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20.0 WHITEMANS CREEK TIER 3 WATER BUDGET AND RISK ASSESSMENT

The purpose of the Whitemans Creek Tier 3 Water Budget and Water Quantity Risk Assessment (Tier 3 Study) is to determine the likelihood that future water demands for the Whitemans Creek Subwatershed can be met. This was completed by evaluating the risk of water quantity impacts to municipal drinking water supplies, namely the Bright Well Field in Oxford County, and the Bethel Well Field in the County of Brant, based on combinations of current and proposed land use, average climate, and drought conditions. The Tier 3 Study was triggered by predictions during the Tier 2 Water Budget Study, of insufficient water availability at the Bright Well Field to maintain supply during drought conditions (AquaResource Inc., 2009a).

Tier 3 Studies must be completed per the Technical Rules for Assessing Risks to Sources of Drinking Water in Ontario under the *Clean Water Act, 2006*, S.O. 2006, c.22 (Technical Rules) (MECP, 2011/2017/2018). Each study consists of the following components:

- Characterization of the surface water and groundwater systems;
- Estimation of existing and future (allocated) water demands;
- Development and calibration of a numerical water budget model to simulate water use;
- Delineation of vulnerable areas to evaluate impacts to water quantity;
- Assignment of risk levels (low, moderate or significant) to each vulnerable area; and
- Identification of drinking water quantity threats in each significant vulnerable area.

20.1 Surface Water and Groundwater Characterization

The Whitemans Creek Tier 3 Local Area Water Budget and Risk Assessment Model Development and Calibration Report (EarthFx, 2018) contains a detailed description of the Tier 3 Study Area including a site characterization of the entire Whitemans Creek and surrounding area. The Study Area (**Map 20-1**) covers 1,400 km^2 including the Whitemans Creek subwatershed and surrounding areas that contribute to the subwatershed's water budget.

20.1.1 Topography, Physiography and Climate

round surface is a mix of areas with higher elevations (drumlins or moraines) and lower elevations (modern or ancient river valleys), decreasing from 360 m above mean sea level (AMSL) in the northwest to 230 m AMSL in southeast (**Map 20-2**).

The Study Area was grouped into three general physiographic regions:

- The **Upper Whitemans Till Plain** is located in the Study Area north of Highway 401, including the area around the community of Bright. This region is comprised of Oxford and Stratford Till, and characterized by poorly drained clay to silty clay soils (Chapman and Putnam 1984). The region is generally flat with occasional higher elevation features (drumlins) and lower elevation features (glacial meltwater valleys) present.

- The **Central Whitemans Glacial Outwash** deposits are situated within the centre of the Study Area, south of Highway 401 and east to the community of Cathcart. The region is a complex area of moraines, outwash deposits and till plains. There are many ponds and wetlands present in this area which have resulted from poor drainage.

- The **Lower Whitemans Sand Plain** extends to the southeast of the Study Area and includes the area around the community of Burford and the Bethel Well Field south of Paris. The region is comprised of Horseshoe Moraine and Norfolk Sand Plain deposits (Chapman and Putnam 1984). The region has extensive glaciolacustrine and outwash sand deposits with near surface groundwater levels. There are swamps and other wetlands with large seasonal variations in hydroperiod that are typically found in low-lying and riparian areas.

20.1.2 Climate

Average climate conditions were calculated based on precipitation and temperature data for 79 climate stations within 15 km of the Study Area. The average annual precipitation is highest in the northwest at 950mm/year and decreases towards the southeast where it is 850 mm/year. The annual average daily temperature follows the opposite trend with temperatures increasing from a low in the northwest of 7.1 degrees Celsius to a high in the southwest of 7.6 degrees Celsius.

20.1.3 Surface Water

The stream network consists of both natural channels and constructed municipal drains. The upper watershed is drained by Horner Creek, while the western watershed is drained by Kenny Creek. These two creeks join upstream of Burford to form Whitemans Creek which flows into the Grand River south of Paris. In poorly drained areas, such as the Upper Whitemans Till Plains and near Kenny Creek, tile drains are common in agricultural fields.

The less permeable till units in the Upper Whitemans Till Plains generate significant overland runoff, resulting in relatively flashy streamflow in Horner Creek. Similarly, the southwestern portion of the subwatershed adjacent to Kenny Creek also generates significant streamflow volumes, but very low baseflow. Whitemans Creek is in the Lower Whitemans Sand Plain with high infiltration and a near surface groundwater table. High groundwater discharge into watercourses in the Lower Whitemans Sand Plain region results in high baseflow and supports cold water fish habitat.

Geology and Hydrogeology

Hydrologic Field Program

To better understand groundwater - surface water interactions and groundwater level trends, hydrogeologic field investigations were completed. Drivepoint piezometers were installed at 19 locations throughout the Study Area to allow for continuous groundwater and surface water level monitoring. Additionally, 10 private water wells were continuously monitored over the same period. Spot flow measurements on a number of watercourses were completed during dry periods to better quantify baseflow. These data were used to supplement other continuous water level data obtained from local municipalities and the province.

Regional Characterization

Regional stratigraphy is characterized by Quaternary-aged overburden overlying Paleozoic-aged bedrock. The overburden consists of regionally extensive till units (e.g., Wentworth Till, Maryhill Till, Main Catfish Creek Till) with intervening sand and gravel deposits. The main aquifers in the Study Area are formed by thick and/or laterally extensive layers of the intervening sand and gravel deposits, while the till units form the aquitards. Bedrock consists of sedimentary rocks that were deposited in an ancient marine environment. Groupings of mudstones (shale), carbonates (limestone and dolostone) and/or evaporites (anhydrite, gypsum and halite) are therefore common. The top 5 to 10 m of bedrock is often highly weathered and may yield sufficient groundwater to act as an aquifer, although water quality may be poor. The various bedrock units may act as aquifers or aquitards, depending on the hydraulic properties of the rock formation.

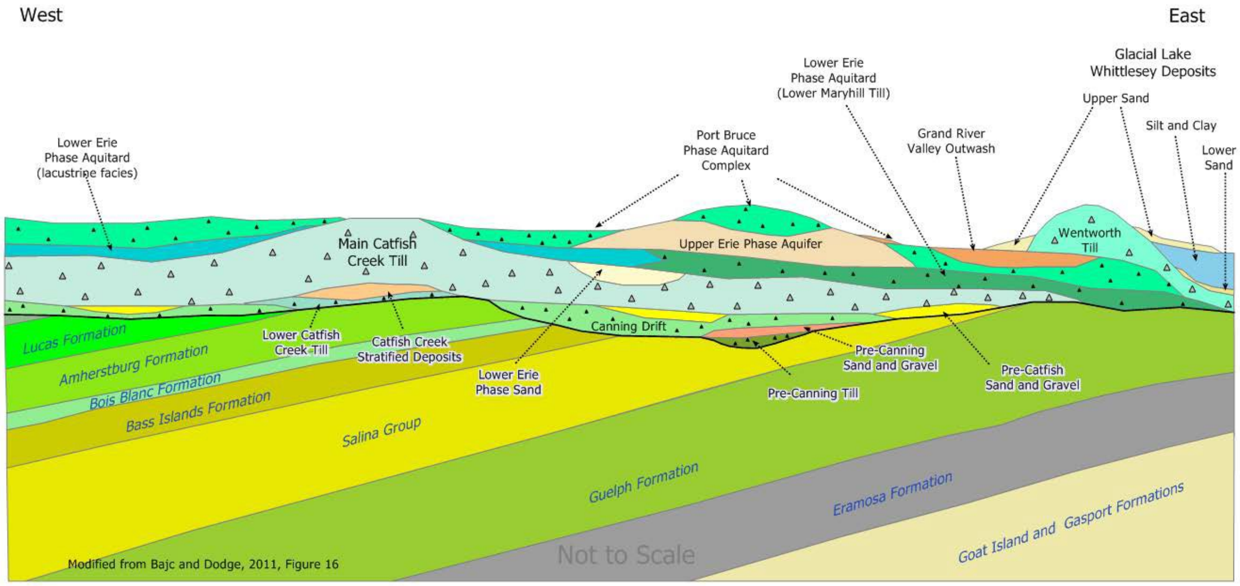


Figure 20-1 shows a typical east-west schematic of the regional geology, after Bajc and Dodge (2011).

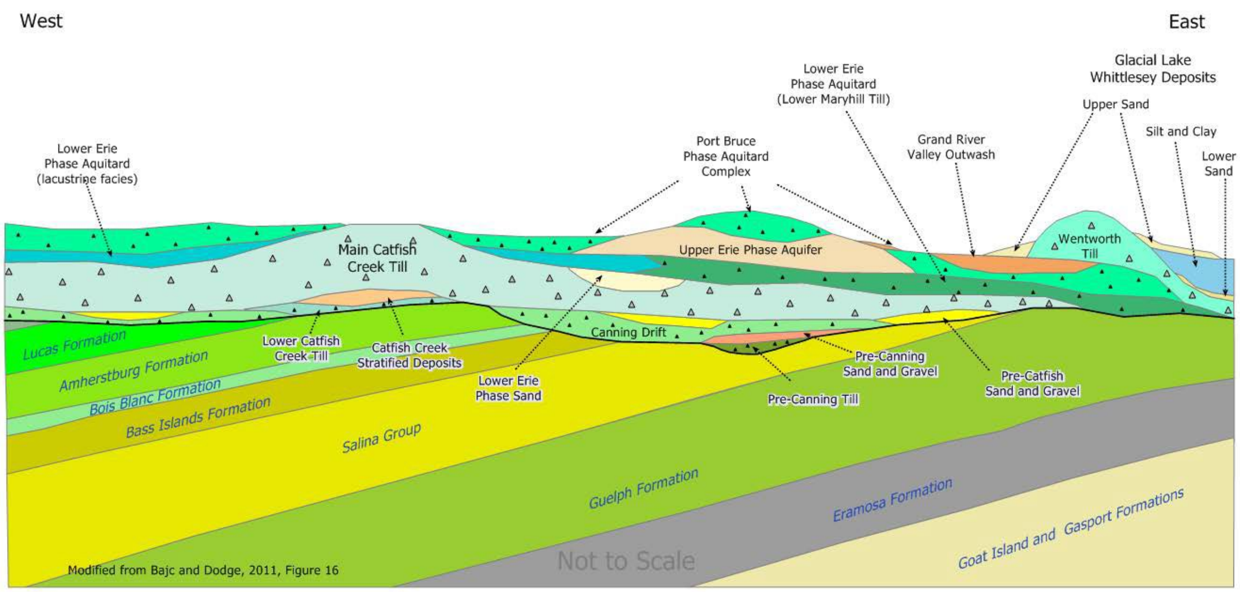


Figure 20-1: Representative Hydrostratigraphic Section

Existing three-dimensional hydrostratigraphic models from the Ontario Geological Survey (OGS) were extended and refined to create the Whitemans Tier 3 hydrostratigraphic model. Data for the refinements were sourced from the Ontario Ministry of the Environment, Conservation and Parks (MECP) water well information system (WWIS), municipal drilling data, and the Ontario Oil, Gas and Salt Resources Library. The resulting Tier 3 hydrostratigraphic model contains 18 layers: 11

overburden aquifers and aquitards, a weathered bedrock unit representing the upper 10 m of bedrock, and 7 bedrock aquifers and aquitards. These layers are summarized in **Table 20-1**.

Table 20-1: Hydrostratigraphic Units

Unit Number	Unit Name	Hydrogeologic Role
Overburden		
1	Whittlesey Sand	Aquifer/Aquitard
2	Whittlesey Aquitard	
3	Wentworth Aquitard	Aquitard
4	Sand Plain and Outwash Aquifer	Aquifer
5	Port Stanley / Tavistock Aquitard	Aquitard
6	Waterloo Moraine Aquifer	Aquifer
7	Maryhill Till Aquitard	Aquitard
8	Post Catfish Aquifer	Aquifer
9	Catfish Creek Till Aquitard	Aquitard
10	Pre-Catfish Aquifer	Aquifer
11	Canning Till Aquitard	Aquitard
Bedrock		
12	Weathered Bedrock Contact Aquifer	Aquifer
13	Dundee-Lucas-Amherstburg Aquifer	Onadaga Limestone Aquifer
14	Bois Blanc Aquifer	
15	Bass Island Aquifer	
16	Upper Salina Port Aquifer/Aquitard	Aquifer/Aquitard
17	Lower Salina Shale Aquitard	Aquitard
18	Guelph-Eramosa Aquifer	Aquifer

The availability of groundwater resources in the Study Area varies by physiographic region.

- In the **Upper Whitemans Till Plains**, groundwater resources are mainly found in the thin, intermittent, sand and gravel deposits of the overburden. These discontinuous deposits receive limited amounts of groundwater recharge, have low storage capacities, and are not a significant groundwater resource.
- In the **Central Whitemans Glacial Outwash**, groundwater resources are typically found in outwash deposits, which can be thick and laterally extensive enough to yield supply and groundwater storage for municipal needs. The numerous wetlands in this region also provide additional groundwater storage.
- In the **Lower Whitemans Sand Plain**, the thick sand and gravel deposits of the Whittlesey Sand and Sand Plain and Outwash Aquifer provide significant groundwater resources. They are potentially sensitive to water quality threats because they are unconfined.

Regional groundwater levels and flow were characterized by reviewing static water level data from the MECP WWIS, and transient water level data from municipal monitoring programs, the Provincial Groundwater Monitoring Network (PGMN), and the Tier 3 hydrogeologic field program. Groundwater elevations in the overburden range from approximately 370 m AMSL in the north/northwest of the Study Area to 210 m AMSL in the southeast (**Map 20-6**). Groundwater flow follows a similar pathway, from the north/northwest to the south/southeast, however local variations are observed where groundwater discharges to the surface. Groundwater elevations in the bedrock are approximately 10 m lower than in the overburden, with a flow pattern similar to that in the overburden (**Map 20-7**).

Local Characterization – Bright and Bethel Wellfields

The Bright Well Field is located in the community of Bright in Oxford County (**Map 20-1**). The well field consists of two production wells, Production Well 4A and Production Well 5, which are completed in the overburden at depths between 25.9 to 38.4 m below ground surface (290.5 to 293.9 m AMSL), in a confined to semi-confined aquifer.

The Bethel Well Field is located near the southeast boundary of Whitemans Creek subwatershed in the County of Brant (**Map 20-1**). The well field has four production wells; TW1/05 (P52), PW1/12 (P51), PW2/12 (P53), PW4/12, which are completed in the overburden at depths ranging from 22.3 to 33.0 m below ground surface (222.5 to 227.2 m AMSL) in a confined to semi-confined aquifer.

Both the Bright and Bethel production wells are completed in the Waterloo Moraine Aquifer (unit 6, **Table 20-1**). This aquifer is overlain by up to 10 m of surficial till at the Bright Well Field, corresponding to the Port Stanley/Tavistock Aquitard (unit 5, **Table 20-1**). At the Bethel Well Field, the Waterloo Moraine Aquifer is overlain by up to 25 m of silty clay interpreted to be the Port Stanley/Tavistock Aquitard, which is itself overlain by deposits of the Sand Plain and Outwash Aquifer (unit 3, **Table 20-1**) and the occasional surficial till of the Wentworth Aquitard (unit 1, **Table 20-1**).

The thickness of the Port Stanley/Tavistock Aquitard varies at both well fields. At the Bright Well Field, the aquitard thins and gradually disappears to the south, where the Waterloo Moraine Aquifer becomes unconfined. At the Bethel Well Field, the Port Stanley/Tavistock aquitard is also noted to pinch out to the south, allowing the Waterloo Moraine Aquifer and Sand Plain and Outwash Aquifer to function as one continuous aquifer unit. The Waterloo Moraine Aquifer is highly heterogeneous in the vicinity of both well fields. Beneath the aquifer, the Maryhill Till Aquitard forms a regionally extensive and competent till unit.

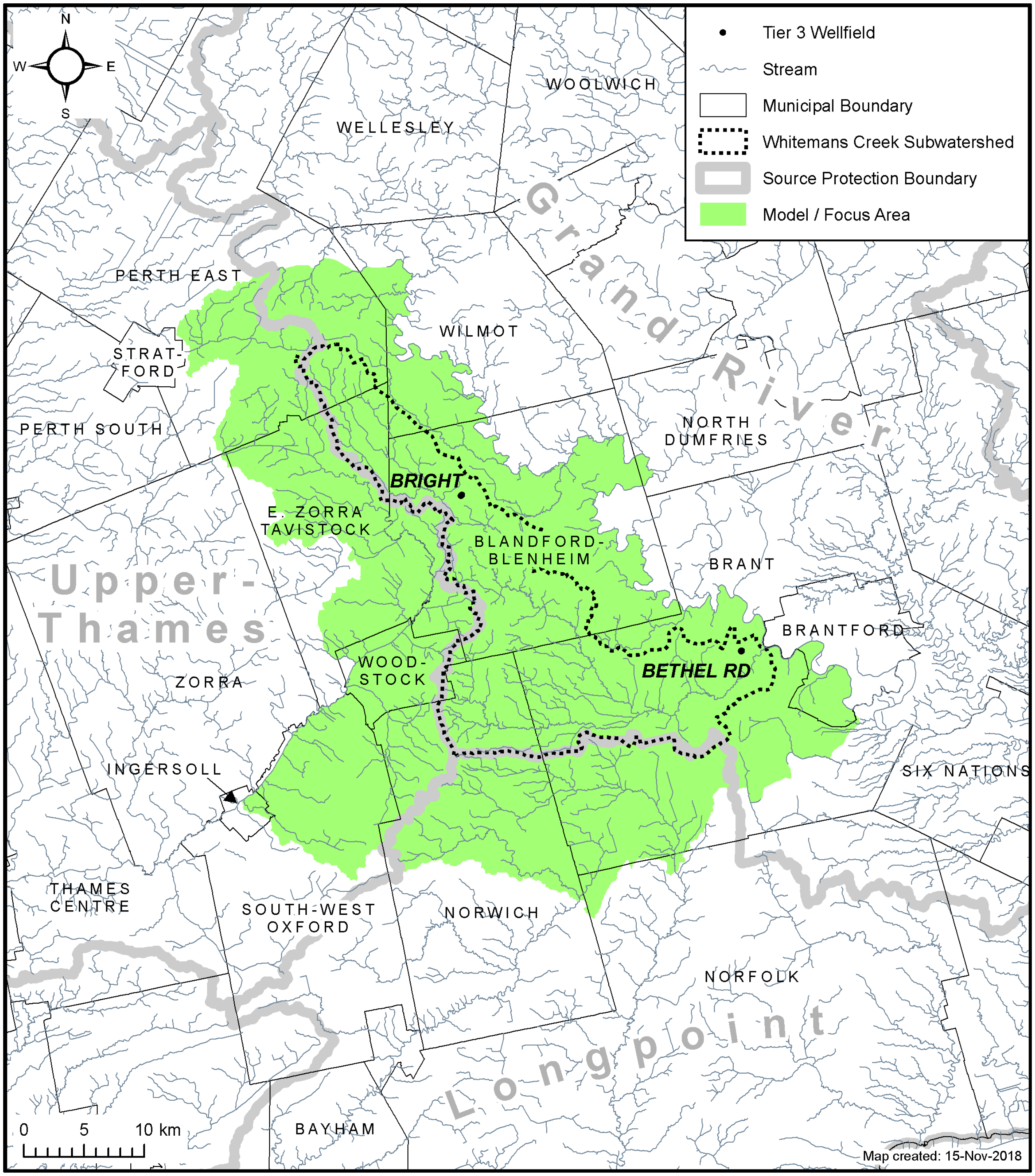
20.1.4 Land Use

Land Use in the Study Area is predominantly rural. Approximately 76% of land use is agricultural, with 60% as actively cultivated fields and 16% as undifferentiated uses (e.g., orchards, fallow fields, and undeveloped pasture). The remaining land use consists of 19% natural areas (e.g., forests and treed swamps) and 5% developed areas (e.g., rural residential, transportation, industrial/commercial).

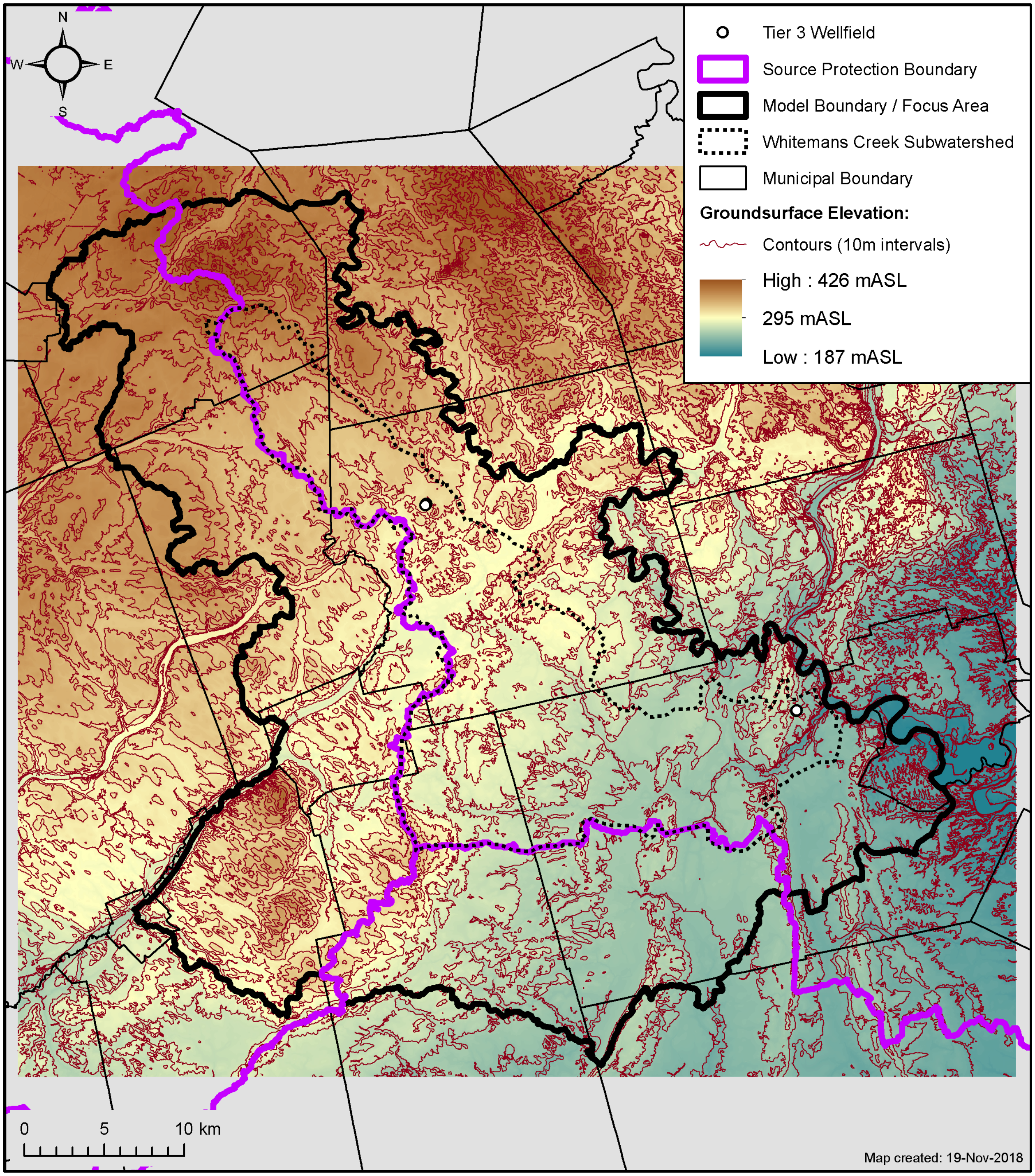
Municipal water demand at both the Bright and Bethel well fields may be affected by future land development. A small residential subdivision and aggregate extraction pit near the Bright Well Field in Oxford County (**Map 20-3**); and a business park, two commercial areas, an urban residential area and an aggregate extraction pit near the Bethel Well Field in the County of Brant

(**Map 20-4**). The effect of land development on water demand is discussed further in the Risk Assessment section.

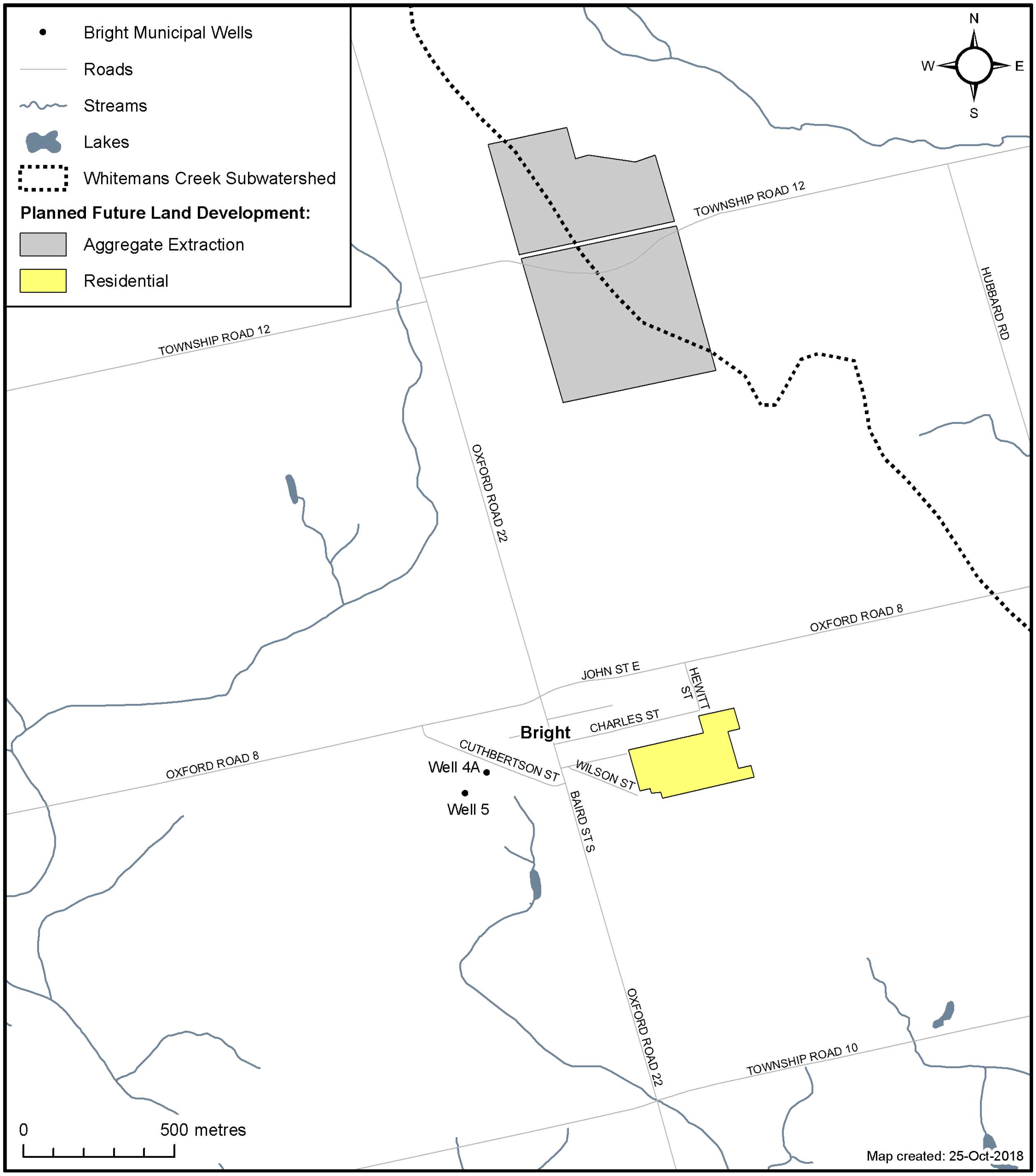
Map 20-1: Tier 3 Study and Focus Area



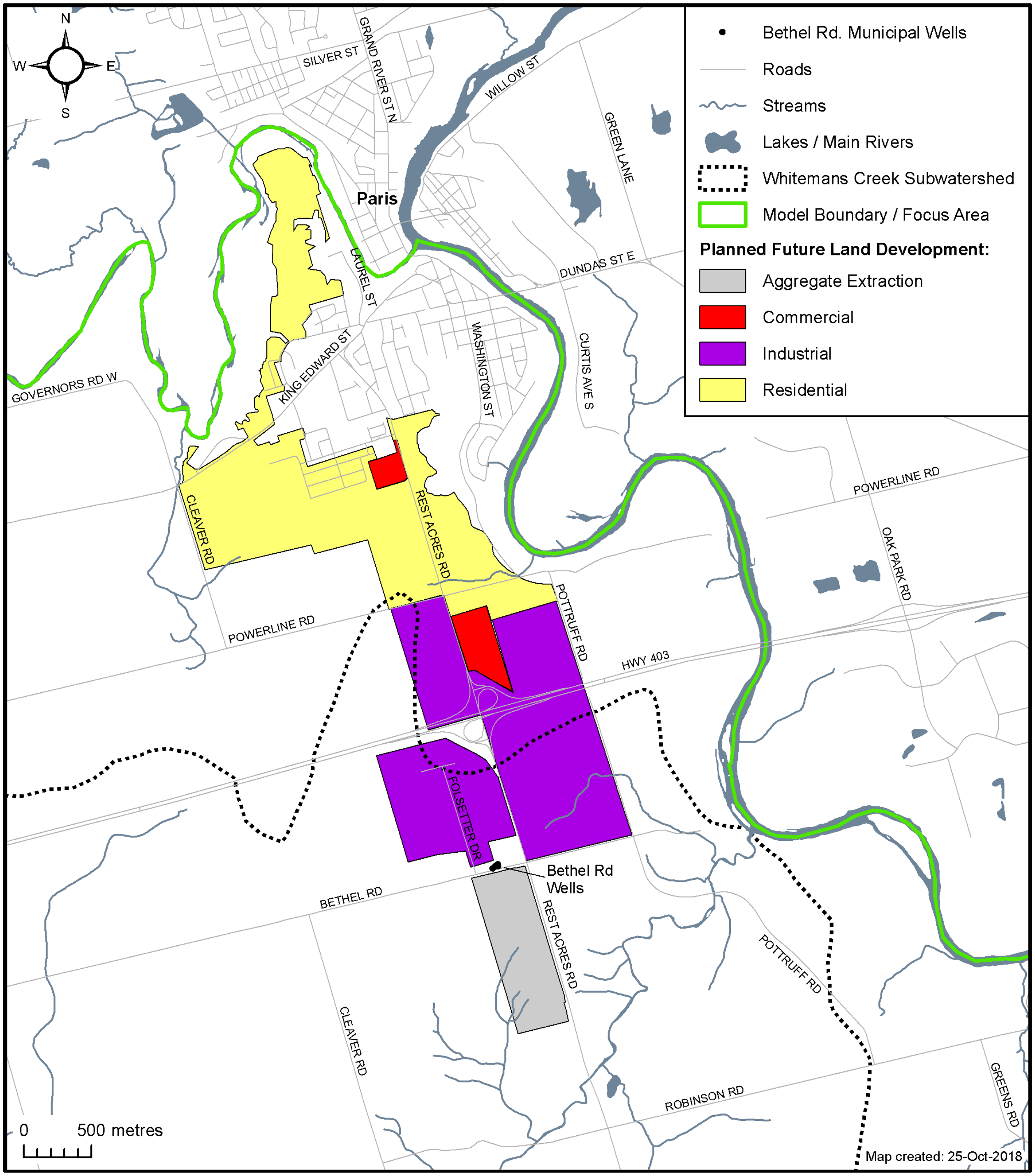
Map 20-2: Tier 3 Study and Focus Area Topography



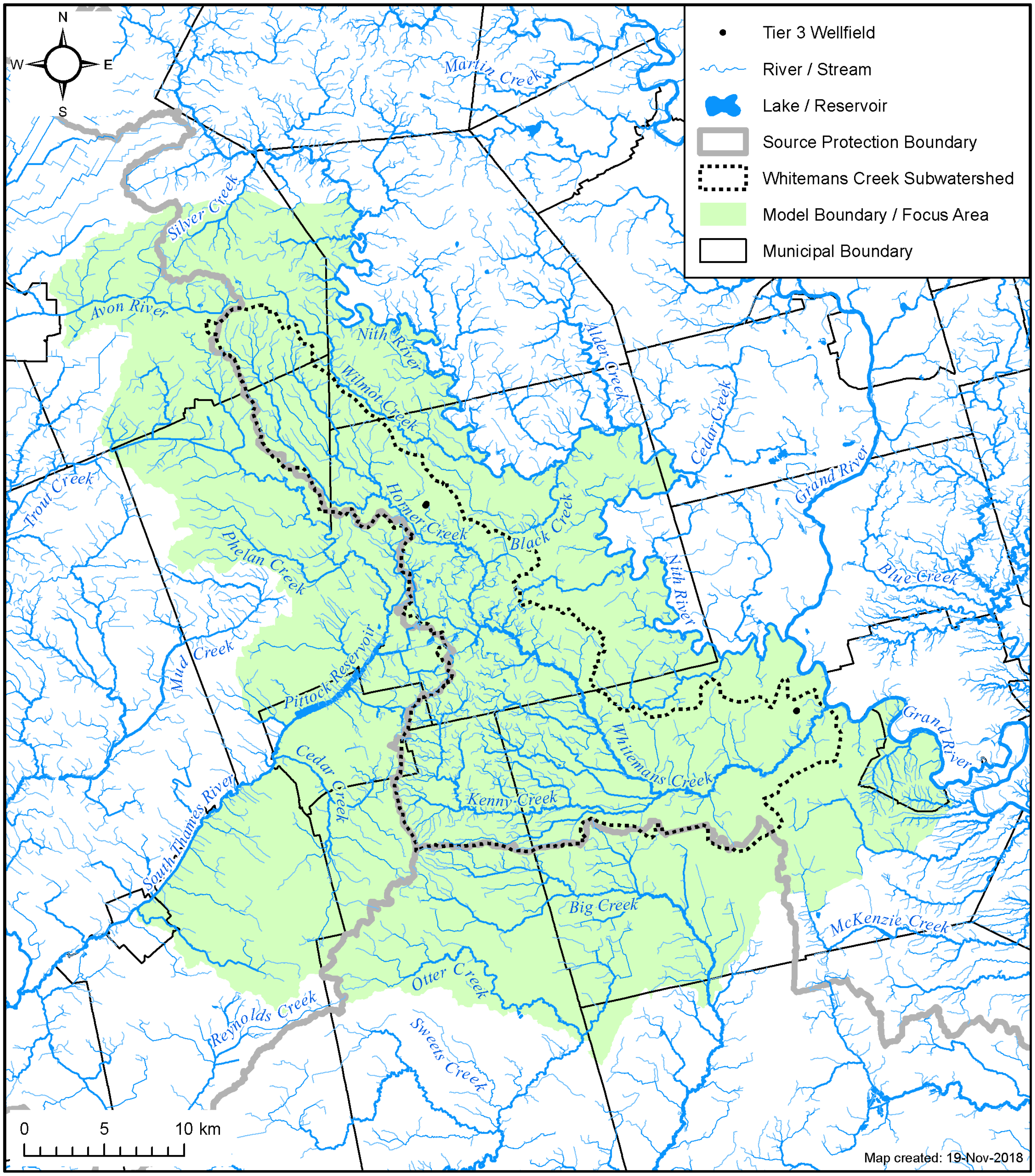
Map 20-3: Land Use Change – Bright Well Field



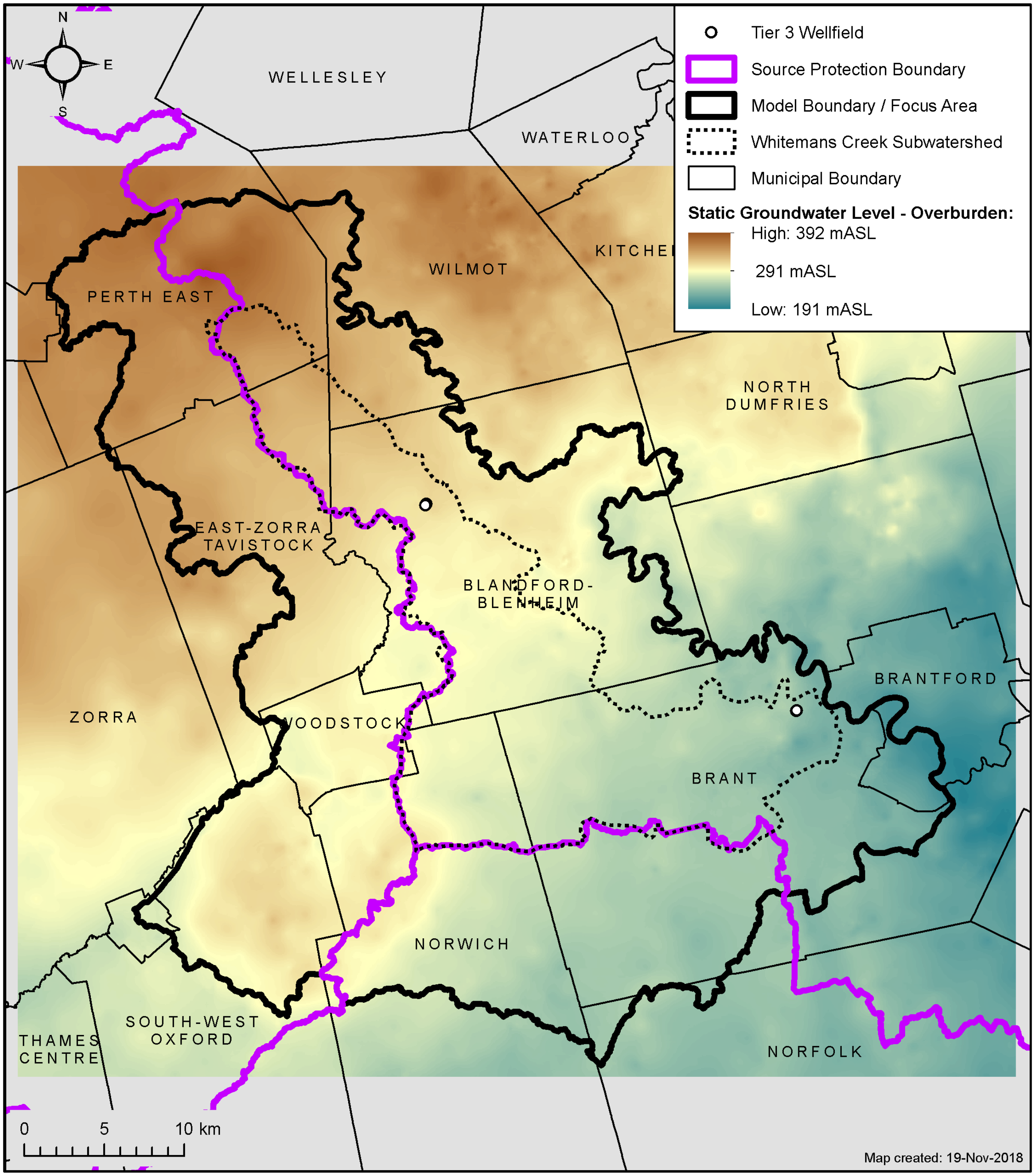
Map 20-4: Land Use Change – Bethel Well Field



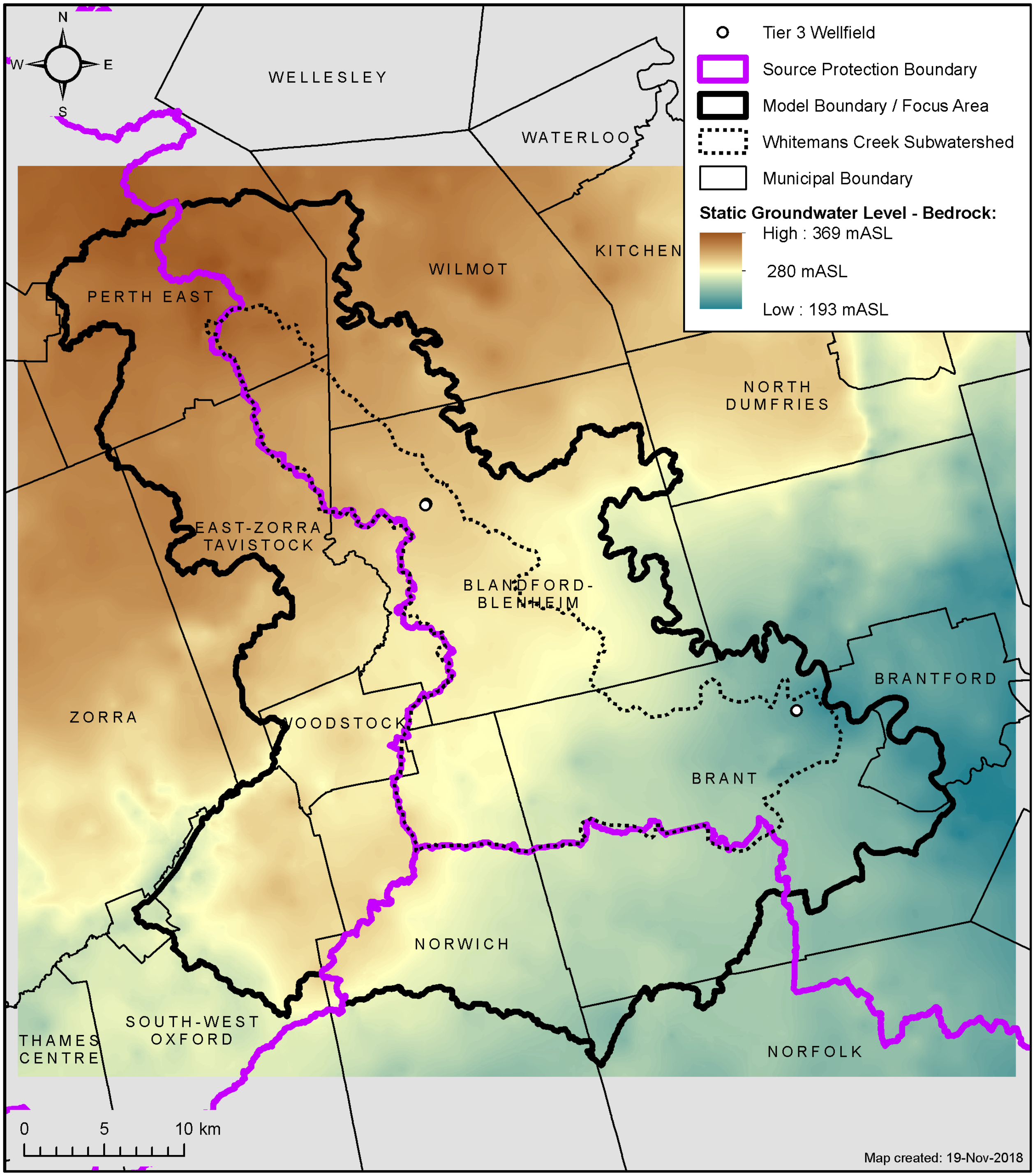
Map 20-5: Tier 3 Study Area Surface Water Features



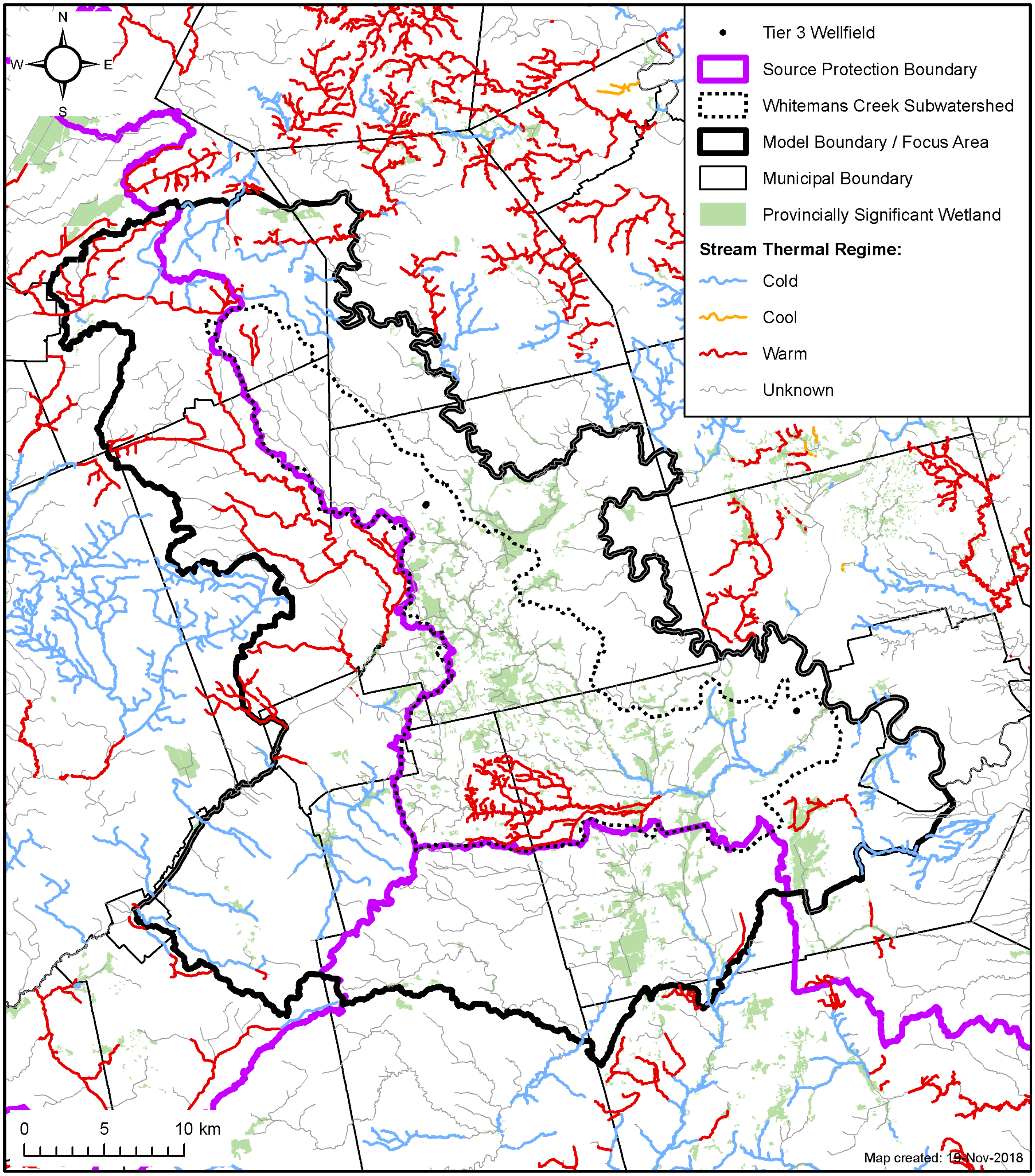
Map 20-6: Static Groundwater Levels in the Overburden



Map 20-7: Static Groundwater Levels in the Bedrock



Map 20-8: Provincially Significant Wetlands and Coldwater Streams



20.2 Water Demand

20.2.1 Municipal Water Supply

Existing demand for each water supply system was calculated as the average of reported pumping from 2015 to 2016 for the Bethel Well Field and 2012 to 2014 for the Bright Well Field.

Future (allocated) demand is a combination of the existing, committed and planned demand. Committed demand is the increase in supply required if the serviced area were developed according to the local Official Plan, while planned demand is the increase in supply needed to meet growth associated with a Master Plan. There are no plans to expand either well field beyond their existing capacity; therefore, no planned demand is associated with either the Bright or Bethel well fields.

Table 20-2 lists the existing, committed, and future water demand for each well field (Earthfx 2018a). For both well fields, the future demand is below the currently permitted rate.

Table 20-2: Municipal Water Demand

Well Name	Permitted Rate (m^3/day)	Existing Demand (m^3/day)	Committed Demand (m^3/day)	Future Demand (m^3/day)
Bright Municipal Drinking Water System				
Well 4A	327	88.8	12.4	101.2
Well 5		6.7	0.9	7.6
	Total	***95.5***	***13.3***	***108.8***
Bethel Municipal Drinking Water System				
TW1/05	3,240	53.7	376.9	430.6
P1/12		80.4	234.0	314.4
P2/12		89.9	224.5	314.4
P4/12		90.1	224.3	314.4
	Total	***314.1***	***1,059.7***	***1,373.8***

Consumptive demand is the amount of water taken from a water source that is not returned to the same source within a reasonable amount of time. Municipal takings from both the Bright and Bethel well fields are conservatively assumed to be 100% consumptive.

20.2.2 Non-Municipal Water Demand

Non-municipal water demands were assessed by examining the MECP PTTW database. The MECP Water Taking Reporting System (WTRS) database was also consulted for the periods 2009 to 2014.

The largest category of permitted water takers in the area is agricultural. The Study Area includes 369 permitted groundwater users and 90 surface water users for agricultural purposes. The majority are in the Norfolk Sand Plain region, in the southeastern portion of the Study Area: the well-drained soils in this region require crops to be irrigated more regularly. In the Whitemans Creek subwatershed, agricultural water users account for 98% of the non-municipal permits. The volume and timing of agricultural water use was estimated with a custom irrigation demand module within the water budget numerical model that considered factors such as farm size, crop type, crop needs, equipment limitations, and soil properties.

Other non-municipal permitted water users were also identified. These included water supply for commercial (aquaculture and golf courses), construction, industrial, and other water supply well uses. These non-municipal, permitted, water uses are distributed fairly evenly across the Study Area and were assumed be 100% consumptive.

Non-municipal, non-permitted, water users in the Study Area include domestic supply wells and livestock watering. The consumptive demand of private domestic supply wells was not considered in the analysis because their water taking rates are relatively low compared to other takings and are well distributed across the Study Area. Livestock water demand was estimated based on the type and quantity of livestock animals for each farm and assigned to a well in the water well database.

20.2.3 Coldwater Streams and Provincially Significant Wetlands

Water demand assessments must consider an area's ability to meet municipal water demand while maintaining requirements for other users who rely on groundwater resources to sustain their habitat, such as coldwater streams and provincially significant wetlands.

The coldwater reaches within the Study Area include the lower part of Horner Creek, Whitemans Creek, and Landon's Creek, which is a small tributary to Whitemans Creek. The Whitemans Creek subwatershed also contains many provincially significant wetlands. A wetland complex flanks the majority of Whitemans Creek and its main tributaries, Kenny Creek and Horner Creek. These features are shown on **Map 20-8**. The risk assessment evaluated the impacts of allocated demand to water levels in these sensitive features.

20.3 Water Budget Model

20.3.1 Model Development

A fully-integrated surface and groundwater modelling approach was used to address the significant interaction between the groundwater and surface water systems in the Whitemans Creek watershed. The United States Geological Survey's GSFLOW code (Markstrom et al., 2008) was used to develop the Water Budget Model. Earthfx (2018a) added an Irrigation Demand Submodel to GSFLOW to estimate irrigation water demands and simulate the fate of applied irrigation water.

The surface water and groundwater characterization formed the framework for the numerical model. Modelling the surface water system required inputs of climate, topography, land use, and surficial geology. For the groundwater system, flow was simulated in the overburden and upper bedrock layers. Additionally, stresses on groundwater flow such as water takings, were incorporated based on water demand estimates including inputs into the irrigation demand model.

20.3.2 Model Calibration

The integrated model was calibrated to conditions observed from 2006 to 2015. Calibration targets included shallow subsurface water level data collected for the Tier 3 field program; continuous groundwater levels from the PGMN; and continuous groundwater levels from municipal monitoring and production wells. Surface water calibration targets included continuous stream flow data collected by the Water Survey of Canada between 2006 and 2015.

There was limited calibration data available for the Bethel Well Field, since the four production wells have only been in operation since summer 2015. The limited data created some uncertainty in model results, which affected the confidence in risk assessment results for this well field.

20.4 Risk Assessment

20.4.1 Vulnerable Areas

A WHPA-Q1 was defined for each well field using the results of existing conditions and the future (allocated) water demand-average climate scenario, with a drawdown threshold of 1.0 m for the Bright Well Field and 0.5 m for the Bethel Well Field. Drawdown thresholds were selected based on a review of seasonal groundwater level fluctuations at each well field.

The simulated drawdown did not exceed the 1.0 m drawdown threshold at the Bright Well Field. The WHPA-Q1 was therefore delineated as a circle with a radius of 100 m around each production well (**Map 20-9**). The WHPA-Q1 for the Bethel Well Field is a 6 km^2 gum-drop shaped area that extends approximately 250 m to the north and south, 300 m to the west, and 400 m to the east (**Map 20-10**).

A WHPA-Q2 is defined as the WHPA-Q1 plus any area where future reductions in recharge from proposed development would have a measureable impact on water levels at the municipal wells. Model simulations were run with recharge rates adjusted for proposed developments. These simulations did not result in a measureable impact. Therefore the WHPA-Q2 was determined to equal the WHPA-Q1 at both Bethel and Bright and is referred to as the WHPA-Q.

WHPA-Q Risk Levels

Eight risk assessment scenarios were simulated with the Water Budget Model to determine the likelihood that the Bright and Bethel well fields would be able to meet future water demands. The scenarios simulated existing conditions as well as future land use and water demand under average climate conditions and a 10-year drought. The period from 1975 to 2010 was used for average climate conditions. Precipitation input for the 10-year drought were taken from the 1957 to 1962 drought, which had an average of 829 mm/yr of precipitation; this is 126 mm/yr (13%) lower than the typical annual average.

Risk levels were assigned to each WHPA-Q by assessing the change in simulated water level at each production well compared to the safe available drawdown. The safe available drawdown is the difference between the average pumped water level in a production well and the lowest water level at which the production well can be safely operated. The available drawdown at the Bright Well Field was estimated at 7 m for Production Well 4A and 12.5 m for Production Well 5. At the Bethel Well Field, available drawdown estimates were 14.7 m, 9.4 m, 9.5 m, and 8.9 m for Production Well TW1/05 (P52), PW1/12 (P51), PW2/12 (P53), and PW4/12 (P54), respectively.

Bright Wellfield

Production Well 4A and Well 5 met existing and future water demand, under future land use, average climate and drought condition scenarios without exceeding safe available drawdown. No impacts were predicted to other groundwater users, aquatic habitat, or wetlands with future land use, future water demand and the 10-year drought scenario, which is the worst-case for potential impacts. These results are consistent with the prediction of minimal drawdown, less than 0.5 m, near the production wells between existing conditions and the future water demand-average climate scenario.

Based on this assessment, the WHPA-Q for the Bright Well Field was assigned a risk level of “low”. The level of uncertainty in the Bright risk level assignment is considered low.

Bethel Wellfield

Production Wells TW1/05, PW1/2, PW2/12, and PW4/12 all met existing water demands under future land use, average climate and drought conditions, without exceeding safe available drawdown. The same was true for future water demand, under future land use and average climate. However, under drought conditions, the production wells could not meet future water demand because drawdown exceeded the available drawdown and water level impacts were predicted for some nearby shallow wells. These results suggest that the Bethel Well Field can meet water demands under drought conditions with future land use changes, assuming water taking rates remain at current levels, but cannot meet high future rates under the same conditions.

No aquatic habitat near the Bethel Well Field experienced a flow reduction of 10% or greater under the worst-case scenario for potential impacts. The overall risk of impact to aquatic habitat is considered to be low. Five unevaluated wetlands lie within the WHPA-Q for the Bethel Well Field, indicating that drawdowns greater than 0.5 m are expected at these features. These wetlands should be evaluated to better assess the potential risk of impact.

The WHPA-Q for the Bethel Well Field was assigned a risk level of “significant” because it could not meet future demand under drought conditions. However, less than one year of data were available for model calibration because combined pumping at the well field only began in summer 2015. Having such scarce data reduces the confidence in the model results and creates a high level of uncertainty in the Bethel Well Field WHPA-Q risk level assignment. Depending on the significance of risk assessment results to land use and water management policies in the County of Brant, the Tier 3 Model may need to be revisited as additional calibration data become available for the Bethel Well Field.

Significant Groundwater Recharge Areas

Significant Groundwater Recharge Areas (SGRAs) were delineated as areas that annually recharge water to the underlying aquifers at a rate that is greater than 1.15 or more of the annual rate of recharge across the Study Area.

The average annual rate of recharge across the Tier 3 Study Area is 295 mm/yr. Therefore, any area with an average annual recharge greater than 340 mm/yr was identified as a SGRA. Smoothing/infilling was then completed to remove holes within large groupings of these areas, or to remove isolated areas that were considered anomalies. The smoothing/infilling procedure was completed to make it easier to use SGRAs for land use and water management planning.

Map 20-11 shows the SGRAs mapped as part of this Study. These areas are largely associated with areas of greater rates of groundwater recharge such as the Lower Whitemans Sand Plain in the south of the Study Area and the Central Whitemans Glacial Outwash in the centre of the Study Area, where sand and gravel is found at surface.

20.4.2 Significant Water Quantity Threats

A significant water quantity threat can exist in a WHPA-Q where a moderate or significant risk level has been assigned. Water quantity threats apply to existing or proposed consumptive water uses or activities that reduce groundwater recharge.

The WHPA-Q for the Bright Well Field was assigned a low risk level; significant water quantity threats therefore were not identified for this municipal water supply.

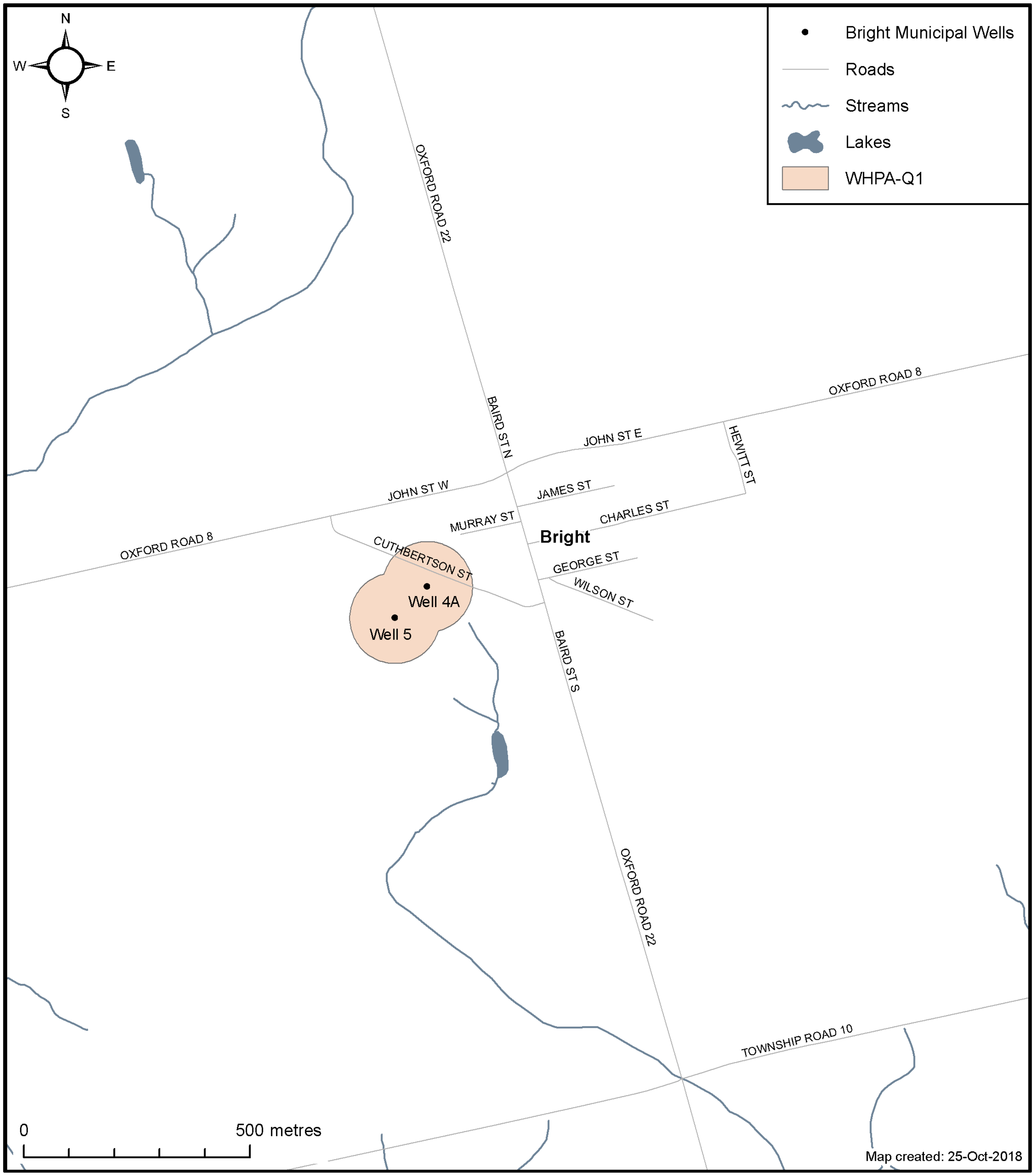
A total of 19 consumptive water uses were identified in the Bethel WHPA-Q: 14 non-municipal, non-permitted uses (e.g., private domestic and livestock water supply wells); four municipal permitted uses (e.g., the Bethel Production Wells); and one non-municipal, permitted water use (e.g., water supply for an aggregate operation). Each of these consumptive water uses is considered a significant water quantity threat to the Bethel municipal water supply. A total of 243 ha of existing and future land development were also identified as a significant water quantity threat: this development will increase the total area of impervious surfaces (e.g., paved roads) and therefore has the potential to reduce groundwater recharge within the WHPA-Q. The significant water quantity threats to the Bethel municipal water supply are illustrated on **Map 20-12** and **Table 20-3**.

Table 20-3: Summary of Significant Water Quantity Threats – Bethel Well field

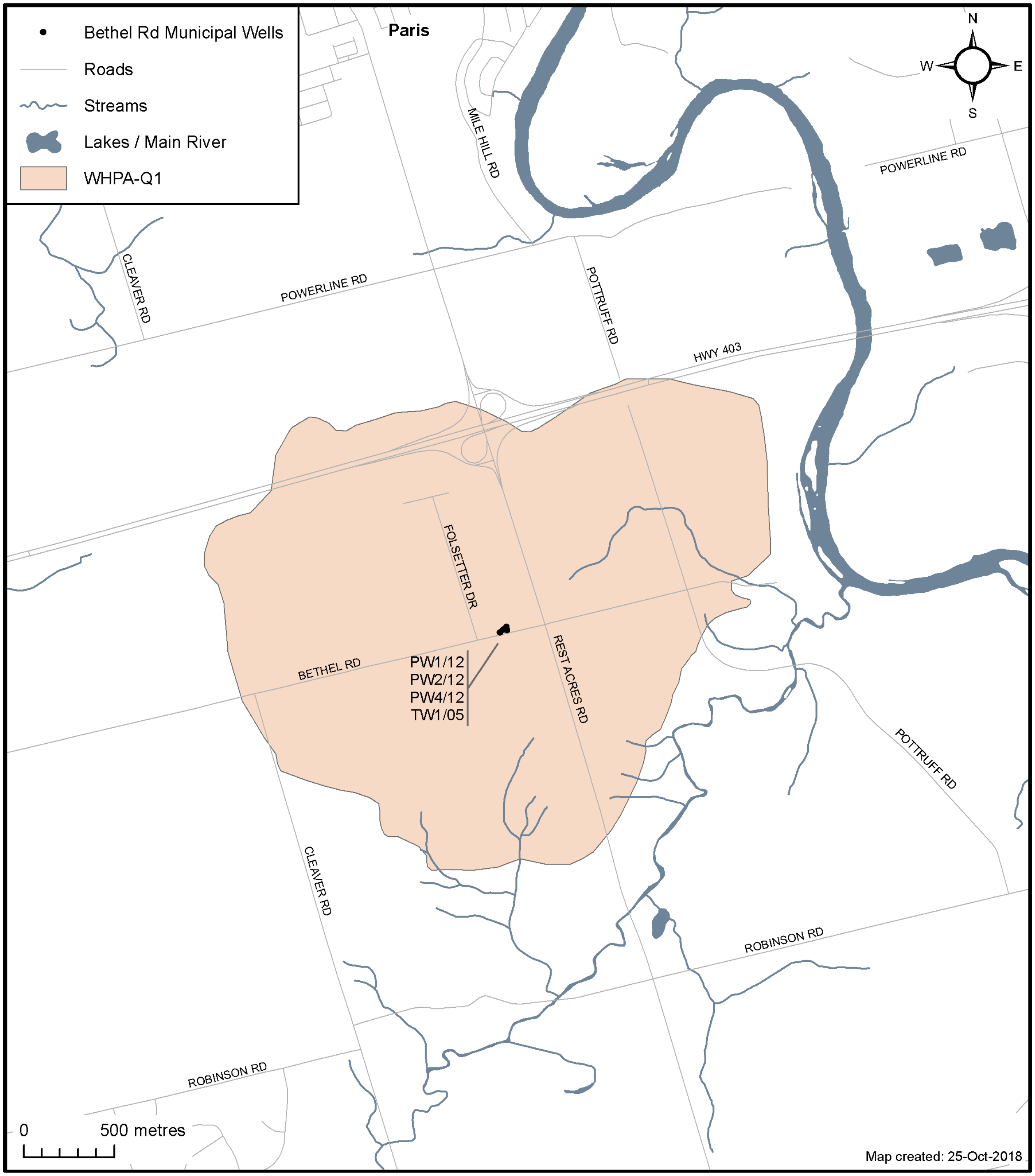
Threat Group	Vulnerable Area
	WHPA-Q1
Municipal	4
Non-municipal Permitted	1
Non-municipal, Non-permitted[1]	14
Total	19
Recharge Reduction[2]	2.43 km^2

Notes:
[1]Only domestic water wells recorded in the Water Well Information System database (MOE 2012) are included. These are exempt from permitting if they are taking less than 379,000 L/day.
[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

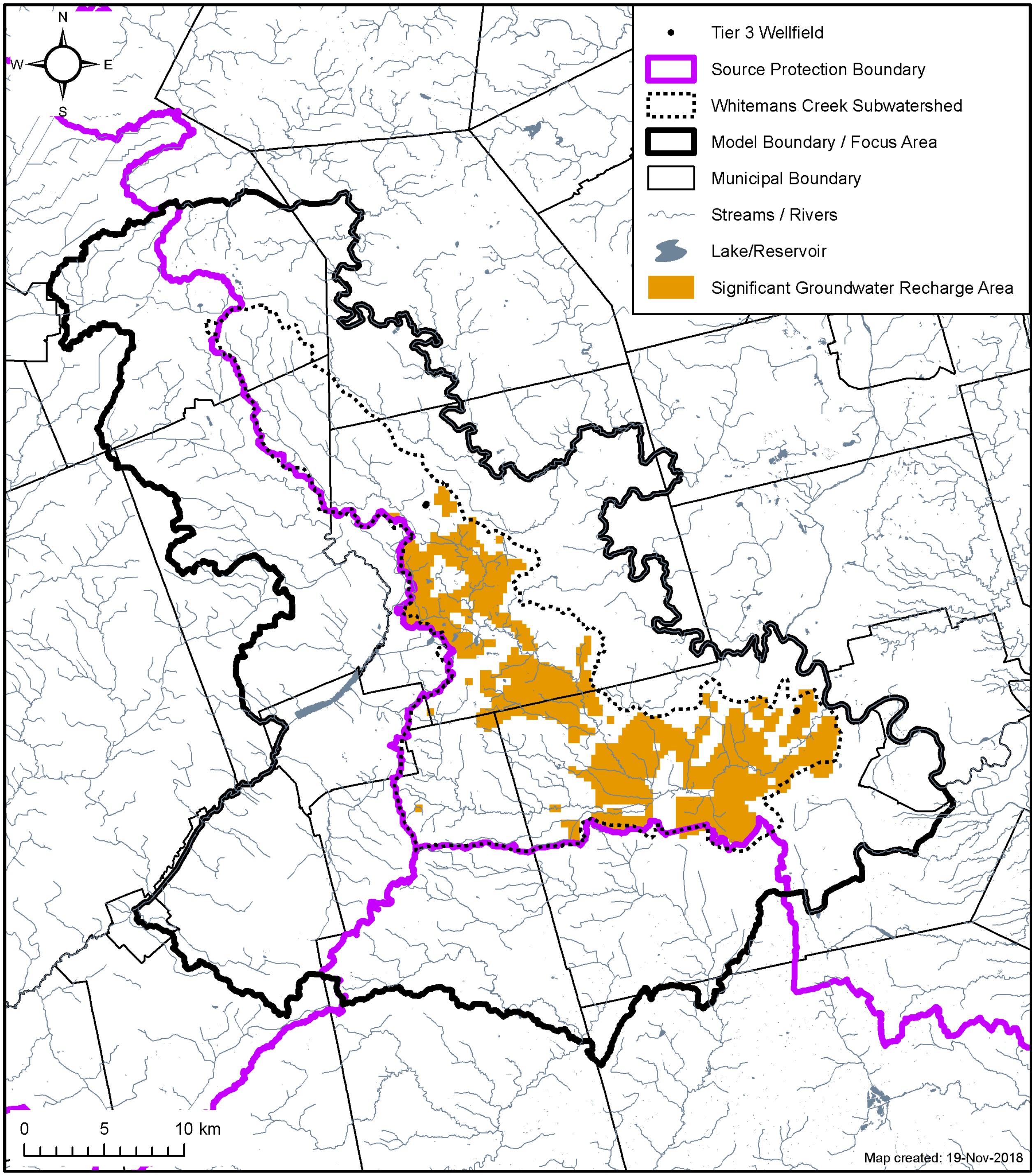
Map 20-9: Wellhead Protection Area for Quantity (WHPA-Q1) – Bright Well Field



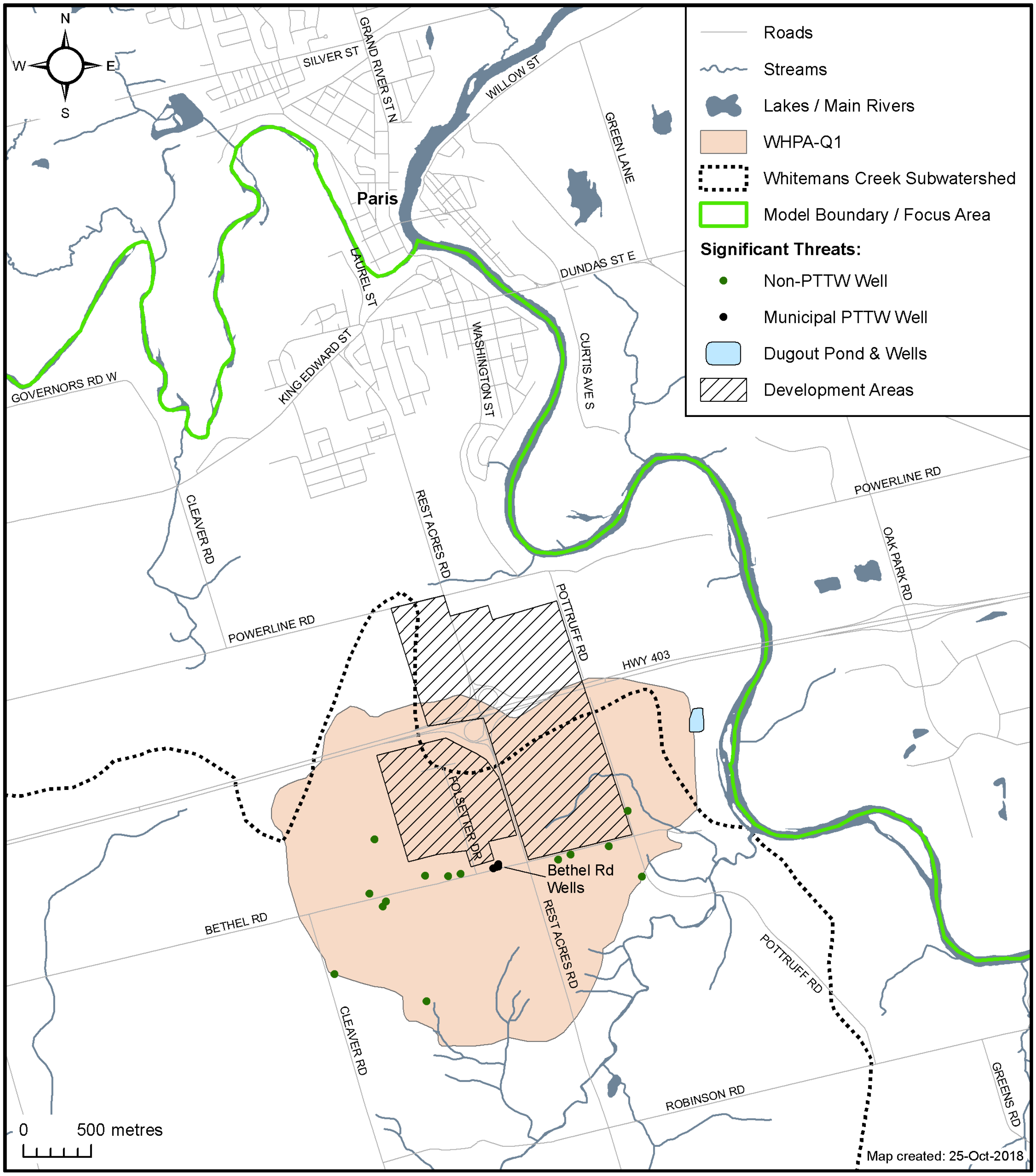
Map 20-10: Wellhead Protection Area for Quantity (WHPA-Q1) – Bethel Well Field



Map 20-11: Significant Groundwater Recharge Areas



Map 20-12: Significant Water Quantity Threats – Bethel Municipal Water Supply



20.5 Summary

The Whitemans Creek Tier 3 Study evaluated the risk of water quantity impacts to the Bright Well Field in Oxford County and to the Bethel Well Field in the County of Brant, given planned growth (future land use and future anticipated water demand) and variable climate (average and drought conditions).

A refined characterization of the groundwater and surface water regimes was completed and a numerical water budget model was developed using GSFLOW. The water budget model was used to simulate water use across the Whitemans Creek subwatershed and surrounding areas contributing to the watershed's water balance.

Results of the Risk Assessment indicate that the WHPA-Q for the Bright Well Field is a circle of 100 m radius around each production well, with a "low" risk level for water quantity impacts. This finding was based on the production well's ability to meet existing and future water demand, under future land use, average climate and drought condition, without exceeding available drawdown; and a prediction of no impacts to other groundwater users, aquatic habitat or wetland under the worst-case conditions for water-quantity impacts.

The WHPA-Q for the Bethel Well Field is a 6 km^2 area with a "significant" risk level for water quantity impacts. This finding was based on the production well's inability to meet future demand under drought conditions; and the potential for impacts to neighbouring shallow private wells and wetlands under worst-case conditions for water quantity impacts. There is a high level of uncertainty in the risk assessment results for the Bethel Well Field due to the scarcity of well field calibration data.

20.6 References

AquaResource Inc., 2009a. Tier 2 Water Quantity Stress Assessment Report, Grand River Watershed. Final Report December 2009.

AquaResource Inc., 2009b. Integrated Water Budget Report, Grand River Watershed. Final Report. Prepared for the Grand River Conservation Authority. June 2009.

Bajc, A.F. and J.E.P. Dodge 2011. Three-dimensional mapping of surficial deposits in the Brantford–Woodstock area, southwestern Ontario; Ontario Geological Survey, Groundwater Resources Study 10, 86p.

Earthfx Inc., 2018a. Model Development and Calibration Report: Whitemans Creek Tier Three Local Area Water Budget and Risk Assessment. Prepared for the Grand River Conservation Authority on behalf of the Lake Erie Source Protection Region. March 2018.

Earthfx Inc., 2018b. Risk Assessment Report: Whitemans Creek Tier Three Local Area Water Budget and Risk Assessment. Prepared for the Grand River Conservation Authority on behalf of the Lake Erie Source Protection Region. May 2018.

Leavesley, G.H., Lichty, R.W., Troutman, B.M., Saindon, L.G., 1983, Precipitation-Rrunoff Modeling System–User's Manual: U.S. Geological Survey Water Resources Investigations Report 83–4238

Markstrom, S.L., Niswonger, R.G., Regan, R.S., Prudic, D.E., and Barlow, P.M., 2008, GSFLOW-coupled ground-water and surface-water FLOW model based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005): U.S. Geological Survey Techniques and Methods book 6, chap. D1, 240 p.

Niswonger, R.G., Panday, Sorab, and Ibaraki, Motomu, 2011, MODFLOW-NWT, A Newton formulation for MODFLOW-2005: U.S. Geological Survey Techniques and Methods 6–A37, 44 p.

Ontario Ministry of the Environment, Conservation and Parks, 2011. *Technical Rules: Assessment Report, Clean Water Act, 2006.* Proposed Amendments, March 22, 2011.

Ontario Ministry of the Environment, Conservation and Parks, 2017. *2013 Technical Rules for Assessment Risks to Sources of Drinking Water in Ontario under the Clean Water Act.* Published May 19, 2016. Updated June 23, 2017. [Online] https://www.ontario.ca/page/2013-technical-rules-under-the-clean-water-act Accessed October 9, 2018.

Ontario Ministry of the Environment, Conservation and Parks, 2018. *2017 Technical Rules for Assessment Risks to Sources of Drinking Water in Ontario under the Clean Water Act, 2006, S.O. 2006, c.22.* Published June 13, 2017. Updated June 28, 2018. [Online] https://www.ontario.ca/page/2017-technical-rules-under-clean-water-act Accessed October 9, 2018.

Ontario Ministry of Natural Resources and Forestry, 2014. Southern Ontario Land Resource Information System (SOLRIS) Version 2.0.