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8.0 OVERVIEW OF THE WATER BUDGET FRAMEWORK

A water budget looks at how much water enters a watershed, is stored, and leaves the watershed. This information helps determine the amount of water available for human uses, while making sure there is still enough left for natural processes (i.e. there has to be enough water in a watershed to keep rivers, streams and lakes healthy).

The objective of the water quantity framework is to help managers identify: 1) drinking water sources which may not be able to meet current or future demands and 2) threats which may potentially impact the quantity of municipal water supply. Water budgets are classified into three tiers, with each tier representing increased detail to the water budget.

A Tier 1 conceptual water budget is a watershed scale study which largely characterizes water use in the watershed. The Tier 1 water budget was not completed for Long Point Region because much this data had been previously assessed as a part of earlier studies and is documented in the Tier 2 water budget study. A Tier 2 water budget uses numerical models to quantify water use within subwatershed assessment areas within the larger watershed region, and Tier 3 water budgets use detailed numerical models at the municipal level to quantify local water use.

Tier 2 Framework

As part of the water budget assessment process, the *Clean Water Act (2006)* requires the completion of a Tier 2 Water Budget and Water Quantity Stress Assessment. A Tier 2 Water Budget estimates and compares existing and future water demands against available surface and groundwater supply for subwatersheds within the larger watershed region.

A Tier 2 Stress Assessment assesses the level of potential stress placed on each subwatershed. This assessment estimates a Percent Water Demand for a subwatershed by comparing water demands to the available surface water and groundwater supply for that subwatershed (AquaResource, 2009b). Where the ratio of water demand to water supply is high, subwatersheds are classified as having a moderate or significant potential for water quantity stress. Under the *Clean Water Act (2006)*, Source Protection Regions are required to complete a Tier 3 Assessment when municipal water supply wells are located within a subwatershed that is classified by a Tier 2 study as having a moderate or significant potential for water quantity stress (Matrix, 2015).

An Integrated Water Budget and Tier 2 Stress Assessment was completed for Long Point Region as part of a larger study for Catfish Creek, Kettle Creek, and Long Point Region Conservation Authorities (AquaResource, 2009a, 2009b). The Long Point Region water budget and Tier 2 stress assessment is documented in two reports: *Long Point Region, Kettle Creek and Catfish Creek Integrated Water Budget – Final Report,* April 2009 and *Long Point Region, Catfish Creek and Kettle Creek Tier 2 Water Quantity Stress Assessment – Final Report*, May 2009 and *Addendum: Long Point Region Water Quantity Stress Assessment Otter Creek at Tillsonburg Subwatershed – Groundwater,* April 2014. The Addendum report documents an update to the stress assessment for the *Otter at Tillsonburg* subwatershed using revised values for groundwater supply and future water demand estimates to reduce high uncertainty in the original stress assessment for the subwatershed.

Tier 3 Framework

The Tier 2 Water Quantity Stress Assessment completed for Long Point Region, Catfish Creek, and Kettle Creek Conservation Authorities (AquaResource, 2009b) identified the Big Above Minnow Creek, Lynn River, and Upper Nanticoke subwatersheds as having a significant or moderate potential for surface water or groundwater stress when water demands were compared to available surface water and groundwater supply for that subwatershed. This identification led to the requirement of municipal systems located within these subwatersheds to be assessed under a Tier 3 Water Budget and Local Area Risk Assessment (Tier 3 study).

The purpose of a Tier 3 study is to determine whether a municipality is able to meet their current and future water demands. Tier 3 assessments estimate the likelihood that a municipal drinking water aquifer or surface water feature (such as a river or lake) can sustain pumping at their future pumping rates while accounting for the needs of other water uses such as coldwater streams, or other permitted water takers in the area. Within Long Point Region, a Tier 3 study has been completed for the municipal drinking water systems for the Towns of Waterford, Simcoe, and Delhi.

Results of the Tier 2 Assessment also identified the Otter at Tillsonburg subwatershed, which contains the Town of Tillsonburg, as having a moderate potential for stress. However, due to the uncertainty of this stress classification, the assessment of the subwatershed was re-examined during the initial stages of the Tier 3 study using a refined numerical groundwater flow model. The updated assessment lead to the classification of a low potential for stress for the Otter at Tillsonburg subwatershed, resulting in the removal of the Town of Tillsonburg from the Tier 3 study (Matrix, 2015).

9.0 TIER 2 WATER BUDGET

The Tier 2 Water Budget and Water Quantity Stress Assessment reports were completed to increase the understanding of water quantity and availability in the Long Point Region (AquaResource 2009a, 2009b).

The Integrated Water Budget Report was completed using numerical hydrologic and groundwater flow models. A continuous hydrologic model for the Long Point Region watershed was developed using a Guelph all-weather storm-event runoff model (GAWSER) to simulate surface water flows and the partitioning of precipitation (Schroeter & Associates, 2006c). Groundwater flows were simulated by the development of a regional-scale numerical groundwater flow model using the FEFLOW software package which was calibrated to available water level and streamflow data. The regional groundwater flow model was designed to represent average annual groundwater flow conditions, with a particular focus on volumetric flow from one subwatershed to another. Together these modelling tools provided a physical means of quantifying flows through the system to determine available water resources in the Long Point Region.

The Tier 2 Water Quantity Stress Assessment (AquaResource, 2009b) evaluated the degree of potential water quantity stress within the subwatersheds by comparing the volume of water demand to that which was practically available for use. The results of streamflow and groundwater flow modelling and water demand estimates from the Integrated Water Budget were incorporated into the Tier 2 Water Quantity Stress Assessment.

The Water Budget and the Water Quantity stress assessment was calculated based on twenty-four subwatersheds as summarized in **Table 9-1.**

Table 9-1: Long Point Region Watershed Area Subwatersheds

Watershed	Subwatershed	Area (km^2)	Municipal System/Sources
Otter Creek	Otter Above Maple Dell Road	99	Norwich
	Otter at Otterville	75	Otterville
	Otter at Tillsonburg	153	Tillsonburg
	Spittler Creek	116	Springford, Dereham Centre
	Lower Otter	168	Richmond
	Little Otter	118	None
Lake Erie Tribs	South Otter	120	None
	Clear Creek	87	None
Big Creek	Big Above Cement Road	89	None
	Big Above Kelvin Gauge	64	None
	Big Above Delhi	154	None
	North Creek	58	Delhi (Surface Water)
	Big Above Minnow Creek	72	Delhi (Groundwater)
	Big Above Walsingham Gauge	123	None
	Venison Creek	98	None
	Lower Big	96	None
Lake Erie Tribs	Dedrick Creek	138	None
	Young/Hay Creek	120	None
Lynn River	Lynn River	172	Simcoe
	Black Creek	134	None

Table 9-1: Long Point Region Watershed Area Subwatersheds			
Watershed	**Subwatershed**	**Area (km^2)**	**Municipal System/Sources**
Nanticoke Creek	Upper Nanticoke	114	Waterford
	Lower Nanticoke	85	None
Eastern Tributaries	Sandusk Creek	182	None
	Stoney Creek	186	None

Note: The Richmond municipal water system did not exist at the time of the 2009 Tier 2 Water Budget and Stress Assessment.

9.1 Surface Water Budget

9.1.1 Surface Water Budget

The Long Point Region watershed area continuous surface water model was built using the GAWSER model program. This modelling software is a physically-based deterministic hydrologic model that is used to predict the total streamflow resulting from inputs of rainfall and/or snowmelt. The infiltration routine used the Green-Ampt equation to partition precipitation into runoff and infiltrated water (recharge). Potential evapotranspiration was calculated using the Linacre model. Evapotranspiration was then calculated by removing available water from depression storage and the soil layers until wilting point was reached. Runoff, recharge and evapotranspiration were then aggregated to the subwatershed scale for the water budget. Modelling procedures are fully documented in the GAWSER Training Guide and Reference Manual (Schroeter & Associates, 1996).

The surface water budget components were determined from the hydrologic model (precipitation, evapotranspiration, runoff and recharge) and from the water use study for surface water takings. Some small watersheds which drain directly to Lake Erie were not included in the Long Point Region hydrologic model. Surface water budget components from the same hydrologic response unit and same subwatershed were applied to these areas for the water budget. Surface water budget components have significant temporal variability. Results presented are based on average annual conditions for the 1980-2004 period and it is recognized that these results may vary significantly based on climate conditions. The analysis does not account for changes in water storage that would occur from one time period to the next.

As shown on **Table 9-2** the average annual precipitation is approximately 956 mm/year. The hydrologic model has estimated average annual evapotranspiration to be 542 mm/year. The average runoff rate across Long Point Region is 191 mm/year, with an average groundwater recharge rate of 223 mm/year. Water removed from watercourses that is not immediately returned to the surface water system, is approximately 0.79 m^3/s, or 9 mm/year. While precipitation and evapotranspiration rates have some degree of spatial variability, runoff and recharge rates have the most significant spatial variability due to changing soils, surficial geology, and land cover.

Table 9-2: Average Annual Water Budget (Surface Water)		
Water Budget Parameter	**Value (m^3/s)**	**Value (mm/year)**
Precipitation	85.5	956
Evapotranspiration	48.4	542
Runoff	17.1	191
Recharge	20.0	223
SW Taking	0.79	9

Table 9-3 and **Table 9-4** summarize the water budget components for each of the subwatersheds in mm and m^3/s, respectively. The negative values in the 'SW Taking' column represent the amount of water taken from the surface water source that is not immediately returned to the source.

Table 9-3: Surface Water Budget (mm)									
Subwatershed	**Area (km^2)**	**Precip**	**ET**	**Runoff**	**Recharge**	**SW Taking**	**Inflow**	**Outflow**	**Flow Yield**
Otter Above Maple Dell Road	99	992	542	223	226	-6		439	439
Otter at Otterville	75	973	541	223	209	-9	582	997	415
Otter at Tillsonburg	153	971	498	264	208	-12	825	1305	480
Spittler Creek	116	973	529	274	170	-2		447	447
Lower Otter	168	968	535	227	206	-9	1487	1942	455
Little Otter	118	969	552	123	294	-6		426	426
South Otter	120	974	564	96	314	-18		384	384
Clear Creek	87	952	562	88	302	-6		284	284
Big Above Cement Road	89	914	534	191	189	-2		322	322
Big Above Kelvin Gauge	64	914	545	101	269	-2	449	731	283
Big Above Delhi	154	951	549	114	288	-17	304	840	536
North Creek	58	970	565	83	322	-20		252	252
Big Above Minnow Creek	72	993	564	81	348	-15	1996	2367	371
Big Above Walsingham	123	993	563	135	295	-26	1395	1880	485
Venison Creek	98	980	563	102	315	-16		422	422
Lower Big	96	984	490	281	213	-7	2830	3282	452
Dedrick Creek	138	1006	551	180	274	-15		270	270
Young/Hay Creeks	120	1004	563	136	305	-13		243	243
Lynn River	172	983	584	116	283	-8		422	422
Black Creek	134	979	566	250	163	-1		381	381
Nanticoke Upper	114	915	553	178	185	-5		344	344
Nanticoke Lower	85	897	514	299	84	-1	463	790	327
Sandusk Creek	182	874	505	301	68	-1		338	338

Table 9-3: Surface Water Budget (mm)

Subwatershed	Area (km^2)	Precip	ET	Runoff	Recharge	SW Taking	Inflow	Outflow	Flow Yield
Stoney Creek	186	874	506	302	68	-1		313	313
Total Area	**2821**	**956**	**542**	**191**	**223**	**-9**			**386**

Table 9-4: Surface Water Budget (m^3/s)

Subwatershed	Area (km^2)	Precip	ET	Runoff	Recharge	SW Taking	Inflow	Outflow	Flow Yield
Otter Above Maple Dell Road	99	3.12	1.71	0.70	0.71	-0.02		1.38	1.38
Otter at Otterville	75	2.31	1.28	0.53	0.50	-0.02	1.38	2.36	0.98
Otter at Tillsonburg	153	4.71	2.42	1.28	1.01	-0.06	4.01	6.34	2.33
Spittler Creek	116	3.57	1.94	1.01	0.62	-0.01		1.64	1.64
Lower Otter	168	5.16	2.85	1.21	1.10	-0.05	7.93	10.35	2.42
Little Otter	118	3.61	2.06	0.46	1.10	-0.02		1.59	1.59
South Otter	120	3.70	2.14	0.36	1.19	-0.07		1.46	1.46
Clear Creek	87	2.63	1.55	0.24	0.83	-0.02		0.78	0.78
Big Above Cement Road	89	2.59	1.52	0.54	0.54	-0.01		0.91	0.91
Big Above Kelvin Gauge	64	1.86	1.11	0.21	0.55	0.00	0.91	1.49	0.58
Big Above Delhi	154	4.66	2.69	0.56	1.41	-0.08	1.49	4.11	2.62
North Creek	58	1.78	1.04	0.15	0.59	-0.04		0.46	0.46
Big Above Minnow Creek	72	2.28	1.29	0.18	0.80	-0.04	4.58	5.43	0.85
Big Above Walsingham	123	3.86	2.19	0.52	1.15	-0.10	5.43	7.31	1.89
Venison Creek	98	3.03	1.74	0.31	0.97	-0.05		1.31	1.31
Lower Big	96	3.00	1.49	0.86	0.65	-0.02	8.62	10.00	1.38
Dedrick Creek	138	4.39	2.41	0.79	1.20	-0.07		1.18	1.18
Young/Hay Creeks	120	3.83	2.15	0.52	1.16	-0.05		0.93	0.93
Lynn River	172	5.35	3.18	0.63	1.54	-0.04		2.30	2.30
Black Creek	134	4.15	2.40	1.06	0.69	0.00		1.61	1.61
Nanticoke Upper	114	3.32	2.00	0.64	0.67	-0.02		1.25	1.25
Nanticoke Lower	85	2.42	1.39	0.81	0.23	0.00	1.25	2.13	0.88
Sandusk Creek	182	5.03	2.91	1.73	0.39	0.00		1.95	1.95
Stoney Creek	186	5.15	2.98	1.78	0.39	0.00		1.84	1.84
Total Area	**2821**	**85.51**	**48.44**	**17.08**	**19.99**	**-0.79**			**34.53**

Many elements of the water budget modelling process using the hydrologic model are subject to uncertainty. Although the calibration process is performed in an attempt to reduce uncertainty, the model results and water budgets reflect the uncertainty in the input parameters as well as limitations in the modelling approach. The model is designed to reflect general characteristics of each catchment relating to land cover, climate, soils and vegetation, and stream and river hydraulics. Calibration is limited to the available stream flow data and does not include many of the smaller Lake Erie tributaries.

9.2 Groundwater Budget

9.2.1 Groundwater Budget

A steady-state groundwater FEFLOW model was developed for the Long Point Region, Catfish Creek, and Kettle Creek watershed areas as part of the Integrated Water Budget Study for Long Point Region. The model development and results are fully documented in the Long Point Region, Kettle Creek and Catfish Creek Integrated Water Budget-Final Report (AquaResource 2009a).

Table 9-5 summarizes the average annual groundwater budget for the Long Point Region study area. The groundwater budget is linked to the surface water budget by the recharge rate. Water pumped from aquifers that is not immediately returned to the groundwater system is approximately 1.53 m^3/s. The groundwater model estimates the average annual groundwater discharge to surface water features to be 16.01 m^3/s. Additionally, approximately a net flow of 0.81 m^3/s flows into the Study Area from adjacent watersheds, and 2.67 m^3/s flows out of the area to Lake Erie.

Table 9-5: Average Annual Water Budget Summary (Groundwater)

Water Budget Parameter	Value (m^3/s)	Value (mm/year)
Recharge	20.0	223
Net Flow In Across Watershed Boundaries	0.81	9
Net Flow into Lake Erie	2.67	30
Net Discharge to Surface Water Features	16.01	179
GW Taking	1.53	17

Table 9-6 and **Table 9-7** summarize the water budget components for each of the subwatersheds in mm and m^3/s, respectively. The negative values in the 'GW Taking' column represent the amount of water taken from an aquifer that is not immediately returned to the source. Negative values in the River Discharge column indicate that flow is leaving the groundwater system to the surface water system.

Table 9-6: Groundwater Water Budget (mm/yr)

Subwatershed	Area (km^2)	Recharge	GW Taking	Lake Erie Discharge	Outside watershed	River Discharge	Inter-Basin Transfer	Flow In Ratio
Otter Above Maple Dell Road	99	226	-10		35	-174	-80	-19%
Otter at Otterville	75	209	-12			-176	-21	-10%

Otter at Tillsonburg	153	293	23		87	376	138	-36%
Spittler Creek	116	170	-3		43	-130	-82	-22%
Lower Otter	168	206	-5	-17	56	-203	-39	1%
Little Otter	118	294	-17			-266	-5	-4%
South Otter	120	314	-10	-68		-222	-16	-26%
Clear Creek	87	302	-16	-109		-185	7	-33%
Big Above Cement Road	89	189	-4		57	-181	60	-1%
Big Above Kelvin Gauge	64	269	-55		-84	-136	15	-29%
Big Above Delhi	154	288	-33		-25	-264	31	3%
North Creek	58	322	-52			-203	-82	-21%
Big Above Minnow Creek	72	348	-50			-342	39	12%
Big Above Walsingham	123	295	-13			-322	36	13%
Venison Creek	98	315	-16			-365	64	21%
Lower Big	96	213	-7	-26		-126	-53	-38%
Dedrick Creek	138	274	-9	-165		-158	55	-39%
Young/Hay Creeks	120	305	-22	-113		-130	-50	-50%
Lynn River	172	283	-38	-24		-206	-9	-14%
Black Creek	134	163	-10	-35		-117	-2	-22%
Nanticoke Upper	114	185	-40		-14	-145	11	0%
Nanticoke Lower	85	84	-2	-33		-73	22	-11%
Sandusk Creek	182	68	-2	-28		-36	-3	-43%
Stoney Creek	186	66	-2	-44		-15	-5	-74%
Total Area	**2821**	**223**	**-17**	**-30**	**9**	**-179**		

Table 9-7: Groundwater Water Budget (m^3/s)

Subwatershed	Area (km^2)	Recharge	GW Taking	Lake Erie Discharge	Outside watershed	River Discharge	Inter-Basin Transfer	Flow In Ratio
Otter Above Maple Dell Road	99	0.71	-0.03		0.11	-0.55	-0.25	-19%
Otter at Otterville	75	0.50	-0.03			-0.42	-0.05	-10%
Otter at Tillsonburg	153	1.5	-0.11		0.42	-1.88	0.67	36%
Spittler Creek	116	0.62	-0.01		0.16	-0.48	-0.30	-22%
Lower Otter	168	1.10	-0.03	-0.09	0.30	-1.08	-0.21	1%
Little Otter	118	1.10	-0.06			-0.99	-0.02	-4%
South Otter	120	1.19	-0.04	-0.26		-0.84	-0.06	-26%
Clear Creek	87	0.83	-0.04	-0.30		-0.51	0.02	-33%
Big Above Cement Road	89	0.54	-0.01		0.16	-0.52	-0.17	-1%
Big Above Kelvin Gauge	64	0.55	-0.11		-0.17	-0.28	0.03	-29%
Big Above Delhi	154	1.41	-0.16		-0.12	-1.29	0.15	3%
North Creek	58	0.59	-0.10			-0.37	-0.15	-21%
Big Above Minnow Creek	72	0.80	-0.11			-0.78	0.09	12%

Table 9-7: Groundwater Water Budget (m^3/s)								
Subwatershed	Area (km^2)	Recharge	GW Taking	Lake Erie Discharge	Outside watershed	River Discharge	Inter-Basin Transfer	Flow In Ratio
Big Above Walsingham	123	1.15	-0.05			-1.25	0.14	13%
Venison Creek	98	0.97	-0.05			-1.13	0.20	21%
Lower Big	96	0.65	-0.02	-0.08		-0.38	-0.16	-38%
Dedrick Creek	138	1.20	-0.04	-0.72		-0.69	0.24	-39%
Young/Hay Creeks	120	1.16	-0.08	-0.43		-0.49	-0.19	-50%
Lynn River	172	1.54	-0.21	-0.13		-1.12	-0.05	-14%
Black Creek	134	0.69	-0.04	-0.15		-0.50	-0.01	-22%
Nanticoke Upper	114	0.67	-0.14		-0.05	-0.53	0.04	0%
Nanticoke Lower	85	0.23	-0.01	-0.09		-0.20	0.06	-11%
Sandusk Creek	182	0.39	-0.01	-0.16		-0.21	-0.02	-43%
Stoney Creek	186	0.39	-0.01	-0.26		-0.09	-0.03	-74%
Total Area	**2821**	**19.99**	**-1.53**	**-2.67**	**0.81**	**-16.01**		

Any model developed to represent a natural system is inherently a simplification of that system. One of the largest points of uncertainty in the groundwater flow model is in the geologic conceptual model. This uncertainty has led to the definition of numerical model layers that are neither representative of hydrostratigraphic conditions, nor uniformly distributed. A lack of borehole logs that penetrate to depth in this area exacerbate the uncertainty associated with the geologic conceptual model and the assigned hydraulic conductivities. Every effort was made to minimize the uncertainty, but results should only be viewed from a regional flow system scale.

9.3 Integrated Water Budget

The development of the integrated water budget for Long Point Region considered average annual estimates of key hydrologic parameters related to surface water and groundwater resources, and the integration between the two.

Values reported are based on annual averages, and may exhibit significant seasonal variation. The analysis was completed from a regional perspective, therefore subwatershed descriptions may lack details that have local hydrologic significance. Local scale interpretations and models may provide different results than those presented here, which are averaged spatially and temporally. **Table 9-8** and **Table 9-9** summarize the water budget components for each of the subwatersheds in mm and m^3/s, respectively. **Table 9-10** describes the components of the water budget and explains the significance of negative flow values with respect to the movement of water in, through and out of the watershed.

Section 9.3.1 through Section 9.3.20 provide a summary of the integrated water budget results for each of the subwatershed assessment areas in Long Point Region.

Table 9-8: Integrated Water Budget (mm/year) (AquaResource, 2009a,b)

	Surface Water System								Groundwater System					
Subwatershed	**Precip**	**ET**	**Runoff**	**Recharge**	**Average Inflow**	**Average Outflow**	**Flow Yield**	**SW Taking**	**GW Taking**	**Lake Erie Discharge**	**Outside watershed**	**Surface Water Discharge**	**Inter-Basin Transfer**	**Flow In Ratio**
Otter Above Maple Dell	992	542	223	226		439	439	-6	-10		35	-174	-80	-19%
Otter at Otterville	973	541	223	209	582	997	415	-9	-12			-176	-21	-10%
Otter at Tillsonburg	971	498	264	208	825	1305	480	-12	23		87	376	138	-36%
Spittler Creek	973	529	274	170		447	447	-2	-3		43	-130	-82	-22%
Lower Otter	968	535	227	206	1487	1942	455	-9	-5	-17	56	-203	-39	1%
Little Otter	969	552	123	294		426	426	-6	-17			-266	-5	-4%
South Otter	974	564	96	314		384	384	-18	-10	-68		-222	-16	-26%
Clear Creek	952	562	88	302		284	284	-6	-16	-109		-185	7	-33%
Big Above Cement	914	534	191	189		322	322	-2	-4		57	-181	60	-1%
Big Above Kelvin	914	545	101	269	449	731	283	-2	-55		-84	-136	15	-29%
Big Above Delhi	951	549	114	288	304	840	536	-17	-33		-25	-264	31	3%
North Creek	970	565	83	322		252	252	-20	-52			-203	-82	-21%
Big Above Minnow	993	564	81	348	1996	2367	371	-15	-50			-342	39	12%
Big Above Walsingham	993	563	135	295	1395	1880	485	-26	-13			-322	36	13%
Venison Creek	980	563	102	315		422	422	-16	-16			-365	64	21%
Lower Big	984	490	281	213	2830	3282	452	-7	-7	-26		-126	-53	-38%
Dedrick Creek	1006	551	180	274		270	270	-15	-9	-165		-158	55	-39%
Young/Hay Creeks	1004	563	136	305		243	243	-13	-22	-113		-130	-50	-50%
Lynn River	983	584	116	283		422	422	-8	-38	-24		-206	-9	-14%
Black Creek	979	566	250	163		381	381	-1	-10	-35		-117	-2	-22%
Nanticoke Upper	915	553	178	185		344	344	-5	-40		-14	-145	11	0%
Nanticoke Lower	897	514	299	84	463	790	327	-1	-2	-33		-73	22	-11%
Sandusk Creek	874	505	301	68		338	338	-1	-2	-28		-36	-3	-43%
Stoney Creek	874	506	302	68		313	313	-1	-2	-44		-15	-5	-74%
Total Area	**956**	**542**	**191**	**223**			**386**	**-9**	**-17**	**-30**	**9**	**-179**		

Table 9-9: Integrated Water Budget (m^3/s) (AquaResource, 2009a,b)

	Surface Water System								Groundwater System					
Subwatershed	**Precip**	**ET**	**Runoff**	**Recharge**	**Average Inflow**	**Average Outflow**	**Flow Yield**	**SW Taking**	**GW Taking**	**Lake Erie Discharge**	**Outside watershed**	**Surface Water Discharge**	**Inter-Basin Transfer**	**Flow In Ratio**
Otter Above Maple Dell	3.12	1.71	0.70	0.71		1.38	1.38	-0.02	-0.03		0.11	-0.55	-0.25	-19%
Otter at Otterville	2.31	1.28	0.53	0.50	1.38	2.36	0.98	-0.02	-0.03			-0.42	-0.05	-10%
Otter at Tillsonburg	4.71	2.42	1.28	1.01	4.01	6.34	2.33	-0.06	-0.11		0.42	-1.88	0.67	-36%
Spittler Creek	3.57	1.94	1.01	0.62		1.64	1.64	-0.01	-0.01		0.16	-0.48	-0.30	-22%
Lower Otter	5.16	2.85	1.21	1.10	7.93	10.35	2.42	-0.05	-0.03	-0.09	0.30	-1.08	-0.21	1%
Little Otter	3.61	2.06	0.46	1.10		1.59	1.59	-0.02	-0.06			-0.99	-0.02	-4%
South Otter	3.70	2.14	0.36	1.19		1.46	1.46	-0.07	-0.04	-0.26		-0.84	-0.06	-26%
Clear Creek	2.63	1.55	0.24	0.83		0.78	0.78	-0.02	-0.04	-0.30		-0.51	0.02	-33%
Big Above Cement	2.59	1.52	0.54	0.54		0.91	0.91	-0.01	-0.01		0.16	-0.52	-0.17	-1%
Big Above Kelvin	1.86	1.11	0.21	0.55	0.91	1.49	0.58	0.00	-0.11		-0.17	-0.28	0.03	-29%
Big Above Delhi	4.66	2.69	0.56	1.41	1.49	4.11	2.62	-0.08	-0.16		-0.12	-1.29	0.15	3%
North Creek	1.78	1.04	0.15	0.59		0.46	0.46	-0.04	-0.10			-0.37	-0.15	-21%
Big Above Minnow	2.28	1.29	0.18	0.80	4.58	5.43	0.85	-0.04	-0.11			-0.78	0.09	12%
Big Above Walsingham	3.86	2.19	0.52	1.15	5.43	7.31	1.89	-0.10	-0.05			-1.25	0.14	13%
Venison Creek	3.03	1.74	0.31	0.97		1.31	1.31	-0.05	-0.05			-1.13	0.20	21%
Lower Big	3.00	1.49	0.86	0.65	8.62	10.00	1.38	-0.02	-0.02	-0.08		-0.38	-0.16	-38%
Dedrick Creek	4.39	2.41	0.79	1.20		1.18	1.18	-0.07	-0.04	-0.72		-0.69	0.24	-39%
Young/Hay Creeks	3.83	2.15	0.52	1.16		0.93	0.93	-0.05	-0.08	-0.43		-0.49	-0.19	-50%
Lynn River	5.35	3.18	0.63	1.54		2.30	2.30	-0.04	-0.21	-0.13		-1.12	-0.05	-14%
Black Creek	4.15	2.40	1.06	0.69		1.61	1.61	0.00	-0.04	-0.15		-0.50	-0.01	-22%
Nanticoke Upper	3.32	2.00	0.64	0.67		1.25	1.25	-0.02	-0.14		-0.05	-0.53	0.04	0%
Nanticoke Lower	2.42	1.39	0.81	0.23	1.25	2.13	0.88	0.00	-0.01	-0.09		-0.20	0.06	-11%
Sandusk Creek	5.03	2.91	1.73	0.39		1.95	1.95	0.00	-0.01	-0.16		-0.21	-0.02	-43%
Stoney Creek	5.15	2.98	1.78	0.39		1.84	1.84	0.00	-0.01	-0.26		-0.09	-0.03	-74%
Total Area	**85.51**	**48.44**	**17.08**	**19.99**			**34.53**	**-0.79**	**-1.53**	**-2.67**	**0.81**	**-16.01**		

Table 9-10: Summary of Water Budget Components (AquaResource, 2009a,b)

Parameter	Source	Description
Precipitation	Data Analysis / GAWSER	Climate data used to represent the precipitation over each of the subwatersheds is summarized by GAWSER.
Evapotranspiration	GAWSER	GAWSER estimates actual evapotranspiration for each hydrologic response unit (HRU).
Runoff	GAWSER	When the precipitation exceeds the infiltration capacity of a soil, overland runoff is created.
Recharge	GAWSER	GAWSER estimates the amount of groundwater recharge for each HRU.
Average Inflow	GAWSER	The total streamflow entering the subwatershed from upstream subwatersheds.
Average Outflow	GAWSER	The total average annual streamflow leaving the subwatershed. This includes any upstream inflows to the subwatershed as well as flow generated by the specific subwatershed in question.
Flow Yield	GAWSER	This component quantifies the amount of streamflow increase seen in the particular subwatershed, on an average annual basis. The value is the difference between the average inflow and the average outflow.
Surface Water Taking	Water Use Estimates	The amount of water taken from a surface water source (represented as a negative value) and not immediately returned to that source. Includes estimates from permits as well as rural domestic and permit-exempt agricultural use.
Groundwater Taking	Water Use Estimates	The amount of water taken from an aquifer (represented as a negative value) and not immediately returned to that source. Includes estimates from permits as well as rural domestic and permit-exempt agricultural use.
Lake Erie Discharge	FEFLOW	This component identifies groundwater flow through the boundary of the groundwater flow model at Lake Erie (represented as a negative value). This is representative of groundwater flux to Lake Erie.
Outside Watershed	FEFLOW	This component identifies groundwater flow through the boundaries of the groundwater flow model, except for Lake Erie. This is representative of groundwater flow out of, or into, the Study Area. Negative flows indicate water leaving the basin, positive flows indication water entering the basin.
Surface Water Discharge	FEFLOW	This parameter quantifies the groundwater flux to rivers and streams in the particular subwatershed. Negative values indicate that flow is leaving the groundwater system to the surface water system
Inter-Basin Transfer	FEFLOW	The amount of groundwater flow to another subwatershed within the Study Area. Positive values indicate where the subwatershed is experiencing a net increase of groundwater flow from adjacent subwatersheds. Negative values indicate where the subwatershed is experiencing a net loss of groundwater flow to adjacent subwatersheds.

Table 9-10: Summary of Water Budget Components (AquaResource, 2009a,b)		
Parameter	**Source**	**Description**
Flow In Ratio	FEFLOW	$= \frac{(RiverDischarge + WellExtractions)}{Recharge} - 1$ This parameter is the ratio of groundwater discharge (river discharge + extractions) to the amount of recharge in a particular subwatershed. Where the value is negative, it indicates a percentage of recharge that is leaving the basin. Where the value is positive, it indicates how much water, with respect to existing recharge, is entering the subwatershed.

9.3.1 Big Otter Creek Above Maple Dell Road Subwatershed

The surficial materials in Big Otter Creek Above Maple Dell Road Subwatershed are characterized as a mixture of Port Stanley Till and pervious deposits associated with the Norfolk Sand Plain. Port Stanley Till dominates in the westerly portion of the subwatershed, with the majority of the pervious deposits in the easterly portion. Precipitation for this area is 990 mm, which is higher than average, with evapotranspiration being estimated at 540 mm, which is lower than average. Runoff and recharge estimates are the same, with the Subwatershed producing 225 mm of each.

There are a number of groundwater aquifers located in this subwatershed, as well as the Spittler Creek and Otter Creek at Otterville Subwatersheds. Singer et al. (2003), identified a number of local aquifers located within the St. Thomas Moraine, near the northwest boundary of LPRCA. These aquifers are typically confined, approximately 10 m thick, and consist of sand and gravel. The aquifers are located nearby Culloden, Mount Elgin, Holbrook and Burgessville. Numerous wells are also completed in the bedrock (Dundee Formation) in this region of the Study Area. Groundwater discharge is moderate, with a total of 0.31 m^3/s being discharged within the subwatershed. The majority of the discharge occurs in the easterly portion of the subwatershed, within the pervious deposits.

Water demand within the subwatershed is moderate, with 0.57 m^3/s of groundwater takings permitted and 0.31 m^3/s of surface water takings permitted. Including non-permitted takings, it is estimated that 0.11 m^3/s is pumped, with 0.05 m^3/s consumed. The Norwich municipal wells are located within this subwatershed.

9.3.2 Otter Creek at Otterville Subwatershed

The surficial materials found in the Otter at Otterville Subwatershed are similar to the Otter Above Maple Dell Road Subwatershed. The western portion is dominated by Port Stanley Till, with the easterly portion mainly comprising pervious deposits. Precipitation for the Otter at Otterville Subwatershed is 973 mm, which is higher than the area average of 955 mm. Evapotranspiration is estimated to be approximately 540 mm, which is close to the area average of 555 mm. Much like Otter Above Maple Road Subwatershed, this Subwatershed is estimated to generate similar amounts of runoff (225 mm) and recharge (210 mm).

Significant aquifers within the Subwatershed are limited to local aquifers found within the St. Thomas Moraine, as described above, as well as the Dundee bedrock aquifer. A moderate amount of groundwater discharge, 0.40 m^3/s is predicted to occur almost exclusively within the main channel of Big Otter Creek, with no significant discharge occurring in the westerly portions of the Subwatershed. There is a negligible net groundwater outflow of 0.05 m^3/s to adjacent subwatersheds.

Water demand is moderate within the subwatershed, and is driven primarily by agricultural uses in the easterly portions of the Otter at Otterville Subwatershed. In total, 0.69 m^3/s of groundwater takings are permitted, with 0.50 m^3/s of surface water takings permitted. It is estimated, that including non-permitted uses, on an annual average basis, approximately 0.05 m^3/s is pumped and not returned to its original source. The Otterville municipal supply wells are located within this subwatershed.

9.3.3 Spittler Creek Subwatershed

The predominant quaternary material throughout the Subwatershed is Port Stanley Till. Sand and gravel deposits are present, on the eastern portion of the Subwatershed grouping, and are also interspersed throughout the Port Stanley Till. Precipitation for this area is 975 mm, which is higher than the area average of 955 mm. Evapotranspiration is estimated to be slightly below the area average of 555 mm, with a subwatershed estimate of 530 mm. In comparison to the first two Big Otter subwatersheds, Spittler Creek Subwatershed has a smaller proportion of granular deposits. As a result, the Subwatershed is predicted to have a higher runoff depth, of 275 mm, and lower rate of groundwater recharge (170 mm).

The groundwater aquifers located within the Spittler Creek Subwatershed are similar to those of the Otter at Otterville and Otter Above Maple Road Subwatersheds, and are generally limited to the local St. Thomas Moraines and the Dundee bedrock aquifer. Spittler Creek generates a moderate amount of groundwater discharge, with 0.48 m^3/s predicted to discharge, mostly in the easterly portion of the subwatershed. There is a net groundwater outflow of approximately 0.30 m^3/s into the Otter Creek at Otterville Subwatershed.

Water demand is low in the Spittler Creek Subwatershed, with permitted rates being 0.07 m^3/s for groundwater and 0.07 m^3/s for surface water. The total estimated permitted and non-permitted pumping rate is 0.02 m^3/s and considered as entirely consumptive. The municipal wells for Springford and Dereham Center are located within the Spittler Creek Subwatershed.

9.3.4 Otter Creek at Tillsonburg Subwatershed

The surficial materials of the Otter Creek at Tillsonburg Subwatershed are characterized as a mixture of pervious materials associated with the Norfolk Sand Plain on the east, and Port Stanley deposits to the west. The Subwatershed also includes the urban area of Tillsonburg. The average precipitation for the subwatershed is 970 mm, which is more than the area average of 955 mm. Evapotranspiration is estimated to be approximately 500 mm per year, which is less than the area average of 555 mm. Runoff is estimated to be 265 mm per year, which is higher than the watershed average (195 mm). Average annual recharge is estimated to be 210 mm per year.

Singer et al. (2003) described a significant confined aquifer in the Tillsonburg area. This aquifer is described as consisting of sand and gravel deposits up to 20 m in thickness. The confined aquifer is overlain by tills and clays that range from 2-56 m in thickness. There is also extensive groundwater discharge predicted throughout the subwatershed, but is focused on the main channel of Big Otter Creek. It is estimated that 1.88 m^3/s of groundwater discharges into surface water in this Subwatershed. This Subwatershed also receives 0.97 m^3/s of net groundwater inflow from adjacent subwatersheds.

Water demand is significant in this subwatershed, with permitted groundwater takings totaling 1.39 m^3/s and permitted surface water takings totaling 1.41 m^3/s. Including non-permitted uses, it is estimated that 0.21 m^3/s of water is pumped, of which 0.19 m^3/s is not returned to the source from which it was taken. The town of Tillsonburg's municipal wellfields for the town of Tillsonburg are located within this subwatershed.

9.3.5 Little Otter Creek Subwatershed

The Little Otter Creek Subwatershed is characterized as having a mixture of pervious deposits associated with the Norfolk Sand Plain, as well as finer-grained deposits associated with Port Stanley Till. Precipitation for Little Otter is 970 mm, which is slightly higher than the area average of 955 mm. Evapotranspiration is estimated to be approximately 552 mm, which is slightly lower than the area average of 555 mm. Estimated runoff for the Subwatershed is 125 mm, which is lower than the area average (195 mm). Average annual recharge is estimated to be 295 mm, which is significantly higher than the area average (205 mm).

Groundwater discharge is significant throughout Little Otter Creek Subwatershed. The groundwater model estimates that approximately 1.00 m^3/s of discharge occurs within the Subwatershed, and is fairly evenly distributed along the creek. There is low net groundwater outflow from Little Otter to adjacent subwatersheds equal to 0.02 m^3/s.

Water demand within the Little Otter Subwatershed is high and primarily driven by agriculture. In total, 1.15 m^3/s of groundwater extractions are permitted and 0.89 m^3/s of surface water is permitted. Including non-permitted takings, it is estimated that 0.10 m^3/s of water is pumped, with 0.08 m^3/s of pumped water being classified as consumptive.

9.3.6 Lower Otter Creek Subwatershed

Lower Otter Creek Subwatershed, the last subwatershed before Big Otter Creek discharges into Lake Erie, consists of a mixture of pervious deposits, Port Stanley Till and glaciolacustrine deposits. The average annual precipitation is 970 mm and average annual evapotranspiration is estimated to be 535 mm per year. Surface runoff and recharge are estimated to be 230 mm and 205 mm, respectively.

The estimated groundwater discharge for Lower Otter Creek Subwatershed is 1.08 m^3/s and is estimated to be focused in the upper reaches of this Subwatershed. A significant discharge flux is predicted at the confluence of the Little Otter and Big Otter Creeks, where the main channel of Big Otter has incised into the surficial deposits. Little Otter has a low groundwater outflow to Lake Erie, totaling 0.09 m^3/s.

The total permitted groundwater taking from the Lower Otter Subwatershed is 0.57 m^3/s. The total permitted surface water taking from the Subwatershed is 1.52 m^3/s. Including non-permitted water takings, it is estimated that on an annual average basis, 0.08 m^3/s of water is pumped and that 0.07 m^3/s of pumped water is not returned to the original source. The municipal wells for Richmond are located within the Lower Otter Creek subwatershed. However, the system only became a municipal system after completion of the Tier 2 Water Budget, with replacement groundwater sources going into production in 2013 and incorporated into the Assssement Report in 2015.

The municipal wells for Richmond are located within the Lower Otter Creek subwatershed, however the system only became a municipal system after completion of the Tier 2 Water

Budget; with replacement groundwater sources going into production in 2013 and incorporated into the Assssement Report in 2015.

9.3.7 South Otter and Clear Creek Subwatersheds

The South Otter and Clear Creek Subwatersheds discharge directly to Lake Erie and almost exclusively comprise permeable surficial materials. They have been grouped together here, only for descriptive purposes. Precipitation for South Otter and Clear Creek is 975 mm and 950 mm, respectively, which is close to the area average of 955 mm. Evapotranspiration is estimated to be in the 560-565 mm range for both Subwatersheds, which is roughly equal to the area average (555 mm). Due to the South Otter and Clear Creek Subwatersheds primarily consisting of granular material, runoff depths (95 mm, 90 mm) are much lower than the area average (195 mm). Recharge rates for South Otter and Clear Creek Subwatersheds are estimated to be 315 mm, and 300 mm respectively, which is significantly higher than the area average (205 mm).

The primary aquifer in both Subwatersheds is a very large unconfined aquifer created by the Norfolk Sand Plain. Underlying aquifers likely exist; however, the availability of sufficient amounts of available water near the surface has resulted in minimal drilling into deeper deposits. Groundwater discharge in the South Otter and Clear Creek Subwatersheds is moderate, with 0.84 m^3/s and 0.51 m^3/s, respectively, predicted to occur in each Subwatershed. Approximately 0.50 m^3/s of groundwater flow is predicted to discharge to Lake Erie from both Subwatersheds.

Water demand in both Subwatersheds is high. For the South Otter Subwatershed, permitted groundwater takings total 1.23 m^3/s and permitted surface water takings total 1.88 m^3/s. Of this, approximately 0.12 m^3/s, on an annual average basis, is estimated to be actually pumped, and 0.10 m^3/s is not returned to the source from which it came. In total, 0.08 m^3/s is not returned to any location within the Subwatershed. For the Clear Creek Subwatershed, approximately 1.41 m^3/s of groundwater is permitted and 0.61 m^3/s of surface water is permitted. For permitted and non-permitted uses, it is estimated that 0.08 m^3/s is pumped, with 0.06 m^3/s not being returned to its original source.

9.3.8 Big Creek Above Cement Road Subwatershed

The Big Creek Above Cement Road Subwatershed is located in the headwaters of the Big Creek Watershed Area and is characterized by having a mixture of low permeability surficial materials and granular, high permeability materials. The high permeability materials are predominately located in the eastern portions, but are also scattered throughout the remainder of the subwatershed. The average precipitation for the subwatershed is 915 mm, which is less than the area average of 955 mm. Evapotranspiration is estimated to be approximately 535 mm per year, which is also less than the area average of 555 mm. Due to the mixture of surficial materials, surface runoff (190 mm) and recharge (190 mm) are close to the area averages, 195 mm and 205 mm, respectively.

Groundwater aquifers are generally limited to unconfined aquifers present in areas with granular deposits, and the deeper bedrock aquifer. Simulated groundwater discharge is minimal throughout the Subwatershed, with most of the discharge predicted to occur where pervious materials are present at surface. Approximately 0.17 m^3/s of groundwater outflow is predicted to leave the subwatershed, likely to the headwaters of Big Otter Creek. There is also an estimated groundwater inflow of 0.16 m^3/s through the model boundary from adjacent watersheds.

Water demand is low in this subwatershed, with 0.28 m^3/s of groundwater extractions being permitted, and 0.12 m^3/s of surface water takings being permitted, and is predominantly agricultural in nature. It is estimated that 0.03 m^3/s is actually pumped on an annual average basis, and that 0.02 m^3/s is not returned to its original source.

9.3.9 Big Creek Above Kelvin Subwatershed

The Big Creek Above Kelvin Subwatershed consists predominantly of materials associated with the Norfolk Sand Plan; however, isolated deposits of Port Stanley Till are present. The average precipitation for the Subwatershed is 915 mm, which is lower than the area average of 955 mm. The estimated evapotranspiration is approximately 545 mm, which is close to the average value (555 mm) for the Study Area. The predominance of granular material within this Subwatershed produces significantly less runoff (100 mm) than the area average (195 mm) and more groundwater recharge (270 mm) than average (205 mm).

As with most areas within the Norfolk Sand Plain, the most significant aquifer and source of water is the unconfined aquifer created by the Sand Plain. A number of bedrock wells within this Subwatershed are completed at depth into the Dundee formation. Groundwater discharge within this Subwatershed is relatively low, with 0.28 m^3/s of discharge predicted, largely focused on the main channel of Big Creek. Approximately 0.17 m^3/s of groundwater flow is predicted by the groundwater model to exit the Long Point Region watershed and enter the Grand River watershed along the easterly boundary.

Permitted water takings are predominately groundwater based with 1.91 m^3/s of groundwater takings permitted and 0.08 m^3/s of surface water takings permitted. It is estimated that 0.14 m^3/s is pumped on an annual average basis, of which 0.11 m^3/s is not returned to its original source.

9.3.10 Big Creek Above Delhi Subwatershed

The Big Above Delhi Subwatershed reaches from Delhi to the Big Creek at Kelvin gauge. Like many subwatersheds in the Norfolk Sand Plain, it almost exclusively comprises permeable surficial materials, interspersed with some deposits of Port Stanley Till. Average precipitation for the Subwatershed is 950 mm, which is close to the area average of 955 mm. Evapotranspiration for the area is predicted to be 550 mm, which is similar to the area average (555 mm). Due to the high percentage of permeable materials, surface runoff (115 mm) is lower than average (195 mm), and groundwater recharge (290 mm) is higher than average.

The model predicts groundwater discharge to be 1.30 m^3/s, and this discharge is focused on the main Big Creek channel. As with the Big Creek Above Kelvin Subwatershed, the Big Creek Above Delhi Subwatershed also discharges groundwater flow to the east (0.12 m^3/s), into the Grand River Watershed. The Big Creek Above Delhi Subwatershed is also estimated to receive a net inflow of groundwater, of 0.15 m^3/s, from upstream subwatersheds including the Big Creek Above Kelvin Subwatershed and the headwaters of Big Otter Creek.

Permitted water demand within this Subwatershed is high, with 4.9 m^3/s of groundwater extractions permitted, and 2.1 m^3/s of surface water takings permitted. Including non-permitted takings, it is estimated that 0.33 m^3/s on an annual average basis is pumped. The annual average amount of water taken and not returned to its original source is 0.24 m^3/s; however, the monthly maximum consumptive demand is 0.93 m^3/s.

9.3.11 North Creek Subwatershed

North Creek is a small tributary that joins Big Creek in the town of Delhi. The North Creek Subwatershed is characterized as being dominated by pervious surficial materials, with a small proportion being Port Stanley Till. The average annual precipitation is 970 mm for the Subwatershed, which is slightly above the area average of 955 mm. Evapotranspiration is 565 mm which is similar to the average of 555 mm. The predominance of the Norfolk Sand Plain results in runoff being very low (85 mm) and recharge very high (320 mm) as compared to area average values.

Simulated groundwater discharge is moderate, with a predicted discharge volume of 0.37 m^3/s, or 205 mm of equivalent depth. The majority of the discharge is predicted to occur along the North Branch of North Creek, with minimal discharge along the South Branch. The North Creek Subwatershed also exhibits a net outflow of approximately 0.15 m^3/s to adjacent subwatersheds.

Water demand is substantial with permitted groundwater takings equal to 1.00 m^3/s and permitted surface water takings equal to 1.04 m^3/s. Including non-permitted takings, it is estimated that 0.20 m^3/s is pumped, and that 0.13 m^3/s is pumped and not returned to the source from which it came. The North Creek Subwatershed contains the Delhi surface water intake located at Lehman Reservoir.

9.3.12 Big Creek Above Minnow Creek Subwatershed

The Big Creek Above Minnow Creek Subwatershed is located in the middle of the Norfolk Sand Plain, and is characterized by its permeable surficial materials. The buried Galt Moraine is also present in some locations, which is indicated by Wentworth Till at the surface. The average precipitation for the Subwatershed is 993 mm which is above the area average of 955 mm. Evapotranspiration is estimated to be 565 mm which is slightly higher than the area average (555 mm). The surface runoff is estimated to be 80 mm and groundwater recharge to be 350 mm, which reflects the nature of the pervious surficial materials.

Groundwater discharge is predicted to be high, with approximately 0.78 m^3/s of groundwater entering the surface water system. This discharge is highest along the main channel of Big Creek. There is a small net groundwater inflow, equal to 0.09 m^3/s, entering the Subwatershed from adjacent subwatersheds.

As with other subwatersheds located within the Norfolk Sand Plain, water demand is high due to agricultural use. Permitted groundwater takings total 2.65 m^3/s and permitted surface water takings total 1.02 m^3/s. It is estimated that including non-permitted takings, a total of 0.18 m^3/s is pumped, and that 0.15 m^3/s of that total is not returned to its original source. The municipal supply wells for the town of Delhi are located in this Subwatershed.

9.3.13 Big Creek Above Walsingham Subwatershed

The Big Creek Above Walsingham Subwatershed is characterized by the pervious surficial deposits of the Norfolk Sand Plain. Isolated deposits of silt and clay are also present in the central portion of the Subwatershed. On average, the Subwatershed receives approximately 995 mm of precipitation, which is higher than the area average. Estimated evapotranspiration is approximately 565 mm, which is close to the area average. Runoff and recharge rates are reflective of the pervious surficial materials, and estimated to be 135 mm and 295 mm, respectively.

Whereas the Big Above Minnow Creek Subwatershed had the majority of its groundwater discharge predicted to occur along the main channel, the majority of discharge in the Big Above Walsingham Subwatershed is estimated to occur in the tributaries of Big Creek. Approximately 1.25 m^3/s of discharge is estimated to occur largely in the tributaries of Trout Creek, Mosquito

Creek, Cattle Creek, Silverthorn's Creek, and Deer Creek. The Subwatershed also receives a net groundwater inflow of approximately 0.14 m^3/s from adjacent subwatersheds.

Water demand is high and dominated by the agricultural sector. There is approximately 1.89 m^3/s of groundwater takings permitted, and 2.32 m^3/s of surface water takings permitted. It is estimated that on an annual basis, 0.37 m^3/s of water is pumped, and that 0.15 m^3/s is taken that is not returned to its original source.

9.3.14 Venison Creek Subwatershed

Venison Creek is a tributary that joins Big Creek just below the Walsingham stream gauge. The Subwatershed is characterized by predominantly pervious surficial materials, with some isolated deposits of Port Stanley Till in the headwaters. The average precipitation received by the Subwatershed is 980 mm, and the estimated evapotranspiration is 565 mm. As with all subwatersheds in the Norfolk Sand Plain, runoff (100 mm) is lower than the area average (195 mm) and recharge is higher (315 mm) than average (205 mm).

There is a significant amount of groundwater discharge predicted to occur within the Venison Creek Subwatershed. On an annual basis, 1.13 m^3/s of groundwater is estimated to discharge, and this is estimated by the model to be evenly distributed over the watercourses within the Venison Creek Subwatershed. Adjacent subwatersheds also provide the Venison Creek Subwatershed with a net groundwater inflow of 0.20 m^3/s.

There is a high water demand within the Venison Creek Subwatershed, driven predominantly by agricultural requirements. Approximately 1.76 m^3/s of groundwater takings is permitted, and 1.84 m^3/s of surface water takings is permitted. Including non-permitted takings, on an annual basis, it is estimated that 0.14 m^3/s is pumped, and 0.10 m^3/s is not returned to its original source.

9.3.15 Lower Big Creek Subwatershed

The Lower Big Creek Subwatershed is the last subwatershed before Big Creek enters into Lake Erie. The surficial materials of the Subwatershed contain the pervious materials of the Norfolk Sand Plain, Wentworth Till associated with the buried Paris Moraine, as well as glaciolacustrine deposits close to Lake Erie. A large portion of the Subwatershed has wetlands as the dominant land cover. The Subwatershed receives, on average, 984 mm of precipitation a year. Evapotranspiration is estimated to be approximately 490 mm per year, which is lower than the area average (555 mm). With the presence of glaciolacustrine deposits as well as wetlands, the runoff component of the water budget is estimated to be higher (280 mm) than average (195mm), with recharge (215 mm) being close to average (205 mm). Due to the high proportions of wetlands in this Subwatershed, there is more uncertainty surrounding these water balance estimates, as GAWSER's representation of wetland features may not fully represent groundwater/surface water interactions and evapotranspiration.

Approximately 0.38 m^3/s of groundwater discharge is estimated to occur within the Lower Big Subwatershed. Most of this discharge is estimated to occur in the upper reaches of Big Creek, near the Venison Creek/Big Creek confluence. Groundwater discharge downstream of the confluence to Lake Erie is lower. The Subwatershed has a net groundwater outflow of approximately 0.16 m^3/s, to the Dedrick Creek Subwatershed to the east, and a groundwater outflow to Lake Erie of 0.08 m^3/s.

Water demand is moderate within the Lower Big Subwatershed, with 0.68 m^3/s of groundwater takings permitted and 0.64 m^3/s of surface water takings permitted. It is estimated that, on an annual average basis, 0.06 m^3/s of water is pumped, and 0.04 m^3/s is withdrawn and not returned to the source from where it was drawn.

9.3.16 Dedrick Creek and Young/Hay Creeks Subwatersheds

The Dedrick Creek and Young/Hay Creek Subwatersheds drain directly to Lake Erie and have been grouped here for description purposes. Both Subwatersheds are predominantly comprised of pervious surficial materials commonly associated with the Norfolk Sand Plain. The Dedrick Creek Subwatershed has a significant portion consisting of Wentworth Till associated with the buried Paris Moraine, and the Young/Hay Creeks Subwatershed has minimal isolated pockets of glaciolacustrine deposits. The average annual precipitation received by the Subwatersheds is 1005 mm, which is the highest in the Study Area. Evapotranspiration is estimated to range between 550-565 mm, which is close to the area average of 555 mm. Due to the presence of Wentworth Till, Dedrick Creek produces more runoff (180 mm) than Young/Hay Creeks (135 mm), and less recharge (275 mm) than Young/Hay Creeks (305 mm).

Groundwater discharge is estimated to be 1.18 m^3/s, or 150 mm/year of equivalent depth within the Subwatersheds. This discharge is estimated to be evenly distributed throughout the stream reaches. A large amount of groundwater flow, 1.2 m^3/s leaves the Subwatersheds into Lake Erie.

Water demand is high in both Subwatersheds and is predominately agricultural based. Permitted takings in the Dedrick Creek Subwatershed total 1.27 m^3/s for groundwater sources and 1.2 m^3/s for surface water sources. Permitted takings in the Young/Hay Creeks Subwatershed total 1.48 m^3/s for groundwater takings and 0.94 m^3/s for surface water takings. Including non-permitted takings, total pumping from the Dedrick Creek Subwatershed equals 0.52 m^3/s and 0.10 m^3/s is not returned to its original source. For the Young/Hay Creeks Subwatershed, total pumping equals 0.28 m^3/s, and 0.13 m^3/s is not returned to the source from where it was drawn.

9.3.17 Lynn River Subwatershed

The surficial materials of the Lynn River Subwatershed are predominately pervious materials associated with the Norfolk Sand Plain, with some pockets of Wentworth Till associated with the buried Galt Moraine. Glaciolacustrine deposits are present near the outlet of the Lynn River. The Subwatershed, on average, receives about 985 mm of precipitation and it is estimated that evapotranspiration removes 585 mm of that precipitation. Surface runoff depths are typical of a pervious subwatershed, and are estimated to be 115 mm, compared to the area average of 194 mm. Recharge is estimated to be 285 mm, compared to the area average of 205 mm.

As with most subwatersheds located within the Norfolk Sand Plain, the predominant groundwater source is the unconfined aquifer that comprises the Norfolk Sand Plain. There is 1.12 m^3/s of groundwater discharge predicted to occur within the Lynn River and its tributaries, with the majority of it occurring within Patterson Creek and in the main channel of the Lynn River, just downstream of Simcoe. The groundwater model predicts a small net groundwater outflow from the Lynn River to adjacent subwatersheds equal to approximately 0.05 m^3/s.

Water demand within the Lynn River Subwatershed is high and predominantly driven by agricultural uses. Groundwater takings for the Subwatershed total 3.7 m^3/s, and surface water takings total 0.92 m^3/s. It is estimated that actual pumping, on an annual average basis, totals 0.28 m^3/s, of which, 0.24 m^3/s is not returned to the source from which it was taken. Municipal supply wells which service the town of Simcoe are located in this Subwatershed.

9.3.18 Black Creek Subwatershed

The Black Creek Subwatershed is situated on the interface between the Norfolk Sand Plain and the Haldimand Clay Plain. The extreme westerly portion of the Subwatershed contains pervious materials associated with the Norfolk Sand Plain, with the eastern portion comprising glaciolacustrine deposits. On average, the Subwatershed receives 980 mm of precipitation per year, and 566 mm of that becomes evapotranspiration. Due to the higher proportion of glaciolacustrine deposits, runoff is higher (250 mm) than the area average (195 mm), and recharge is lower (165 mm) than the area average (205 mm).

In the western areas of the Subwatershed, the main aquifer is the Norfolk Sand Plain aquifer; however, the only viable aquifer towards the east is the Dundee bedrock aquifer, which tends to have natural water quality issues. Groundwater discharge is moderate along most of Black Creek, with 0.50 m^3/s predicted to discharge (120 mm equivalent). Areas of higher discharge are located in the westerly portions of the Subwatershed, near the pervious deposits of the Sand Plain. Approximately 0.15 m^3/s of groundwater flow exits the Subwatershed to Lake Erie to the south.

Water demand is moderate within the Black Creek Subwatershed, and similar to other subwatersheds, is primarily driven by agriculture. Permitted water demands total 0.61 m^3/s from groundwater sources and 0.03 m^3/s from surface water sources. It is estimated that for all demands, including non-permitted uses, approximately 0.05 m^3/s of water is pumped, of which 0.04 m^3/s is not returned to its original source.

9.3.19 Upper Nanticoke Creek Subwatershed

The Upper Nanticoke Creek Subwatershed is almost completely within the Norfolk Sand Plain, and therefore predominately consists of permeable surficial materials, but also includes deposits of Wentworth Till associated with the buried Galt/Paris Moraines, and glaciolacustrine deposits of the Haldimand Clay Plain in the extreme eastern portions of the Subwatershed. The Subwatershed receives, on average, 915 mm of precipitation per year, which is lower than the area average of 955 mm. Evapotranspiration is estimated to be approximately 555 mm, which is equal to the area average. Simulated runoff, 180 mm, is slightly lower than the simulated recharge, 185 mm. Due to the lower precipitation, both values are less than the area average of runoff (195 mm) and recharge (205 mm).

Groundwater discharge in Upper Nanticoke is estimated to be 0.53 m^3/s, and is focused on the western reaches in Subwatershed. Little to no discharge occurs in the eastern reaches in the Subwatershed, where the Clay Plain is predominant. There is minimal net groundwater inflow from adjacent subwatersheds and minimal groundwater outflow to the north to the Grand River Watershed.

There are substantial water demands within the Upper Nanticoke Subwatershed, driven primarily by agricultural requirements. In total, there are 4.2 m^3/s of groundwater takings permitted and 0.61 m^3/s of surface water takings permitted. It is estimated that, including non-permitted takings, the total amount of water pumped is 0.20 m^3/s, of which 0.16 m^3/s is not returned to the source from which it was taken. The Upper Nanticoke Creek Subwatershed includes the Waterford municipal supply wells.

9.3.20 Lower Nanticoke Creek, Sandusk Creek and Stoney Creek Subwatersheds

Lower Nanticoke Creek, Sandusk Creek, and Stoney Creek Subwatersheds are all located within the Haldimand Clay Plain, and share similar characteristics. Each has been grouped together here for discussion purposes only. The three Subwatersheds in the eastern portion of

LPRCA overwhelmingly comprise glaciolacustrine deposits associated with the Haldimand Clay Plain. The Lower Nanticoke Creek Subwatershed does have some small portions of its area containing pervious deposits. The precipitation over the eastern Subwatersheds ranges from 875-900 mm, which is less than the area average of 955 mm. Evapotranspiration is estimated to range between 505-515 mm for these Subwatersheds, which is also lower than the area average. Surface runoff is typical of an area dominated by fine-grained materials, and is estimated to be 300 mm, which is the highest of all the subwatersheds investigated. Recharge is much lower than average, at 65-85 mm per year. Lower Nanticoke has the highest recharge of the three, at 85 mm, due to the localized pervious deposits.

The main groundwater source within the three Subwatersheds is the Dundee bedrock aquifer. As is the case in Black Creek Subwatershed, natural water quality issues are common with such wells, which indicate a very slow-moving groundwater flow system. Groundwater discharge is minimal, with 0.50 m^3/s (~50 mm/year equivalent) of discharge predicted. The majority of this discharge occurs along the Lower Nanticoke reaches. Discharge to Lake Erie from all three Subwatersheds totals 0.50 m^3/s.

Water demand is low for all three Subwatersheds. For all Subwatersheds, the total permitted groundwater takings is 0.20 m^3/s and 0.02 m^3/s for surface water takings. Including the non-permitted water takings, it is estimated that 0.03 m^3/s is pumped, and 0.01 m^3/s is not returned to its original source.

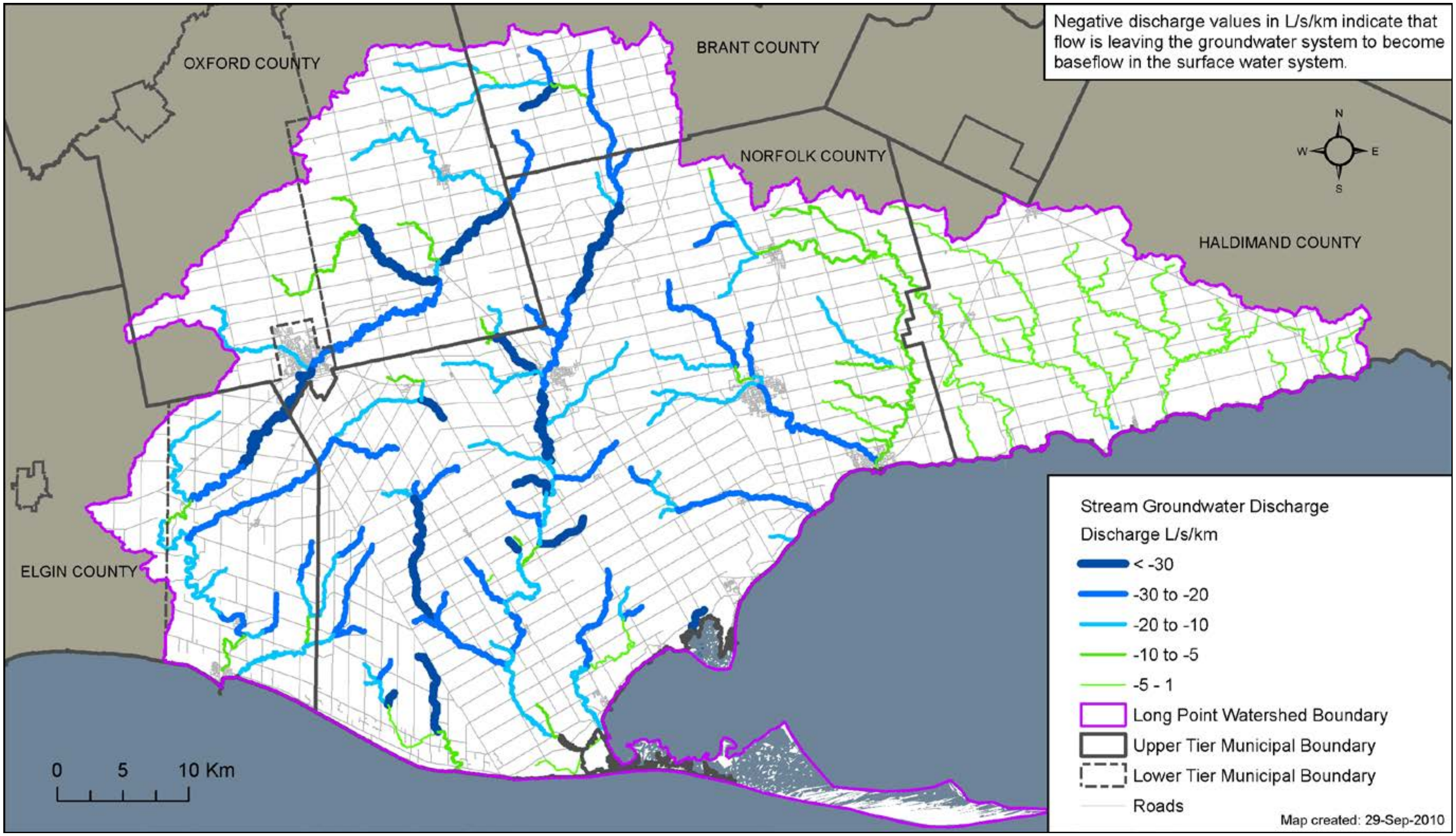
9.4 Interactions Between Groundwater and Surface Water

The calibrated groundwater model provides a synthesis of available information that can be used to increase the understanding of the groundwater flow system and its interaction with the surface water system. **Map 9-1** presents the distribution of groundwater discharge flux to the streams and rivers throughout the Long Point Region Area. The majority of the stream network in the Long Point Region watershed has high discharges from groundwater.

Groundwater and surface water interaction occurs predominantly in the central/western portion of the watershed, where a shallow groundwater system is located within the sandy, coarse-grained deposits of the Norfolk Sand Plain. Big Creek, Big Otter Creek and Little Otter Creek and their associated tributary creeks (e.g., Spittler Creek) are supported by significant groundwater discharge. Temperature mapping (**Map 2-21**) of the water courses in this area shows that they are typically classified as cold water with sustained baseflows indicating groundwater discharge into the creeks and streams. Ground and surface water pumping in the summer months when flows are reduced has the potential to affect the groundwater-surface water interactions. Years where precipitation and recharge are decreased can lead to increased water demand for various uses, and this can place stress on both the surface water and groundwater systems, and the ecological systems dependent on sustained baseflows.

In the eastern portion of the watershed region, the low permeability Haldimand Clay Plain limits the interaction between the groundwater and surface water features. The watercourses in this area are runoff-driven and there is little baseflow provided by groundwater discharge.

Map 9-1: Modelled Groundwater Discharge Map in the Long Point Region Watershed



9.5 Tier 2 Water Quantity Stress Assessment

All Long Point Region subwatersheds were evaluated at the Tier 2 level for groundwater and surface water quantity potential stress using the percent water demand calculation given below. Subwatersheds with either a 'moderate' or 'significant' potential for stress and a municipal drinking water system within the subwatershed were recommended to complete a Tier 3 Water Quantity Risk Assessment for the municipal systems within the subwatershed.

$$\text{Percent Water Demand} = \frac{Q_{DEMAND}}{Q_{SUPPLY} - Q_{RESERVE}} \times 100\%$$

Full details on the methodology for calculating the stress classification are documented in Long Point Region, Catfish Creek and Kettle Creek Tier 2 Water Quantity Stress Assessment-Final Report (AquaResource 2009b).

9.5.1 Surface Water Stress Assessment

For surface water systems, the percent water demand was calculated using monthly estimates. The maximum monthly percent water demand was used to categorize the surface water quantity potential for stress into one of three levels; Significant, Moderate or Low (see **Table 9-11**).

Table 9-11: Surface Water Potential Stress Thresholds

Surface Water Potential Stress Level Assignment	Maximum Monthly % Water Demand
Significant	> 50%
Moderate	20% - 50%
Low	<20 %

The resulting surface water stress classification for each of the subwatersheds is summarized in **Table 9-12**.

Table 9-12: Subwatershed Surface Water Potential for Stress Classification

Subwatershed	Potential Stress Classification	Municipal Water Supply (Surface Water)
Otter Above Maple Dell Road	Low	None
Otter at Otterville	Low	None
Otter at Tillsonburg	Low	None
Spittler Creek	Low	None
Lower Otter	Low	None
Little Otter	Low	None
South Otter	Moderate	None
Clear Creek	Low	None
Big Above Cement Road	Moderate	None
Big Above Kelvin Gauge	Low	None
Big Above Delhi	Moderate	None
North Creek	**Significant**	**Delhi**
Big Above Minnow Creek	Low	None

Table 9-12: Subwatershed Surface Water Potential for Stress Classification

Subwatershed	Potential Stress Classification	Municipal Water Supply (Surface Water)
Big Above Walsingham	Low	None
Venison Creek	Moderate	None
Lower Big	Low	None
Dedrick Creek	Moderate	None
Young / Hay Creeks	**Significant**	None
Lynn River	Low	None
Black Creek	Low	None
Nanticoke Upper	Moderate	None
Nanticoke Lower	Low	None
Sandusk Creek	Low	None
Stoney Creek	Moderate	None

The surface water intake for Delhi is located in Lehman Reservoir within the North Creek subwatershed, and as summarized in **Table 9-12**, was identified as having a Significant potential for stress. The Delhi municipal system relies on both surface and groundwater sources (10% and 90% respectively). Based on consultation with Norfolk County staff, it has been assumed that all future demand will be serviced from the groundwater wells. As a result no further assessment was required for the Delhi surface water system.

The Surface Water Subwatershed Stress Assessment classified the following subwatersheds as having a **Moderate** potential for stress:

- South Otter Creek;
- Big Creek Above Cement Road;
- Big Creek Above Delhi;
- Venison Creek;
- Dedrick Creek;
- Lynn River;
- Nanticoke Upper; and
- Stoney Creek.

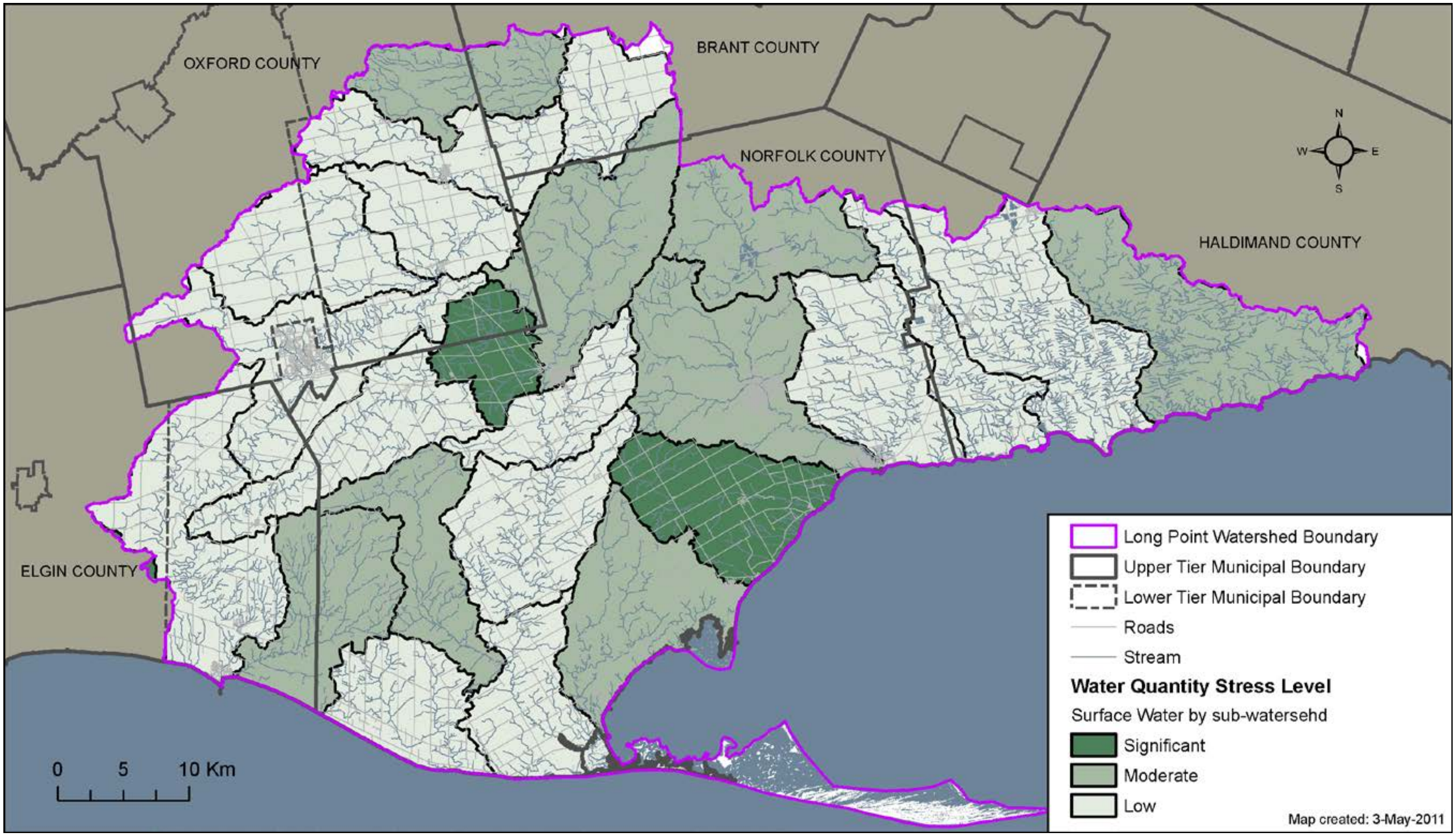
And the following subwatersheds were classified as having a **Significant** potential for stress:

- North Creek; and
- Young/Hay Creeks.

All other subwatersheds in the Long Point Region are classified as having a Low potential for surface water stress, as defined within the Technical Rules (MOE, 2008).

The following sections summarize the subwatersheds which were classified as having a **Moderate** or **Significant** potential for surface water stress. The principle hydrologic factors for the identification are discussed, and municipal supplies located within the subwatershed are identified. The results of the Tier 2 Surface Water Stress Assessment (AquaResource 2009a,b) are illustrated on **Map 9-2**

Map 9-2: Tier 2 Surface Water Stress Assessment in the Long Point Region Watershed



9.5.2 Groundwater Stress Assessment

For groundwater systems, the Stress Assessment was calculated using average annual demand conditions and for the monthly maximum demand conditions, groundwater supply was considered constant. The resulting stress level for groundwater systems was categorized into three levels (Significant, Moderate or Low) according to the thresholds listed in **Table 9-13** and **Map 9-3**.

Table 9-13: Groundwater Potential Stress Thresholds

Groundwater Potential Stress Level Assignment	Average Annual	Monthly Maximum
Significant	> 25%	> 50%
Moderate	> 10%	> 25%
Low	0 – 10%	0 – 25%

9.5.3 Groundwater Stress Assessment Results

Based on the Percent Water Demand calculations for current and future demand conditions, and the results of the Drought Scenario, the groundwater stress classifications are included in **Table 9-14**.

Table 9-14: Subwatershed Groundwater Stress Classification

Subwatershed	Potential Stress (Average Annual Demand)	Potential Stress (Maximum Monthly Demand)	Municipal Water Supplies
Otter Above Maple Dell Road	Low	Low	**Norwich**
Otter at Otterville	Low	Low	**Otterville**
Otter at Tillsonburg	Low	Low	**Tillsonburg**
Spittler Creek	Low	Low	**Springford, Dereham Center**
Lower Otter	Low	Low	**Richmond**
Little Otter	Low	Low	None
South Otter	Low	Low	None
Clear Creek	Low	Low	None
Big Above Cement Road	Low	Low	None
Big Above Kelvin Gauge	Moderate	Significant	None
Big Above Delhi	Moderate	Moderate	None
North Creek	Moderate	Moderate	None
Big Above Minnow Creek	Moderate	Moderate	**Delhi**
Big Above Walsingham	Low	Low	None
Venison Creek	Low	Low	None
Lower Big	Low	Low	None
Dedrick Creek	Low	Low	None
Young / Hay Creeks	Low	Low	None
Lynn River	Moderate	Moderate	**Simcoe**
Black Creek	Low	Low	None
Nanticoke Upper	Moderate	Significant	**Waterford**
Nanticoke Lower	Low	Low	None
Sandusk Creek	Low	Low	None
Stoney Creek	Low	Low	None

The Groundwater Subwatershed Stress Assessment classified the following subwatersheds as having a Moderate or Significant potential for stress:

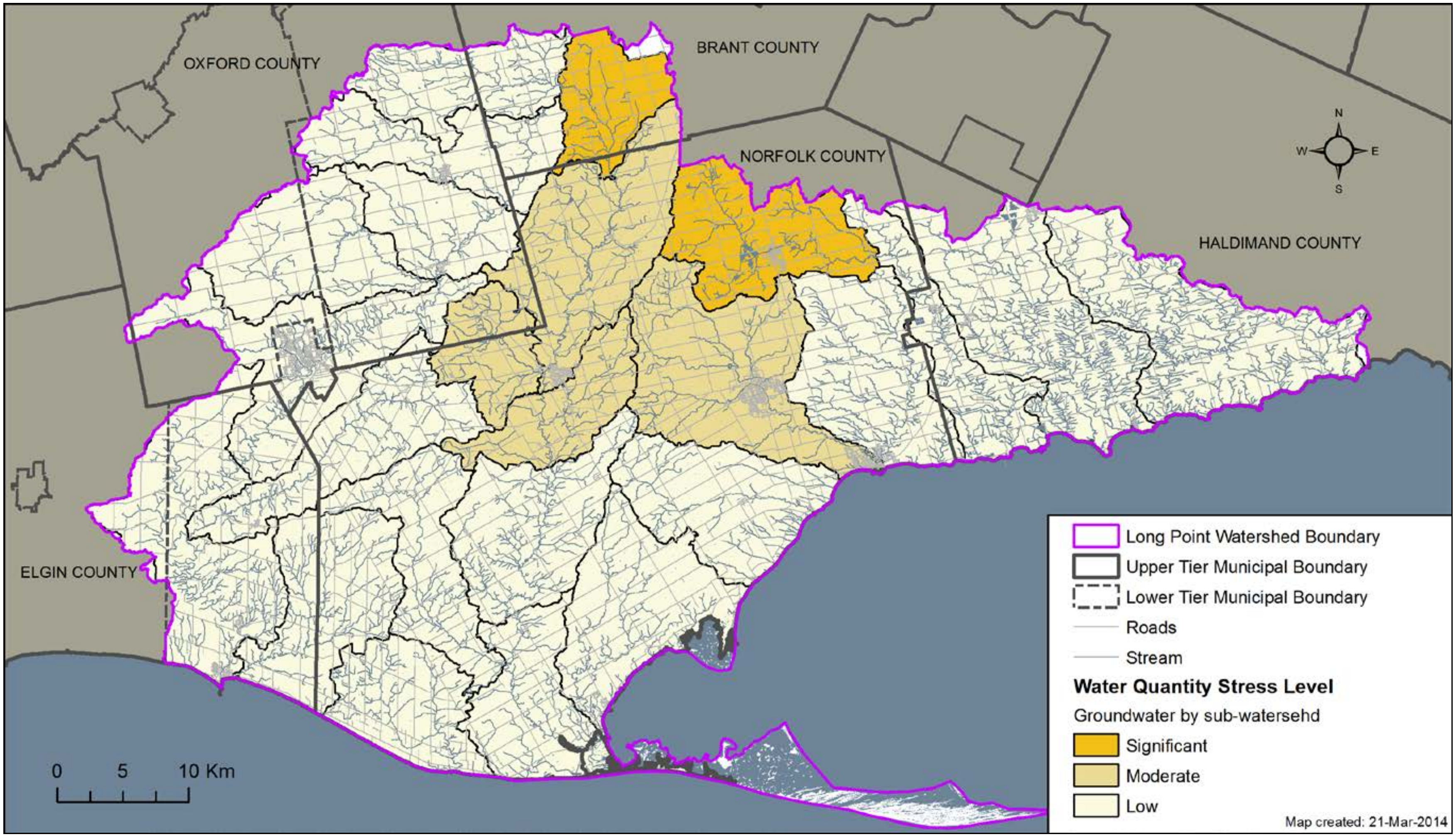
- Big Creek Above Kelvin Gauge;
- Big Creek Above Delhi;
- Big Creek Above Minnow Creek;
- North Creek;
- Lynn River; and
- Nanticoke Upper.

These subwatersheds represent the upstream portion of the Big Creek, Lynn River and Nanticoke Creek subwatersheds, as well as the most developed portion of the Big Otter Creek subwatershed. As three of these six subwatersheds did not have a municipal drinking water system located within them, they did not meet the requirements to continue with a Tier 3 water quantity risk assessment. The other three subwatersheds that did meet the requirement to advance to a Tier 3 water quantity risk assessment were the Big Creek Above Minnow Creek Subwatershed for the Delhi-Courtland supply (Norfolk County); the Lynn River Subwatershed for the Simcoe supply (Norfolk County); and the Upper Nanticoke Creek Subwatershed for the

Waterford supply (Norfolk County). A summary of the Tier 3 assessment completed for these systems is found in Section 10 of this report.

All other subwatersheds in the Long Point Region were classified as having a Low potential for groundwater stress, as defined within the Technical Rules (MOE, 2008).

Map 9-3: Water Quantity Stress Levels by Groundwater Sub-watershed in the Long Point Region Watershed



9.6 Section Summary

- A Water Budget is an understanding and accounting of the movement of water and the uses of water over time, on, through and below the surface of the earth. The Water Quantity Stress Assessment was undertaken at a Tier 2 level. Methods used and amount of data available were suitable for regional water budgeting purposes.

- There are six municipal groundwater systems: Simcoe, Tillsonburg, Waterford, Oxford South (Norwich and Otterville/Springford), Dereham Centre and Richmond. There are three municipal Great Lakes intakes serving the communities of Port Rowan, Port Dover, Hagersville, Jarvis and Townsend. There is one combined groundwater and surface water system, Delhi-Courtland, utilizing both groundwater wells and an intake on Lehman Reservoir.

- Water budget components were aggregated to the subwatershed and watershed scale. Surface water components of the water budget were determined using a continuous numerical hydrologic model, while the groundwater components of the water budget were determined using a steady-state numerical groundwater flow model. Water taking components were estimated based on surveys, modeling, and water use inventories.

- Recharge estimates were taken from the hydrologic model and applied to the groundwater model to provide a connection between the surface and groundwater numerical models.

- The western subwatersheds have low runoff and high recharge rates through the sand plain region. Water use is high and there is a large amount of groundwater discharge to surface water from the shallow aquifer system. In the till areas, runoff and recharge rates are fairly balanced. In the eastern subwatersheds, the recharge rates are low and runoff is high. Water use is low and there is little discharge to surface water from groundwater.

- The surface water subwatershed stress assessment classifies eight subwatersheds as having a moderate potential for stress under existing conditions (South Otter, Big Creek Above Cement Road, Big Creek Above Delhi, Venison Creek, Dedrick Creek, Lynn River, Nanticoke Upper and Stoney Creek) and two subwatersheds significant potential for stress under existing conditions (North Creek and Young/Hay Creeks).

- The groundwater subwatershed stress assessment classifies four subwatersheds as having a moderate potential for stress under existing conditions (Big Creek Above Delhi, Big Creek Above Minnow Creek, North Creek and Lynn River) and two subwatersheds significant potential for stress under existing conditions (Big Creek Above Kelvin Gauge and Nanticoke Upper).

- Tier 3 assessments were required for three municipal water systems: Delhi-Courtland, Simcoe, and Waterford in Norfolk County. Results of the Tier 3 assessment are summarized in Section 10 of this report.

10.0 TIER 3 WATER BUDGET AND RISK ASSESSMENT

This section describes the Tier 3 Water Budget and Local Area Risk Assessment (Tier 3 Assessment) completed for the municipal drinking water systems of the Towns of Delhi, Simcoe and Waterford, located in Norfolk County. This project was undertaken to evaluate the current and future sustainability of the water supply wells and intake, and to identify potential threats to the drinking water supplies from a quantity perspective.

10.1 Introduction

Tier 3 Assessments aim to determine if a municipality is able to meet their current and future water demands. Specifically, Tier 3 Assessments estimate the likelihood that a municipal drinking water aquifer or surface water feature (i.e., river or lake) can sustain pumping at their future pumping rates, while accounting for the needs of other water uses such as coldwater streams, or other permitted water takers in the area. Tier 3 Assessments consider current and future municipal water demand, future land development plans, drought conditions, and other water uses as part of the evaluation.

Specific tasks completed within the Tier 3 Assessment included:

1. The development of detailed mathematical models to predict whether or not municipal drinking water aquifers or surface water features could meet the current or future municipal water demands;

2. Evaluation of whether a municipal drinking water source could reliably pump its future (Allocated) pumping rates, while maintaining the requirements of other water uses (e.g. ecological requirements and other water takings);

3. Maps of water quantity vulnerable areas (areas that contributes water to a municipal drinking water system) and assigned risk levels to those areas; and

4. The identification of water quantity threats that may influence a municipality's ability to meet their future (Allocated) rates.

The MOECC released a set of Technical Rules that require Tier 3 Assessments be completed in subwatersheds that have a moderate or significant water quantity stress where there are municipal drinking water supplies. The Tier 2 Assessment for the Long Point Region (Section 9) identified that a Tier 3 Assessment was required for the Delhi-Courtland, Simcoe, and Waterford systems in Norfolk County (AquaResource 2009).

The water supply system for the Town of Delhi consists of a surface water intake and two groundwater wells completed in an overburden aquifer. Waterford is serviced by two groundwater wells, and Simcoe is serviced by nine overburden wells located in three well fields, as well as one shallow infiltration gallery, all of which draw water from overburden aquifers.

The following sections outline the steps taken in the Tier 3 Assessment to characterize the groundwater and surface water systems, undertake additional hydrogeologic field work, develop and calibrate numerical modelling tools, and complete a water quantity risk assessment for the municipal water supplies for Delhi, Simcoe and Waterford.

10.1.1 Tier 3 Assessment Methodology

The following sections describe the general steps undertaken to complete a Tier 3 Assessment.

Estimated Allocated Rates

The future municipal water demands are called the “Allocated Rates”, and estimating this demand for wells and surface water intakes is an important part of the Tier 3 Assessment process. The Allocated Rates are the sum of the following demands:

a) Current municipal water demand (Existing Demand);

b) Additional demand required to meet future population projections outlined in approved land development areas, as outlined in an Official Plan (Committed Demand); and,

c) Additional demand required to meet the growth identified in a Master Plan or Class Environmental Assessment, outside of the growth identified in the Official Plan (Planned Demand).

Characterization, Model Development and Calibration

The Tier 3 Assessment involves a more detailed level of modelling as compared to the previous water budget studies, and in some areas involves the collection of additional data near the municipal wells and intakes. Newly collected data is used to ensure the model that is developed simulates water levels and results that are as close as possible to water levels observed in the real world. Detailed characterization of the surface water and groundwater flow systems are then developed and used to create mathematical (numerical) models that simulate the groundwater or surface water flow systems. The models are calibrated so that the simulated water levels and groundwater discharge rates in the model match observed values as closely as possible. Once the model is calibrated, an external team of experts (Peer Reviewers) review the reports and provide comments on how the model or reports should be updated to meet the objectives of the project.

Delineate Vulnerable Areas

For groundwater wells, the calibrated groundwater flow models are applied to delineate the following vulnerable areas around the municipal wells:

a) WHPA-Q1: the area(s) above the depression in the water table (or potentiometric surface) created by pumping one or more wells at their future (Allocated) pumping rates where the municipal drinking water system could be affected by other existing, new or expanded water takings.

b) WHPA-Q2: the WHPA-Q1 area plus any area(s) where a reduction in groundwater recharge (precipitation that infiltrates down into the groundwater flow system) would have a measurable impact on the water levels in a municipal well.

For this Tier 3 Water Budget and Risk Assessment in Norfolk County, the WHPA-Q2 is the same as WHPA-Q1, and is called the WHPA-Q. There are no areas, i.e. development that would result in an increase in impervious surfaces, where a reduction in groundwater recharge would have a measurable impact on the water levels in a municipal well

For surface water systems, calibrated surface water or integrated models are applied to delineate a vulnerable area around a surface water intake called the IPZ-Q. This area is defined as the drainage area that contributes surface water to an intake, plus the area that provides recharge to an aquifer that contributes groundwater discharge to the drainage area. The IPZ-Q is another type of vulnerable area.

Complete Risk Assessment

This portion of a Tier 3 Assessment involves using groundwater and/or surface water models to assess the municipality's ability to pump water under different stressors. The stressors or the different model scenarios that need to be evaluated are prescribed by the Province. In general, the models are applied to evaluate how water levels will change under the following conditions:

a) When land is development to the extent described in the municipality's Official Plan;

b) Municipal wells are pumped at their future (Allocated) pumping rates; and

c) Long term drought conditions.

Table 10-1 outlines the scenarios that are evaluated in each Tier 3 Assessment in the Province.

The predicted water level elevations in each of the scenarios are compared to operational criteria to determine whether the municipal aquifers or surface water bodies can meet the future demands.

Tier 3 Assessments must also evaluate how municipal pumping at future rates (Allocated Rates) impacts groundwater discharge into coldwater streams and Provincially Significant Wetlands (PSW). Potential reductions in the amount of groundwater that discharges into coldwater streams to support fish habitat, or into provincially significant wetlands to sustain ecological habitat are also estimated.

Table 10-1: Risk Assessment Scenarios

Groundwater Risk Assessment Scenario	**Climatic Conditions**	**Land Use**	**Municipal Demand**
C – Existing conditions	Average climate	Existing	Existing
G – Planned growth	Average climate	Official Plan	Allocated Rates
D – Longterm drought	10 year drought	Existing	Existing
H – Longterm drought plus growth	10 year drought	Official Plan	Allocated Rates
Surface Water Risk Assessment Scenario	**Climatic Conditions**	**Land Use**	**Municipal Demand**
A – Existing conditions	Average climate	Existing	Existing
E – Planned growth	Average climate	Official Plan	Allocated Rates
B – Long term drought	10 year drought	Existing	Existing
F – Long term drought plus growth	10 year drought	Official Plan	Allocated Rates

Assign Risk Level to Vulnerable Area

According to the Rules, the risk level may be "low", "moderate" or "significant" depending on whether the municipal water supply is predicted to be able to meet the water needs of its customers under the modelled risk scenarios. If the water level in a well or surface water intake is predicted to fall below acceptable operating levels under any of the scenarios listed in **Table 10-1**, then the vulnerable area containing the wells or intakes is assigned a "Significant" water quantity Risk Level. If increased municipal pumping due to growth (scenario G) is predicted to cause an unacceptable decline in groundwater contribution to a surface water course, a Risk Level of "Moderate" is assigned. If none of these triggers are met the wells or intakes are assigned a "Low" water quantity Risk Level. After this Risk Level is assigned, any activity in a vulnerable area that reduces groundwater recharge to the aquifer, or removes water from an aquifer without returning it to the same aquifer (consumptive use), is classified as a drinking water threat.

Identify Drinking Water Threats

Drinking water threats are classified as low, moderate or significant depending on the Risk Level assigned to the vulnerable area. If the Risk Level of the vulnerable area is significant, then all consumptive water uses and reductions in groundwater recharge are classified as significant drinking water threats. If the Risk Level of the vulnerable area is moderate, only future activities (new or increased water takings) are classified as significant threats. Policies are then drafted by the Source Protection Committee to manage or mitigate all significant drinking water threats.

10.2 Groundwater and Surface Water Characterization

The Long Point Region Tier 3 Water Budget and Local Area Risk Assessment Characterization Report (Matrix, 2013) contains a detailed description of the Tier 3 Study Area, including characterization for the entire Long Point Region and the Tier 3 Focus Area (**Map 10-1**). The Focus Area includes the lands immediately surrounding the Towns of Delhi, Simcoe and Waterford as well as the town of Tillsonburg. The following sections provide a brief overview of the physical setting of the Focus Area.

10.2.1 Topography and Physiography

Regionally, ground surface elevation in the Tier 3 Study Area varies through the three Conservation Authorities from a high of approximately 340 m above sea level (asl) north of Tillsonburg, along the St. Thomas Moraine, to a low of approximately 174 m asl to the south, along the Lake Erie shoreline. In the Focus Area, ground surface topography varies from 307 m asl on the St. Thomas Moraine, to 190 m asl along the valleys of Big Otter Creek, Big Creek, and Lynn River. Topographic highs are also associated with moraines in the area including the Westminster, Norwich, Tillsonburg, Courtland, Mabee, Paris, Galt, and Moffat Moraines.

The Tier 3 Focus Area is contains portions of four physiographic regions; Norfolk Sand Plain, Mount Elgin Ridges, Horseshoe Moraines, and the Haldimand Clay Plain (Chapman and Putnam 1984). The Towns of Delhi, Simcoe, and Waterford are found within the Norfolk Sand Plain, which is the predominant region in the Focus Area and is characterized by relatively flat lying, coarse grained sand deposits with some silt.

The Tillsonburg and Paris Moraines are part of the Horseshoe Moraines region and are located north and east of Delhi. These two moraines are characterized by irregular ridges of Wentworth Drift, as well as layers of sand, gravel and till (Barnett 1982).

The Haldimand Clay Plain is located east of Waterford and Simcoe. This area is characterized as relatively flat-lying clay; however, the clay thins and is interbedded with till in areas to the north (Chapman and Putnam 1984; Barnett 1978).

10.2.2 Surface Water Features

The Tier 3 Focus Area contains several surface water features that are important from a hydrologic perspective (**Map 10-2**). In the western portion of the Focus Area, Big Otter Creek flows from the northeast, through Tillsonburg and continues southwest, eventually draining into Lake Erie. Tributaries to these creeks are small with the exception of Little Otter Creek, which flows south of the Town of Courtland and feeds Big Otter Creek southwest of the Focus Area.

Near Delhi, Big Creek flows from the north, through the northwestern part of Delhi, and continues south, where it ultimately enters Lake Erie. The Big Creek tributaries of North and South Creeks converge from the west and are dammed to form the Lehman Reservoir before entering Big Creek. This five hectare reservoir supplies a portion of the municipal water supply for the residents of Delhi and Courtland (AECOM 2010). Several kilometers south of Delhi, Stony Creek feeds into Big Creek, originating from the northeast and passing to within 500 m of the two water supply wells that service Delhi and Courtland.

Major surface water features in the northeastern part of the Focus Area include Nanticoke Creek, which flows southward where it flows into and beside the Waterford Ponds and subsequently turns east, through the Town of Waterford, before continuing southeast and into Lake Erie. The two Waterford wells are located adjacent to these ponds, which are former gravel pits now used for recreation. The coarse grained texture of the pond/lake substrate is interpreted to allow surface water infiltration during municipal pumping (Lake Erie SPRTT 2008) from these two wells classified as Groundwater Under Direct Influence (GUDI) of surface water.

In the southeastern portion of the Focus Area, Patterson and Davis Creeks flow southward and converge to form the Lynn River in the northern extent of the Town of Simcoe. Lynn River flows southwards, through Simcoe, where it is fed by Kent Creek, originating from the west. Lynn River continues through Simcoe and southeastward until it reaches its terminus at Lake Erie. The municipal wells of the Northwest Well Field lie adjacent to former sand and gravel pits (that have formed ponds), as well as adjacent to the upper reaches of Patterson Creek. The infiltration gallery and groundwater wells of the Cedar Street Well Field are located adjacent to Kent Creek.

10.2.3 Geology and Hydrogeology

Hydrogeologic Field Program

Most of the water wells in the Focus Area have a depth less than 20 m, because there is a thick sand and gravel aquifer present at or near ground surface (Norfolk Sand Plain) across the central portions of the Study Area. As such, one of the key geological uncertainties (AquaResource, 2009a) was the lack of detailed geological and hydrogeological data beneath the upper sand aquifer. To address these data gaps, a drilling program was undertaken as part of the Tier 3 Assessment to improve the understanding of the geology across the Focus Area (Stantec et al. 2015).

Twenty six boreholes were drilled into the top of bedrock as part of the drilling program with the main purpose of refining the regional geology of the area. The 26 boreholes were converted into monitoring well nests with one to three monitoring wells per location for a total of 58 monitoring wells. Nine drive-point piezometers were installed in various reaches of Patterson Creek, Stoney Creek and Kent Creek to refine the understanding of how groundwater and surface water interact in these creeks. Field studies included water level monitoring, water quality sampling, and hydraulic testing at the monitoring wells. **Map 10-3** illustrates the locations of the boreholes, monitoring wells and mini-piezometers installed across the Long Point area. The data collected in the field program was assembled and used to develop an improved understanding of the geology and hydrogeology of the Tier 3 Focus Area and the surrounding lands.

Regional Characterization

The Tier 3 Focus Area is underlain by dolostones and limestones of the Dundee, Lucas, Amherstburg, Onondaga, Bois Blanc, and the Bass Islands/Bertie formations. These bedrock aquifers are seldom used in the Focus Area as overburden aquifers are thick and transmissive. East of Delhi and Simcoe where the Haldimand Clay Plain lies at surface, the limestone and dolostone units of the Dundee and Onondaga Formations are used for domestic water supply. The Dundee, Lucas and Amherstburg formations are productive bedrock aquifers but in places exhibit elevated concentrations of sulphur (Armstrong and Carter 2010).

The characterization of the overburden geologic and hydrogeologic units was based on high quality drilling (corehole) data collected as part of the Tier 3 Assessment and the general understanding of the glacial history of the area. Other data sources including lower quality water well data were also used to fill in gaps where high quality data was more limited. Regional- and local-scale cross sections were generated and interpreted to extend through various depositional and erosional landforms and a total of eleven overburden hydrostratigraphic layers that represent hydrostratigraphic units within the Regional Area. **Table 10-2** lists the hydrostratigraphic units.

Table 10-2: Hydrostratigraphic Units within the Long Point area

Number	Geologic Unit	Aquifer / Aquitard
1	Haldimand Clay Plain/ Surficial Clay	Aquitard
2	Norfolk Sand Plain	Aquifer
3	Wentworth Till (upper)	Aquitard
4	Sand and Gravel	Aquifer
5	Wentworth Till (lower)	Aquitard
6	Sand and Gravel	Aquifer
7	Port Stanley Till (upper)	Aquitard
8	Sand and Gravel	Aquifer
9	Port Stanley Till (lower)	Aquitard
10	Sand and Gravel	Aquifer
11	Catfish Creek Till	Aquitard
12	Bedrock	Aquifer/ Aquitard

Overburden aquifers include coarse-grained sands and gravel that often lie between layers of fine-grained till, creating a complex aquifer system, especially in the Focus Area. The Norfolk Sand Plain is the most spatially extensive aquifer and it lies within the Long Point Region. This unconfined aquifer lies at surface and has a thickness that exceeds 20 m in some areas, including Delhi.

Beneath the upper Norfolk Sand Plain aquifer is an intermediate aquifer that is commonly overlain by Wentworth or Port Stanley Till in the western portions of the Focus Area. The sand aquifer pinches out in the eastern portions of the Focus Area where the Haldimand Clay Plain is mapped at surface. Overburden aquifers are absent east of the Focus Area beneath the clay plain.

Due to their high transmissivity, few boreholes penetrate below the shallow and intermediate aquifers and information regarding the spatial extent of the lower aquifers is sparse. Deep borehole data collected in the Tier 3 field program indicated the deeper aquifers are thin and discontinuous so unlikely to be productive aquifers for municipalities. The conceptual hydrostratigraphic framework presented in **Table 10-2** was used as the basis for the development of the groundwater and integrated models used in the Tier 3 Assessment.

Regional-scale maps of shallow and deep groundwater elevations were created using all available water level data. The maps included high quality monitoring well data and lower quality water level data from water well records. Shallow groundwater levels correlate with wells that have a depth less than 15 m below surface, and deep are those with a depth greater than 15 m.

As illustrated in **Map 10-4**, shallow groundwater levels are highest (305 m asl) in the northwest beneath the St. Thomas Moraine and groundwater flows from these features to the south and southeast towards the Lake Erie shoreline (174 masl). Shallow groundwater flows towards and into surface water features such as Big Creek, Big Otter Creek and the Lynne River, which flow through Delhi, Tillsonburg and Simcoe, respectively.

Deeper water levels (**Map 10-5**) show a similar pattern to the shallow water levels with the highest water level elevations occurring in the northwest and the lowest water levels along the surface water features and Lake Erie shoreline.

Local Characterization – Delhi

The municipal supply aquifer for the Delhi wells consists of fine to coarse grained sand, which is overlain by approximately 17 m of Wentworth Drift and approximately 18 m of sand and gravel that lies at surface. Geological cross sections reveal windows in the Wentworth Drift that may hydraulically connect the deeper municipal aquifer to the shallow surficial aquifer.

Local Characterization – Simcoe

The Town of Simcoe is serviced by three well fields located in the transition zone between the Norfolk Sand Plain in the west and the Haldimand Clay Plain in the east, resulting in a complex aquifer/aquitard system in this area.

The municipal production wells of the Northwest Wellfield draw their water from the bottom of a 15 to 30 m thick fine to medium-grained sand aquifer that is overlain in the north by a discontinuous and thin (<2 m) layer of fine-grained Wentworth Till. South of Northwest Well 2, the till is absent and the aquifer lies at ground surface and is therefore, is considered unconfined. The municipal aquifer thins from the Northwest Wellfield to the south towards the Chapel Street Wellfield. Boreholes logs in the area note that the Wentworth Till is absent in some areas, leading to connections between shallow ponds created from historic aggregate extraction operations, and the deeper municipal production aquifers.

Three overburden aquifers located in the Cedar Street Wellfield area are separated by aquitards. The uppermost surficial sand aquifer is part of the Norfolk Sand Plain and locally is approximately 6 m thick. It is underlain by a discontinuous layer of Wentworth Till. The Wentworth Till is not present at Cedar Street Well 1A, Cedar Street Infiltration Gallery, or areas west of Cedar Street Wells 2A and 3. Where the Wentworth Till is absent the sand aquifer and intermediate aquifer are connected and have a total thickness of approximately 12 m at the production wells. Underlying the intermediate aquifer is a thick unit of Wentworth and Port Stanley tills.

In the area surrounding Chapel Street Well 3, the municipal well obtains water from a 5 m thick aquifer that is overlain by approximately 10 m of fine-grained Wentworth Drift, and the well is located far from sensitive surface water features.

Local Characterization – Waterford

The Waterford municipal production wells are completed in a 6 m thick discontinuous sand and gravel aquifer that is part of the Norfolk Sand Plain. The aquifer is overlain by Wentworth Till. The till is absent in some areas resulting in a hydraulic connection between the municipal supply aquifer and the nearby Waterford Ponds. The municipal production aquifer thins in the areas north and south of the well field and pinches out to the west where the Wentworth Till thickens. Underlying the production aquifer is a 15 m thick unit of fine-grained silty clay to sand interpreted as the Port Stanley Till.

10.2.4 Water Demand and Other Water Uses

Municipal Water Supply Systems

Existing demand for each water supply well and intake was calculated as the average reported demand between 2008 and 2012 (**Table 10-3**). An average was used to avoid skewing the data if one well was shut down for an extended period for maintenance while the pumping rate in others was increased to compensate. The following paragraphs outline the permitted and existing rates for the three communities.

Table 10-3: **Municipal Water Demand**

Well / Intake Name	Permitted Rate (m^3/day)	Average Existing Demand (m^3/day) (2008-2012)	Committed Demand (m^3/day)	Allocated Demand (m^3/day)
Waterford				
Thompson Rd. Well 3	3,270	529	197	726
Thompson Rd. Well 4	2,946	507	197	705
Total	**6,216**	**1,036**	**395**	**1,431**
Simcoe				
Northwest Well 1	2,292	100	0	100
Northwest Well 2	2,292	1,025	0	1,025
Northwest Well 3	2,292	976	102	1,078
Cedar Street Well 1A	6,819	401	102	503
Cedar Street Well 2A		257	102	359
Cedar Street Well 3		447	102	549
Cedar Street Well 4		282	102	383
Cedar Street Well 5		374	102	476
Infiltration Gallery	5,236	569	0	569
Chapel Street Well 3	3,437	1,482	102	1,584
Total	**22,368**	**5,913**	**713**	**6,626**
Delhi				
Delhi Well 1	2,300	487	132	619
Delhi Well 2	2,300	976	132	1,108
Lehman Reservoir	6,815	195	0	195

Total	**11,415**	**1,658**	**264**	**1,921**

Drinking water for the community of Waterford is serviced by two shallow overburden groundwater supply wells (Thompson Road Wells 3 and 4). These wells are located adjacent to former aggregate extraction pits that infilled with water, creating ponds. The total average taking for the wells from 2008 to 2012 was 1,036 m^3/d and total maximum permitted taking is 6,216 m^3/d (**Table 10-3**).

Simcoe relies entirely on groundwater to meet the drinking water needs of the community. There are nine groundwater wells and an infiltration gallery including; Northwest Wells 1, 2, and 3; Cedar Street Wells 1A, 2A, 3, 4, and 5; and Chapel Street Well 3. The shallow infiltration gallery is completed within the overburden aquifer. The nine municipal wells in the Simcoe area are permitted to take over 22,000 m^3/d, and the average annual reported taking between 2008 and 2012 was 5,913 m^3/d. Half of the water supply is provided by Northwest Wells 2 and 3, and Chapel Street Well 3 (**Table 10-3**).

The water supply system in Delhi consists of a surface water intake at the Lehman Reservoir where North and South Creeks converge and are dammed, as well as two overburden wells (Wells 1 and 2). The groundwater and surface water sources are combined and service Delhi as well as the nearby community of Courtland. Wells 1 and 2 and the Lehman Reservoir are permitted to take 11,415 m^3/d, and the average annual reported taking between 2008 and 2012 from all three sources was 1,658 m^3/d, with 88% of that water derived from the groundwater wells.

Future water demand was estimated using information from Norfolk County staff. The number of unconnected lots (e.g., lots that are registered, draft approved or committed) for each of the communities was estimated with the number of people per dwelling to estimate the future population increase. The future water demand was calculated using an estimated per capita water use value, and this value was distributed amongst the existing wells and surface water intake. Environmental Assessments have not been completed for any future potential water supply wells, so there are no Planned Demands. **Table 10-1** lists the committed demands, and the Allocated Rates for the municipal wells and surface water intake calculated in the Tier 3 Assessment.

Non-Municipal Water Demand

Other water uses that are reliant on groundwater and/or surface water were also identified in this assessment. Consumptive water demand is defined as the amount of water that is removed from a water source and not returned to the same water source within a reasonable amount of time. Consumptive water takers within the Focus Area including both municipal and non-municipal permitted water takings were compiled for the Tier 3. Average consumptive demand was estimated for the non-agricultural permitted water takers using data from the MOECC and agricultural (irrigation) water use was estimated using an irrigation demand module in the integrated surface water and groundwater model.

Other Water Uses; Coldwater Streams and Provincially Significant Wetlands

Coldwater streams supporting coldwater fish communities such as brook and brown trout are prevalent across the Focus Area, especially in areas where coarser surficial sediments of the Norfolk Sand Plain are present at ground surface (Lake Erie SPRTT 2008).

In the western portion of the Focus Area (**Map 10-6**), coldwater streams are found along Big Otter Creek. Similarly, the entire lengths of Cedar Creek and Little Otter Creek were observed to support coldwater fisheries. In the central portion of the Focus Area, coldwater stream reaches are found along the length of Big Creek and the majority of South Creek. Below the Town of Delhi, similar conditions exist along Stony Creek and its tributaries approximately 450 m north of the Delhi municipal supply wells (**Map 10-6**). In the vicinity of the Town of Waterford, in the north-eastern portion of the Focus Area, stream conditions entering the town from the north and south are predominately coldwater. Nanticoke Creek becomes a warmwater stream downstream of the Waterford Ponds (**Map 10-6**). In the south-eastern portion of the Focus Area, above the Town of Simcoe, tributaries of Lynn River (i.e., Patterson and Davis Creeks) have been mapped as coldwater groundwater discharge areas. West of Simcoe, Kent Creek transitions to coldwater approximately 2 km upstream of the municipal supply wells, on the western edge of town (**Map 10-6**). The Lynn River leaves the Focus Area as a coldwater stream below Simcoe.

Wetlands are evaluated using a standard methodology that take into account the biological, hydrological, and socio-economic features and functions of the wetland. Based on this system, some wetlands are identified as Provincially Significant and are protected under the Provincial Policy Statement. A total of 24 Provincially Significant Wetlands (PSWs) are located in the Tier 3 Focus Area.

In the central part of the Focus Area, small PSWs are located along the entire length of Big Creek, including a small area less than 200 m from the Lehman Reservoir intake. PSWs located nearest to the Delhi groundwater wells include the Nixon Ellaton Wetlands and Kent Creek Complex located to the north and southeast, respectively. The Waterford groundwater wells found in the northeastern portion of the Focus Area are surrounded by a PSW (NC2) that follows Nanticoke Creek and its southern tributaries and surrounds the Waterford Ponds. Three PSWs are found near Simcoe including: LR13, which follows the upper reaches of Patterson Creek and runs adjacent to the Northwest Well Field; the Kent Creek Complex, which follows Kent Creek and lies close to or encompasses the Cedar Street Well Field and infiltration gallery; and the LR16 Complex, which follows Lynn River as it flows to the southeast away from Simcoe (**Map 10-6**).

10.2.5 Land Use and Land Use Development

Land use development has the potential to reduce groundwater recharge. Tier 3 Assessments evaluate the impact of future changes in land use, as outlined in the Official Plan, on municipal water supplies. To identify areas of future land use change (and potential recharge reduction), a map of the areas where the land use is expected to change was created using existing land use data from Land Information Ontario and the Southern Ontario Land Resources Information System (SOLRIS) and compared with a map of land use specified in the Official Plan (**Map 10-7**). Recharge reductions were assumed to be equal to estimated percent impervious values (Brabac et al. 2002) for future land uses noted in the Official Plan; these land uses and impervious estimates are summarized below in **Table 10-4** for each land use.

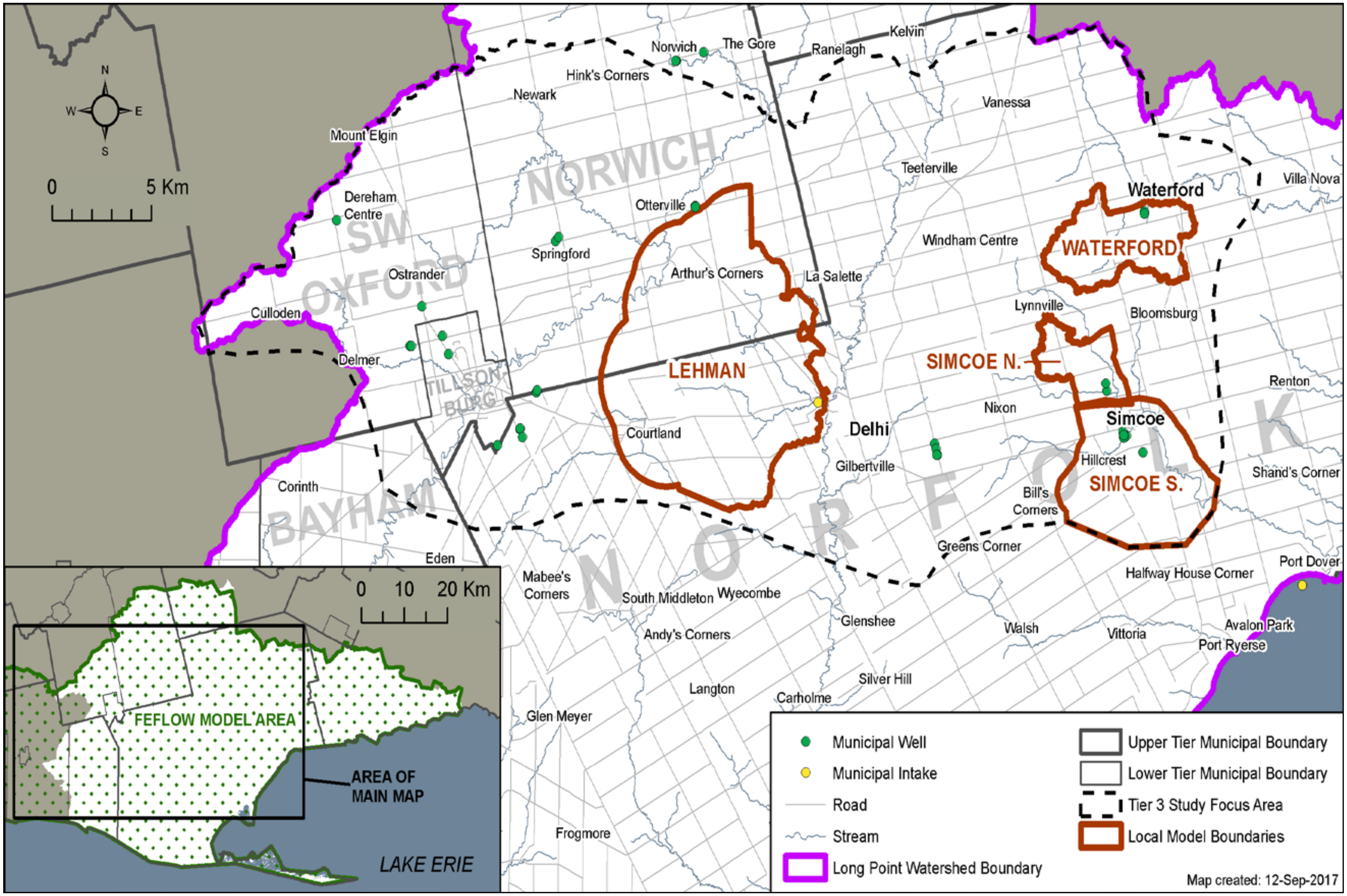
Table 10-4: Recharge Reduction Estimates Applied for Future Land Use Areas

Official Plan Land Use	Simplified Land Use	Assumed Percentage Impervious
Institutional	Parks and Recreation	10%
Hamlet	Residential	30%

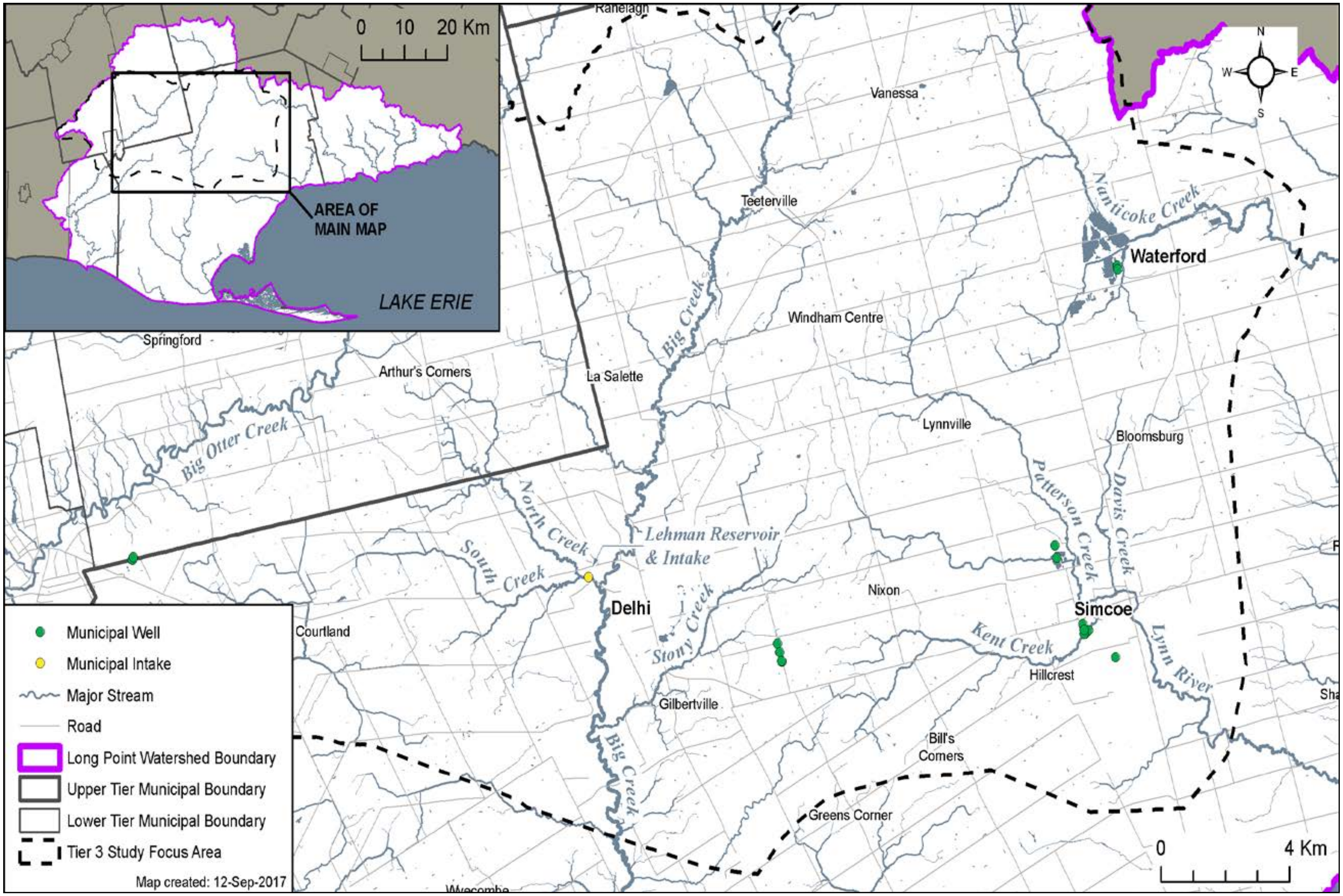
Urban Residential		
Commercial	Commercial	70%
Shopping Centre Commercial		
Central Business District		
Industrial / Business Park	Industrial	70%

In Waterford, land use changes will mainly include the introduction of new urban residential development, with small industrial/business park and commercial areas in the western and southern parts of the town. In Simcoe, most of the residential development will occur along the outskirts of the southern portion of the town, whereas land use along the northern parts of the town is predicted to change to industrial/business parks and commercial land uses. In the community of Delhi, development will primarily be residential in the northern and southern parts of town, whereas development towards industrial/business park land uses is anticipated to occur in the eastern and northwestern parts of town. Commercial development is anticipated to be minor with limited areas of land located in the northern part of Delhi identified for development. In the community of Courtland, land use is predicted to change to residential uses in the central and southern parts of the town, whereas areas to the east and northwest are predicted to change to more industrial/business park uses.

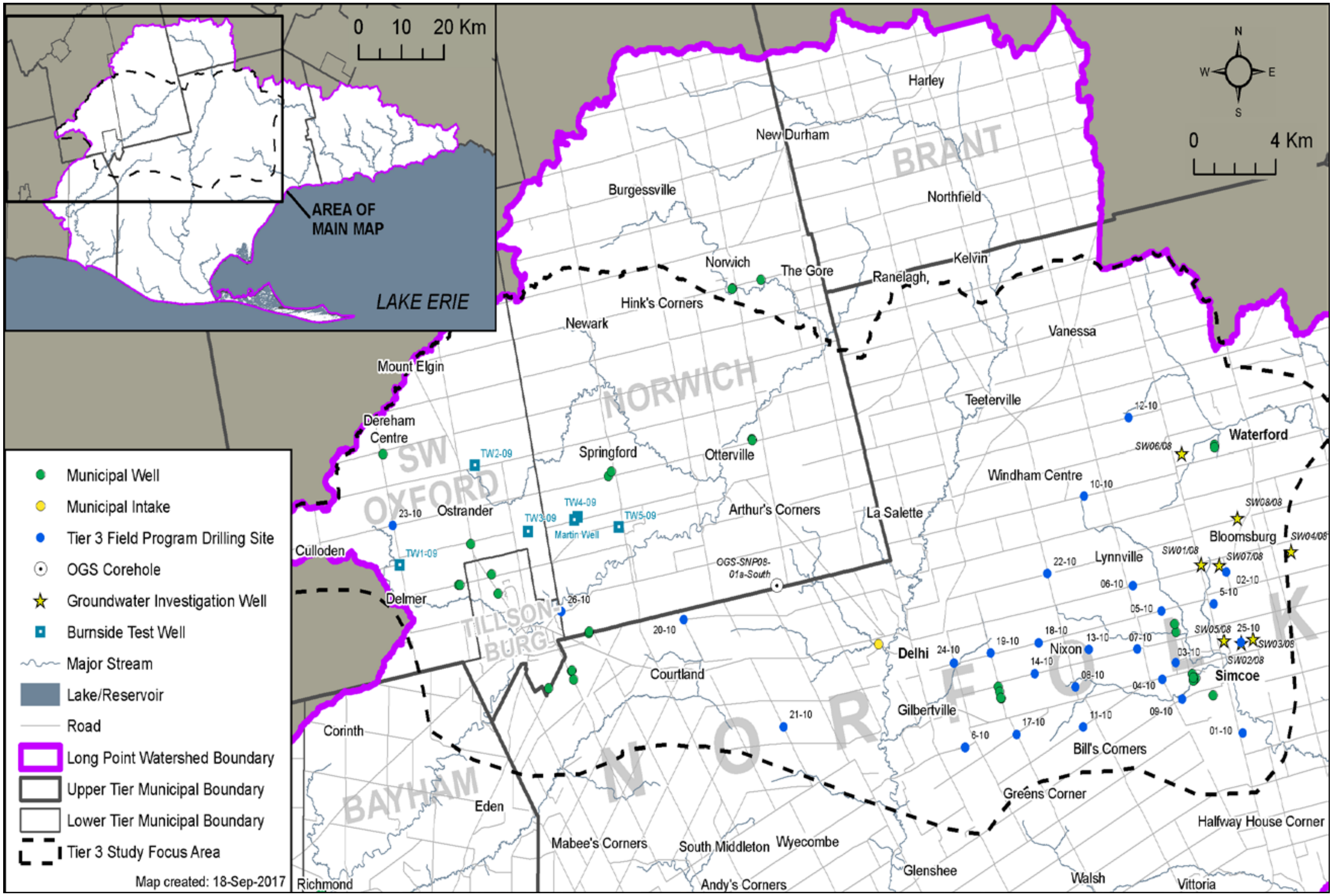
Map 10-1: Tier 3 Study and Focus Area



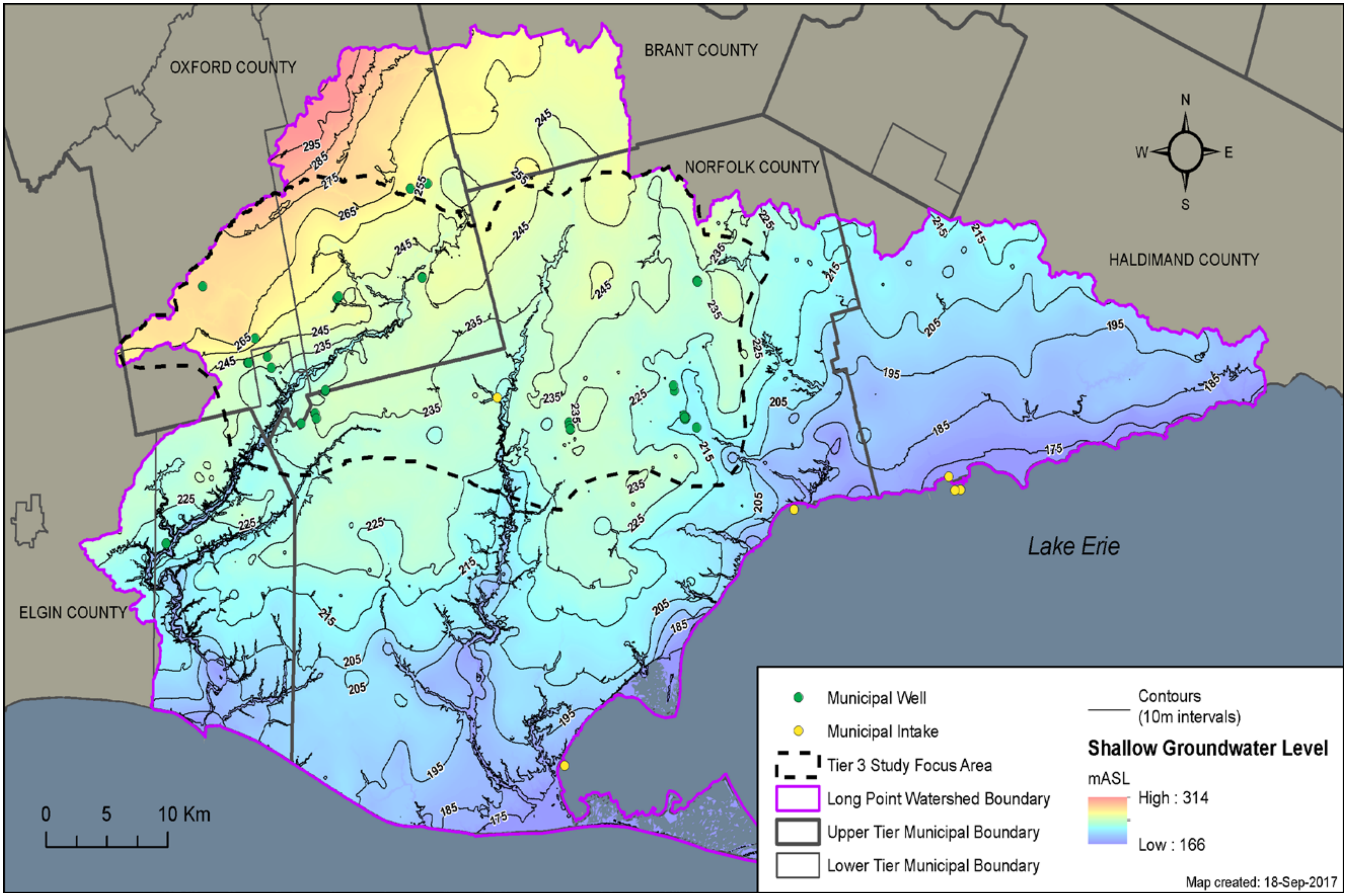
Map 10-2: Tier 3 Focus Area - Surface Water Features



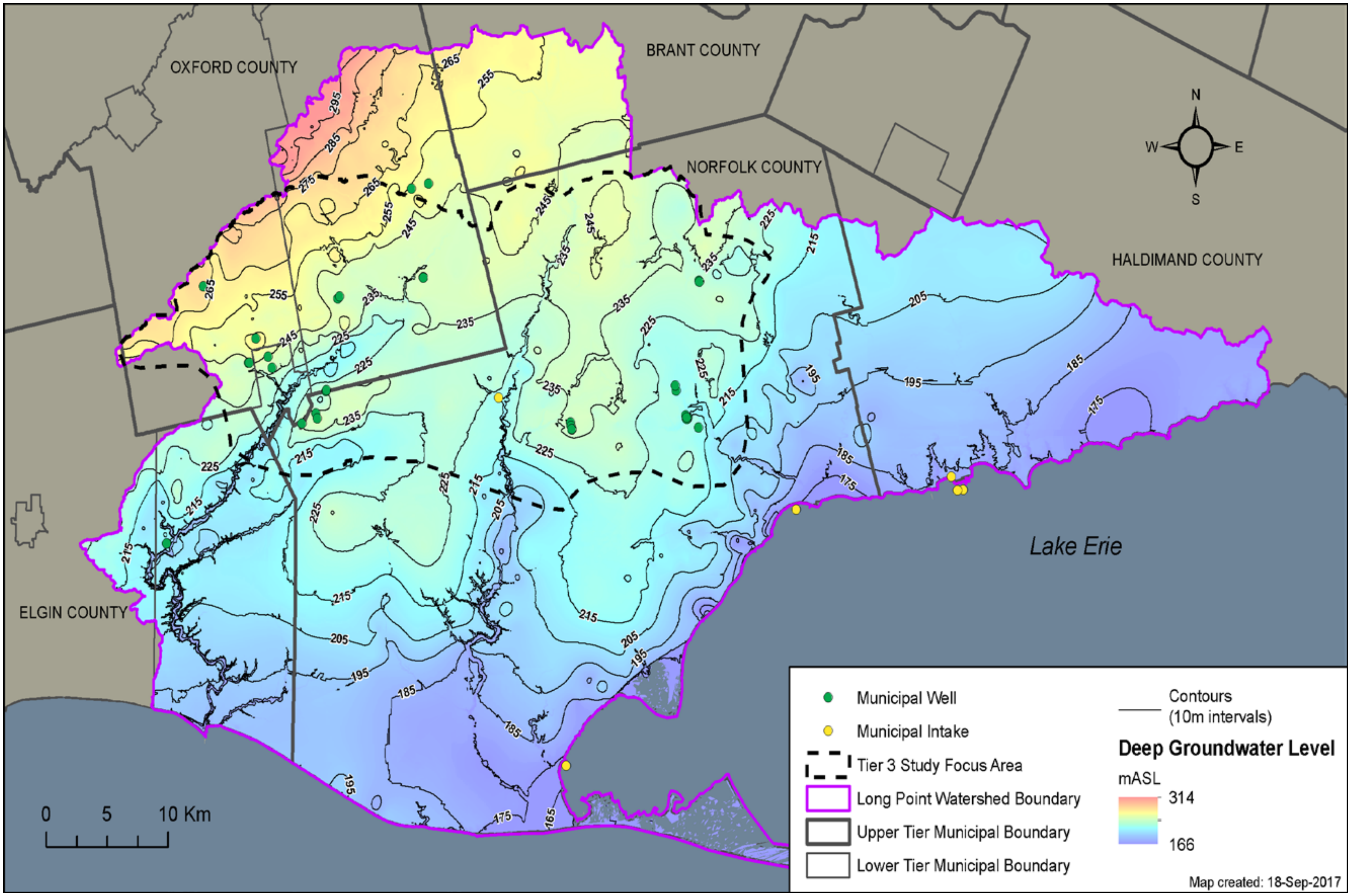
Map 10-3: Tier 3 Focus Area - High Quality Well Locations



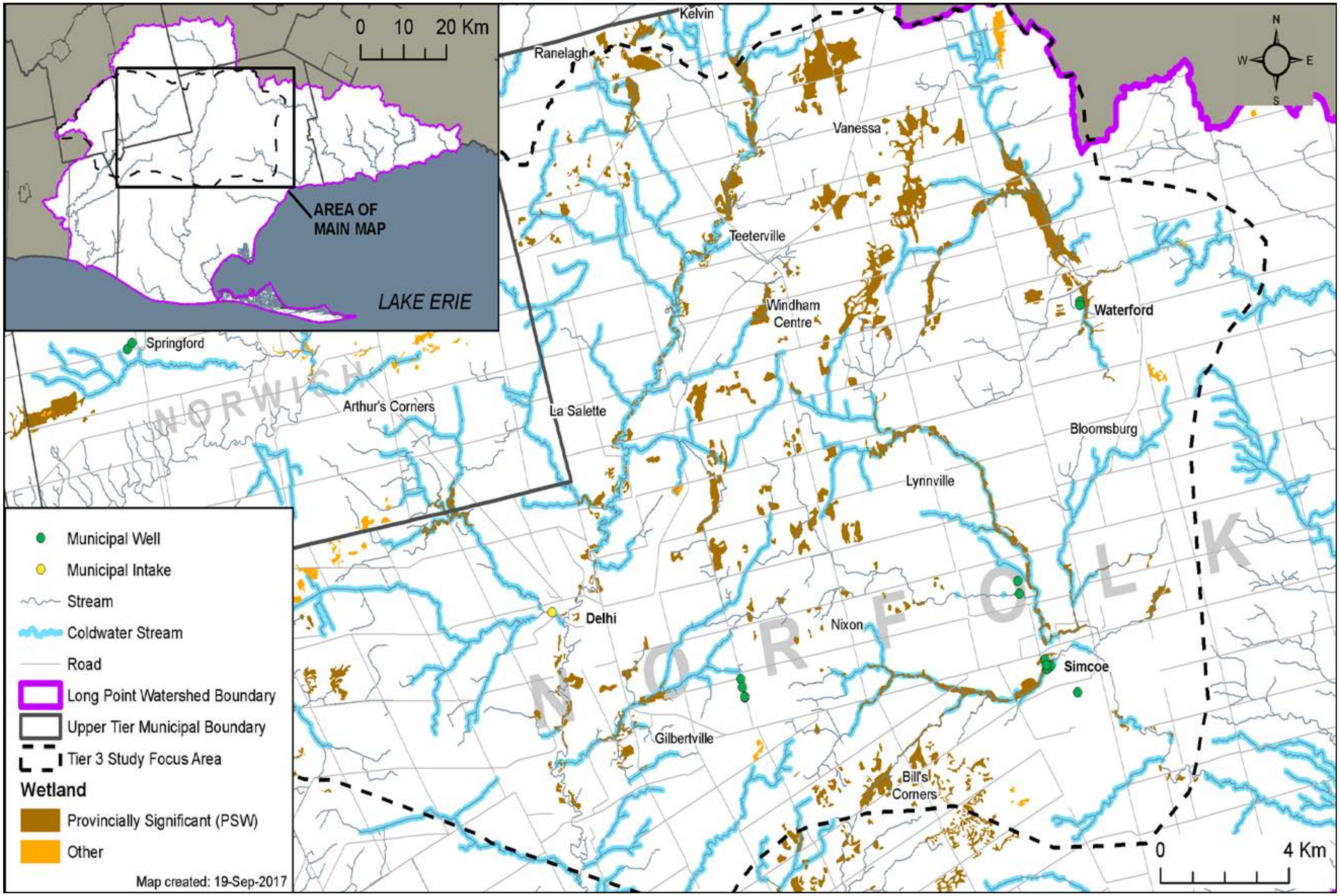
Map 10-4: Tier 3 Focus Area - Shallow Groundwater Levels



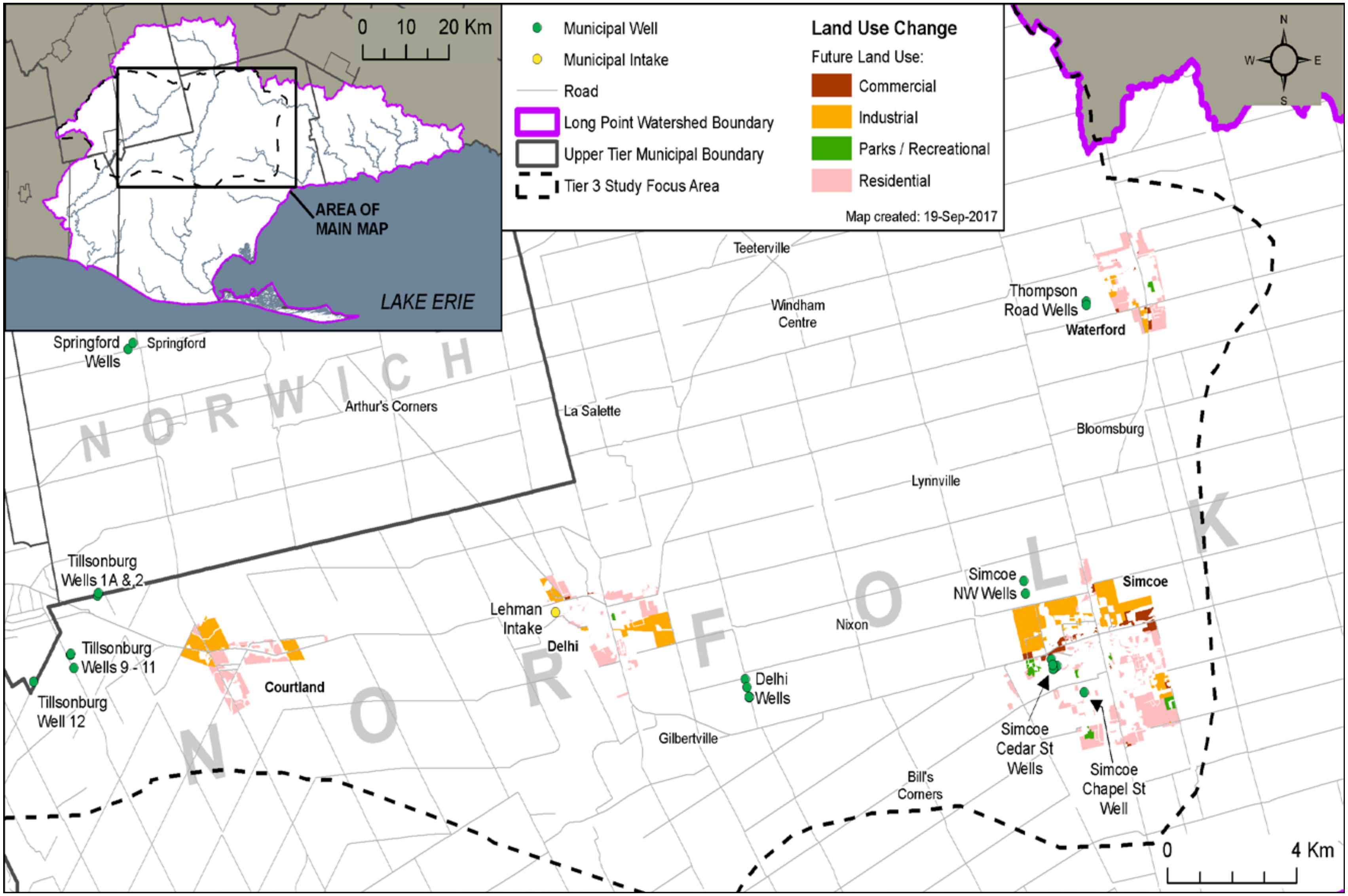
Map 10-5: Tier 3 Focus Area - Deep Groundwater Levels



Map 10-6: Tier 3 Focus Area – Provincially Significant Wetlands and Coldwater Streams



Map 10-7: Tier 3 Focus Area – Land Use Change



10.3 Risk Assessment

10.3.1 Model Development

To represent the complex hydrological and hydrogeological conditions present in the Study Area, a regional-scale groundwater flow model, and regional- and local-scale integrated surface and groundwater flow models were developed. A dedicated groundwater flow provides an efficient method for the calibration of regional groundwater flow. The integrated surface and groundwater flow models were developed based on the hydrostratigraphic model discussed in Section 10.2.3, and a detailed local characterization of the groundwater, and surface water systems. The Tier 3 Assessment Report (Matrix, 2015) describes the development and calibration of the groundwater and integrated models in detail. A brief summary of each are provided below.

Groundwater Flow Model

With the development and refinement of a detailed conceptual model of the geologic, hydrologic, and hydrogeologic systems for the Study Area, the numerical groundwater flow model previously developed for the Tier Two Stress Assessment using FEFLOW (DHI Water & Environment; DHI 2012a), was updated with more recently collected data. While the entire model domain was updated, greater refinement and attention during calibration was given to the Focus Area where the municipal water supply systems of interest are located.

The groundwater flow model applied in the Tier 2 Assessment was updated as follows:

- updated hydrostratigraphy using borehole data derived from the field study program;
- refined stream network to include smaller watercourses adjacent to municipal well fields;
- refined groundwater recharge distribution developed using a physically based model that links surface water and groundwater processes (MIKE SHE; DHI 2012b) calibrated to streamflow measurements;
- refined steady-state calibration with additional high quality hydraulic head data and streamflow gauge observations; and,
- refined model calibration using transient model simulations.

The groundwater flow model and a regional-scale integrated model of the Focus Area were calibrated together so the two models had consistent input values, and each model was able to reasonably replicate observed water levels and streamflows. Within the Focus Area, the regional integrated model was used to predict streamflow, evapotranspiration, agricultural water takings, groundwater recharge, and streamflow. The regional integrated model simulates regional surface water flow systems; however, as it has a large spatial extent, the resolution of the model is too coarse to make confident predictions on a well field scale. As such, local-scale, higher resolution integrated models were built using the values and insights gained from the groundwater flow model and regional-scale integrated model.

The groundwater flow model was calibrated at the well field scale to long term average conditions, as well as time-varying conditions. The wells used to calibrate the model included high quality water level data collected in the field program, as well as provincial and municipal monitoring wells. The model was also calibrated to groundwater discharge estimates collected from streamflow gauges, and water level elevations collected over time in municipal wells and monitoring wells.

The groundwater flow model was used to simulate groundwater flow conditions across the Long Point Region. The model was used to conduct the Tier 3 Assessment scenarios for the Delhi municipal wells, as these wells were assumed to have minimal interaction with nearby surface water features. In contrast, the municipal water supply wells in Simcoe and Waterford are located close to ponds or creeks, where the groundwater aquifers and surface water features are hydraulically connected. The fully integrated models were used in Simcoe and Waterford to assess the long-term sustainability of the municipal water supply wells. An integrated model was also used in Delhi to evaluate the intake in the Lehman Reservoir.

Integrated Numerical Models

A regional scale MIKE SHE integrated model (DHI 2012b) was developed for the Focus Area to simulate the regional groundwater and surface water flow system. In addition, four local scale integrated models were constructed at a higher resolution in the areas of Delhi, Waterford, and Simcoe to simulate local scale hydrologic and hydrogeologic features that influence the reliability of the municipal wells and Delhi surface water intake. The location of the model domains are illustrated on **Map 10-1**. Model parameters, as well as surface and subsurface boundary conditions, were provided from the regional scale groundwater flow model to the local scale integrated models.

Calibration and verification of the integrated models was achieved using observed streamflow data from eight Water Survey of Canada (WSC) gauges as well as the observed groundwater levels. The integrated models predicted reasonable water budgets (e.g., runoff, evapotranspiration, groundwater recharge) demonstrating that precipitation was realistically partitioned into the various hydrologic components. Additionally, the groundwater levels simulated by the integrated models were similar to the FEFLOW results and the observed high quality data, reinforcing that the models were operating similarly for the groundwater system.

Most natural components of the hydrologic cycle were explicitly included in the integrated models (i.e., precipitation, evapotranspiration, snow melt, overland flow, channel flow, unsaturated flow, interflow, and saturated flow), as well as some of the effects of human activity (i.e., land use, irrigation, and water usage).

10.3.2 Risk Assessment Results

Using the groundwater and integrated models described in the previous section, seven vulnerable areas were delineated surrounding the municipal supply wells, infiltration gallery, and surface water intake. These areas were delineated based on a combination of the following:

- the cone of influence of the municipal wells;
- land areas where recharge has the potential to have a measurable impact on water levels at the municipal wells;
- surficial drainage areas, which may contribute water to the Lehman intake; and
- surface water bodies that contribute significant amounts of recharge to municipal wells.

Map 10-8, **Map 10-9**, and **Map 10-10** illustrate the delineated vulnerable areas. In Simcoe, there are two vulnerable areas; the largest (WHPA-Q-A) encompasses the municipal wells of the Cedar Street Wellfield and the Chapel Street Well. In the Northwest Well Field, drawdown was minimal, and therefore the vulnerable area was calculated as 100 m around each well and including a 100 m buffer surrounding the nearest ponds (WHPA-Q-B,). In Waterford, the vulnerable area is represented by a single zone (WHPA-Q-C) consisting of a combined 100 m buffer area surrounding each well and including a 100 m buffer surrounding the nearest ponds. In Delhi, the WHPA-Q consists of a single circular zone (WHPA-Q-D), which encompasses Delhi Wells 1 and 2.

One IPZ-Q was delineated as the surface water drainage area contributing to the Lehman Reservoir in Delhi (**Map 10-10**).

The Risk Assessment scenarios listed in **Table 10-1** were evaluated in the groundwater and local-scale integrated models. The predicted water levels in the municipal wells and surface water intake in the Lehman Reservoir under average and drought conditions were compared to operational water levels. In addition, changes in the water table near Provincially Significant Wetlands and the impacts to groundwater discharge to coldwater streams under average climate conditions were also assessed. The impact of takings by the Lehman intake on downstream water uses was assessed by simulating the decline in reservoir water level relative to the reservoir overflow structure. **Table 10-5** summarizes the results of the Risk Assessment in for the wells and intake for each of the delineated vulnerable areas.

Table 10-5: **Risk Assessment Summary Results**

Community	Vulnerable Area	Source Name	Reliably Meet Allocated Rates?	Impacts to Surface Water?	Risk Level	Uncertainty
Simcoe	WHPA-Q-A	Cedar Street Well 1A	Yes	Yes	Significant	Low
		Cedar Street Well 2A	No			
		Cedar Street Well 3	No			
		Cedar Street Well 4	No			
		Cedar Street Well 5	No			
		Infiltration Gallery	Yes			
		Chapel Street Well 3	Yes			
	WHPA-Q-B	Northwest Well 2	Yes	No	Low	Low
		Northwest Well 3	Yes			
Waterford	WHPA-Q-C	Thompson Rd. Well 3	Yes	No	Low	Low
		Thompson Rd. Well 4	Yes			
Delhi	WHPA-Q-D	Delhi Well 1	Yes	No	Low	Low
		Delhi Well 2	Yes			
	IPZ-Q	Lehman Reservoir	Yes	No	Low	Low

The Risk Assessment scenarios predicted that there is a Low Risk Level associated with the operation of the Lehman intake and the wells in Waterford, Delhi, Simcoe Northwest, and Simcoe Chapel Street.

A Significant Risk Level was assigned to the Cedar Street Wellfield as the simulated drawdown exceeded the operational thresholds in Wells 2A, 3, 4, and 5 of the Cedar Street Wellfield under existing conditions, planned growth and long term drought conditions. Additionally, there is a potential for unacceptable declines in groundwater contributions to surface water courses and a Provincially Significant Wetland (PSW) near Kent Creek and the Cedar Street Wellfield.

The uncertainty of all results is low. The Significant Risk assignment to the Cedar Street Wellfield is consistent with the feedback from the drinking water system operators, who are faced with operating the wells at water levels that are below preferred operational water levels.

10.3.3 Significant Water Quantity Threats

Following the Province's Technical Rules, all consumptive water use of groundwater, including non-municipal and municipal water takings, are classified as significant water quantity threats within vulnerable area WHPA-Q-A. Reductions of groundwater recharge within this vulnerable are also classified as significant water quantity threats.

A summary of the number of significant water quantity threats within the WHPA-Q-A is provided in **Table 10-6**. Seven threats from permitted municipal uses have been identified. Two significant threats from non-municipal, non permitted uses are aslo enumerated. The recharge reduction area covers 0.14 km^2 and represents less than eleven percent of the total WHPA-Q-A.

Table 10-6: **Significant Water Quantity Threats in Long Point Region WHPA-Q-A**[1]

Threat Group	WHPA-Q-A
Municipal	7
Non-Municipal, Permitted	0
Non-Municipal, Non-Permitted	2
Recharge Reduction[2]	0.14 km^2
Total[3]	9

[1]This table does not include non-municipal, non-permitted uses other than water supply wells (e.g., test wells, remediation wells)
[2]Recharge reduction threats are summarized by identifying the total area represented by recharge reduction polygons and as a percentage of the total area of interest
[3]Total number of Significant threats does not include individual Recharge Reduction Polygons as those threats have been identified on a per-area basis.

10.3.4 Significant Groundwater Recharge Areas

A Significant Groundwater Recharge Area (SGRA) is defined as a specific type of vulnerable area on the landscape which has a hydrologic connection to an aquifer that is a source for a municipal drinking water system.The role of significant groundwater recharge areas is to support the protection of drinking water across the broader landscape.

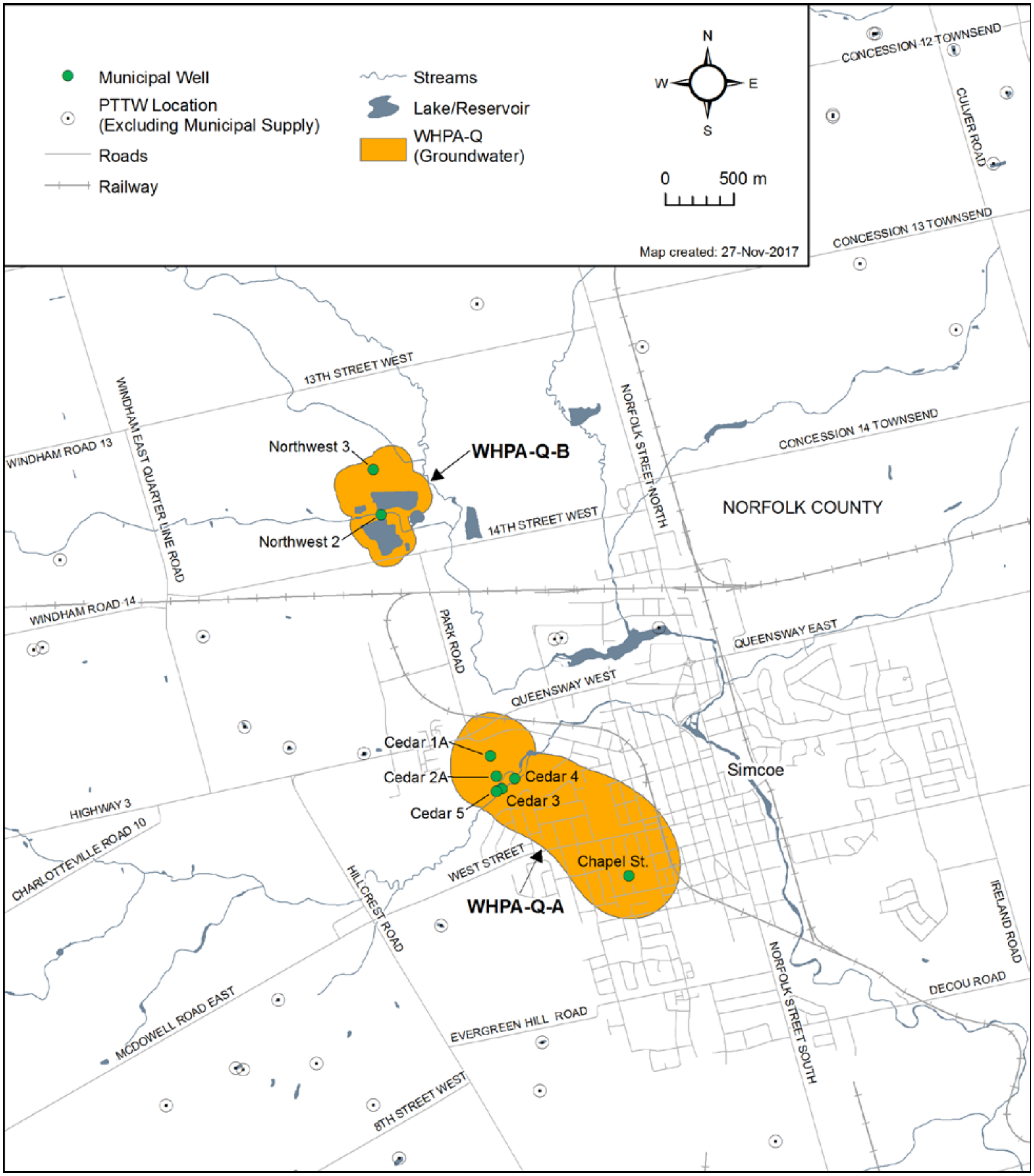
Map 10-11 shows the SGRAs mapped as a part of the Tier 2 Assessment (AquaResource, 2009a) across Long Point Region. A threshold of 115% of the average groundwater recharge rate was used to define SGRAs and a 1 km^2 filter was applied to remove small, isolated areas. The groundwater recharge rate was estimatetd using a regional GAWSER model (Schroeter, 1996).

SGRA maps were later updated as part of the Long Point Region Tier 3 Assessment (Matrix, 2015). The threshold of 115% of the average groundwater recharge rate determined for each watershed in the Tier Two Study was applied against the groundwater recharge rates estimated by the regional MIKE SHE integrated model for the Focus Area.

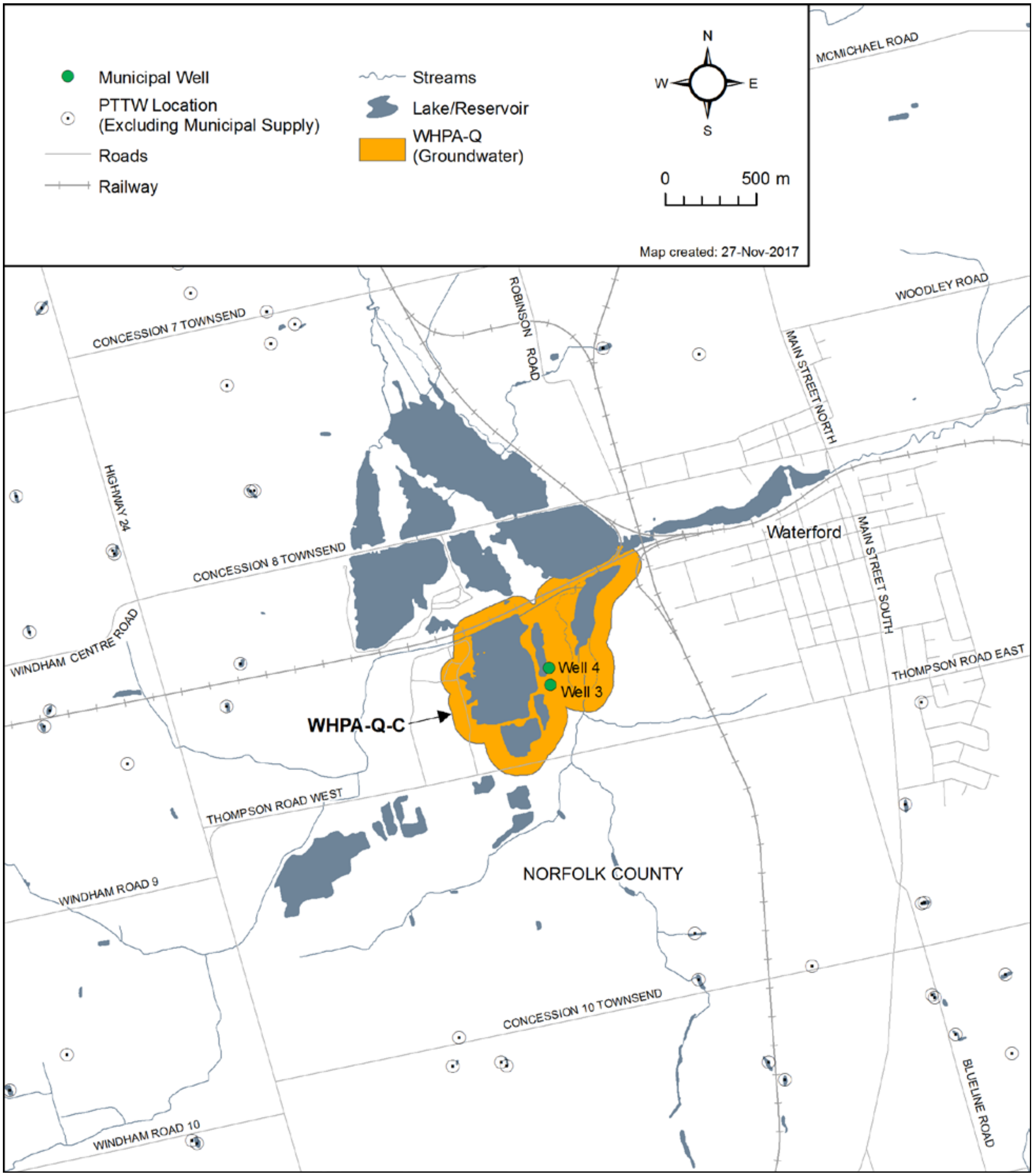
Lands within the Focus Area which had groundwater recharge estimates greater than a specified threshold of 115% were identified as Significant Groundwater Recharge Areas. Similar to the Tier Two Significant Groundwater Recharge Area mapping exercise, a 1 km^2 filter was applied to remove small, isolated, identified areas, or to infill small, non-identified areas that were surrounded by identified areas. **Map 10-12** illustrates the Significant Groundwater Recharge Areas within the Focus Area, which include large portions of the Norfolk Sand Plain.

Delineation of significant groundwater recharge areas is limited by the processes used by the hydrologic model to estimate recharge, the mapping used to create hydrologic response units, and the climate data available. The hydrologic model is a simplification of natural processes. Advancements in Tier 3 models allowed for better representation of evapotraspiration rates both in sandy soils and clay/silt soils. The updated model also incorporated a better representation of overland runoff estimates by having individual runoff that is generated by an individual cell, which flows on a neighbouring cell, to include factors such as land slope, surface roughness, soil water content, and infiltration potential.

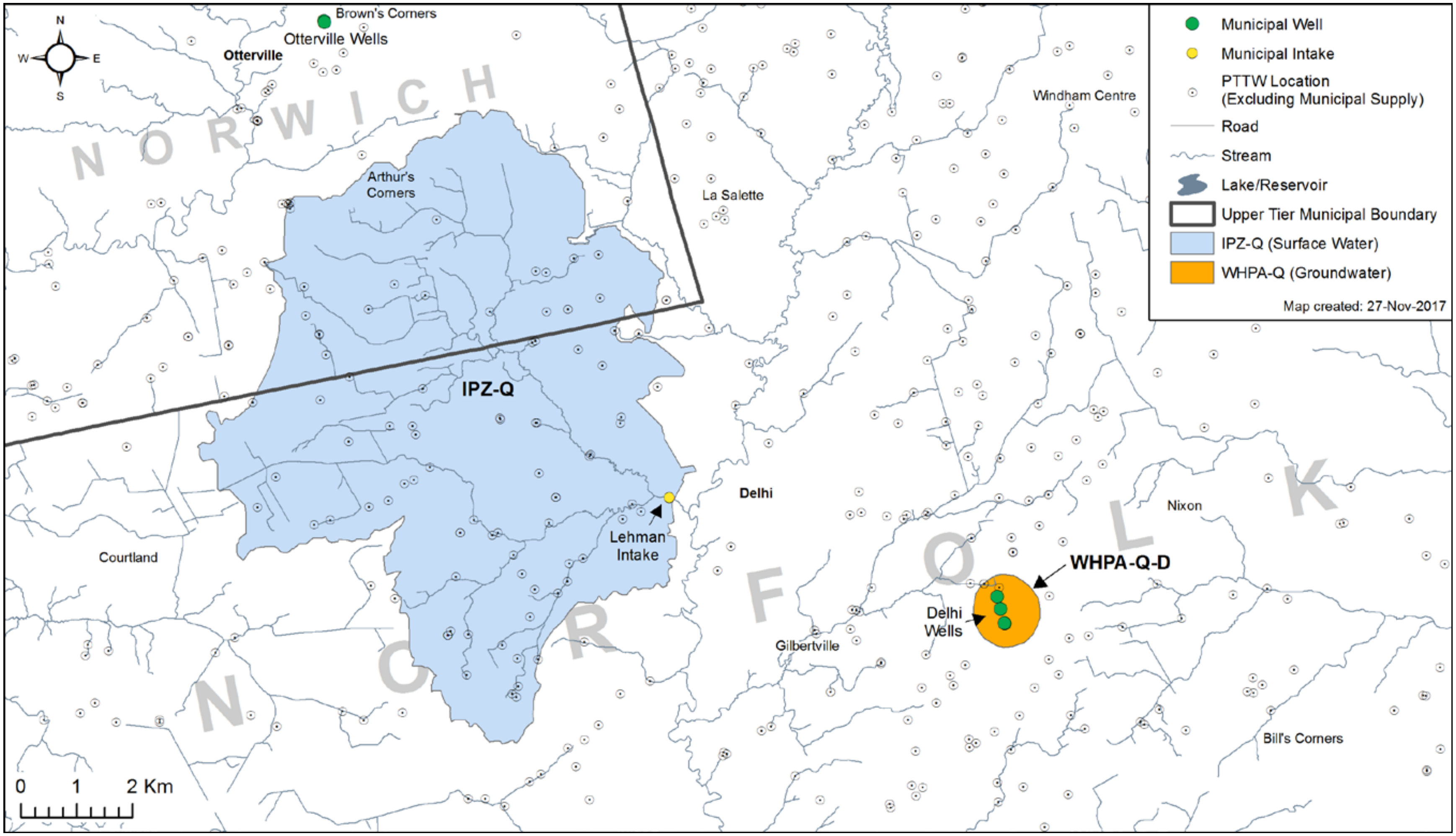
Map 10-8: Tier 3 Focus Area – Simcoe



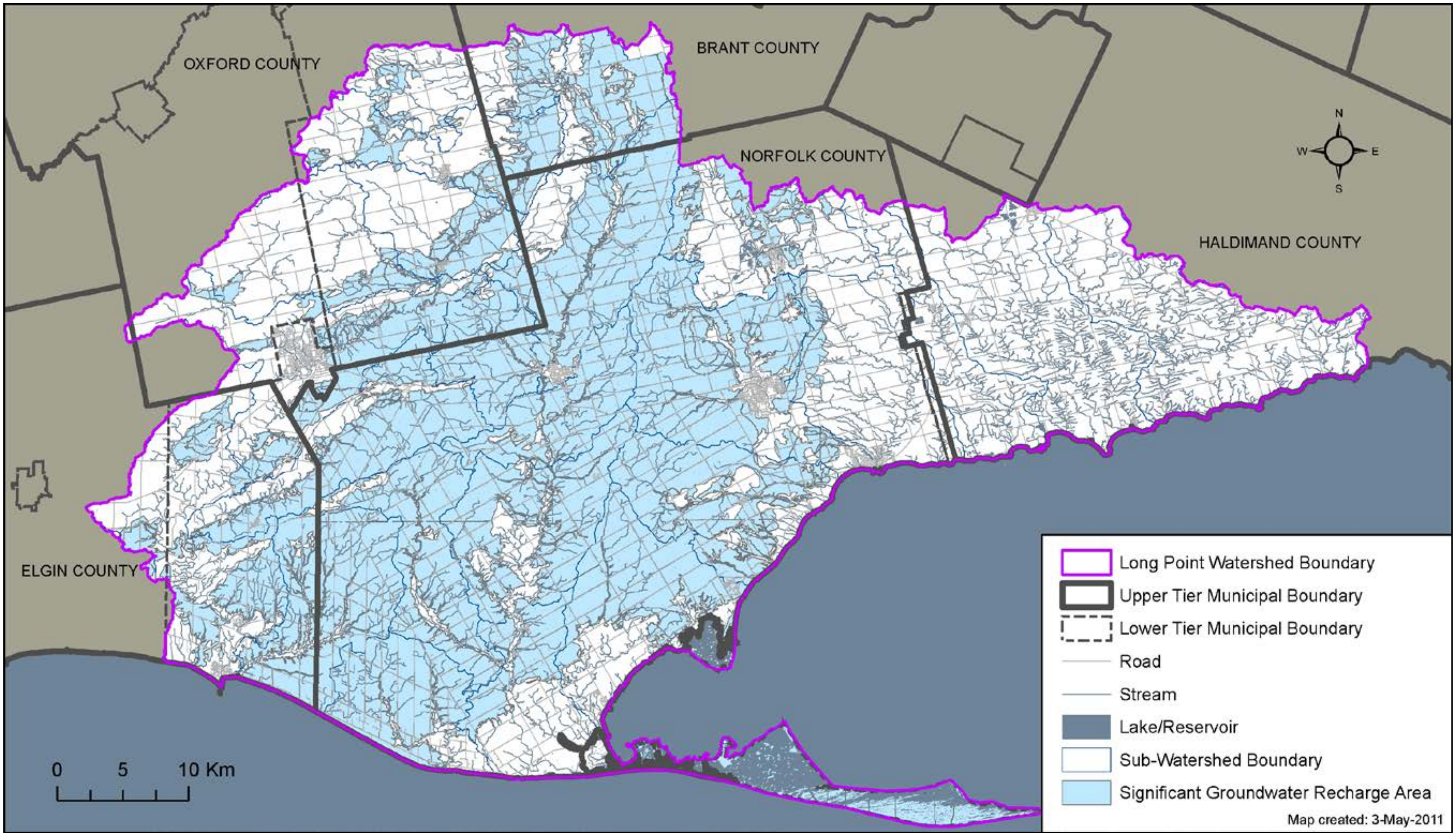
Map 10-9: Tier 3 Focus Area – Waterford



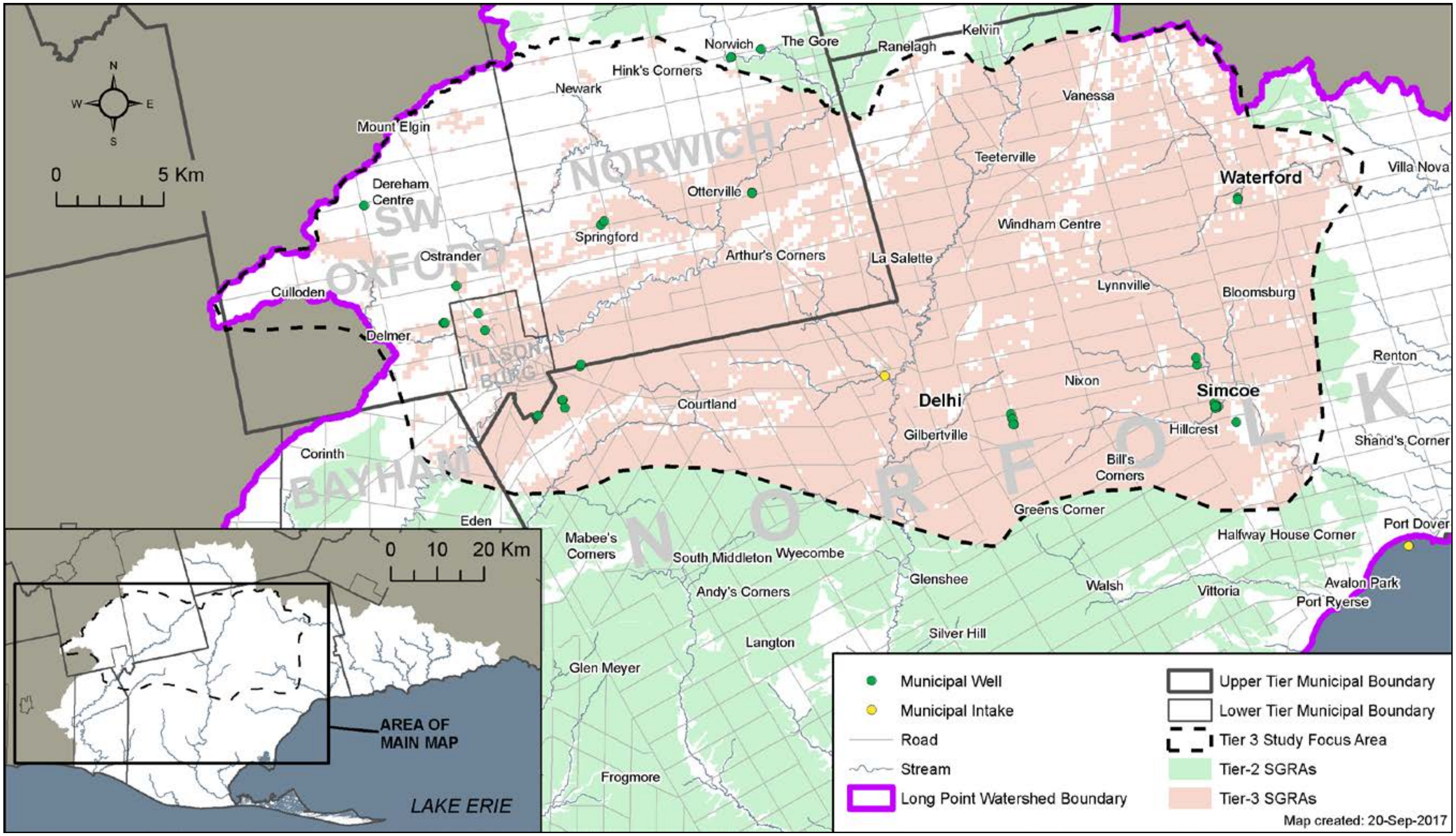
Map 10-10: Tier 3 Focus Area – Delhi



Map 10-11: Tier 2 - Significant Groundwater Recharge Areas



Map 10-12: Tier 2 and 3 - Significant Groundwater Recharge Areas



10.4 Risk Management Measures Evaluation

The Risk Management Measures (RMM) Evaluation Process is completed following the Tier 3 Assessment to inform the policy development process. The goal of the evaluation is to identify and assess alternative Risk Management Measures that would effectively manage the Significant water quantity threats within vulnerable areas that have Significant Risk Levels. The key deliverable from the RMM evaluation is a Threats Management Strategy that provides guidance to the Source Protection Committee to establish policies that will help ensure the long-term sustainability of the municipal drinking water supplies.

The RMM Evaluation Process approach was applied to the municipal water supplies within Simcoe vulnerable area WHPA-Q-A (Chapel Street and Cedar Street Wellfields). The RMM Evaluation was applied to rank the Significant Threats within the area, and to evaluate potential risk management measures that could be applied to reduce the Risk Level of the Local Area to Moderate or Low. The Tier 3 Assessment local-scale integrated model for Simcoe was refined and applied in this study.

The significant threats were identified and ranked using the integrated model to identify the impact that each threat has on the water levels within nearby municipal wells. The following three RMM scenarios were evaluated using the integrated model assuming long-term average climate conditions:

1. Reduce pumping from Cedar Street Wells 1A and 2A and increase pumping from the Chapel Street Well;

2. Reduce pumping from Cedar Street Wells 1A, 2A, and 3 and increase pumping from the Chapel Street Well;

3. Reduce pumping from the Cedar Street Wells and assign pumping to a new well field located northwest of Simcoe that is currently undergoing a Municipal Class EA.

The study found that Scenarios 1 and 2 were not viable options as the drawdown at some of the Cedar Street wells still exceeded their safe water levels under the future pumping conditions. However, the introduction of the new wellfield in Scenario 3 has the potential to reduce the Risk Level of the vulnerable area.

The study evaluated other options for Norfolk County to mitigate the Water Quantity Risk in vulnerable area WHPA-Q-A which did not result in a reduced risk level. Increases in water conservation measures will reduce the demand but not enough to reduce the Risk Level. The RMM Evaluation recommended that the County continues to pursue additional water supplies outside of Local Area A, and the Northeast Well Class EA currently in progress represents the best measure at this time to manage the Significant Risk Level applied to the WHPA-Q-A in Simcoe.

10.5 Section Summary

This section described the Tier 3 Assessment completed for the municipal drinking water systems of the Towns of Delhi, Simcoe and Waterford, located in Norfolk County. This project was undertaken to evaluate the current and future sustainability of the water supply wells and intake and identify potential threats to the drinking water supplies from a quantity perspective. The Tier 3 Assessment Report (Matrix, 2015) describes the development and calibration of the groundwater and integrated models in detail.

The Tier 3 Risk Assessment involved the development of detailed surface water and groundwater models in the areas surrounding, Delhi, Simcoe, Waterford. To represent the complex hydrological and hydrogeological conditions present in the Focus Area, both a regional-scale groundwater flow model, and regional- and local-scale integrated surface and groundwater flow models were developed. A dedicated groundwater flow provided an efficient method for the calibration of the groundwater flow system in the area. The integrated surface and groundwater flow models represent a detailed local characterization of the groundwater, and surface water systems.

Four vulnerable areas were delineated surrounding the municipal intake and water supply wells in Delhi, Waterford and Simcoe. The areas were delineated following the Technical Rules and are based on a combination of the following: drawdown associated with the municipal wells; land areas where reductions in recharge may impact water levels in the municipal wells; surficial drainage areas that may contribute water to surface water intakes; and, the surface water bodies that contribute recharge to municipal wells.

The future municipal pumping rates (Allocated Rates) were estimated and evaluated within the Risk Assessment scenarios using the groundwater flow and integrated models. The models predicted the ability of the municipal wells and intake to meet future demands considering the predicted water levels at the wells and intake, as well as the impact of increased municipal pumping on coldwater streams and PSWs.

A Low Risk Level was assigned to the vulnerable areas containing the Lehman Reservoir intake and the groundwater wells in Waterford, Delhi, Simcoe Northwest, and Simcoe Chapel Street. However, a Significant Risk Level was assigned to the vulnerable area containing the Cedar Street Well and Chapel Street wells in Simcoe. The simulated water levels were lower than the operational water levels in Wells 2A, 3, 4, and 5 of the Cedar Street Well Field during all groundwater risk scenarios. In addition, potential impacts to baseflow and a PSW near Kent Creek and the Cedar Street Well Field was also predicted, leading to the Significant Risk Level for the vulnerable area.

An assessment of measures available to reduce the risk to the Simcoe water supply wells recommended that the County continues to pursue additional water supplies outside of the vulnerable area. The Northeast Well Class EA currently in progress represents the best measure at this time to manage the Significant Water Quantity Risk Level.