. Summer precipitation is mainly from convective storms, which can be highly localized and represent a large percentage of the total summer precipitation, while the northern tip of the watershed can receive heavy snowfall coming off of Lake Huron. These factors have contributed to some local areas of low precipitation surrounded by areas of high precipitation. Total precipitation amounts have not changed significantly over the last half century, but the portion of winter precipitation falling as snow has decreased.

Figure 1 shows the watershed average precipitation and temperature on a monthly basis. Across the watershed, July is the warmest month with an average of 20 degrees. It is also the wettest month with an average of 91 mm. The driest month is February, with only 57 mm of precipitation. February and January are the coldest months with a daily average temperature of -6.4 degrees. These were also the snowiest months with approximately 55% of precipitation across the watershed falling as snow. At the northern stations, snow accounted for about 65% of the total precipitation during the months of January and February, while at the most southern stations it only accounted for about 35%.

Map 2-18: Average Annual Temperatures (1986 to 2016) in the Grand River Watershed



Map 2-19: Average Annual Precipitation (1986 to 2016) in the Grand River Watershed



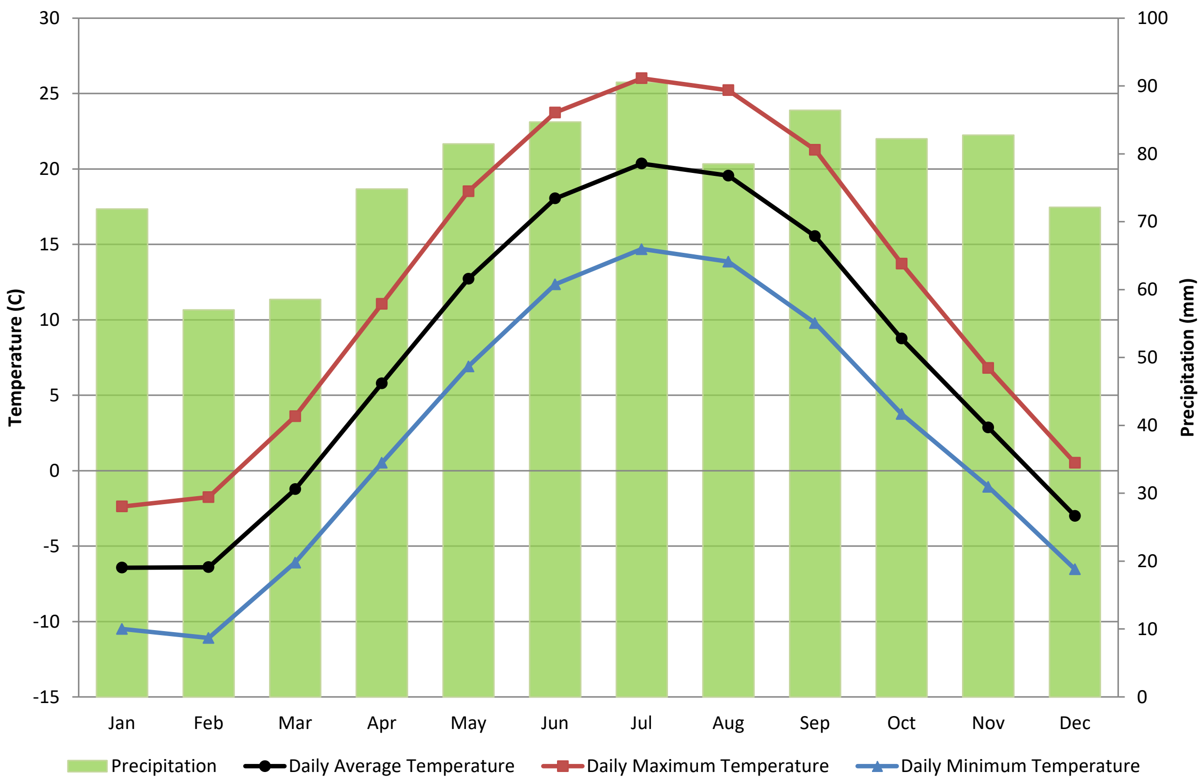


Figure 1: Watershed average monthly precipitation and temperature (1986-2016)

2.10 Land Cover in the Grand River Watershed

2.10.1 Forest and Vegetation Cover

Forest and vegetation cover are important factors in overall watershed health. In particular, increased forest and vegetation cover greatly reduces soil erosion and surface water runoff, which are often significant sources of contamination in streams, rivers and lakes. These areas contribute to improved water quality and quantity by slowing erosion and runoff, increasing evapotranspiration, increasing groundwater infiltration and uptake of nutrients and other contaminants. Reduced erosion and runoff translates into fewer contaminants and sediments entering surface waters. **Map 2-20** illustrates forest cover within the Grand River watershed.

The Grand River watershed straddles two distinct forest regions: the Great Lakes-St. Lawrence Forest Region to the north and the Deciduous Forest Region, also known as the Carolinian Zone, in the south. The forests of both regions share many of their dominant tree species including: sugar and silver maple, beech, ash species, basswood, white elm, red and bur oak, bitternut hickory and black cherry. In the Great Lakes - St. Lawrence Region conifer species, including white pine, eastern hemlock and eastern white cedar, make up a greater percentage of the forest composition, while the Carolinian zone is more dominated by deciduous species including a greater number of oak and hickory species. The Carolinian zone is also home to a number of tree species that are at the northern edges of their natural ranges including pignut, giant shellbark and shagbark hickory, black, Chinquapin and northern pin oak, sycamore, tulip tree, sassafras and American chestnut.

Forests currently cover approximately 16% of the Grand River watershed, below the 30% cover suggested by Environment Canada as the level required to sustain a healthy watershed. Forest cover levels are highest in the McKenzie Creek (26%) and Speed River (24%) subwatersheds and lowest in the agriculturally dominated Conestogo (11%) and Upper Middle Grand (12%) subwatersheds **(Map 2-20).**

Through most of the watershed, forest patches tend to be small and fragmented. In agricultural areas the historic practice of leaving a small woodlot at the back of the farm lots resulted in narrow forest bands that provide some forest connectivity across the landscape. Large blocks or high concentrations of forest in the watershed are often associated with poorly drained areas and wetlands. Large forest blocks and interior forest are uncommon and therefore where present they are especially valuable to sensitive woodland species that require a more secluded woodland habitat.

For more detailed description and history of the forests of the Grand River watershed, see *A Watershed Forest Plan for the Grand River* (2004).

2.10.2 Wetlands

Wetlands are a significant landscape feature in terms of providing habitat to a diverse range of species, as well as providing moderation to surface water flow by absorbing surface water runoff and releasing it slowly. This process acts as a filter and can reduce contamination reaching downstream surface and groundwater sources, thereby improving water quality and drinking water sources.

Wetlands often contribute to groundwater recharge, especially in areas of permeable soils (gravel, sand or loam). Where groundwater is used for drinking water or other uses, these wetland recharge areas can play a significant role in enhancing groundwater resources. However, contamination of the wetlands and upstream water can lead to contamination of groundwater sources, as wetlands recharging groundwater provide a direct conduit to aquifers.

Wetlands can also be areas of groundwater discharge, where aquifers located close to the surface release water. These are significant areas for habitat creation and species diversity, and can moderate surface water flow conditions and temperatures of streams and rivers that drain wetlands.

Within the Grand River watershed, over 65 percent of historical wetlands have been lost. In some areas of the watershed this exceeds 85 percent. A minimum of ten percent wetland coverage within a watershed is thought to be required to indicate a healthy watershed. Overall wetland coverage in the Grand River watershed meets this goal. However, in over half of the subwatersheds the percentage of existing wetlands is significantly lower, indicating considerable regional variation in wetland loss from one sub-watershed to another.

Wetland cover meets or exceeds the federal target in the following subwatersheds: Upper Grand (18%), Speed (17%), Whitemans (13%), Middle Grand (11%), and Fairchild (11%). Wetland cover is below the federal target in the following subwatersheds: Upper Middle Grand (7%), Nith (6%), Lower Grand (5%), Conestoga (5%), Lower Middle Grand (4%), McKenzie Creek (4%).

Map 2-22 shows the distribution of wetlands throughout the Grand River watershed.

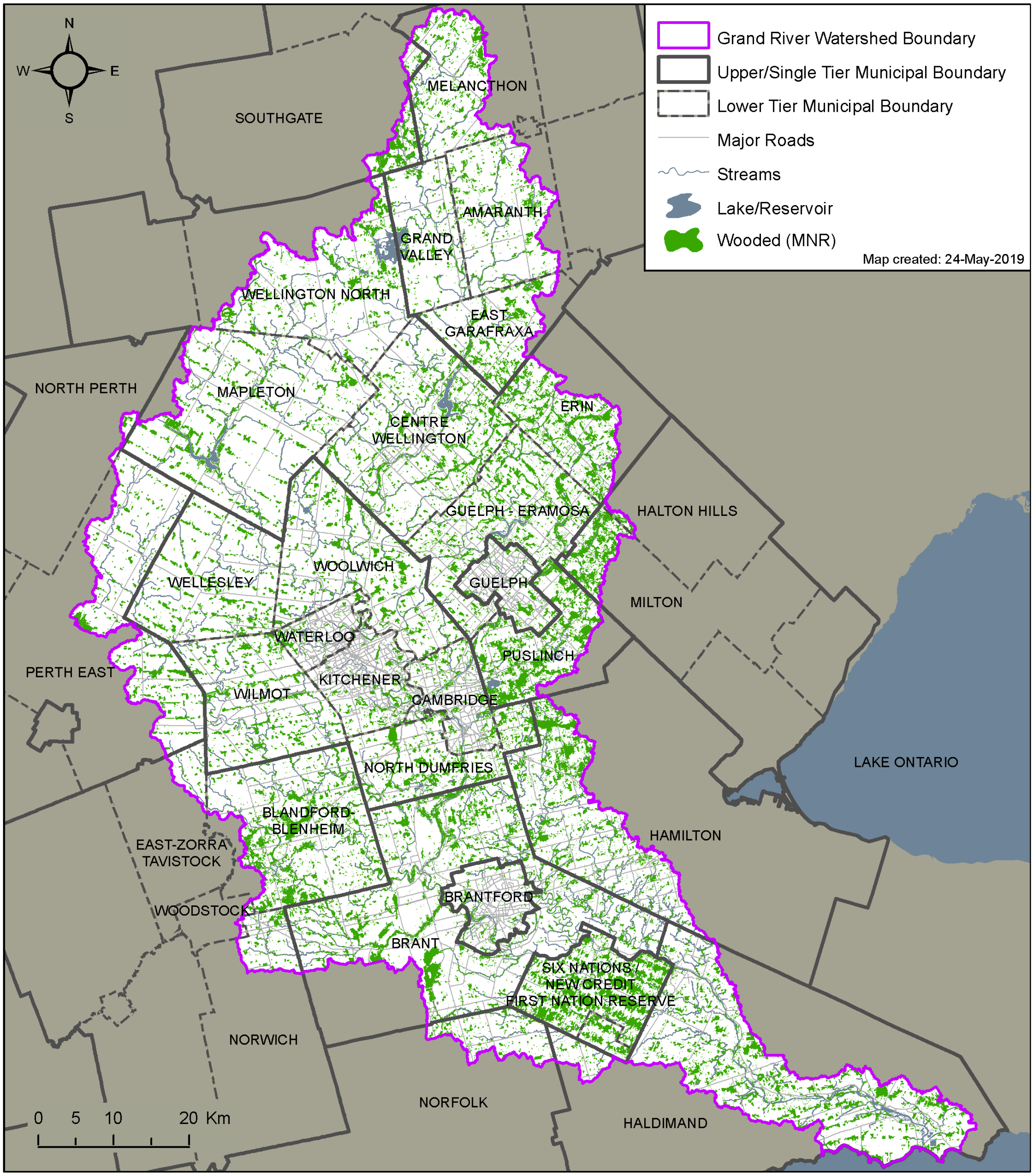
Despite the historical loss of these areas, there are many significant wetland complexes found throughout the watershed, including:

- Luther Marsh – covering approximately 4029 hectares in the Dundalk Till Plain at the headwaters of the Grand River;
- Brisbane Swamp – a major headwater for the Eramosa River in the Guelph Drumlin Field; not in our watershed; perhaps highlight the Eramosa-Blue Springs PSW Complex (3089 ha) as an important headwater wetland;
- Horseshoe Moraine – over 5,000 hectares of groundwater fed wetlands; comprises several wetland complexes, including the Mill Creek PSW Complex (1804 ha), Spottiswood-Pinehurst Lake PSW Complex (100 ha), many small kettle wetlands that are internally drained (i.e. no surface water outlet);
- Beverly Swamp – at approximately 2,000 hectares, it is the third largest remaining interior wetland in Southern Ontario in the southeast portion of the watershed;
- Keldon Swamp in the north, approximately 920 hectares;
- Amaranth Source Area in Dufferin County; (Melanchton Swamp PSW Complex is the largest (approx. 2800 hectares);
- Roseville Swamp in North Dumfries Township, (approx. 630 hectares);
- Several provincially-significant wetlands in the Oxford Till Plain draining into Whitemans Creek; Whitemans Creek-Horner Creek PSW Complex (3492 ha) and Whitemans Creek-Kenny Creek PSW Complex (2082 ha) are the 2 largest complexes but these span several physiographic regions;
- Provincially-significant alluvial and riparian swamps in the southwest portion of the watershed in the Mount Elgin Ridges Region, providing warm water fishery habitat. Several smaller and more isolated wetlands remain unevaluated but provide flood storage and groundwater recharge functions; and,

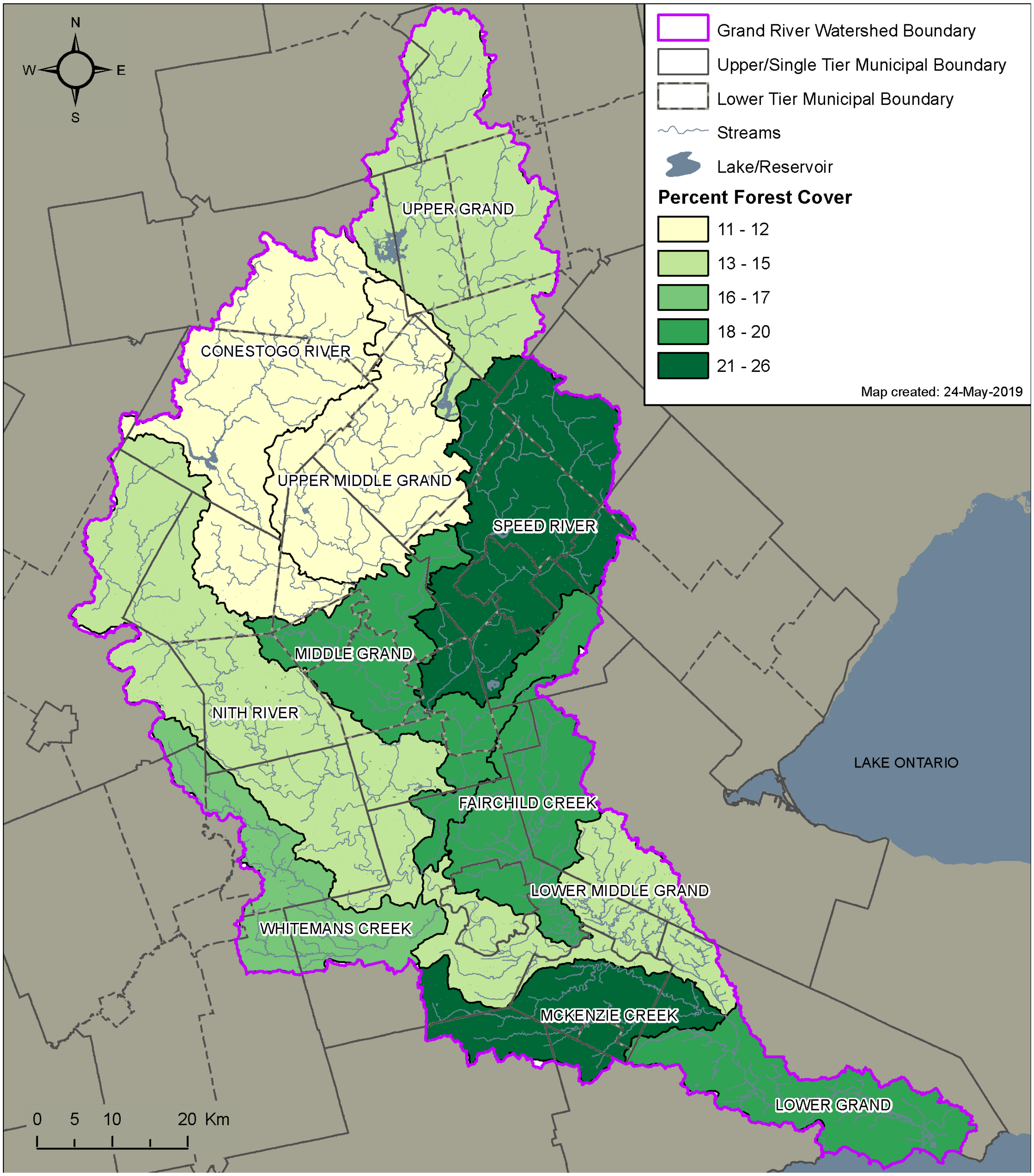
At approximately 5700 hectares and located on the Guelph Drumlin Field, the Speed-Lutteral-Swan Creek PSW Complex is the largest evaluated wetland in our watershed. The highest concentrations of wetlands are located in the eastern portion of the watershed, in the Speed and Eramosa subwatersheds, as well as in Puslinch Township. The northern most portion of the watershed, near the towns of Dundalk, Grand Valley and Damascus, also holds significant wetland complexes. The wetlands and wet meadows in the poorly drained till plains and clay and gravel soils in the north are very significant source areas for the headwaters of the Grand, Nith and Conestogo Rivers.

Although wetlands were drastically reduced throughout the watershed during the period of European settlement, and more recently through the processes of agricultural drainage and urbanization, they continue to play a significant role in water quality improvement and surface water flow regulation, as well as providing habitat for a diverse range of species.

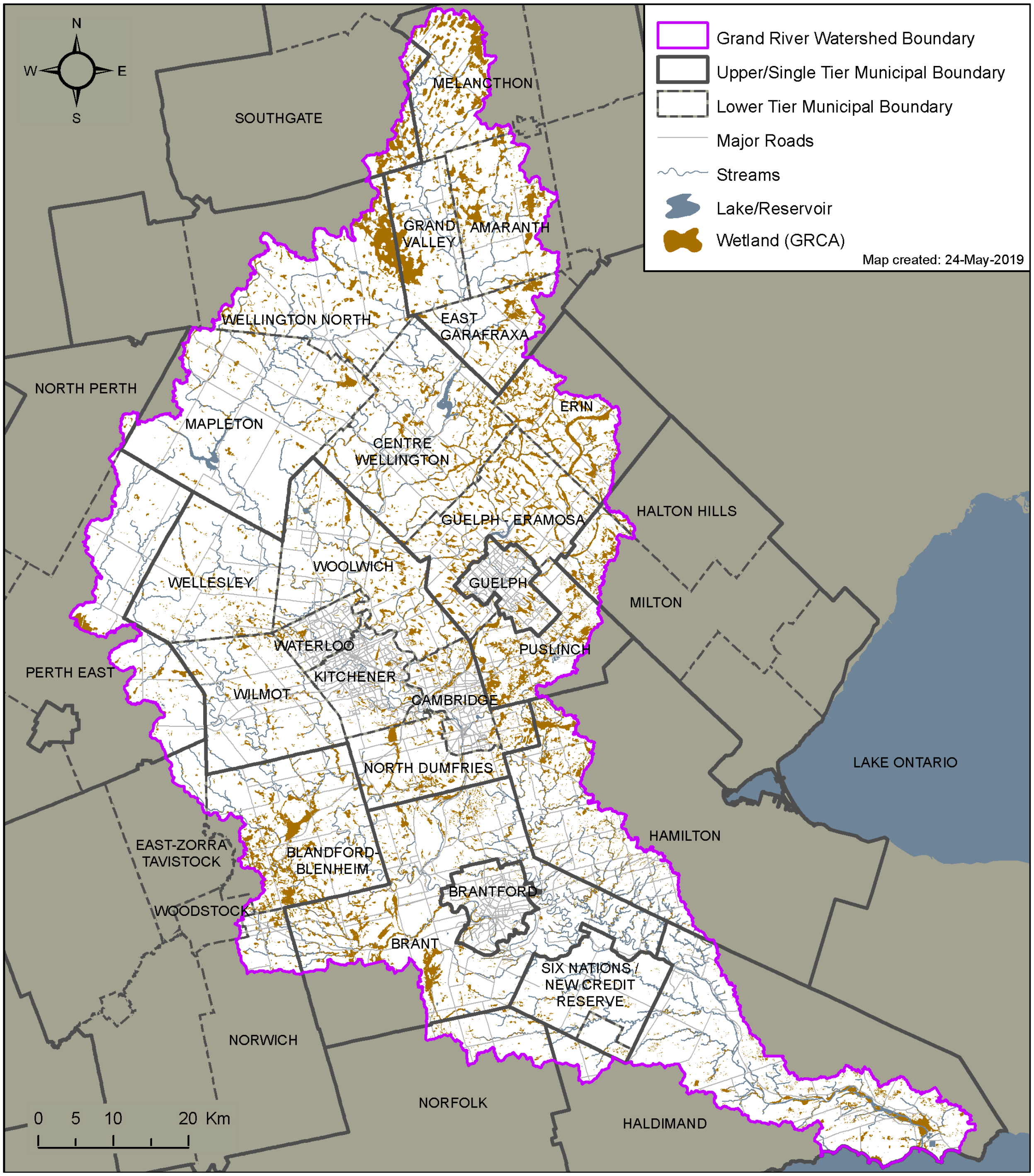
Map 2-20: Forest Cover in the Grand River Watershed



Map 2-21: Percent Forest Cover by Watershed



Map 2-22: Distribution of Wetlands in the Grand River Watershed



2.11 Surface Water Characterization

The Grand River drains approximately 6,800 square kilometres from its headwaters in the Dundalk Highlands to where it empties into Lake Erie at Port Maitland. Total elevation change along its 300 kilometres length is approximately 180 metres. The major tributaries of the Grand River include: the Conestogo and Nith Rivers, draining the western half of the watershed; and the Speed and Eramosa Rivers, which drains the north-east. Several smaller tributaries drain the southern half of the watershed. The largest of these include Fairchild, Whitemans and McKenzie creeks.

The Grand River is a managed river system where reservoir operations, water supply and wastewater management were designed as an integrated system on a watershed basis. The surface water system can be characterized with three regions: the northern till plains, the central moraines, and the southern clay plain. Water is managed primarily through a system of multi-purpose reservoirs and an extensive monitoring system of stream flow gauges.

2.11.1 Multi-Purpose Reservoirs

The Grand River Conservation Authority operates seven dams and reservoirs that have the dual purpose of flood damage reduction and low flow augmentation. The four largest reservoirs, Shand, Luther, Conestogo and Guelph, are operated as a system to provide flow augmentation and flood control for the main Grand River and the lower portion of the Speed River.

The reservoirs are managed to provide maximum flood storage during the spring, to handle spring snow melt, and the fall, to deal with remnants of tropical hurricanes. During periods of high flow, water is taken into storage at the reservoirs and downstream peak flows are reduced. During dry periods, water is released from storage to maintain minimum flows in the river system. Low flow augmentation is critical to the operation of municipal wastewater treatment plants to assist with assimilating wastewater effluent and to provide sufficient supplies for municipal drinking water systems in Waterloo Region, Brantford and Ohsweken.

2.11.2 Northern Till Plains

The northern till plains cover most of the headwaters of the Grand, Conestogo, Speed and Nith Rivers. This region is characterized by high surface runoff that results in high flood flows, but little to no flow in watercourses during sustained dry periods. Watercourses are well defined and much of the land is tile drained for agriculture. Flow distribution from the Leggatt gauge (**Figure 2-1**) shows both high flows during the spring freshet period and low flows during the summer months. This flow distribution is fairly typical of watercourses in this region.

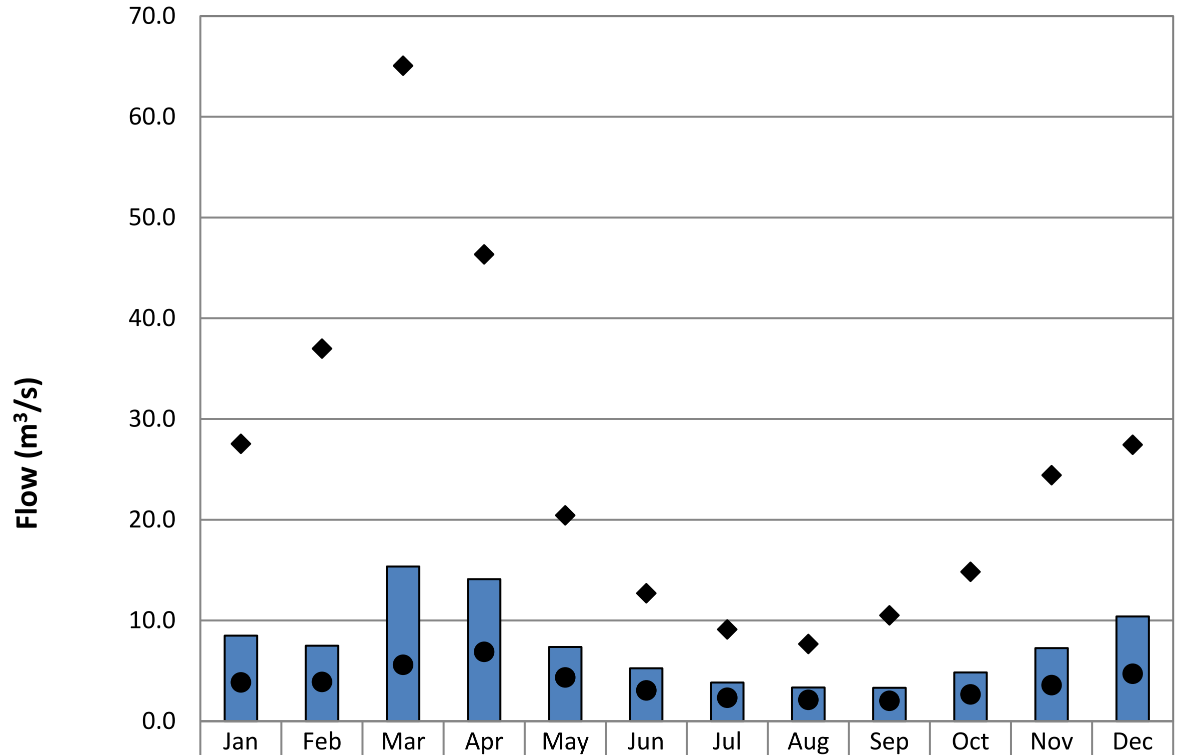
The multi-purpose reservoirs were built on the fringe of these till plains to manage high surface runoff. Some watercourses downstream of the reservoirs are influenced by reservoir operations, but most watercourses in this region are unregulated.

2.11.3 Central Moraines and Sand Plains

The central portion of the watershed contains most of the watershed's moraines and sand/gravel deposits left by glaciation. The drainage network is not well defined and stream flows are maintained by groundwater discharge and/or flow augmentation from upstream reservoirs. Urbanization in this part of the watershed has led to an increase in surface runoff from impervious area and localized flooding issues.

There are three main types of watercourses in this region. The main Grand River and the lower Speed River are regulated by upstream reservoirs that add significant flow augmentation during the summer dry period and decrease flood peaks. An example is the flow distribution at the Galt gauge on the

Grand River in Cambridge (**Figure 2-2**) where the summer months have a very consistent median flow. The second types are unregulated rural watercourses, such as the Nith River (



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	8.5	7.5	15.4	14.1	7.4	5.3	3.8	3.4	3.3	4.8	7.3	10.4
10th Percentile Flow	3.8	3.9	5.6	6.9	4.3	3.0	2.3	2.1	2.0	2.7	3.6	4.7
90th Percentile Flow	27.5	37.0	65.1	46.3	20.4	12.7	9.1	7.7	10.5	14.8	24.4	27.4

Figure 2-3). Although there is no flow augmentation on the Nith River, summer flows are maintained by groundwater discharge from the Waterloo moraine. The final types are the urban watercourses. These watercourses react quickly during storm events since they are a major receiver of urban storm water runoff. Low flow conditions are variable depending on the condition of the watercourse and design of local storm water retention ponds.

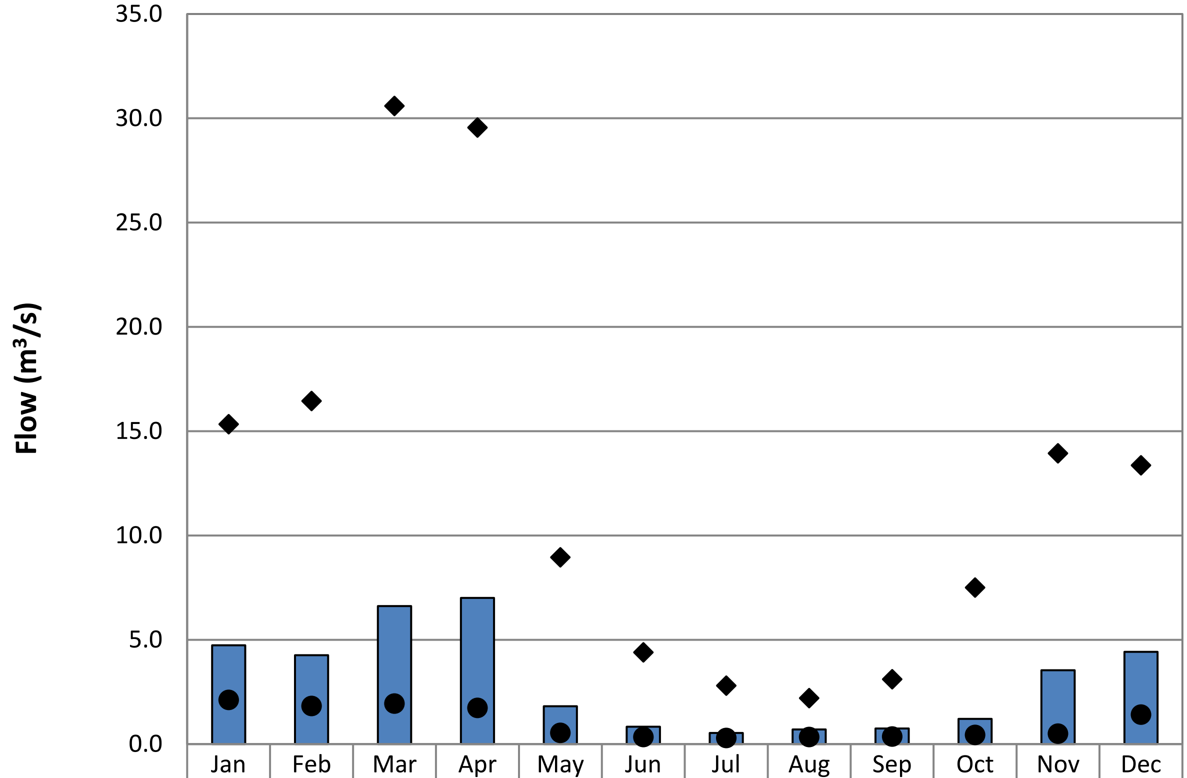
2.11.4 Southern Clay Plain

The southern portion of the watershed is dominated by the Haldimand Clay Plain. The landscape produces extremely high surface runoff and has a dense drainage network. There are few stream gauges monitoring the smaller tributaries in this reach and the few that do exist monitor flows in watercourses with headwaters in the central moraines. An example is McKenzie Creek, **Figure 2-4**, which has a flow distribution that is similar to the distribution in the northern till plain. On the other hand, flows in the Grand River are sustained by upstream flow augmentation and groundwater discharge. **Figure 2-5** shows the flows at the York gauge on the Grand River with high and consistent flows during the summer months.

2.11.5 Surface Water Monitoring

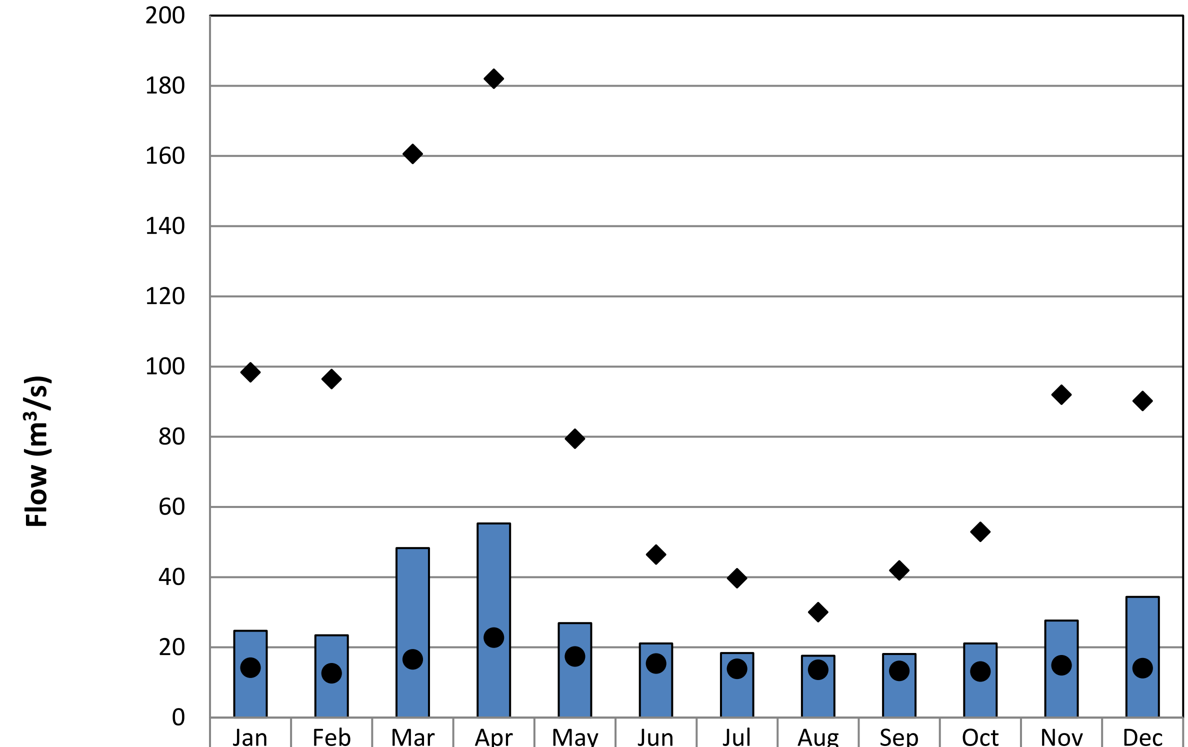
The flow monitoring network in the Grand River watershed consists of a dense network of stream gauges funded under the Federal/Provincial cost share agreement, gauges operated solely by the GRCA, and gauges operated in partnership between the GRCA and its member municipalities. The gauge network has been designed to support a number of water management activities such as flood management, low flow augmentation, water quality analysis, low water response, subwatershed planning, and basin reporting.

There are over 65 stream flow and level gauges currently in operation in the watershed, shown in **Map 2-23**. The gauge network covers both the regulated and the unregulated portions of the watershed, as well as inflow to major reservoirs and outflow from major dams. Many of the gauges record sub-hourly flow, with flow data available in real-time. Some gauges are operated seasonally for specific purposes, while others are operated continuously for various water management activities. Flow records in the Grand River Watershed date back to 1913 for some of the oldest gauges, predating the major dams and reservoirs.



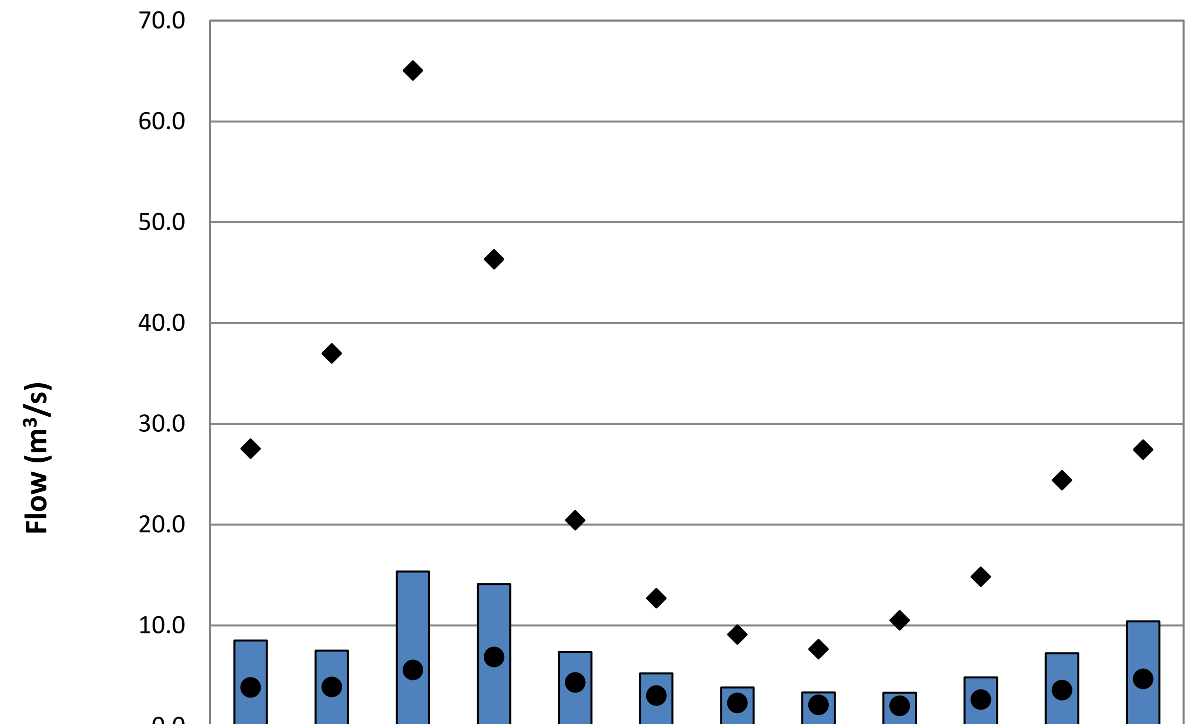
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
■ Median Flow	4.7	4.3	6.6	7.0	1.8	0.8	0.5	0.7	0.8	1.2	3.5	4.4
● 10th Percentile Flow	2.1	1.8	1.9	1.7	0.5	0.3	0.3	0.3	0.4	0.4	0.5	1.4
◆ 90th Percentile Flow	15.3	16.4	30.6	29.6	9.0	4.4	2.8	2.2	3.1	7.5	13.9	13.4

Figure 2-1: Flow Distribution for the Grand River at Leggatt



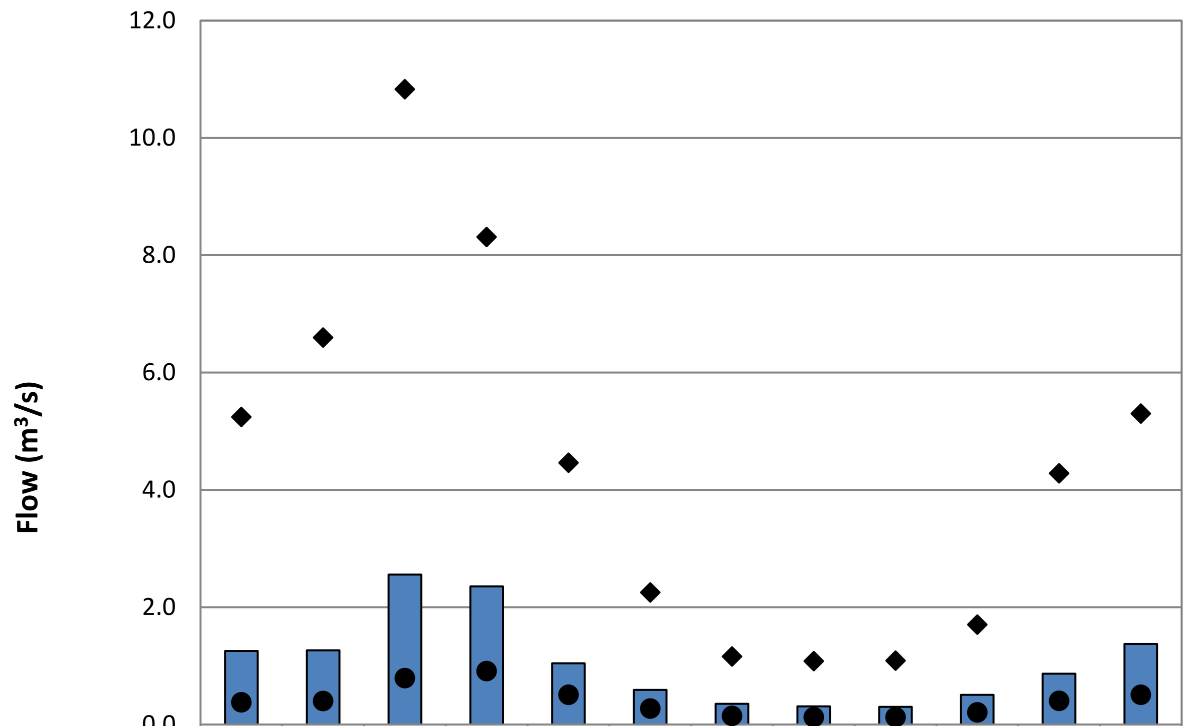
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	25	23	48	55	27	21	18	18	18	21	28	34
10th Percentile Flow	14	13	17	23	17	15	14	14	13	13	15	14
90th Percentile Flow	98	96	161	182	79	46	40	30	42	53	92	90

Figure 2-2: Flow Distribution for the Grand River at Galt



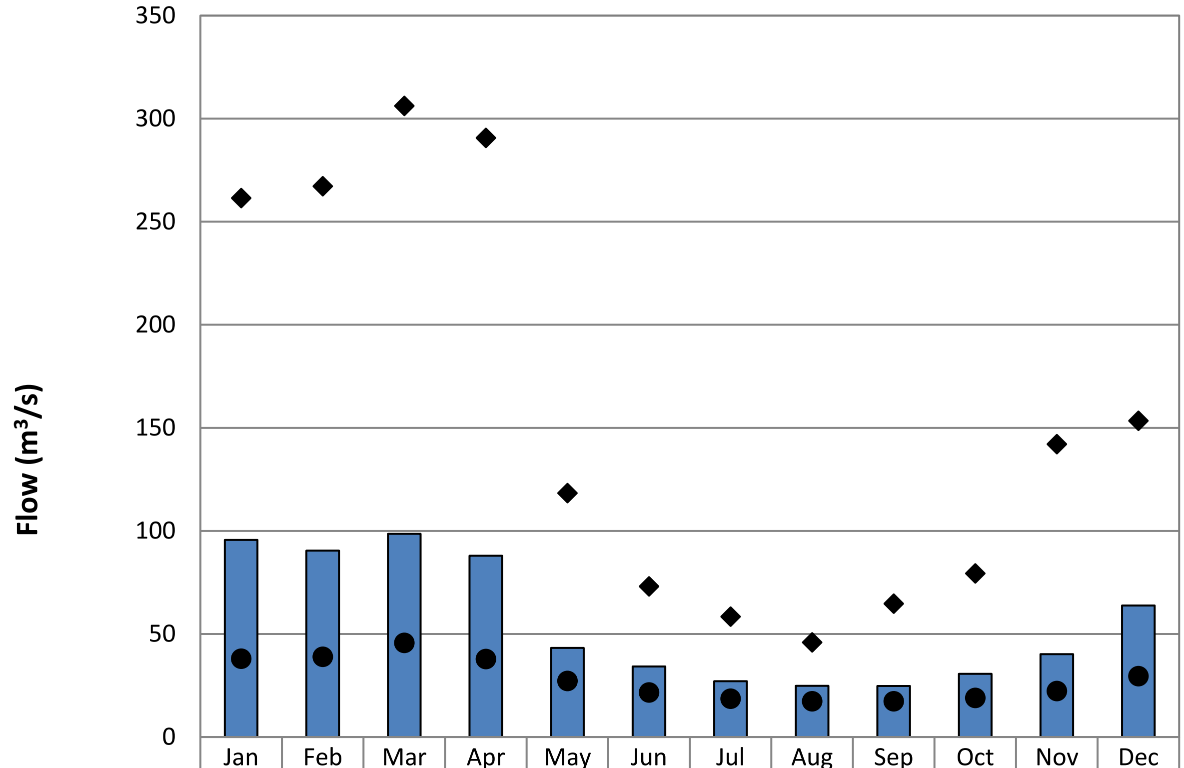
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	8.5	7.5	15.4	14.1	7.4	5.3	3.8	3.4	3.3	4.8	7.3	10.4
10th Percentile Flow	3.8	3.9	5.6	6.9	4.3	3.0	2.3	2.1	2.0	2.7	3.6	4.7
90th Percentile Flow	27.5	37.0	65.1	46.3	20.4	12.7	9.1	7.7	10.5	14.8	24.4	27.4

Figure 2-3: Flow Distribution for the Nith River at Canning



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
■ Median Flow	1.26	1.27	2.56	2.36	1.05	0.59	0.35	0.31	0.30	0.51	0.87	1.38
● 10th Percentile Flow	0.38	0.40	0.79	0.91	0.51	0.27	0.15	0.13	0.12	0.21	0.40	0.51
◆ 90th Percentile Flow	5.24	6.60	10.83	8.31	4.46	2.25	1.16	1.08	1.09	1.70	4.28	5.30

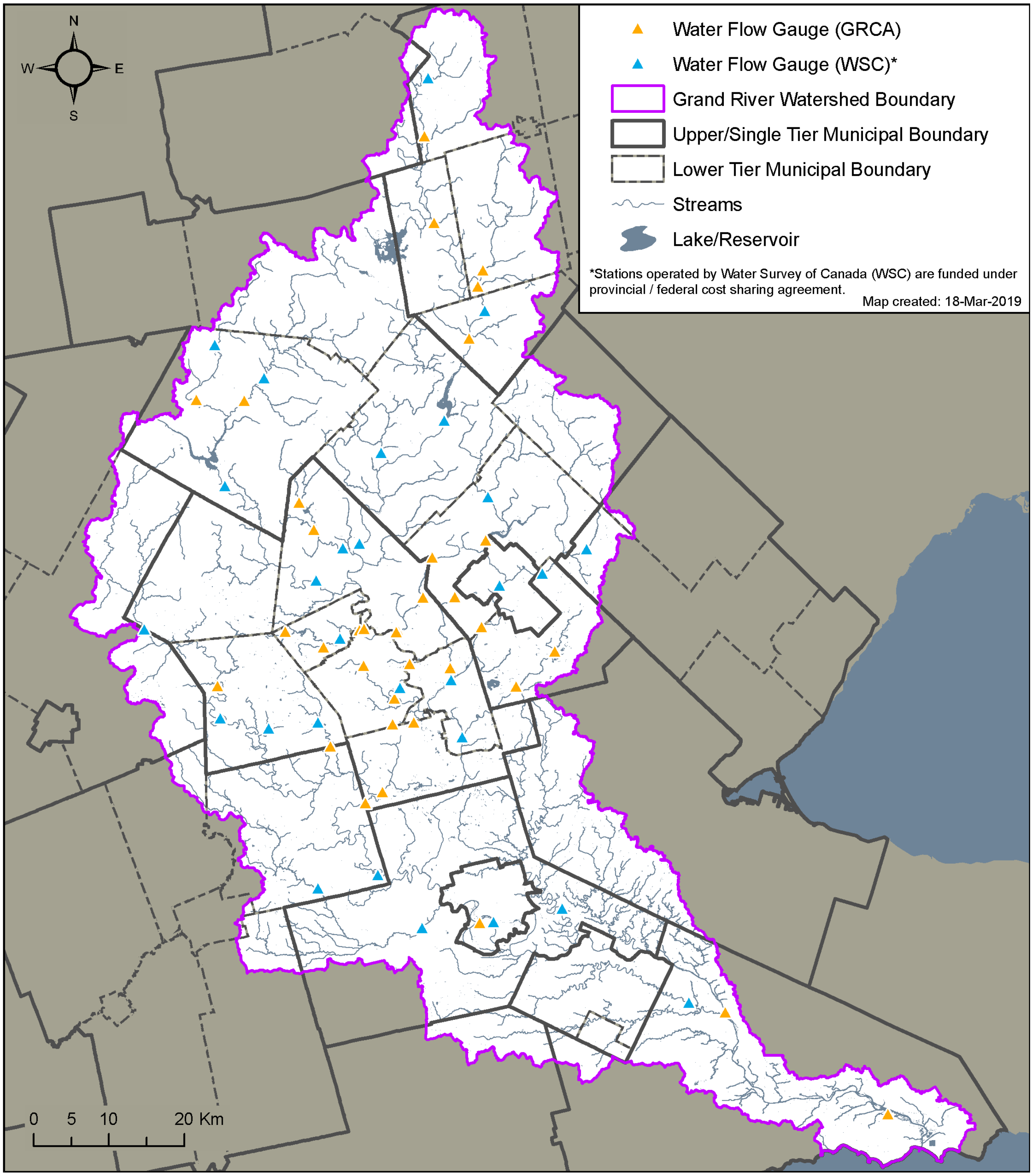
Figure 2-4: Flow Distribution for McKenzie Creek



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median Flow	96	90	99	88	43	34	27	25	25	31	40	64
10th Percentile Flow	38	39	46	38	27	22	19	17	17	19	22	30
90th Percentile Flow	261	267	306	291	118	73	58	46	65	79	142	153

Figure 2-5: Flow Distribution for the Grand River at York

Map 2-23: Water Flow Gauges in the Grand River Watershed



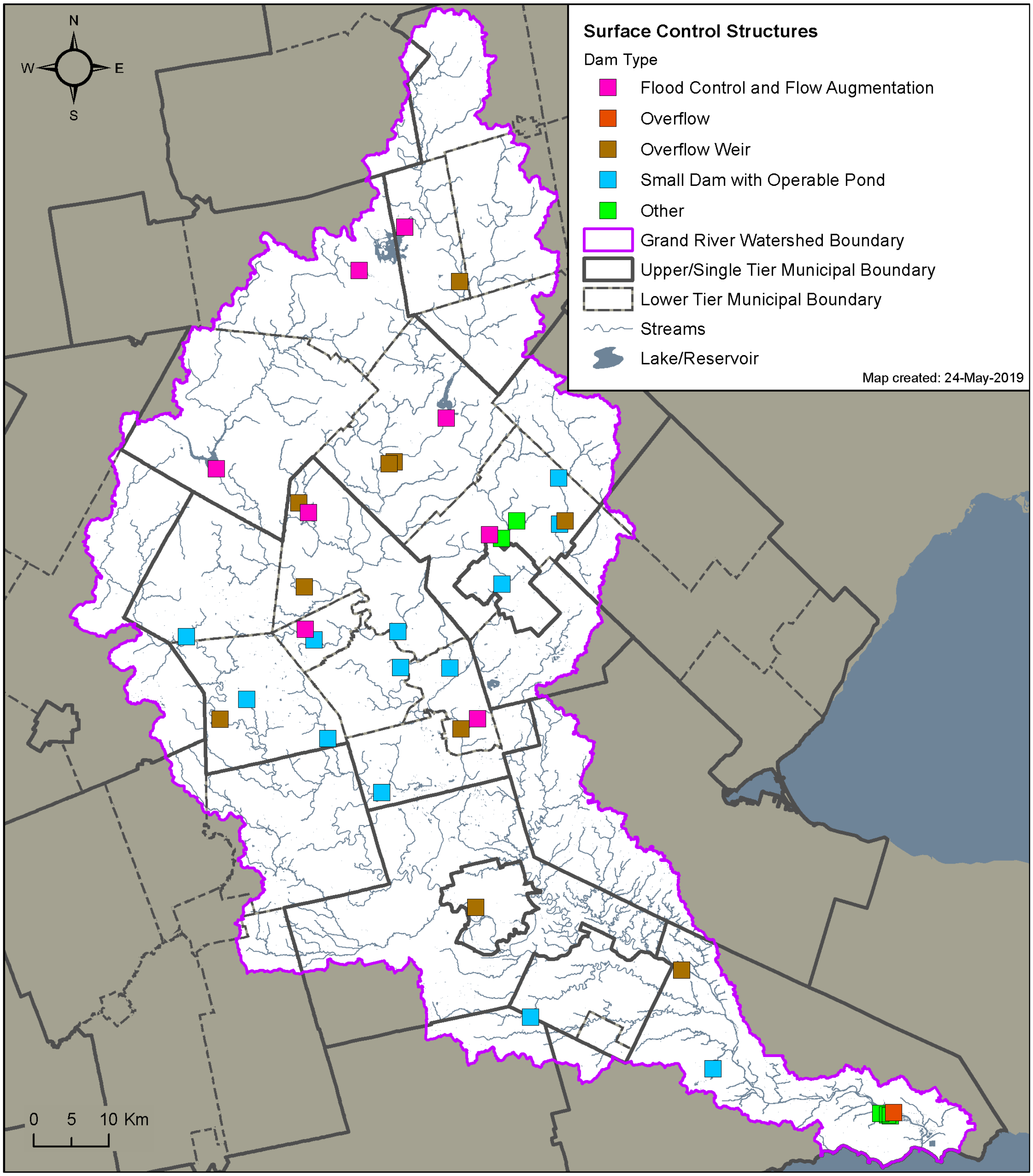
2.11.6 Water Control Structures

There are approximately thirty-four water control structures operated by the Grand River Conservation Authority throughout the watershed. These structures range from simple overflow weirs to large multi-purpose dams and reservoirs. **Map 2-24** shows the location of GRCA control structures throughout the watershed.

There are also approximately 103 private and municipally-owned dams located throughout the watershed. Small mill ponds and overflow weirs are remnants of the valley's early industrial heritage. These structures are often a community focal point and recreational area. While they back water up and deepen the river channel locally, they do not provide flood control or improve river flow. A dam inventory describing what is known about all dams in the watershed is maintained by the GRCA.

A series of multi-purpose reservoirs were constructed in the mid-20th century to control flooding and for low flow augmentation. There are seven significant water control structures that are used for active river management by the GRCA. The current operating procedure for the large dams (Shand, Conestogo, Guelph, and Luther) was established as a recommendation of the 1982 Grand River Basin Water Management Study. At that time, reservoir system operation was optimized to meet downstream flow targets for the dual purpose of waste assimilation and drinking water takings, while still providing an adequate level of protection for flood control. The reservoirs are filled during the spring snowmelt, the most active flooding season, and then gradually drawn down over the summer and early fall, thereby supplying more flow in the river than would normally be. The current operating procedures for the reservoir system were modified in 2004 to provide more flexibility to respond to warmer winters and less accumulation of snow. The reservoir system has a very significant effect on the flows in the Grand, Conestogo, and Speed Rivers.

Map 2-24: Surface Water Control Structures in the Grand River Watershed



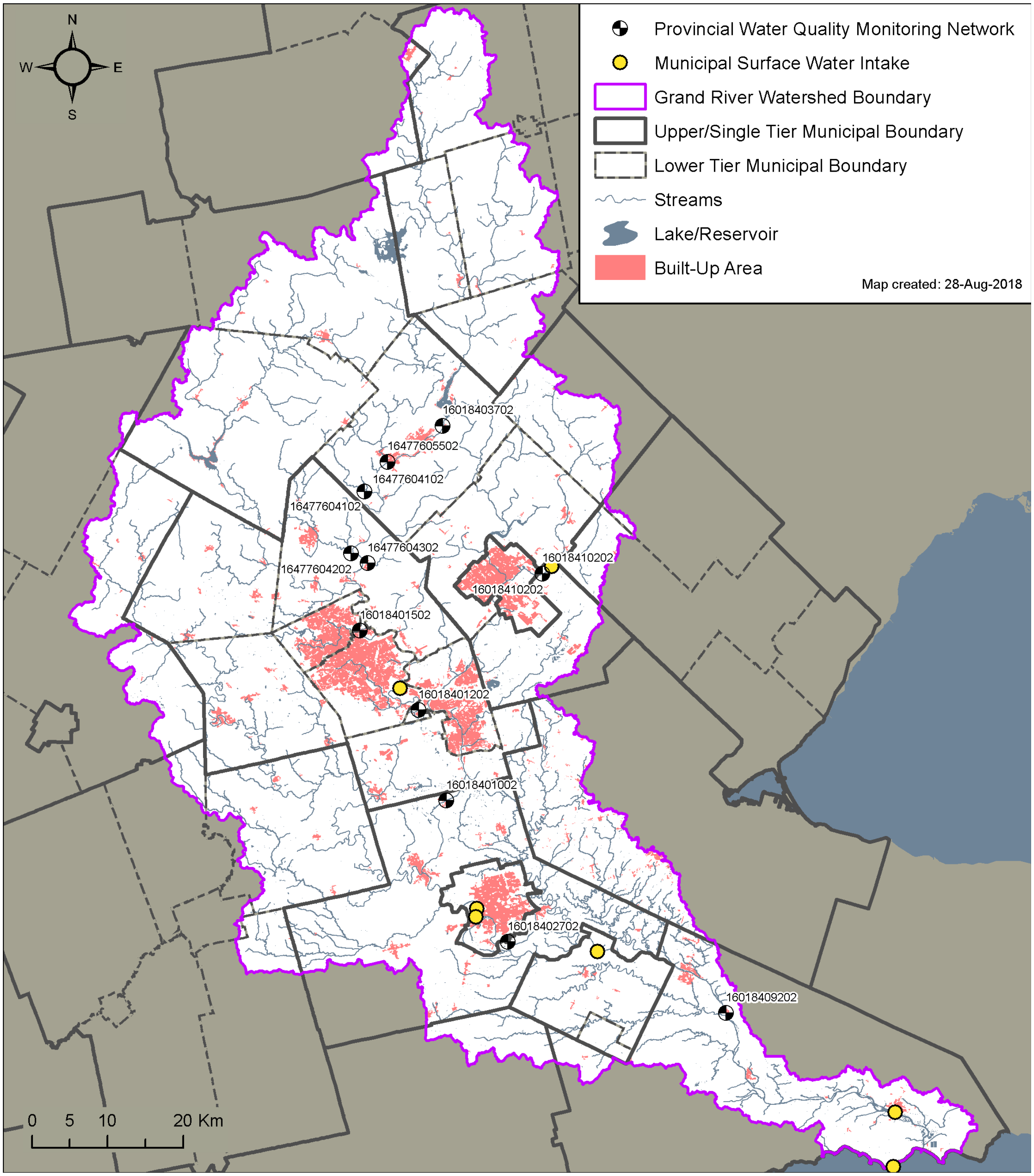
2.12 Surface Water Quality

Historic characterization of the water quality in the Grand River watershed can be found in the following reports: Loomer and Cooke (2011) Water Quality in the Grand River Watershed: Current Conditions and Trends (2003-2008).

There are 37 long-term water quality monitoring sites that are sampled roughly 9-10 times per year during the open water season (March – November). These sites are sampled in partnership with the Ministry of Environment, Conservation and Parks through their Provincial Long Term Monitoring Network (PWQMN).

The following describes the ambient water quality in the Grand River above and below surface water intakes. The parameters characterized including chloride, sodium and nitrates are likely of interest for municipal drinking water supplies. **Map 2-25** shows the long term water quality monitoring sites in the vicinity of municipal drinking water intakes in the Grand River watershed.

Map 2-25: Water Quality Monitoring Sites in the Grand River Watershed



2.12.1 Grand River

The Grand River flows through the central region from the Shand Dam to Brantford. Above the Mannheim drinking water intake, it collects surface water from the Conestogo River and the Irvine, Canagagigue, Laurel creeks. The Grand River continues to flow downstream and collects surface water from other major tributaries including the Speed and Nith rivers and Whitemans Creek before it reaches the Brantford drinking water intake at Wilks Dam.

In addition to surface water, groundwater discharges into the Grand River downstream of Cambridge as well as into many smaller tributaries draining the Waterloo and Paris-Galt moraines.

Water quality is reflective of both the geology and land use in the watershed however, within the central Grand River region, land use plays a significant role. Agricultural production tends to be much more intense in the Conestogo River basin and Canagagigue Creek and can significantly influence water quality in the Grand River especially during the spring freshet and following major rainfall events. The urban area is quite hydrologically dynamic and can also impact the river especially following intense rainfall events.

There are a number of small wastewater treatment plants that discharge treated effluent into the Grand River and its tributaries prior to reaching Bridgeport. Specifically, the Waterloo wastewater treatment plant is a large plant that discharges into the river approximately 17 km upstream of the Mannheim drinking water intake.

The Grand and Speed rivers then collect treated effluent from the Kitchener, Preston, Galt, Paris, Guelph and Hespeler wastewater treatment plants prior to surface water reaching the Brantford intake. Ongoing upgrades to wastewater treatment plants in the Region of Waterloo are improving the ambient river quality (GRCA Board Report, February 2017).

Descriptive statistics for chloride, sodium and nitrates are listed in **Table 2-6**.

Chloride concentrations reflect the influence of urban point and non-point sources but levels in the Grand River do not exceed the aesthetics guideline for drinking water supplies of 250 mg/L. Levels do, however, approach the guideline for the protection of aquatic life (150 mg/L) albeit occasionally, usually during the spring freshet. Levels in the smaller urban tributaries such as Schneider’s Creek and Laurel Creek are routinely above this benchmark, primarily due to the use of road salt. Previous unpublished studies have illustrated increasing trends in chloride (GRCA, unpublished). Further, chloride levels in the Speed River appear to contribute substantially to the overall chloride levels found in the Grand River below the urban area at Glen Morris (Loomer and Cooke, 2011).

Sodium levels in drinking water supplies are flagged for those people who are on a sodium restricted diet. Levels in the Grand River are substantially below the Canadian Drinking water guideline of 200 mg/L yet are above the levels required for reporting to local medical officer of health (20 mg/L), particularly in the Grand River near Brantford.

Elevated nitrate concentrations are found in the Grand River upstream of Bridgeport during the winter months. Research in the watershed indicated that shallow tile drainage may have an important role in the elevated nitrate concentrations seen in the upper central Grand River area (see **Table 2-7).** Nitrate levels above 10 mg/L, the drinking water quality guideline for treated water, may cause concern for municipal supplies. The 75th percentile in winter sampling ranged from 2.0 mg/L in the Grand River below the Shand Dam to 7.2 mg/L in the Canagagigue Creek. The maximum concentration seen during the sampling program was 9.2 mg/L in the Canagagigue Creek in February 2013. Nitrate is a conservative parameter and treatment to remove this chemical is costly. The GRCA has installed a continuous monitoring probe for nitrate at the Bridgeport Water Quality Station for near-real time surveillance of nitrate during the winter.

2.12.2 Eramosa River

Water quality in the Eramosa River is of relatively high quality for all uses. Chloride, sodium and nitrate levels are far below the guidelines for both drinking water and for the protection of aquatic life.

Table 2-6: Descriptive statistics for chloride, nitrate and sodium at select water quality monitoring sites in the Grand and Eramosa Rivers for the open water season (March – November)

River	Site Description	Site No.	Minimum Chloride (mg/L)	Average Chloride (mg/L)	Median Chloride (mg/L)	75th percentile Chloride (mg/L)	95th percentile Chloride (mg/L)	Maximum Chloride (mg/L)
Eramosa River	Wellington Country Rd. 41, Arkell	16018410202	13.8	33.6	33.8	35.6	41.7	42.3
Grand River	Bridgeport Bridge	16018401502	16.2	32.9	31.0	35.6	45.9	68.0
Grand River	Blair Bridge	16018401202	0.2	69.4	72.9	87.7	110.0	118.0
Grand River	Glen Morris Bridge	16018401002	20.5	84.3	90.8	107.3	130.2	145.0
Grand River	Cockshutts Bridge, Brantford	16018402702	0.2	73.5	82.9	92.7	110.5	117.0
Grand River	Bridge, York	16018409202	22.1	77.5	83.2	96.7	111.8	132.0

River	Site Description	Site No.	Minimum Nitrates (mg/L)	Average Nitrates (mg/L)	Median Nitrates (mg/L)	75th percentile Nitrates (mg/L)	95th percentile Nitrates (mg/L)	Maximum Nitrates (mg/L)
Eramosa River	Wellington Country Rd. 41, Arkell	16018410202	0.53	0.99	0.98	1.18	1.42	1.76
Grand River	Bridgeport Bridge	16018401502	0.46	3.50	2.84	4.80	7.65	8.10
Grand River	Blair Bridge	16018401202	1.15	3.09	2.98	3.86	4.67	6.63
Grand River	Glen Morris Bridge	16018401002	1.17	3.41	3.43	3.89	4.99	6.56
Grand River	Cockshutts Bridge, Brantford	16018402702	1.93	3.31	3.22	3.84	4.88	6.74
Grand River	Bridge, York	16018409202	1.50	3.16	3.02	3.58	4.85	5.83

River	Site Description	Site No.	Minimum Sodium (mg/L)	Average Sodium (mg/L)	Median Sodium (mg/L)	75th percentile Sodium (mg/L)	95th percentile Sodium (mg/L)	Maximum Sodium (mg/L)
Eramosa River	**Wellington Country Rd. 41, Arkell**	16018410202	--	--	--	--	--	--
Grand River	**Bridgeport Bridge**	16018401502	9.6	17.3	17.1	19.1	24.0	31.7
Grand River	**Blair Bridge**	16018401202	12.6	41.5	43.6	54.1	66.9	69.6
Grand River	**Glen Morris Bridge**	16018401002	12.2	50.9	53.3	64.4	80.5	88.1
Grand River	**Cockshutts Bridge, Brantford**	16018402702	11.6	44.3	48.5	57.4	67.5	72.2
Grand River	**Bridge, York**	16018409202	--	--	--	--	--	--

Table 2-7: Nitrate concentrations at select monitoring sites in the central Grand River region during winter months (January – March) between 2011-2015

River	Site Description	Site No.	Minimum Nitrates (mg/L)	Average Nitrates (mg/L)	Median Nitrates (mg/L)	75th Percentile Nitrates (mg/L)	95th Percentile Nitrates (mg/L)	Maximum Nitrates (mg/L)
Grand River	**First Conc. d/s of Bellwood Lake**	16018403702	1.30	1.80	1.77	2.00	2.62	2.70
Irvine Creek	**Upstream of confluence**	16477605502	3.30	4.27	4.00	4.65	5.97	6.30
Carroll Creek	**Middlebrook Rd, Pilkington 5-6**	16477604102	4.80	5.58	5.59	5.73	6.58	6.80
Swan Creek	**Wellington Rd 21, Inverhaugh**	16018412102	3.46	4.11	4.19	4.41	4.62	5.10
Cox Creek	**Waterloo Rd 23, Winterbourne**	16477604302	4.27	5.42	4.92	6.30	7.34	7.90
Canagagigue Creek	**Woolwich Twp Rd 46**	16477604202	5.24	6.65	6.40	7.18	8.83	9.20
Conestogo River	**at Glasgow Street, Conestogo Village**	16018413402	3.40	5.02	4.73	5.90	7.24	7.80
Grand River	**Bridgeport Bridge**	16018401502	2.90	4.15	4.04	4.58	5.78	6.60

2.13 Aquatic Habitat

2.13.1 Upper Grand River Subwatershed

The Upper Grand River is considered as that part of the Grand River watershed that drains into the Grand River upstream of Belwood Lake. The Upper Grand is dominated by till/clay plains and till moraines with small, localized areas of gravel and sand deposits. Much of the upper watershed was once composed of wetlands. The dense soils permit little infiltration, and flows are highly variable, with low summer and winter base flows. Most streams support coolwater fish communities, while the main stem of the Grand also contains warmwater fisheries. Downstream of Grand Valley, the river enters a narrow gravel spillway with some groundwater influences, and a sandy plain exists southeast of Grand Valley, which supports coldwater fisheries.

2.13.2 Lower Middle Grand River Subwatershed

The subwatershed includes a stretch of the Grand River from the mouth of the Nith River just north of Paris to York, and comprises portions of Brant County, the southeast quadrant of the City of Brantford, rural portions of the City of Hamilton, and small sections of Haldimand County, and Six Nations of the Grand River.

The subwatershed can be characterized as largely agricultural with a small section of urban land use in the City of Brantford. Natural areas include a wide variety of habitat types such as open water areas with shallow marsh, grasslands, meadows, and mix of deciduous and coniferous forests and swamps.

Coldwater tributaries sustained by groundwater discharge include Mount Pleasant Creek and D'Aubigny Creek, which provide suitable habitat for cold water species such as brook trout as well as cool and warm water species. Mixed water (warm to cool) tributaries, such as Big Creek, are sustained primarily by overland surface runoff but also provide suitable habitat for a diverse fish community consisting of top predators such as northern pike and largemouth bass. A total of 65 fish species representing 40 genera have been recorded in the Lower Middle Grand River and its tributaries. Sport fishes include non-indigenous rainbow trout and brown trout, which were deliberately introduced, as well as indigenous brook trout, channel catfish, northern pike, rock bass, smallmouth bass, largemouth bass, black and white crappie, walleye, and yellow perch (GRCA Natural Heritage, 2017).

Major Tributaries of the Lower Middle Grand River Subwatershed

Some of the tributaries that are associated with physiographic features composed of coarse parent materials receive significant base flow, and contain coldwater fish communities. Others receive little groundwater and experience warm summer temperatures. Fish communities range from coldwater to warmwater. Many of the major tributaries enter the main stem of the Grand River within the Middle watershed area (i.e. Conestogo River, Nith River, Speed River, Whitemans Creek).

Conestogo River

The upper sections were historically associated with swamp wetlands which have since been converted to primarily agricultural lands. Adjacent lands generally contain tight soils with poor to extremely poor infiltration and high runoff, which results in very flashy flows and very low base flows. Water in these streams tends to be turbid because of the clay and silty soils and resuspension of sediment. High rates of nutrient loading have led to the proliferation of algae and high bacterial levels (GRCA Natural Heritage, *In progress* 2018).

Flows in the lower main channel are heavily regulated by the Conestogo Dam. Conestogo Reservoir is subject to periodic outbreaks of blue-green algae owing to nutrient loading and seasonably warm temperatures. The poor water quality can be harmful to aquatic organisms as well as people and their pets. The reservoir experiences frequent fish kills during spring, a condition associated with Columnaris Disease. This disease affects brown bullheads as waters warm up in spring. The disease is not considered a threat to humans (Conestogo Lake Conservation Area Fish Die off Response Protocol, July 2011, M. Anderson, GRCA).

A “Tailwater Fishery” was established below Conestogo Dam downstream to Hawksville following an Environmental Assessment to assess potential. Since the spring of 2004 many volunteers, neighboring landowners, municipal politicians, representatives from the Ministry of Northern Development, Mines, Natural Resources and Forestry, and the Grand River Conservation Authority have been stocking brown trout into this reach of river. In order to maintain this fishery, the province stocks 17,000 – 20,000 fish annually.

Top predators and sport fishes typically include species adapted to warm or cool water such as Northern Pike, Largemouth Bass, and Smallmouth Bass.

Nith River

Heavy agricultural use, particularly in the upper watershed, reduces riparian zones and results in increased sediment and nutrient runoff into the river, impacting the aquatic habitat. As the river moves downstream groundwater discharges and healthier riparian zones help to restore the habitat. Fish communities range from coldwater fisheries in some tributaries, to warmwater fisheries.

Speed River

Large portions of the upper Speed River subwatershed remain forested and as such the aquatic habitat is less impacted here. In addition, the geology of the area is such that groundwater discharge is significant in certain tributaries and sections of the main stem. These conditions allow coldwater fisheries to exist in the upper watershed. Moving downstream through Guelph, the river transitions into a warmwater fish community.

2.13.3 Southern Grand River Subwatershed

The southern watershed is a region of geologically recent glacial lake deposits or silts overlying older clay/till deposits, giving the river a natural increase in turbidity. Many of the tributaries are highly productive, with large drainage areas, deep pools and extensive littoral zones. Unlike most of the upstream watershed where macrophytes dominate the primary production, in the Southern Grand phytoplankton can account for the majority of the primary production, as increased turbidity quickly filters light out of the water column. This creates a shift from a benthic dominated to a more pelagic system. The Southern Grand also features extensive wetlands which can provide significant habitat for many aquatic organisms, and potentially acting as a nursery ground for juvenile fish.

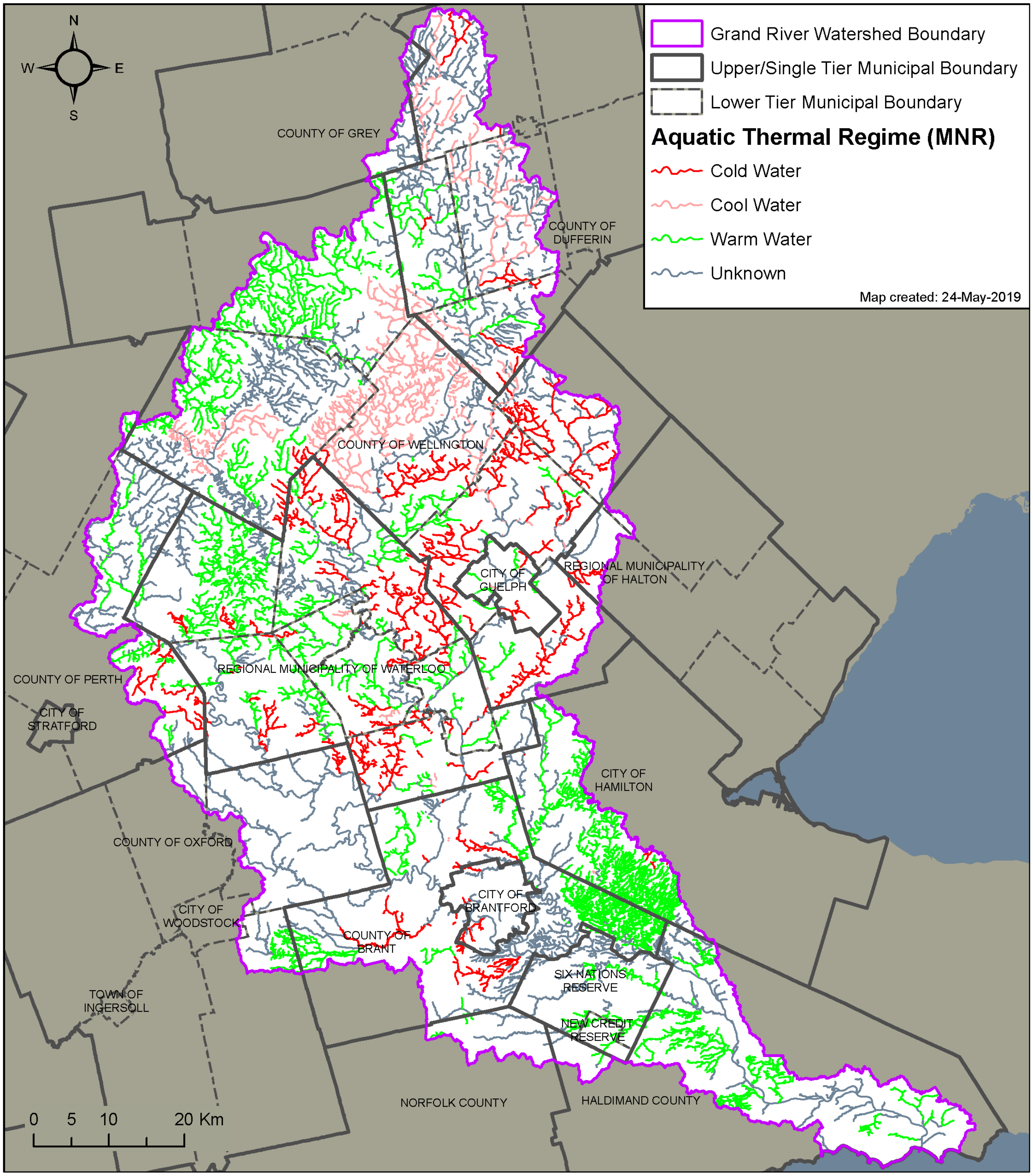
The fish communities in this area range from coolwater to warmwater, with a select few coldwater tributaries. Additionally the fish assemblage in this area is influenced by the close proximity of the Lake Erie, creating a very diverse fish community.

2.13.4 Major Tributary of the Southern Grand River Subwatershed

Whitemans Creek

This subwatershed has a high concentration of agricultural water taking activity during the summer months, which is not sustainable from an ecological perspective (Wong and Boyd, 2014). Low flows caused by low precipitation and water takings for large scale agricultural irrigation is a recurring problem. This can have economic impacts on the human users of the creek as well as adverse impacts on fish and wildlife that depend on the creek for survival. The majority of irrigation water is sourced from groundwater (Wong, 2011). However, because of the close connection between groundwater aquifers and surface water features such as creeks and wetlands, additional stress is often placed on these natural features during the summer months, when creek flows and water levels in wetlands are at their lowest. In spite of the ongoing agriculture and high water use, lower portions of Whitemans Creek downstream of Burford support a recreational fishery consisting of Brown Trout, Brook Trout, and Smallmouth Bass (GRCA Natural Heritage, 2017).

Map 2-26: Aquatic Habitat in the Grand River Watershed



2.13.5 Species at Risk

A complete list of species of animals and plants known to be at risk, rare or endangered in the Grand River Watershed is included in **Table 2-8**.

Table 2-8: List of Species at Risk in the Grand River Watershed

Taxonomy	Common Name	Scientific Name	NDMNRF Status	Notes
Amphibians	Jefferson Salamander	Ambystoma jeffersonianum	Threatened	
Amphibians	Fowler's Toad	Anaxyrus fowleri	Threatened	
Birds	Henslow's Sparrow	Ammodramus henslowii	Endangered	
Birds	Short-eared Owl	Asio flammeus	Special Concern	
Birds	Whip-poor-will	Caprimlugus vociferus	Threatened	
Birds	Chimney swift	Chaetura pelagica	Threatened	
Birds	Black Tern	Chlidonias niger	Special Concern	
Birds	Common nighthawk	Chordeiles minor	Special Concern	
Birds	Northern Bobwhite	Colinus virginianus	Endangered	
Birds	Cerulean Warbler	Cendroica cerulea	Special Concern	
Birds	Acadian Flycatcher	Empidonax virescens	Endangered	
Birds	Bald Eagle	Haliaeetus leucocephalus	Special Concern	
Birds	Yellow-breasted Chat	Icteria virens	Special Concern	
Birds	Least Bittern	Ixobrychus exilis	Threatened	
Birds	Red-headed Woodpecker	Melanerpes erythrocephalus	Special Concern	
Birds	King Rail	Rallus elegans	Endangered	
Birds	Louisiana Waterthrush	Seiurus motacilla	Special Concern	
Birds	Barn Owl	Tyto alba	Endangered	
Birds	Canada warbler	Wilsonia canadensis	Special Concern	
Birds	Hooded Warbler	Wilsonia citrina	Special Concern	
Fish	Eastern Sand Darter	Ammocrypta pellucida	Endangered	Member of the perch family. Found in the main stem of the Grand River from of Dunnville to Brantford.
Fish	Redside Dace	Clinostromus elongatus	Endangered	Inhabit part of the Irvine Creek. Only known population on north shore of Lake Erie. Limited due to its

Table 2-8: List of Species at Risk in the Grand River Watershed				
Taxonomy	**Common Name**	**Scientific Name**	**NDMNRF Status**	**Notes**
				preference for cool headwater streams.
Fish	Northern Brook Lamprey	Ichthyomyzon fossor	Special Concern	
Fish	River Redhorse	Moxostoma carinatum	Special Concern	Found from the mouth of the Grand River up to Caledonia. Requires moderate to large sized, fast flowing rivers, low silt substrates and clear water.
Fish	Black Redhorse	Moxostoma duquesnei	Threatened	Inhabits moderate to large rivers; is limited to the main stem of the Grand River and ilarger tributaries such as the Nith River. Water quality at capture sites in Ontario can be characterized as well oxygenated and relatively fertile.
Fish	Bigmouth Buffalo	Ictiobus cyprinellus	Special Concern	Found only downstream of Dunnville. Documented to inhabit areas where the current is slow. Will tolerate high turbidity and prefer waters that are warm and highly eutrophic.
Fish	Silver Shiner	Notropis photogenis	Special Concern	Distributed in various locations including the main Grand River, the Nith River, the Conestogo River,

Table 2-8: List of Species at Risk in the Grand River Watershed

Taxonomy	Common Name	Scientific Name	NDMNRF Status	Notes
				Whitemans Creek, Schneider Creek, Rogers Creek and McKenzie Creek.
Insects	Monarch	Danaus plexippus	Special Concern	
Mammals	Woodland Vole	Microtus pinetorum	Special Concern	
Mammals	American Badger	Taxidea taxus	Endangered	
Mammals	Grey Fox	Urocyon cinereoargenteus	Threatened	
Molluscs	Kidneyshell	Ptychobranchus fasciolaris	Endangered	Historically located in southern portion of the main stem of the Grand River. Populations in the Grand River watershed likely extirpated due to the combined effects.
Molluscs	Wavy-Rayed Lampmussel	Lampsilis fasciola	Endangered	Found in Southern sections of the Grand River, in Branford area Township of Woolwich and in some areas of the main stem of the Nith River.
Molluscs	Round Pigtoe	Pleurobema sintoxia	Endangered	Found in the main stem of the Southern Grand River. High loadings of sediment, nutrients and toxic compounds originating from urban and agricultural sources are potential threats.
Molluscs	Mapleleaf Mussel	Quadrula quadrula	Endangered	
Molluscs	Fawnsfoot	Truncilla donaciformis	Endangered	
Molluscs	Rainbow Mussel	Villosa iris	Threatened	

Table 2-8: List of Species at Risk in the Grand River Watershed				
Taxonomy	**Common Name**	**Scientific Name**	**NDMNRF Status**	**Notes**
Molluscs	Pygmy Pocket Moss	Fissidens exilis	Special Concern	
Plants	Gattinger’s Agalinis	Agalinis gattingeri	Endangered	
Plants	Green Dragon	Arisaema dracontium	Special Concern	
Plants	American Chestnut	Castanea dentata	Endangered	
Plants	American Columbo	Frasera caroliniensis	Endangered	
Plants	Goldenseal	Hydratis canadensis	Threatened	
Plants	Large Whorled Pogonia	Isotria verticillata	Endangered	
Plants	Butternut	Juglans cinerea	Endangered	
Plants	American Water-willow	Justicia americana	Threatened	
Plants	American Ginseng	Panax quinquefolius	Endangered	
Plants	Broad Beech Fern	Phegopteris hexagonoptera	Special Concern	
Plants	Hill’s Pondweed	Potamogeton hillii	Special Concern	
Plants	Common Hoptree	Ptelea trifoliata	Threatened	
Plants	Bird’s-foot Violet	Viola pedata	Endangered	
Reptiles	Spiny Softshell	Apalone spinifera	Threatened	
Reptiles	Snapping Turtle	Chelydra serpentina	Special Concern	
Reptiles	Blanding’s Turtle	Emydoidea blandingii	Threatened	
Reptiles	Wood Turtle	Glyptemys insculpta	Endangered	
Reptiles	Northern Map Turtle	Graptemys geographica	Special Concern	
Reptiles	Eastern Hog-nosed Snake	Heterodon platirhinos	Threatened	
Reptiles	Milksnake	Lampropeltis triangulum	Special Concern	
Reptiles	Eastern Foxsnake (Carolinian population)	Pantherophis gloydi	Endangered	
Reptiles	Gray Rattlesnake (Carolinian population)	Pantherophis spiloides	Endangered	
Reptiles	Queensnake	Regina septemvittata	Threatened	
Reptiles	Eastern Musk Turtle	Sternotherus odoratus	Threatened	
Reptiles	Butler's Gartersnake	Thamnophis butleri	Threatened	
Reptiles	Eastern Ribbonsnake	Thamnophis sauritus	Special Concern	

2.14 Interactions Between Human and Physical Geography

Some land uses in the watershed can pose an increased threat to drinking water sources depending on the geology of the area. The geology of the Grand River watershed varies significantly. Deposits of clay and till found in the northern and southern portions of the watershed, form relatively impermeable barriers to the infiltration of water. As a result, runoff to nearby watercourses is increased. Glacial moraines and drumlins, located in the central portion of the watershed, can allow for higher levels of infiltration through permeable sand and gravel deposits.

The northern and southern portions of the watershed are predominantly rural, with agriculture as the main land use. Runoff of precipitation over the tight till and clay deposits can quickly move soils, nutrients (manure and fertilizer) and other contaminants into nearby watercourses. Tile drainage of farm fields and wetlands, and removal of riparian buffers, fence lines and forest cover to increase tillable acreage has increased runoff, and subsequently increased contamination of surface water over the decades. However, recent trends to adopt more environmentally friendly farming practices have increased riparian buffers and tree cover throughout the watershed.

The permeable sand and gravel deposits of the moraines and drumlins in the central portion of the watershed are overlain by both intense agriculture and densely populated urban areas. Much of the population in this area obtains their drinking water from the rich groundwater sources, characteristic of the middle watershed. In permeable areas, where aquifers don’t have additional shallow or deep aquitards, there is an increased potential for spills and runoff from both urban and rural areas to infiltrate into the ground and contaminate groundwater resources.

2.15 Watershed Characterization Data Gaps

The following data gaps have been identified in the Watershed Characterization component of the Grand River Source Protection Area Assessment Report.

Data	Plan to Address Data Gap	Progress to Address Data Gap
Location of federal lands in the watershed	As new information is released, it will be included in an updated Assessment Report.	Data on the location of federal lands is not currently available as of October 2018
List of non-municipal drinking water systems	Working with the public health units and the Ministry of the Environment to improve the available data on non-municipal drinking water systems. This information will be included in an updated Assessment Report.	This item remains as a data gap as efforts are still being made to fully characterize existing non-municipal drinking water systems.
Location of monitoring wells related to drinking water systems	Working with municipalities to improve the available data on municipal drinking water monitors. This information will be included in an updated Assessment Report.	Municipal monitoring well data is provided where there have been studies to delineate WHPAs. Although the data is used in local groundwater models for model calibration it has not been documented in the updated Assessment Report.
Geologic characterization	While the regional flow system is less sensitive to the errors in geologic characterizations, local flow systems are more sensitive to such errors. To reduce uncertainty associated with local studies, it is recommended that additional effort be expended on accurately characterizing the local subsurface, including interpreting cross sections and drilling additional boreholes (LESPR, 2010).	Four Tier 3 water budget studies have been implemented within the Grand River Watershed; Whitemans Creek, Centre Wellington, Region of Waterloo, and Guelph-Guelph Eramosa. As a part of each of these studies, a detailed assessment of the local groundwater regime was completed by way of review of municipal wells, monitoring wells, and all local high quality borehole data. The studies also included the development of numerical groundwater flow models. With the exception of Centre Wellington, a field component was incorporated into each of the studies. In the Region of Waterloo and Guelph-Guelph Eramosa studies, extensive drilling and monitoring well installations were completed to better understand the local groundwater flow system. As a part of the Whitemans study, water levels in local wetlands were monitored to improve the understanding of local groundwater/surface water interactions.

2.16 Watershed Characterization Section Summary

- The Grand River watershed covers an area of approximately 6,800 square kilometres in south-central Ontario, and contains 39 upper-, lower- and single-tier municipalities and two First Nations bands.

- The length of the Grand River is 300 kilometres. The major tributaries of the Grand River include: the Conestogo and Nith, draining the western half of the watershed; and the Speed, which drains the north-east. Several smaller tributaries drain the southern half of the watershed. The largest of these include the Fairchild, Whitemans and McKenzie creeks.

- The Grand River Source Protection Area had a population of approximately 994,000 people, with approximately 87% serviced by municipal water supplies.

- The majority of the population of the Grand River watershed relies on groundwater as a clean, safe, drinking water supply. In addition to providing a safe source of drinking water, groundwater is used in agriculture, commercial, and industrial applications.

- The Grand River is a managed river system where reservoir operations, water supply and wastewater management were designed as an integrated system on a watershed basis. Water is managed primarily through a system of multi-purpose reservoirs and an extensive monitoring system of stream flow gauges.

- The Grand River Watershed is comprised of eleven physiographic regions: Dundalk Till Plains, Stratford Till Plains, Hillsburgh Sandhills, Guelph Drumlin Field, Oxford Till Plain, Horseshoe Moraines, Waterloo Hills, Flamborough Plain, Mount Elgin Ridges, Norfolk Sand Plain, and Haldimand Clay Plain.

- The entire watershed is underlain by carbonate bedrock formations which form north to south trending bands. Unconsolidated sediments overlay the bedrock formations and were deposited by the movement of glaciers across the landscape.

- Groundwater resources are found within both bedrock and overburden aquifers, with regional groundwater flow from the upper reaches of the watershed where there is a topographic high, to the south toward Lake Erie.

- Groundwater within the aquifers provides for municipal and private water takings, and also supports cold water surface water features through the provision of baseflow from groundwater discharge.

- Groundwater quality in the Grand River watershed is influenced by both natural and anthropogenic impacts. In the Grand River watershed, three distinctive land use activities have impacted groundwater quality: road salting, the application of manures/fertilizer, and the use of dense non-aqueous phase liquids (DNAPLS).

- Annual average precipitation from the years 1986 to 2016 is 921 mm, which is highly variable within the watershed. The northern part of the watershed had the highest annual precipitation at over 1000 mm, while the lowest annual precipitation occurred near Brantford at 850 mm.

- Over the 30 year period of 1986 to 2016, the Grand River watershed had an average temperature of 7.2 degrees with the coolest temperatures in the north of the watershed.

- Observed data shows an increase in average temperatures of about 0.5 degrees over the last half century with the winter months having the highest increase at approximately 1.0 degrees.

- The Grand River watershed straddles two distinct forest regions: the Great Lakes-St. Lawrence Forest Region to the north and the Deciduous Forest Region, also known as the Carolinian Zone, in the south.

- The Grand River watershed straddles two distinct forest regions: the Great Lakes-St. Lawrence Forest Region to the north and the Deciduous Forest Region, also known as the Carolinian Zone, in the south. Forests currently cover approximately 16% of the Grand River watershed.

- The highest concentrations of wetlands are located in the eastern portion of the watershed, in the Speed and Eramosa subwatersheds, as well as in Puslinch Township. The northern most portion of the watershed, near the towns of Dundalk, Grand Valley and Damascus, also holds significant wetland complexes.

- Surface water quality is reflective of both the geology and land use in the watershed. The parameters of interest for municipal drinking water supply including chloride, sodium and nitrates.

- The Grand River watershed supports a combination of coldwater, cool water and warm water fisheries with a variety of aquatic species.

- As of 2009, there are 64 species at risk found in the Grand River watershed area, including 15 reptiles and amphibians, 19 birds and insects, 14 fish and mollusks, 13 plants and 3 mammals.

- Progress to address data gaps identified in the Grand River watershed characterization report have been made and include; detailed Tier 3 water budget studies which contain updated local geologic and groundwater flow data determined through detailed field investigations and modeling.