Whitemans Creek Tier Three Local Area Water Budget and Risk Assessment

Risk Assessment Report

Prepared for:

Grand River Conservation Authority
400 Clyde Road, P.O. Box 729
Cambridge, Ontario, N1R 5W6

On behalf of:

Lake Erie Source Protection Region

Prepared by:

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May 2018

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May 2nd, 2018

Stephanie Shifflett, P.Eng.
Water Resources Engineer
Grand River Conservation Authority
400 Clyde Road, P.O. Box 729
Cambridge, Ontario, N1R 5W6

RE: Whitemans Creek Tier 3 – Risk Assessment Report

Dear Ms. Shifflett:

We are pleased to provide a copy of our *Whitemans Tier 3 Risk Assessment Report*. The report details the Risk Assessment component of the Tier 3 water budget and local area risk assessment for the Bright and Bethel wellfields located within the Whiteman's Creek subwatershed. The purpose of the Tier 3 study is to investigate the sustainability of the municipal drinking water systems in terms of being able to meet their allocated pumping rates considering future increases in municipal demand, future land use change, drought, and impacts to other uses.

The Whitemans Creek subwatershed was assessed as being moderately stressed in the Tier 2 Water Budget and Stress Assessment. As such, a Tier 3 study was required to determine the sustainability of the Bright and Bethel municipal drinking water supply under average climate and drought conditions. A Local Area Risk Assessment was completed for each wellfield. The Bright Wellfield Local Area was assessed a *low level of risk* because it was able to meet its water demand under all conditions and was shown to have minimal impact to other users. The Bethel wells were able to meet future water demand under average climate conditions but unable to meet future water demand under drought conditions. Accordingly the Bethel Road Wellfield Local Area was assessed a *significant level of risk*.

We trust this work report meets with your satisfaction, and we look forward to discussing it with you. If you have any questions, please call.

Yours truly,
Earthfx Incorporated

Dirk Kassenaar, M.Sc., P.Eng.
President

E.J. Wexler, M.S.E., M.Sc., P.Eng.
Vice-President, , Director of Modelling Services

Acknowledgements

Earthfx would like to acknowledge a number of groups and individuals for their assistance in the preparation of this report. First we wish to thank Stephanie Shifflett P. Eng., Water Resources Engineer, GRCA for coordinating this study. We also acknowledge the following GRCA personnel for their contributions to this project:

- Sonja Strynatka, P.Geo., Senior Hydrogeologist
- Martin Keller, Lake Erie Source Protection Program Manager

This study benefited greatly from the foundational work completed by members of the Ontario Geologic Survey. The work of Bajc and Dodge through Groundwater Resources Study 10 *"Three-Dimensional Mapping of Surficial Deposits in the Brantford–Woodstock Area, Southwestern Ontario"* provided the hydrostratigraphic framework employed in this study. We would further like to acknowledge Dr. Bajc's personal input regarding the application of the Ontario Geological Survey (OGS) geologic framework to this study.

We also acknowledge the contributions made by Source Water Protection Program staff including:

- Scott Bates, Water Budget Program Analyst, OMNRF
- Kathryn Baker P.Geo., Hydrogeologist – Source Protection Planning, MOECC
- Lynne Milford, Water Budget Program Analyst, MOECC

The depth and quality of this study was greatly enhanced by comments provided by members of the study Peer Review Team:

- Roger Freymond, P.Eng., Stantec (representing the County of Brant)
- Tony Lotimer, P.Geo., (representing the County of Oxford)
- Chris Neville, P.Eng., S.S. Papadopulous & Associates
- Dr. David L. Rudolph, P.Eng., Waterloo Hydrogeology Advisors Inc.
- Dr. Rob Schincariol, P.Geo., University of Western Ontario
- Dr. Hugh R. Whiteley, P.Eng.

We appreciate the input and data provided by Alex Davidson, Director of Water, County of Brant, throughout this project

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1 Introduction

The Ontario government passed the Clean Water Act in October 2006 to protect drinking water at the source as part of an overall commitment to human health and the environment. Conservation Authorities have been charged with coordinating the Source Water Protection (SWP) process, including the provision of technical expertise to determine the best ways to protect the quality and quantity of sources of drinking water within a watershed. This is considered to be the first step in a multi-barrier approach to ensuring safe drinking water. SWP studies are funded by the Province of Ontario.

Source Water Protection Plans are being prepared by the Conservation Authorities for each Source Protection Region with the support of regional and municipal governments. An important element of each SWP plan is the technical assessment of potential risks to municipal water supplies from both a water quantity and water quality perspective. A three-tiered approach has been defined under the Clean Water Act for the purpose of assessing the risks to water quantity for municipal water supplies.

A Tier 2 Water Quantity Stress Assessment was completed for the Grand River watershed in 2009 (AquaResource, 2009a and 2009b). The report stated that:

> *"The Whiteman's Creek Assessment area was classified as having a Moderate potential for stress based on drought impacts simulated to occur at the Bright #4 well, and supplemental information provided by County of Oxford hydrogeological support staff. Based on this classification, the Bright system meets the requirement under the Technical Rules for the completion of a* [Tier 3] *local water budget and risk assessment."*

According to the SWP assessment process, municipal supplies within subwatersheds that are identified as being potentially stressed are required to undergo a Tier 3 Local Area Water Budget and Risk Assessment. This Tier 3 study is therefore being undertaken for the groundwater municipal supplies operated by the County of Oxford in the Village of Bright and for the Bethel Road wellfield servicing the Town of Paris, both situated within the Whitemans Creek subwatershed. The wellfields are herein referred to as the Bright wellfield and the Bethel wellfield.

1.1 *Project Objectives and Scope*

The primary objective of this project was to complete a Tier 3 water budget and water quantity risk level assignment for the area surrounding the Bright and Bethel wellfields. The work program for the Tier 3 Water Budget and Water Quantity Risk Level Assignment (Tier 3 Assessment) was designed in accordance with the Technical Rules for Assessment Reports (under the Clean Water Act of 2006) and the updated Water Budget and Water Quantity Risk Assessment Guide (referred to herein as the Water Budget Guide) developed for the Ontario Ministry of Natural Resources and Ontario Ministry of the Environment (MNR and MOE, 2011).

The objective of a Tier 3 Assessment, as defined in the Water Budget Guide, is to *"estimate the likelihood that a municipality's drinking water wells will be able to supply their allocated pumping rates considering increased municipal water demand, projected land development, drought conditions, and other water uses"*. Specifically, the Tier 3 Assessment includes the development of refined surface water and/or groundwater flow models and the application of the model to evaluate groundwater and surface water resources in the local area surrounding the municipal supply wells. Various scenarios (related to future land-use practices, future water demand, and drought conditions) are evaluated with the model to assess the response of the groundwater and surface water systems and evaluate the risk that a community may not be able to meet its current or planned water demands from the municipal water source.

1.2 *Technical Approach*

The hydrologic and hydrogeologic conditions in the Whitemans Creek subwatershed are highly variable. Previous studies indicated that there is a significant interaction between the groundwater and surface water systems. Characterizing the response of streams, wetlands, and aquifer levels to changing climate and water use is essential to the understanding the overall water budget and function of the subwatershed.

To address this complexity and groundwater/surface water interaction, a fully-integrated surface and groundwater modelling approach was followed in this study. Project objectives were addressed with an integrated modelling tool that represented the physical processes in the two systems as well as the dynamic feedback between them in a consistent manner. The integrated model simulates daily fluctuations as well as longer-term seasonal and inter-annual changes in storage under a wide range of climatic and water-use conditions.

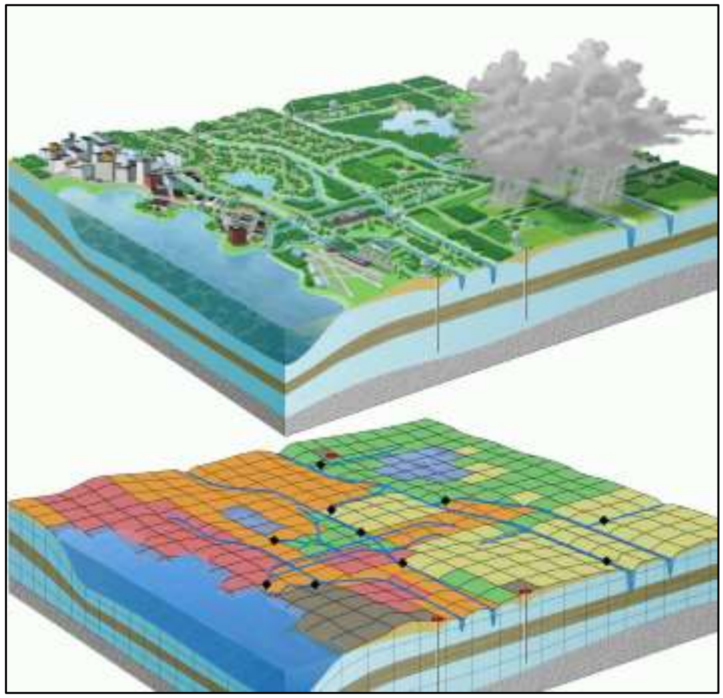

Figure 1.1: The physical system (upper image) and a numerical model representation in a fully distributed, cell-based, integrated model (lower image).

The U.S. Geological Survey (USGS) GSFLOW integrated model computer code (Markstrom *et al*., 2008) was selected for use in this study. GSFLOW is constructed from two proven submodels: MODFLOW and PRMS. The model represents all surface water features (streams, wetlands, lakes and ponds) along with the subsurface geologic and hydrogeologic setting of the study area. The components and linkage of these models is described in detail in a companion report titled *Whitemans Creek Tier Three Local Area Water Budget and Risk Assessment - Model Development and Calibration Report* (Earthfx, 2017).

Earthfx (2017) discusses the selection of appropriate boundaries for the integrated model. As “groundwater watershed” boundaries can be larger than surface watershed catchment boundaries, the model boundaries were expanded to include additional area adjacent to the subwatershed. This ensured that cross-watershed groundwater flows were correctly represented in the model. The model boundaries are shown in Figure 1.2. The area encompassed by the model boundaries constitutes the “study area” referred to throughout this report.

1.3 *Tier 3 Assessment Methodology and Project Scope*

The MNR Water Budget Guide lists 10 steps for completing a Tier 3 water budget and local area risk assessment. These are discussed below with specific reference to this study, project scope, and organization of this report.

Develop the Tier 3 water budget model: The surface water and groundwater models should be based on conceptual models representing detailed conditions around the wells. The models should be calibrated to represent typical operating conditions under average climate conditions and drought. As noted earlier, an integrated groundwater/surface water model was developed for the study area. Model development and calibration is described in Earthfx (2017). This work is summarized in Sections 2 and 3.

Characterize the municipal wells: The Tier 3 assessment requires a detailed characterization of the municipal wells with focus on identifying the low-water operating constraints. Section 4.1 and Section 4.2 of this report contain figures and discussions regarding the Bright and Bethel municipal wellfields.

Estimate allocated plus planned quantity of water: Municipal water takings, in terms of existing, committed, and planned pumping rates for municipal wells, should be quantified for the Tier 3 analysis. Section 4.3 of this report describes the existing takings along with allocated demand (existing plus committed demand) for the Bright and Bethel municipal wellfields.

Identify and characterize drinking water quantity threats: Threats to drinking water quantity can include municipal and non-municipal consumptive water demands as well as reductions to groundwater recharge. Section 4.5 of this report discusses other water takings in the study area. Land use changes that can affect the rate of recharge are discussed in Section 4.7.

Characterize projected land use: Changes in land use due to the expansion of urban or settlement areas and agricultural activities can affect recharge rates by increasing imperviousness and changing vegetative cover. An evaluation of the potential impact of projected land use changes on water supply is included in the Tier 3 analysis. Projected land use change was determined by comparing Official Plans with existing land use. Projected change in recharge was determined through simulations with the GSFLOW model and incorporated reasonable assumptions relating to imperviousness, vegetative type, and cover density for projected land use changes. These are described in detail in Section 4.7 and Section 6 of this report.

Characterize other water uses: Other water uses that might be affected by municipal pumping need to be identified as part of the Tier 3 analyses. In addition to non-municipal permitted takings, these water uses include aquatic habitat, provincially significant wetlands, wastewater assimilation, and recreational water use. Other water uses are discussed in Section 4.6 and Section 6.5.

Delineate vulnerable areas: A specific requirement of the Tier 3 assessment is that the model should represent the "local area" around the municipal wells. Vulnerable areas from a groundwater quantity perspective (i.e., the WHPA-Q1 and WHPA-Q2) were delineated using the Tier 3 model. The WHPA-Q1 was delineated by computing the drawdown cone for the municipal wells with existing plus committed plus planned rates. The WHPA-Q2 expanded this zone to include areas where recharge reductions resulted in a measurable impact to water levels at municipal wells. The WHPA-Q2 is, by definition, identical to the “local area”. Further descriptions of the analyses done to delineate the WHPA-Q1 and WHPA-Q2 are presented in Section 6.2.

Evaluate risk scenarios: A set of risk analysis scenarios have been developed to consider the allocated quantity of water, average climate and drought conditions, and projected change in land use. The prescribed scenarios were evaluated for the Bright and Bethel municipal wellfields using the Tier 3 model to determine the sustainability of municipal pumping and, where required, impacts to other water uses. The analyses are described in Section 6.4.

Assign risk level: A risk ranking (low, moderate, or significant) must be assigned to the well based on the results of each risk scenario. An uncertainty level (high/low) is also derived for each risk ranking. Risk levels for the local areas surrounding the Bright and Bethel wellfields are presented in Section 6.6.

Identify drinking water quantity threats: Drinking water quantity threats, such as consumptive uses or reductions in recharge, must be identified at the significant and moderate levels within the WHPA-Q1 and WHPA-Q2 areas. Water quantity threats in the vicinity of the Bright and Bethel wellfields are discussed in Section 7.

1.4 *Figures*

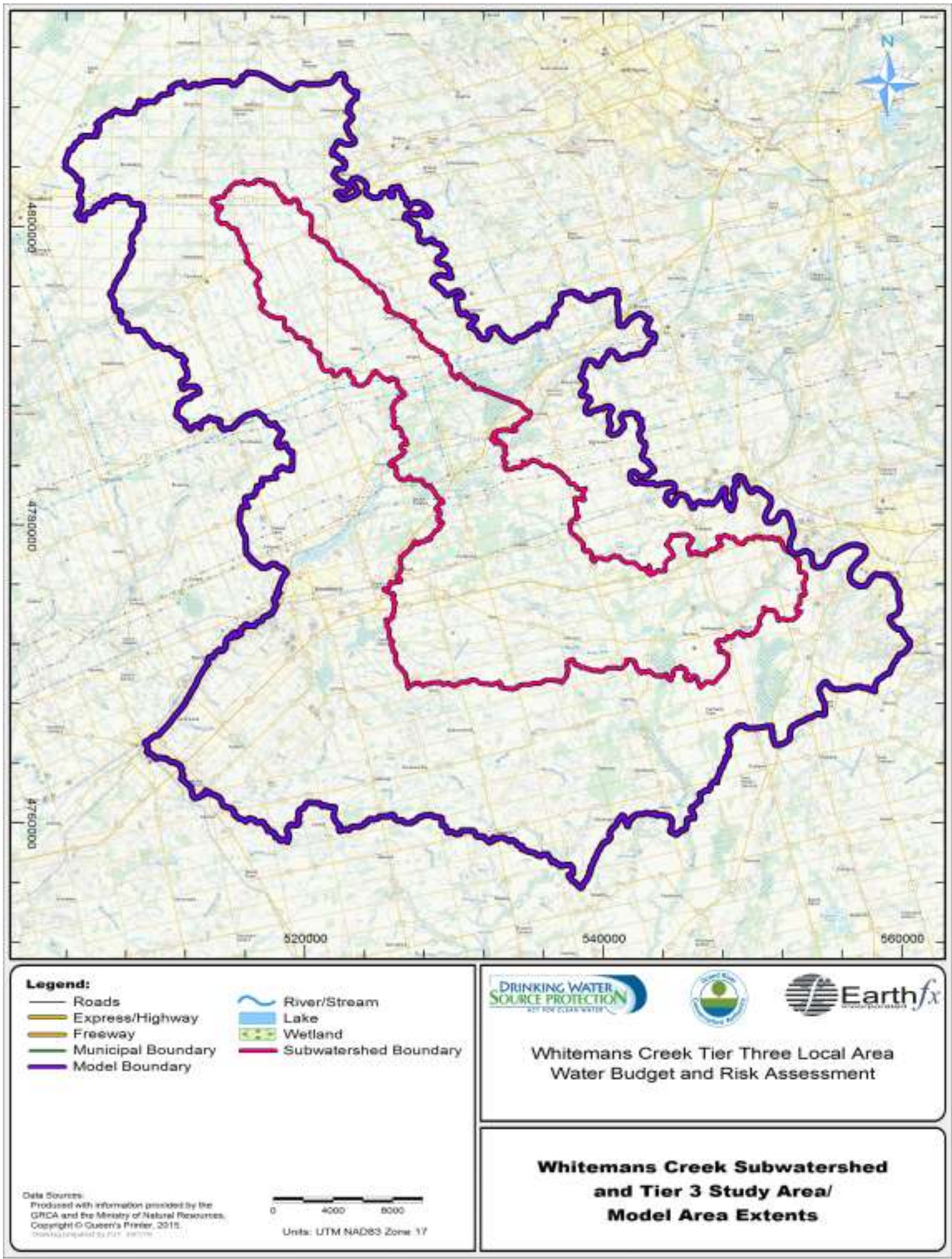

Figure 1.2: Whitemans Creek subwatershed and Tier 3 study area and model area boundaries.

2 Physical Setting

Developing a detailed understanding of the hydrologic and hydrogeologic function of the watershed is a critical part of the Tier 3 study. A companion model development and calibration report (Earthfx, 2017) provides a detailed description of the geology, hydrogeology and water resources of the study area. This section provides a brief summary of the key findings regarding the physical setting (topography, land use, physiography, hydrology, geology, and hydrogeology) of the Whitemans Creek subwatershed and the surrounding area.

2.1 *Watershed Overview*

The Whitemans Creek subwatershed is located in southwestern Ontario between the City of Brantford to the east and City of Woodstock to the west (Figure 1.2). Land surface topography, based on a 10-metre (m) Digital Elevation Model (DEM) provided by the Ontario Ministry of Natural Resources (MNR), is shown in Figure 2.4. Land surface slopes from north to south and from west to east, with local areas of high relief within the Paris and Woodstock moraines and areas of low relief adjacent to incised streams. The subwatershed drains an area of approximately 400 square kilometres (km^2) from headwaters in the northwest to an outfall into the main branch of the Grand River to the southeast. From the Whitemans Creek outfall, the Grand River turns southeastward and eventually discharges into Lake Erie at Port Maitland.

The western and southern extent of the Whitemans Creek subwatershed defines the watershed divide between the Grand River and the Thames River to the west and Big Creek to the south. Whitemans Creek is shown in relation to its neighbouring catchments on Figure 2.5. The subwatershed contains three main tributaries; Whitemans, Horner, and Kenny creeks, which have a combined stream length of 369 km. Horner Creek becomes Whitemans Creek upstream of the town of Princeton, while the Kenny Creek tributary joins Whitemans Creek from the west near Burford.

2.1.1 Land Use

Current land use and land cover within the Whitemans Creek subwatershed were evaluated with the Southern Ontario Land Resource Information System (SOLRIS v2) mapping compiled by MNR (2014). Actively cultivated agricultural fields comprise 60% of the watershed, with "undifferentiated uses" encompassing an additional 16%. Within the Whitemans Creek subwatershed, the undifferentiated classification includes some agricultural features not included in tilled classification such as orchards, fallow lands, and undeveloped pastures. This brings the total estimated agricultural coverage to 76% (304 km^2) of the subwatershed. Natural areas, including deciduous forests and treed swamps and other (forest/wetlands), cover 19% of this largely rural area. Developed or settled areas (i.e., rural residential, transportation, parks, industrial, and commercial lands) cover the remaining 5% of the subwatershed area. A detailed breakdown of the SOLRIS land coverage for the subwatershed is presented in Figure 2.1.

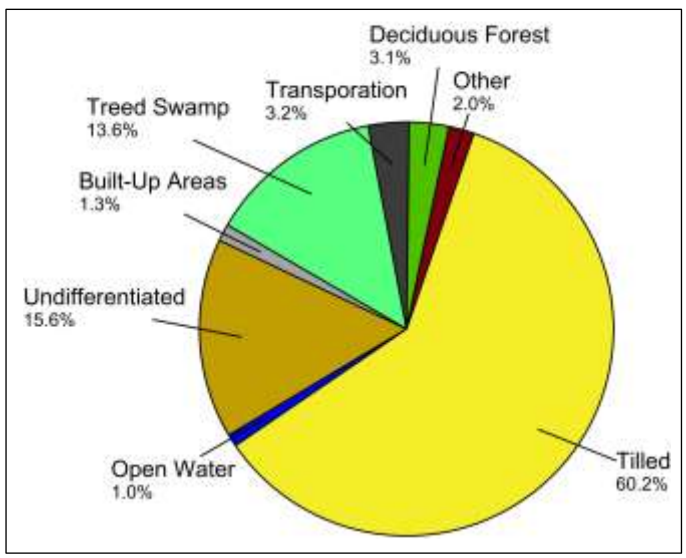

Figure 2.1: Summary of land use within the Whitemans Creek watershed (MNR SOLRIS v2, 2014).

2.2 *Physiography*

The Whitemans Tier 3 study area contains portions of six physiographic regions as identified by Chapman and Putnam (1984). The four main regions include the Norfolk Sand Plain, Horseshoe Moraines, Mount Elgin Ridges, and Oxford Till Plain (Figure 2.6). The Stratford Till Plain and, farther to the north, the Waterloo Hills are of limited extent in the study area. While the study area is complex, the physiography of the Whitemans Creek watershed can be generally divided into three broad regions: 1) the Upper Whitemans Till Plains; 2) the Central Whitemans Glacial Outwash; and 3) the Lower Whitemans Sand Plain. The three regions have generally similar physiographic, hydrologic, and geologic characteristics and are defined further in Earthfx (2017).

2.3 *Geology*

The geology in the Whitemans Creek subwatershed and the surrounding region consists of a complex assemblage of Quaternary age unlithified clastic sediments (primarily tills and intervening sand and gravel units), that unconformably overlie Silurian and Devonian marine sedimentary bedrock units. Figure 2.2 presents the conceptual stratigraphy of the Whitemans Creek subwatershed.

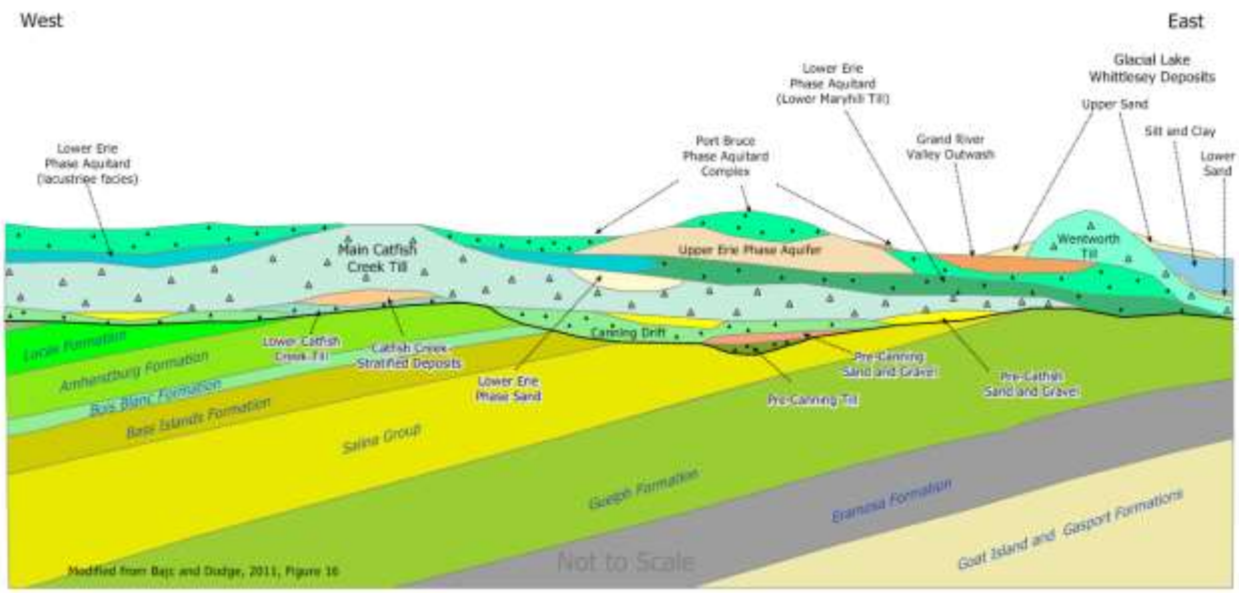

Figure 2.2: Schematic representation of Stratigraphic Framework

2.3.1 Bedrock Geology

The Paleozoic sedimentary rocks dip gently to the south or southwest, becoming progressively younger in that direction (presented schematically in cross section in Figure 2.2). As shown in Figure 2.7, the Whitemans Creek subwatershed is underlain largely by the Salina Group - a thick, complex of shales, carbonate rocks, and evaporites (anhydrite, gypsum, and halite). Few bedrock outcrops occur in the region outside of the deeply incised river valleys such as the Grand River valley. The distribution and lithologic character of the rocks was characterized as part of the Brantford-Woodstock OGS model (OGS, 2010) and incorporated in this study. The units are further described in Earthfx (2017).

2.3.2 Quaternary Geology

Like all of southern Ontario, the study area was repeatedly glaciated during the Pleistocene Epoch. Locally, much of the earlier sediments have been removed and there is only clear evidence for glacial activity from the Wisconsinan, the final major glacial episode (Barnett, 1992). The complex geologic history has resulted in highly variable geologic conditions across the region. In general, the region is characterized by low permeability tills in the northwest transitioning to the highly permeable Norfolk Sand Plain in the southeast.

Surficial geologic for the study area, based on OGS mapping (OGS, 2010) is presented in Figure 2.8 and shows the locations of the tills (various shades of green) and the more permeable ice contact and coarse glaciofluvial and glaciolacustrine deposits (yellow and orange shades).

There are a number of moraines in the region associated with the various ice lobes and till units. Most of these moraines are products of minor glacial re-advances' during ice margin recession (Barnett, 1992). The major Erie-Ontario lobe moraines include the Ingersoll, St. Thomas, Norwich, and Tillsonburg moraines, which are associated with the Port Stanley Till, and the Paris, Galt, and Moffat moraines, associated with the Wentworth Till (Cowan, 1972, 1975; Barnett, 1978, 1982).

2.4 *Climatic and Hydrologic Setting*

As introduced in the previous section, the Whitemans Creek subwatershed can be generally divided into three broad hydrologic regions:

- **Upper Whitemans Till Plains** (*Upper Horner Creek*): Dominated by poorly drained till plains due to low permeability Tavistock Till at surface.
- **Central Whitemans Outwash Area** (*Kenny Creek and Lower Horner Creek*): A complex area of moraines, outwash deposits, and till plains. These sediments are host to the many ponds and wetlands owing to poor drainage.
- **Lower Whitemans Sand Plain** (*Lower Whitemans Creek*): Extensive glaciolacustrine and outwash sand deposits with near surface groundwater levels. Swamps and other wetlands with large seasonal variation in hydroperiod are typically found in low-lying and riparian areas.

2.4.1 Stream Network and Wetlands

The stream network within the Whitemans Creek subwatershed is presented in Figure 2.9, along with major lakes, ponds, swamps and wetlands. The stream network consists of both natural channels and constructed municipal drains. In poorly drained areas, such as the Upper Whitemans Till Plains, tile drains are common in agricultural fields.

The less permeable Tavistock Till unit in the Upper Whitemans Till Plains generates significant overland runoff compared to other portions of the Whitemans Creek subwatershed, resulting in relatively flashy streamflow in Horner Creek. Similarly, the southwestern portion of the subwatershed adjacent to Kenny Creek also generates significant streamflow volumes. The sandy, shallow deposits at surface in the upper Central Whitemans Outwash Area have higher infiltration rates, thereby reducing overland runoff and increasing baseflow to the lower reaches of Horner Creek. Recharge in this area supports numerous ponds and wetlands. The areas of highest recharge occur within the Lower Whitemans Sand Plain.

The distribution of Water Survey of Canada (WSC) stream gauge locations is shown on Figure 2.10. There are two active and one discontinued streamflow gauges within the Whitemans Creek subwatershed (Quaternary Watershed ID 02GB-05). There are 21 active or historic Water Survey of Canada (WSC) stream gauge stations within a 10-km buffer of Whitemans Creek and each of the quaternary subwatersheds adjacent to Whitemans Creek is currently gauged by the WSC. Detailed information about the gauge network, including streamflow records, is presented in Earthfx (2017).

2.4.2 Precipitation and Temperature

There are several climate stations located around the Whitemans Creek subwatershed (Figure 2.11). Data were obtained from stations within 15 km of the model boundary. A total of 79 representative stations were used to characterize climate in the subwatershed. The period of record for each station varies, but data (either precipitation or temperature) are available from 1865 onwards.

Average annual precipitation varies from a high of 950 millimetre (mm) in the northwest of the study area to a low of 850 mm in the southeast around Brantford (Figure 2.12). Annually averaged daily temperature (Figure 2.13) demonstrates an inverse relationship with elevation, with a 1°C difference observed across the watershed roughly correlating to topography (Figure 2.4).

2.5 *Hydrogeologic Setting*

The Whitemans subwatershed was subdivided above into three general physiographic regions, as described in Section 2.2. This subdivision provides a useful framework to introduce the complex glacially-modified drift deposits that control subsurface hydrogeologic conditions. Table 2.1, below, summarizes the hydrogeologic conditions in each region. Cross sections, presented in Figure 2.2 and Figure 2.3, further illustrate the subsurface conditions described below.

Table 2.1: Conceptualization of regional hydrogeologic setting.

Upper Whitemans Till Plains	Central Whitemans Outwash Area	Lower Whitemans Sand Plain
Poorly drained till plains due to low permeability Port Bruce Phase aquitards at surface.	Complex system of moraines, outwash deposits and till plains. Upper Erie Phase sands form a shallow, regional aquifer that is confined to the south by the Port Bruce Phase aquitards. To the north, the shallow aquifer is unconfined where glacial outwash events have removed the surficial tills and unconfined sand aquifers occur at surface.	Extensive and thick (up to 65 m) glaciolacustrine and outwash sand deposits form a regional unconfined water-table aquifer.
Underlain by sequences of thick, continuous till aquitards, which are separated by relatively thin, discontinuous sand aquifer units.		Underlain by largely uninterrupted sequence of till aquitards down to bedrock.
Regionally confined bedrock aquifer system, except locally where rivers or outwash channels have eroded through drift deposits (e.g., the bottom of Whitemans Creek and Thames River near Woodstock). The southwestern half of study area is underlain by productive Devonian limestone aquifers (the Onondaga limestone aquifers). The northeastern half of study area is underlain by the Salina Formation aquifer with water of poorer quality.		

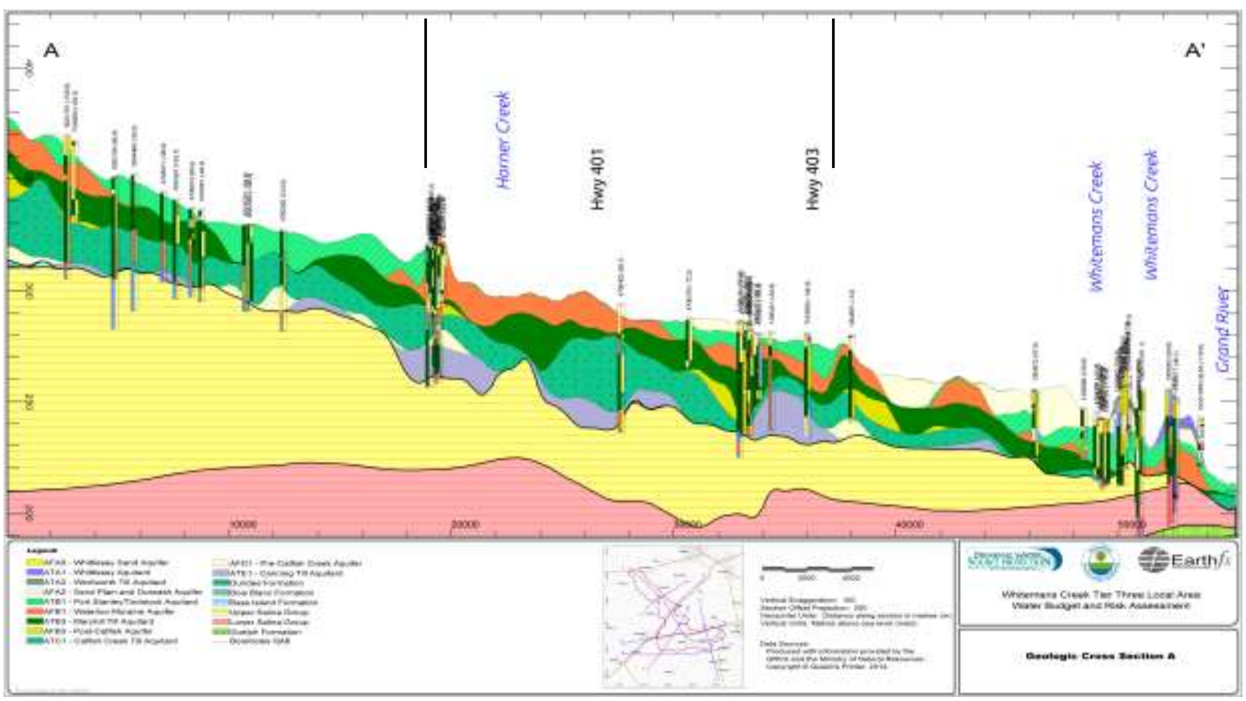

Figure 2.3: Hydrogeologic cross section down the central axis of the subwatershed

The cross section shown in Figure 2.3 is based on an interpretation of borehole logs and illustrates the complexity of the shallow Quaternary aquifer and aquitard layers. The cross section traverses down the centre of the watershed, and three hydrologic zones (upper, middle and lower) each correspond to one third of the cross section. An overview of the hydrostratigraphy can be found in Section 3.2, and a more complete description can be found in Earthfx (2017).

2.5.1 Regional Water Level Patterns

Regional water level patterns were evaluated using static water level data from the Ontario Ministry of Environment and Climate Change (MOECC) Water Well Information System (WWIS). Water level data from shallow wells were interpolated across the study area, as shown in Figure 2.14. Flow is assumed to be perpendicular to the potentiometric surface contours for the overburden aquifers and the map can be used to infer patterns of groundwater flow.

In general, groundwater flow in the shallow system is from topographic highs in the northwest and north (corresponding to the Waterloo Moraine) toward topographic lows in the southeast. A region of high groundwater levels is also noticeable to the south of the City of Woodstock (corresponding to the Woodstock and Ingersoll moraines). Prominent “v-shaped” groundwater contours can be seen pointing upstream along the main branches of the Thames River, Whitemans Creek, the Nith River and the Grand River, suggesting the river valleys are areas of significant groundwater discharge.

Interpolated water levels in the bedrock are presented in Figure 2.15. The water level patterns are more subdued but generally consistent with those in the overburden aquifers. Regional highs corresponding to the Waterloo and Woodstock Moraines are still visible, as are v-shaped contours around the main river branches.

2.6 *Figures*

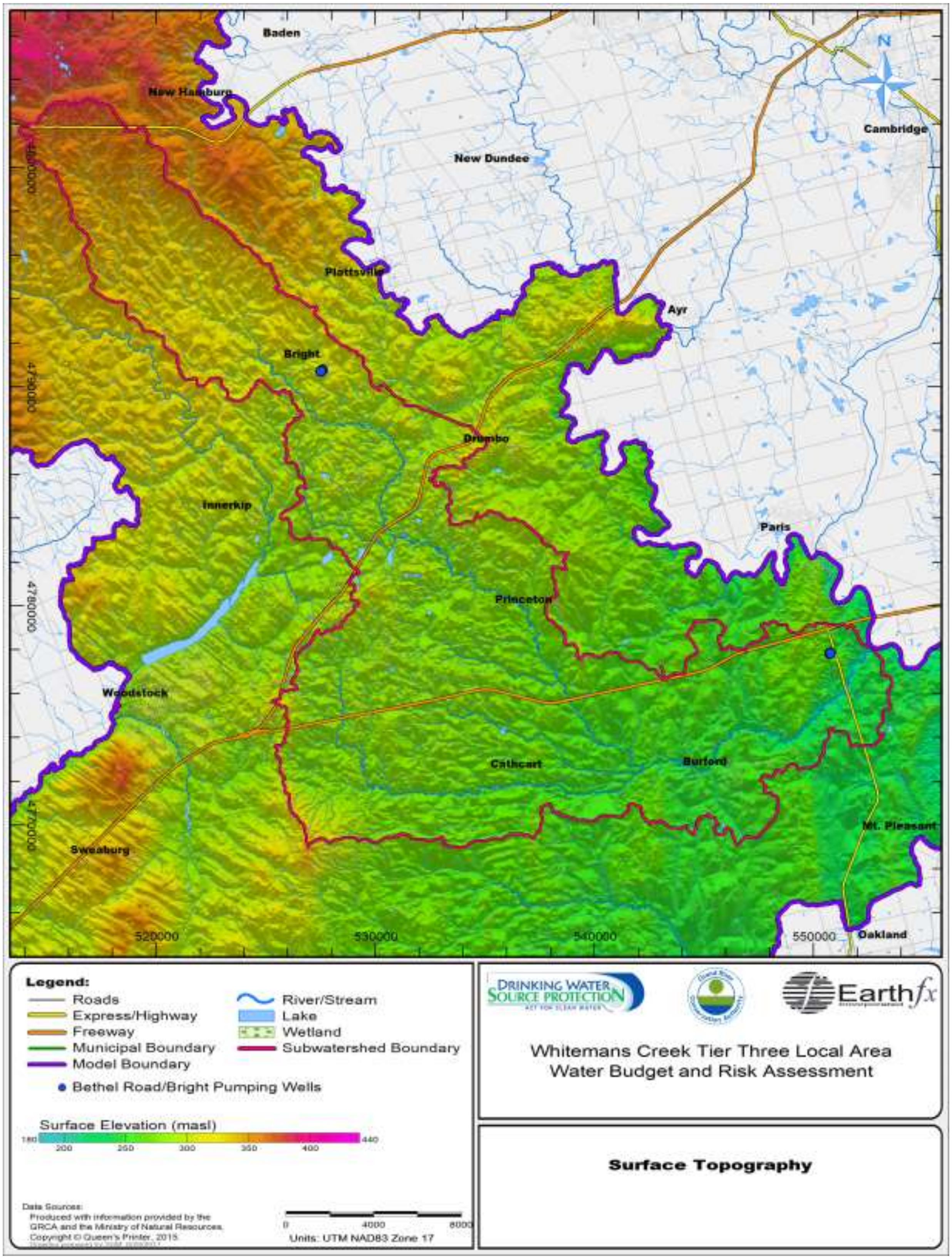

Figure 2.4: Surface topography in the Whitemans Creek subwatershed and surrounding area.

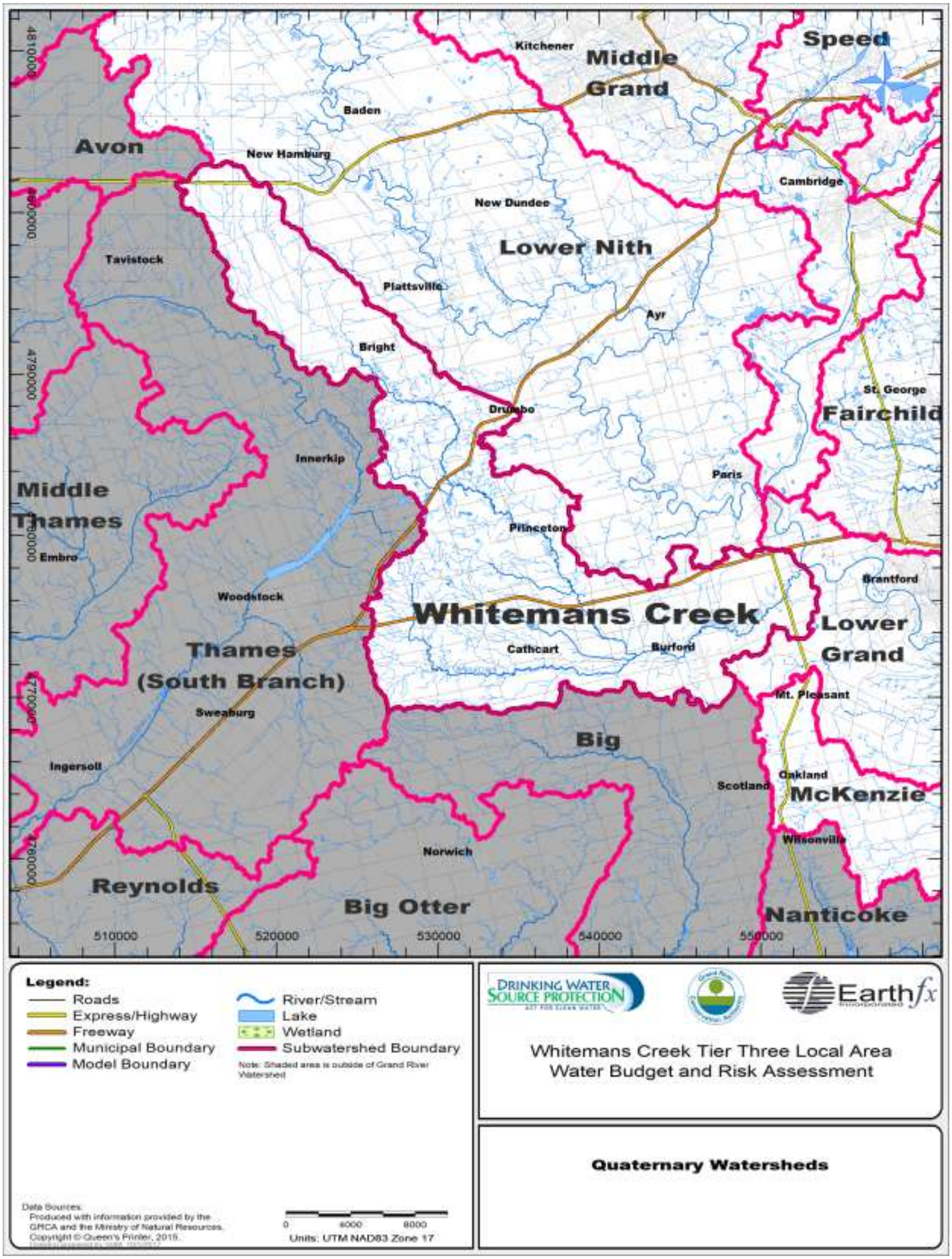

Figure 2.5: Quaternary subwatersheds of the Grand River, Thames River, and Big Creek within the study area.

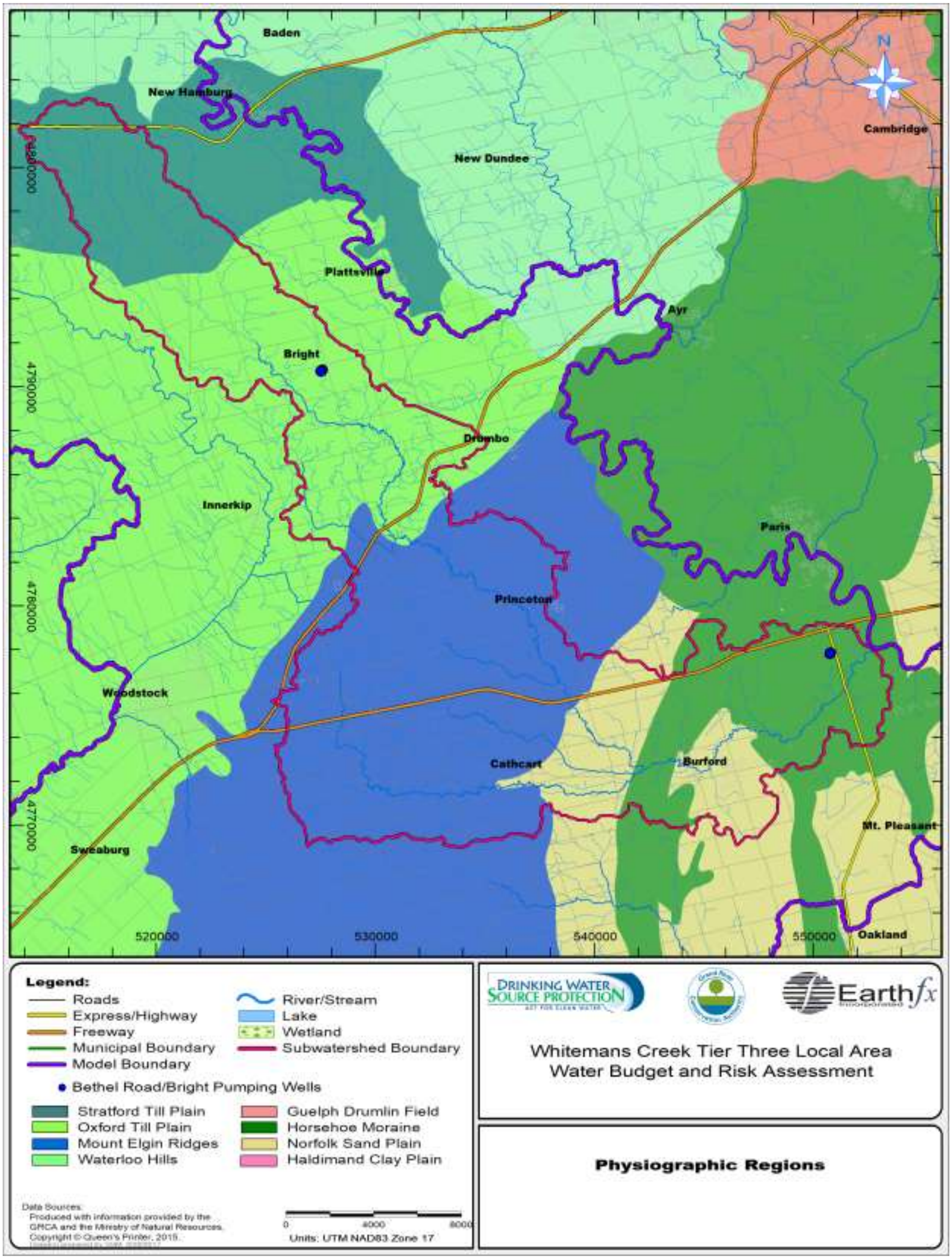

Figure 2.6: Physiographic regions in the study area.

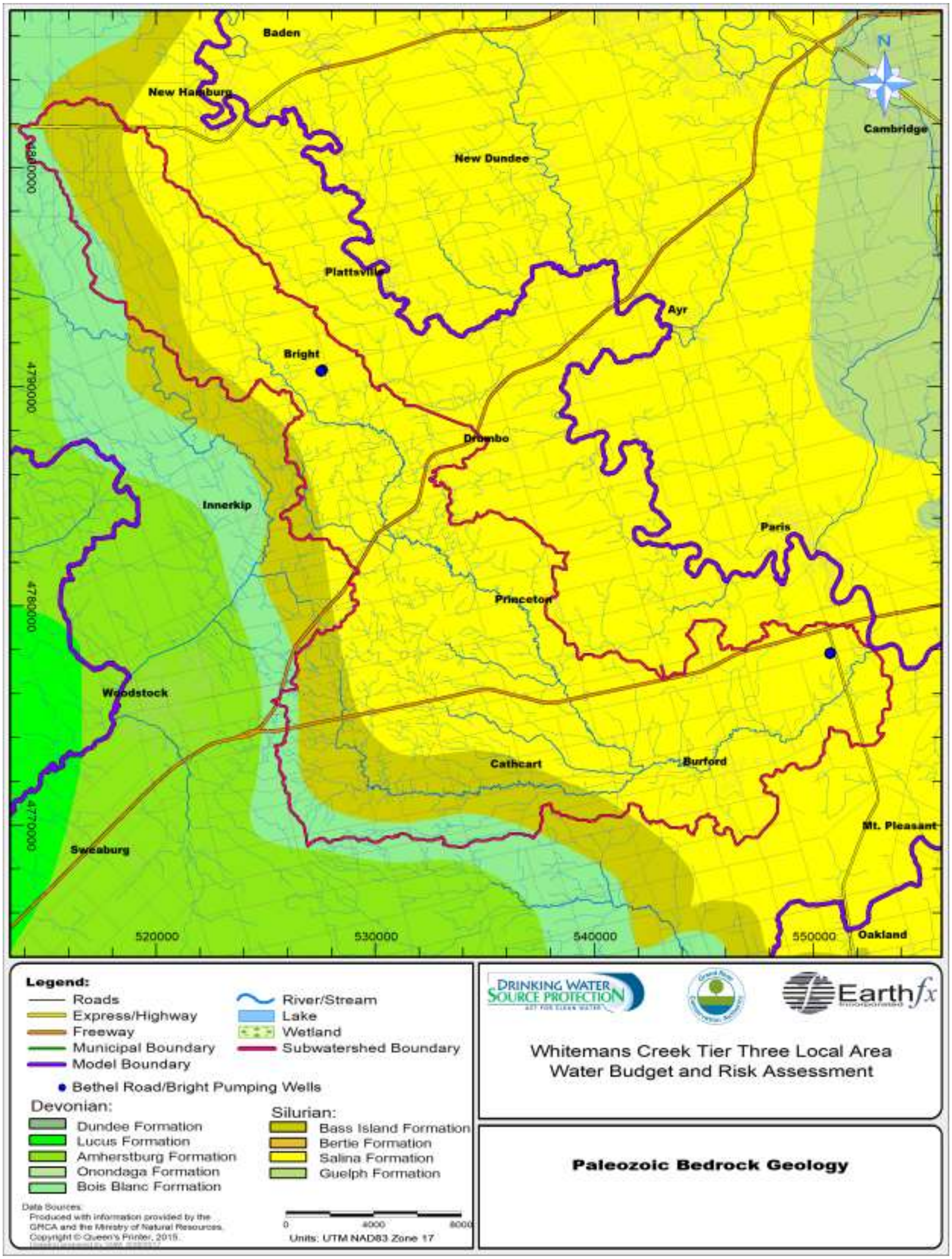

Figure 2.7: Paleozoic bedrock geology in the study area.

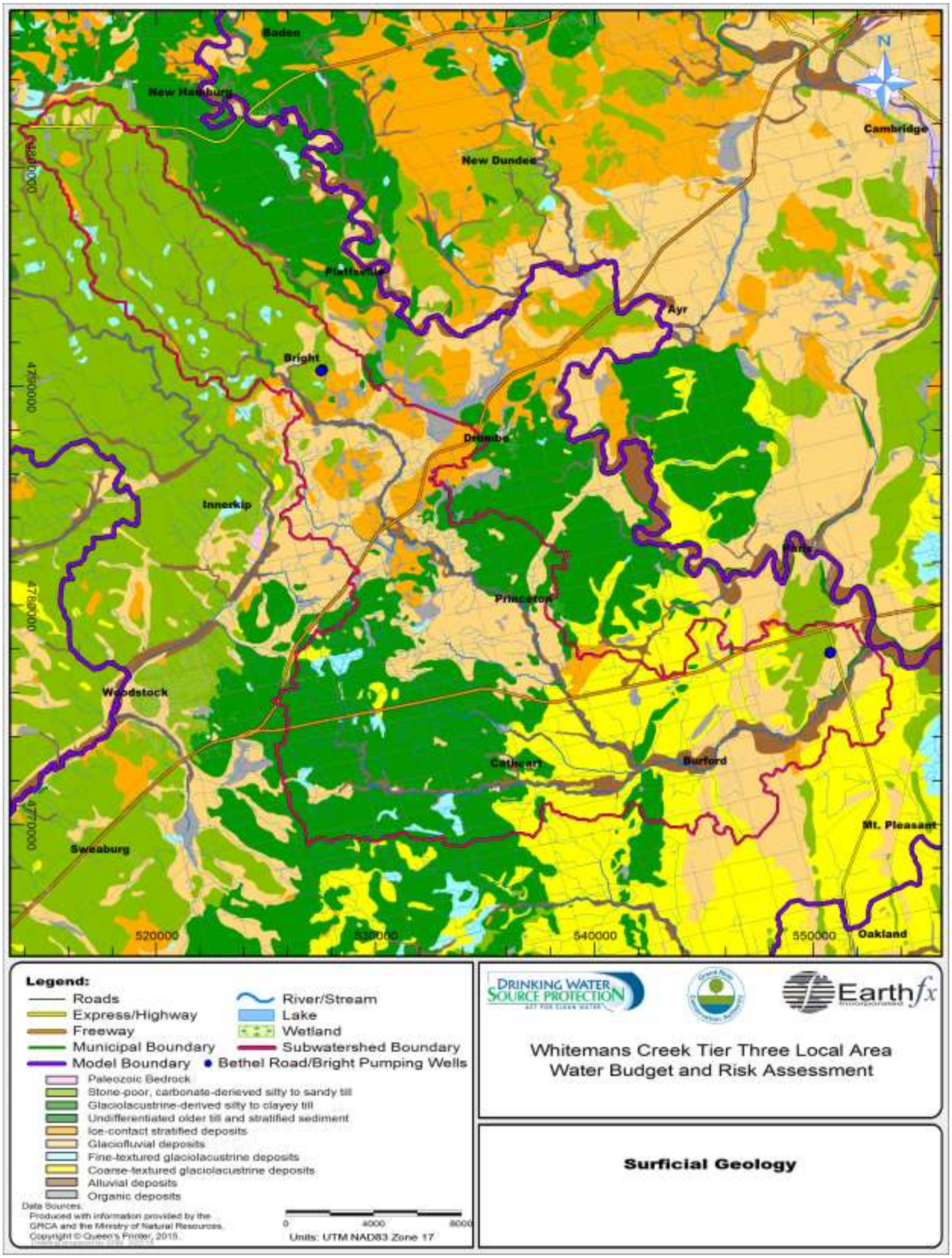

Figure 2.8: Surficial geology in the study area (from OGS, 2010).

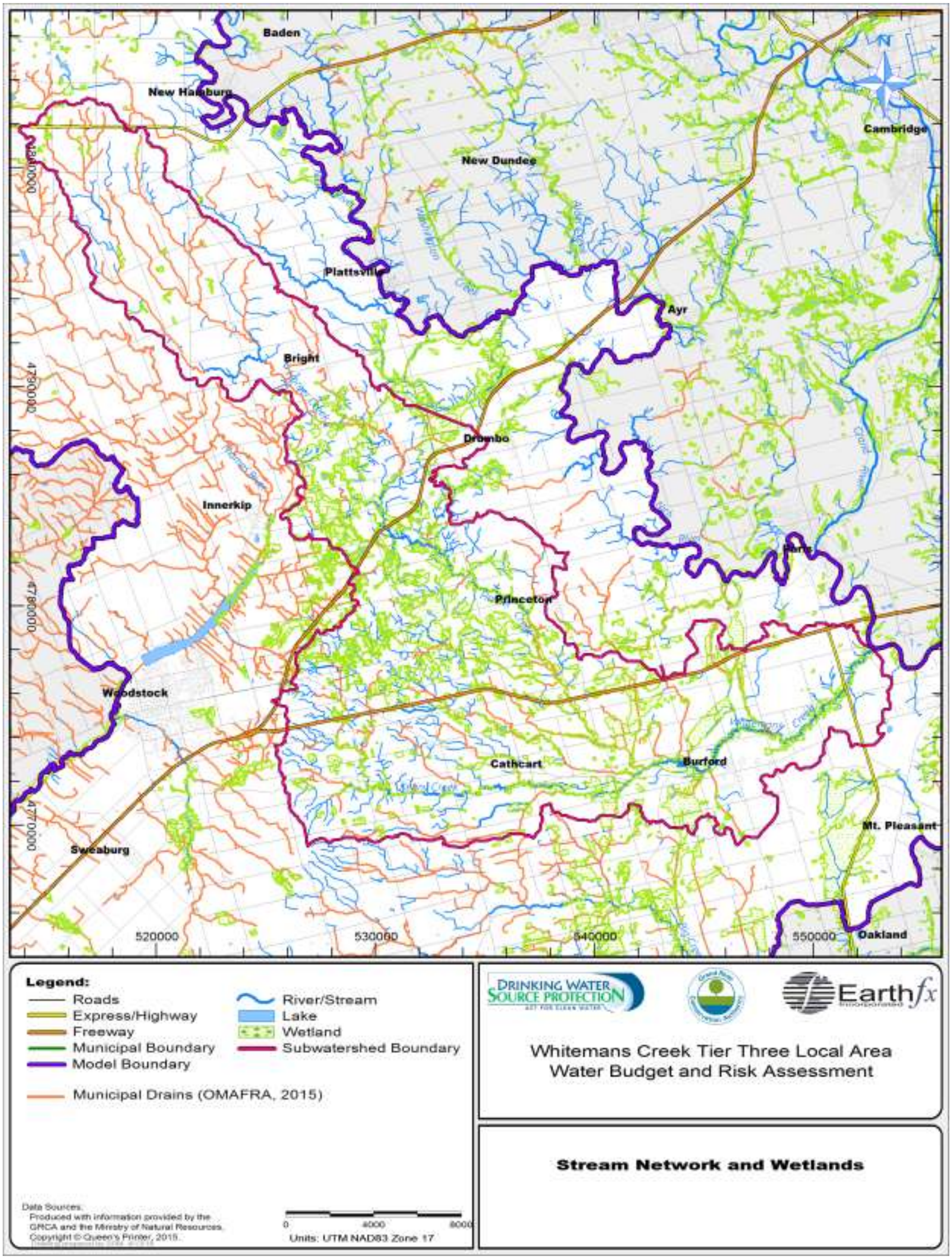

Figure 2.9: Stream network and wetlands in the study area.

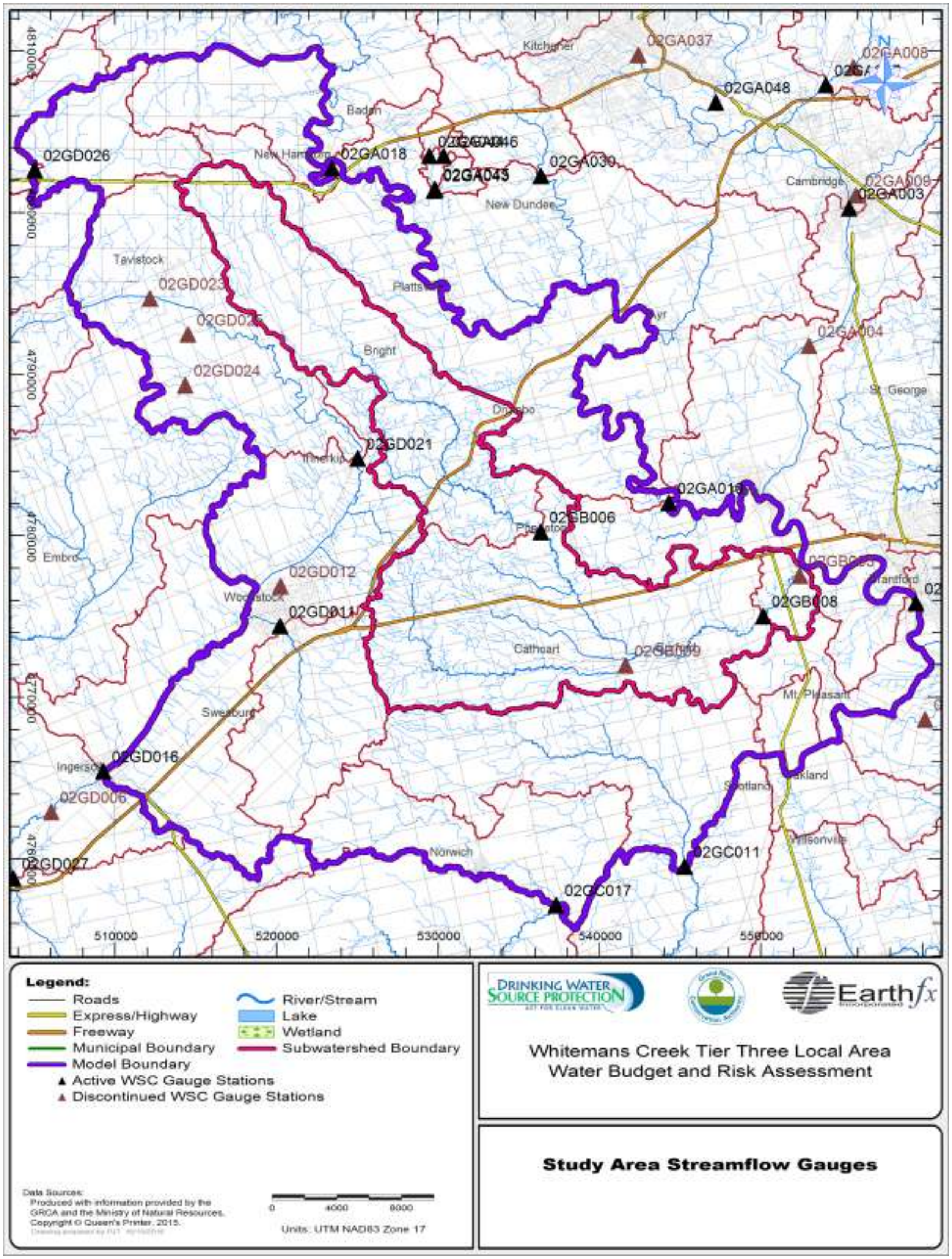

Figure 2.10: Water Survey of Canada (WSC) streamflow gauges proximal to the study area.

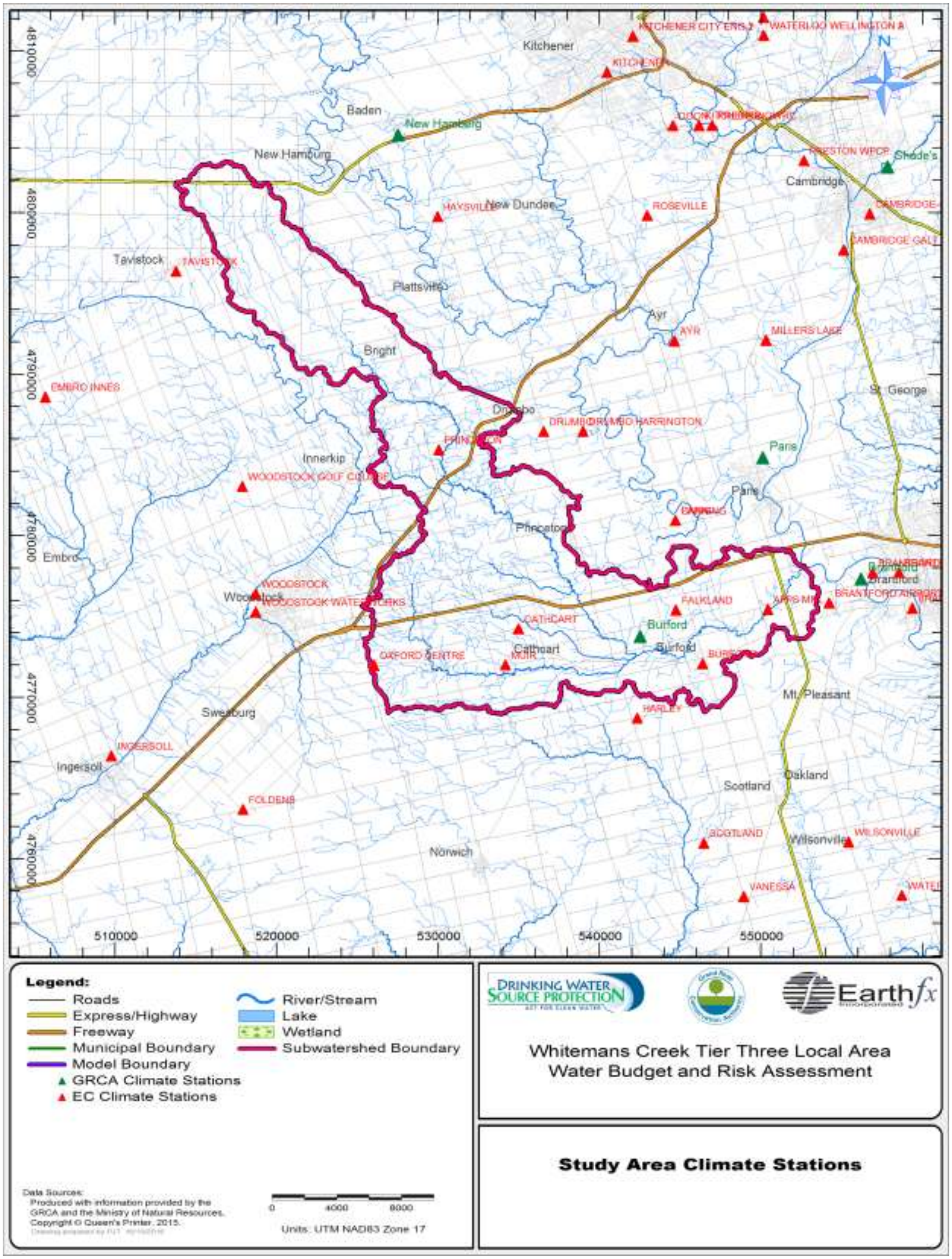

Figure 2.11: Climate stations proximal to the study area.

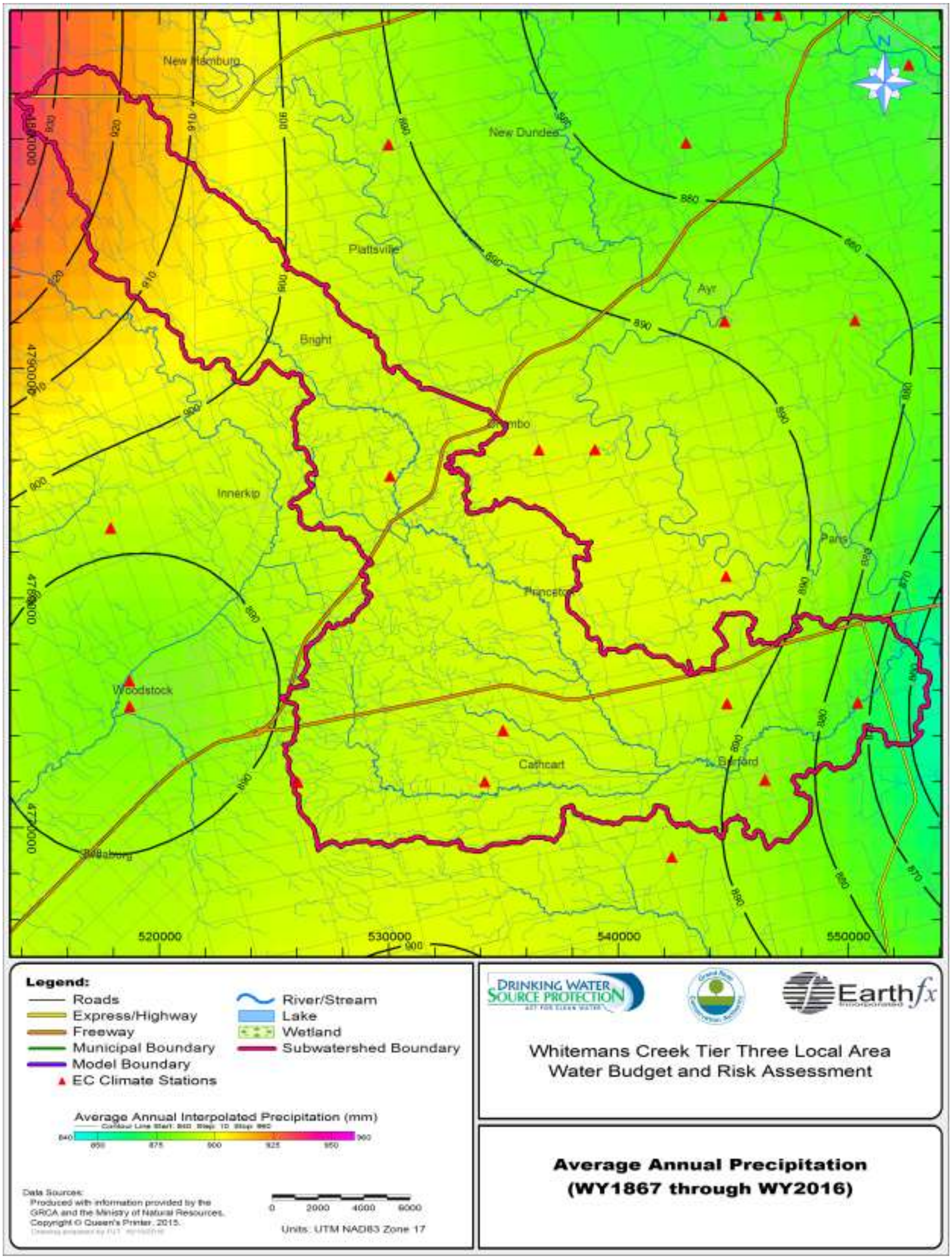

Figure 2.12: Annual average interpolated precipitation (WY1867 through WY2016).

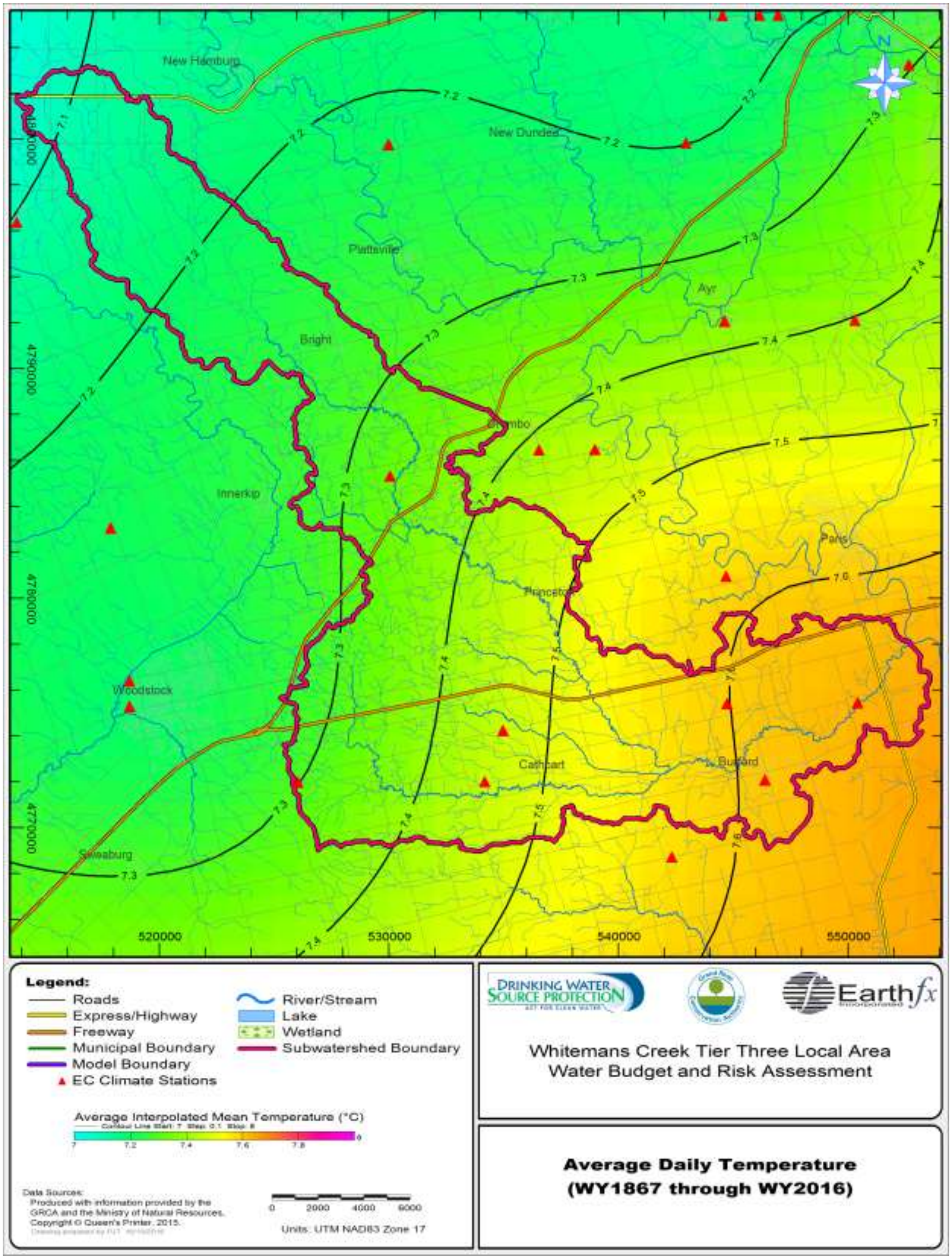

Figure 2.13: Daily average interpolated mean temperature (WY1872 through WY2016).

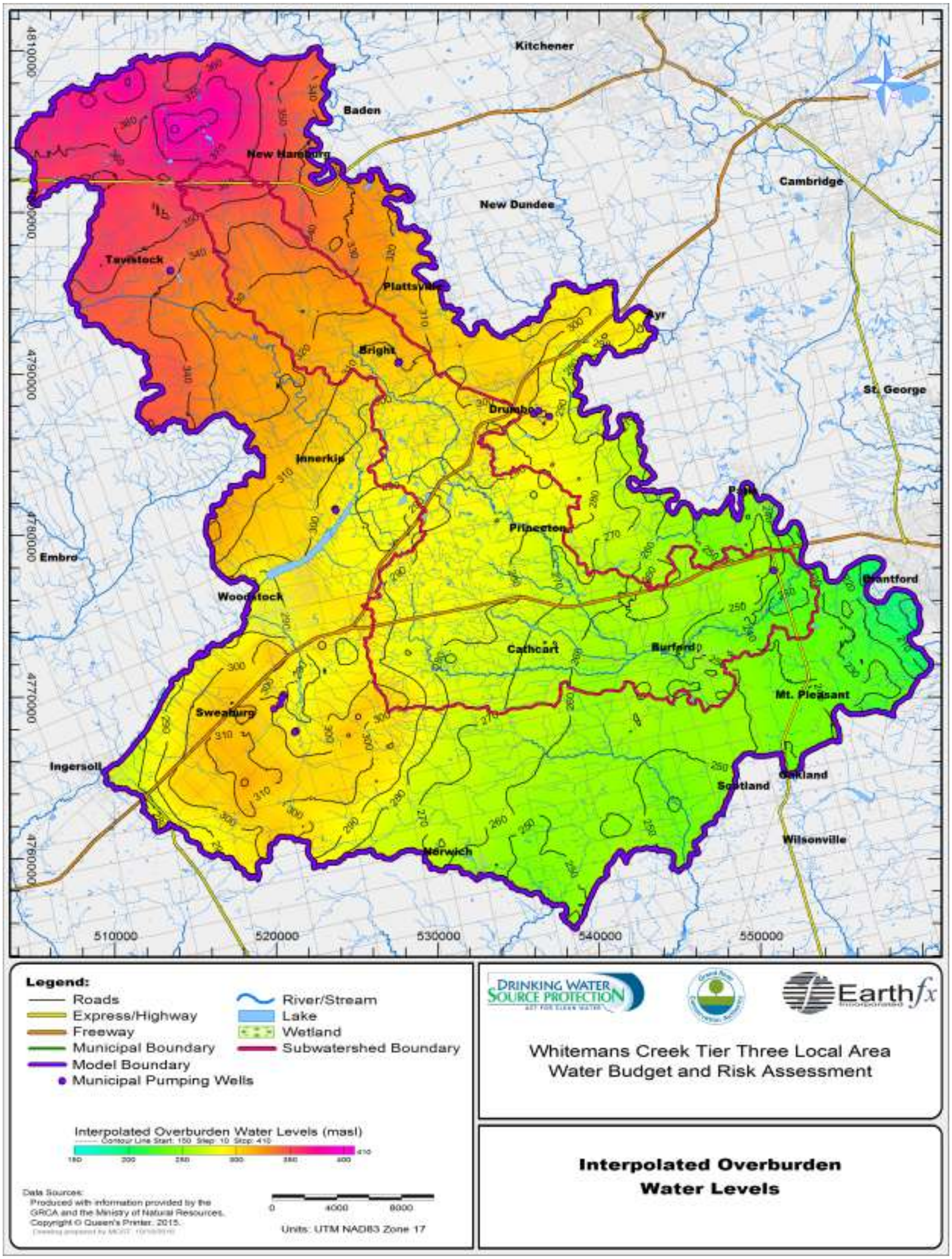

Figure 2.14: Interpolated static groundwater levels in overburden wells.

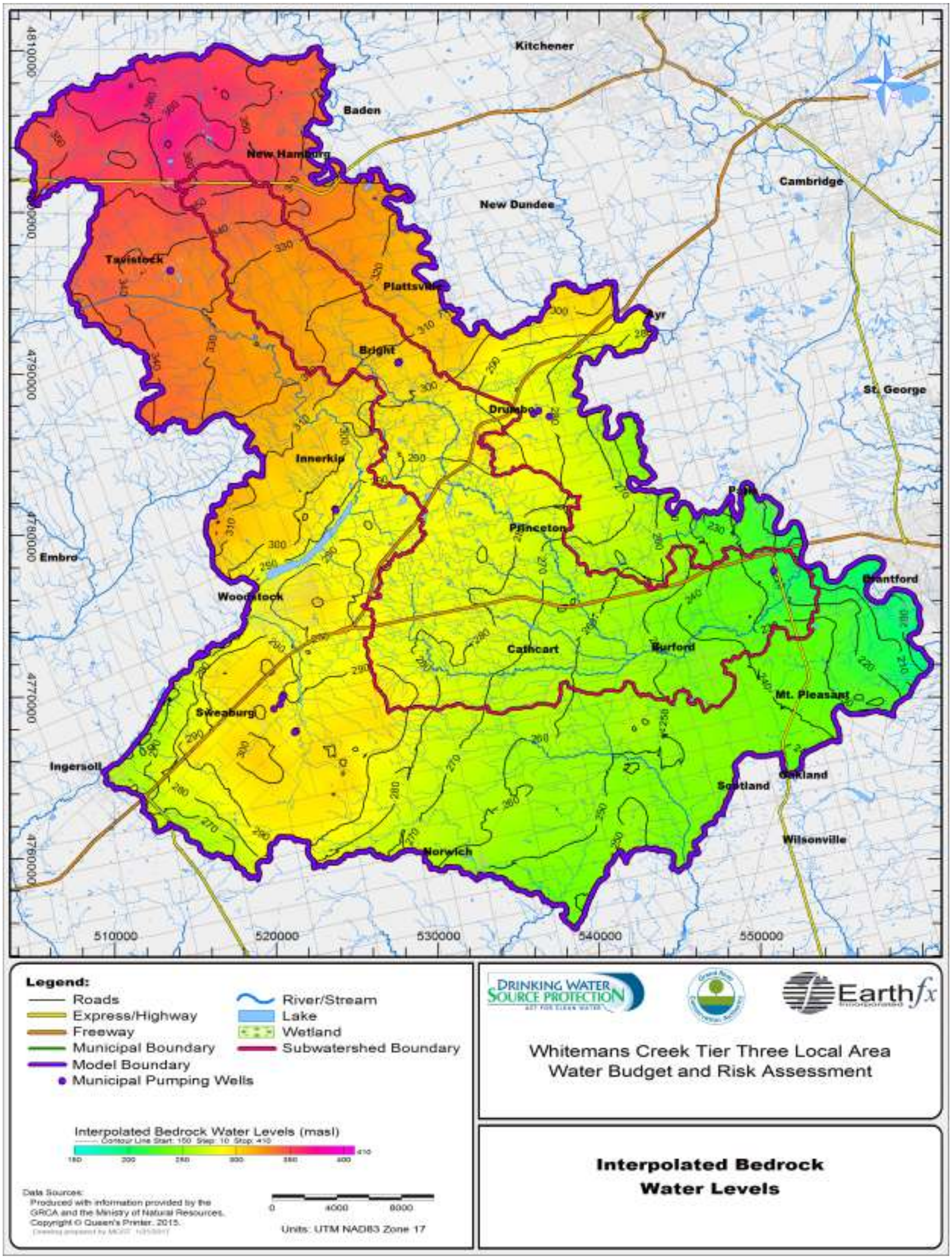

Figure 2.15: Interpolated static groundwater levels in bedrock wells.

3 Geologic and Numerical Modelling

The development of refined surface water and groundwater flow models is another critical part of the Tier 3 study. A companion report (Earthfx, 2017) describes the conceptual model developed for this study which followed an extensive data compilation and analysis task. The report documents the construction and calibration of an integrated groundwater/surface water model using the USGS GSFLOW code (Markstrom, *et al*., 2008) based on the conceptual model. This section provides a brief summary of the conceptual and numerical models employed to complete the Tier 3 water budget and risk assessment scenarios. Further detail can be found in Earthfx (2017).

3.1 *Geologic Model Development*

The hydrostratigraphic model developed for the Whitemans Creek Tier 3 study is based extensively upon work completed by the OGS in the Brantford Woodstock area (Bajc and Dodge, 2011). The OGS study involved the construction of a three-dimensional hydrostratigraphic model of the regional Quaternary deposits, using field investigations and computer modelling. The OGS model provided a sound conceptual foundation for the hydrostratigraphic and numerical groundwater flow model developed in this study. Localized refinement of the OGS model and extension of the OGS surfaces to the study area boundaries were undertaken, as described in Section 5.2 of Earthfx (2017).

Local revisions to the OGS model were made in the vicinity of three municipal wellfields (shown in Figure 3.4): the Bethel Road wellfield, the Community of Bright wellfield, and the Brantford Airport wellfield, to provide a more detailed representation of local hydrostratigraphic conditions. These local revisions were needed to address the wellfield-scale focus of the Tier 3 risk assessment and achieve a level of detail not found in the regional-scale OGS model. New geologic and hydrogeologic data obtained after the 2011 OGS study provided additional information to update the understanding of local subsurface conditions. In particular, three of the municipal supply wells (PW1/12, PW2/12 and PW4/12) in the Bethel wellfield were completed after 2011. Although the Brantford Airport wellfield was not a focus of this study, the GRCA requested that attention be placed on local conditions at this wellfield in anticipation of upcoming source protection investigations in the area.

3.2 *Hydrostratigraphic Model Development*

The key OGS geologic surfaces were extended and refined to create a set of conceptual surfaces for the Whitemans Tier 3 study. Some units were combined and the 20 OGS surfaces were reduced to 11 major overburden aquifer and aquitard units. In addition, seven Paleozoic bedrock units were also interpolated from existing well records and added to the conceptual model, as well as an upper weathered bedrock contact unit. This set of digital layers is referred to as the "Tier 3 Hydrostratigraphic Model" and the layers are listed in Table 3.1. A series of layer thickness (isopach) maps are presented in Section 5.2 of Earthfx (2017). Cross sections showing the Tier 3 hydrostratigraphic model layers were provided in Earthfx (2017) to illustrate the complex layering and often discontinuous nature of the hydrostratigraphic units across the study area. A discussion of key aquifer units was also provided.

3.2.1.1 Surficial Deposits and Moraines

Layers 1 through 4 in Table 3.1 represent surficial deposits and the Wentworth Till moraine. The Wentworth Aquitard includes the Paris, Galt and Moffat moraines of the lower Whitemans Creek subwatershed, but the units are not extensive or very thick. The Whittlesey Sand Aquifer and Whittlesey Aquitard are limited to the eastern-most portion of the study area. The most significant shallow aquifer unit (referred to as the "Sand Plain and Outwash Aquifer" includes the Norfolk Sand Plain and the Grand River Outwash sediments.

Table 3.1: Whitemans Tier 3 Hydrostratigraphic Model Layers

Layer	Conceptual Unit Name	Main OGS Unit	Comments
Overburden Units			
1	Whittlesey Sand Aquifer	AFA0	
2	Whittlesey Aquitard	ATA1	
3	Wentworth Aquitard	ATA2	
4	Sand Plain and Outwash Aquifer	AFA2	
5	Port Stanley/Tavistock Aquitard	ATB1	includes absent ATA3
6	Waterloo Moraine Aquifer	AFB1	
7	Maryhill Till Aquitard	ATB3	includes negligible ATB2
8	Post Catfish Aquifer	AFB3	
9	Catfish Creek Till Aquitard	ATC1	Includes negligible AFC1 and ATC2
10	Pre-Catfish Aquifer	AFD1	
11	Canning Till Aquitard	ATE1	Includes patchy AFF1 and ATG1
Bedrock Units			
*12	Weathered Bedrock Contact Aquifer		Assumed 10 m across model
13	Dundee-Lucas-Amherstburg Aquifer		
14	Bois Blanc Aquifer		
15	Bass Island Aquifer		
16	Upper Salina Poor Aquifer/Aquitard		Salina Units A-F
17	Lower Salina Shale Aquitard		Salina G Unit
18	Guelph-Eramosa Aquifer		

3.2.1.2 Post-Catfish Aquifer and Aquitard Systems

For the remainder of the discussion, the hydrostratigraphic units in the overburden will be grouped as "Pre" and "Post' Catfish Creek Till age. The Post-Catfish units include the Port Stanley/Tavistock Till Aquitard Complex and Waterloo Moraine Aquifer. The Waterloo Moraine Aquifer is frequently unconfined, except in the middle portions of the Whitemans Creek subwatershed where it is confined by the Port Stanley/Tavistock Till Aquitard. The Post-Catfish Aquifer (Layer 8) is limited to lenses that can be considered locally significant but patchy in terms of regional continuity. This aquifer unit sits on the Catfish Creek Till Aquitard and has been referred to as "re-worked" Catfish Creek Till. The Catfish Creek Till Aquitard (Layer 9) is continuous across much of the Whitemans Creek subwatershed.

3.2.1.3 Pre-Catfish Aquitard and Aquifer Systems

The Pre-Catfish Aquifer (Layer 10) is only locally significant. Recharge to this unit is likely limited by the relatively continuous overlying Catfish Creek Till Aquitard. The deeper Canning Till Aquitard is frequently found in bedrock depressions and is discontinuous. Two localized pre-Canning Till aquifer zones, sitting on bedrock, were too limited, deep, and isolated to be included as full layers and have therefore been combined in with the weathered bedrock contact aquifer.

3.2.1.4 Onondaga Escarpment Aquifer Units

The Onondaga Escarpment is a significant feature in the western part of the study area. Where the escarpment is present, overburden is generally thinner. The majority of the private and public wells above the escarpment are completed in the limestones and dolomites. Recharge in these areas may also supply water to deeper units in the Whitemans Creek subwatershed. Outwash channels south of Bright may also interconnect with the units above the escarpment and potentially support cross-watershed flow into the headwaters of the Thames River.

The three shallow bedrock units, the Dundee, Lucas and Amherstburg formations, were combined in the Whitemans Conceptual Hydrostratigraphic Model as Layer 12 while the Bois Blanc and Bass Island Aquifer units were separated. Mapping of the top of the Bass Island Formation indicated that a significant portion of the southwestern region of the Whitemans subwatershed is underlain by Bass Island Formation limestones as much as 20 m in thickness (see Earthfx (2017)).

3.2.1.5 Salina Formation

The Salina Group consists of a number of sub-elements. Eight units of formational rank have been recognized in the Salina Group (Armstrong and Carter, 2010), with the lower two members exhibiting an increase in shale content. While data were insufficient to map all eight units, the lower two members were identified and mapped as the Lower Salina Aquitard. Previous studies have referred to the Salina as a "poor aquifer". The Guelph and Eramosa formations sub-crop beyond the northeast extent of the study area. These units were mapped to help define the base of the model.

3.3 *GSFLOW Model Development and Calibration*

The USGS GSFLOW code (Markstrom *et al*., 2008) was used in developing the integrated surface water/groundwater model. GSFLOW was developed from two widely-recognized USGS submodels: (1) the Precipitation Runoff Modelling System (PRMS, Leavesly *et al*., 1986) and (2) the modular groundwater flow model MODFLOW-NWT (Niswonger *et al*., 2011) with the UZF unsaturated flow module (Niswonger *et al*., 2006) and the SFR2 and LAK surface water modules (Niswonger and Prudic, 2005 and Merritt and Konikow, 2000). The different processes and submodels in GSFLOW are listed in Table 3.2 and are shown schematically in Figure 3.1. The submodels include numerical representations of hydrologic processes that occur within each submodel domain. A complete description of the GSFLOW code can be found in Markstrom *et al*. (2008), a simplified overview is presented below and, in more detail, in Earthfx (2017).

Table 3.2: Processes and GSFLOW submodels.

Region	Process Component	GSFLOW Submodel
1	Hydrology – (Soil Water Processes)	Hydrologic Submodel (PRMS)
2	Unsaturated Flow	UZF module for MODFLOW
2	Streamflow, lakes and wetlands	SFR2 and LAK modules for MODFLOW
3	Groundwater flow	Groundwater Submodel (MODFLOW-NWT)

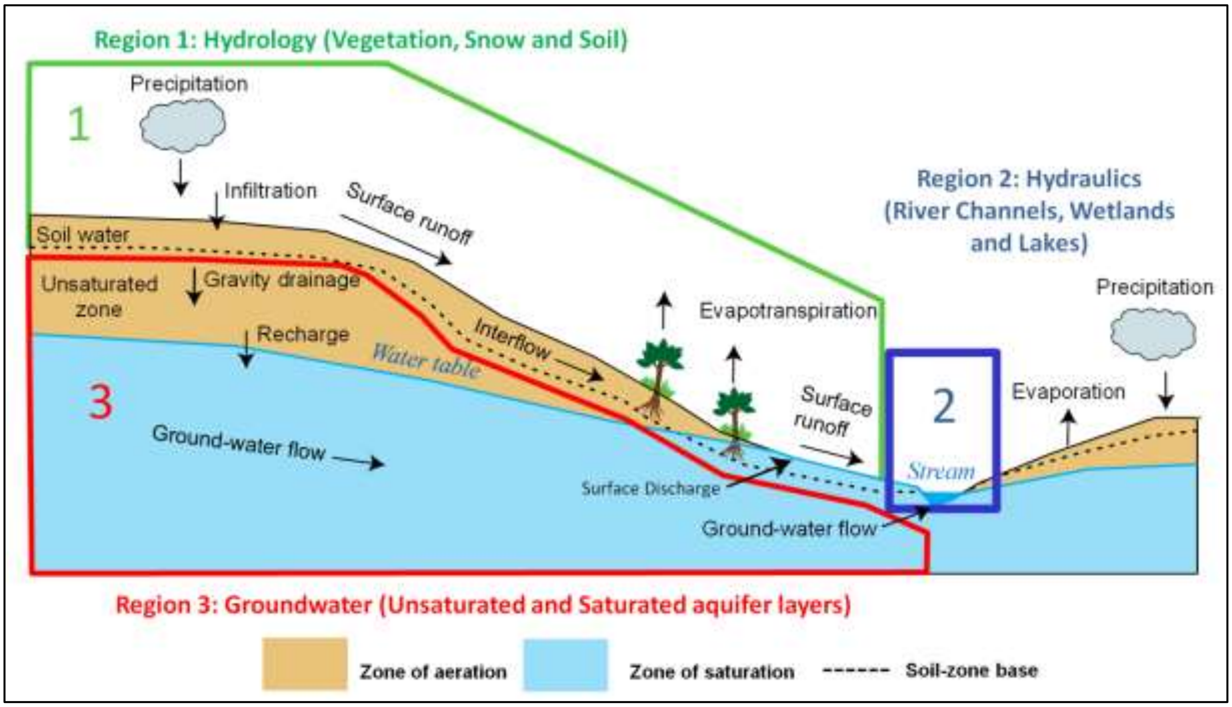

Figure 3.1: Schematic diagram of the GSFLOW process regions (modified from Markstrom *et al*., 2008).

3.3.1 Overview

The hydrologic (PRMS) submodel is an open-source code for calculating all components of the hydrologic cycle at a watershed, subwatershed, or cell-based scale. PRMS is a modular, deterministic, physically-based, fully-distributed model developed to evaluate the impacts of various combinations of precipitation, climate, topography, soil type, and land use on streamflow and groundwater recharge. The PRMS code is extremely well documented and has been used recently in Source Water studies in nearby watersheds (e.g., Earthfx (2008), Earthfx (2010), Earthfx (2013), and Earthfx (2014)). Feedback between each submodel (surface water or groundwater) is particularly important to this study because of the strong interaction between the surface water and groundwater processes across the Whitemans Creek subwatershed.

PRMS itself is composed of many process-based submodels, including:

- A climate submodel that distributes precipitation and determines potential evapotranspiration (PET) rates based on temperature, topography, and solar radiation;
- An energy-balance snowmelt submodel that simulates snowpack dynamics and accounts for snowmelt quantities;
- A canopy interception submodel; and
- A soil-water accounting algorithm that computes infiltration, overland runoff, interflow, actual evapotranspiration (AET), change in storage, and groundwater recharge.

Groundwater flow in GSFLOW is simulated by MODFLOW-NWT (Niswonger et al., 2011), a version of MODFLOW-2005 especially well-suited for simulating flow in shallow thin aquifers and in areas with sharp topographic relief. Additional modules in MODFLOW-NWT simulate unsaturated flow between the base of the soil zone and the water table, lake and wetland water balances, streamflow, and groundwater/surface water interaction. Inputs to these routines were adjusted so that the model could also simulate agricultural irrigation water demand within the study area.

3.3.2 Model Calibration

The PRMS and MODFLOW submodels were first pre-calibrated independently to get initial estimates of model parameter values. Much of the calibration effort for the PRMS hydrologic submodel focused on matching observed flows at the three historical WSC gauges within the Whitemans Creek subwatershed, however, stations within the Upper Thames, Avon, Big, and Big Otter subwatersheds were also considered. This well-distributed gauge network, with a period of record spanning over 50-years, allowed for multiple calibration and validation periods to be employed during parameterization. A Monte-Carlo approach was undertaken to jointly measure model sensitivity and refine model calibration.

PRMS was calibrated in stand-alone mode to gain insight into the function of the model and the appropriateness of the parameterization. Integration with the groundwater submodel and calibration of the fully-integrated GSFLOW model proceeded after an acceptable submodel calibration was achieved. This corresponded to when the daily Nash-Sutcliffe efficiency factor (NSE) was greater than 0.50 for the majority of the calibration period, and the volumetric percent difference was less than 10%. These calibration statistics are discussed in Earthfx (2017) and are measures of the differences between the observed flows (Q_O) and simulated flows (Q_S) where NSE is given by Nash and Sutcliffe (1970) as:

$$\text{Nash Sutcliffe Efficiency } = 1 - \frac{\sum_{n=1}^{nobs}(Q_o - Q_s)^2}{\sum_{n=1}^{nobs}(Q_o - \overline{Q}_o)^2} \qquad \text{(Equation 1)}$$

NSE can range from 1 to minus infinity, with 1 being a perfect fit (Nash and Sutcliffe, 1970). Percent volumetric difference or bias is given by:

$$\text{Volumetric Difference (Percent Bias)} = \frac{\sum(Q_S - Q_O)}{\sum Q_O} \times 100 \qquad \text{(Equation 2)}$$

The PRMS submodel was not fully calibrated as a stand-alone model because the submodel itself has no major purpose in this study. The goal of the pre-calibration was to produce reasonable estimates of parameter values for use in the GSFLOW model, particularly for parameters not overly affected by groundwater/surface water interaction. These parameters were further adjusted during calibration of the integrated GSFLOW model which represented the complete hydrologic cycle through both the groundwater and hydrologic submodel domains.

The groundwater submodel was initially run under steady-state conditions and parameter values were adjusted to match the interpolated WWIS static groundwater level (head) data. The goal of this pre-calibration was also to produce reasonable estimates of parameter values for use in the GSFLOW model, particularly for parameters not sensitive to transient recharge and streamflow. Figure 3.5 shows the distribution of the steady-state calibration dataset for the MODFLOW submodel, along with the calibration residuals (i.e. difference between observed heads (h_O) and simulated heads (h_S)). The blue symbols indicate simulated heads were low relative to the observed values. Areas where the match was not as good also tended to be areas where observation data were sparse and the interpolated values were less certain. The distribution of model residuals also showed a tendency for model under-predictions near the southern portion of the eastern model boundary. A second area of high model residuals is noted in the vicinity of Tavistock, near the northwestern boundary of the model, where there is a tendency for the model to over-predict water levels. These residuals are associated with bedrock observation points, and suggest that flow across the model boundary near Tavistock may be underestimated by the model. The higher residuals are almost entirely limited to the bedrock aquifers, and generally do not extend into the Whitemans Creek subwatershed.

Calibration statistics for the 6,030 observed groundwater levels are shown in Table 3.3. The three statistics used are given by Anderson and Woessner (1992) as:

$$\text{Mean Error} = \frac{1}{n}\sum_{1}^{n}(h_O - h_S)_i \qquad \text{Equation 3}$$

$$\text{Mean Absolute Error} = \frac{1}{n}\sum_{1}^{n}\left|(h_O - h_S)_i\right| \qquad \text{Equation 4}$$

$$\text{Root Mean Squared Error} = \sqrt{\frac{1}{n}\sum_{1}^{n}(h_O - h_S)_i^2} \qquad \text{Equation 5}$$

Calibration statistics for subsets of the observed groundwater level dataset are also provided in Table 3.3 for each of the major regional aquifers. The negative value for Mean Error (ME) indicates that model predicted values are generally higher than the observed values by 0.41 m. The Mean Absolute Error and the Root Mean Squared Error (RMSE) provide a good estimate of the average magnitude of the difference and variance between observed and simulated values. The groundwater model currently has a MAE of 4.01 m and a RMSE of 5.41 m. Discussions regarding sources and magnitudes of intrinsic errors in the observation data and calibration statistics for the high quality wells are provided in Earthfx (2017).

Table 3.3: Calibration statistics for the groundwater submodel.

Unit	Number of Wells (n)	ME (m)	MAE (m)	RMSE (m)	Range in Observations (m)	RMSE as Percent of Range (%)
Whittlesey Sands	7	-1.51	1.51	1.59	1.5	103.1%
Sand Plain-Outwash Aquifer	844	1.38	3.18	4.98	47.7	10.5%
Waterloo Moraine Aquifer	1,087	0.61	3.35	4.41	33.4	13.2%
Post Catfish Aquifer	255	-1.08	3.42	4.78	41.5	11.5%
Pre-catfish Creek Aquifer	97	1.58	4.59	5.62	21.6	26.1%
Weathered Bedrock	2,035	-1.41	4.64	5.87	45.7	12.8%
Onondaga Escarpment Aquifer	339	-2.22	4.22	6.33	54.0	11.7%
Salina Poor Aquifer	96	-2.21	4.78	5.91	26.1	22.6%
Overall	**6,030**	**-0.41**	**4.01**	**5.41**	**186.6**	**2.9%**

Note: Calibration to 1,270 monitors screened in aquitard layers (based on the geologic layer surfaces) were excluded from the analysis of individual aquifer units; but were included in the ***Overall*** calibration statistics.

Once the PRMS and MODFLOW submodels were reasonably well calibrated, the additional data sets and required changes to the model input were made to set up GSFLOW model runs. The GSFLOW model was calibrated to available streamflow monitoring and groundwater level monitoring for the 10-year period from October 2006 to September 2015 (WY2007 to WY2015). The calibration period covers the 2007 and 2012 drought years, as well as several average and wet years to test the model response across a range of climate inputs. While temporal coverage of the regional streamflow and groundwater calibration datasets is good throughout this period, the latter third of the simulation contains almost the entirety of the transient calibration data available at the Bethel wellfield. Data collected from piezometers and private wells as part of the Tier 3 field program are mostly limited to WY2015.

Model calibration was performed using an iterative process through which results of successive model runs helped improve the initial estimates of model parameters. Checks on the calibration were done by comparison of hydrographs of simulated and observed flows at WSC gauges (Figure 3.2) and groundwater levels (Figure 3.3) aided by statistical measures such as NSE and RMSE.

Calibration statistics for the surface water gauges are provided in Table 3.4 (shaded rows indicate calibration stations within the Whitemans Creek subwatershed, white rows indicate validation gauges outside of the study catchment). The model achieved NSE values between 0.52 and 0.66 for the daily flows during the calibration period. Log NSEs (i.e., NSE with log transformed flows to emphasize low-flows) compare favourably. Values between 0.55 and 0.64, suggested a good match to low flow conditions in the study subwatershed. Daily results were aggregated over each month, and monthly NSEs from 0.67 to 0.77 were calculated, but monthly Log NSEs generally showing slightly poorer results compared to the non-transformed monthly flows. The model provides a good match to net streamflow volume (model bias), with a tendency to underpredict.

Table 3.4: Calibration statistics for the integrated GSFLOW model (WY2009-WY2011).

Gauged Basin	Daily		Monthly		Volumetric Difference
	Nash-Sutcliffe	*Log Nash-Sutcliffe*	*Nash-Sutcliffe*	*Log Nash-Sutcliffe*	
Horner Creek near Princeton	0.58	0.64	0.77	0.62	-8.8%
Whitemans Creek near Mount Vernon	0.66	0.55	0.74	0.50	-5.4%
Big Creek Near Kelvin	0.61	0.61	0.73	0.59	-8.4%
Big Otter Creek above Otterville	0.44	0.58	0.71	0.59	-5.7%
Cedar Creek at Woodstock	0.55	0.44	0.71	0.38	-9.8%
Thames River at Innerkip	0.61	0.34	0.75	0.35	-11.9%
Avon River above Stratford	0.52	0.17	0.79	0.49	-5.9%

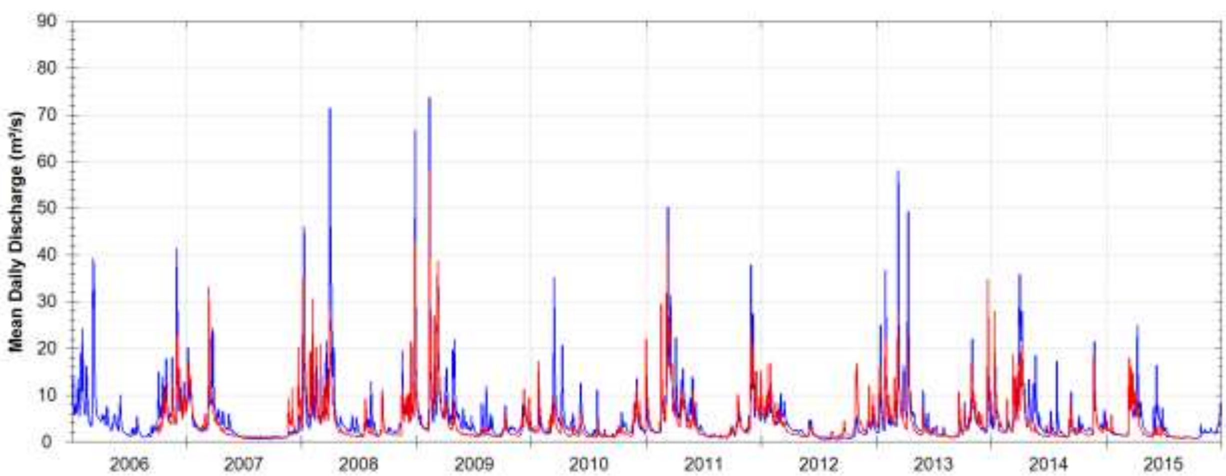

Figure 3.2: Calibration plots for Whitemans Creek near Mount Vernon (02GB008); observed (blue) versus simulated (red) daily streamflow.

To further test the adequacy of the GSFLOW model for predicting flows within the Whitemans Creek subwatershed, an additional series of validation runs were completed with historical data for WY1980 to WY1986. The model outperformed the calibration period, producing daily NSE's between 0.59 and 0.72 for the six year span. Log NSE's for the validation period are also superior, with daily values ranging between 0.62 and 0.68. The number of climate stations available during this period is almost three times the number available during the calibration period, which likely explains the increase in predictive power.

The groundwater component of the integrated GSFLOW model was calibrated to time series data from observation wells across the model area and included three observation datasets: PGMN monitoring well, monitoring wells and supply wells from the Bright and Bethel Road wellfields, and monitoring data from the Tier 3 Field Program. In general, hydrographs show that the calibrated model provided a good match to both the magnitude and timing of the observed seasonal patterns in the regional (PGMN, Figure 3.3) and shallow system monitors (Tier 3 piezometers). At the wellfield scale, the simulated water levels capture the natural seasonal fluctuations in the water levels, as well as local response to pumping, particularly in the Bethel wellfield. The transient calibration results show that the model generally captures the aquifer response to pumping on a daily-basis; while peaks and troughs observed at sub-daily time scales are beyond the capabilities of the model at this time.

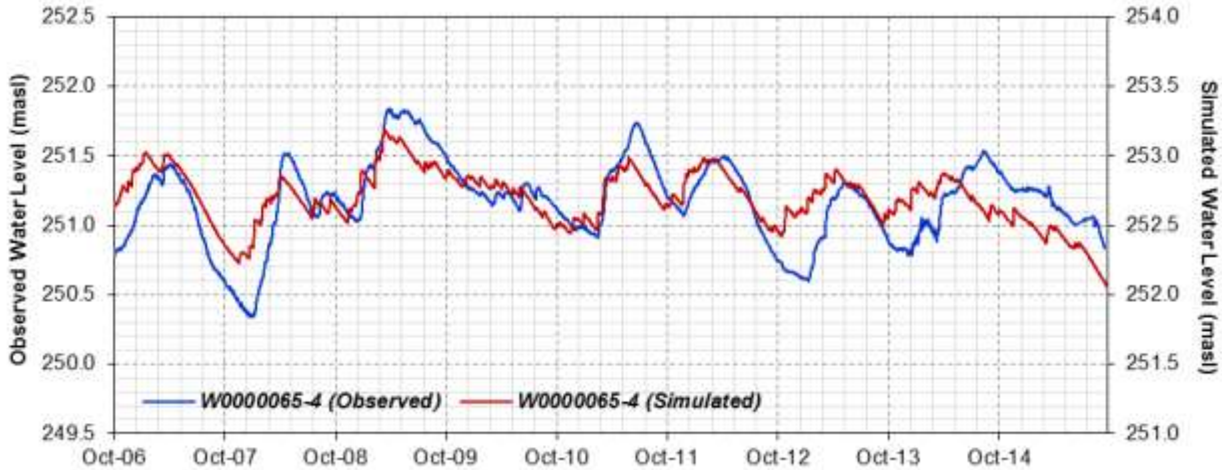

Figure 3.3: Relative water level calibration to observed head in PGMN well W0000065-1 in the Sand Plain-Outwash Aquifer.

The calibrated model was able to provide a good match to the complex patterns in the observed streamflow and groundwater level monitoring data at both the subwatershed and local wellfield scales. The quality of the model calibration was further demonstrated through the use of calibration statistics, which indicated a good fit to the available groundwater and surface water data. These results suggest that the hydrologic and hydrogeologic processes are well represented in the model and that the calibrated GSFLOW model was suitable for use in the local area risk assessment of the Bethel and Bright wellfields.

3.4 *Figures*

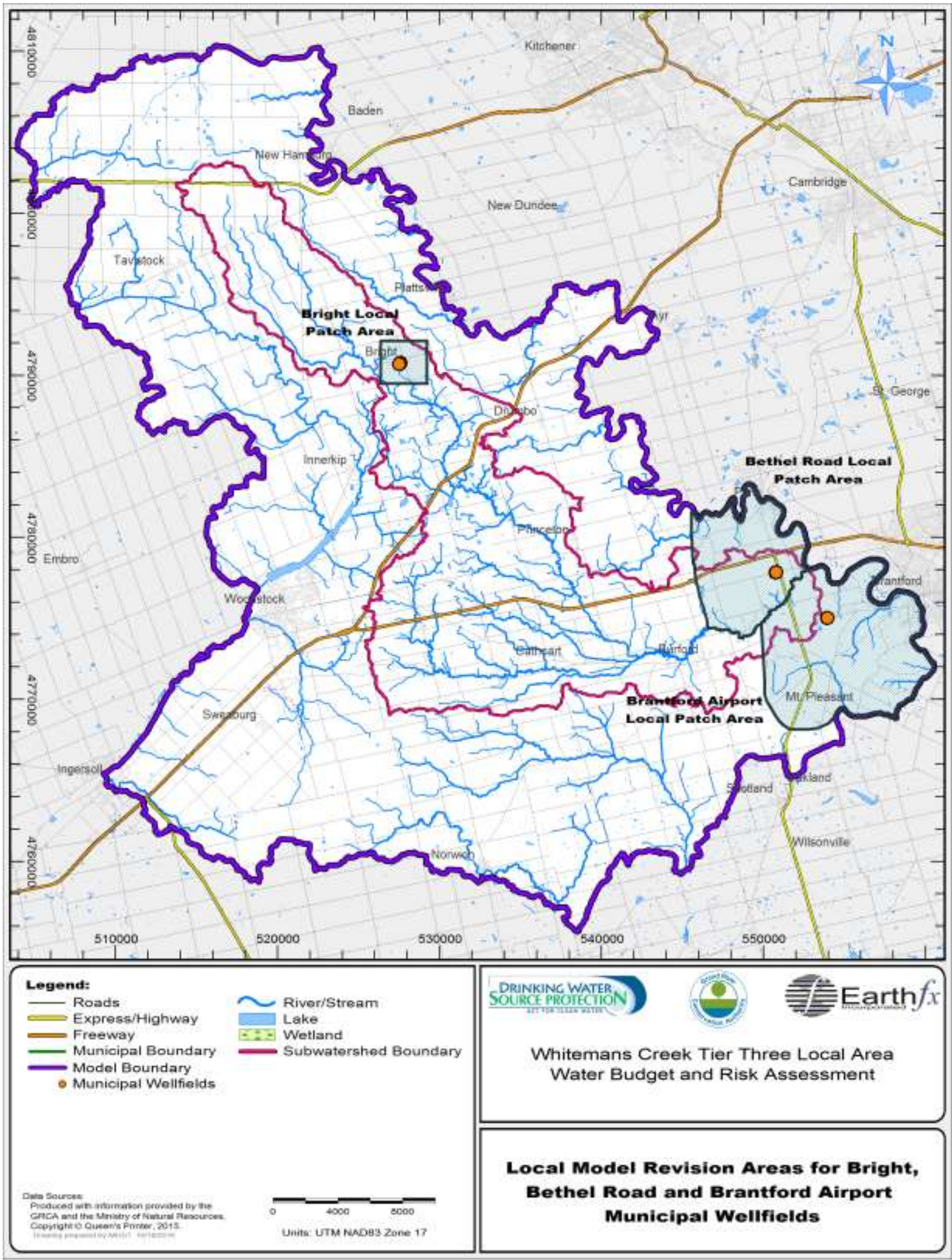

Figure 3.4: Areas of local hydrostratigraphic model revision around the Bright, Bethel and Brantford Airport wellfields.

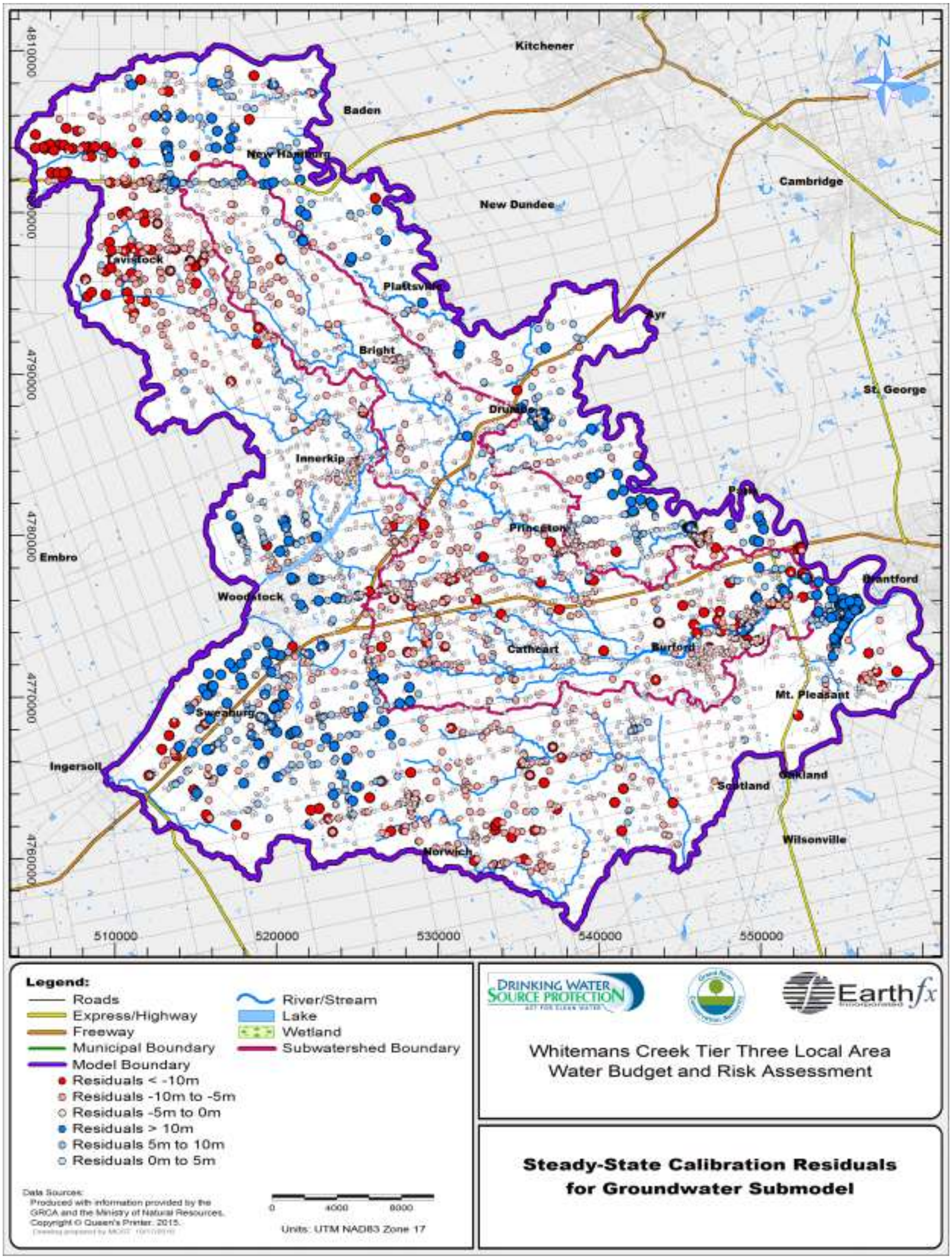

Figure 3.5: Distribution of calibration residuals for the groundwater submodel.

4 Well Characterization, Water Demand, and Land Use Change

4.1 *Existing and Planned Municipal Supply Systems*

Assessing the sustainability of the Bright and Bethel Road municipal water supply systems is a primary goal of this Tier 3 study. Figure 4.1 shows the locations of municipal wellfields in the Tier 3 study area and, in particular, the Community of Bright and Bethel Road municipal wellfields, located within the Whitemans Creek subwatershed. Data on municipal takings were provided in June 2015 by the Counties of Oxford and Brant, which operate the Bright and Bethel Road municipal systems, respectively. Background information on well locations, well depths, and capacities were obtained from earlier studies. Annual reports on municipal water quality are also published online with the County of Oxford, supplying data on monthly and annual water takings. Daily water takings are reported to the MOECC and these data were extracted for this study from a copy of the MOECC Water Taking Reporting System (WTRS) database for 2009 to 2014.

The following sections present detailed descriptions of the two water supply systems.

4.1.1 Community of Bright Drinking Water System

The Bright Drinking Water System, operated by the County of Oxford, is located in the upper part of Whitemans Creek subwatershed and provides water from two wells, Well 4A and Well 5, which are 27 m and 38 m deep, respectively. The wells serve a population of approximately 436 residents as of 2016 and are allowed a maximum permitted taking of 327 m^3/d. A summary of the 2011 to 2014 production data is shown in Table 4.1.

Table 4.1: Annual production rates and water taking summary from the Bright wellfield

Annual Report (Year)	Average Daily Flow (m^3/d)	Maximum Daily Flow (m^3/d)	Total Annual Production (m^3)	Total Well 4 (m^3)	Total Well 4A (m^3)	Total Well 5 (m^3)
2011	87	177	31,609	-	31,602	7
2012	96	200	35,150	-	35,138	12
2013	94	195	34,266	-	34,264	1
2014	96	213	35,217	-	32,764	2,453

Well 4A is used as the main production well. Well 4 is no longer used and Well 5 was idle most of 2011, 2012, and 2013 due to poor well efficiency. The annual report for 2016 noted that the wells are not capable of producing at the maximum permitted rate and a more realistic maximum capacity of the system was estimated at 296 m^3/d. Annual reports are available at the Oxford County website (www.oxfordcounty.ca/drinkingwater). At the time of this study, the County was undertaking exploratory investigations to identify an additional groundwater source but has yet to locate a suitable groundwater source. Multiple test wells have been drilled near to the existing production wells, many of which were unsuccessful at finding water in with acceptable quantity and quality. This provides a good indication of the heterogeneity of the municipal source aquifer in the wellfield vicinity as well as the importance of protecting the existing wells.

4.1.2 Bethel Road (Town of Paris) Drinking Water System

The Bethel Road municipal wellfield is operated by the County of Brant, and is one of three wellfields that supply the Town of Paris. The Bethel Road site is located at the eastern end of the Whitemans Creek subwatershed and provides water to the Brant 403 business park and the Town of Paris water distribution pressure Zone 3. Four wells were drilled near Bethel Road west of the intersection with Rest Acres Road. The wells are completed in the intermediate to deep overburden sediments (with well depths ranging from 22.3 to 33.0 m). A study by International Water Consultants (IWC, 2012) concluded that the wells are not considered “groundwater under direct influence of surface water” (GUDI) although earlier studies had provisionally designated the wells as "GUDI with effective filtration" due to the unconfined nature of the aquifer (IWC, 2008). The Bethel wellfield was officially put into production in May 2013.

Pumping at the Bethel Road site is governed under PTTW No. 8545-A48Q8C (which replaced PTTW 1823-9X6HYC in November 2015). The permit allows pumping from TW1/05 at a maximum rate of 15 L/s (1,296 m^3/d), while PW1/12, PW2/12 and PW4/12 can each pump at maximum individual rates of 15.2 L/s (1,311 m^3/d). The total combined daily taking from the wellfield, however, cannot exceed 3,240 m^3/d. The permit allows combined peaking rates of 50 L/s (or 4,320 m^3/d daily taking) for a 30-day period.

Table 4.2 provides a summary of the 2012 to 2016 production rates and water takings from the Bethel wellfield. Production at the wellfield increased in 2015 compared to the preceding years as all four wells came into operation, with a combined production of 76,000 m^3. It should be noted that PW1/12 and PW2/12 entered into operation in July of 2015 and pumping at PW4/12 began in August of 2015

Table 4.2: Annual production rates and water taking summary from the Bethel wellfield

Annual Report (Year)	Average Daily Flow (m^3/d)	Maximum Daily Flow (m^3/d)	Total Annual Production (m^3)	Total TW 1/05 (m^3)	Total PW 1/12 (m^3)	Total PW 2/12 (m^3)	Total PW 4/12 (m^3)
2012	15.3	744	5,590	5,590	0	0	0
2013	44.7	442	16,308	16,308	0	0	0
2014	68.1	485	24,857	24,857	0	0	0
2015	208.3	1,741	76,033	21,587	18,316	19,130	17,000
2016	280.5	918	102,657	16,936	26,279	29,685	29,755

Note: Only half a year of data is available for PW1/12, PW2/12 and PW4/12 in 2015.

4.2 Well Characterization Graphs

The Tier 3 assessment requires a detailed characterization of wells, identifying their operating constraints relative to water levels in the wells. Figure 4.2 through Figure 4.7 present graphs showing the well system characterization information for the Bright and Bethel municipal wells. The purpose of these graphs is to illustrate:

1. **Well construction and pump-setting information**: A schematic showing land surface, well depth, well screen interval, and pump setting within the well are presented to the left of the graph;
2. **In-well water levels**: Water levels measured in the pumped well (where available) from pressure transducers or air-line measurements are presented as hydrographs. Note that the operating levels may be lower than in the adjacent aquifer due to well losses (discussed below);
3. **Aquifer levels**: Average water levels, measured in nearby observation wells, are presented to characterize the heads in the aquifer outside the pumped well;
4. **Pumping history**: Individual well and total wellfield production is displayed to aid in the assessment of the water level data. Note that the scale is on the right axis of the graph;
5. **Minimum Safe Water Level**: Calculated values for the minimum Safe Water Level are shown on the schematics and hydrographs; the method for determining minimum Safe Water Level and the Safe Additional Drawdown is discussed below; and,
6. **Simulated low water levels**: Minimum water levels from the transient numerical simulations, based on the maximum drawdown in the well observed during the 10-year drought simulation with future land use (Scenario H(1)), as discussed further on in Section 6.4, are shown on the schematics and hydrographs.

Figure 4.2 and Figure 4.3 present the well characterization plots for the two Bright municipal wells. These plots show the response of groundwater levels, both in the supply well and in monitoring wells, to pumping at Bright municipal Wells 4A and 5. These characterization plots include the observed water levels in monitoring well MW-1, located 20 m south of Well 4A and 85 m northeast of Well 5. Water levels in these monitors show a strong seasonal response to variations in groundwater recharge, with peak water levels occurring in late spring and a gradual decrease over the summer months, followed by a recovery in the fall. The water takings also show seasonal increases with water use, peaking in early July. This may contribute to the overall decline in water levels in the pumping wells; however, it should be noted that MW-1D and MW-1S show little response to the daily variations in pumping.

The impact of increased pumping at Well 4A, in 2010, (when Well 4 was shut down and the wellfield production was shifted entirely to this well) can be seen by a significant decline in the in-well water levels during pumping (shown in orange; Figure 4.2). Problems with well efficiency in Well 5 can also be seen in Figure 4.3. Use of Well 5 in 2010 lowered pumping water levels (orange line in Figure 4.3) to the well screen, after which pumping was shifted to Well 4A. Water levels in Well 5 recover after 2010 with the cessation of pumping and levels responded in a similar manner as those in nearby monitor MW-1D.

The well characterization plots for Bethel Road wells PW1/12, PW2/12, TW1/05 and PW4/12 are provided in Figure 4.4 through Figure 4.7, respectively. Pumping from TW1/05 (Figure 4.6) has been ongoing since October 2012. This well is interpreted as being screened across a deeper confined to semi-confined sand aquifer. Water levels from the nearby shallow monitoring well, SMW6/12, located 10 m to the south and screened in the Sand Plain/Outwash Aquifer, show a dampened response to variations in pumping rates and indicate that the degree of confinement is high at this location. PW1/12 and PW2/12 entered into operation in July of 2015 and pumping at PW4/12 began in August of 2015. Water level data for the nearby municipal monitoring wells were not available for this period (at the time of this study), making it difficult to evaluate the effects of municipal pumping on adjacent monitoring wells.

4.3 *Allocated Quantity of Water*

The Tier 3 Water Budget and Risk Assessment process assesses the sustainability of a municipal water supply in terms of its ability to provide the “allocated quantity of water”. The allocated quantity of water, as it relates to an existing water supply system, can be subdivided into (1) existing demand and (2) committed and/or planned demand in excess of the existing pumping rates. The existing, committed and planned demand are described below based on definitions provided by MNR and MOE (2011):

Existing Demand: The existing demand is estimated as the average of the reported pumping during the study period. For this study, reported daily pumping rates were gathered from the WTRS database.

Committed Demand: The committed demand is defined as the increase in the quantity of water provided by a drinking water system that would be required if the area served by the system were developed according to the Official Plan. The existing plus the committed demand must be less than the current maximum permitted rate or the water treatment plant Certificate of Approval.

Planned Demand: The planned demand is defined as the maximum quantity of water that can be lawfully taken. It also includes any expected future demand above the current maximum permitted rate.

Information on allocated quantity of water for the Bright drinking water system was provided by the County of Oxford. Information on allocated quantity of water for the Bethel Road drinking water system was determined through correspondence with the County of Brant and the GRCA.

4.3.1 Community of Bright Wellfield

4.3.1.1 Existing Demand

Table 4.3 presents existing demand for the Bright wellfield expressed as a daily average taking. Existing demand for the Bright Wellfield is estimated as the average demand during the period of 2012 to 2014.

The average pumping was 95.5 m³/d. Note that 2011 was not included in the calculation due to a roughly 10% increase in wellfield production starting in 2012. The current demand represents about 29% of the permitted takings (equal to 327 m³/d). For simulation purposes, the existing demand was split between Well 4A (93%) and Well 5 (7%) based on the ratio of pumping rates in 2014, when both wells were in service (See Table 4.3).

4.3.1.2 Committed Demand

The Bright municipal supply system is expected to service an additional 18 homes in the future. No changes to the current permitted capacity are expected. At the time of this study, the Bright system has a serviced population of 436 people occupying 151 private dwellings (as estimated based on a count of land parcels within the community). Assuming the same household population density (2.89 people per household) and a per-capita water use of 0.25 m³/day, a demand increase of approximately 14% (13 m³/d), is expected for the 18 new homes. The existing and committed demand (allocated demand) is therefore estimated as 108.8 m³/d (See Table 4.3). This is still considerably below the maximum permitted taking of 327 m³/d, as well as the estimated system capacity of 296 m³/d.

4.3.1.3 Planned Demand

There are no plans to expand Bright wellfield beyond its current capacity.

Table 4.3: Summary of allocated water demand for Bright wellfield.

Well	Existing Demand (m³/d)	Committed Demand (m³/d)	Allocated Quantity of Water (m³/d)	Planned Demand (m³/d)
Well 4A	88.8	12.4	101.2	0.0
Well 5	6.7	0.9	7.6	0.0
Total	**95.5**	**13.3**	**108.8**	**0**

4.3.2 Bethel Road (Town of Paris) Wellfield

4.3.2.1 Existing Demand

Existing demand for the Bethel wellfield was estimated as the average demand during the latter half of 2015 and all of 2016. This was the only period in which all 4 wells were in operation and represents the most realistic record of the current water use in the wellfield. The average existing demand for the wellfield was 314.4 m³/d as shown in Table 4.4. When compared with the permitted rates, this represents about 10% of the permitted takings (equal to 3,240 m³/d).

4.3.2.2 Committed Demand:

The Bethel wellfield services the Town of Paris water distribution Zone 3. This zone also receives water from the M. Sharpe Reservoir, which is supplied by the Gilbert and Telfer wellfields. The standard operating capacity of the Bethel wellfield is 35 L/s (WSP, 2016), which roughly corresponds to the entire future demand of Zone 3. It is more realistic, however, to assume that the demand of Zone 3 would be shared between the Bethel wellfield and the M. Sharpe Reservoir. Based on discussions with the County of Brant and the GRCA, a total allocated quantity of 15.9 L/s (1,373.8 m³/d) was established for the Bethel wellfield. An explanation of the selection of the allocated quantity was summarized in a memorandum to the GRCA and the County of Brant, and is provided in Appendix A. For simulation purposes, the flow was distributed across the four wells through an optimization approach, taking into account the safe additional drawdown available at each well (see Section 4.4). The resulting committed demand for each well is summarized in Table 4.4.

4.3.2.3 Planned Demand

There are no plans to expand Bethel wellfield beyond its current capacity.

Table 4.4: Summary of allocated water demand for the Bethel wellfield.

Well	Existing Demand (m^3/d)	Committed Demand (m^3/d)	Allocated Quantity of Water (m^3/d)	Planned Demand (m^3/d)
TW1/05	53.7	376.9	430.6	0
P1/12	80.4	234	314.4	0
P2/12	89.9	224.5	314.4	0
PW4/12	90.1	224.3	314.4	0
Total	**314.1**	**1059.7**	**1373.8**	**0.0**

4.4 *Safe Additional Drawdown*

The MNR Water Budget Guide defines safe additional drawdown as the additional depth that the water level within a pumping well could fall and still maintain that well's allocated pumping rate. It is calculated as the additional drawdown that is available in addition to the drawdown created by the pumping rate under existing conditions. To establish the safe additional drawdown for the Bright and Bethel municipal wellfields, the following components were evaluated:

Safe Water Level Elevation: This is the lowermost elevation at which the operators feel that the well can be pumped. This elevation may be limited to the well screen elevation, pump intake elevation or similar operational limitation, such as the top of a confined aquifer. The minimum safe water level in the Bright municipal pumping wells was defined by the County of Oxford as 2 m above each well screen, whereas the minimum safe level in Bethel was defined by the County of Brant as 3 m above each well screen. Minimum safe water levels, based on reported well screen elevations, are summarized in Table 4.5.

Average Water Level in the Pumping Well: The average pumped water level was determined for the existing conditions year from daily water level data provided by the County of Oxford and the County of Brant for the Bright and Bethel wellfields, respectively. Average pumped water levels for each well are also summarized in Table 4.5

Table 4.5: Safe additional drawdown for the Bright and Bethel wellfield

Well	Ground Elevation (masl)	Average Pumped Water Level (masl)	Pump Setting (masl)	Top of Screen Elevation (masl)	Minimum Safe Level (masl)	Available Drawdown (m)
Bright Wellfield						
Well 4A	317.2	305.6	298.3	296.6	298.6	7.0
Well 5	319.7	311.3	unknown	296.8	298.8	12.5
Bethel Wellfield						
TW1/05 (P52)	256.0	246.3	232.5	228.6	231.6	14.7
P1/12 (P51)	256.5	245.8	231.8	233.4	236.4	9.4
P2/12 (P53)	256.1	244.1	231.3	233.5	236.5	7.6
PW4/12(P54)	257.0	244.7	232.7	232.8	235.8	8.9

Estimated Non-linear Head Losses in the Well: Additional drawdowns can occur within the well due to well inefficiencies (e.g., losses at the screen and around pump intakes). Well losses need to be considered because the additional available drawdown refers specifically to the water level inside the well and not the water level in the aquifer.

Theoretical relations can be used to relate well losses to pumping rates (e.g., Jacob, 1950) as:

$$s_w = B\,Q + CQ^2$$

where s_w is the total drawdown, B is the formation loss coefficient as determined by a Theis (1935) or other analytical relation, Q is the pumping rate, and C is the well loss coefficient. The non-linear well loss coefficient (C) can be estimated by analyzing step test results using a graphical method developed by Jacob (1948). The inverse of the specific capacity, defined as the drawdown divided by the pumping rate, can be plotted versus the pumping rate. The slope of the best-fit line through the data is equal to the well loss coefficient. Non-linear well loss coefficients and subsequent well losses are summarized for existing and allocated conditions for the Bright and Bethel wellfields in Table 4.6.

Table 4.6: Summary of non-linear well loss for the Bright and Bethel wells.

Well	Existing Demand (m^3/d)	Allocated Quantity of Water (m^3/d)	Nonlinear Well-Loss Coefficient (d^2/m^5)	Nonlinear Well Loss (m)	
				Existing	Allocated
Bright Wellfield					
Well 4A	88.8	101.2	5.1x10-07	0.00	0.00
Well 5	6.7	7.6	5.1x10-07	0.00	0.00
Bethel Wellfield					
TW 1/05	53.7	430.6	3.75x10-7	0.00	0.07
PW 1/12	80.4	314.4	1.60x10-7	0.00	0.02
PW 2/12	89.9	314.4	6.96x10-8	0.00	0.01
PW 4/12	90.1	314.4	2.50x10-7	0.00	0.03

Convergent Head Loss Corrections: The numerical model calculates the average water level in the grid cell containing the pumping well. Water levels in the well will be different than the average cell value due to convergent head losses at the well. A correction based on the Theis relationship was proposed first by Prickett and Lonnquist (1971) as:

$$s_w = \frac{Q}{2\pi T}\ln\left(\frac{0.208\Delta x}{r_w}\right)$$

where Q is the pumping rate, T is the aquifer transmissivity, Δx is the model grid spacing, and r_w is the effective well radius. The calculated values are presented in Table 4.7

Table 4.7: Summary of convergent head loss corrections for the Bright and Bethel wells.

Well	Well Radius (m)	Cell Size (m)	Transmissivity (m^2/d)	Existing Demand (m^3/d)	Allocated Quantity of Water (m^3/d)	Convergent Well Loss (m)	
						Existing	Allocated
Bright Wellfield							
Well 4A	0.15	30.0	130	88.8	101.2	*0.449*	0.512
Well 5	0.08	30.0	130	6.7	7.6	*0.034*	0.039
Bethel Wellfield							
TW 1/05	0.20	15.0	220	53.7	430.6	0.134	1.072
PW 1/12	0.20	15.0	220	80.4	314.4	0.200	0.782
PW 2/12	0.20	15.0	220	89.9	314.4	0.224	0.782
PW 4/12	0.20	15.0	220	90.1	314.4	0.224	0.782

4.5 *Non-Municipal Water Demand*

4.5.1 Data Sources

4.5.1.1 MOECC Permit to Take Water (PTTW) Database

The MOECC maintains a database of Permits to Take Water issued under the Ontario Water Resources Act for water takings larger than 50,000 L/d. The PTTW database includes information on the maximum permitted water taking rates along with the maximum number of hours per day and/or days per year of permitted operation. Permits are classified by primary and secondary purposes (e.g., water supply/municipal or agriculture/tobacco). Each permit can have multiple sources (e.g., Well 1 and Well 2). PTTW holders are required to report water use, but water use information is not part of this database.

4.5.1.2 MOECC Water Taking Reporting System (WTRS) Database

Under the Ontario Water Resources Act, all PTTW holders are now required to report actual daily water takings to the MOECC for each source listed in the permit. To facilitate compliance, the MOECC developed the Water Taking Reporting System (WTRS) to accept self-reported information electronically over the internet.

The GRCA provided a copy of yearly WTRS data for the Whitemans Creek area spanning 2009 to 2014. Data prior to 2009 is generally incomplete because the requirement to report was phased in over time (2005 to 2008) for different classes of users. Consequently, data prior to 2009 were not used.

4.5.1.3 MOECC WWIS Database

The WWIS database provides information on the well location, well depth, screen setting, static water level, specific capacity, well yield and pump capacity, and well purpose. Each well is assigned a unique alphanumeric Well ID. The well information can be used to determine the aquifer from which the groundwater takings are drawn. Digital copies of the paper records (for data verification and location sketches) can be obtained from the MOECC website.

There is no direct link between the information in the WWIS and the PTTW or WTRS databases although sometimes a reference is made to a Well ID in the PTTW Source description. A significant effort was made in this study to link the PTTW sources to the appropriate well records and thereby determine which hydrostratigraphic unit was being pumped. This methodology employs a computer script to automatically process the two databases and conduct a proximity analysis, and is described in detail in Earthfx (2017).

4.5.2 Permitted Water Users

In addition to the Bright and Bethel municipal drinking water systems discussed above, there are a large number of permitted water uses in the Whitemans Creek subwatershed and in the larger study area. A total of 557 sources were included in the Tier 3 study based on the criteria discussed in Earthfx (2017). The sources included 401 unique permits in the model area and 144 unique permits within the Whitemans Creek subwatershed. All active surface and groundwater permits in the Whitemans Creek subwatershed are summarized in Appendix B and Appendix C, respectively. The summary tables in these appendices include: the permit number, the location, the source description, the primary and secondary use category, and permitted and reported takings (discussed in Section 4.5.3). A complete list of all simulated permits for the study area can be found in Earthfx (2017).

As noted, permit sources are categorized by primary and secondary use. The largest primary category is agriculture, with a total of 369 groundwater sources and 90 surface water sources in the study area. In the Whitemans Creek subwatershed, agricultural water use accounts for 190 of 194, or 98%, of the non-municipal permits. A breakdown of permitted water takings in the model area and in the Whitemans Creek subwatershed are provided in Table 4.8, organized by primary and secondary use. The location of groundwater and surface water permits by primary and secondary use are shown on Figure 4.8 and Figure 4.9, respectively. The non-agricultural permits are distributed across the study area; however, the agricultural permits are largely concentrated in the Norfolk Sand Plain region in the southeastern portion of the study area. The well-drained soils within this region requires crops to be irrigated regularly, offering an explanation as to the large number of agricultural permits.

Table 4.8: Number of active permitted sources categorized by primary and secondary purpose.

Primary Purpose	Secondary Purpose	Study Area		Whitemans Creek	
		Groundwater	*Surface Water*	*Groundwater*	*Surface Water*
Agricultural	Field/Pasture Crops	173	35	59	19
	Fruit Orchards	3	2	0	0
	Mkt. Garden/Flowers	2	0	0	0
	Nursery	3	0	2	0
	Other Agricultural	79	19	28	9
	Sod Farm	11	1	10	1
	Tender Fruit	2	0	1	0
	Tobacco	96	33	37	23
Commercial	Aquaculture/Other	2	3	0	0
	Golf Courses	10	6	4	0
	Other	1	0	0	0
Construction/	Construction	2	0	0	0
Dewatering	Pits and Quarries	0	0	0	0
Industrial	Aggregate Washing	11	0	0	0
	All Other	4	0	0	0
Miscellaneous	All	4	0	0	0
Recreational	All	0	0	0	0
Remediation	All	0	0	0	0
Water Supply	Municipal	41	0	7	0
	All Other	14	0	0	0
Totals		**458**	**99**	**149**	**52**

Table 4.9 compares maximum permitted takings and reported water use within the Whitemans Creek subwatershed by source and specific use. Total maximum permitted takings are about 82,000 m³/d while total reported takings are only about 4,400 m³/d. Reported takings are dominated by agricultural water use related to irrigation. While it is understood that irrigation requirements can vary widely from year to year, there appears a general tendency to apply for permitted maximum takings far in excess of actual needs. It is our understanding that the MOECC has been attempting in recent years to re-issue permits with lower, more realistic limits. The comparison also shows the importance of using the WTRS data in assessing water use rather than the PTTW values, which were used in many of the previous water budget and Source Water Protection studies and likely resulted in significantly overestimating actual water use.

Table 4.9: Permitted and reported water use within the Whitemans Creek subwatershed by primary and secondary use for 2012 to 2014.

Source	Purpose	Specific Use	Mean Annual Permitted Taking (m³/d)	Reported 2012 Average Demand (m³/d)	Reported 2013 Average Demand (m³/d)	Reported 2014 Average Demand (m³/d)	Average Reported Demand (m³/d)
Groundwater	*Agricultural*	Field and Pasture Crops	28,861	993	1431	747	1057
		Fruit Orchards	60	0	0	0	0
		Nursery	333	0	5	1	2
		Other - Agricultural	4,709	320	375	333	343
		Sod Farm	9,215	1303	1027	225	852
		Tender Fruit	42	0	0	0	0
		Tobacco	18,376	1520	1700	506	1242
	Commercial	Golf Course Irrigation	1,067	33	34	29	32
		Other	131	0	0	0	0
	Water Supply	Municipal	5,251	111	139	166	139
	Total		**68,045**	**4,280**	**4,711**	**2,007**	**3,666**
Mixed GW/SW	*Agricultural*	Field and Pasture Crops	2,108	16	305	93	138
		Fruit Orchards	6	0	0	0	0
		Market Gardens / Flowers	4	0	0	0	0
		Other - Agricultural	1,001	14	0	0	5
		Sod Farm	2,597	575	432	60	356
		Tobacco	199	65	0	0	22
	Total		**5,915**	**670**	**737**	**153**	**520**
Surface Water	*Agricultural*	Field and Pasture Crops	2,582	38	25	30	31
		Other - Agricultural	948	0	0	81	27
		Sod Farm	487	0	0	1	0
		Tobacco	4,212	272	242	74	196
	Total		**8,228**	**309**	**267**	**186**	**254**
Grand Total			***82,188***	***5,259***	***5,714***	***2,345***	***4,440***

4.5.3 Consumptive Demand

Consumptive demand, as defined in the MNR Water Budget Guide, is the amount of water that is taken from a water source and not returned locally to the same source of water within a reasonable amount of time. While reported actual takings can be determined from the WTRS data, estimating consumptive use is difficult and requires information on the locations, rates, and timings of the return flows.

Municipal takings, including the Bright and Bethel wellfields, were treated in a conservative manner by assuming they are 100% consumptive. While it is likely that a portion of the water extracted from the overburden aquifers is returned to the soil zone through septic systems and activities such as lawn watering, there are many cases in which groundwater is delivered to domestic users and ultimately discharged away from the source. For example, water from the Bethel wellfield is pumped to the Brant 403 Business Park and to the Town of Paris, located outside the Whitemans Creek subwatershed. The water is used, processed by the Paris wastewater treatment facility, and discharged to the Grand River. As such, it is unlikely that any of this water would be returned to the source aquifer.

Because agriculture is the largest category of water takings within the study area, it was important that the consumptive nature of these takings be represented as accurately as possible. Rather than simply applying a seasonally-adjusted factor to the estimated demand, a custom irrigation demand module was developed to estimate the timing and volume of irrigation (based on a rules-based approach and simulated soil moisture). The soil water balance module was used to calculate the changes in soil moisture, ET, and groundwater recharge over the irrigated areas. While some parameter values still had to be estimated (e.g., irrigation application efficiency), the irrigation demand module attempted to achieve a more accurate representation of agricultural water use by incorporating farm size, crop type, crop needs, equipment limits, and soil properties in estimating water takings. The consumptive volume of agricultural water use was estimated by applying the irrigation water to the HRUs and letting the PRMS code calculate soil water balance and groundwater recharge. A full description of the irrigation demand module can be found in Earthfx (2017).

The remaining simulated takings (i.e., non-municipal and non-agricultural) were assumed to be entirely consumptive. These include commercial and industrial sources, along with livestock watering (discussed in Section 4.5.4.2). It should also be noted that these takings represent a small fraction of the total takings within the study area.

4.5.4 Non-Permitted Water Users

4.5.4.1 Private Domestic Water users

According to the MOECC WWIS database, a total of 4,463 wells with primary or secondary purpose designated as “domestic water supply” are located in the study area, 1,258 of which are located in the Whitemans Creek subwatershed. Assuming a private domestic daily water use rate of 0.9 m³/d with a consumptive use factor of 0.2, the private domestic wells in the subwatershed represent a mean daily consumptive taking of approximately 226 m³/d. The individual local takings, however, are widely-distributed and small relative to other permitted sources. Consequently, private domestic water use was not represented in the Tier 3 model. Note that the estimated committed demand for the Bright municipal wellfield used different assumptions for domestic water use because more data were available, specific to the Community of Bright. For the regional calculation above, a more conservative value of 0.9 m³/d was selected based on a Canadian historical estimate of per-capita water use (347 L/d per person) and the Ontario average of 2.6 people per dwelling (Statistics Canada, 2017)

4.5.4.2 Livestock watering

Unlike water takings for irrigation purposes, livestock watering does not require a permit. In addition, the demand for livestock watering is generally year-round rather than seasonal. The average daily livestock water use on a per-farm basis was calculated by multiplying the average number of animals by their average water requirement. A breakdown of the different livestock types and their water requirements is presented in Table 4.10. The total simulated livestock water demands for the study area and the Whitemans Creek subwatershed are 4,866 m³/d and 1,445 m³/d, respectively. The locations of livestock farms within the study area are shown in Figure 4.11. The methodology used to determine the magnitude and location of livestock takings is presented in more detail in Earthfx (2017).

Table 4.10: Summary of simulated livestock water takings

Livestock Type	Average Daily Water Use Per Farm (m³/d)	Number of Farms in Study Area	Average Water Use in Study Area (m³/d)	Number of Farms in Whitemans Creek	Average Water Use in Whitemans Creek (m³/d)
Beef	4.99	104	519.5	37	184.8
Dairy	4.84	474	2292.3	135	652.9
Fur	0.59	4	2.4	1	0.6
Goats	0.49	12	5.8	3	1.5
Horse	0.26	75	19.5	21	5.5
Poultry	1.58	153	242.0	52	82.3
Sheep	0.52	13	6.7	4	2.1
Swine (regular)	10.27	134	1374.8	44	451.4
Swine (large scale)	21.25	19	403.7	3	63.8

4.6 *Other Water Uses*

The Tier 3 Risk Assessment must also consider whether the allocated and planned quantity of municipal water demand can be met while maintaining the requirements of "other water uses" in the area. The analysis identified other water uses in the study area and estimated water quantity requirements for them, where possible. As per the Technical Rules, other water uses include requirements for:

- aquatic habitat,
- provincially significant wetlands (PSW),
- wastewater assimilation, recreation, navigation, and
- other water takings including agricultural, commercial and industrial water takings.

The first three items are discussed in more detail in the following sections. Other water takings were discussed previously in Section 4.5.

4.6.1 Aquatic Habitat and Provincially Significant Wetlands

Cold water fisheries depend on a supply of groundwater discharge along the stream reach and are likely to be sensitive to reductions in groundwater discharge due to increased groundwater takings or decreases in groundwater recharge due to drought and/or land use change. The mapped thermal regime of the Whitemans Creek subwatershed is shown in Figure 4.12. The critical cold water reaches are located in the lower portion of Horner Creek, Whitemans Creek, and Landon's Creek, a small tributary of Whitemans Creek.

Reductions in groundwater discharge to cold water streams that exceed specified thresholds are considered as moderate or significant impacts in the Tier 3 scenario analyses and are discussed in more detail as part of the Local Area Risk Assessment (Section 6.5). No specific threshold has been assigned to reductions in baseflow to warm water fisheries other than the decrease in baseflow should not "constitute an unacceptable impact".

The Whitemans Creek subwatershed contains a number of provincially significant wetlands (PSWs). A wetland complex flanks the majority of Whitemans Creek and its main tributaries, Kenny Creek and Horner Creek. PSWs found in the Whitemans Creek subwatershed are shown in Figure 4.13. These wetland features contain significant areas of natural and scientific interest (ANSI) and other natural features including Chesney Bog, Black Creek Swamp, Burgess Lake Swamp, Buck Pond, Park Haven Lake, Pine

Pond, Benwall Swamp, and Apps Mill. Impacts to water levels in the wetland features were evaluated as part of the risk assessment.

4.6.2 Wastewater Assimilation, Navigation, and Recreation

Wastewater generated by residents within the Whitemans Creek subwatershed is managed by private septic systems. There are no communal wastewater treatment facilities and therefore no wastewater assimilation requirements for receiving watercourses. Similarly, no watercourses were considered as recreation or navigation-worthy and therefore no analysis was needed for these water uses.

4.7 *Land Use and Land Use Change*

As part of the Tier 3 scenarios, changes in land use must be accounted for to quantify potential effects on groundwater recharge and, consequently, on municipal water supplies. Conversion of natural or agricultural lands to urban land use often increases the amount of impervious cover resulting in reduced evapotranspiration but increases in both the frequency and volume of overland runoff. Net recharge is often reduced unless some or all of the overland runoff from the impervious surfaces is redirected to pervious areas and infiltrated before entering a watercourse. The PRMS submodel was used in this study to quantify the impact of future land use change on groundwater recharge and other water budget components.

The MNR Water Budget Guide identified the following steps to characterize potential recharge reductions:

1. *Create a map of existing land use.*
2. *Create a map of projected land use (Official Plan).*
3. *Identify areas of land use change by comparing projected land use against existing land use.*
4. *Estimate the projected change in imperviousness for each of the areas of land use change. This will require making assumptions relating to the imperviousness of land use categories.*
5. *Create a map of projected imperviousness changes for areas of land use change.*

The potential impact of stormwater management measures and low-impact developments designed to redirect overland runoff and enhance groundwater recharge are not to be accounted for when estimating the effects of projected land use change and increased imperviousness.

4.7.1 Existing Conditions Land Use

Current land use within the Whitemans Creek subwatershed is summarized in Section 2.1.1. The Bright wellfield is located in a residential setting within the community of Bright. The community itself is largely surrounded by agricultural lands. The Bethel wellfield is also surrounded by agricultural lands although it is in close proximity to some industrial developments, including the Brant 403 Business Park, an active aggregate extraction pit to the east, and the urban area of the Town of Paris to the north.

4.7.2 Planned Land Use

The community of Bright has a small residential subdivision planned for the east side of the settlement. There is also an aggregate extraction pit under development 1.2 km north of the Bright wellfield. The development zones are shown in Figure 4.14. The aggregate extraction is more likely to result in increased recharge due to the stripping of overburden.

In the Bethel wellfield area, the County of Brant has planned for the continued development of the Brant Business Park in addition to two commercial areas and a considerable urban residential area in the Town of Paris between the wellfield and the Nith River to the north. There is also a 46 hectare (ha) property on the south side of Bethel Road zoned for aggregate extraction. Again, the aggregate extraction is more likely to result in increased recharge. The development areas are shown in Figure 4.15.

4.8 Figures

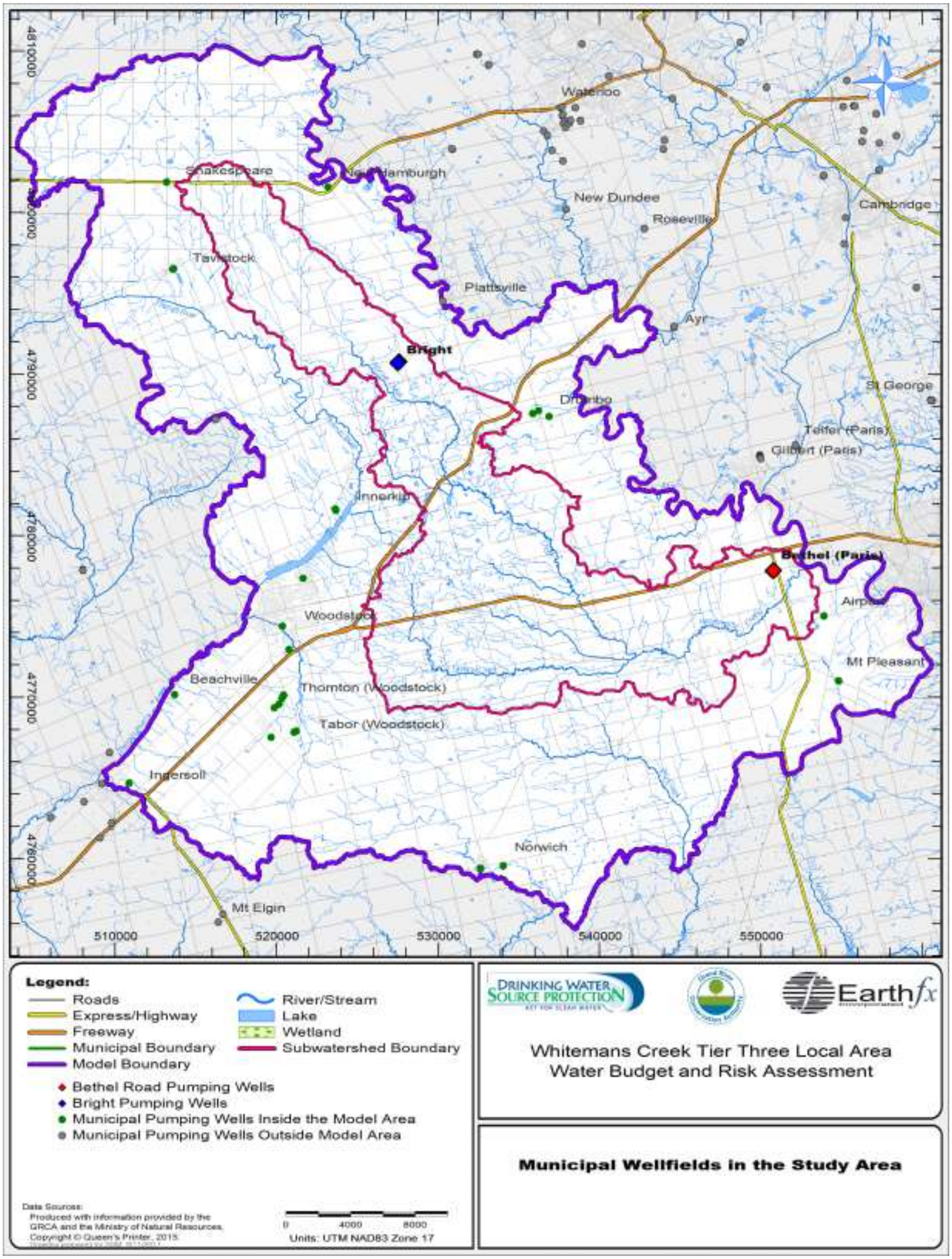

Figure 4.1: Location of the municipal wellfields within the Whitemans Creek subwatershed.

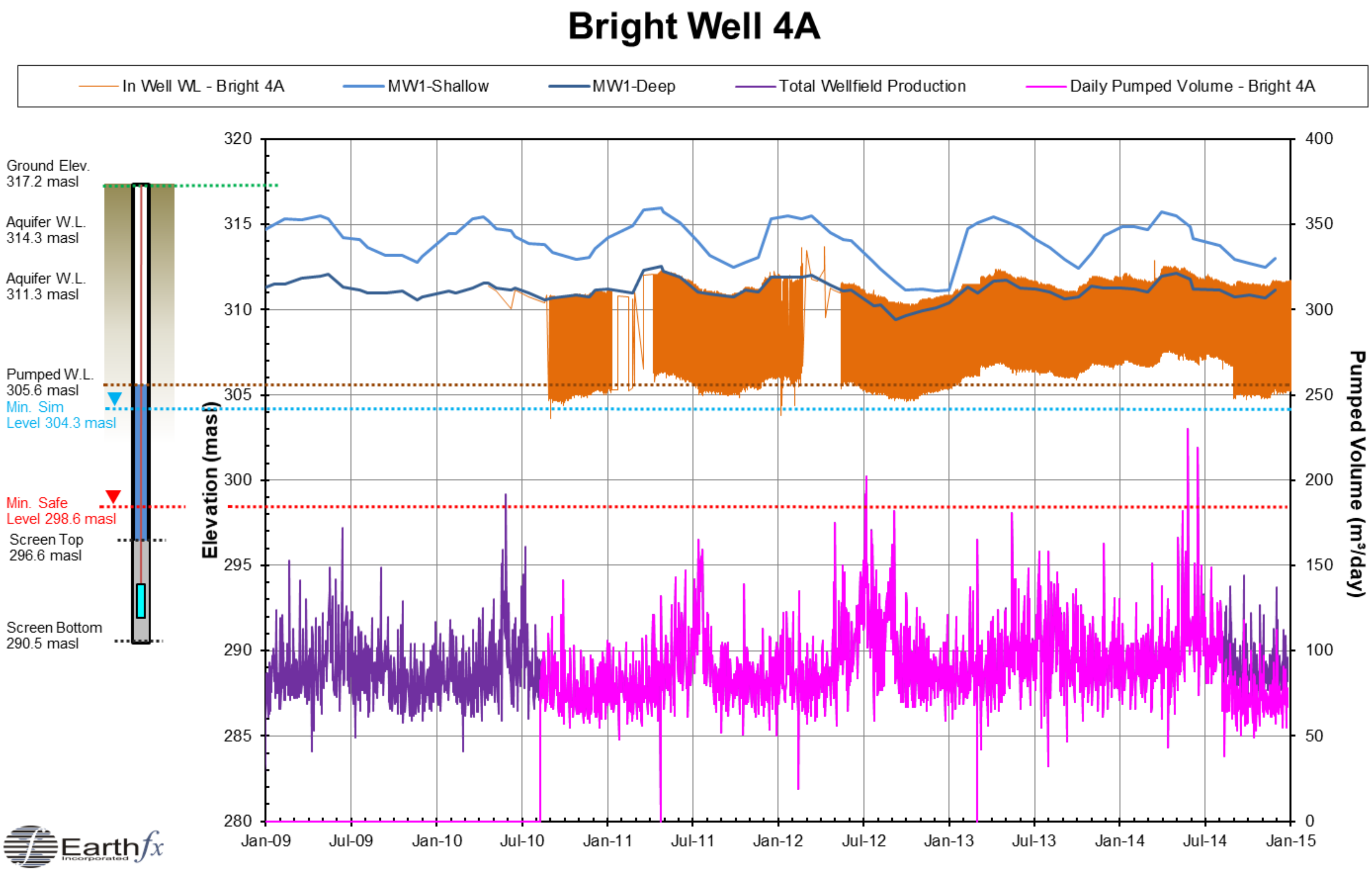

Figure 4.2: Daily water levels and pumped volumes at Bright Well 4A with observed water levels at adjacent monitors.

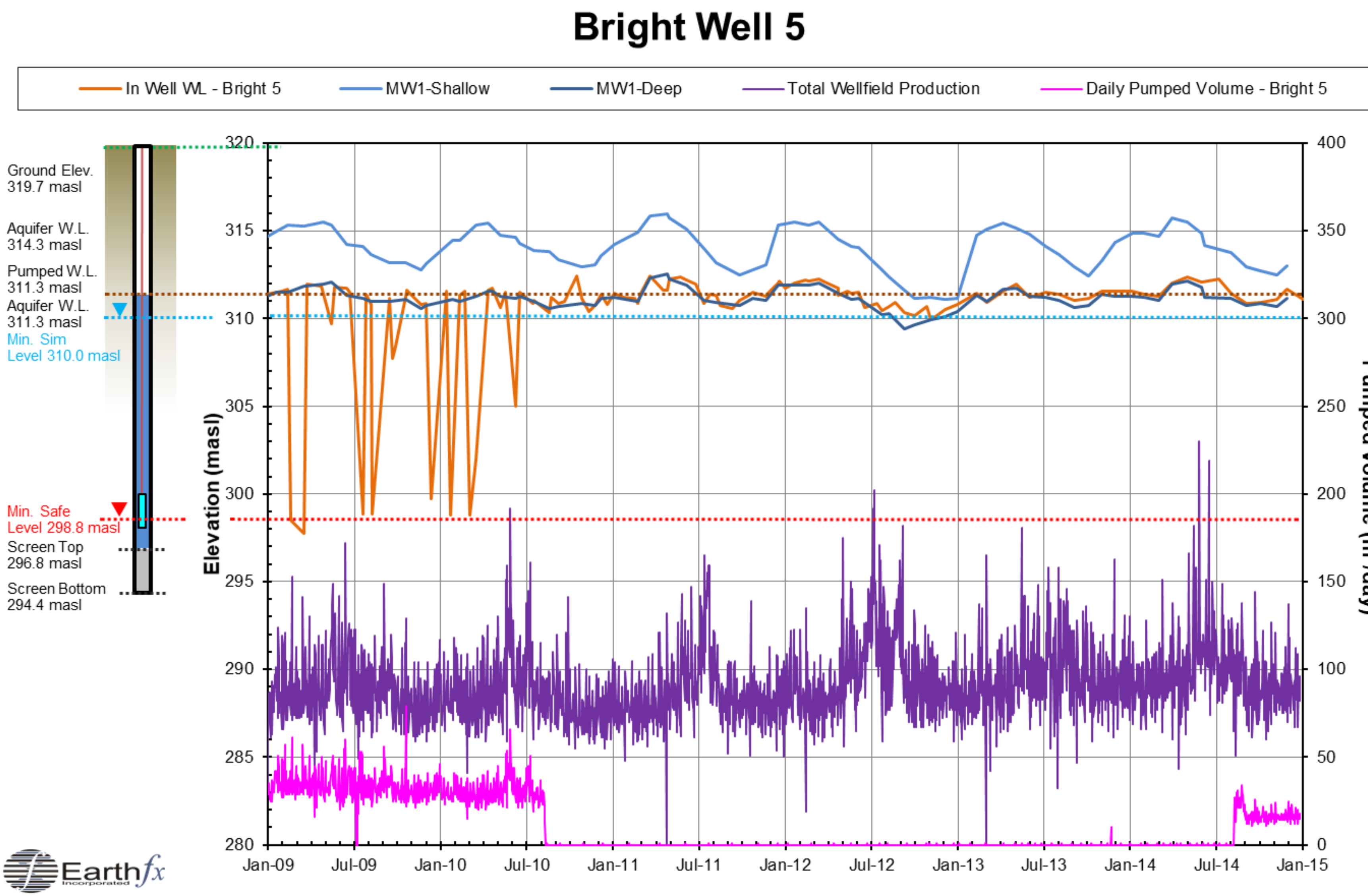

Figure 4.3: Daily water levels and pumped volumes at Bright Well 5 with observed water levels at adjacent monitors.

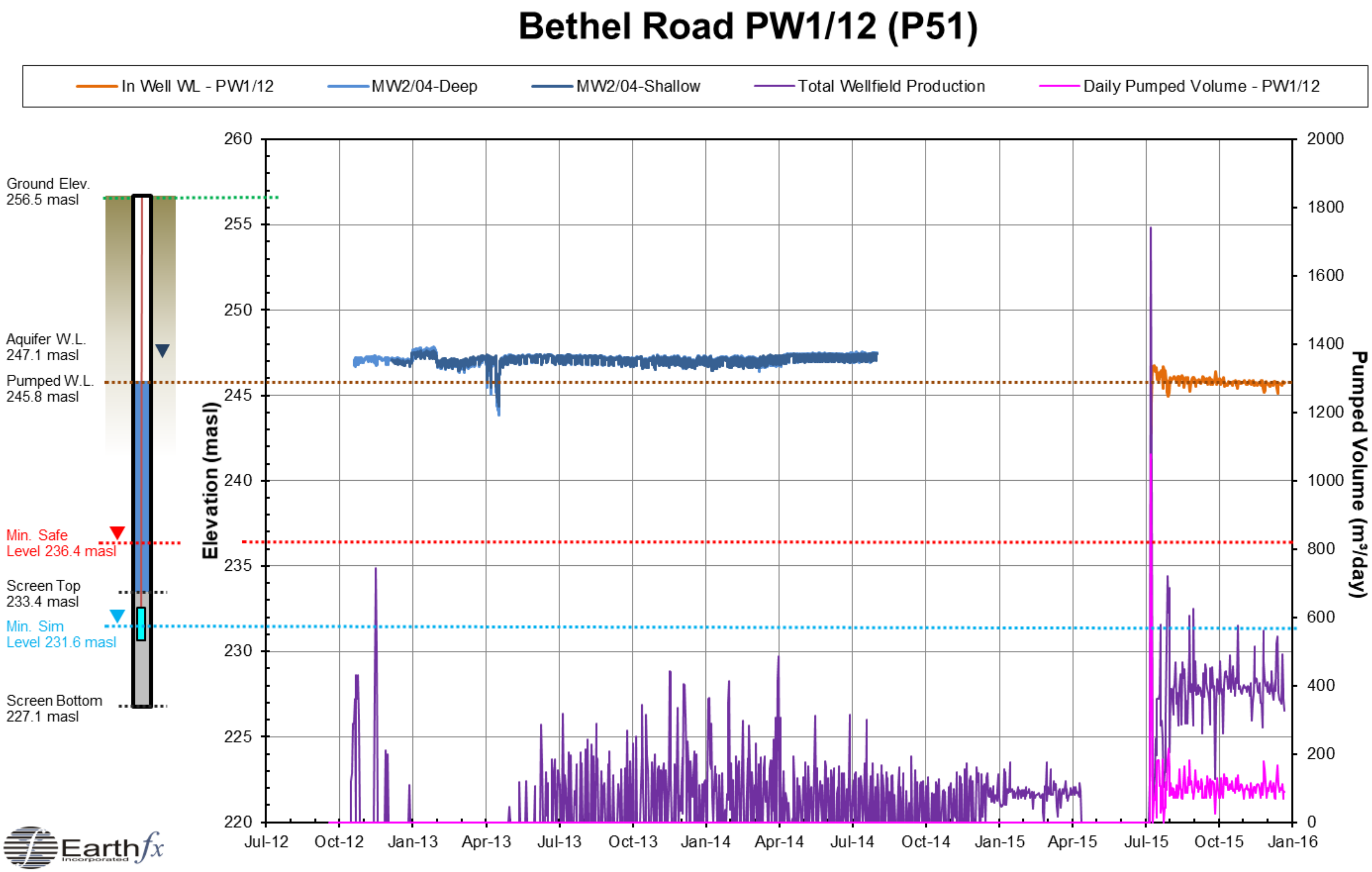

Figure 4.4: Daily water levels and pumped volumes at Bethel Road PW1/12 with observed water levels at adjacent monitors.

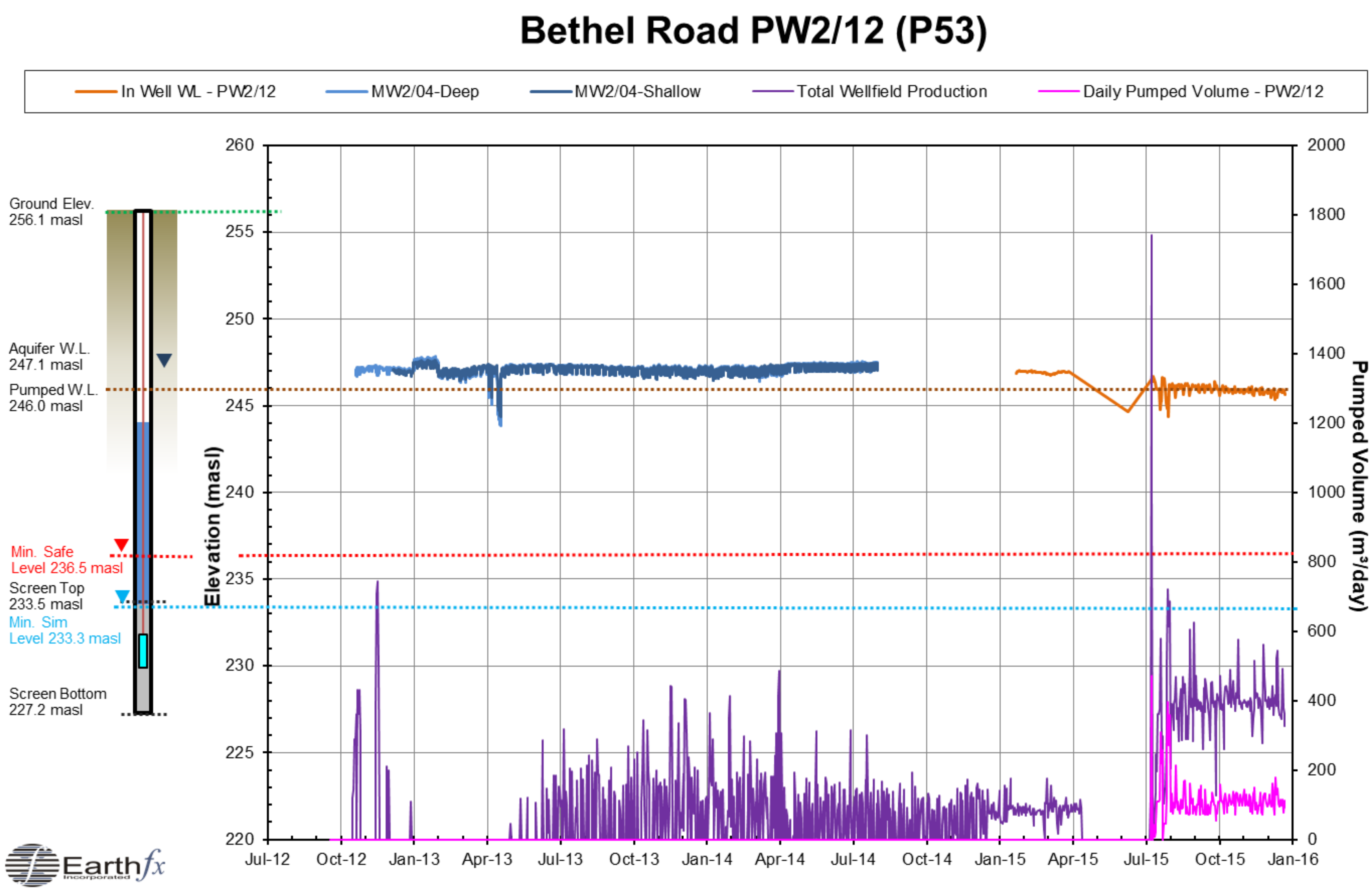

Figure 4.5: Daily water levels and pumped volumes at Bethel Road PW2/12 with observed water levels at adjacent monitors.

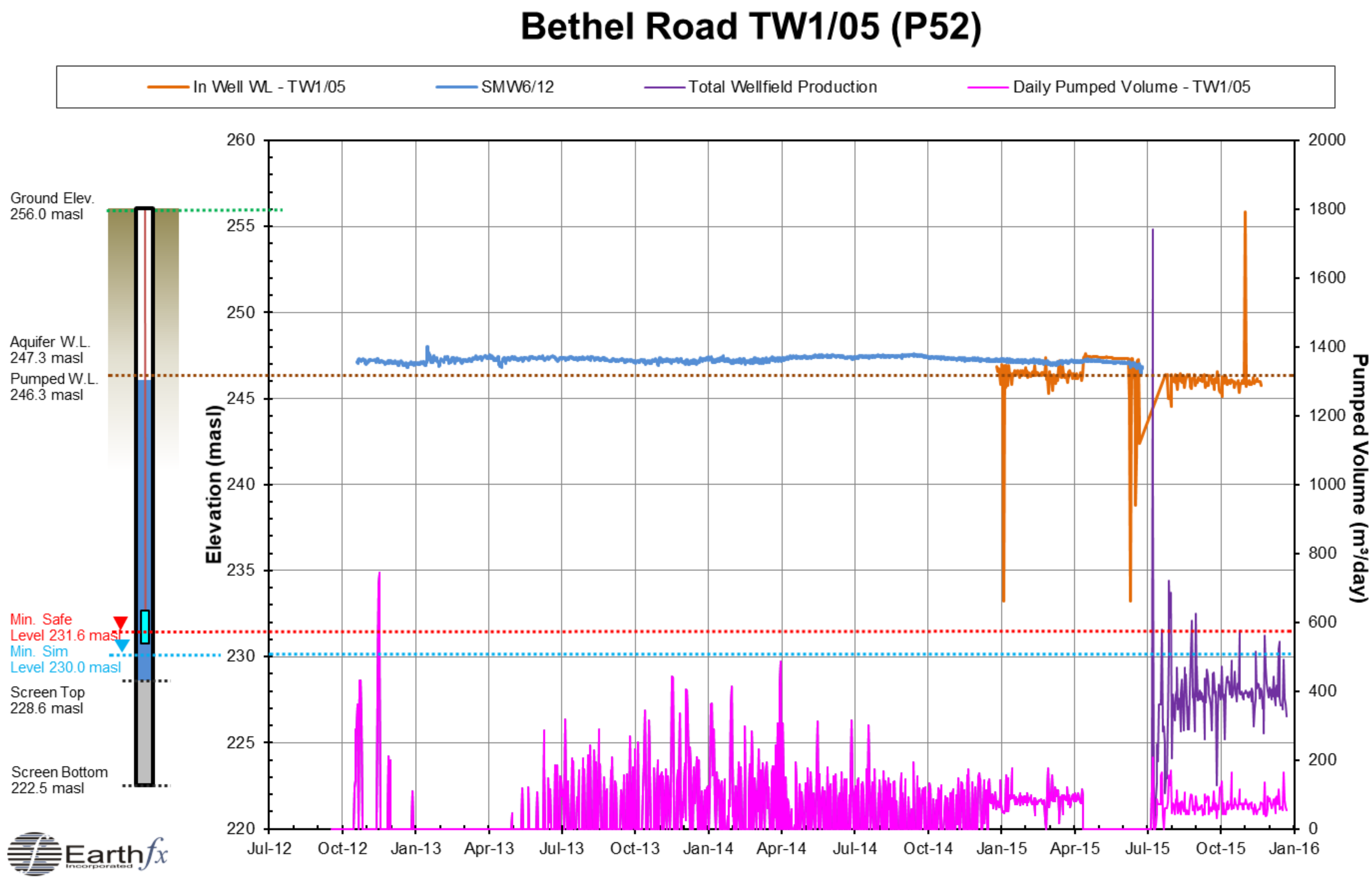

Figure 4.6: Daily water levels and pumped volumes at Bethel Road TW1/05 with observed water levels at adjacent monitors.

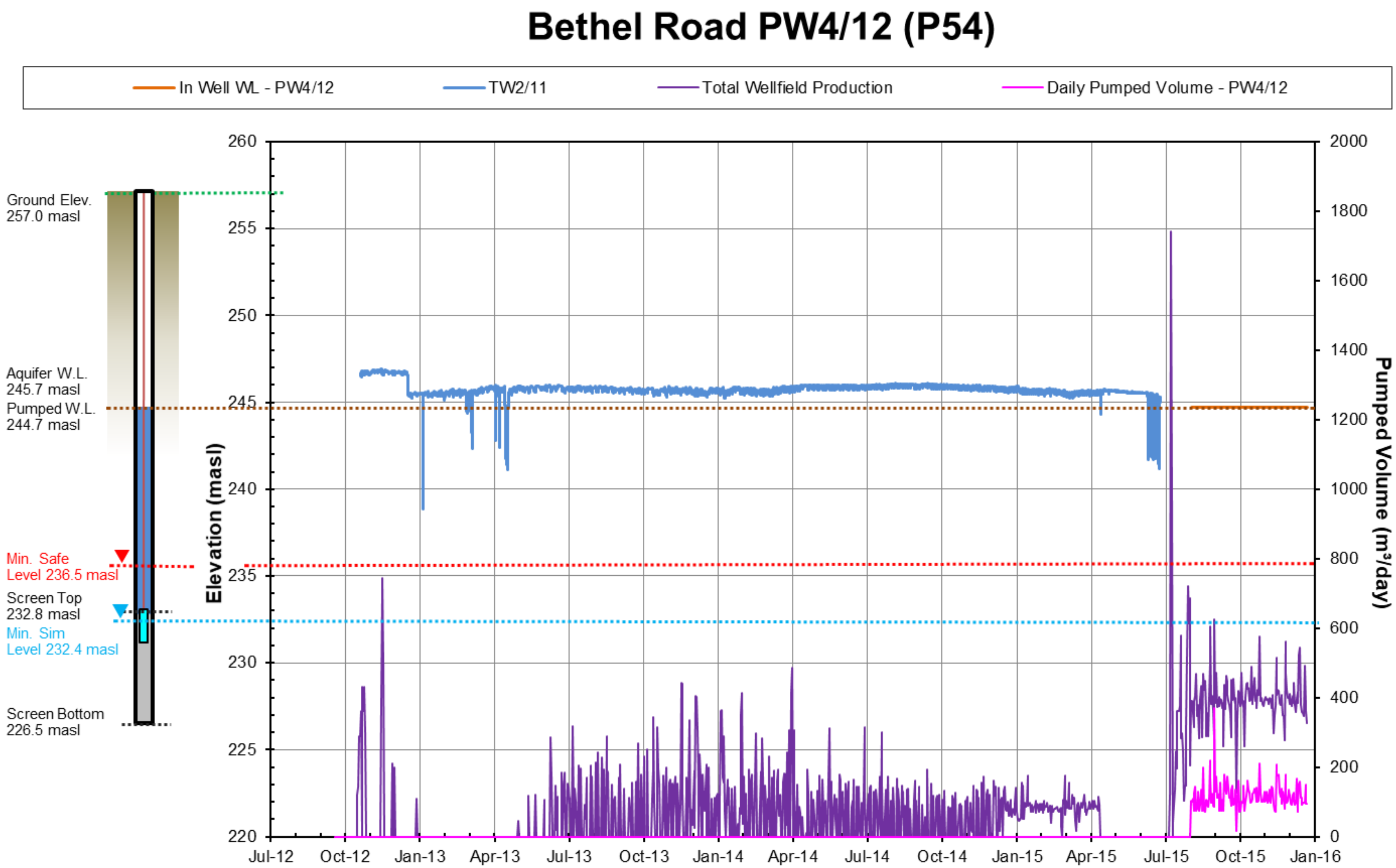

Figure 4.7: Daily water levels and pumped volumes at Bethel Road PW4/12 with observed water levels at adjacent monitors.

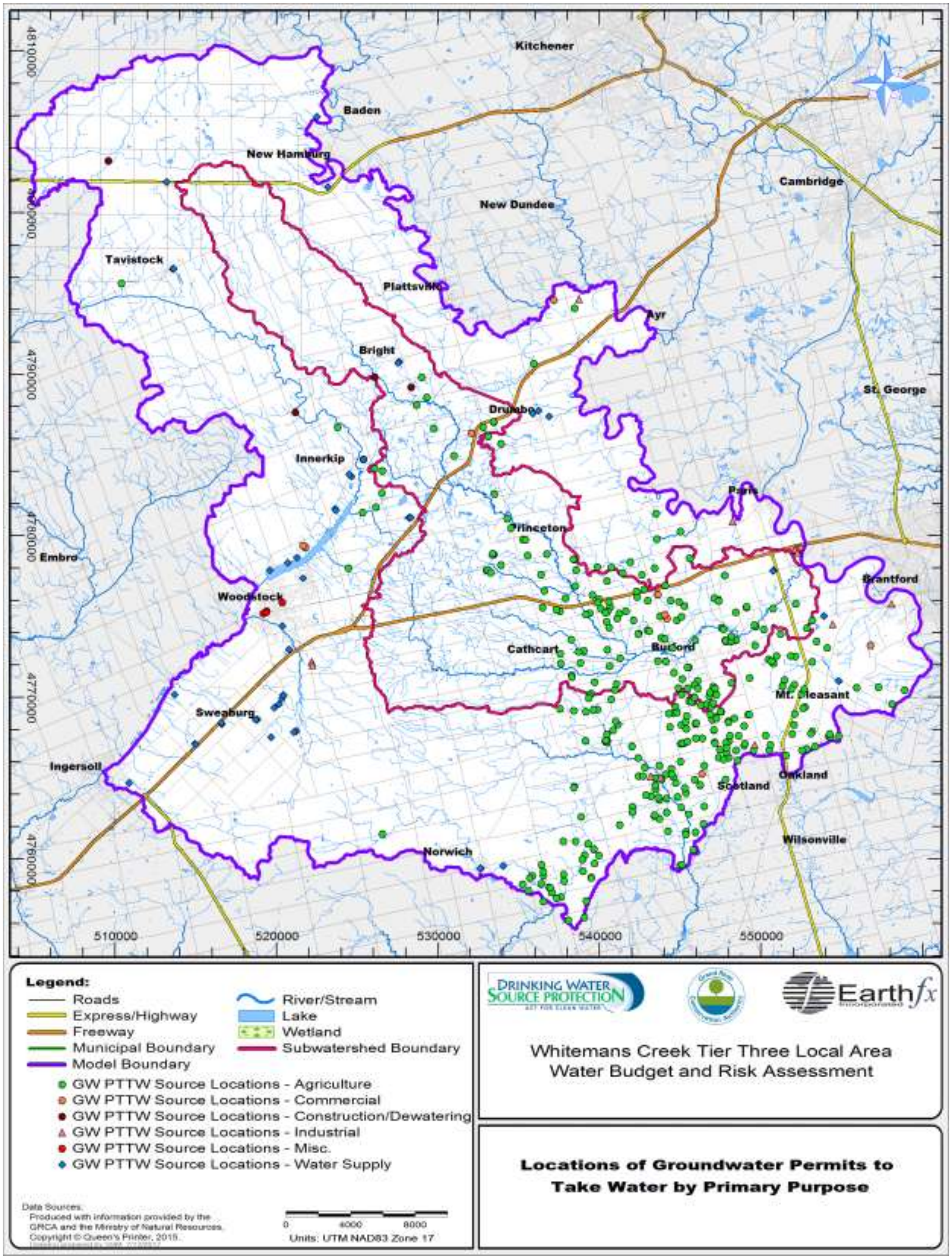

Figure 4.8: Locations of groundwater Permits to Take Water sorted by primary purpose.

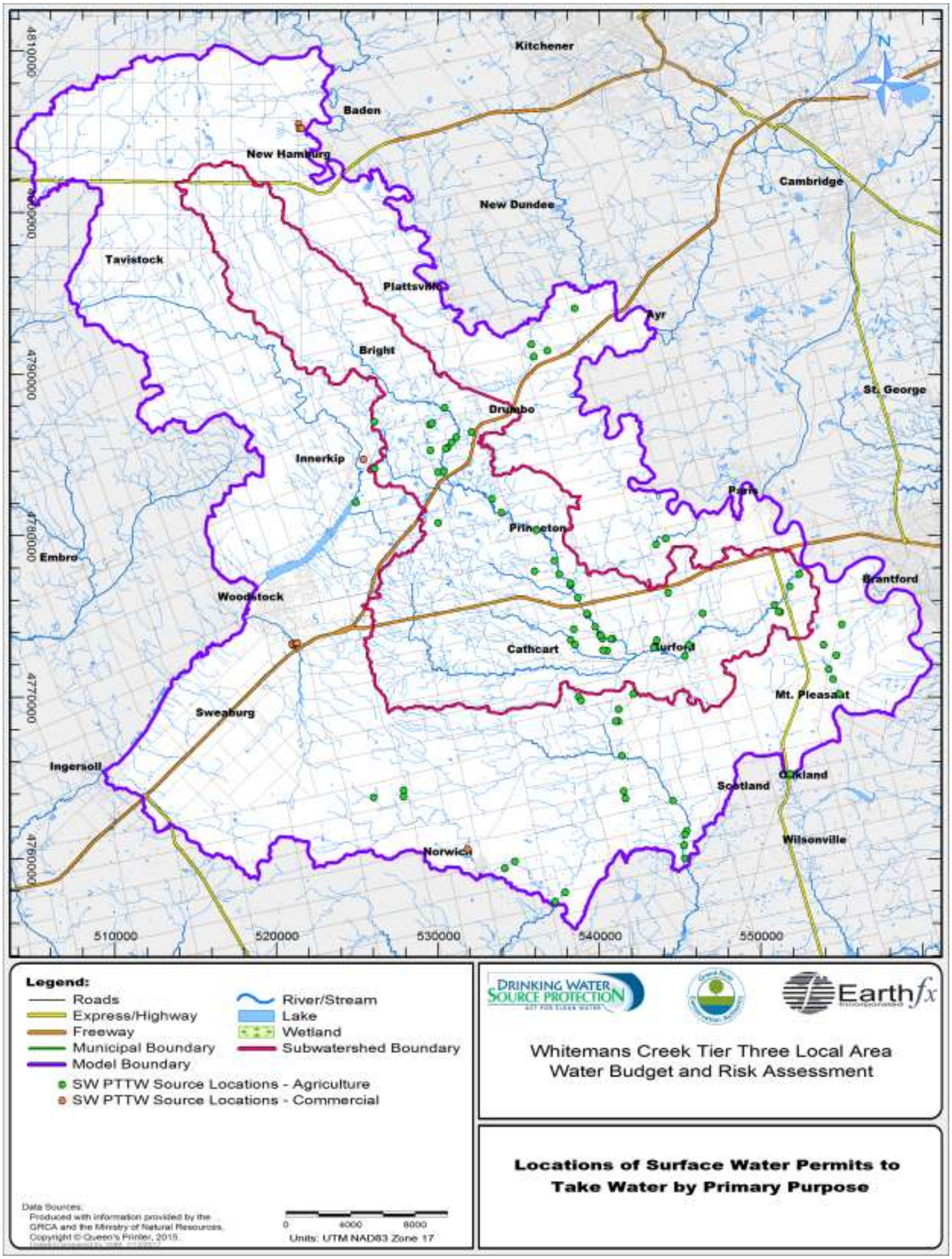

Figure 4.9: Locations of surface water Permits to Take Water sorted by primary purpose.

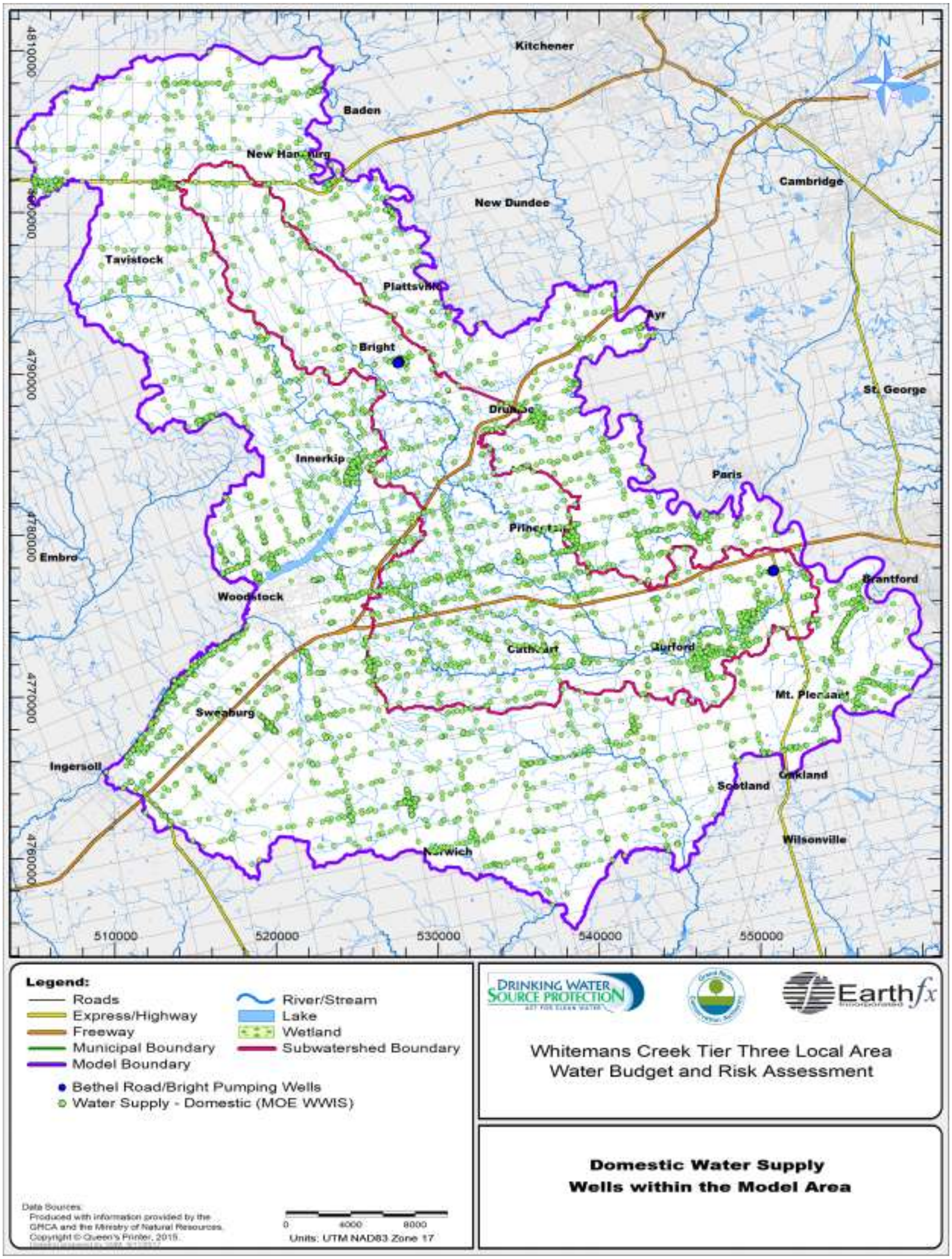

Figure 4.10: Private domestic water supply wells in the study area.

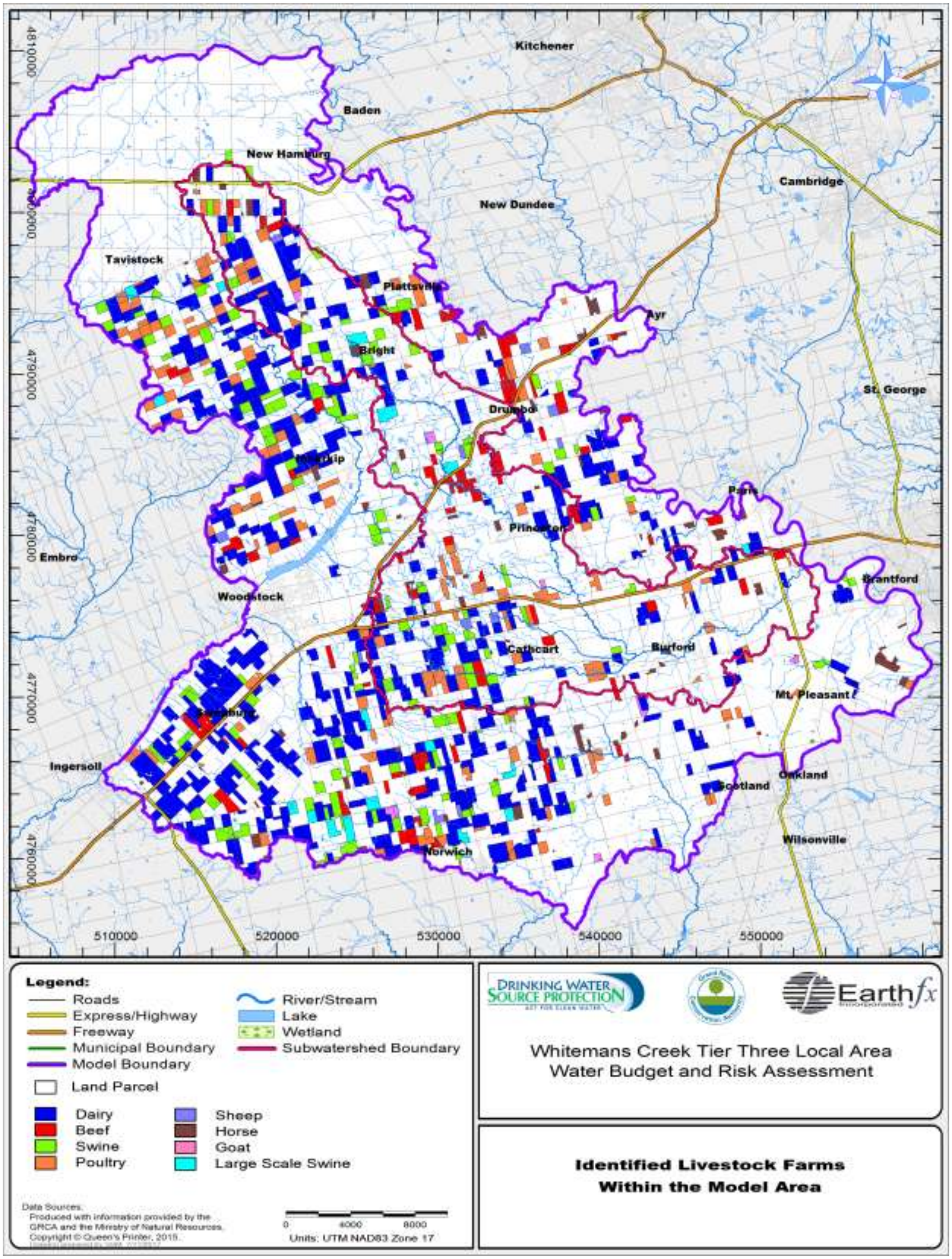

Figure 4.11: Location of livestock farms in the study area.

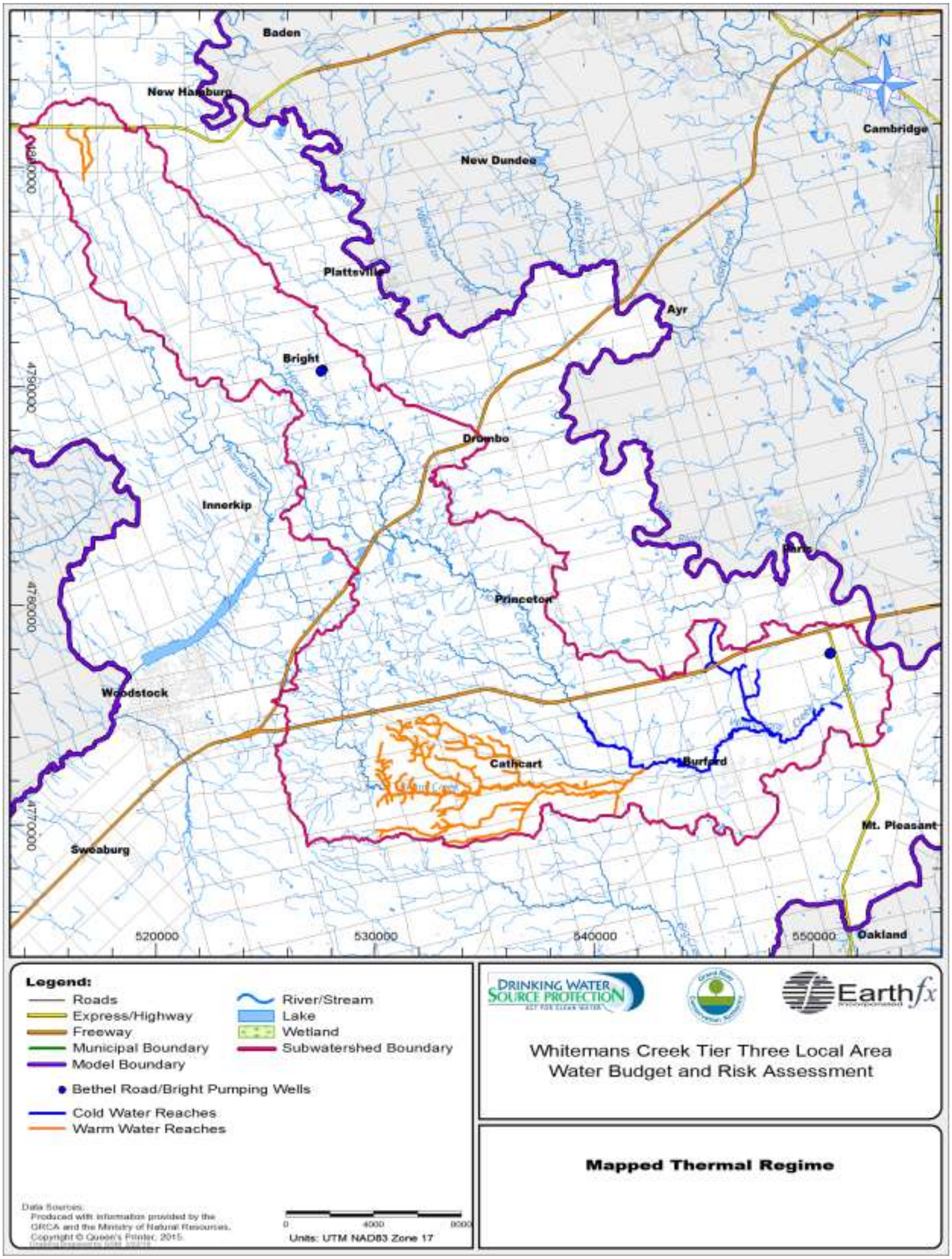

Figure 4.12: Mapped thermal regime for streams in the Whitemans Creek subwatershed.

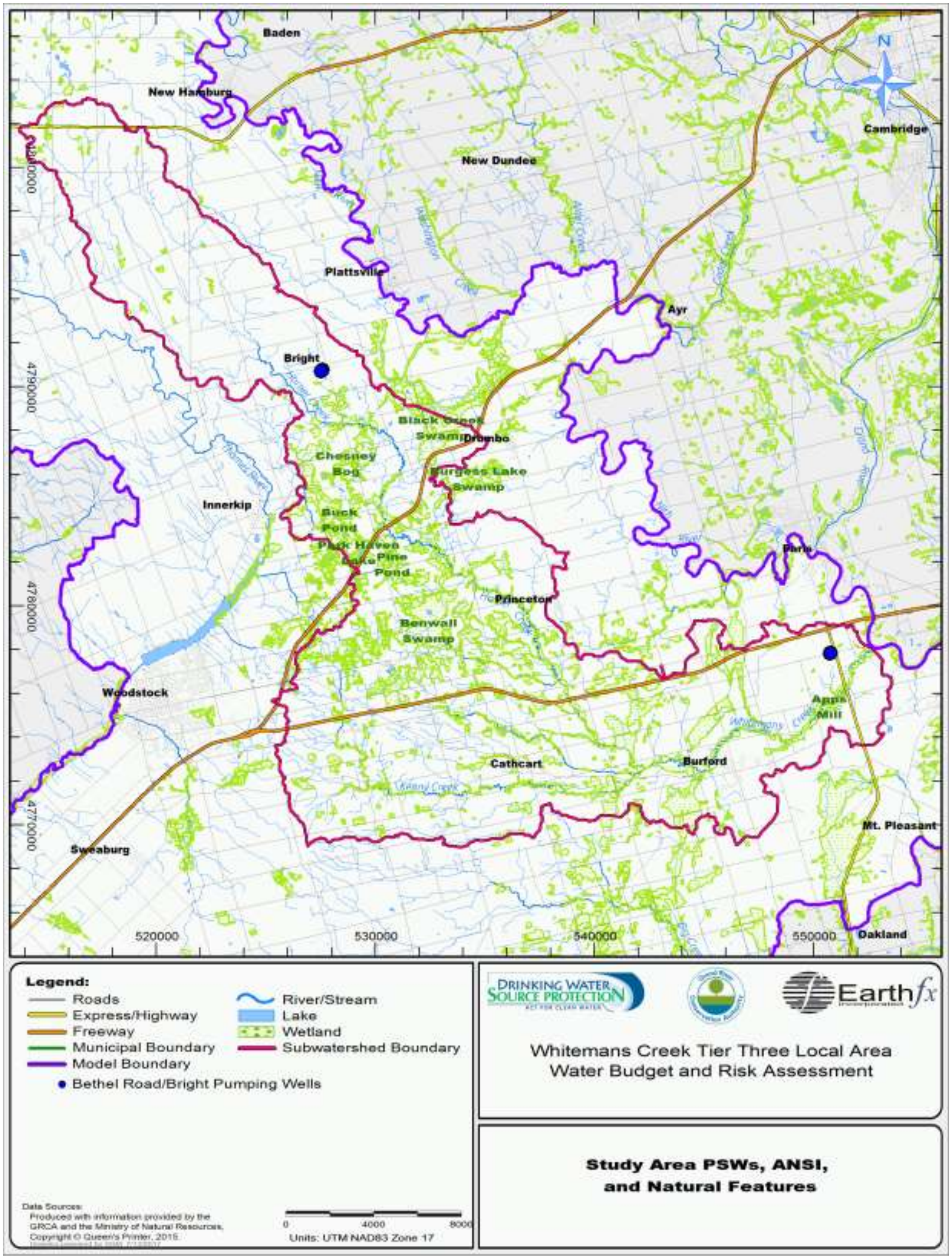

Figure 4.13: Provincially significant wetlands (PSWs), areas of natural and scientific interest (ANSI), and other natural features in the Whitemans Creek subwatershed.

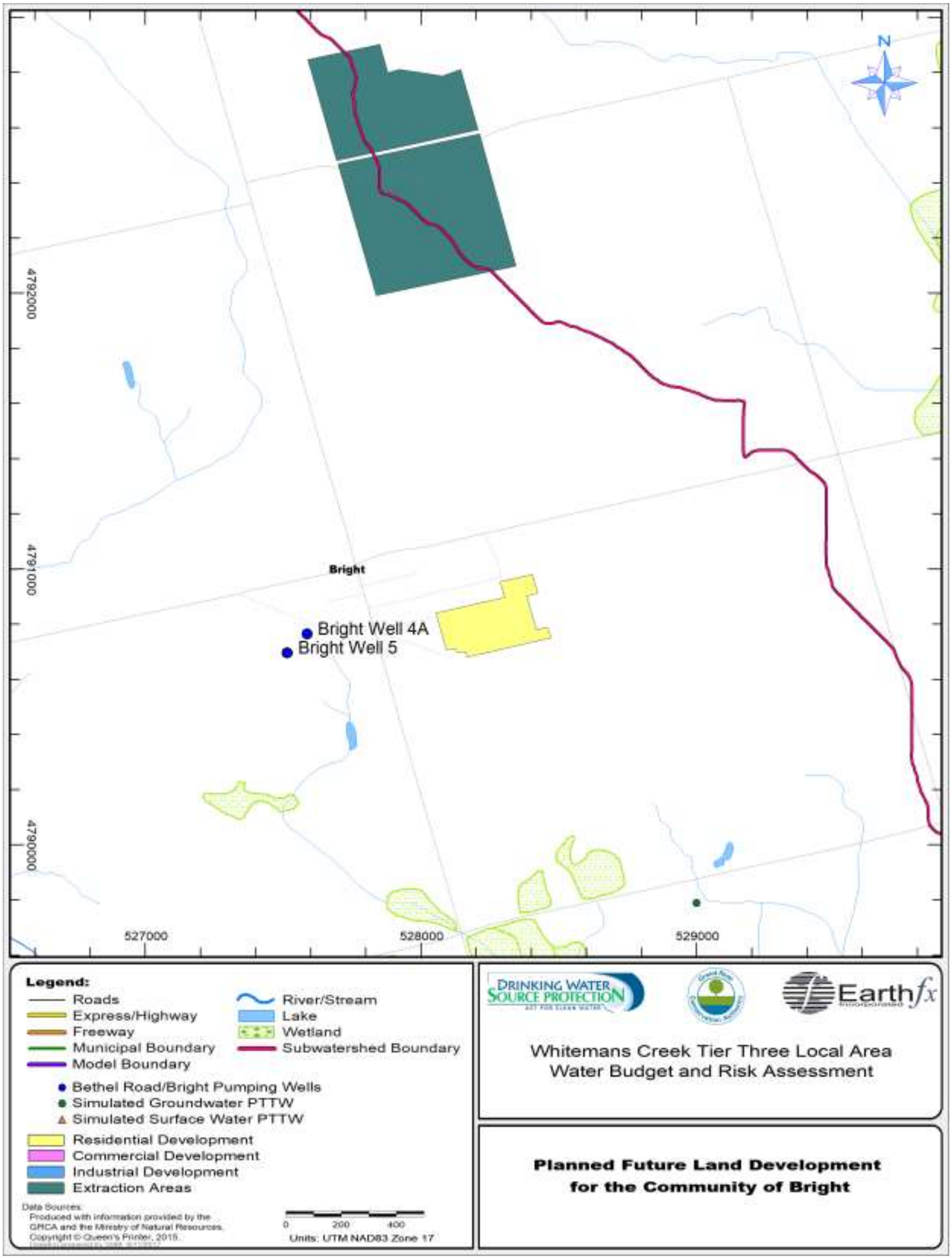

Figure 4.14: Planned future land development for the community of Bright.

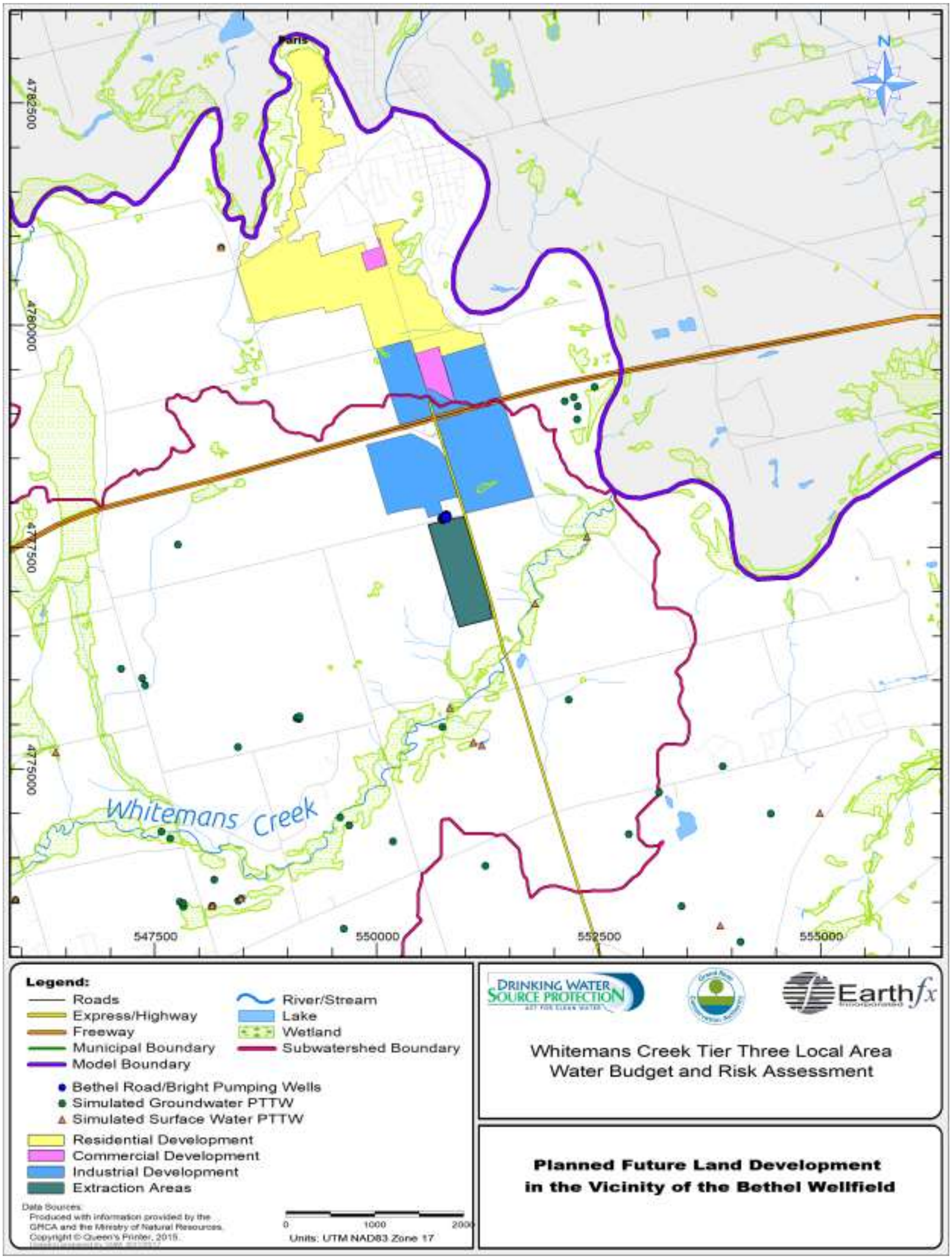

Figure 4.15: Planned future land development in the vicinity of the Bethel wellfield.

5 Tier 3 Water Budget

5.1 *Introduction*

The Whitemans Creek Tier 3 integrated surface water/groundwater model was used to compute the water budget elements for the Whitemans Creek subwatershed. The coupling of the surface water and groundwater systems in the integrated model makes it an ideal tool for obtaining detailed quantitative estimates of all water budget components.

GSFLOW model outputs are similar to those generated for the PRMS and MODFLOW submodels but with a number of significant enhancements. Over 85 different groundwater and surface water flow components can be output on a cell-by-cell basis each simulation day. Earthfx has added additional components to the output and combined some flow components so that local (cell-based) and subcatchment-based water balances can be easily obtained. Daily results are aggregated into monthly, yearly, and long-term averages. All results presented in the following water budget analysis were based on a 25-year GSFLOW simulation from WY1980 to WY2005 and are expressed as annual averages.

5.2 *Whitemans Creek Subwatershed Water Budget*

The water budget components for the Whitemans Creek subwatershed were calculated by two different methods: first, an overall water balance was calculated, taking into account the inputs and outputs to the hydrologic system as a whole; second, an integrated surface water and groundwater budget was calculated. The key difference between the two methods is that exchanges between the surface water and groundwater system (e.g., groundwater recharge or groundwater discharge to the soil zone, referred to in MODFLOW terminology as “surface leakage”) are contained within the overall water balance and do not represent net losses or gains to the system. True losses and gains to the system are therefore only possible via processes that move water into and out of the subwatershed, such as precipitation, lateral groundwater flow across model boundaries, streamflow exiting the area, or evapotranspiration (ET).

5.2.1 Whitemans Creek Subwatershed Overall Water Budget

The overall water budget for the Whitemans Creek subwatershed is presented in Table 5.1. Precipitation represents the largest component of inflow to the subwatershed (95%), with an average annual rate of 953 millimetres per year (mm/y). ET represents the largest loss component from the subwatershed (58.3%), with an average annual rate of 585 mm/y. Average potential ET varies across the study area within a fairly narrow range (between 1050 and 1170 mm/y (see Earthfx, 2017)). The distribution of AET was calculated from the hydrologic submodel and is presented in Figure 5.1. The spatial variability is a function of rainfall, vegetative cover, soil-type, depth-to-water, overland runoff, and infiltration, which can limit the amount of soil water available for ET in summer months. AET rates are high within wetland and riparian areas where soil-water is readily available and rates approach PET demand. Lowest AET rates are typically coincident with urban development and in areas away from streams and wetlands.

No lateral inflow and outflow of overland runoff occurs across the subwatershed boundaries which represent topographic divides. Within the boundaries of the subwatershed, overland runoff is highly variable and dependent on land-cover type, percent imperviousness, topography, and the available soil water capacity. Figure 5.2 shows the spatial distribution of long-term net Hortonian runoff (i.e., infiltration limited runoff) generated in each model cell. Cells with the highest overland runoff correspond to urban areas and the lowest overland runoff corresponds to areas of highly permeable surficial materials. The total runoff out of each model cell is shown in Figure 5.3, which includes, Hortonian runoff (i.e., overland flow), Dunnian runoff (i.e., saturation excess), and interflow.. Dunnian processes are responsible for the largest local quantities of runoff, particularly in the steeply-sloped river banks, where the water table is shallow. Note that not all runoff generated within a cell arrives at a water body due to the distributed nature of the hydrologic submodel. Runoff from one model cell is routed to adjacent cells along the cascade network. Consequently, runoff generated in one cell, may infiltrate in another (see the Model Development Report (Earthfx, 2017) for a more detailed explanation. Cells at the bottom of a cascade flow path tend to have higher soil moisture content, have more available water for ET and groundwater recharge, and contribute more to Dunnian runoff.

Streamflow represents the third largest component of the water budget, making up 34% of the outflows. The subwatershed is drained by Whitemans Creek and its tributaries and there is a single point of discharge from the subwatershed at the confluence with the Grand River. Lateral flows of groundwater across the subwatershed boundary represent a small portion of the overall water budget, making up 4.2% and 6.3% of the total inflow and outflow, respectively. Groundwater pumping and surface water takings also make up a small component of the subwatershed outflows at 0.7%.

Table 5.1: Overall water budget for the Whitemans Creek subwatershed, as simulated by the Tier 3 GSFLOW model.

Water Budget Components	**Inflows (m^3/d)**	**Inflows (mm/y)**	**% of Total Inflows**
Precipitation	1,061,687	953	95.0%
Irrigation	7,125	6	0.6
Lateral Groundwater Flow	46,150	41	4.2%
Change in Storage	2,341	2	0.2%
Total Inflow:	1,117,303	1,003	100%
Water Budget Components	**Outflows (m^3/d)**	**Outflows (mm/y)**	**% of Total Outflows**
Evapotranspiration	652,198	585	58.3%
Groundwater and Surface Water Pumping	8,286	7	0.7%
Lateral Groundwater Flow	70,167	63	6.3%
Streamflow	387,334	348	34.6%
Total Outflow:	1,117,985	1,003	100%

5.2.2 Whitemans Creek Subwatershed Integrated Water Budget

Due to the importance of groundwater-surface water interaction within the subwatershed, an integrated water budget was also calculated. The integrated water budget, summarized in Table 5.2, contains the internal hydrologic processes that move water between the groundwater and surface water environments in addition to the components of the overall water budget. Note that flows in the integrated water budget are presented as net values, where positive values represent net inflows and negative values represent net outflows. Overland runoff to streams and interflow to streams, combined with groundwater discharge to streams and direct precipitation minus evaporation in the stream channel, contribute to stream discharge. It should be noted that groundwater discharge to the soil zone within the riparian areas often emerges as interflow and overland runoff to streams and could be counted as part of the total groundwater discharge to streams (i.e., hyporheic zone discharge).

While the surface water budget is driven by precipitation, the groundwater budget is driven by groundwater recharge. Groundwater recharge, presented in Figure 5.4, is typically highest within the outwash and other coarse granular deposits in the central and southeastern region of the Whitemans Creek subwatershed (see Figure 2.8) and occurs in the higher elevation areas between the wetland complexes. The large distribution of high recharge in the southeast also corresponds to the extensive well-drained soils of the Norfolk Sand Plain.

Flow from the groundwater system to the surface water system is made up largely of groundwater discharge to streams. Long-term average groundwater discharge to streams is presented in Figure 5.5. Discharge to streams (i.e., negative streambed flux values) dominates the subwatershed, with only a small number of losing reaches that tend to correspond to areas of high recharge. Surface leakage (i.e. groundwater discharge to the soil zone in areas of high water table) also represents a significant component of groundwater-surface water interaction. High rates of soil zone discharge occur in areas where the water table is shallow, such as riparian zones or wetlands, while low values tend to occur in areas where the water table is deeper. Groundwater discharge to lakes makes up the final component of groundwater surface water interaction

Precipitation, irrigation, lateral groundwater flow, and streamflow all represent the same quantities discussed above in the overall water budget. AET also represents the same quantity as above, however it is broken into its components simulated in each submodel. Likewise, pumping has been broken into components of groundwater and surface water extraction.

Table 5.2: Water budget for the Whitemans Creek subwatershed (groundwater system).

Water Budget Components	Flows (m^3/d)	Flows (mm/y)
Surface Water Budget		
Precipitation	1,061,687	953
Irrigation	7,125	6
Groundwater Discharge to Soil Zone	34,690	31
Groundwater Discharge to Streams	142,261	128
Groundwater Discharge to Lakes	1,339	1
Evapotranspiration	-622,639	-559
Streamflow	-387,334	-348
Overland Runoff to Streams	180,016	-220
Interflow to Streams	65,360	-59
Surface Water Pumping	-2,567	-2
Groundwater Recharge	-235,479	-211
Groundwater Budget		
Groundwater Recharge	235,479	211
Change in Storage	2,341	2
Groundwater Evapotranspiration	-29,559	-27
Cross Boundary Groundwater Flow	-24,017	-22
Groundwater Discharge to Soil Zone	-34,690	-31
Groundwater Discharge to Streams	-142,261	-128
Groundwater Discharge to Lakes	-1,339	-1
Well Pumping	-5,719	-5

Notes: [1] Highlighted cells represent components of internal groundwater-surface water interaction

5.3 *Stress Assessment*

The Tier 1 and Tier 2 subwatershed stress assessments were aimed at identifying subwatersheds where there is a potential for hydrologic stress. The Whitemans Creek subwatershed was originally assessed as having a stress level of low (AquaResource, 2009b) based on the percent water demand procedure outlined in the Water Budget and Water Quantity Risk Assessment Guide (MNR and MOE, 2011). Ultimately, however, the stress level was increased to moderate due to the performance of Bright Well 4 under drought conditions.

Considerable changes to municipal pumping have occurred in the Whitemans Creek subwatershed since the Tier 2 Stress Assessment. Bright Well 4 has been replaced by a new well (Bright Well 4A), which is capable of meeting the municipal water demands. The Bethel Road wellfield has also been brought online. As such, a re-assessment of the stress level in the subwatershed was completed using the Tier 3 integrated model.

5.3.1 Groundwater Demand Calculation and Stress Assessment Methodology

The subwatershed stress level is assessed using the "percent water demand". Percent water demand is calculated based on the ratio of the water demand to the quantity of water that is available within the subwatershed, where:

$$Percent\ Water\ Demand = \frac{Q_{DEMAND}}{Q_{SUPPLY} - Q_{RESERVE}} x100$$

Q_{DEMAND} is calculated as the average annual and monthly consumptive groundwater takings within the subwatershed; Q_{SUPPLY} is estimated as the groundwater recharge rate plus the annual estimated groundwater inflow into the subwatershed; and $Q_{RESERVE}$ is calculated as 10% of the estimated average annual groundwater discharge rate (assumed in the MOE Guidelines (2009) as representing the amount needed to maintain baseflow in streams).

The stress assessment thresholds are assigned as either low, moderate or significant, and are summarized in Table 5.3. Subwatersheds with a stress assessment level of moderate or significant are considered to be at an increased risk of not being able to meet their required water demand and subject to a Tier 3 Water Quantity Risk Assessment.

Table 5.3: Summary of groundwater stress thresholds.

Groundwater Quantity Stress Level Assignment	Average Annual Percent Water Demand	Monthly Maximum Percent Water Demand
Significant	>25%	>50%
Moderate	>10%	>25%
Low	0-10%	0-25%

5.3.2 Groundwater Demand Calculation and Stress Assessment Results

The percent water demand was calculated using the results from the groundwater budget, discussed above. The average groundwater demand was 5,719 m³/d (see Table 5.2) and the monthly maximum was 22,429 m³/d, occurring in July. The planned average and maximum monthly demand was determined by adding the committed water takings for the Bright and Bethel Road municipal wells of 13.3 and 1059.7 m³/d, respectively, to the existing demand. The percent water demand suggests that the subwatershed stress level is low with existing and planned average demand falling below the 10% threshold and existing and planned maximum monthly demand falling below 25% (see Table 5.4).

The percent water demand results were compared to the Tier 2 analysis (AquaResource, 2009b) for verification. Differences in the models used to complete each analysis meant that not all water budget components could be directly compared. Recharge was slightly lower for the Tier 3 model and consequently, the groundwater supply term used in the percent water demand calculation was approximately 25% smaller than that of the Tier 2 analysis. The groundwater reserve component was also smaller than the Tier 2 analysis, which was a consequence of the lower recharge.

The groundwater demand component represents the largest discrepancy between the Tier 2 and Tier 3 models. The difference can be explained by the different assumptions used to estimate permitted agricultural groundwater takings. The Tier 2 analysis used consumptive demand factors applied to maximum permitted pumping rates, whereas the Tier 3 model used reported (WTRS) pumping rates and applied irrigation water on an as-needed basis based on simulated soil moisture using a custom irrigation demand module (See Earthfx, 2017).

The existing and planned percent water demand from the Tier 3 model was smaller than that of the Tier 2 model on an average and maximum monthly basis. The stress assessment outcome, however, is considered low for both analyses.

Table 5.4: Whitemans Creek subwatershed stress assessment summary.

Percent Water Demand Component		Tier 3 Water Budget Quantity (m^3/d)	Tier 2 Water Budget Quantity (m^3/d)
Groundwater Supply	Groundwater Recharge	235,479	282,873
	Groundwater Recharge From Streams	8,948	10,368[1]
	Groundwater Recharge From Lakes	168	
	Lateral Flow	-24,017	
	Total:	220,578	293,241
Groundwater Reserve		18,741	23,414
Groundwater Demand	Existing Average	5,719	10,109
	Existing Max Monthly	22,429	40,176
	Planned Average	6,792	10,109
	Planned Max Monthly	23,502	40,176
Percent Water Demand	Existing Average	2.8%	4.0%
	Existing Max Monthly	11.1%	15.0%
	Planned Average	3.4%	4.0%
	Planned Max Monthly	11.6%	15.0%

Notes: [1] Tier 2 water budget quantity “Flow In”

5.4 Figures

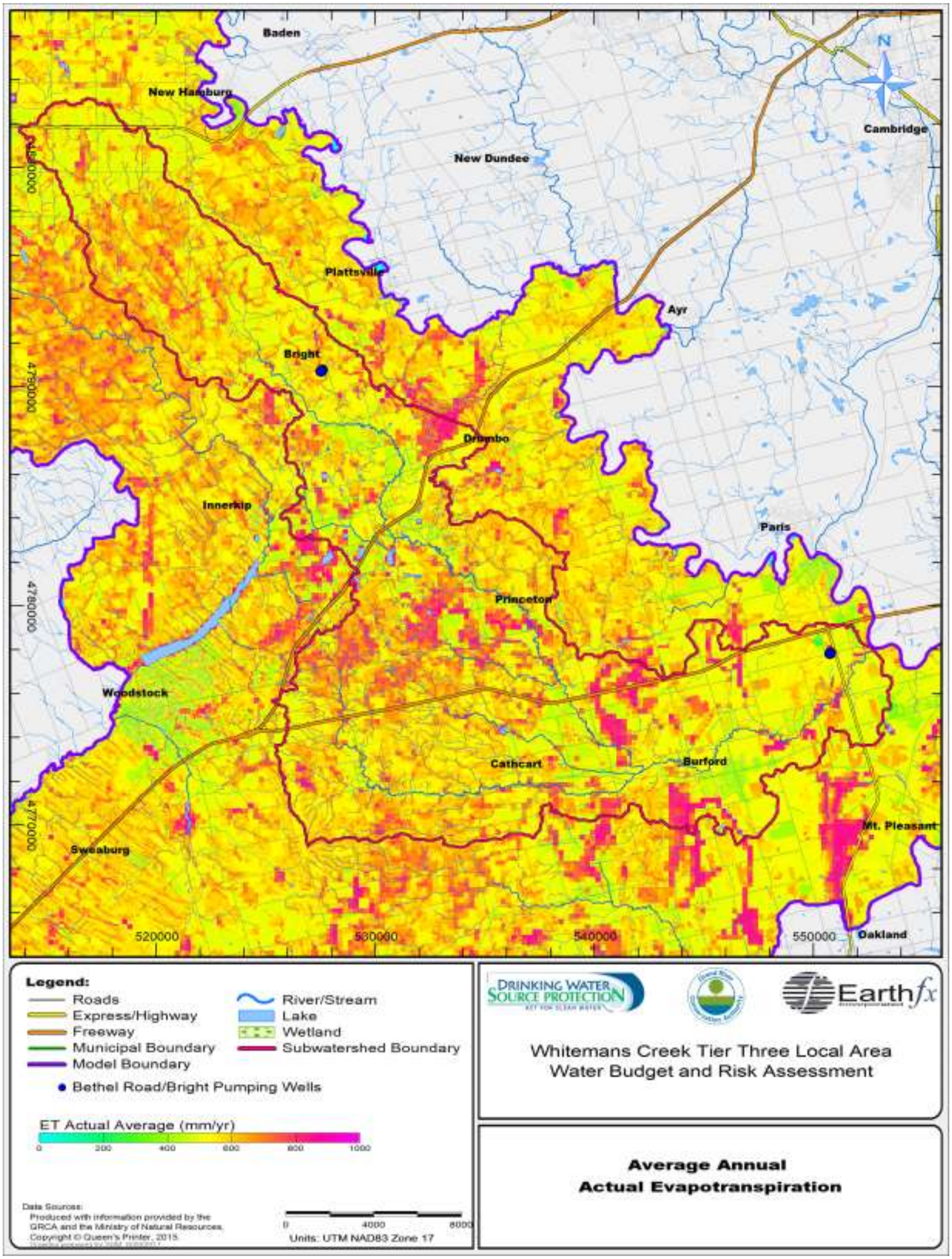

Figure 5.1: Average annual actual ET.

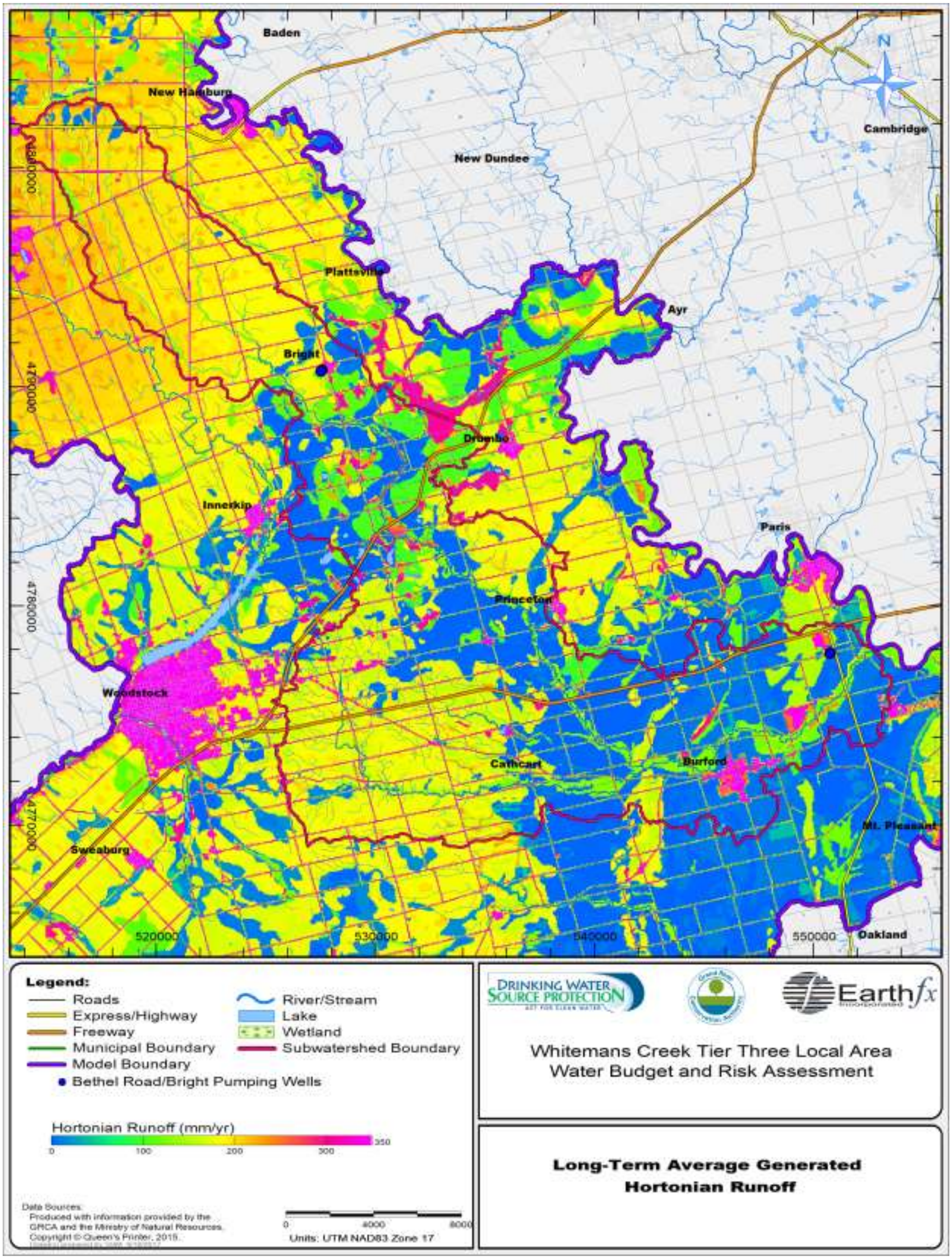

Figure 5.2: Long-term average generated Hortonian runoff.

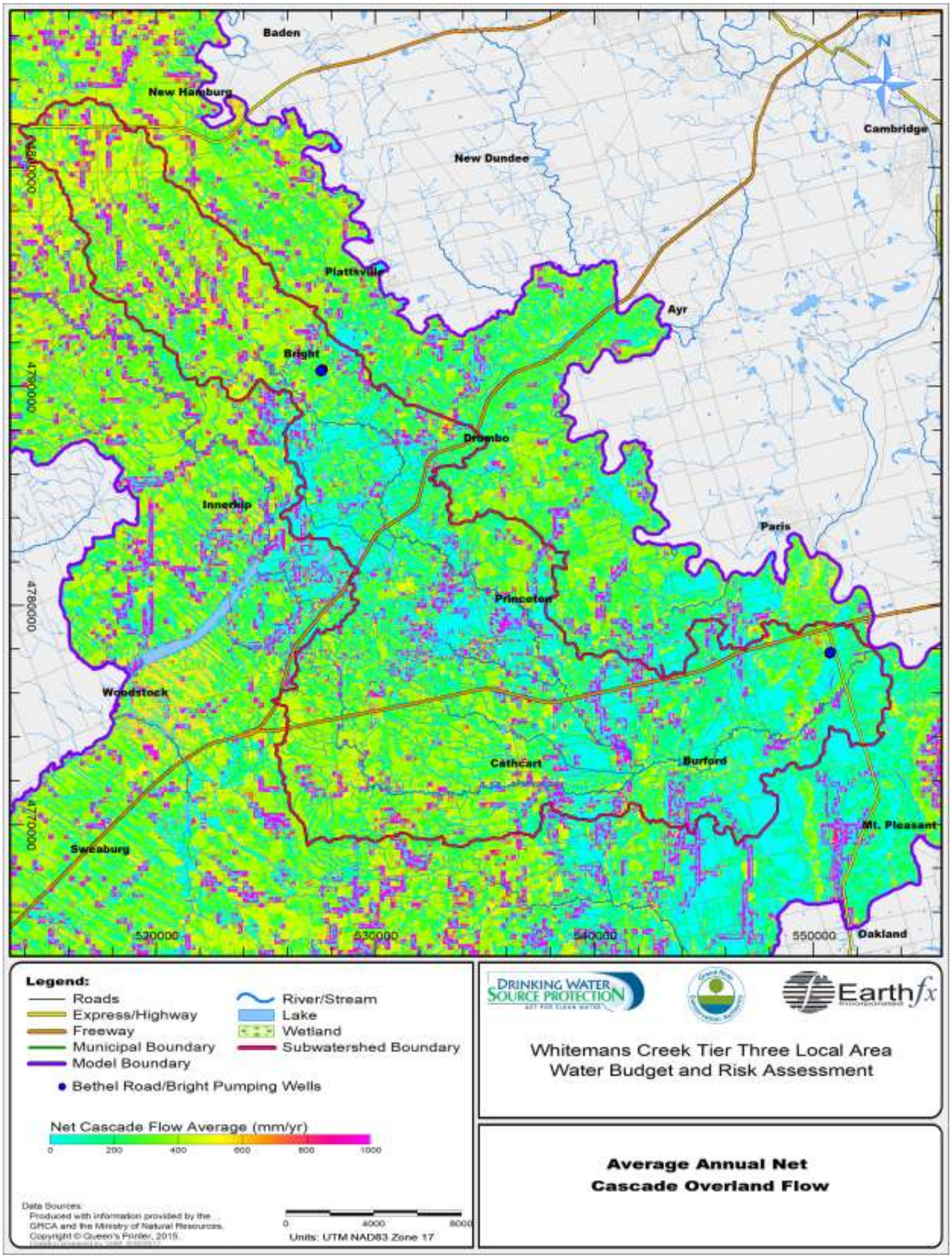

Figure 5.3: Average annual net cascade overland flow.

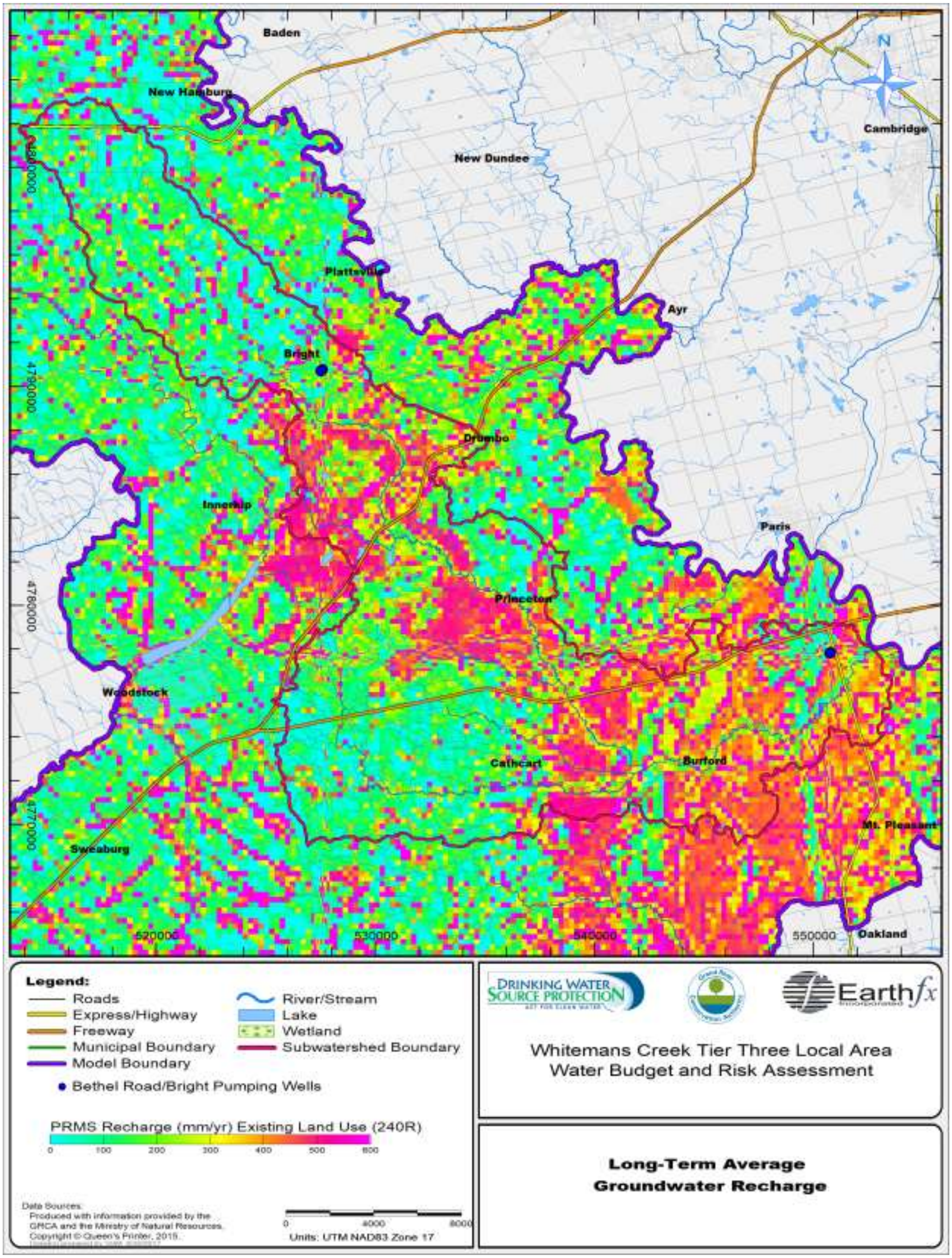

Figure 5.4: Long-term average groundwater recharge applied to the MODFLOW submodel.

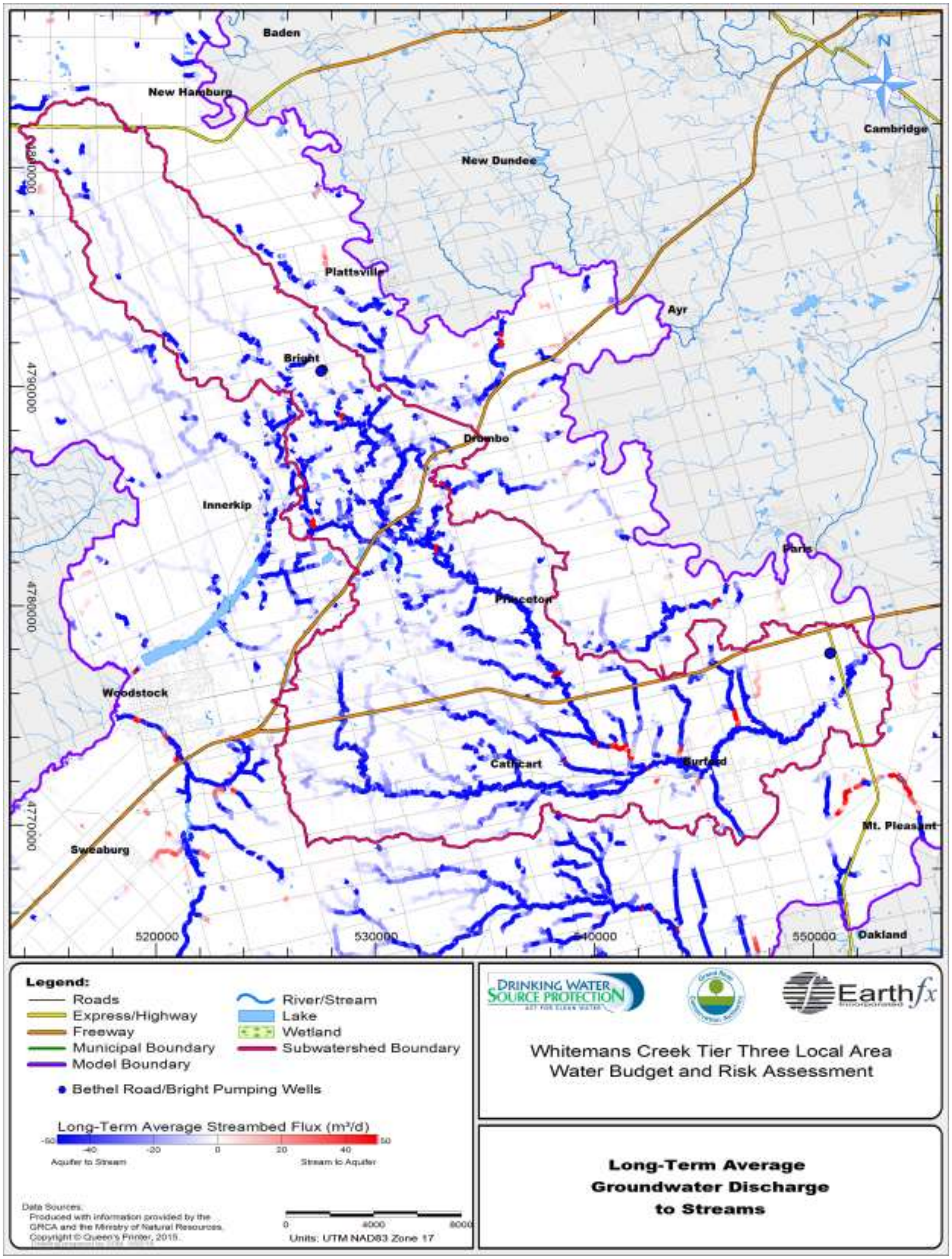

Figure 5.5: Long-term average groundwater discharge to streams.

6 Local Area Risk Assessment

6.1 *Introduction*

A Tier 3 Risk Assessment is undertaken to determine if a groundwater supply is able to meet the needs of a municipality under a variety of water demand, drought, and land development conditions. The following steps are outlined in the MNR Water Budget Guide for completing the local area risk assessment and are the subject of this section of the report:

- **Delineate vulnerable areas:** The groundwater quantity vulnerable areas, WHPA-Q1 and WHPA-Q2, are delineated using the Tier 3 model. These terms are defined in the next section.

- **Define the Local Area:** A "local area" is delineated around the municipal wells for the risk assessment analysis. This term is also defined in the next section.

- **Evaluate risk scenarios**: A set of scenarios are prescribed in the Technical Rules and the Water Budget Guide that consider the impact of changes in allocated quantity of water, long-term average climate, drought conditions, and land use on the sustainability of the municipal wells.

The scenarios, summarized in Table 6.1, were evaluated using the Tier 3 model. Sustainability was measured in terms of the ability to maintain pumping at the municipal well. Impacts to other water uses (e.g., other water takings, wetlands, and aquatic habitat) were evaluated in Scenario G only. Specific details related to each scenario and subsets of each scenario are discussed in Section 6.3.

Table 6.1: Summary of risk assessment scenarios (from MNR and MOE (2011)).

Scenario	Time Period	Data
C	Period for which climate and streamflow data are available for the local area	Data related to average daily pumping rates for water takings and land cover are reflective of conditions during the study period.
D	Ten-year drought period	Data related to average daily pumping rates for water takings and land cover are reflective of conditions during the study period.
G	Period for which climate and streamflow data are available for the local area	Data related to average daily pumping rates for water takings and land cover are reflective of conditions during the year in which the planned system or an existing system with a committed demand is operating at its allocated quantity.
H	Ten-year drought period	Data related to average monthly pumping rates for water takings and land cover are reflective of conditions during the year in which the planned system or an existing system with a committed demand is operating at its allocated quantity.

6.2 *Wellhead Protection and Local Area Delineation*

6.2.1 WHPA-Q1

The WHPA-Q1 is defined in the Technical Rules for the Assessment Report (MOE, 2009), as:

> "*…the combined area that is the cone of influence of the [municipal] well and the whole of the cones of influence of all other [municipal and non-municipal] wells that intersect that area"*.

The cone of influence for a single well or multiple wells can be determined by subtracting the simulated steady-state potentiometric heads (referred to as heads or potentials) in the aquifer under pumping conditions from the simulated steady-state heads with no pumping. The WHPA-Q1 is delineated by determining the change in simulated heads within the production aquifers between the following two model scenarios:

1. Steady-state baseline model using existing land use and no municipal or non-municipal pumping to determine "pre-development" water-use conditions; and

2. Steady-state model using existing land use and planned quantity of water rates for municipal pumping and consumptive use rates for all other water uses as presented in Section 4.

In theory, the cone of influence of a well or group of wells grows until recharge over the area of the drawdown cone balances the pumping withdrawals. However, because the drawdown decreases exponentially away from the pumping centre, the drawdown at large distances may not be measureable and/or may not be distinguishable from natural variation in groundwater levels due to precipitation events and other water takings. Accordingly, a drawdown threshold of 1 m and 0.5 m were selected as the practical limit of the cone of influence for the WHPA-Q1 delineation for the Bright and Bethel wellfields, respectively. These threshold values were established by a review of seasonal variations in monitoring wells at each wellfield, as summarized in Appendix D.

The Bright and Bethel municipal wells draw water from the Waterloo Moraine Aquifer (or equivalent sediments), which is represented largely by Layer 5 of the numerical model. It should be noted, however, that this aquifer unit also occupies a small area in model Layer 4 surrounding the Bethel wellfield. The Waterloo Moraine Aquifer is believed to be in connection with the overlying unconfined Sand Plain/Outwash Aquifer, represented by Layer 3, within the Bethel wellfield area. The WHPA-Q1 was determined by analyzing the cone of influence in Layer 5 for the Bright wellfield, and the combined cones of influence in Layer 3, 4 and 5 for the Bethel wellfield. Water level contour maps for the baseline conditions for Layers 3, 4, and 5 are presented in Figure 6.1, Figure 6.2, and Figure 6.3, respectively.

The simulated drawdown for the Bright wellfield wells does not exceed the established 1 m drawdown threshold and no non-municipal permitted takings are expected to produce drawdowns that coincide with the drawdowns of the municipal wells. The WHPA-Q1 was therefore delineated as a 100 m radius around each well, shown in Figure 6.4.

The cones of influence in model Layers 3, 4 and 5, representing the Sand Plain/Outwash Aquifer and Waterloo Moraine Aquifer, were considered in the WHPA-Q1 analysis for the Bethel wellfield. The 0.5 m drawdown contours for each layer are shown in Figure 6.5. The cones of influence in each model layer were superimposed to delineate the maximum extent of the WHPA-Q1, totalling 6 km², as shown in Figure 6.6.

The drawdown cone produced by the municipal wells is not expected to coincide with drawdowns generated by non-municipal permitted water users, based on the pumping rates used in the model. Specifically, drawdowns from five groundwater sources, corresponding to two PTTWs for aggregate washing located 1.75 km northeast of the Bethel wellfield, did not influence the WHPA-Q1 delineation. The two permits were active from 2004 to 2013 and from 2013 to 2016, respectively; however, they did not report any takings to the WTRS. Consequently, no pumping was simulated at any of the five source locations. More recently, a new permit (7748-AC8KHC) was issued on Aug 31, 2016 with an expiry date of Aug, 31, 2021. The permit consists of three sources: two wells and a dugout pond, each with a maximum daily permitted rate of 691 m³/d, 492.5 m³/d, and 5,892 m³/d respectively. Information on the new permit was found on the Ontario Environmental Registry (www.ebr.gov.on.ca/ERS).

6.2.2 WHPA Q2

The WHPA-Q2 is defined in the Technical Rules (MNR and MOE, 2011) as the WHPA-Q1 plus:

> *"...any area where a future reduction in recharge would significantly impact that area".*

This statement has been interpreted in the MNR Water Budget Guide to mean that the WHPA-Q2 includes the map outline of future land developments, identified in a municipality's Official Plan (OP), that are:

1. outside of or straddle the WHPA-Q1 boundary, and
2. could decrease natural groundwater recharge to a point that it would have a measurable impact on water levels at the municipal pumping wells (MNR and MOE, 2011).

The WHPA-Q1 would expand to include the outline of any proposed developments that both straddle the WHPA-Q1 boundary and decrease natural groundwater recharge to the point that it has a measurable impact on water levels at the municipal pumping wells. If the land developments located outside the WHPA-Q1 are shown to decrease natural groundwater recharge to a point that it would have a measurable impact on the municipal pumping wells, separate WHPA-Q2 areas would be delineated.

Future land developments in the vicinity of the Bright and Bethel wellfields were discussed previously in Section 4.7.2 (see Figure 4.14 and Figure 4.15). The expected increase in imperviousness resulting from the future developments is shown in Figure 6.7 and Figure 6.8 for the Bright and Bethel wellfield areas, respectively. Note that in these figures, imperviousness is represented as a fraction, where a maximum value of 1.0 would indicate a 100% impervious area.

The impact of recharge reduction was determined by subtracting the simulated steady-state heads with the adjusted recharge rate for the new land development areas from the simulated steady-state heads using recharge based on current land use. Adjusted groundwater recharge rates were determined through long-term (25-year) simulations with the PRMS submodel using the percent imperviousness and other changes in vegetative cover properties associated with the new land developments. The same drawdown thresholds of 1.0 and 0.5 m were selected for the Bright and Bethel wellfields, respectively, as per the WHPA-Q1 analysis (see Appendix D).

The impact of the recharge reduction due to future land development at the Bright municipal wells was found to be negligible. Simulated drawdowns in the municipal wells were several orders of magnitude smaller than the 1 m threshold. Accordingly, the WHPA-Q2 is coincident with the WHPA-Q1 for this area.

The planned land development and subsequent recharge reduction is expected to affect the Bethel Road municipal wells. Simulated drawdowns in the municipal wells exceeded the 0.5 m threshold in the Waterloo Moraine Aquifers and in the Sand Plain/Outwash Aquifer. The 0.5 m drawdown contours are shown for Layers 3, 4 and 5 in Figure 6.9. It is difficult, however, to determine from this figure if the drawdowns at the wells are impacted most by development areas that are inside, straddle, or are outside the current WHPA-Q1.

To better determine the impact of the various future development areas, five separate steady-state simulations were run, each considering different land use changes. All developments inside the WHPA-Q1 and three different zones outside were tested (Figure 6.10). Zone 1 and 2 were commercial and industrial developments outside the WHPA-Q1, and Zone 3 was primarily residential, also located outside the WHPA-Q1. The results from each additional simulation are summarized in Table 6.2.

Table 6.2: Summary of incremental additional drawdown in development zones.

Well	Additional Drawdown Threshold (m)	Additional Drawdown (m)				
		All Developments	Developments in WHPA-Q1	Zone 1	Zone 2	Zone 3
TW1/05	0.5	0.56	0.56	0.005	0.013	0.024
PW1/12		0.56	0.55	0.005	0.013	0.024
PW2/12		0.56	0.55	0.005	0.013	0.024
PW4/12		0.56	0.55	0.005	0.013	0.024

The simulations with all future developments and just the future developments within the WHPA-Q1 yielded near identical results. The simulated drawdowns in the municipal wells were between 0.005 and 0.024 m when simulating the recharge reduction associated with the development of Zone 1, 2, and 3 individually.

While the results suggest that developments in Zones 1, 2, and 3 have some impact on the water levels in the municipal wells, developments within the WHPA-Q1 represent the largest impact and are primarily responsible for the drawdowns exceeding the 0.5 m threshold (Figure 6.9). Accordingly, the WHPA-Q2 for the Bethel wellfield was not expanded and remained coincident with the WHPA-Q1.

6.2.3 Local Area Delineation

As per the Technical Rules for the Assessment Report (MOE, 2009):

> *"the term 'local area' is introduced in the Technical Rules to focus the Tier 3 water budget assessment around drinking water wells. The local area for a municipal well is created by combining the following areas:*
>
> *(i) The cone of influence of the well;*
> *(ii) The cones of influence resulting from other water takings where those cones of influence intersect that of the well; and*
> *(iii) The areas where a reduction in recharge would have a measurable impact on the cone of influence of the well."*

Based on this definition, the 'local area' is equivalent to the WHPA-Q2. The final local area delineation is shown in Figure 6.11 and Figure 6.12 for the Bright and Bethel wellfields, respectively.

6.3 *Risk Assessment Scenarios Description*

A series of risk assessment scenarios, listed in Table 6.3, were simulated to assess the impact of increases in water use, drought conditions, and planned future land use change on the sustainability of the municipal wells. The scenarios were evaluated using the Tier 3 numerical model. Sustainability of the Bright and Bethel municipal pumping was measured in terms of the simulated change in water levels in the municipal wells relative to their safe additional drawdown (Table 4.5). Where required, the impact to other water uses was also considered. Detailed descriptions of each scenario are provided below.

Table 6.3: Risk assessment scenario details (from MNR and MOE (2011))

Scenario	Time Period	Model Scenario Details		
		Land Cover	Municipal Pumping	Model Simulation
C	Average conditions	Existing	Existing	Steady-state model with average annual recharge
D	10-year drought	Existing	Existing	Transient model (1952 - 1966)
G(1)	Average conditions	Future Land Use	Allocated quantity of water	Steady-state model with average annual recharge
G(2)		Existing	Allocated quantity of water	
G(3)		Future Land Use	Existing	
H(1)	10-year drought	Future Land Use	Allocated quantity of water	Transient model (1952-1966)
H(2)		Existing	Allocated quantity of water	
H(3)		Future Land Use	Existing	

6.3.1 Scenario C: Existing Land Use and Pumping under Average Climate

Scenario C is intended to verify the ability of the municipal water supply wells to maintain existing pumping rates under average climate conditions. This simulation used the Tier 3 numerical model with existing pumping rates for the municipal supply wells and for other, non-municipal permitted groundwater takings.

This scenario is similar to that undertaken in the model calibration. Average pumping rates for 2012 to 2014 and for 2015 to 2016 were selected for quantifying existing demand of the Bright and Bethel wells, respectively. The long-term average annual groundwater recharge rate (Figure 5.4) was estimated from a 25-year PRMS simulation using the Tier 3 model and climate data from 1975 to 2010.

The numerical model simulates the heads in all aquifers across the study area. Simulated head in the cells containing the municipal water supply wells were extracted from the model results for Scenario C for use as reference water level conditions for comparing the results of the other steady-state stress assessment scenarios (i.e., Scenario G).

The simulated streamflow rates, wetland stage, and groundwater discharge to streams and wetlands for Scenario C were also extracted and used as reference conditions for evaluating the effects of municipal pumping on other water uses.

6.3.2 Scenario D: Existing Land Use and Pumping under Drought Conditions

Scenario D evaluates whether the municipal water supply well is able to pump at the existing pumping rates under drought conditions. The drought period was selected after a careful review of data from AES climate stations proximal to the Whitemans Creek subwatershed. Figure 6.13 presents the annual average precipitation observed over the Whitemans Creek subwatershed for a 150-year period showing long-term trends and the number of stations available as data sources for the interpolation (Figure 6.14 presents the same data for the period spanning WY1931 and WY2016). Estimated average annual precipitation between WY1867 and WY2016 was 897 mm/y over the watershed; while over the past 50 years (WY1967-WY2016), annual precipitation has averaged 955 mm/y. Periods of drought in the observed record occur in the 1890s, 1930s, late-1950s to mid-1960s, and the late 1990s.

The transient GSFLOW simulation period was selected to be WY1952 through WY1966. The first five years of the simulation represented a “start-up” period where precipitation is near the historical average. A 10-year span, WY1957 through WY1966, was selected as the drought period, when average annual precipitation was 829 mm/y. This represents the driest 10-year period between 1904 and 2016.

Pumping rates were varied in the model on a daily basis. This was done by cycling average daily extraction rates for the municipal well for each date. The average daily rates were calculated using reported values from 2012 to 2014 for the Bright wells and from 2015 to 2016 for the Bethel wells. Extraction rates for non-municipal wells were also simulated in the model based on reported takings from the available WTRS datasets.

6.3.3 Scenario G: Planned Future Land Use and Future Pumping under Average Climate

Scenario G evaluates the ability of the municipal well to meet allocated water pumping rates (existing plus committed demand) under average climate conditions and with future changes in land use. This scenario was simulated using the Tier 3 model under steady-state conditions with long-term average annual groundwater recharge.

As per MNR and MOE (2011), Scenario G was subdivided into three scenarios to isolate the impacts of increased municipal pumping from those of planned future changes in land use. The subsets of Scenario G (i.e., Scenarios G(1), G(2) and G(3)) are described as follows:

Scenario G(1) - Allocated (Future) Water Demand and Planned Future Land Use: Scenario G(1) evaluates the combined impact of increased municipal pumping to meet allocated water rates and changes in recharge due to future land use. The future annual average groundwater recharge rate map, determined through a 25-year GSFLOW model simulation with adjusted land-use based model parameters was used in this simulation.

Scenario G(2) - Allocated (Future) Water Demand and Existing Land Use: Scenario G(2) evaluates only the effect of increased municipal water demand for the Bright and Bethel wellfields. The average annual groundwater recharge rate was based on existing land use.

Scenario G(3) - Existing Pumping and Planned Future Land Use: Scenario G(3) evaluates only the impact of future land use changes on the municipal water supply wells. Average existing pumping rates for municipal water supply wells and non-municipal permitted groundwater takings were used in this scenario. The future average annual groundwater recharge rate map, discussed above, was used for this scenario.

6.3.4 Scenario H: Future Land Use and Future Pumping under Drought Conditions

Scenario H evaluates whether the municipal well is able to operate under a 10-year drought with the allocated water pumping rates (existing plus committed demand) and with future land use. The drought time period used for Scenario H is the same as that discussed under Scenario D.

As per MNR and MOE (2011), Scenario H was also subdivided into three scenarios to isolate the effects of increased municipal water demand from those of changes in land use. The subsets of Scenario H (i.e., Scenarios H(1), H(2) and H(3)) are described as follows:

Scenario H(1) - Allocated Water Demand and Future Land Use under Drought Conditions: Scenario H(1) evaluates the combined effect of increased municipal pumping to meet allocate rates and reductions in recharge due to future land use changes. Pumping rates for the Bright and Bethel wells were assigned based on the allocated quantity of water defined in Section 4.3.

Land-use based model parameters were adjusted (i.e., percent impervious and vegetative type and cover densities) to represent future land use change. Drought response in the surface water and groundwater systems was simulated by all the processes and feedback provided by the integrated model.

Scenario H(2) - Allocated (Future) Water Demand and Existing Land Use under Drought Conditions: This scenario evaluates only the effect of pumping at allocated water rates during the 10-year drought period. Land use was assumed to represent existing conditions, as in Scenario D.

Scenario H(3): Existing Pumping and Future Land Use under Drought Conditions: This scenario evaluates only the impact of future land use change on the municipal water supply well during the 10-year drought period. Daily municipal pumping rates were applied as in Scenario D. Daily groundwater recharge rates with future land use changes within the model were calculated as in Scenario H(1).

6.4 *Risk Assessment Scenario Results*

6.4.1 Scenario C (Steady-State): Existing Pumping and Current Land Use under Average Climate

The municipal wells in the Bright wellfield are screened in the Waterloo Moraine Aquifer, represented as Layer 5. The Bethel wells are simulated in Layer 4 or 5, representing the Waterloo Moraine Aquifer (Upper Erie Phase aquifer) and the Grand River Outwash Sand and Gravel aquifer. Simulated groundwater heads for Layers 4 and 5 are shown in Figure 6.15 and Figure 6.16, respectively. As noted previously, Scenario C, which represents existing conditions, served as a baseline for calculating the additional (incremental) drawdown for Scenario G.

The drawdown caused by existing pumping relative to the no-pumping condition were relatively small and of limited extent relative to the scale of the subwatershed. The simulated drawdowns in the vicinity of the Bethel wellfield are shown in Figure 6.17 and Figure 6.18, respectively, and the 0.5 m drawdown is within about 1 km of the wells. The simulated drawdowns are not presented for the Bright wellfield because the drawdowns did not exceed the 1-m threshold. Drawdowns in the wells relative to the no-pumping baseline condition are listed in Table 6.4, and have been corrected or convergent head-losses and well efficiency losses in the wells.

Table 6.4: Simulated steady-state drawdown at the Bright and Bethel municipal wells for Scenario C and Scenario G.

Well	Aquifer	Safe Additional Drawdown (m)	Scenario C Drawdown[1] (m)	Additional Drawdown (m) [2][3]		
				Scenario G(1)	Scenario G(2)	Scenario G(3)
Bright Wellfield						
Well 4A	Waterloo Moraine Aquifer	7.0	1.27	0.20	0.20	0.0
Well 5	Waterloo Moraine Aquifer	12.7	0.41	0.10	0.10	0.0
Bethel Wellfield						
TW1/05	Waterloo Moraine Aquifer	14.7	1.98	11.93	10.72	0.56
PW1/12	Waterloo Moraine Aquifer	9.4	1.79	8.93	7.73	0.56
PW2/12	Waterloo Moraine Aquifer	9.5	1.74	8.76	7.48	0.56
PW4/12	Waterloo Moraine Aquifer	8.9	1.48	8.11	7.00	0.56

Notes:
[1] Scenario C drawdown calculated using no-pumping baseline scenario as reference water level.
[2] Additional drawdown values calculated using results from Scenario C as reference water level.
[3] Values include corrections for convergent head losses and non-linear head losses as per MNR and MOE (2011)

6.4.2 Scenario D: Future Water Demand and Future Land Use under Drought Conditions

Results from the drought simulation in Scenario D were produced by the Tier 3 model run in transient mode with a daily time step for a 15-year period starting in WY1952. For these analyses, simulated average aquifer heads and streamflow for a three-year period (WY1955 to WY1957) were taken to represent pre-drought reference conditions for the rest of the drought scenarios.

Hydrographs of daily heads relative to the average reference water level for the Bright and Bethel municipal wells are presented in Figure 6.19 and Figure 6.20, respectively. The hydrographs for the Bright municipal wells (Figure 6.19) show that the lowest water levels were reached in the fall of 1963 (i.e. start of WY1964). This corresponds to the end of a dry period spanning WY1961 – WY1963 where annual precipitation amounts were well below average (see Figure 6.14). The hydrographs for the Bethel municipal wells (Figure 6.20) show a similar trend, with the lowest water levels occurring around the same time as observed in Bright. However, water levels in the Bethel wells were slow to recover during years of normal precipitation (WY1964 – WY1966). This suggests that the Bethel wellfield is less resilient to drought. Simulated heads in Layers 4 and 5 for October 1, 1963 are presented in Figure 6.21 and Figure 6.22, respectively.

The maximum drawdown under Scenario D was compared to the safe additional drawdown at each municipal well. Drawdowns were calculated relative to the average head for the reference period which served as a baseline condition and are summarized in Table 6.5 for each well, along with the results of Scenario H. Drawdowns in Scenario D were between 1.16 and 1.19 m for the Bright wellfield and between 2.11 and 2.83 m for the Bethel wellfield. The drawdowns under Scenario D represent between 10 and 30% of the safe additional drawdown available in each well. The results indicate that the current operating conditions for the Bright and Bethel wellfields are sustainable during a drought.

Table 6.5: Simulated maximum drawdown at the Bright and Bethel municipal wells for Scenarios D and H

Well	Aquifer	Safe Additional Drawdown (m)	Maximum Additional Drawdown (m)[1][2]			
			Scenario D	Scenario H(1)	Scenario H(2)	Scenario H(3)
Bright Wellfield						
Well 4A	Waterloo Moraine Aquifer	7.0	1.16	1.33	1.33	1.16
Well 5	Waterloo Moraine Aquifer	12.7	1.19	1.25	1.25	1.19
Bethel Wellfield						
TW1/05	Waterloo Moraine Aquifer	14.7	2.33	**16.22**	**15.86**	3.43
PW1/12	Waterloo Moraine Aquifer	9.4	2.18	**14.23**	**13.61**	2.93
PW2/12	Waterloo Moraine Aquifer	9.5	2.11	**12.73**	**12.64**	2.89
PW4/12	Waterloo Moraine Aquifer	8.9	2.83	**12.35**	**11.65**	3.58

Notes:

[1] Additional drawdown values were calculated using daily average head for pre-drought simulation period (WY1955 to WY1957) of Scenario D as the reference water level.

[2] Values include corrections for convergent head losses and non-linear head losses as per MNR and MOE (2011)

6.4.3 Scenario G (Steady-State): Future Water Demand, Future Land Use, Average Climate

Additional drawdowns at the Bright and Bethel wellfields under long-term (steady-state) conditions with future water demand and future land use (Scenario G simulations) were calculated and compared to the safe additional drawdown at the Bright and Bethel wells summarized in Table 6.4. Scenario G was subdivided into three scenarios to isolate the impacts of increased consumptive water demands and recharge reduction due to changes in land use. The results of the subsets of Scenario G are discussed below.

6.4.3.1 Scenario G(1)

Additional drawdown at the municipal wells for Scenario G(1), which evaluates future pumping and future land use change, is less than the safe additional drawdown defined for each of the Bright and Bethel municipal wells (Table 6.4). The Bright wells show little cause for concern since the safe additional drawdown far exceeds the additional drawdown simulated under Scenario G(1). The additional drawdowns in the Bethel wells, however, are simulated to be much closer to the safe drawdown limit. Simulated additional drawdown in the Waterloo Moraine Aquifer relative to reference conditions (Scenario C) is presented for model Layers 4 and 5 in Figure 6.23 and Figure 6.24, respectively. The impact of both increased pumping and future land development can be seen with focussed drawdowns occurring around the municipal wells and in areas of future development (shown previously in Figure 4.14 and Figure 4.15). Figures showing the simulated additional drawdowns are not presented for the Bright wellfield because the drawdowns fell below the 1 m threshold.

The results indicate that the additional drawdowns caused by increased municipal pumping and recharge reductions due to future land use change did not compromise the sustainability of the Bright municipal supply wells under average climate conditions. Drawdowns in the Bethel municipal supply wells also did not exceed the safe additional drawdown limit, albeit by a small margin.

6.4.3.2 Scenario G(2)

Additional drawdowns for Scenario G(2), which evaluates the impacts of future increases in pumping, are presented in Table 6.4. The additional drawdown in the Bethel wellfield is shown for Layer 4 and Layer 5 and is simulated to be between 7 and 11 m. Simulated additional drawdown in the Waterloo Moraine Aquifer relative to reference conditions (Scenario C) is presented for model Layers 4 and 5 in Figure 6.25 and Figure 6.26, respectively. The magnitude of the drawdowns are similar to that of Scenario G(1), suggesting that the increase in pumping contributes more to the simulated drawdown at the Bethel municipal wells than future land use change. This is confirmed further in the discussion of Scenario G(3). Figures showing simulated additional drawdowns are not presented for the Bright wellfield because the drawdowns fell below the 1 m threshold.

6.4.3.3 Scenario G(3)

Additional drawdowns for Scenario G(3), which evaluates the effects of future land use, are presented in Table 6.4. The additional drawdown under Scenario G(3) is negligible at the Bright municipal wells and approximately 0.55 m at each of the Bethel municipal wells. Simulated additional drawdown in the Waterloo Moraine Aquifer relative to reference conditions (Scenario C) is presented for model Layers 4 and 5 in Figure 6.27 and Figure 6.28, respectively. As discussed above, the relative impact of the future land use is considerably smaller than that of the increased pumping in Scenario (G2).

6.4.4 Scenario H (Transient Drought): Future Water Demand and Future Land Use under Drought Conditions

Results from the Scenario H transient drought simulations include stream stage, aquifer heads, and other water budget components calculated on a cell-by-cell basis for each simulation day. The maximum additional drawdowns at the Bright and Bethel municipal wells under transient drought conditions (Scenario H) were compared to their respective safe additional drawdowns. Drawdowns were calculated relative to the simulated average aquifer heads during the reference period of WY1955 to WY1957 from Scenario D. Results are summarized in Table 6.5.

6.4.4.1 Scenario H(1)

Scenario H(1) evaluates the combined impacts of increased consumptive water demand and reductions in recharge due to future land use changes under drought conditions. Hydrographs of simulated daily drawdowns under Scenario H for the Bright and Bethel municipal wells are presented in Figure 6.29 to Figure 6.34 along with drawdowns under Scenario D for comparison.

Additional drawdowns at the Bright municipal wells show minimal change from Scenario D (Figure 6.29 and Figure 6.30) and reach a maximum of 1.33 m at Well 4A and 1.25 m at Well 5 (See Table 6.5) in December of 1963. The additional allowable drawdown was not exceeded under these conditions. The results indicate that the Bright municipal wells are capable of meeting the system water demands under future pumping and land use during drought conditions.

Additional drawdowns in the Bethel municipal wells (Figure 6.31 to Figure 6.34) indicate a considerable impact to the wellfield under drought conditions. Future pumping and land use resulted in large drawdowns, similar to those shown in Scenario G(1), in the steady-state solution used to initialize the transient model. These were further exacerbated by the drought conditions. Well TW1/05 exceeded the safe additional drawdown in September of 1961 and maintained this exceedance for the remainder of the simulation period. Wells PW1/12, PW2/12, and PW4/12 exceeded the safe additional drawdown for the entire drought period. The results indicate that the Bethel wellfield has a high risk of not being able to meet the system demands under future pumping and land use during drought conditions.

6.4.4.2 Scenario H(2)

Scenario H(2) evaluates the impact of an increase in consumptive water demand under drought conditions. Hydrographs of simulated daily drawdowns under Scenario H for the Bright and Bethel municipal wells are presented in Figure 6.29 to Figure 6.34 along with drawdowns under Scenario D for comparison.

Additional drawdowns in the Bright municipal wells are virtually identical to those of Scenario H(1), showing that the allocated pumping rates are expected to have minimal impact on the additional drawdown compared to Scenario D. Again, the maximum additional drawdown simulated in Bright wells 4A and 5 are 1.33 and 1.25 m, respectively (See Table 6.5). The results indicate that the Bright municipal wells are capable of meeting the system water demands under future pumping during drought conditions.

Additional drawdowns in the Bethel municipal wells (Figure 6.31 to Figure 6.34) all exceeded the safe allowable drawdown at some point during the drought period. The impact of increased pumping without the future land use change resulted in slightly smaller drawdowns and the exceedance of the safe allowable drawdown occured slightly later in the simulation, compared to Scenario H(1). The similarity in the result of Scenario H(1) and H(2) suggests that the increase in pumping is responsible for most of the additional drawdown in the municipal wells. Similar to Scenario H(1), the results of Scenario H(2) indicate that the Bethel wellfield is at a high risk of not being able to meet the system demands under future pumping during drought conditions.

6.4.4.3 Scenario H(3)

Scenario H(3) evaluates the impact of reductions in recharge due to future land use changes under drought conditions. Hydrographs of simulated daily drawdowns under Scenario H for the Bright and Bethel municipal wells are presented in Figure 6.29 to Figure 6.34 along with drawdowns under Scenario D for comparison.

As in Scenario H(1) and H(2), the drought conditions had minimal impact on the additional drawdowns at the Bright municipal wells under Scenario H(3). The maximum additional drawdown was 1.23 m and 1.19 m for wells 4A and 5 respectively (See Table 6.5). Under these conditions, the safe additional allowable drawdown will not be exceeded. The Bright wellfield is therefore able to meet the system demands during drought conditions when subject to recharge reductions associated with future land use.

Additional drawdowns in the Bethel municipal wells (Figure 6.31 to Figure 6.34) all fall below the safe additional drawdown threshold. Under this scenario, drawdowns reach a maximum of approximately 3 to 3.5 m, suggesting that the wellfield is able meet the system demands during drought conditions when subject only to recharge reductions associated with future land use.

6.5 *Impacts to Other Uses*

One of the goals of the Scenario G simulations is to develop a better understanding of the threats to other water uses posed by the municipal wells. Other water uses, as defined in the Clean Water Act are discussed in Section 4.6, and include aquatic habitat, provincially significant wetlands, wastewater assimilation, navigation, recreation, and other groundwater takings.

6.5.1 Impacts on Aquatic Habitat

With respect to aquatic habitat, the Technical Rules (MOE, 2009) provide specific thresholds to be used in evaluating the impact to cold water stream reaches. Impacts are measured in terms of changes in average monthly baseflow discharge to streams. A reduction by an amount that is greater than either of the following two criteria is deemed significant (when caused by increases in municipal pumping from a planned system or a reduction in recharge due to future land use change):

- 20% of the existing estimated streamflow that is exceeded 80% of the time (Q_{p80}), or
- 20% of the existing estimated average monthly base flow of the stream.

In addition to the 20% threshold for significance, a moderate risk level occurs if the reduction is between 10 and 20%.

The first criterion can be used where the Q_{p80} values are estimated from gauged flows. The second criterion is more applicable to ungauged streams and was selected for use in this study because it is more compatible with the steady-state analyses completed for Scenarios C and G. For the purpose of this analysis, it was assumed that Scenario G(1) would represent the worst-case scenario (i.e., the most impact) and therefore only results of Scenario G(1) are presented.

Long-term average groundwater exchange between the aquifer system and each stream reach is computed by the SFR2 module in the Tier 3 model run under steady-state conditions. A stream reach, for modelling purposes, is defined as the length of the stream within a model cell. The rate of discharge from each groundwater cell is based on: (1) the difference in head between the aquifer and the water level (stage) in the stream, (2) the hydraulic conductivity and thickness of the streambed, and (3) the wetted area of the stream within the cell. The stage in the stream is calculated from stage-discharge relationship using the baseflow accumulated from all upstream reaches. For the purpose of this analysis, the routed groundwater discharge is assumed to be equivalent to the baseflow and referred to in these analyses as “long-term average streamflow”.

The simulated long-term average streamflow is shown in Figure 6.35 for Scenario C (existing pumping and land use). Figure 6.36 presents Scenario G(1) long-term average streamflow, considering future pumping to meet allocated demand and the recharge reduction associated with future land use. A value of $1x10^{-3}$ m^3/s (1 L/s) was used as a cut-off in this figure to reflect the level of accuracy of the model. [Specifically, observed flows at the three Whitemans gauges were never less than 0.1 m^3/s and the model never simulated daily flows at these calibration points at less than 0.01 m^3/s. Because the accuracy of the model at such low flows was never tested, a threshold an order of magnitude less than this value (0.001 m^3/s) was selected.] The change in simulated groundwater discharge to streams between Scenario C and G(1) (in m^3/s) is shown in Figure 6.37. The same information is presented in terms of the percent decrease between Scenario G(1) and Scenario C in Figure 6.38.

No flow reductions of 1 L/s or greater were simulated in the upper region of the Whitemans Creek subwatershed, near the Bright wellfield under Scenario G(1). This result is consistent with the risk assessment (Section 6.4), which showed minimal drawdowns resulting from increased municipal pumping and the change in land use.

Large flow reductions of between 30 and 60% were simulated in two minor tributaries of Whitemans Creek, south and east of the Bethel wellfield. It is likely that increased pumping at the Bethel municipal wells and recharge reductions due to land use change impacted the simulated flow rates in these reaches. Both reaches are considered as intermittent and neither is mapped by the MNRF as aquatic resource areas. It is unlikely that they support any significant aquatic life and therefore no level of risk is believed to be associated with the reduced flows. Furthermore, portions of these intermittent reaches are coincident with the planned aggregate operation on the south side of Bethel Road (across from the municipal wellfield), and are likely to be removed as a result.

Streams classified by the MNRF as aquatic resource areas, and mapped as warm or cold-water reaches were investigated for any impact. Flow reductions between 0 and 10 % are presented for the warm-water and cold-water reaches in Figure 6.39 and Figure 6.40, respectively. The largest flow reduction observed in either of these classified stream types was 2.4% in Landon’s Creek, a cold-water reach located 4 km west of the Bethel wellfield. Spot flow measurements completed by GRCA in Landon’s Creek (GRCA, 2015), near the confluence with Whitemans Creek, are presented in Table 6.6, along with the simulated flow reduction at the measurement location. The small magnitude flow reduction is below the 10% threshold and is not expected to adversely impact aquatic habitat in Landon’s Creek, nor in Whitemans Creek. The overall risk level associated with flow reductions is therefore classified as low.

Table 6.6: Summary of spot flow measurements in Landon’s Creek.

Water Course	Spot Flow Measurement (m^3/s)			Simulated Flow Reduction (%)
	Oct 30, 2014	May 5, 2015	Aug 24, 2015	
Landon’s Creek	0.08	0.07	0.04	1.1

6.5.2 Impacts to Provincially Significant Wetlands

Thresholds for evaluating risk to Provincially Significant Wetlands (PSW) are not specified in the Technical Rules. One approach, used in other Tier 3 studies, identifies wetlands subject to more than a 1 m of drawdown in groundwater levels beneath the PSW as being at risk (e.g., Earthfx, 2013; Matrix Solutions, 2017). For this study, a 0.5 m drawdown threshold was chosen because the potential impacts are focused around the Bethel wellfield and a 0.5 m water level fluctuation is representative of the seasonal variation in groundwater levels for this area (see Appendix D). Drawdowns were determined by subtracting simulated steady-state heads in the Waterloo Moraine Aquifer and the Sand Plain/Outwash Aquifer under Scenario G(1) from those under Scenario C to evaluate the effects of increased municipal pumping and recharge reductions associated with future land use.

Figure 6.41 shows the 0.5 m drawdown contours in the Sand Plain/Outwash Aquifer (Layer 3) and the Waterloo Moraine Aquifer (Layer 4 and 5). Five small wetland features fall within the 0.5 m drawdown contours. All five features are classified as "unevaluated" by the MNRF and are not considered to be PSWs. Nevertheless, the significance of these wetland features should be evaluated to assess the true ecological impact of increased pumping. One PSW, the Whitemans Creek - Kenny Creek Wetland Complex, is located slightly beyond the 0.5 m drawdown contour to the south and southeast, flanking Whitemans Creek. As this feature is located beyond the cone of influence of the wellfield, the increased municipal pumping and reduction in recharge are not expected to have a significant impact on any PSWs.

6.5.3 Other Groundwater Takings

The impacts to other permitted and non-permitted groundwater takings under Scenario G(1) were assessed by analyzing the simulated drawdowns at non-municipal permitted wells and private wells used for domestic purposes and livestock watering. For the purposes of this study, an impact is defined as a drawdown greater than 1 m in the aquifer in which the well is screened. Drawdowns were determined by subtracting simulated steady-state heads in the screened unit under Scenario G(1) from those under Scenario C, as in Section 6.5.2.

The assessment was focused around the Bethel wellfield, because it was the only location in the Whitemans Creek subwatershed where non-negligible additional drawdowns were observed under Scenario G(1). Groundwater PTTW sources in this area are associated with either the Sand Plain/Outwash Aquifer, Weathered Bedrock Aquifer, or the Salina Bedrock Aquifer, as shown in Figure 6.42. It should be noted that several of the groundwater PTTWs correspond to dugout ponds. While it is recognized that a dugout pond may be more sensitive to drawdowns compared to deep wells, they do not represent an increased risk because that they can be easily deepened. Private wells classified for domestic or livestock water use are also shown in Figure 6.42 and are screened in either the Sand Plain/Outwash Aquifer or the Waterloo Moraine Aquifer. The figure shows the simulated 1-m drawdown contour for the numerical model layers associated with the screen depth of the permitted and non-permitted wells. Drawdowns in the bedrock units are not shown because they do not exceed 1 m.

The analysis showed that no PTTW sources fall within the 1-m drawdown zone. Consequently, there are no significant adverse impacts expected on other permitted groundwater users as a result of the increased municipal pumping.

Twelve private domestic wells are located within the 1 m drawdown contour of the numerical model layer that corresponds to the elevation of the well screen. The potentially impacted wells were assessed to determine the available drawdown at each well for comparison with the simulated drawdown. The available drawdown was assumed to be equal to the difference between the average water level measured in the well and the elevation of the top of the well screen. The results are summarized in Table 6.7. The simulated drawdown exceeds the available drawdown in two wells and there are several instances in which the simulated drawdown exceeds 50% of the available drawdown. It should be noted that the average water level comes from a one-time measurement when the well was installed. Numerous errors and biases are known to exist in the water well records data (Kassenaar and Wexler, 2006). Nevertheless, model results and available data indicate that homeowners with shallow private wells may be affected by future pumping and future land use change, which warrants a moderate risk classification (the highest level that can be assigned according to the Technical Rules). The wells listed in Table 6.7 represent a preliminary analysis for potential impacts. Monitoring of private wells may be required in the future to ensure that future municipal pumping does not interfere with private water users.

Table 6.7: Summary of private wells potentially impacted by future pumping and future land use.

MOECC Well ID	Easting (m)	Northing (m)	Primary Purpose	Hydrogeologic Unit	Layer Number	Top of Well Screen Elevation (m)	Average Water Level (m)	Available Drawdown (m)	Simulated Drawdown (m)
1302240	549955	4777576	Domestic	Sand Plain/Outwash Aquifer	3	251.54	253.07	1.52	1.18
1301346	550414	4777763	Domestic	Sand Plain/Outwash Aquifer	3	260.89	262.72	1.82	1.23
1302238	550243	4777766	Domestic	Sand Plain/Outwash Aquifer	3	249.43	250.65	1.21	1.15
1304534	550506	4777779	Domestic	Waterloo Moraine Aquifer	5	239.71	245.81	6.09	3.25
1301283	551594	4777983	Domestic	Sand Plain/Outwash Aquifer	3	236.00	236.62	0.61	1.19
1301649	551314	4777923	Domestic	Sand Plain/Outwash Aquifer	3	241.26	244.32	3.05	2.33
1301294	551224	4777883	Domestic	Sand Plain/Outwash Aquifer	3	243.26	245.09	1.82	2.43
1305918	549933	4777540	Domestic	Sand Plain/Outwash Aquifer	3	246.48	249.23	2.74	1.18
1304920	550825	4780041	Domestic	Sand Plain/Outwash Aquifer	3	236.87	247.23	10.35	2.5
1305088	549870	4778033	Domestic	Waterloo Moraine Aquifer	5	245.01	260.26	15.24	1.41
1300156	551734	4778243	Domestic	Sand Plain/Outwash Aquifer	3	233.33	238.52	5.18	1.16
1301531	549834	4777633	Domestic	Sand Plain/Outwash Aquifer	3	247.39	250.14	2.74	1.3

6.6 *Local Area Risk Assessment Results*

Water Quantity Risk Level Classification was performed for the local areas delineated for the Bright and Bethel municipal wells (Figure 6.11 and Figure 6.12). The assignment of risk was conducted based on the circumstances summarized in the Water Budget Guide. The risk classification considers the tolerance of the wells to peak pumping rates under existing conditions, and the impacts of the risk assessment scenarios on other water uses (i.e., wetlands, streamflow, non-municipal permitted water users) and the municipal wells. The risk assignment was then evaluated for uncertainty.

6.6.1 Tolerance

The Tier 3 assessment considers a municipal water system's tolerance to risk. The Technical Rules state that "tolerance is evaluated to determine whether an existing system is capable of meeting peak demand". Under Rule 100:

> *…a tolerance level shall be assigned to the existing type I, II or III system which the local area relates that is the subject of evaluation in accordance with the following:*
>
> *(1) A tolerance level of high if the existing system is capable of meeting peak demand during all assessment periods.*
>
> *(2) A tolerance level of low if sub-rule (1) does not apply to the existing system.*

Tolerance was evaluated through Scenario D, which used actual reported takings. Peaking rates were implicitly incorporated into the simulated daily takings based on the use of the reported pumping rates. Table 6.8 summarizes existing demand and maximum simulated daily taking under drought Scenario D for each municipal well in the Tier 3 assessment area. Both wellfields take advantage of a multi-well system that allows peak demand to be shared to achieve the minimum impact in each well. The maximum simulated taking rates represent between approximately 50 and 400% increased pumping relative to the average existing demand.

The Tier 2 Water Budget and Stress Assessment (AquaResource, 2009b) expressed concerns regarding the sustainability of one of the older production wells (Well 4) in the Bright wellfield under drought conditions. This well has since been taken offline and Well 4A was installed as a replacement water supply source. According to the Section 5.84 of the Risk Assessment Guidelines (MRN and MOE, 2011), if updates have been made to the system to alleviate the concerns, the tolerance is subsequently assigned as being high. While the Bright wellfield does meet this criteria and the risk assessment analysis indicated that drawdowns at the wells are not at risk of exceeding safe levels under Scenario D (See Figure 6.29 and Figure 6.30), the system still lacks redundancy. Currently, Well 4A is responsible for meeting the majority of the demand and Well 5 is likely not sufficient to meet demands in the event that Well 4A is taken offline for an extended period of time. Finding a more reliable water source for Bright has proven difficult after several nearby test holes yielded insufficient water quality and or quantity. The Bright wellfield is ultimately assigned a tolerance of high under the Tier 3 rules; however, unplanned outages of Well 4A (e.g., pump failure or well screen fouling) could have significant negative consequences as the system may be temporarily unable to meet demand.

The Bethel wellfield is also considered to have a high tolerance under Scenario D despite passing the sustainability Scenario G(1) only by a small margin. The high tolerance of the Bethel wellfield comes from the available storage and redundancy of the Town of Paris water distribution system. The town is serviced by two other wellfields (Gilbert wellfield and Telfer wellfield), which can be used to supply water to the service population of the Bethel wellfield (Pressure Zone 3) through the M. Sharpe Reservoir. The Reservoir has a capacity of 5400 m³ and a standard operating capacity of 150 L/s, which exceeds the average daily and peak daily future water demand of the Bethel wellfield service area (WSP, 2016).

Table 6.8: Summary of existing demand and maximum simulated daily pumping rates under Scenario D.

Well Name	Existing Demand (m^3/d)	Maximum Simulated Daily Taking under Scenario D (m^3/day)
Bright Local Area		
Well 4A	88.8	139
Well 5	6.7	30
Bethel Wellfield		
TW1/05	53.7	122
PW1/12	80.4	141
PW2/12	89.9	234
PW4/12	90.1	373

6.6.2 Risk Classification

6.6.2.1 Bright Municipal Wellfield Local Area

The results of the risk assessment scenarios (G and H) suggest that the Bright municipal wellfield is capable of meeting existing and allocated water demands for current and future land use during both average climate and drought conditions. Despite its lack of redundancy, the tolerance of the Bright municipal wellfield is considered high because there is sufficient additional drawdown in the wells even when pumped at peak rates. Further, no impacts to other users, including aquatic habitat, PSWs, and other permitted takings are anticipated. As such, the Local Area was assigned a risk level of “low” (Table 6.9).

6.6.2.2 Bethel Road Municipal Wellfield Local Area

The results of the risk assessment scenarios suggest that the Bethel wellfield is capable of meeting existing water demands for current and future land use conditions during an average climate period and during a drought. The system was assigned a tolerance level of high based on the performance of each well under existing demand and the availability of storage and other sources of water supply in the distribution network.

However, the system was only able to meet the allocated water demand under an average climate period by a small margin and was not able to meet the allocated water demand under drought conditions. This condition violates the significant risk circumstance in the Water Budget Guide:

> *"In respect of scenarios H1, H2 and H3, it is determined in any of those scenarios that a period of time would exist where the quantity of water that can be taken from the groundwater in the local area would be insufficient to meet the allocated quantity of water of the well."*

Consequently, the local area was assigned a risk level of "significant" (Table 6.9). The municipal wells were assessed as representing a risk to several nearby shallow private wells. This alone would result in a "moderate" level of risk being assigned to the local area. As noted above, a risk level of "high" was already assigned because of the inability of the wells to meet allocated demand under drought conditions. No impacts to other users including aquatic habitat, and PSWs are anticipated.

Table 6.9: Assigned Risk Levels.

Local Area	Tolerance	Risk Level
Bright Municipal Wellfield Local Area		
Well 4A	High	Low
Well 5	High	Low
Bethel Road Municipal Wellfield Local Area		
TW1/05	High	Significant
PW1/12	High	Significant
PW2/12	High	Significant
PW4/12	High	Significant

6.6.3 Uncertainty Assessment

According to the Technical Rules (Rule 108) and MOE (2010), an uncertainty analysis must be conducted after assigning a risk level to a local area that considers the following factors:

(1) the distribution, variability, quality and relevance of the data used to evaluate the scenarios;
(2) the degree to which the methods and models used to evaluate the scenarios accurately reflects the hydrologic system of the local area for both steady state and transient conditions;
(3) the extent and level of calibration and validation achieved for any groundwater and surface models used or calculations and general assessments completed;
(4) the quality assurance and control procedures used in evaluating the scenarios.

These factors were considered to determine whether the uncertainty underlying the risk assignment should be characterized as high or low.

6.6.3.1 Distribution, Variability, Quality and Relevance of Data Used to Evaluate Scenarios

The distribution of data used to describe the geologic, hydrogeologic, and hydrologic setting of the study area was discussed at great length in the Model Development and Calibration Report (Earthfx, 2017). Data from a variety of sources, including climate records, streamflow measurements, static and transient groundwater levels, geologic logs, and pumping data were collected, reviewed, and synthesized for the original work.

Overall, the data coverage for the study area is comparable to and, in some cases, exceeds that for other Tier 3 studies. In particular, the number of transient groundwater monitors is high especially in the vicinity of the municipal wells. The subwatershed has three WSC stream gauges and there are a relatively high number of AES and other climate stations within and adjacent to the study area. Although there were issues noted with the quality, temporal coverage, and spatial coverage of the MOECC WWIS groundwater level data used in the steady-state calibration and gaps in the climate data record, on the whole, the amount of data available, the overall quality of the data, and the density of coverage in the vicinity of the municipal wells is good. Despite these considerations, it is acknowledged that there is always a degree of uncertainty with regards to hydrogeologic properties and model assumptions needed to extrapolate available data. Specifically with respect to the Bethel Wellfield, the wells are relatively new and there is a lack of a long-term history of operations and no long-term aquifer testing data. The lack of long-term data raises the uncertainty of the models predictions of future response to change in pumping and land use.

6.6.3.2 Degree to Which Method and Models Used to Evaluate Scenarios Accurately Reflects the Hydrologic System of the Local Area

The Whitemans Creek Tier 3 model represented a significant localized refinement of the hydrologic, geologic, and hydrogeologic setting compared to the Grand River Watershed Tier 2 model. In particular, the hydrogeologic framework was based on the recent Brantford-Woodstock OGS model (OGS, 2010), which had full coverage of the Whitemans Creek subwatershed and local geologic surfaces were further revised to improve the representation of the geologic conditions around the Bright and Bethel wellfields.

Both the hydrologic and groundwater flow submodels are deterministic, distributed, physically-based models. The hydrologic model considered climate inputs, topography, soils, and land use data in computing dynamic soil water balances, groundwater recharge, and overland flow to streams on a daily basis. The groundwater flow model represents saturated groundwater flow along with streamflow, and lake water balances. These models have been employed in a rigorous manner to model the surface and subsurface hydrologic processes within the local area with specific focus on the interaction and feedback between the groundwater and surface water systems as required under the Technical Rules. The representation of the surface water system, groundwater/surface water interaction, and the effect water takings is much improved over previous Tier 1 and 2 models. The Tier 3 model also included a new irrigation demand module to better estimate the timing and volumes of surface water and groundwater takings for agricultural irrigation based on climate inputs as well as the fate of the applied water.

By integrating the PRMS and MODFLOW submodels in GSFLOW, feedback mechanisms between the groundwater and surface water systems are better represented. The reasonableness of submodel outputs (e.g., groundwater recharge values from the hydrologic submodel and groundwater discharge to the soil zone from the groundwater submodel) and the overall water budget were tested much more rigorously than with a separate, non-integrated model. Although no model can perfectly match the observed behaviour due to inherent simplifications and incomplete information, it is felt that the conclusions based on model results are reasonable, physically-based, and scientifically sound.

6.6.3.3 The Extent of the Calibration and Validation Achieved for any Groundwater and Surface Water Models used or Calculations and General Assessments Completed

The Tier 3 model was calibrated to a wide range of conditions, including extreme wet and dry-year conditions, and across multiple seasons. A local-scale validation test was also completed against two Bethel wellfield pumping tests to further validate the model to anticipated future rates that would be applied as part of the risk assessment scenarios. This validation work was undertaken after the initial model development work (Earthfx, 2017) and has been documented in a separate memorandum.

Between the extensive calibration effort undertaken during the model development, and the supplementary validation work around the Bethel wellfield, a high degree of confidence in model results was obtained. The updated Tier 3 model is therefore suitable for determining the sustainability of the municipal wellfield as part of the Tier 3 Risk Assessment.

6.6.3.4 The Quality Assurance and Control Procedures Used in Evaluating the Scenarios

The models require a large amount of data analysis and preparation prior to initiating a scenario analysis. Great care was used in setting up, documenting, and conducting each risk assessment scenario. Multiple levels of internal review were conducted to ensure that the input data preparation programs produced correct input files. All model outputs were saved and reviewed through visual inspection of hydrographs, digital mapping, and animations.

6.6.3.5 Assignment of Uncertainty

The tolerance and the risk assignment were evaluated based on the above-noted factors. Assignment of risk levels and tolerance ratings to the local areas relied heavily on accurately simulating pumping rates and achieving a realistic hydrologic response from the model. The simulated pumping rates were determined from reported takings and were cycled on an annual basis. This represented realistic operating conditions that included peak rates. The local hydrogeology was also refined to improve the representation of the groundwater flow processes in the vicinity of the local areas. Separate testing was done with the model to match aquifer test results at these locations.

The assignment of risk also required the model to accurately simulate the effects on streamflow, wetlands, and other permitted groundwater users. The model was able to accurately represent the hydrologic and hydrogeologic environment on a subwatershed scale, including the interaction of groundwater and surface water. Groundwater levels and streamflow were also calibrated to multiple transient targets to verify model performance.

As a consequence, the risk level and tolerance assignments for the local area surrounding the Bright Wellfield have been given a low level of uncertainty given the model's ability to represent large-scale and local-scale processes required by the risk assessment scenario analysis. However, the lack of a long-term history of operations and long-term aquifer testing data raised the uncertainty of the model predictions in the Bethel wellfield area. Accordingly, the risk level assignment for the local area surrounding the Bethel Wellfield has been given a high level of uncertainty. The uncertainty assignment is summarized in Table 6.10.

Table 6.10: Summary of uncertainty associated with tolerance and risk level assignment

Local Area	Tolerance	Risk Level
Bright Municipal Wellfield Local Area	Low uncertainty	Low uncertainty
Bethel Road Municipal Wellfield Local Area	Low uncertainty	High uncertainty

6.7 *Figures*

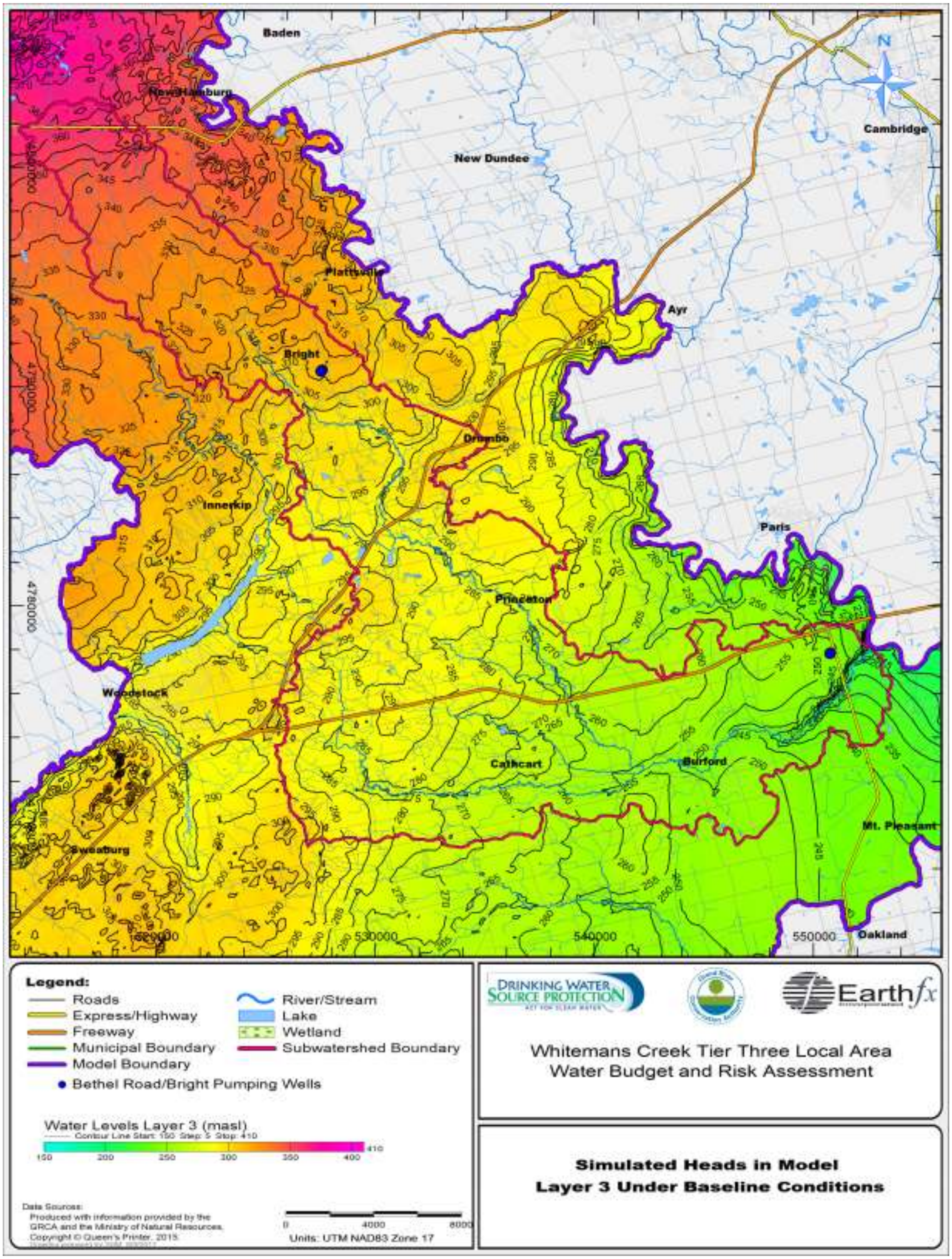

Figure 6.1: Simulated heads in model layer 3 under baseline conditions.

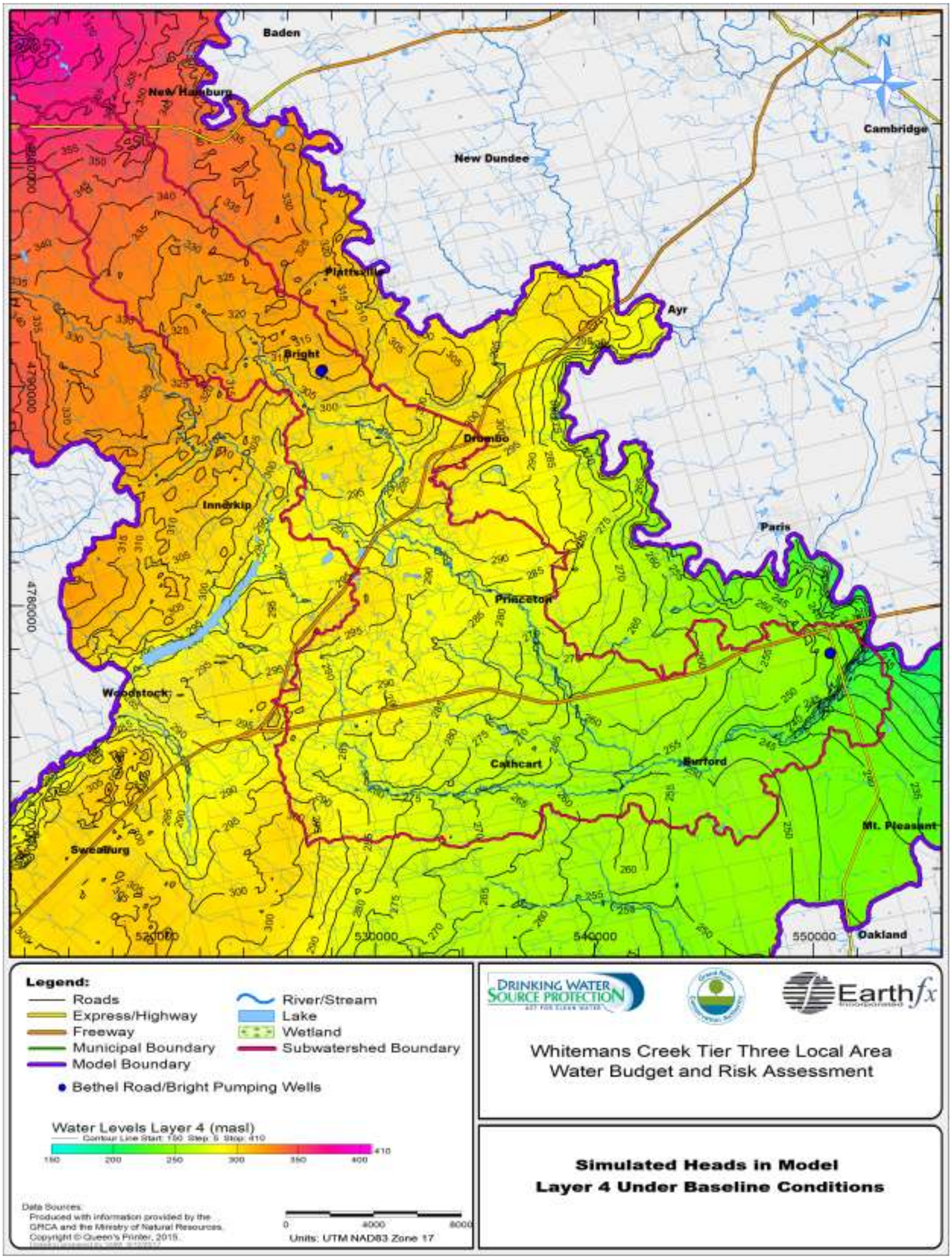

Figure 6.2: Simulated heads in model layer 4 under baseline conditions.

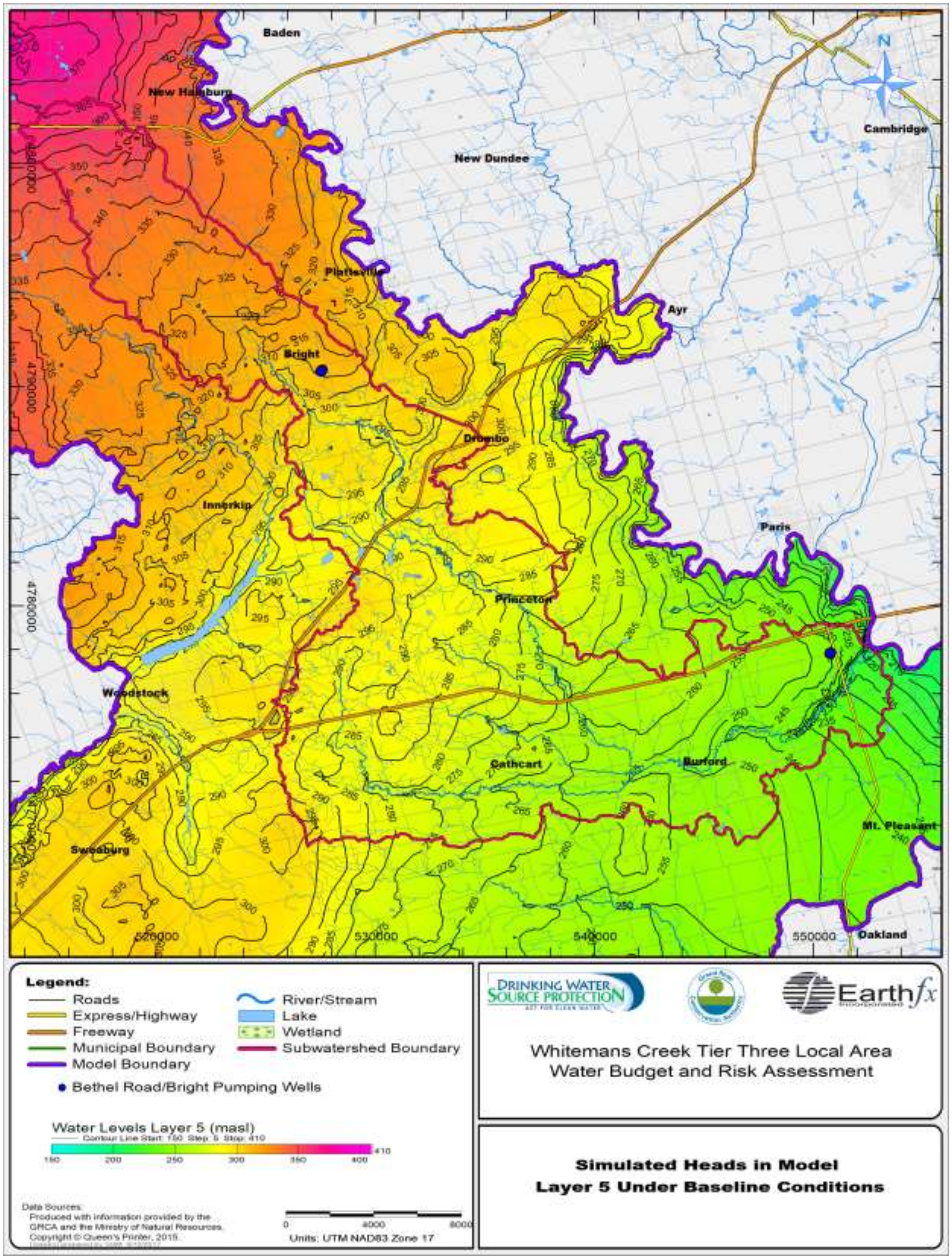

Figure 6.3: Simulated heads in model layer 5 under baseline conditions.

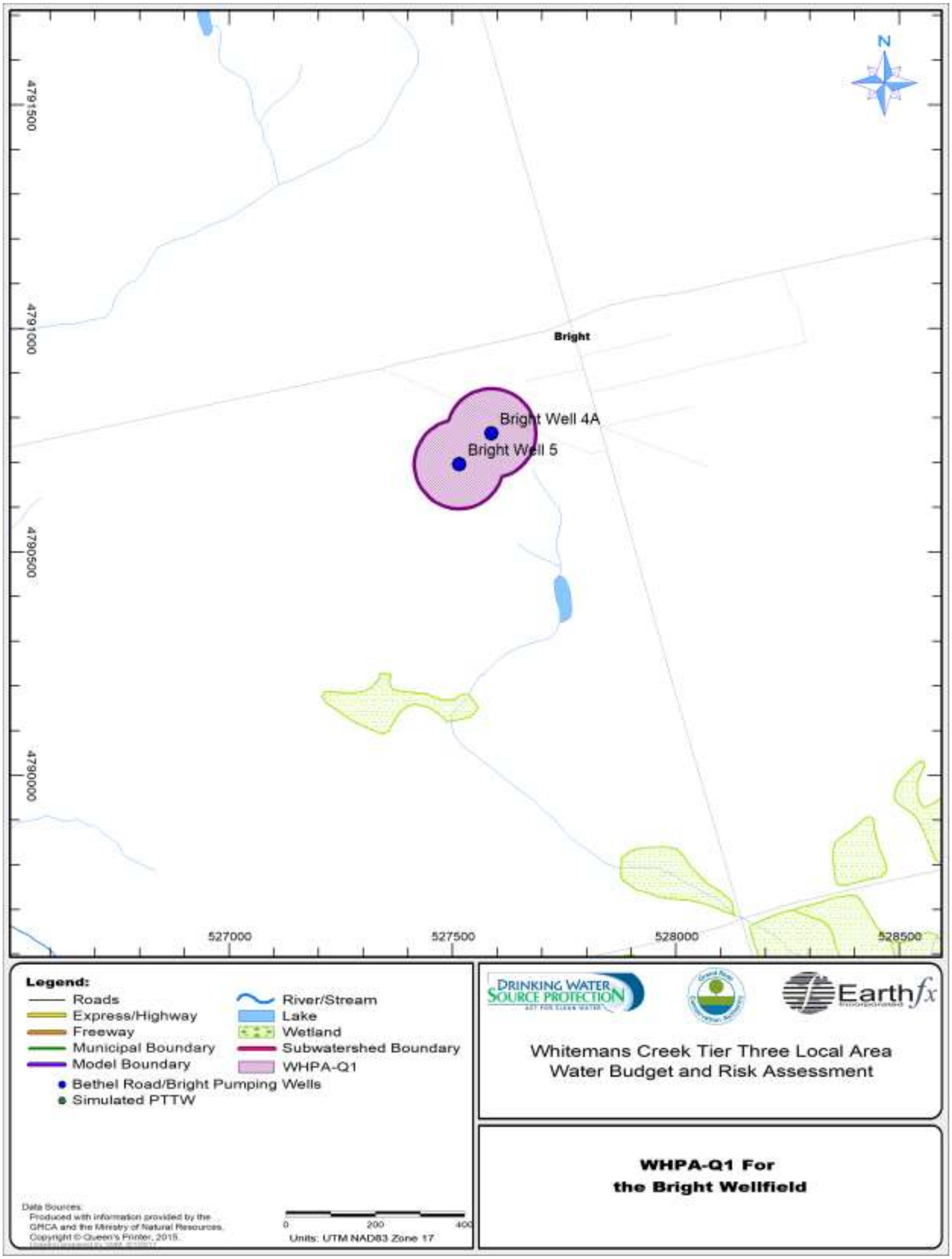

Figure 6.4: WHPA Q1 delineation for the Bright wellfield.

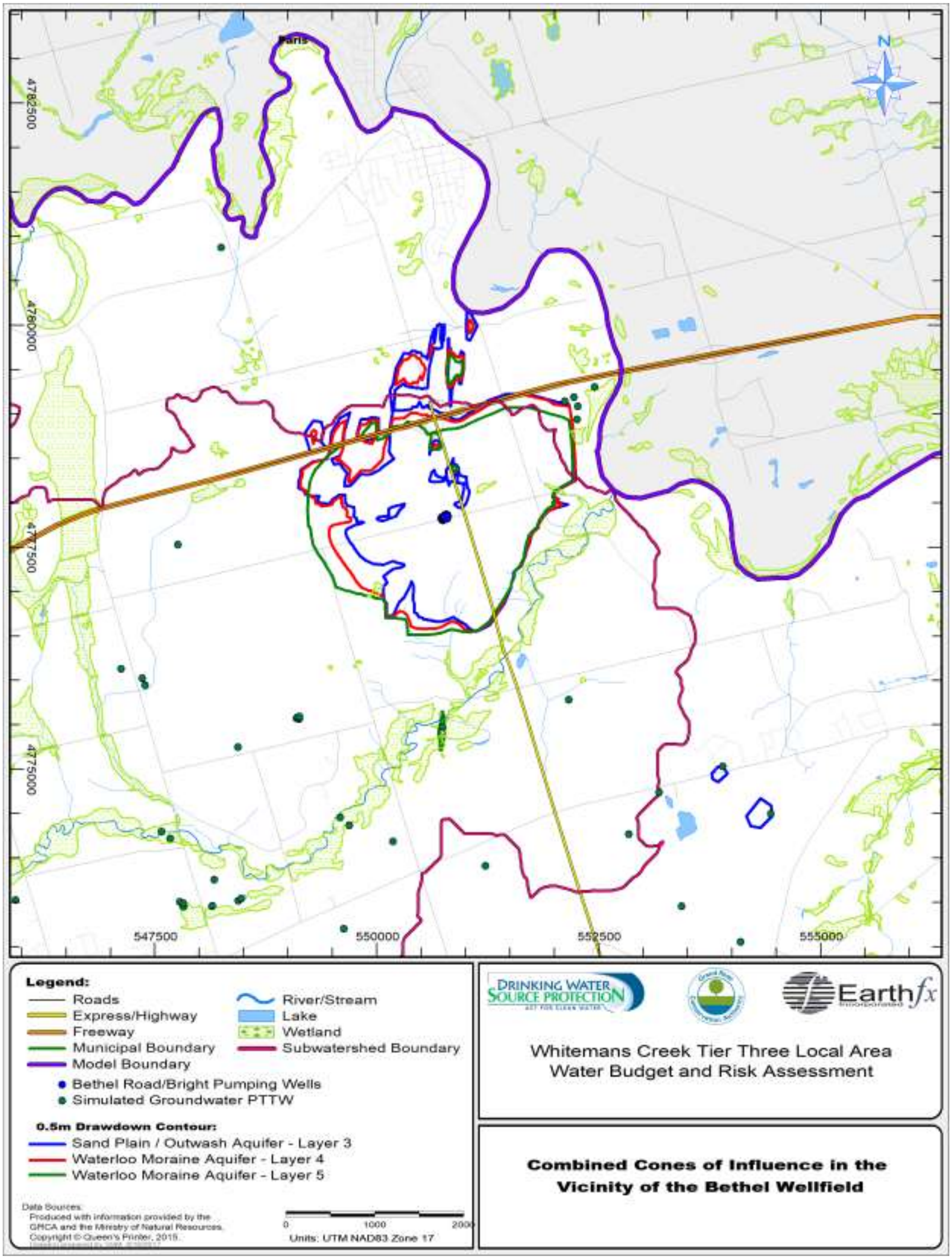

Figure 6.5: Drawdowns under allocated future pumping in the Bethel wellfield.

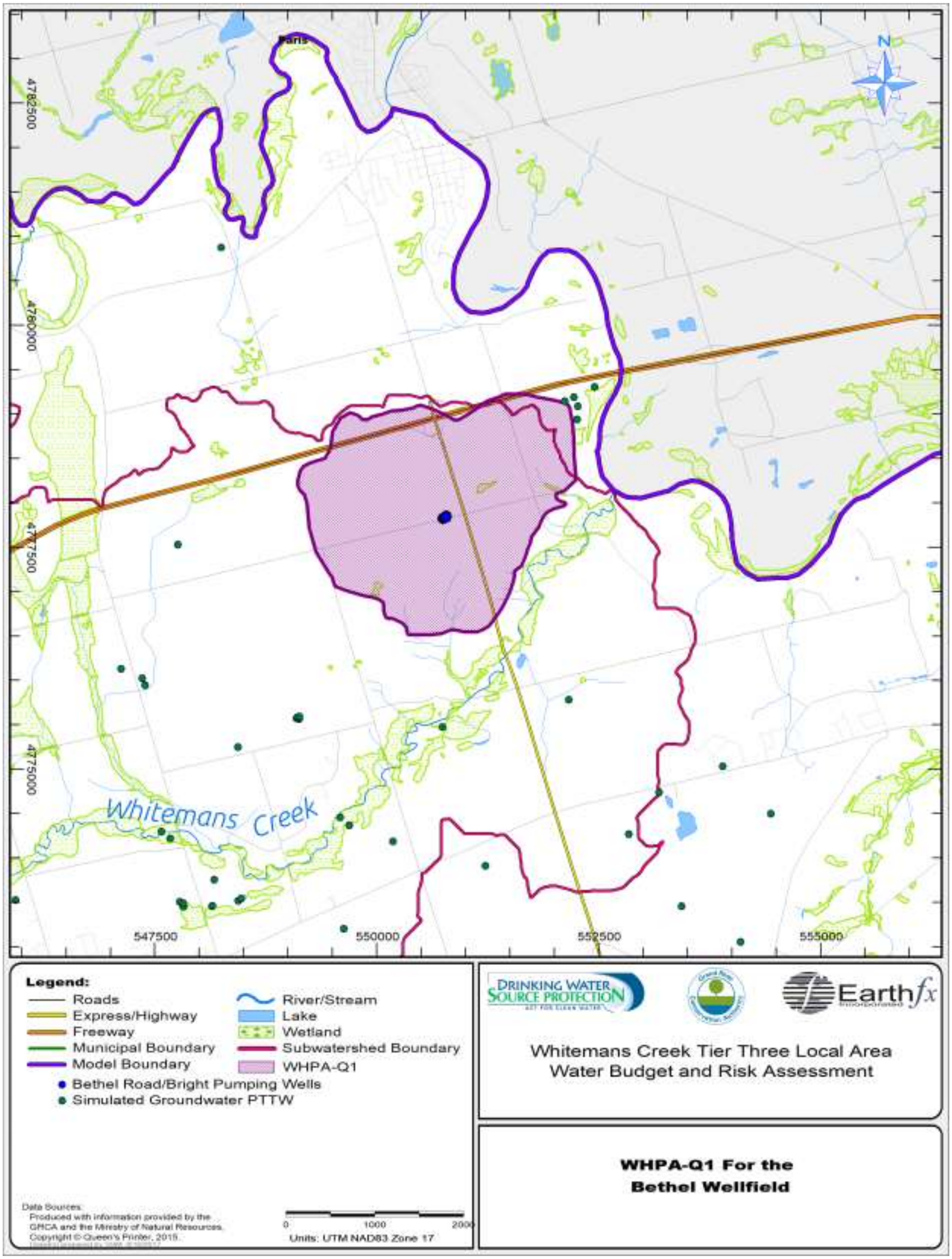

Figure 6.6: WHPA Q1 for the Bethel wellfield.

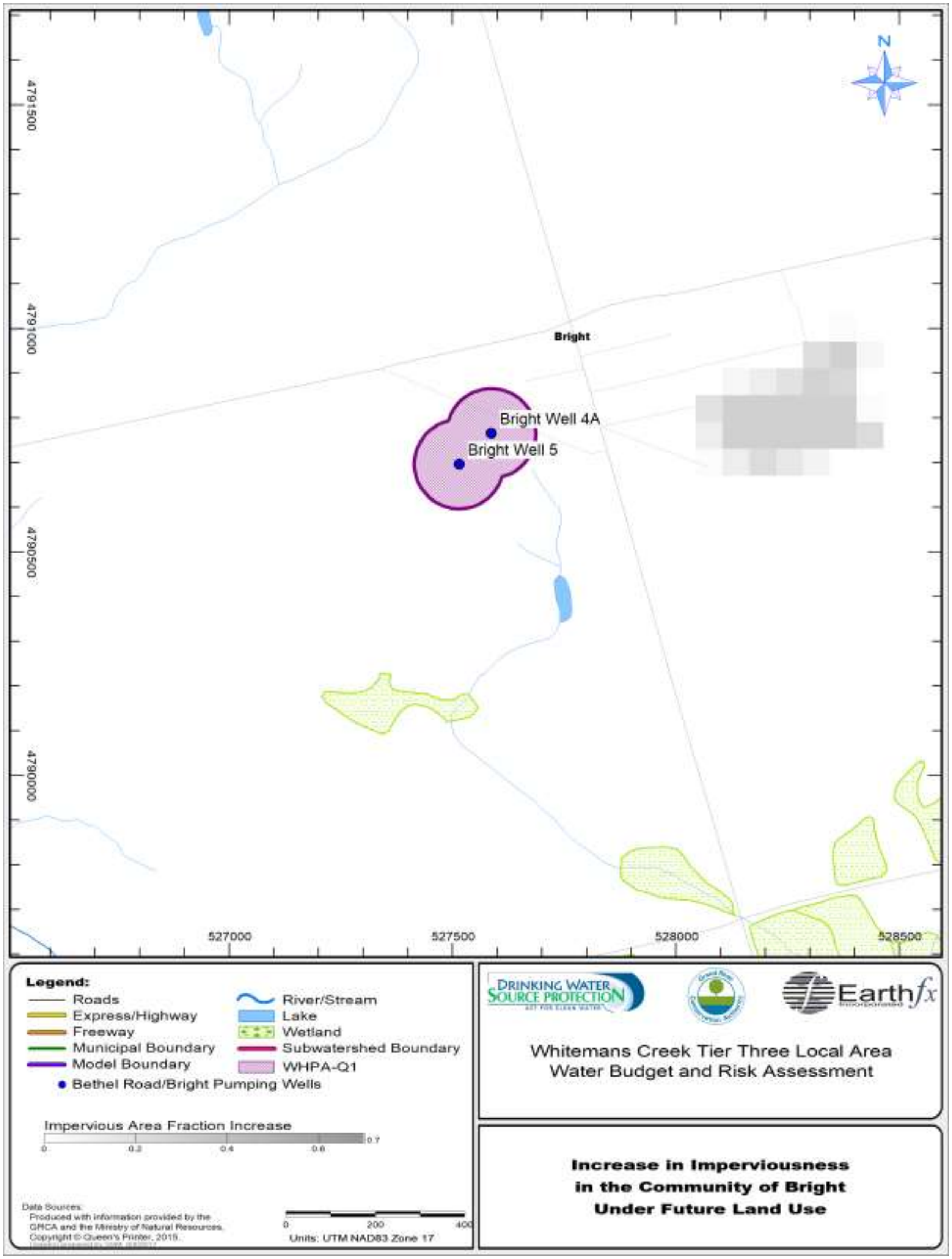

Figure 6.7: Increase in imperviousness in the community of Bright under future land use.

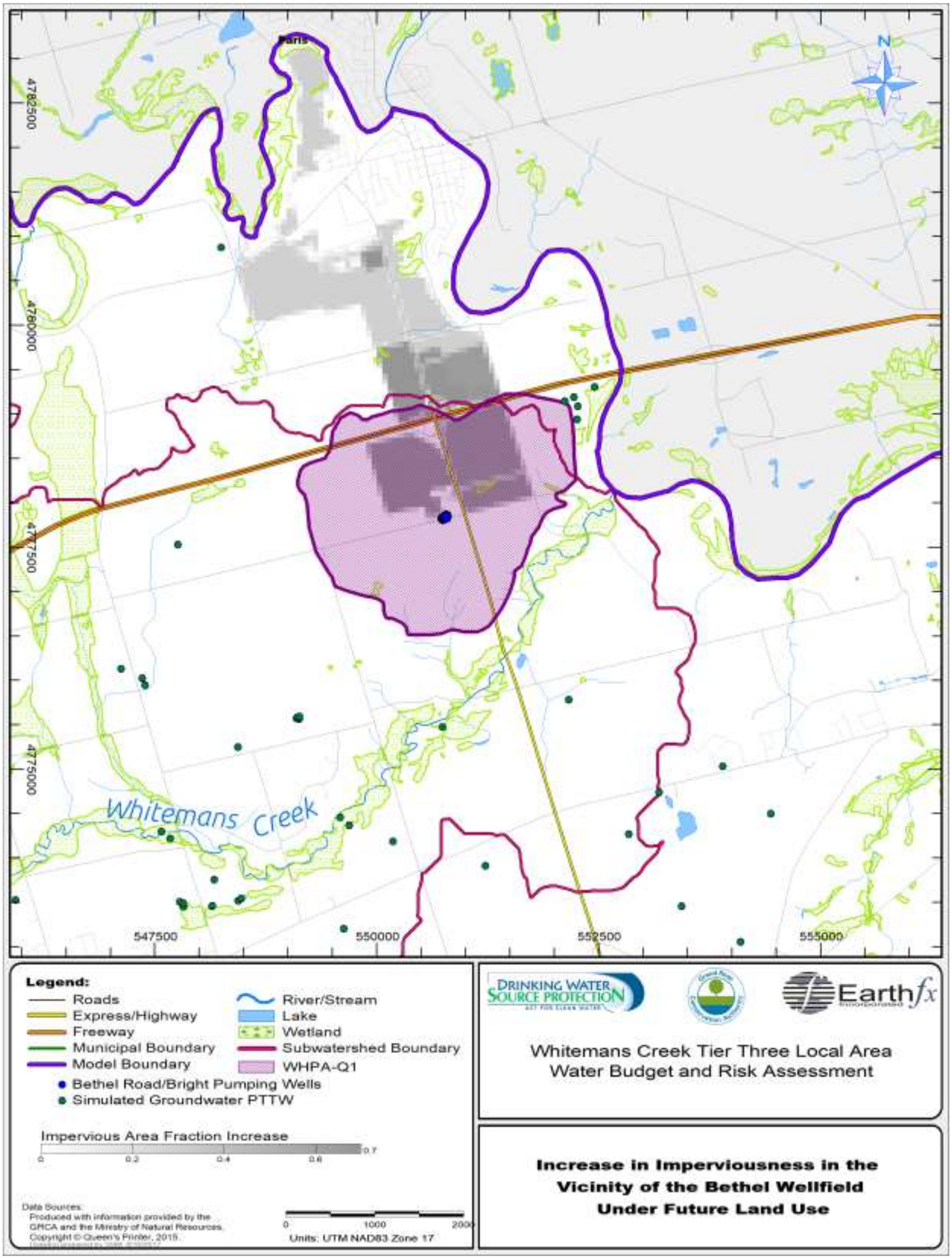

Figure 6.8: Increase in imperviousness in the vicinity of the Bethel wellfield under future land use.

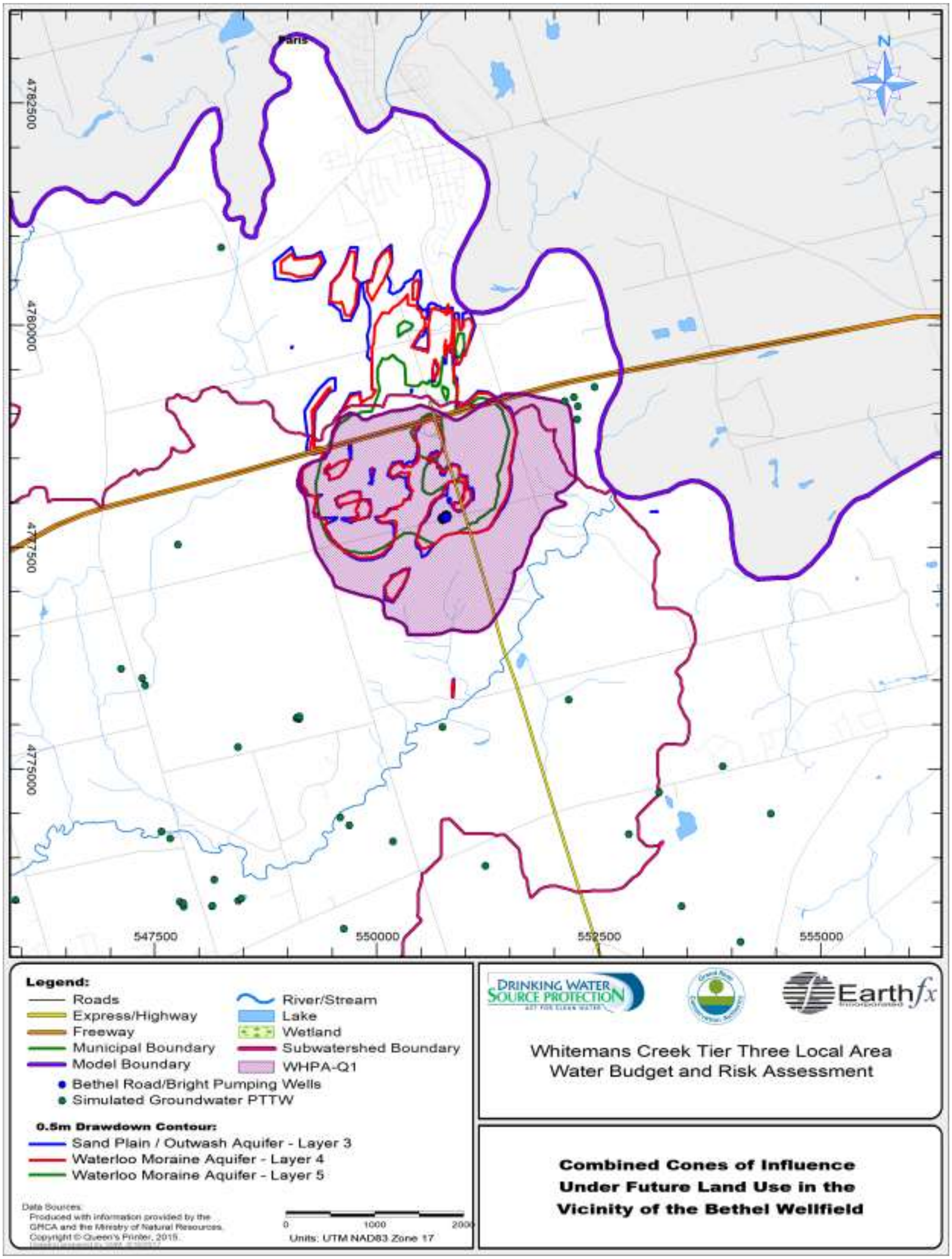

Figure 6.9: Combined cones of influence under future land use in the vicinity of the Bethel wellfield.

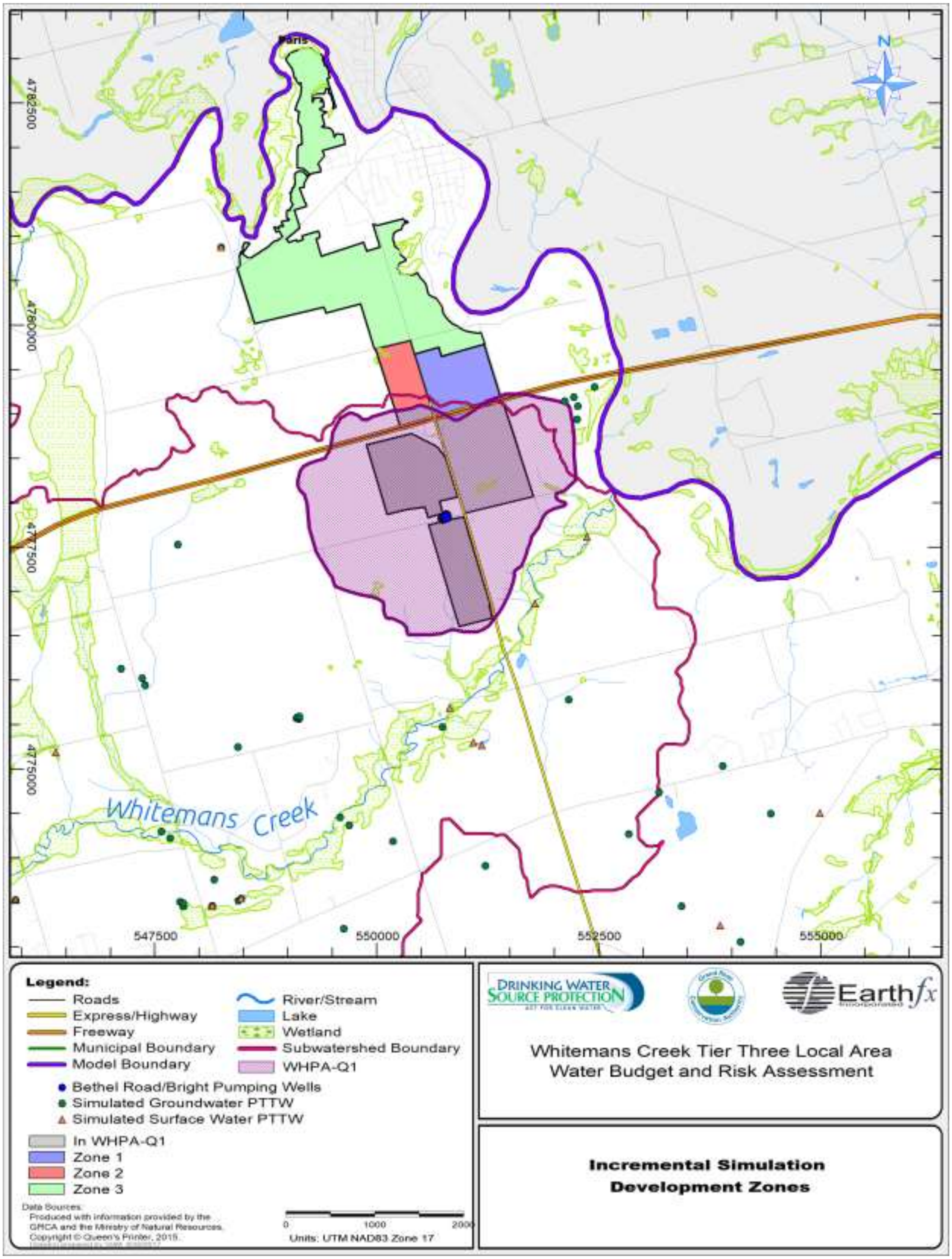

Figure 6.10: D development zones used in WHPA-Q2 analysis

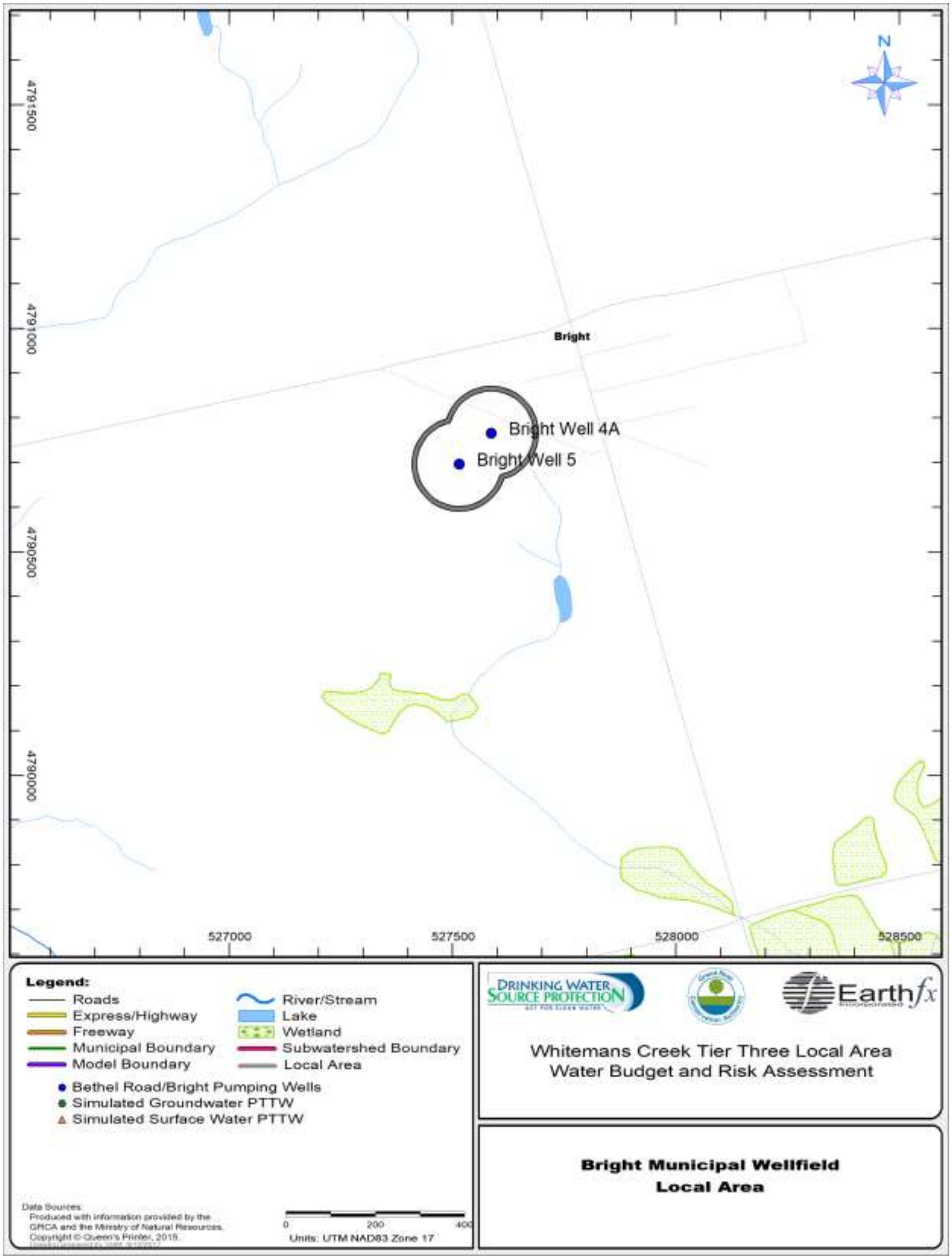

Figure 6.11: Local area for the Bright wellfield.

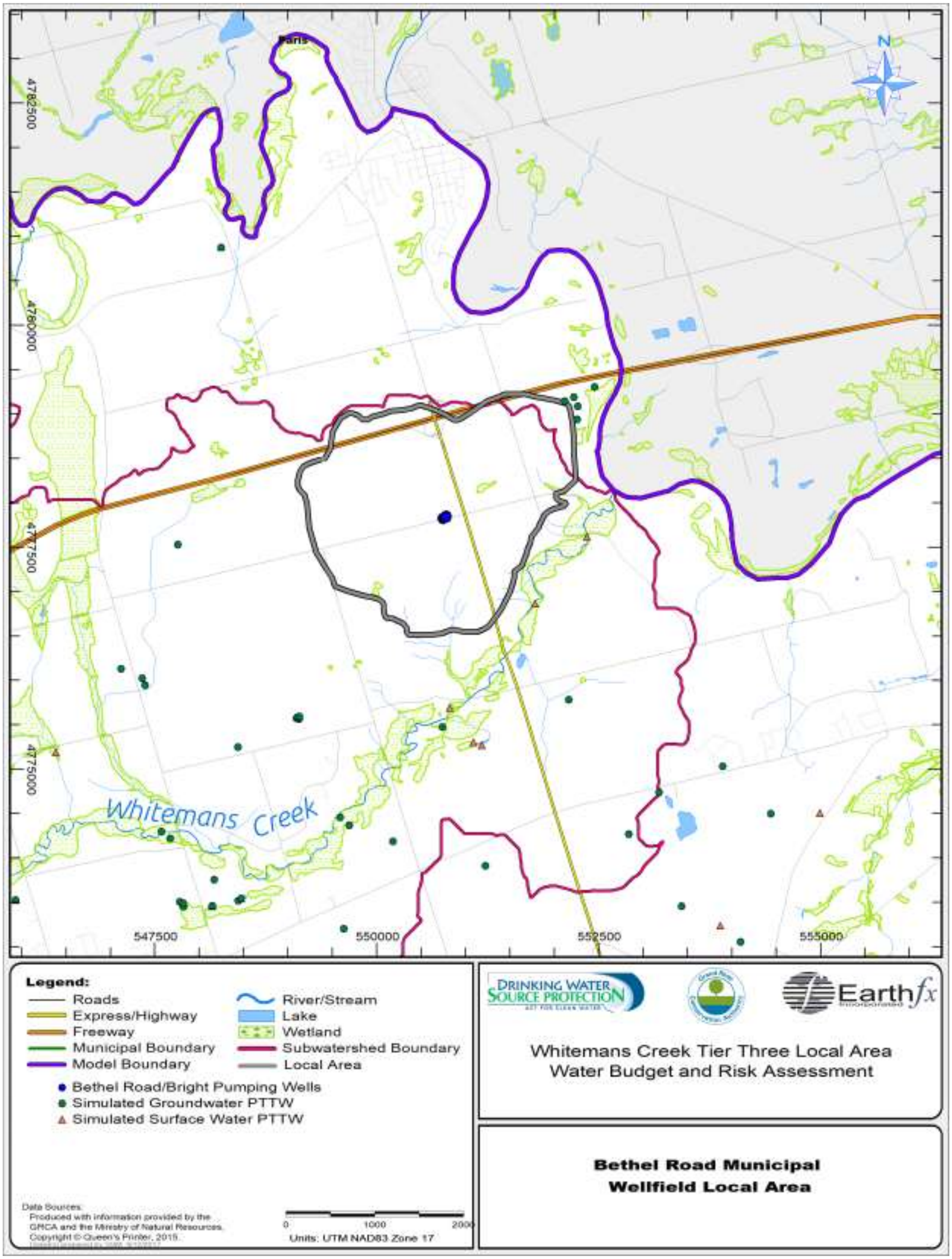

Figure 6.12: Local area for the Bethel wellfield.

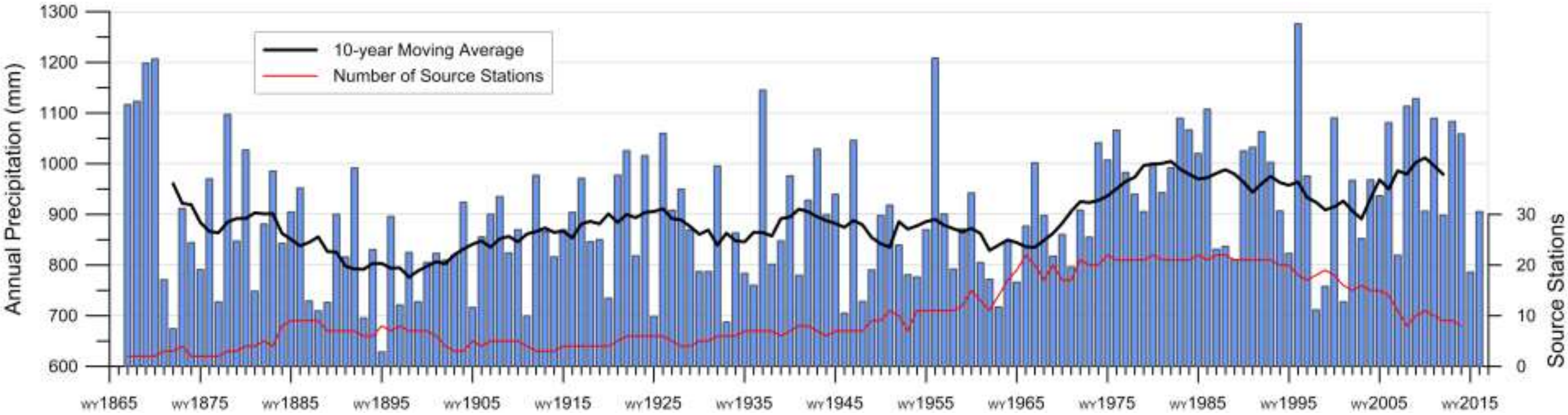

Figure 6.13: Basin-averaged (Whitemans Creek) mean annual precipitation (WY1867 – WY2016).

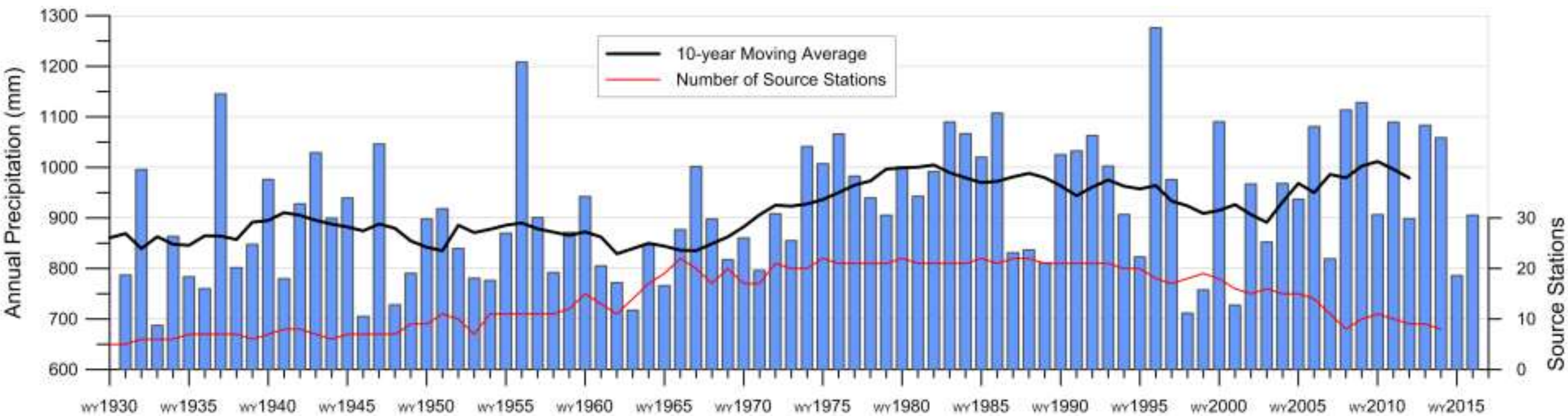

Figure 6.14 : Basin-averaged (Whitemans Creek) mean annual precipitation (WY1931 – WY2016).

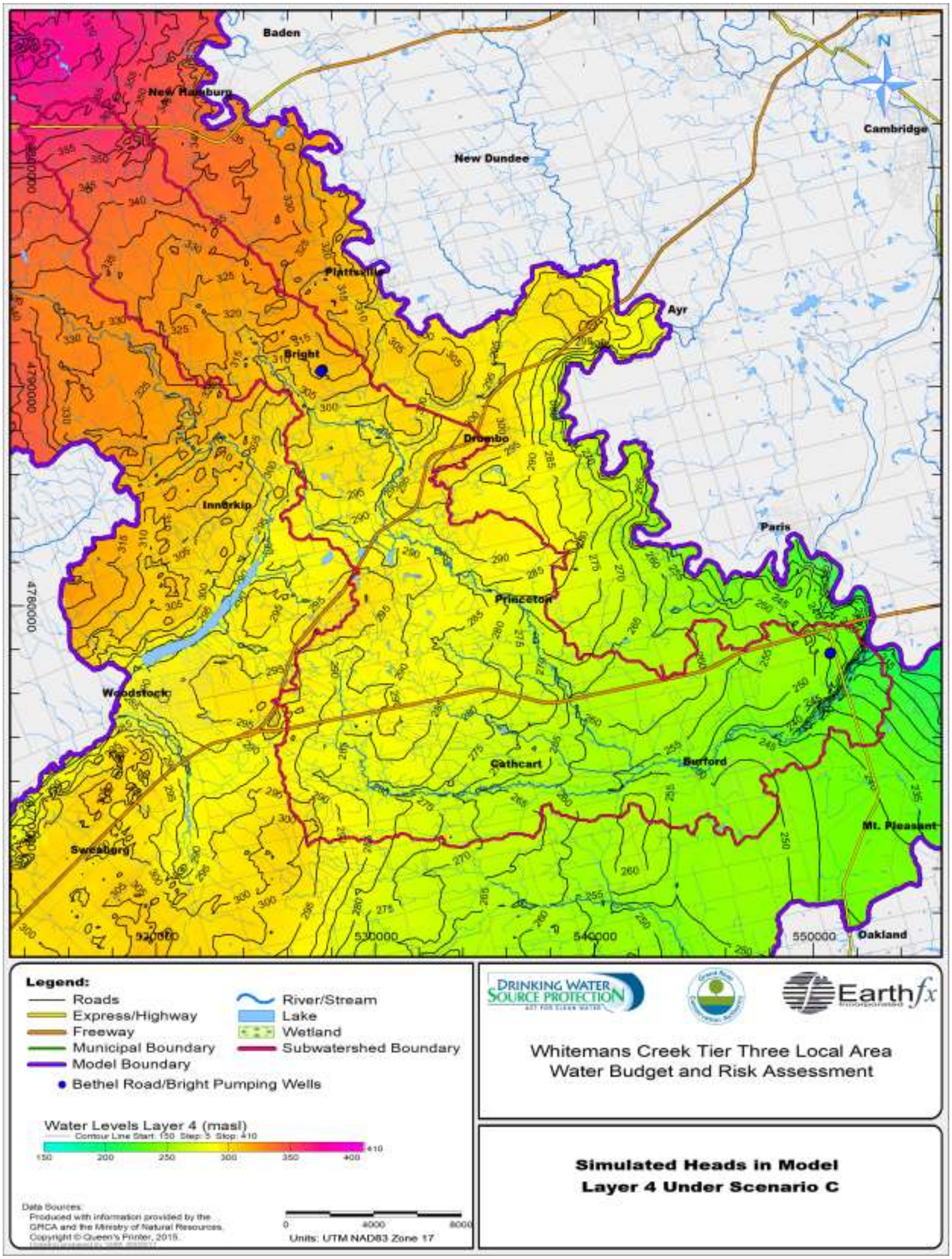

Figure 6.15: Simulated heads in model layer 4 under Scenario C.

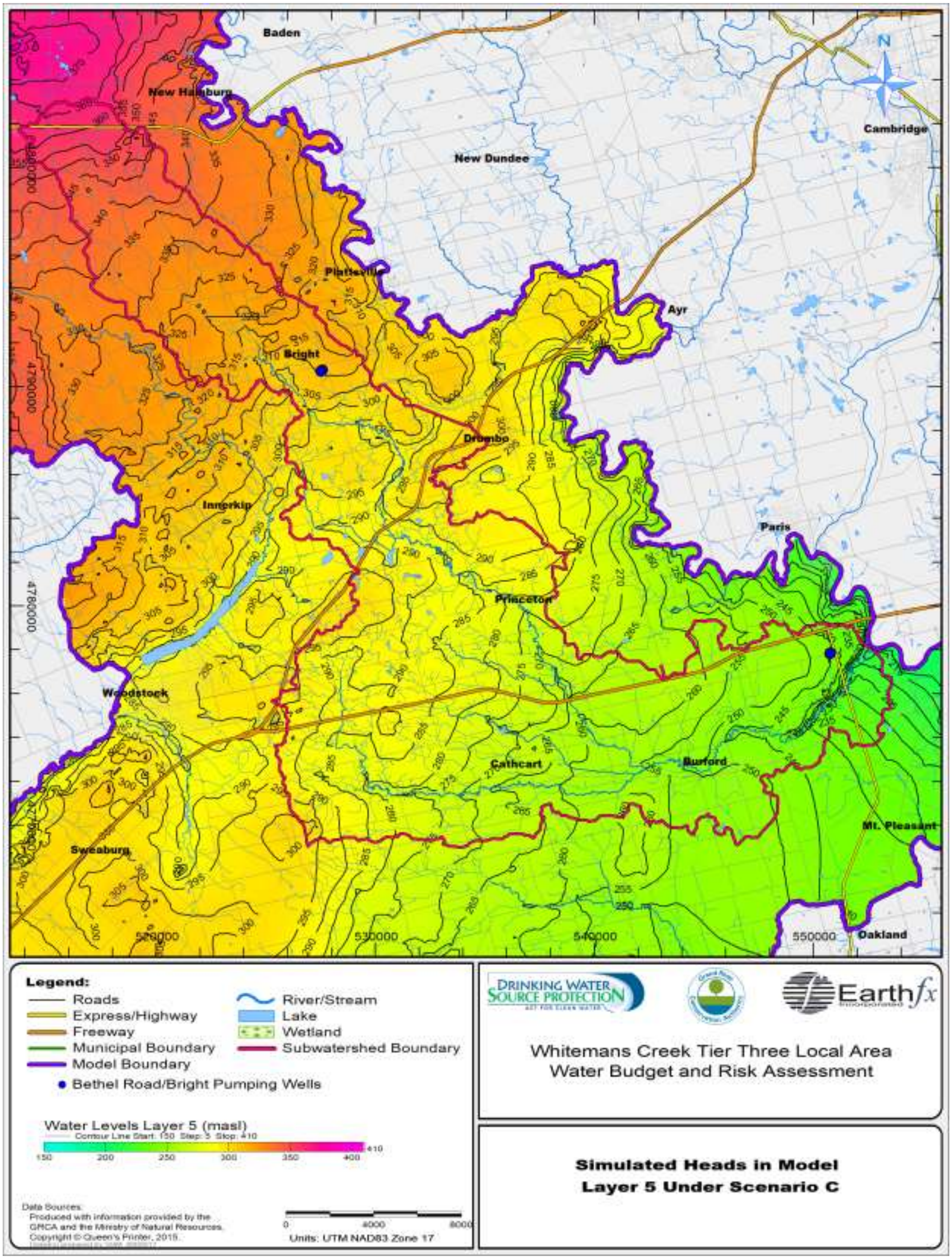

Figure 6.16: Simulated heads in model layer 5 under Scenario C.

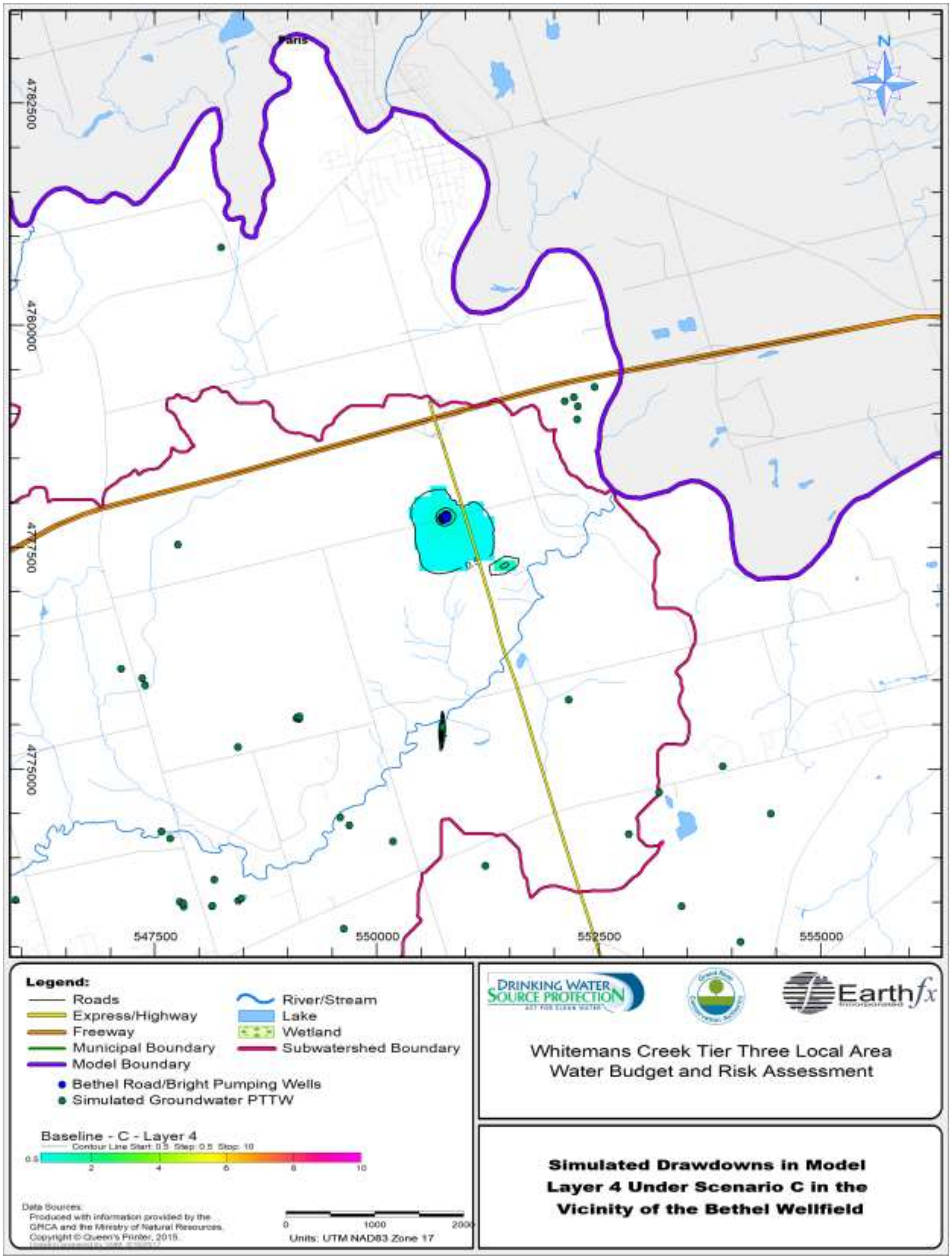

Figure 6.17: Simulated drawdowns in model layer 4 under Scenario C in the vicinity of the Bethel wellfield.

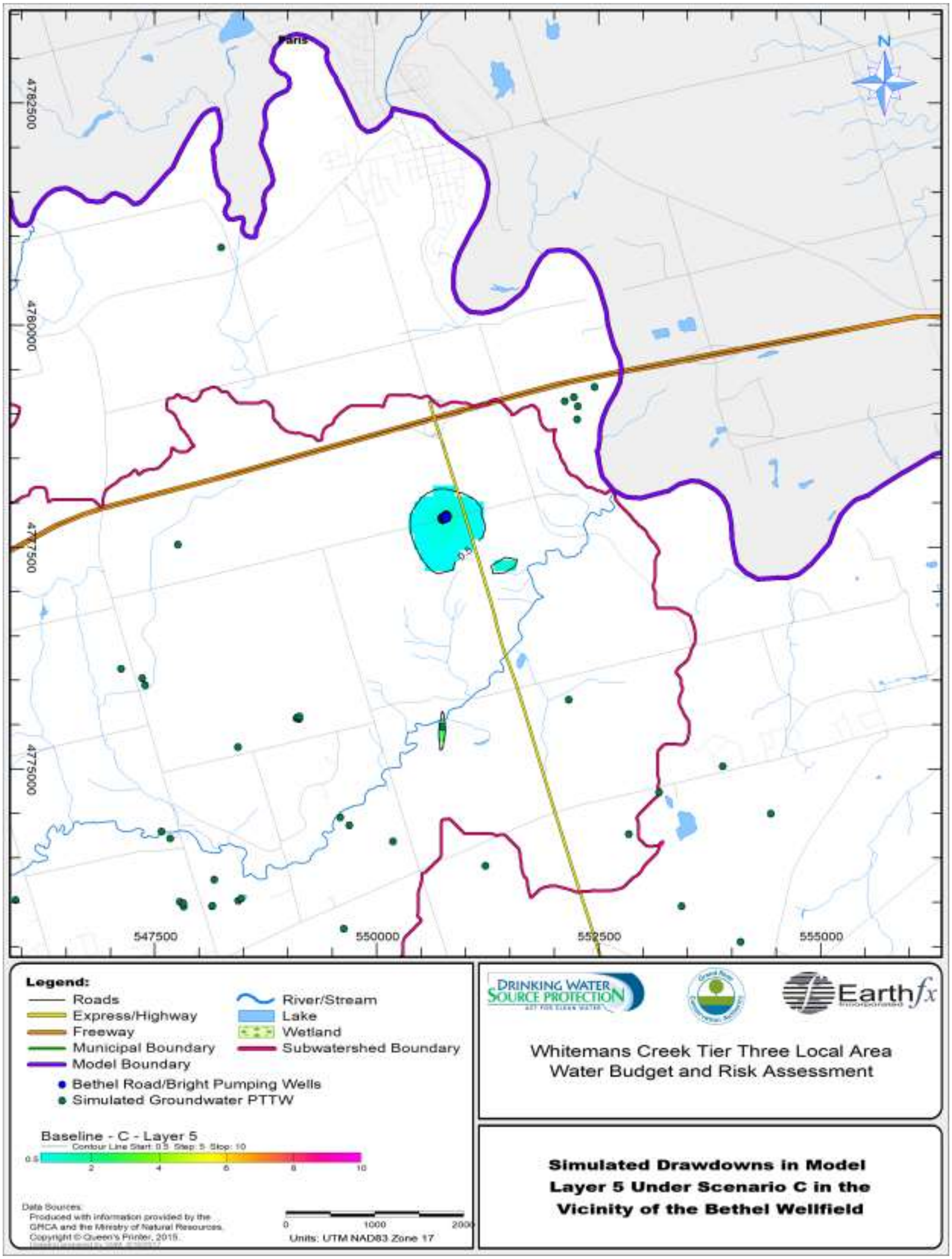

Figure 6.18: Simulated drawdowns in model layer 5 under Scenario C in the vicinity of the Bethel wellfield.

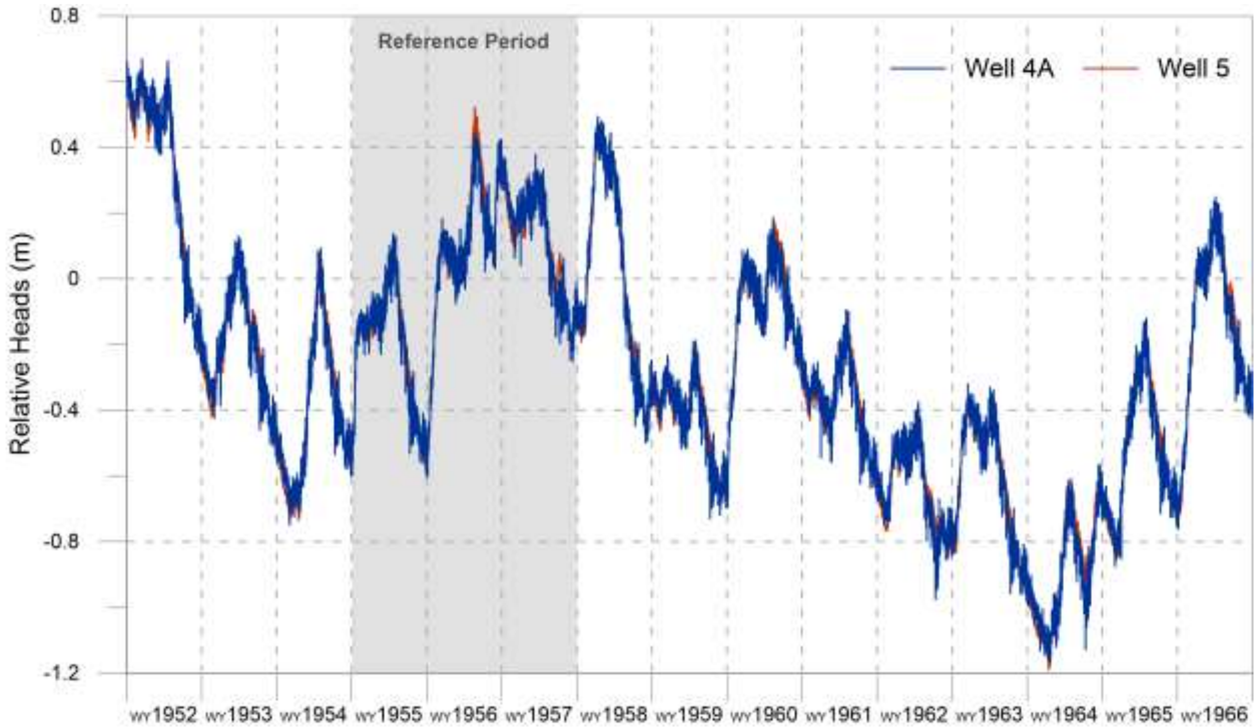

Figure 6.19: Simulated hydrographs in the Bright wellfield. The time period used to calculate the reference water level elevation is shown in grey.

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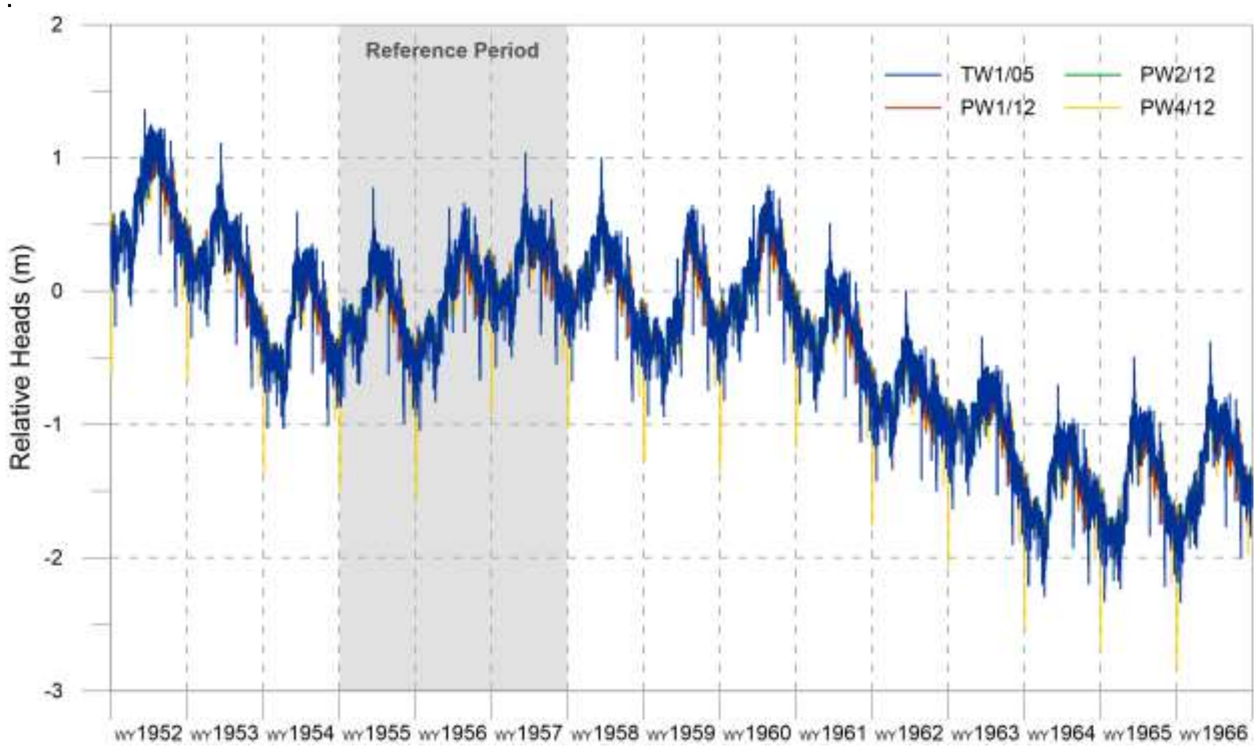

Figure 6.20: Simulated hydrographs in the Bethel wellfield. The time period used to calculate the reference water level elevation is shown in grey.

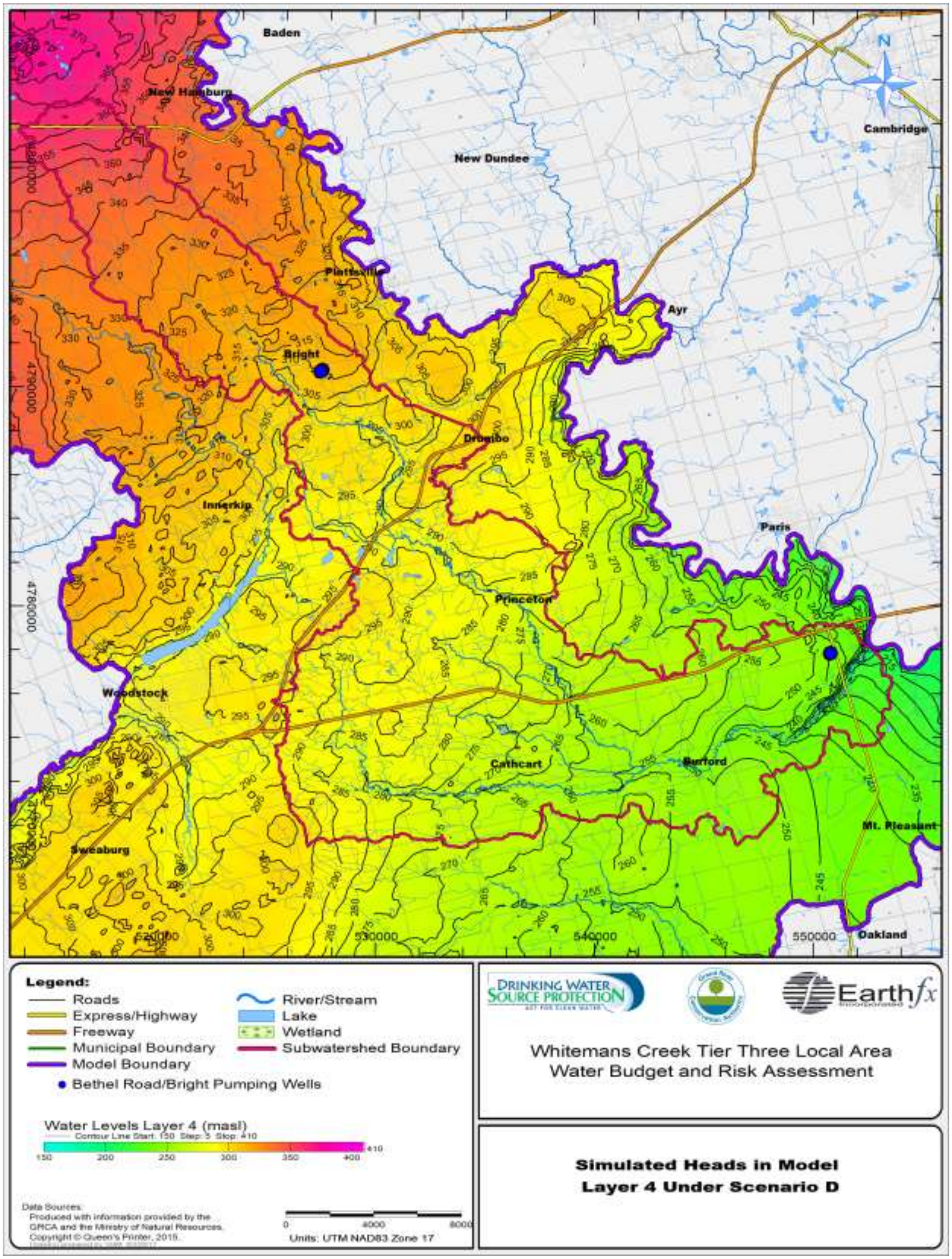

Figure 6.21: Simulated heads in model layer 4 under Scenario D.

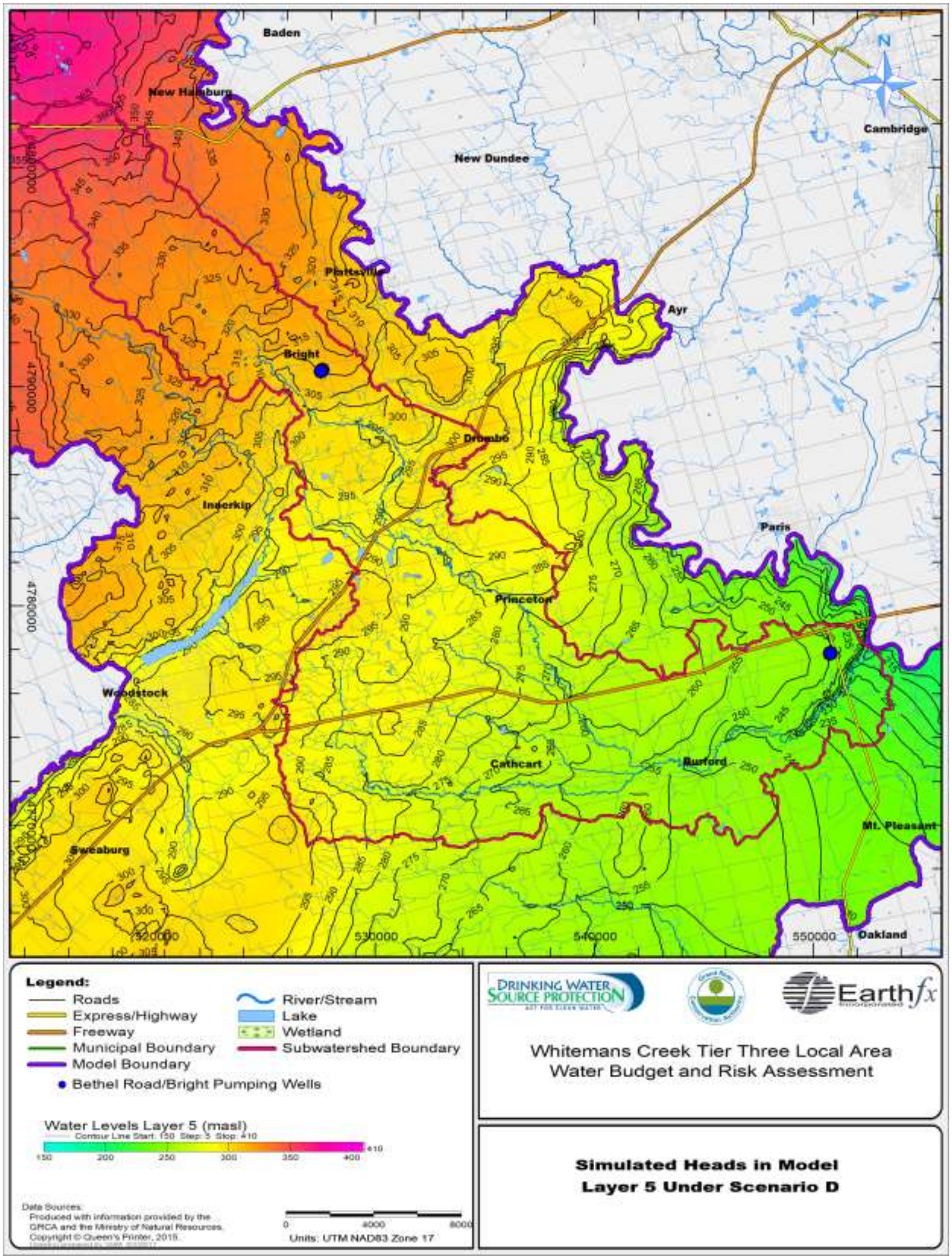

Figure 6.22: Simulated heads in model layer 5 under Scenario D.

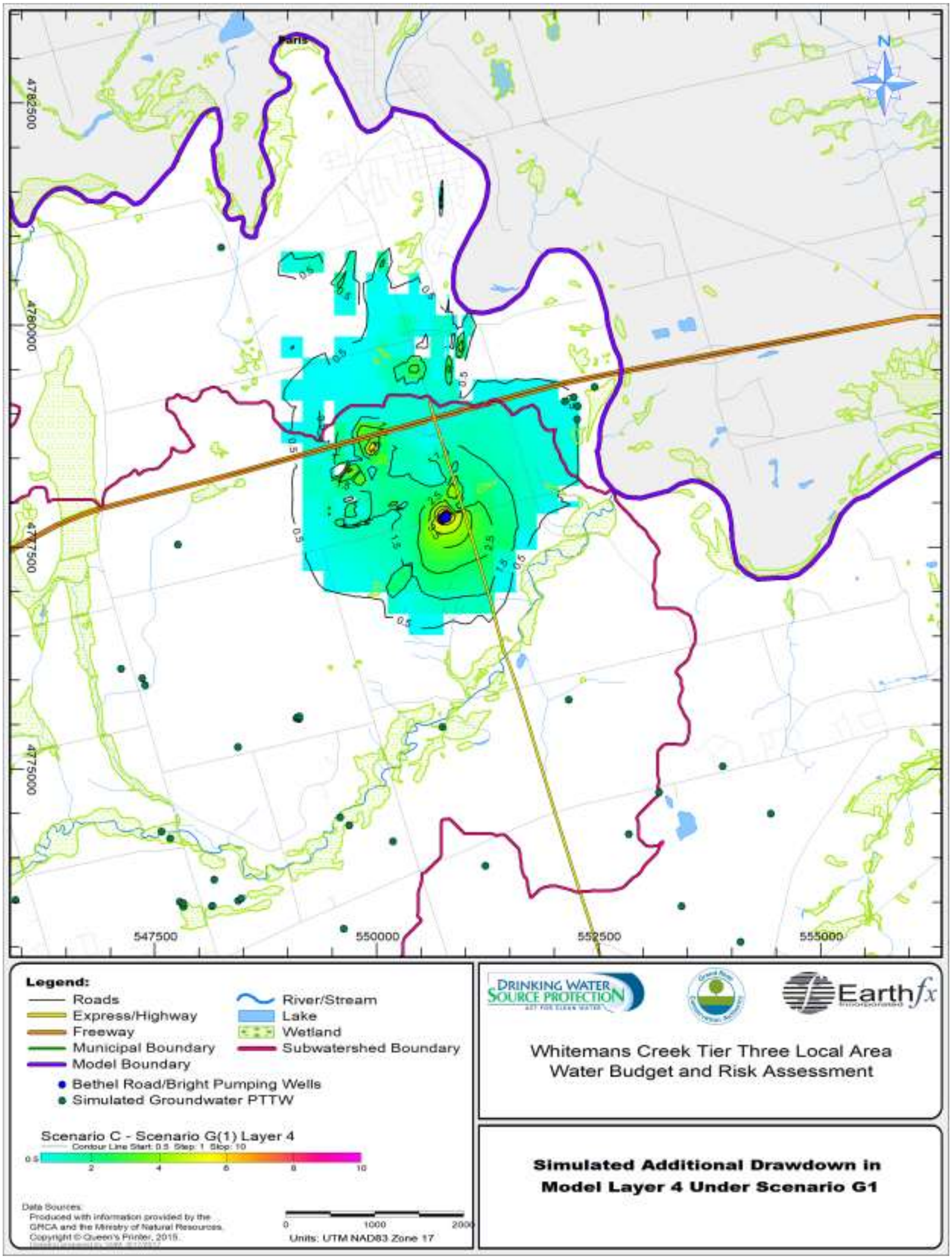

Figure 6.23: Simulated additional drawdown in model layer 4 under Scenario G(1).

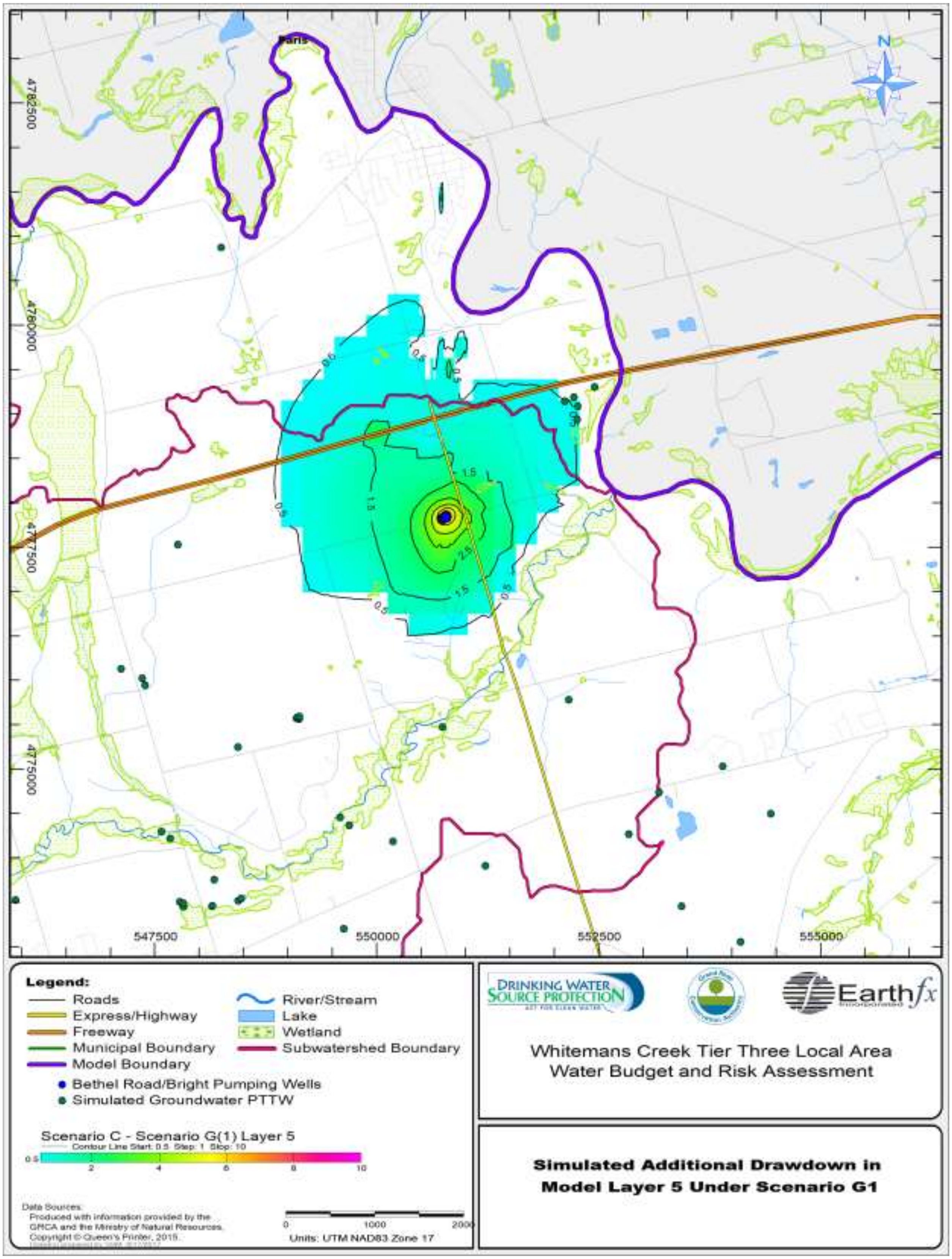

Figure 6.24: Simulated additional drawdown in model layer 5 under Scenario G(1).

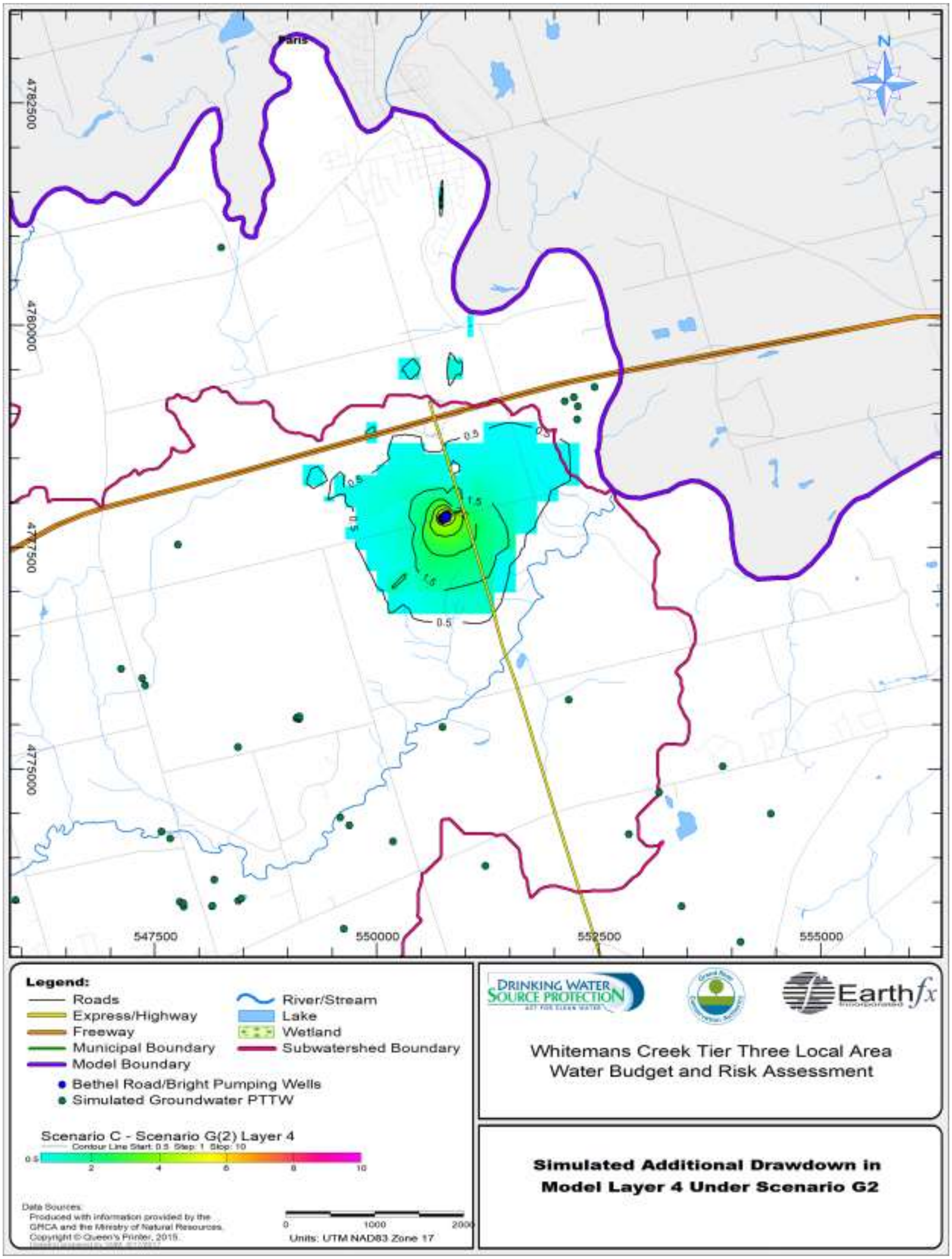

Figure 6.25: Simulated additional drawdown in model layer 4 under Scenario G(2).

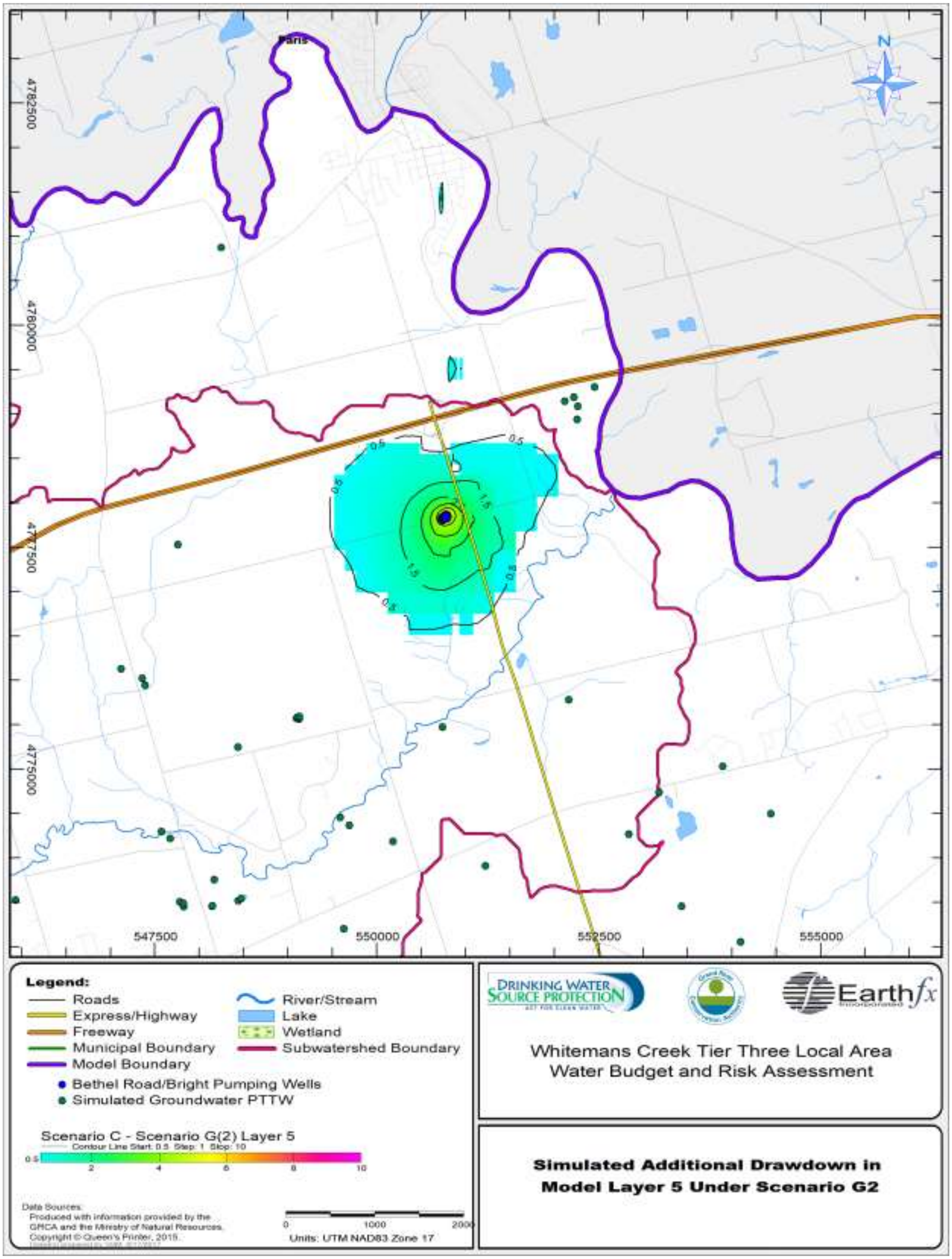

Figure 6.26: Simulated additional drawdown in model layer 5 under Scenario G(2).

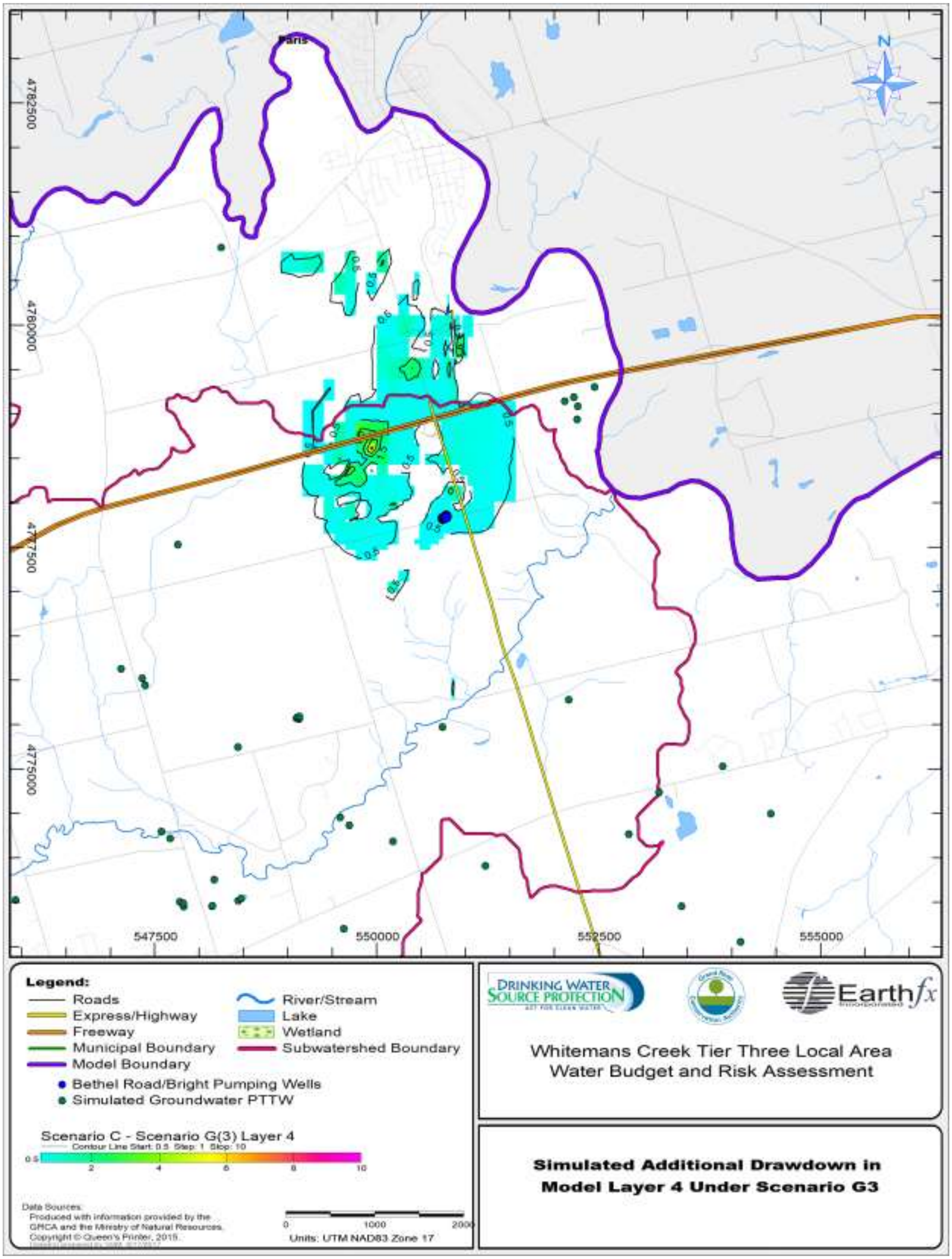

Figure 6.27: Simulated additional drawdown in model layer 4 under Scenario G(3).

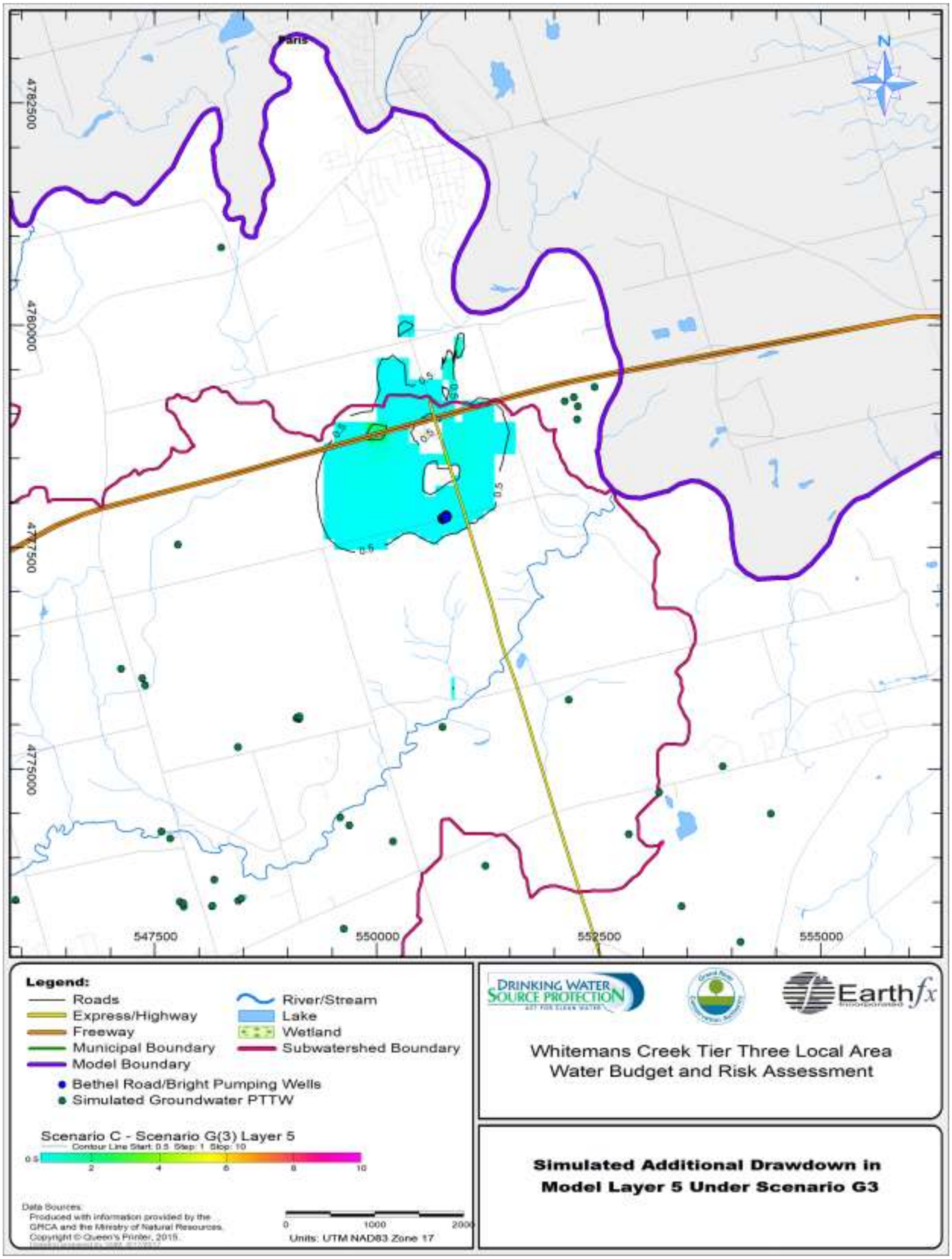

Figure 6.28: Simulated additional drawdown in model layer 5 under Scenario G(3).

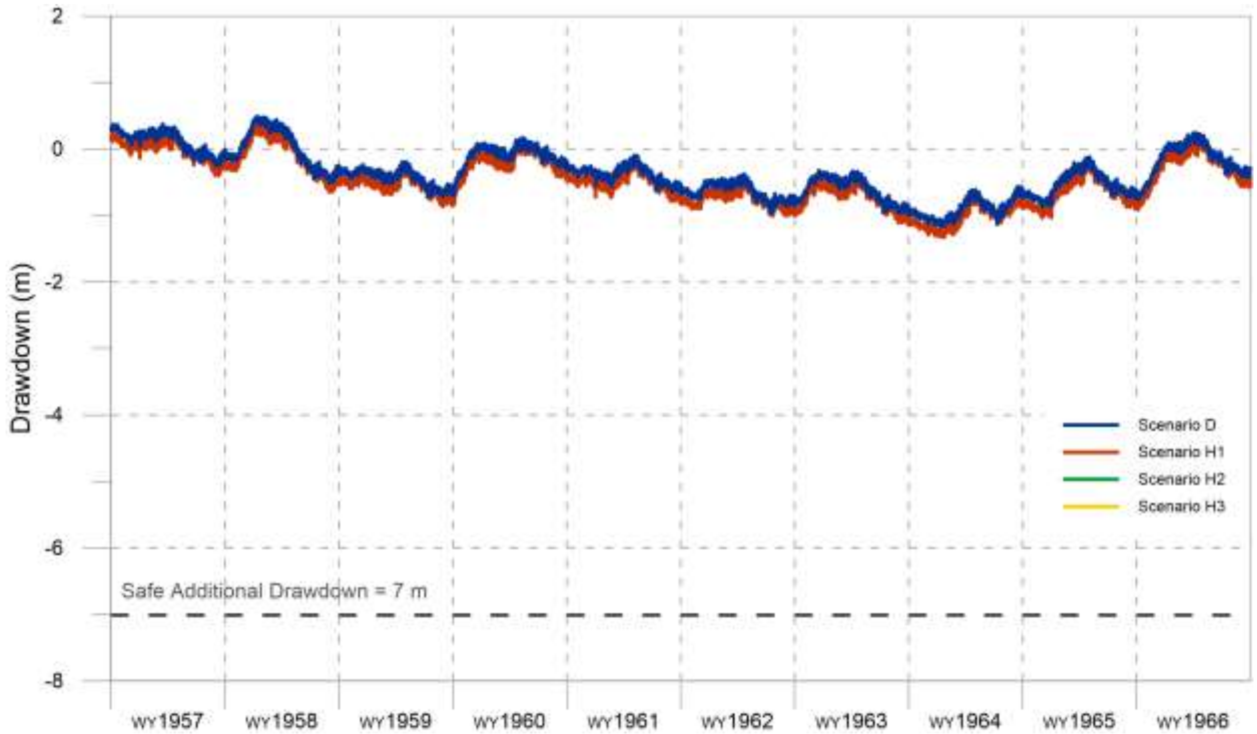

Figure 6.29: Hydrographs for Bright Well 4A for Scenario D and Scenario H.

Figure 6.30: Hydrographs for Bright Well 5 for Scenario D and Scenario H.

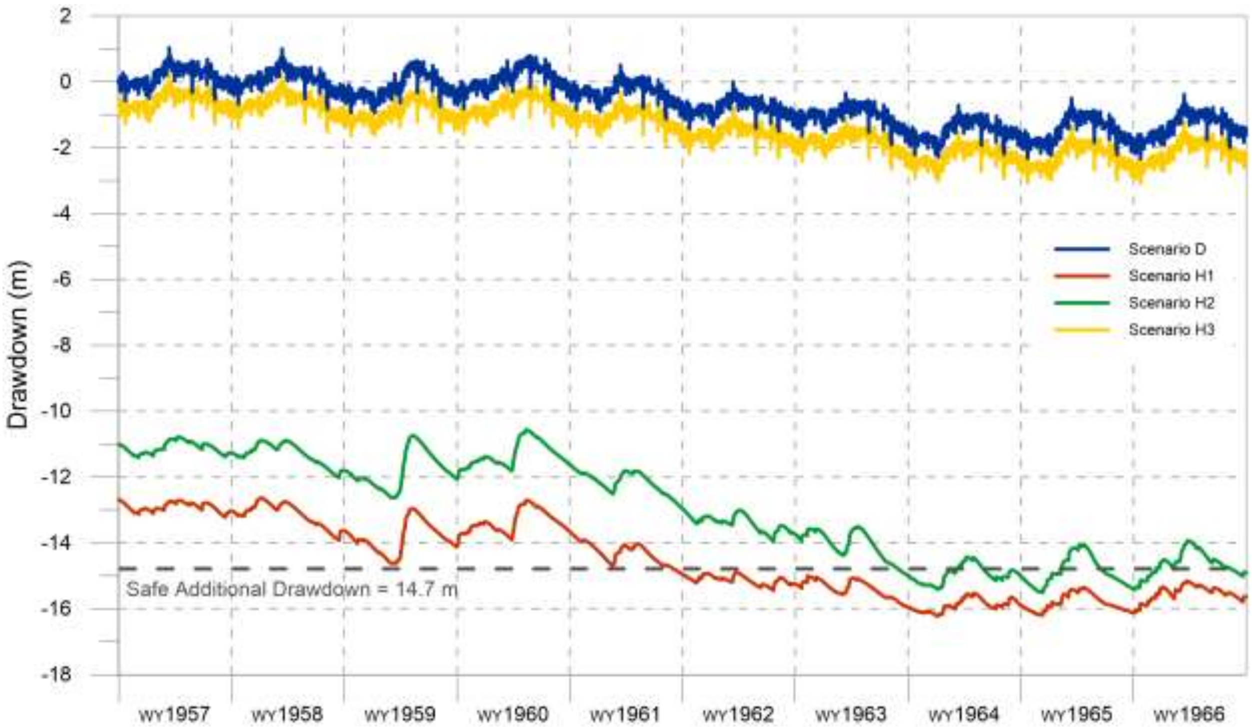

Figure 6.31: Hydrographs for Bethel Well TW1/05 for Scenario D and Scenario H.

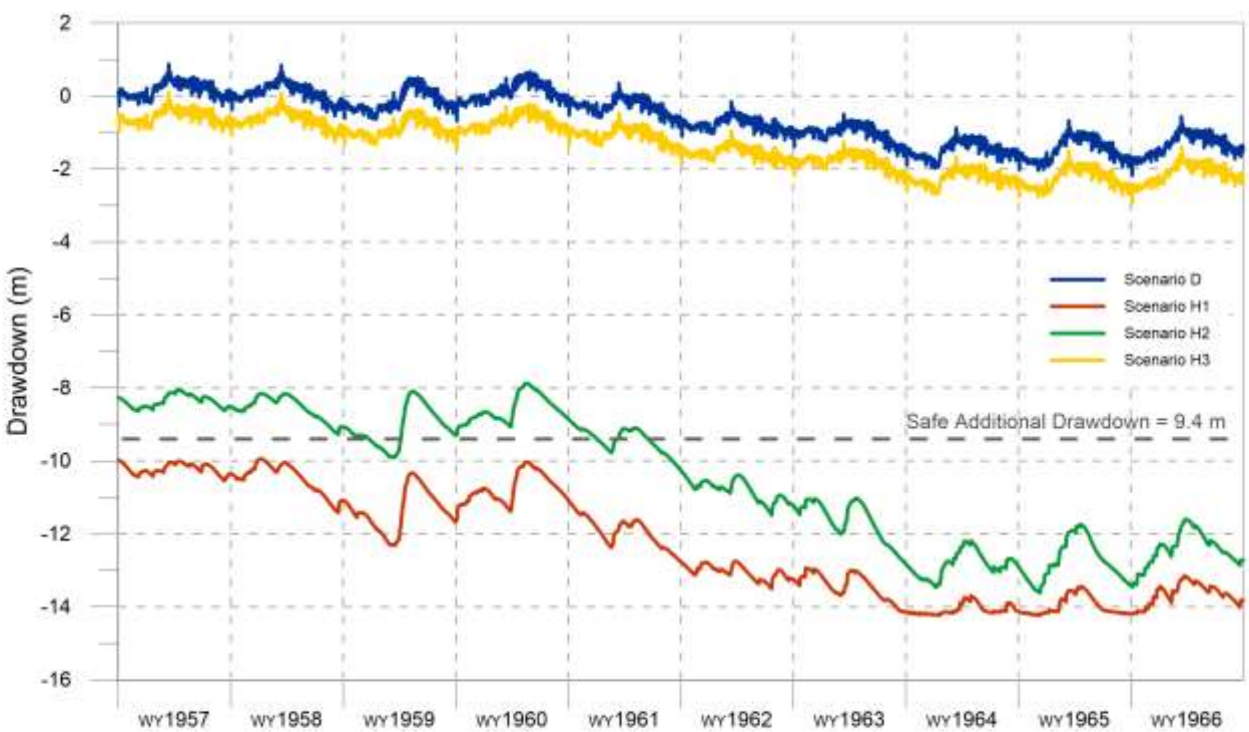

Figure 6.32: Hydrographs for Bethel Well PW1/12 for Scenario D and Scenario H.

Figure 6.33: Hydrographs for Bethel Well PW2/12 for Scenario D and Scenario H.

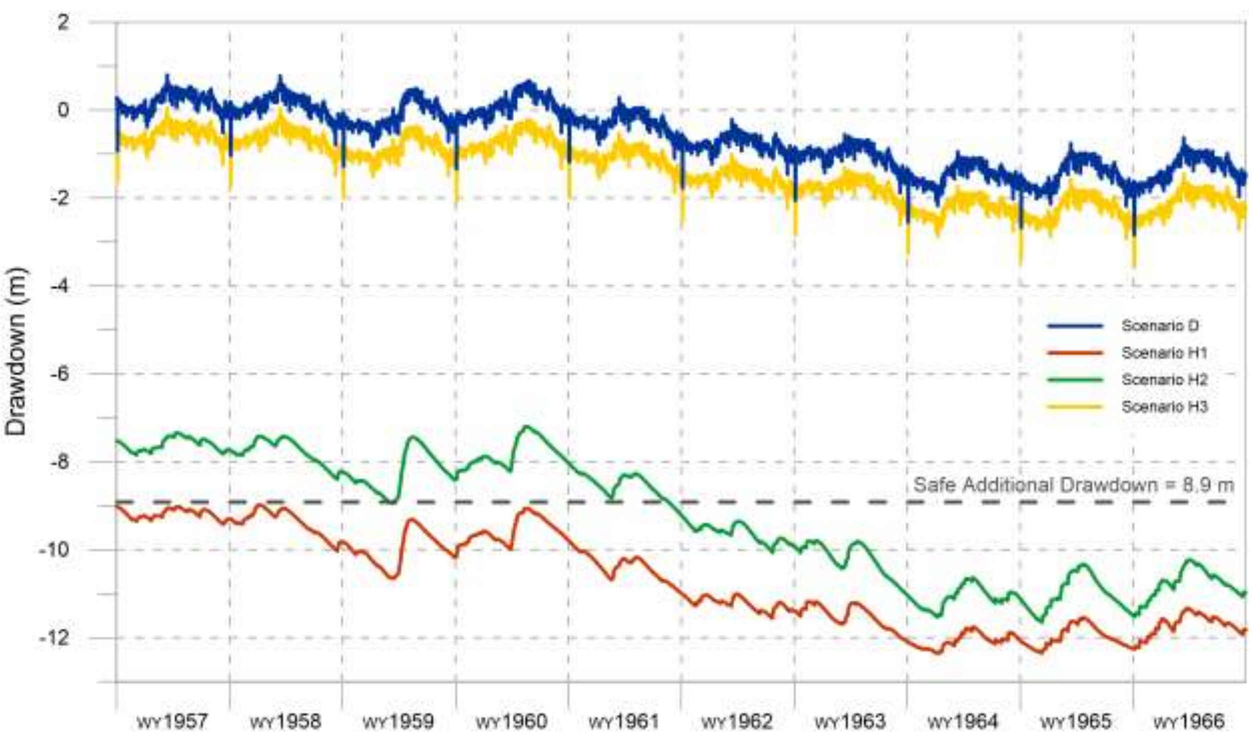

Figure 6.34: Hydrographs for Bethel Well PW4/12 for Scenario D and Scenario H.

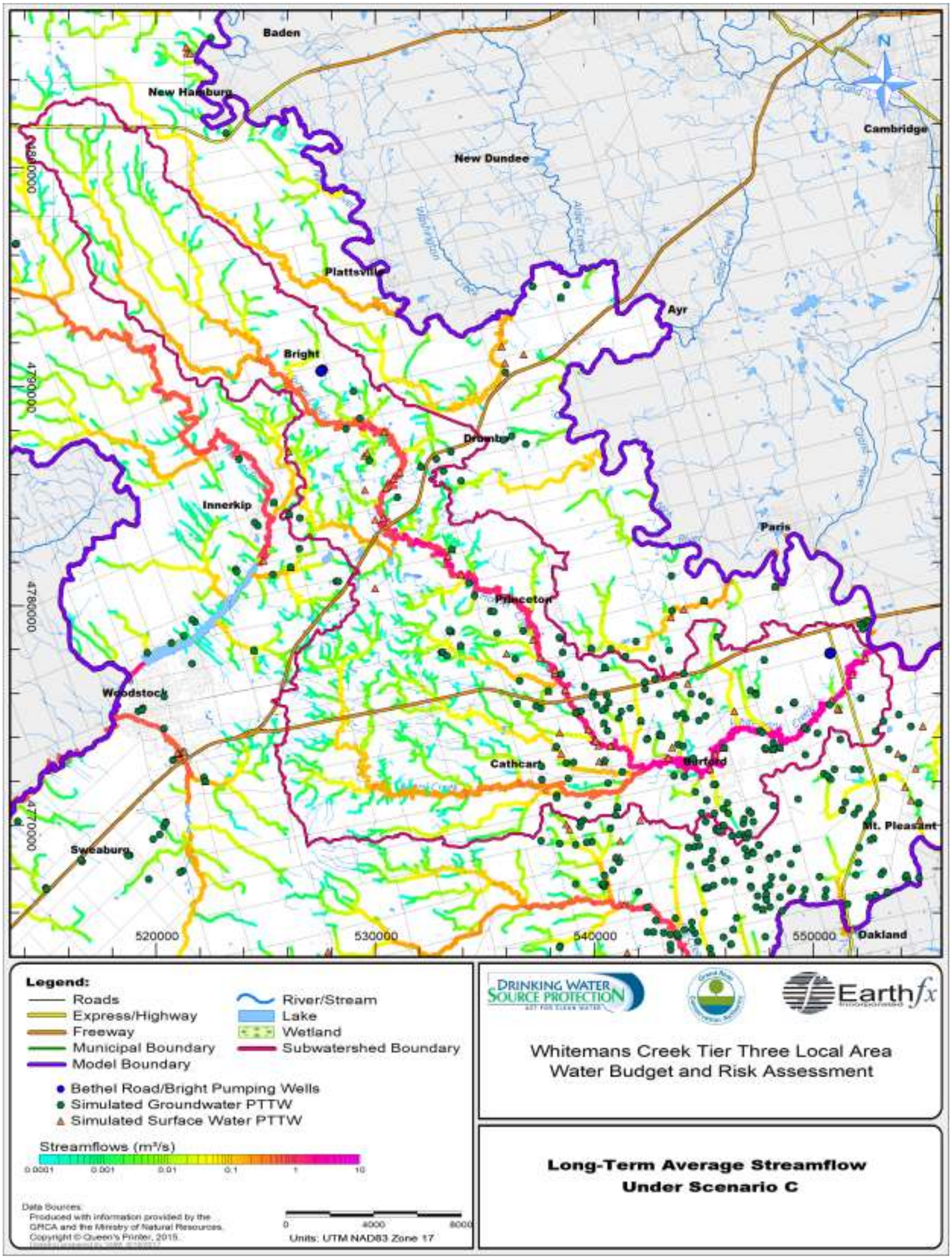

Figure 6.35: Long-term average streamflow under Scenario C.

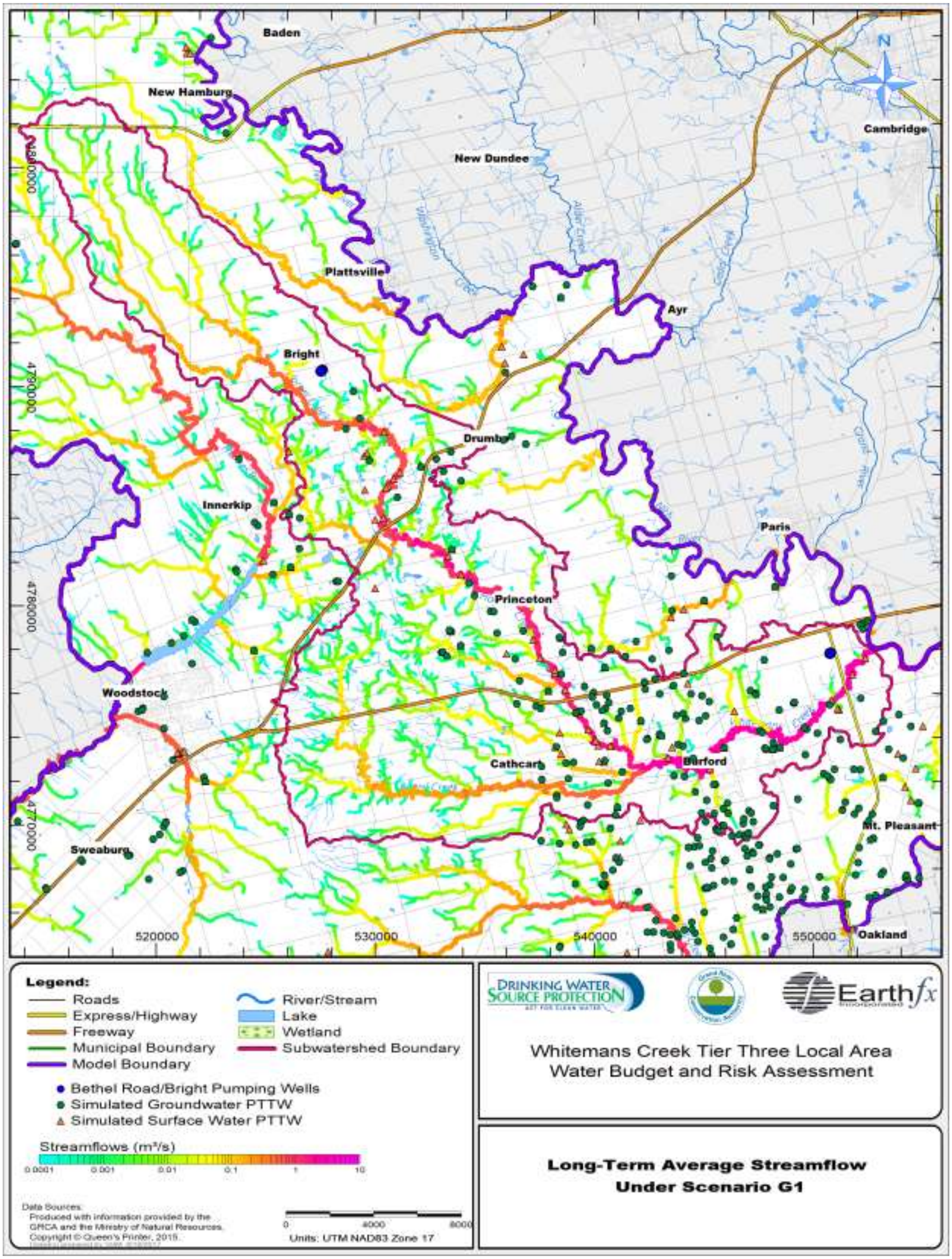

Figure 6.36: Long-term average streamflow under Scenario G(1).

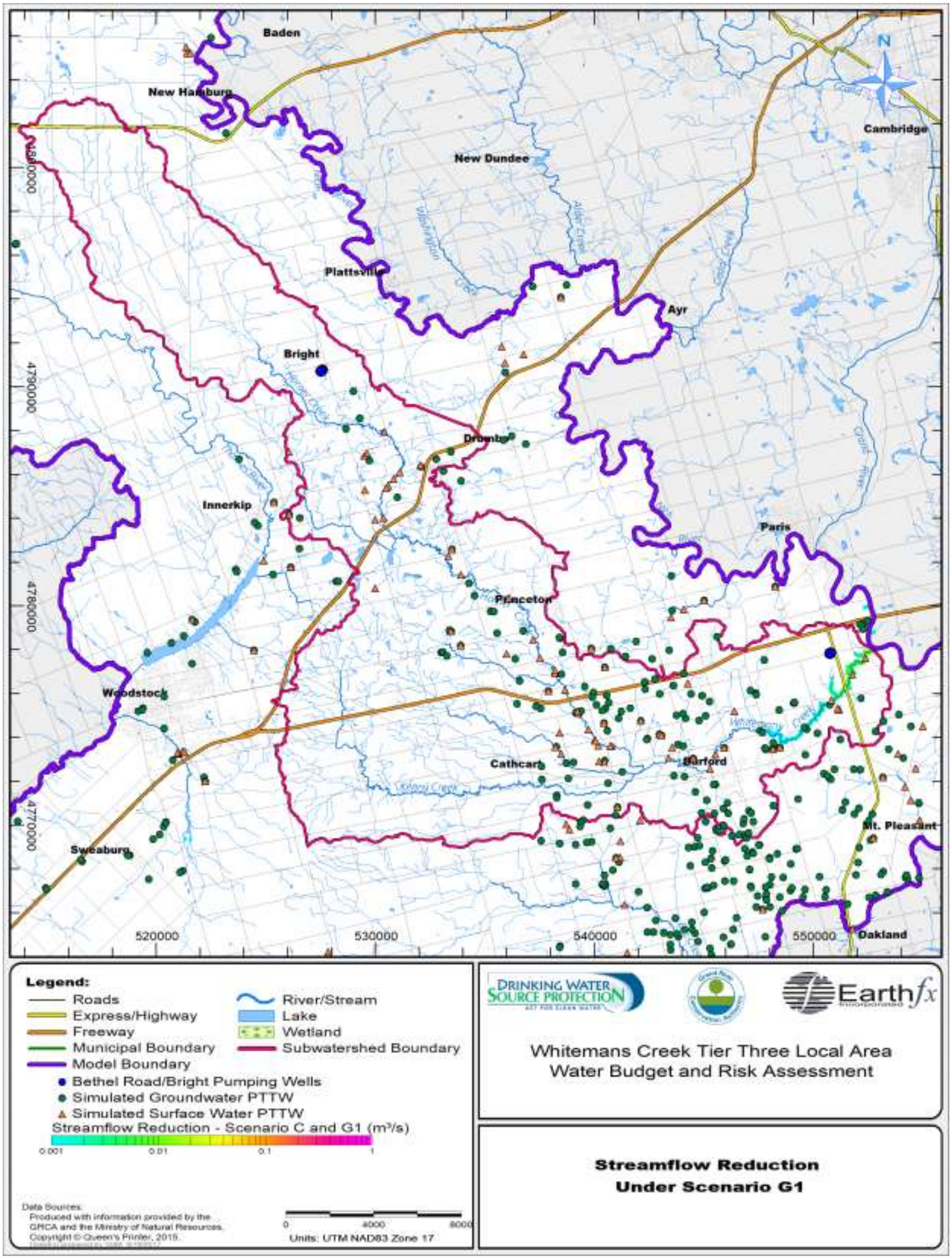

Figure 6.37: Reduction in long-term average streamflow between Scenario C and G(1).

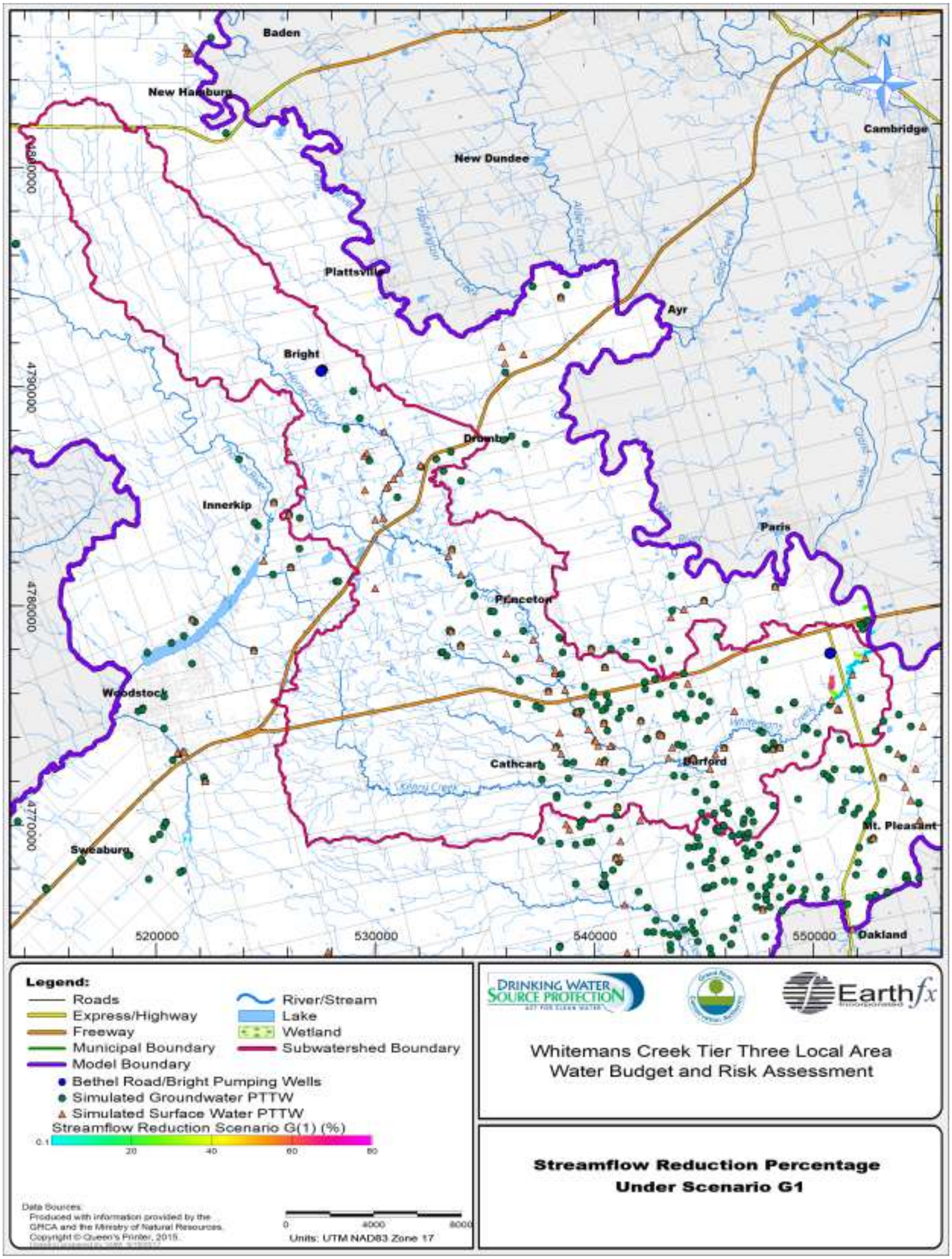

Figure 6.38: Percent reduction in long-term average streamflow under Scenario G(1).

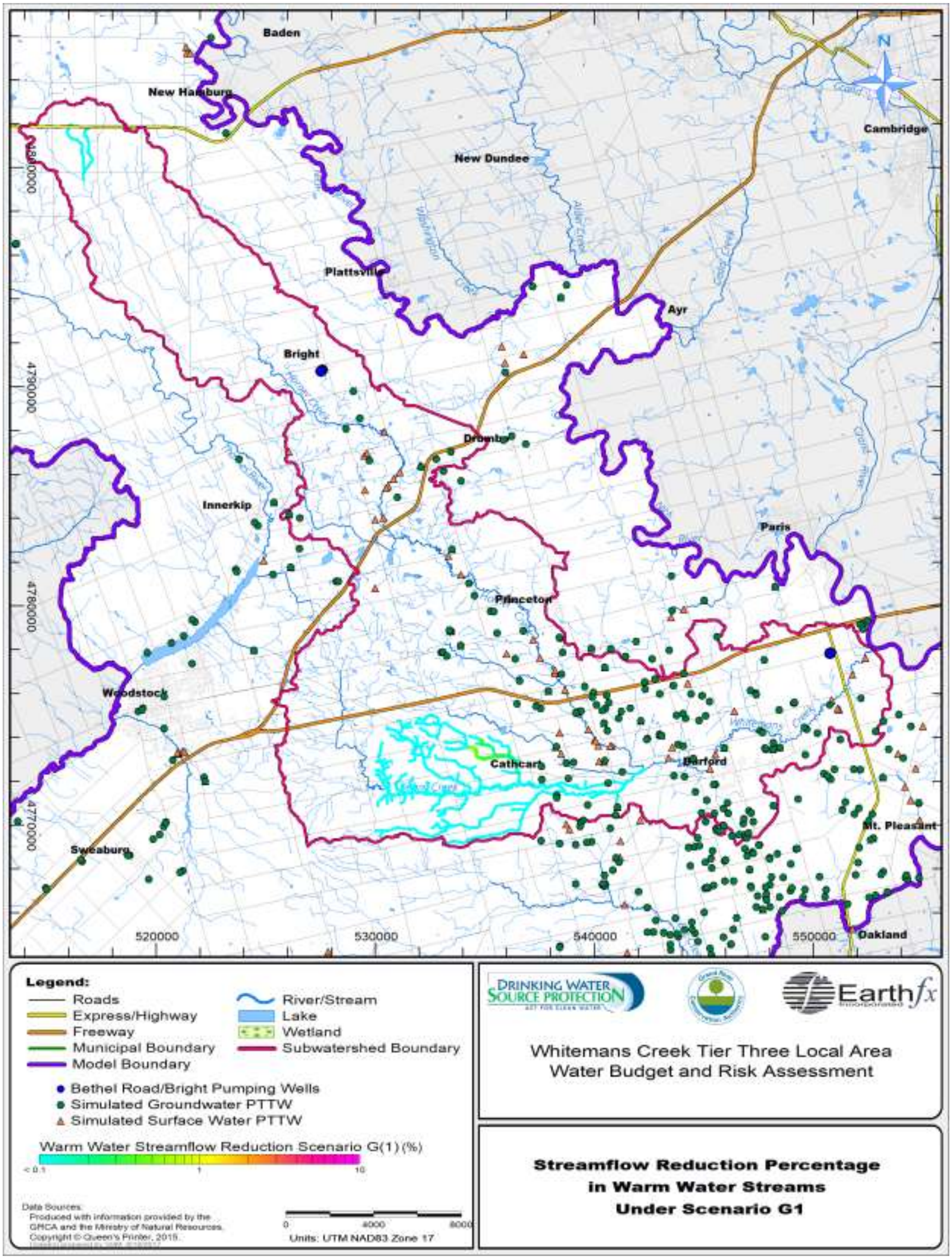

Figure 6.39: : Percent reduction in long-term average streamflow in warm water streams under Scenario G(1).

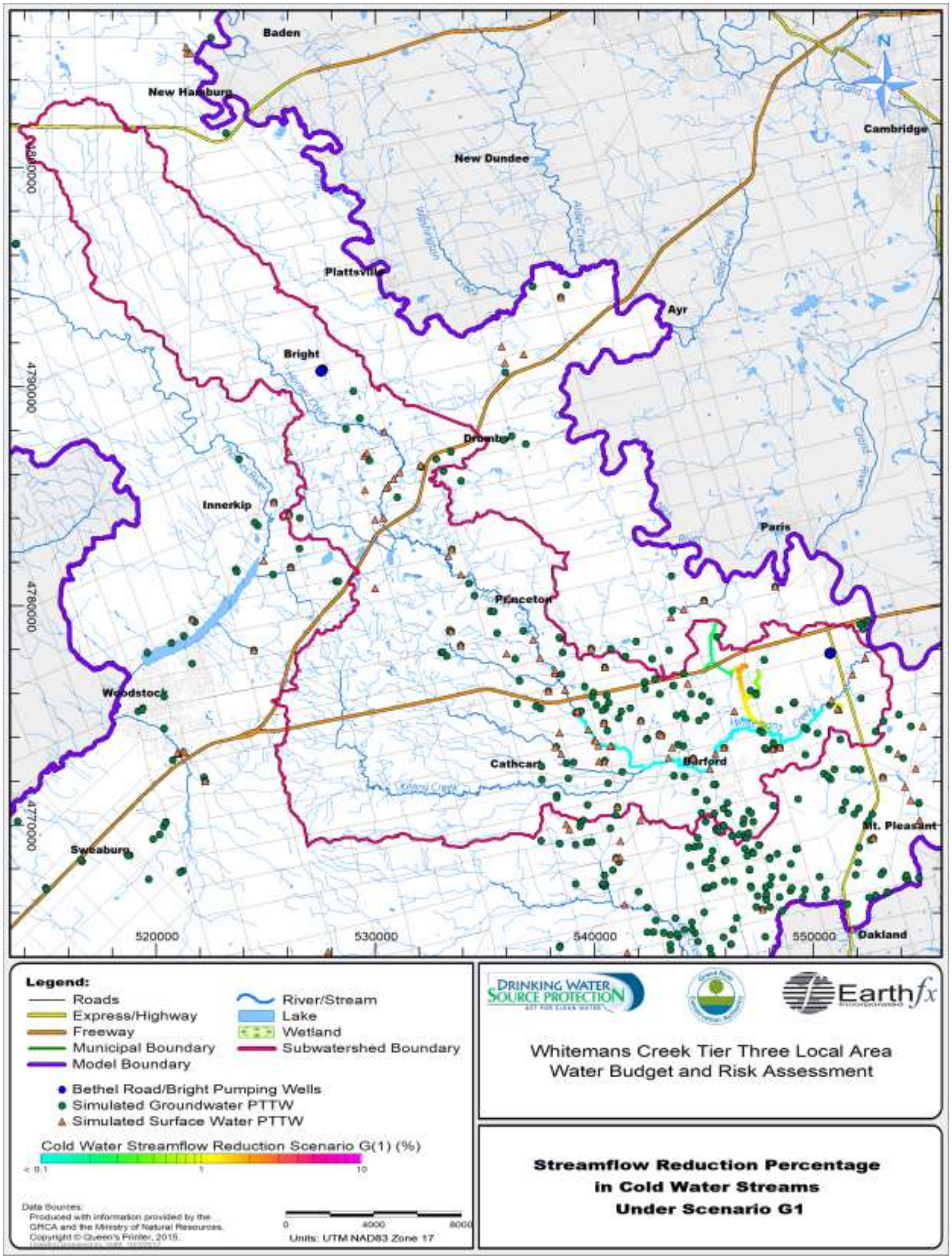

Figure 6.40: Percent reduction in long-term average streamflow in cold water streams under Scenario G(1).

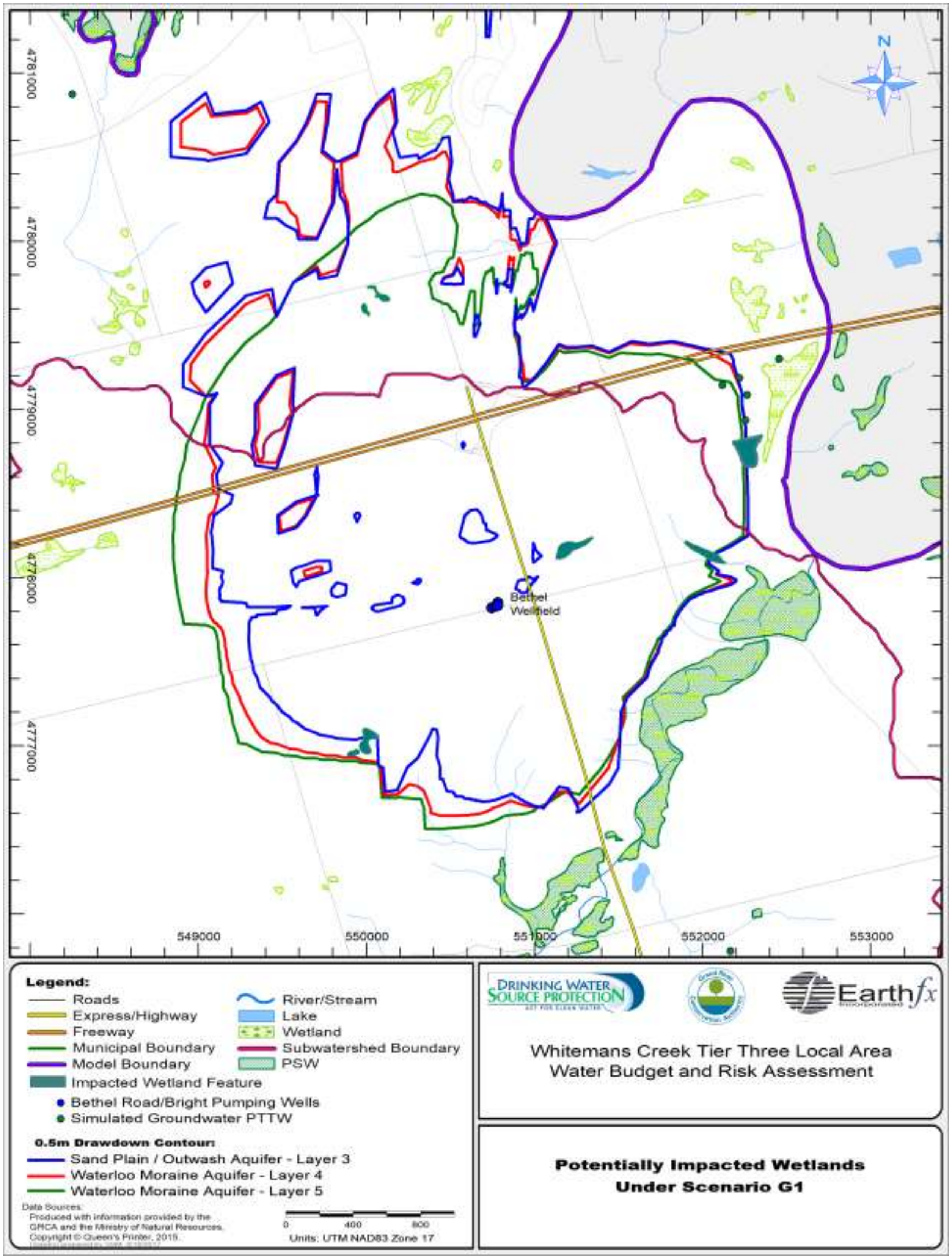

Figure 6.41: Potentially impacted wetlands.

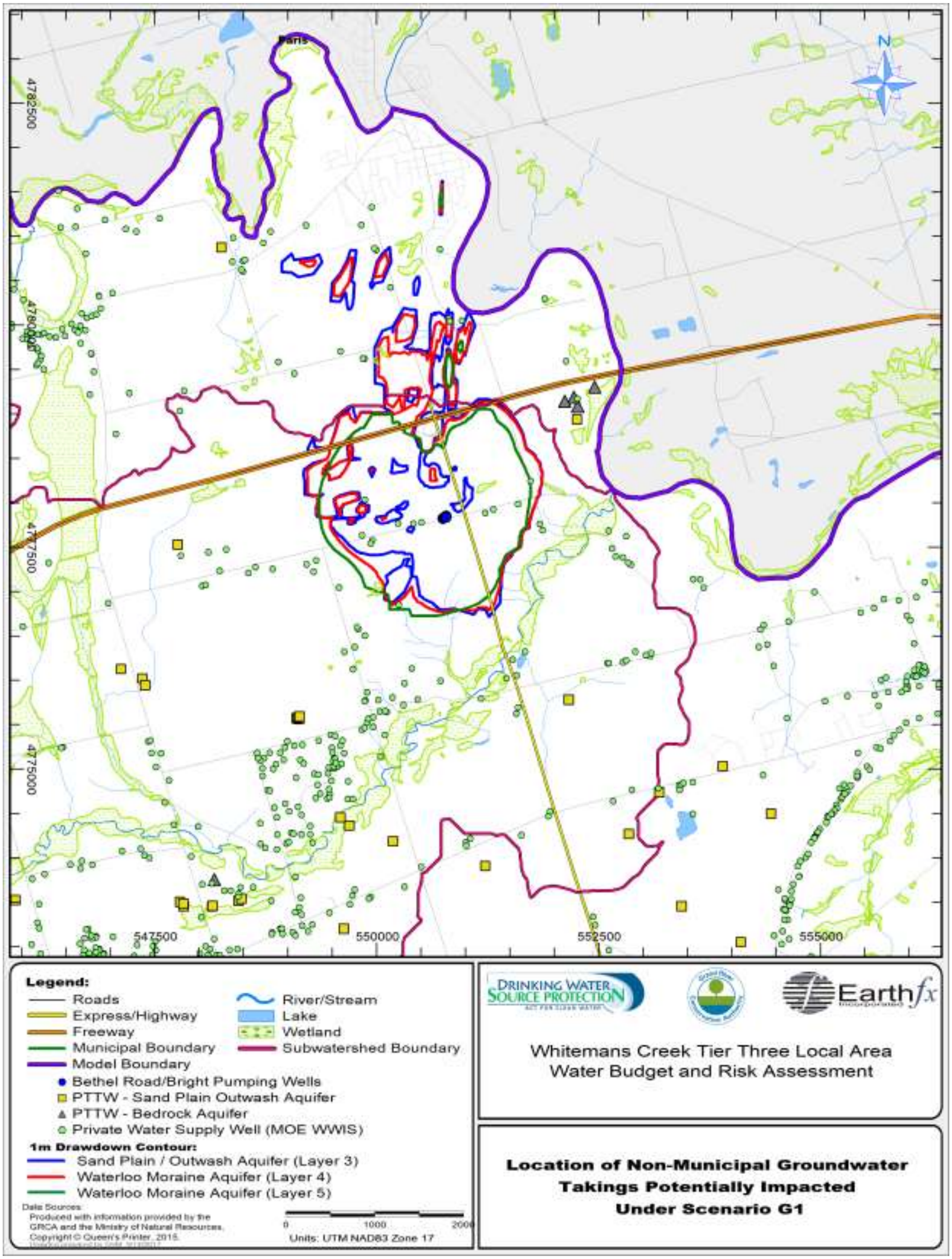

Figure 6.42: Location of non-municipal groundwater takings potentially impacted under Scenario G(1).

7 Water Quantity Threats

Under the Technical Rules (MOE, 2008), local areas classified as having a risk level of significant or moderate must have the water quantity threats that may limit the sustainability of the municipal water supply wells identified. Drinking water quantity threats are defined as: 1) an activity that takes water from an aquifer or a surface water body without returning the water taken to the same aquifer or surface water body (i.e., consumptive water demand); or 2) an activity that reduces the recharge of an aquifer.

7.1 Consumptive Water Demands

Circumstances that warrant consumptive water uses being classified as a significant or moderate drinking water threat are summarized in Table 5 (Ref. Number 2 and 4) of the Technical Rules (MOE, 2009). As per the Technical Rules, drinking water threats are only characterized for Local Areas with a moderate or significant risk level. As such, identifying drinking water threats was required only for the Bethel Road Municipal Wellfield Local Area. All consumptive municipal, non-municipal permitted and non-municipal non-permitted takings (i.e., domestic and livestock wells identified in the MOECC WWIS) are shown in Figure 7.1. The Local Area contains the four production wells associated with the Bethel Road municipal wellfield and intersects a dugout pond associated with an aggregate washing permit (discussed below). It also contains 14 non-permitted domestic takings. The following circumstances were applicable to the consumptive takings identified in the Local Area:

1. *An existing taking, an increase to an existing taking or a new taking.*
2. *The water is or would be taken from within a WHPA-Q1.*
3. *Section 34 of the Ontario Drinking Water Resources Act requires a permit to take water in respect of the increase or new taking.*

As discussed previously, a new aggregate washing permit (7748-AC8KHC) was issued in August of 2016, pertaining to two wells and one dugout pond (See Figure 7.1 inset). The permit is believed to have replaced permit number 3347-9A5LKP, which expired in August of 2016 and shares the same location coordinates and source names (PW1, PW3, and Pond). No takings were ever reported under the previous permit, and only the dugout pond falls within the Bethel Road Municipal Wellfield Local Area. The dugout pond, which is constructed within the Sand Plain/Outwash Aquifer, was issued a permit with a maximum daily taking of 5,892 m^3/d. Assuming a consumptive use factor of 0.2 for aggregate washing, the consumptive taking would be 1,166 m^3/d, which is comparable to the Bethel wellfield municipal takings. The two wells (PW1, and PW3) are located outside but close to the Local Area boundary. The wells are completed in bedrock, which is not believed to be in good connection with the municipal aquifer and their permitted rates are considerably smaller than that of the dugout pond. As such, only the permitted taking associated with the dugout pond is considered a threat to the Bethel wellfield.

The total number of drinking water threats is summarized in Table 7.1. All drinking water threats in the Bethel Road Municipal Wellfield Local Area are classified as significant because the risk level was also classified as significant (Section 6.6.2).

Table 7.1: Summary of consumptive water demand threats in the local area.

Type of Consumptive Water Use	Bright Municipal Wellfield Local Area		Bethel Road Municipal Wellfield Local Area	
	Number of Threats	Threat Classification	Number of Threats	Threat Classification
Municipal	0	-	4	Significant
Non-Municipal Permitted	0	-	1	Significant
Non-Municipal Non-Permitted	0	-	14	Significant
Total	0	-	19	-

7.2 Reductions in Groundwater Recharge

Circumstances that warrant reductions in recharge being classified as a significant or moderate drinking water threat are summarized in Table 5 (Ref. Number 6 and 8) of the Technical Rules (MOE, 2009). As above, only the Bethel Road Municipal Wellfield Local Area was analyzed for drinking water threats. The following circumstances were applicable to recharge reduction activities identified in the Local Area:

1. *An existing activity, a modified activity or a new activity*
2. *The activity is or would be wholly or partly located within a WHPA-Q2*

Recharge reduction activities that have the potential to impact the municipal wells were identified in the WHPA-Q2 analysis (Section 6.2.2). The development activities with the largest impact were those already encircled within the WHPA-Q2 bounds. However, the threats analysis was expanded to include the development activities that straddle, but are outside the WHPA-Q2 (i.e., the Local Area) as per the Technical Rules. A total of 243 ha of recharge reduction activities associated with future land development were identified as drinking water threats (Figure 7.2). A threat classification of significant was assigned because the risk level of the local area was also classified as significant.

7.3 *Figures*

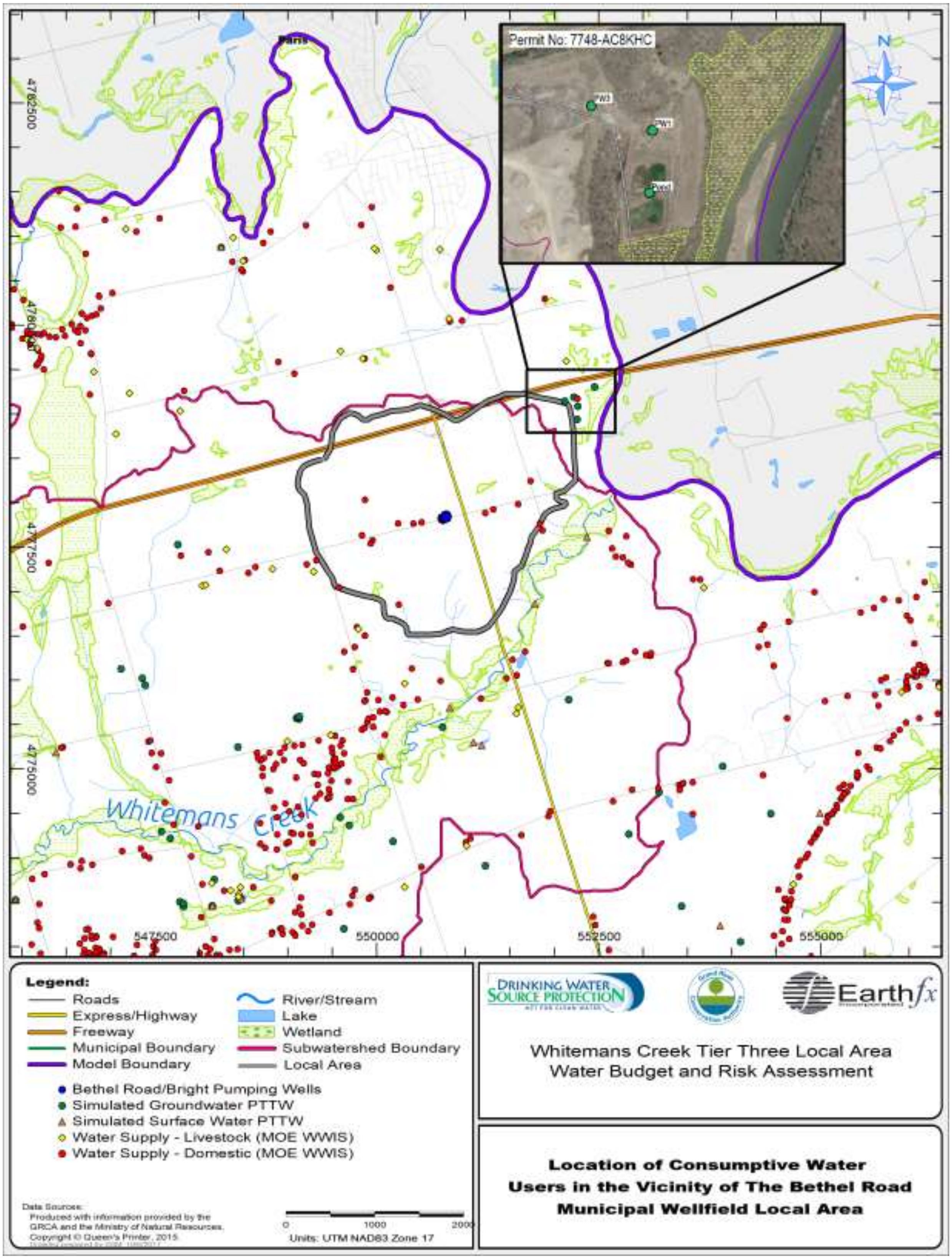

Figure 7.1: Location of consumptive water users in the vicinity of the Bethel Road Municipal Wellfield Local Area.

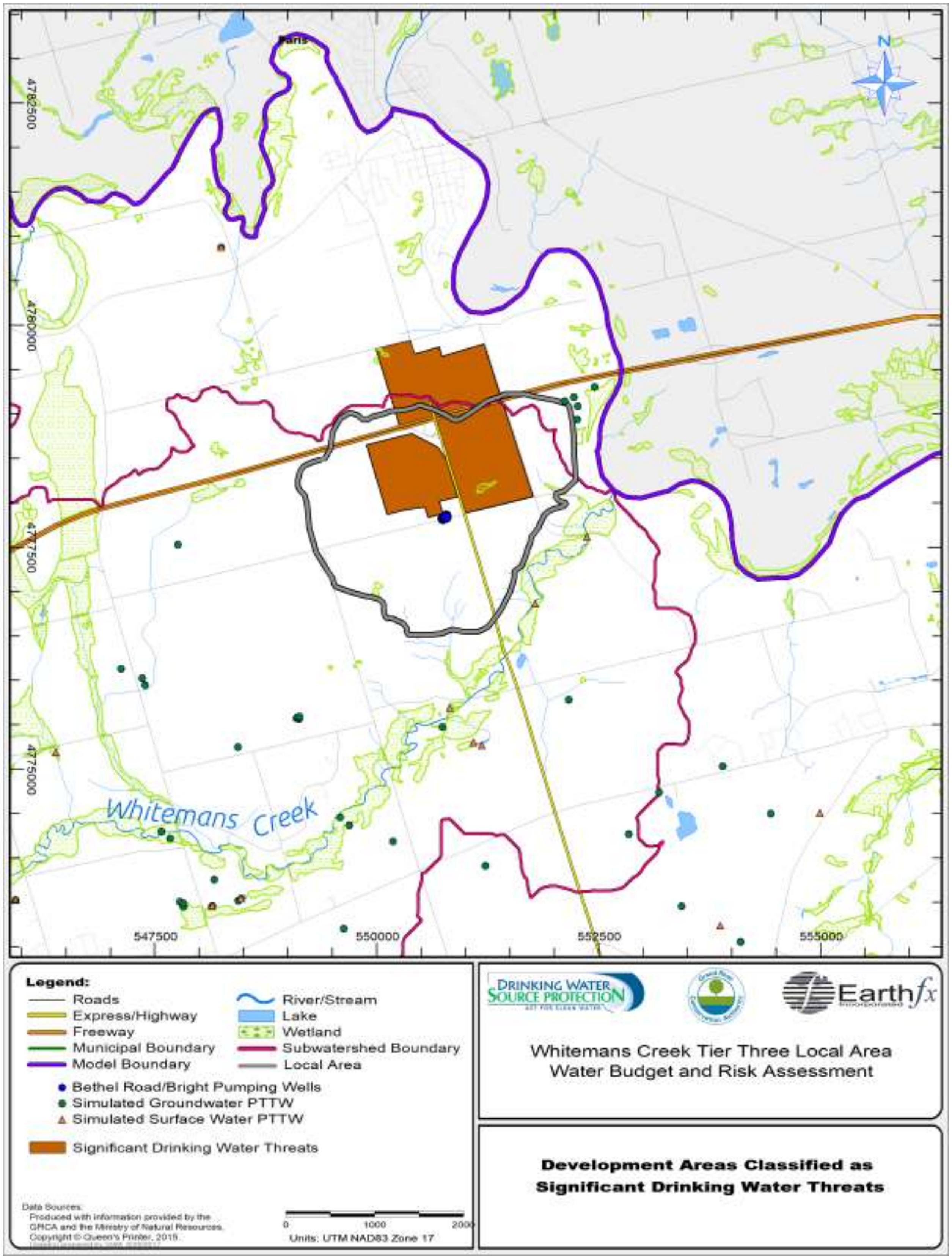

Figure 7.2: Development areas classified as significant drinking water threats.

8 Significant Groundwater Recharge Areas

8.1 *Introduction*

Groundwater recharge is the hydrological process whereby water entering the near-surface soil zone percolates downward through the unsaturated zone to replenish the groundwater system. The rate of recharge is dependent on a wide range of parameters including but not limited to: soil characteristics (e.g., hydraulic conductivity, porosity, field capacity and wilting point), percent impervious cover, vegetation cover type and cover density, potential evapotranspiration, local topography, and depth to water table). To protect sources of high groundwater recharge, the MOECC has implemented in their Technical Rules (MOE, 2009) a requirement that Significant Groundwater Recharge Areas (SGRAs) be delineated in every source protection area.

8.2 *Significant Groundwater Recharge Areas Delineation Methodology*

The Technical Rules for the Assessment Report (MOE, 2009) sets out two alternate methods for delineating SGRAs as follows:

> *44(1): the area annually recharges water to the underlying aquifer at a rate that is greater than the rate of recharge across the whole of the related groundwater recharge area by a factor of 1.15 or more; or*
>
> *44(2): the area annually recharges a volume of water to the underlying aquifer that is 55% or more of the volume determined by subtracting the annual evapotranspiration for the whole of the related groundwater recharge area from the annual precipitation for the whole of the related groundwater recharge area.*
>
> *45: Despite Rule 44, an area shall not be delineated as a significant groundwater recharge area unless the area has a hydrological connection to a surface water body or aquifer that is a source of drinking water for a drinking water system.*
>
> *46: The areas described in Rule 44 shall be delineated using the models developed for the purposes of Part III of these rules and with consideration of the topography, surficial geology, and how land cover affects groundwater and surface water.*

Based on Rule 46, above, SGRAs were delineated using the results of the Tier 3 model. As discussed in the model development report (Earthfx, 2017), the GSFLOW model takes into consideration climate, topography, surficial geology, and land cover (vegetative cover and imperviousness) to estimate daily groundwater recharge rates. Daily rates are aggregated over the simulation period to estimate annual average rates of groundwater recharge.

Figure 8.1 shows a map of annual average groundwater recharge on a cell-by-cell basis. Values were determined by averaging daily values over a 25-year period from WY1975 to WY2010. The SGRA delineation presented below was conducted on a uniform 240 by 240 m grid, corresponding to the maximum cell size of the groundwater component of the GSFLOW model. The groundwater recharge map used in the analysis is similar to that shown earlier in Figure 5.4 except that recharge values from areas with finer grid resolution have been averaged over the uniform 240 by 240 m cells. The average annual recharge, averaged over the entire subwatershed, was 295 mm/y.

8.3 *Delineation of Significant Groundwater Recharge Areas*

Figure 8.1 illustrates the spatial variability in groundwater recharge. Areas of higher recharge occur in the southeast part of the study area (associated with the Norfolk Sand Plain) and in the centre of the Whitemans Creek subwatershed. Areas of low recharge occur where Port Stanley and Tavistock Tills are found at surface. There are also a large number of cells with very low recharge (< 10 mm/y), which correspond to a combination of low permeability surficial units and high runoff due to topography or high imperviousness. Isolated areas of highly focused groundwater recharge shown in Figure 8.1 are associated with "swales", that is, poorly-drained low-lying areas at the ends of the runoff cascade network. The histogram of the recharge distribution, presented in Figure 8.2, also illustrates the bimodal nature of the recharge distribution.

The SGRA analysis presented here is based on the methodology outlined in Rule 44(1). Based on this rule, any cell within the Whitemans Creek subwatershed exceeding 340 mm (295 mm/y x 1.15) was considered a SGRA. The results of the initial SGRA delineation are shown in Figure 8.3.

The use of a cell-based model with spatially-variable parameters resulted in a spatially-variable distribution of groundwater recharge rates. The preliminary analysis resulted in many small isolated parcels of land that were above the SGRA threshold. Most of the isolated patches corresponded to swales at the ends of the overland flow cascade network that function as areas of focussed infiltration.

It is not practical to develop workable policies for the management of small, isolated SGRA zones. As per AquaResource (2012), an infilling/smoothing procedure was applied to the initial SGRA map (Figure 8.3) to remove small holes in the larger contiguous SGRAs and to remove small isolated SGRA patches. The infilling/smoothing approach evaluated whether a given cell was bounded by another of the same classification (i.e., an SGRA or not an SGRA) on at least two of the four sides. In cases where less than two sides were shared with cells having the same classification, the hole/patch was considered to be isolated and removed from the SGRA delineation. This process was repeated until no additional holes/patches were found. The results of the SGRA delineation with infilling and clipping are presented in Figure 8.4. The revised map yielded a more workable SGRA delineation for planning purposes.

According to Technical Rule 45, the areas identified as SGRAs must be hydrologically-connected to a surface water body or to an aquifer that is a source of drinking water. The Bright municipal wells are screened in the semi-confined Waterloo Moraine Aquifer, which is the shallowest major aquifer unit in the area and therefore likely to receive much of the incoming groundwater recharge from the SGRAs. This is evidenced by the fact that the SGRAs are focused in areas where the uppermost major confining unit, the Port Stanley Till Aquitard, is thin or its coverage is sparse, allowing recharge to occur primarily in areas where the Waterloo Moraine Aquifer is near surface.

The Bethel municipal wells are screened in a semi-confined aquifer, overlain by several discontinuous aquitard units and a thick sand deposit. It is known that the level of confinement decreases to the south of the wellfield and it is very likely that the municipal aquifer is in good connection with the Sand Plain/Outwash aquifer, which is associated with high recharge areas. The delineated SGRAs can therefore be considered to be hydrologically connected to the aquifer units supplying the Bethel wellfield, fulfilling the requirements of Technical Rule 45.

8.4 *Figures*

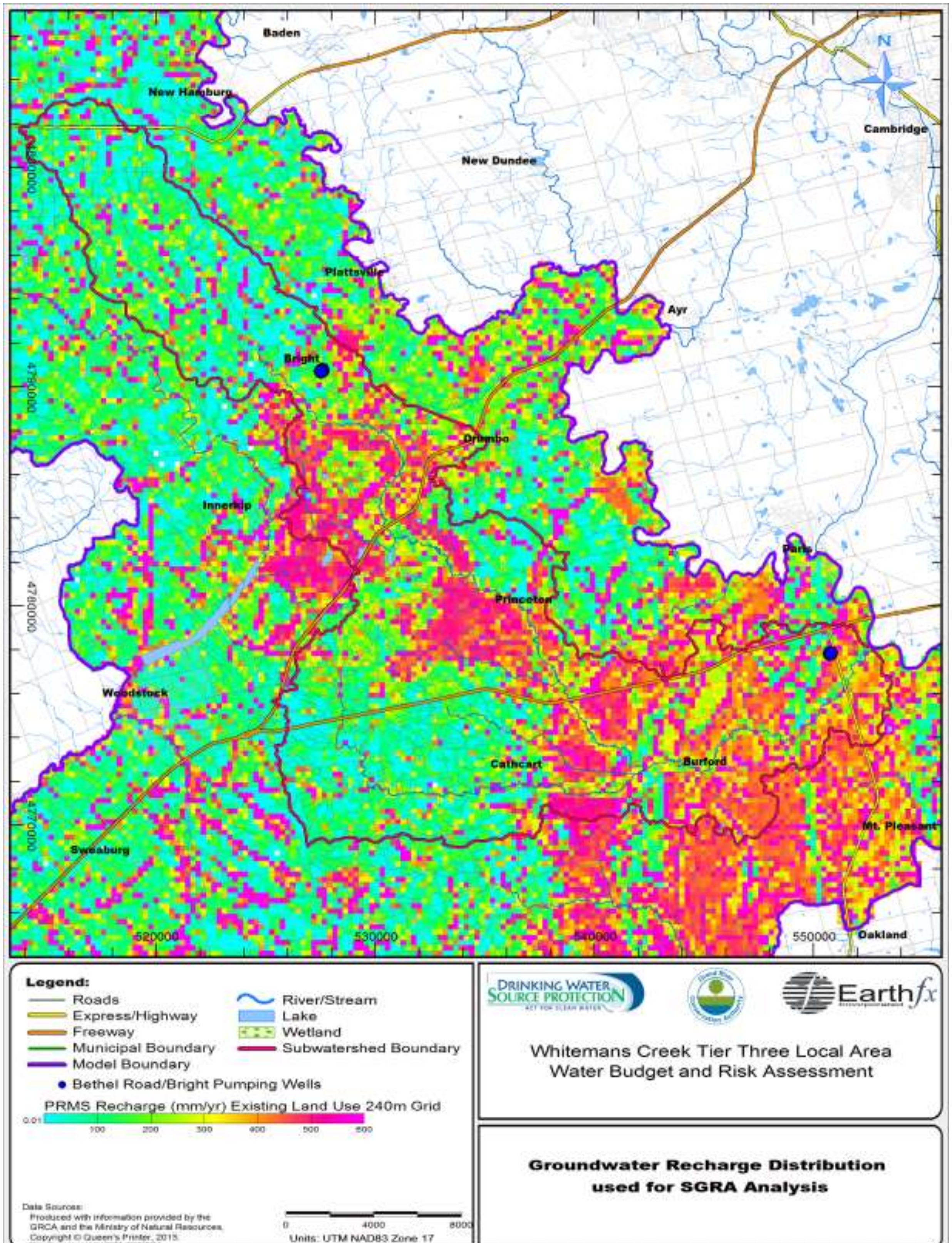

Figure 8.1: Groundwater recharge distribution used for the SGRA analysis.

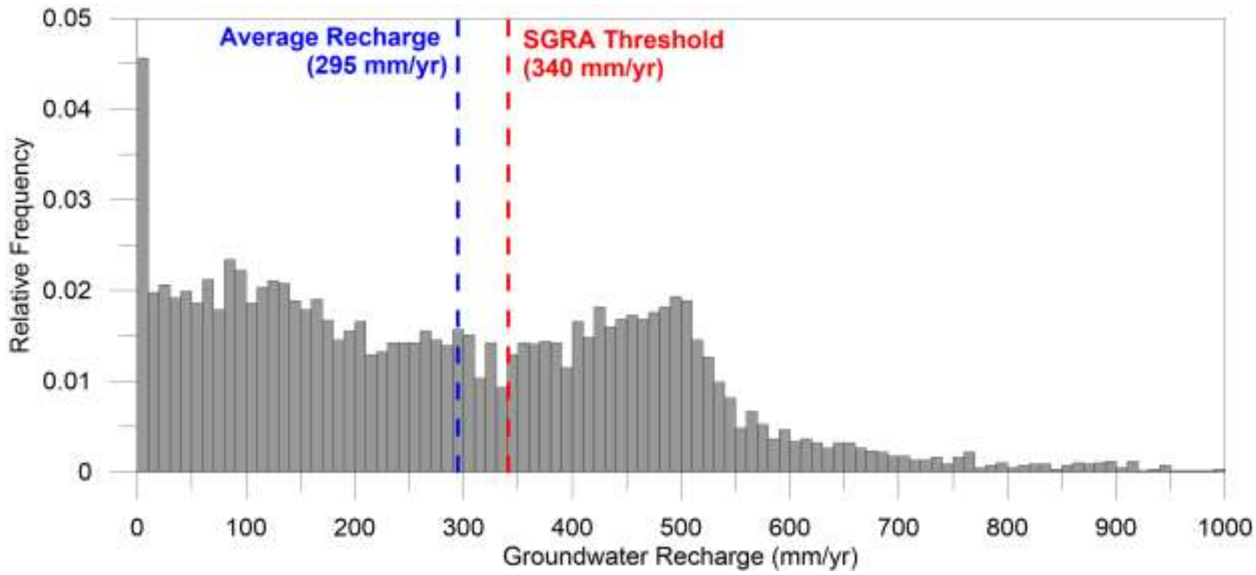

Figure 8.2: Histogram of recharge distribution for the Whitemans Creek Subwatershed (10 mm/y interval).

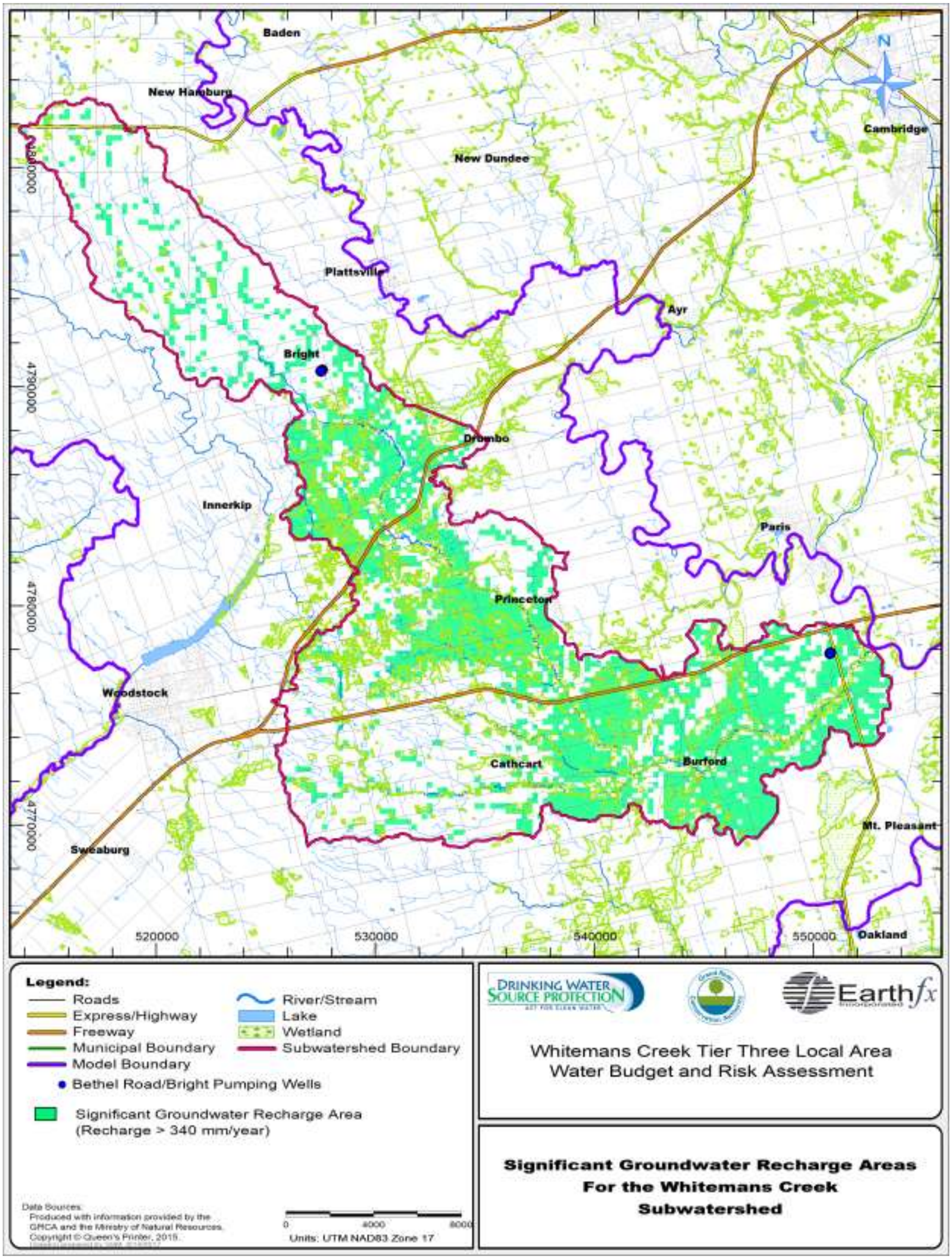

Figure 8.3: Significant groundwater recharge areas in the Whitemans Creek subwatershed

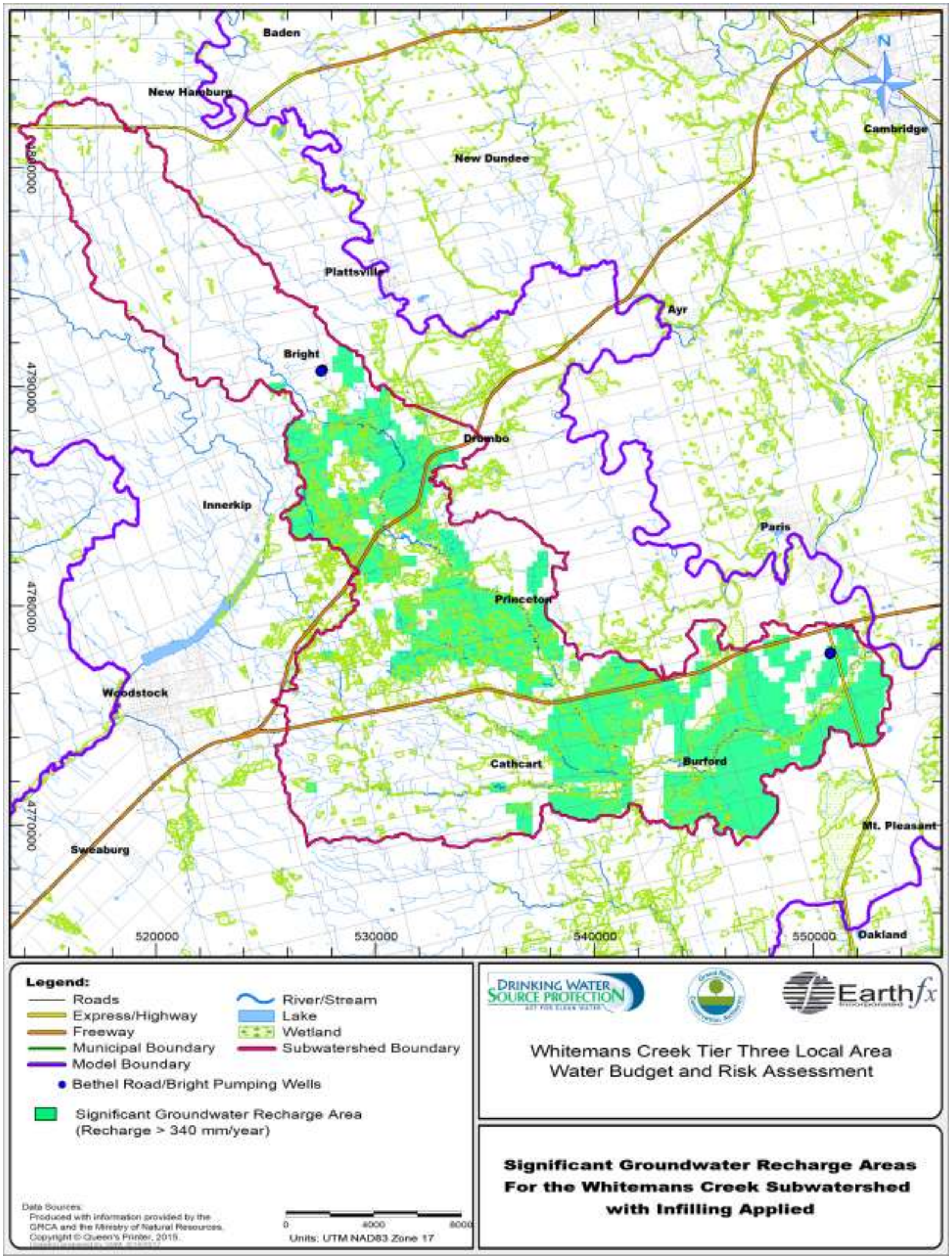

Figure 8.4: Significant groundwater recharge areas in the Whitemans Creek subwatershed with clipping and infilling applied

9 Summary and Conclusions

This report describes the Tier 3 Water Budget and Local Area Risk Assessment completed for the municipal drinking water systems within the Whitemans Creek subwatershed. The purpose of the Tier 3 study is to investigate whether a municipality's drinking water system will be able to meet their allocated pumping rates considering future increases in municipal demand, future land development, future drought, and impacts to other uses.

The Tier 3 water budget model was developed using the U.S. Geological Survey GSFLOW integrated model computer code (Markstrom *et al*., 2008). GSFLOW is constructed from two proven submodels: MODFLOW and PRMS. Municipal wells were characterized and water use was estimated through analysis of the PTTW, WTRS and MOECC WWIS datasets. Consumptive agricultural water use was represented through the application of a custom irrigation demand module developed for GSFLOW. Other water uses, including provincially significant wetlands, streamflow and private domestic and livestock watering supply wells were also investigated. Future land use was determined based on Oxford County and County of Brant official plans and the Ontario inventory of pits and quarries.

The Tier 3 model was used to complete the water budget and stress assessment; the delineation of vulnerable areas, the local area risk assessment, the water quantity threats assessment; and the determination of SGRAs, all of which are summarized below.

9.1 *Water Budget and Stress Assessment*

The water budget and stress assessment are key components of the Tier 1 and Tier 2 analyses. The Tier 2 Water Budget for the Whitemans Creek subwatershed indicated a low level of stress under average climate conditions; however, it was considered to be moderately stressed under drought conditions. The water budget was re-calculated using the Tier 3 model to ensure consistency with the previous studies. A stress assessment was also re-evaluated because the municipal water supply within the Whitemans Creek subwatershed changed substantially since the completion of the Tier 2 analysis. The changes include the replacement of the main production well in the Bright wellfield, and the addition of the Bethel wellfield, which includes four production wells as part of the Town of Paris municipal drinking water supply system. The Tier 3 model also used an updated approach to calculating consumptive water demand for permitted irrigation takings. The groundwater percent water demand was re-calculated using updated water budget parameters. The percent water demand decreased slightly, compared to the Tier 2 analysis, due to different assumptions associated with consumptive water demand and the different simulation methods of the two models. Results from the Tier 3 model suggest that the groundwater supply of the Whitemans Creek subwatershed is under low stress on an average and monthly basis.

9.2 *Delineation of Vulnerable Areas*

WHPA-Q1s were delineated for the Bright and Bethel wellfields using a 1 m and a 0.5 m drawdown threshold, respectively, determined through analyses of seasonal water level variability (see Appendix D). Drawdowns were calculated as the difference in groundwater level elevation between a baseline scenario (i.e., no pumping) and a future pumping scenario (i.e., allocated water demand). An additional 1 m drawdown was not expected to occur anywhere as a result of the increased pumping in the Bright wellfield. The WHPA-Q1 was therefore delineated as a 100 m radius around the two production wells. The extent of the drawdowns in the vicinity of the Bethel wellfield was considerably larger, with the 0.5 m drawdown encompassing a 6 km² area.

Recharge reductions associated with future land use were investigated for their impact on water levels in the municipal wells. Future land use was not expected to have any measureable impact at either of the Bright production wells. Future land use was, however, expected to have an impact of greater than 0.5 m in all four of the Bethel production wells. Incremental land use change was simulated to determine which developments had the largest impact on the municipal wells and if any areas outside the WHPA-Q1 delineation were responsible for producing any measureable impacts at the wells. Drawdown analysis of the incremental land use changes showed that while the developments outside the WHPA-Q1 had some impact, the developments inside the WHPA-Q1 were responsible for the drawdowns exceeding the 0.5 m threshold. Accordingly, the WHPA-Q2 areas were determined to be coincident with the WHPA-Q1 areas. A Local Area, which is, by definition, synonymous the WHPA-Q2, was established for the Bright and Bethel wellfields for the risk assessment.

9.3 *Local Area Risk Assessment*

The Tier 3 risk assessment scenarios were simulated to identify the isolated and cumulative impacts of future pumping and land use, under average climate (Scenario G) and drought conditions (Scenario H). The impacts were measured by comparing the additional drawdown generated under each risk assessment scenario to a safe additional drawdown threshold determined during the preliminary stages of the Tier 3 analysis. The safe additional drawdown for the Bright wells was determined as the difference between the average observed water level in the well and an elevation 2 m above the top of the well screens. An elevation 3 m above the top of the well screens was used to determine the safe additional drawdown for the Bethel wells.

The impacts of future pumping and land use were evaluated under average climate conditions through a set of steady-state simulations. Current pumping and land use conditions were used as a baseline (Scenario C) for calculating additional drawdowns caused by future pumping and future land use (Scenarios G(1), G(2), and G(3)). Drought impacts were evaluated through transient simulations under current pumping and current land use (Scenario D) conditions and future pumping and future land use conditions (Scenarios H(1), H(2), and H(3)). The climate period of WY1955 to WY1966 was selected for the drought analysis. Simulated drawdowns were corrected to account for non-linear and convergent head losses.

The simulated drawdowns in the Bright municipal wells did not exceed the safe additional drawdown limit under any circumstances for average and drought climate periods. While the Bright wellfield was considered to have a high tolerance under the Tier 3 rules, the lack of redundancy of the system and the difficulty to locate an additional water source will be a challenge for future development. The Bethel municipal wells are also expected to be sustainable under future pumping and land use conditions for an average climate period; however, future pumping caused drawdowns that came close to exceeding the safe additional limit. Under drought conditions, the future pumping was not sustainable for any of the Bethel municipal wells and drawdowns exceeded the safe limit by a large margin. Future land use is not expected to have as much of an impact as the future pumping. Risk levels of low and significant were assigned to the Bright and Bethel local areas, respectively.

The Tier 3 analyses consider the risk of future pumping and land use changes to other water uses (e.g., wetlands and aquatic habitat) and other water takings. No impacts are expected to any provincially significant wetlands and all streamflow reductions in mapped warm water and cold water reaches are expected to be well below the 10% threshold. The Bethel municipal wells are expected to represent a risk to nearby private well owners. A “moderate” risk level is the maximum that can be assigned for this condition under the Technical Rules. As noted above, the Local Area was already assigned a “significant” risk level due to the inability of the Bethel municipal wells to meet future pumping demands under drought conditions.

9.4 *Water Quantity Threats*

Water quantity threats were not required to be identified in the Bright Wellfield Local Area because of its risk classification of low. The Bethel Road Wellfield Local Area contains 19 consumptive water demand threats, consisting of the 4 Bethel municipal wells, 1 aggregate washing permit, and 14 private domestic wells. 243 ha of recharge reduction activities were also considered to be a threat to the municipal wells. All threats to the Bethel Road Wellfield Local Area were considered significant in accordance with the significant risk assigned during the Local Area risk assessment.

9.5 *Significant Recharge Areas*

As a final analysis, results of the Tier 3 model were used to develop maps of significant groundwater recharge. SGRAs are primarily found in the central region of the Whitemans Creek subwatershed and in the extensive Norfolk Sand Plain to the southeast.

9.6 *Conclusions*

The Whitemans Creek subwatershed was assessed as being moderately stressed in the Tier 2 Water Budget and Stress Assessment (AquaResource, 2009). As such, a Tier 3 study was required to determine the sustainability and impact of the Bright and Bethel municipal drinking water supply under average climate and drought conditions. A Local Area Risk Assessment was completed for each wellfield. The Bright Wellfield Local Area was assessed a low level of risk because it was able to meet its water demand under all conditions and was shown to have minimal impact to other users. The Bethel wells were able to meet future water demand under average climate conditions but unable to meet future water demand under drought conditions. Accordingly the Bethel Road Wellfield Local Area was assessed a significant level of risk.

9.7 *Recommendations*

Based on the Tier 3 analysis, the following additional recommendations are proposed:

- A long-term pumping test/stress test at the Bethel wellfield would better quantify summer aquifer storage and true long-term wellfield capacity, particularly during dry periods. Potential boundary effects should be explored prior to the next Tier 3 update or before pumping the wellfield near capacity during a sustained drought event. Any understanding or insights gained from further testing tor exploration work at the wellfield should be incorporated into the Tier 3 model update.
- Policies to enhance or maintain recharge in and around the Bethel wellfield should be established, specifically within the local area. These policies could include implementing Low Impact Development strategies within the Brant Business Park. Protection of current recharge rates will be beneficial to the sustainability of the wellfield in the future.
- The risk assessment has indicated that the Bethel wellfield is sustainable under current conditions at a pumping rate of 15.9 L/s The model also indicates the wellfield is sensitive to increases in pumping rates, sustained periods of drought and, to a lesser extent, changes to local recharge. If an opportunity arises in which the wellfield is to be pumped in excess of 15.9 L/s for longer than 72 hours, efforts should be made to monitor water levels within the pumped wells and nearby observation points to look for boundary effects.
- The majority of the water for the Bright system is supplied by Well 4A due to well efficiency problems in Well 5. While the modelling analysis has shown the system to have a high tolerance for both future pumping and drought periods, operationally there remains a potential lack of redundancy. Efforts to find an additional supply for the Community of Bright have been unsuccessful in the past, leading to the installation of a storage facility. While this has addressed the immediate concerns, efforts should be taken to ensure Well 4A is adequately maintained and the efficiency of the wellbore does not deteriorate. Continued efforts should be made to find an alternative source to provide redundancy.
- The existing groundwater monitoring network at the Bethel and Bright wellfields should be maintained. Data from monitors at the KPM Reid property to the south of the Bethel wellfield should be used to complement the existing municipal monitoring wells, if possible. These data would enhance the understanding of the local hydrogeologic system, especially to the south where the aquifer becomes unconfined. The existing PGMN network should be supported and expanded when opportunities exists.
- Data collected at the stream gauging stations within and proximal to the Whitemans Creek subwatershed were critical for this study. These stations should be maintained for use in future

Source Water Protection and water budget studies. During periods of severe drought, spotflow measurements should be undertaken to capture the hydrologic response within the Whitemans Creek subwatershed to low water conditions.

- There are currently no active ECCC climate stations within the Whitemans Creek subwatershed. It was noted that recent data collected at stations in close proximity to the subwatershed such as at Woodstock and the Brantford Airport exhibit gaps. Where possible, climate data (specifically precipitation data) should be collected by GRCA to augment the ECCC network.
- The WTRS data were extremely valuable for characterizing water use across the study area, specifically for developing and calibrating the agricultural irrigation demand module. Efforts should be made to encourage compliance with the permitting and water reporting programs. The MOECC should continue its efforts to better link the WTRS, WWIS, and PTTW databases such that information related to specific permits can be tied to actual water use and geologic conditions.
- The integrated groundwater/surface water model developed for this study represents an ideal tool for assessing and evaluating future management actions within the Whitemans Creek subwatershed. Further analysis could be undertaken to quantify unreported irrigation demands within the watershed, assess the impacts of irrigation pumping on the hydrologic regime of Whitemans Creek, and to evaluate the benefits of moving surface water takers to offline or groundwater sources. Enhancing the drought resilience of Whitemans Creek is consistent with the goals of Ontario's watershed-based Source Water Protection Program.
- The future Tier 3 update should expand the model to include all the wellfields that service the Town of Paris. This would allow the tolerance and quantity requirements of the entire system to be evaluated in a consistent, integrated fashion.

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Appendix A Analysis of Paris Water Supply Memorandum

Earth Science Information Systems

MEMORANDUM

To: Stephanie Shifflett, P.Eng. (GRCA)

CC: Whitemans Creek Tier 3 Project Team

From: Earthfx Incorporated

Date: 2017 June 02

Subject: ***Whitemans Creek Tier 3 - Analysis of Paris Water Supply (Zone 3)***

The following memo presents a brief analysis of the estimated future demand of the Town of Paris Water distribution system with an emphasis on the Zone 3 pressure district which is served in part by the Bethel wellfield. The motivation of this analysis is to determine a future annual average pumping rate from the Bethel Wellfield for use in the Whitemans Creek Tier 3 Water Budget and Risk Assessment. This work draws on analyses previously completed as part of the Community of Paris Master Servicing Plan (WSP, 2016)

PARIS ZONE 3 WATER DISTRIBUTION BACKGROUND

The Paris water distribution system is broken into 4 pressure districts. Zone 3 is supplied by the M. Sharpe Reservoir (herein referred to as Sharpe Reservoir) and the Bethel wellfield. The Permit to Take Water restricts the average pumping rate to 37.5 L/s except for 30 days in a calendar year where pumping can reach 50 L/s (MOECC, 2015). The maximum output of the Bethel wellfield is assumed to be 48 L/s, as it is restricted by its reported maximum pumping capacity of 50 L/s less 2 L/s to operate the ion exchange system at the adjacent water treatment plant. The Sharpe Reservoir has a standard operating capacity of 150 L/s. The Bethel wellfield brings redundancy to the Zone 3 pressure district; however, the current available capacity of Zone 3 far exceeds that of the current and future demand. This memo highlights the rationale behind the selection of a demand partitioning scheme between Bethel and the Sharpe reservoir for Zone 3.

PARIS ZONE 3 WATER DISTRIBUTION ANALYSIS

The future average day demand of the Zone 3 pressure district is determined using the following formula which includes the current Zone 3 demand, residential and employment population growth, and the quantity of water required to operate the ion exchange system at the Bethel Water Treatment Plant.

$$\begin{matrix} Future\ Average\ Day \\ Zone\ 3\ Demand \end{matrix} = \begin{pmatrix} Current\ Average \\ Day\ Demand \end{pmatrix} + \begin{pmatrix} Future\ Growth\ Average \\ Day\ Demand \end{pmatrix} + (Ion\ Exchange)$$

Estimates were obtained from WSP (2016) for each term as discussed below.

CURRENT AVERAGE DAY DEMAND:

- As of 2013, the current average day demand for the town of Paris is conservatively estimated to be **72.3 L/s** based on 2008 data, the highest rate in recent years.
- Zone 3 represents **8.6 percent** of the population and it is therefore assumed that the Zone 3 water demand is directly proportional to this percentage. While this percentage doesn't explicitly represent the different water user categories (i.e., employment and residential) this is a reasonable assumption as the ratio of employment population to residential population for 2013 is the same for all four zones as shown in the Appendix (Sheet D) of WSP (2015).
- Scaled average day demand for Zone 3 is therefore assumed to be 72.3 L/s *0.086, which is equal to **6.2 L/s**.

FUTURE GROWTH AVERAGE DAY DEMAND:

- Average day residential use by Zone 3 growth population of 4057 people at 0.35 m^3/person*day (1419.9 m^3/day)
- Use by Zone 3 employment growth population of 612 people assuming 40 people per ha and 45 m^3/day*ha (688.5 m^3/day)
- Total future average day demand is **24.4 L/s** (2108.4 m^3/d)

ION EXCHANGE

- Requires 2 L/s (WSP, 2016)

FUTURE AVERAGE DAY DEMAND CALCULATION

$$Future\ Average\ Day\ Demand = \ 6.2 + 24.4 + 2 = 32.6\ L/s$$

The estimated future average day demand of Zone 3 of **32.6 L/s** roughly corresponds to the standard operating capacity of the Bethel wellfield (35 L/s).

CONTRIBUTION FROM SHARPE RESERVOIR:

- Operating capacity of Sharpe Reservoir to supply Zone 3 is **150 L/s,** which exceeds entire Zone 3 future maximum day demand of **64.7 L/s** (From Table 5-10; WSP, 2016)
- Zone 1 and 2 supply **39.8 L/s** of peaking requirements to Zone 3 and 4; **23.1 L/s** goes to Zone 4, leaving **16.7 L/s** to supply Zone 3 (Sharpe Reservoir)
- It is therefore assumed that the Sharpe Reservoir can be relied upon to produce **16.7 L/s** under peak conditions, a very conservative assumption based on its rated capacity (150 L/s).

ESTIMATED BETHEL PUMPING RATE:

Based on the assumed contribution from the Sharpe Reservoir, the Bethel wellfield is not expected to supply the full future average day demand of Zone 3 of 32.6 L/s. Instead, it is estimated to be required to supply the balance of the demand as shown below:

$$Bethel\ Demand = \begin{pmatrix} Future\ Average \\ Day\ Demand \end{pmatrix} - \begin{pmatrix} Contribution\ From \\ Sharpe\ Reservoir \end{pmatrix}$$

$$Bethel\ Demand = 32.6\ L/s - 16.7\ L/s = 15.9\ L/s$$

With the Sharpe Reservoir supplying a minimum of 16.7 L/s, the Bethel wellfield is required to supply **15.9 L/s**.

SUMMARY

It is a requirement of the Tier 3 Water Budget and Risk Assessment process to evaluate the impact of all municipal water takings on surrounding groundwater and surface water resources under a realistic pumping scenario. Details of the daily reservoir operation, apart from the standard operating capacity of 150 L/s, were not known prior to this analysis. Because the Sharpe reservoir has the capacity to meet the future demand (average and maximum day) on its own, the Bethel wellfield is needed primarily to provide redundancy to the Zone 3 distribution system. Consequently, a reasonable estimate of the actual Bethel wellfield pumping rate could not easily be inferred.

We used a set of assumptions described above to estimate the future average day water demand from the Bethel wellfield and the Sharpe Reservoir to satisfy the Paris Zone 3 pressure district. We conservatively assumed that the Sharpe Reservoir would only supply the peaking flows at the rate in which it receives them from Zone 1 and 2, 16.7 L/s. In reality, the Sharpe Reservoir can supply considerably larger quantities of water to the Zone 3 distribution system based on the storage capacity of the reservoir.

The Bethel wellfield was estimated to supply an average daily flow of ***15.9 L/s***. This value represents a reasonable estimate of future pumping rates in the Bethel wellfield. It should be noted that all figures and assumptions used in this analysis are consistent with those of the Community of Paris Master Servicing Plan (WSP, 2016). With GRCA and County of Brant approval, we propose to incorporate this value into the Tier 3 steady-state groundwater scenarios.

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Appendix B Active Surface Water Permits in Whitemans Creek Subwatershed

MOECC Permit Number	Source	Purpose	Specific Use	Easting (m)	Northing (m)	Maximum Daily Permitted Taking (m³/day)	Number of Permitted Days per Year	Mean Annual Permitted Taking (m³/day)	Mean Reported Daily Demand (m³/day)	Maximum Reported Daily Demand (m³/day)
00-P-1081	Horner Creek	Agricultural	Other - Agricultural	530371	4784002	5237	30	430	0	0
00-P-1081	Pond	Agricultural	Other - Agricultural	530001	4783928	5237	30	430	0	0
00-P-1082	Pond	Agricultural	Other - Agricultural	526076	4784164	5237	30	430	0	0
0111-6DCMBG	Whiteman's Creek	Agricultural	Other - Agricultural	540796	4773608	1159	8	25	0	0
0184-7GJNVU	Sebok Pond	Agricultural	Field and Pasture Crops	526060	4787030	1488	30	122	0	0
0273-9A6LN4	Horner Creek	Agricultural	Tobacco	538209	4776915	1409	40	154	17	968
0345-9DWSBK	Pond on an intermittent tributary of Horner Creek	Agricultural	Other - Agricultural	551183	4775268	10100	50	1384	536	2741
0370-8NXLJ5	Pond 1	Agricultural	Field and Pasture Crops	538221	4773556	955	80	209	40	714
03-P-2339	Pond	Agricultural	Tobacco	551091	4775302	10100	40	1107	79	1637
0556-9J6SA9	Pond 1 (Big)	Agricultural	Tobacco	529492	4786848	818	22	49	490	490
0556-9J6SA9	Pond 2 (Small)	Agricultural	Tobacco	529632	4786958	409	22	25	245	245
0732-9Y8K6R	Whitemans Creek	Agricultural	Tobacco	543550	4773543	1681	180	829	0	0
0732-9Y8K6R	Pond	Agricultural	Tobacco	543545	4773539	1681	180	829	48	5178
0786-9EGSNK	Whiteman's Creek	Agricultural	Field and Pasture Crops	543377	4773064	912	180	450	0	0
1066-6H5J49	On-stream pond on a tributary of Whiteman's Creek	Agricultural	Field and Pasture Crops	535987	4777804	1079	10	30	0	0
1132-9DNSGT	Horner Creek Site #1	Agricultural	Tobacco	530589	4785464	756	21	43	0	0
1132-9DNSGT	Horner Creek Site #2	Agricultural	Tobacco	531130	4786089	756	21	43	0	0
1463-6PPQQR	Horners Creek	Agricultural	Sod Farm	536090	4780350	912	195	487	0	508
1676-6BVR3P	Whiteman's Creek (Horner Creek)	Agricultural	Tobacco	551782	4776861	2589	40	284	0	0
2016-8GZPT7	Whiteman's Creek	Agricultural	Tobacco	538417	4774208	524	60	86	0	0
2241-9YXNY4	Pond #1	Agricultural	Field and Pasture Crops	540456	4772877	1728	180	852	0	0
2241-9YXNY4	Pond #2	Agricultural	Field and Pasture Crops	540214	4772898	1728	180	852	0	0

MOECC Permit Number	Source	Purpose	Specific Use	Easting (m)	Northing (m)	Maximum Daily Permitted Taking (m^3/day)	Number of Permitted Days per Year	Mean Annual Permitted Taking (m^3/day)	Mean Reported Daily Demand (m^3/day)	Maximum Reported Daily Demand (m^3/day)
2743-6FUJ5L	Horner Creek	Agricultural	Field and Pasture Crops	537206	4778447	1719	25	118	0	0
2767-6APJF9	Whitemans Creek	Agricultural	Tobacco	543377	4773064	999	180	493	0	0
3370-6H6RNJ	Horner Creek	Agricultural	Tobacco	537521	4777623	1623	12	53	0	0
4243-6APPKL	Whiteman's Creek	Agricultural	Tobacco	550825	4775691	2750	35	264	0	0
4561-96SQVQ	Horner Creek	Agricultural	Field and Pasture Crops	530410	4787920	2046	30	168	0	0
4633-63DQLG	Whitemans Creek	Agricultural	Tobacco	545277	4772548	2272	16	100	0	0
4672-9SZJWX	Whiteman's Kenny Creek	Agricultural	Tobacco	539278	4775096	700	20	38	0	0
5488-7VBQMC	horner creek	Agricultural	Field and Pasture Crops	533333	4782267	2455	50	336	1	458
5812-8PRLZF	Whiteman's Creek	Agricultural	Field and Pasture Crops	545532	4773223	2376	42	273	0	0
6052-9RGR3G	Whiteman's Creek Lot 13, Concession 3	Agricultural	Tobacco	552370	4777613	2210	16	97	12	1670
6268-8K7J9K	Horner Creek	Agricultural	Tobacco	530488	4785365	1080	20	59	15	749
63-P-0711	On-stream Pond	Agricultural	Field and Pasture Crops	544258	4776464	1080	125	370	4	764
6654-6DTM5D	Tributary to Whiteman's Creek	Agricultural	Field and Pasture Crops	546388	4775189	1172	10	32	0	0
6733-8WXQXF	Horner Creek	Agricultural	Field and Pasture Crops	530371	4784002	5237	30	430	48	1000
6881-6DCLKL	Whiteman's Creek	Agricultural	Tobacco	539278	4775096	751	20	41	48	600
6881-6DCLKL	Onstream Pond	Agricultural	Tobacco	539224	4775189	1020	20	56	0	0
7218-6LBMK3	Whiteman's Creek	Agricultural	Tobacco	538203	4777051	928	60	153	0	0
73-P-0097	Horner Creek	Agricultural	Other - Agricultural	530847	4785782	1092	5	15	0	0
7411-6DCM29	Whitemans Creek	Agricultural	Field and Pasture Crops	540175	4773621	1545	30	127	0	0
7411-6DCM29	Location 2 Whitemans Creek	Agricultural	Field and Pasture Crops	540024	4773881	1545	30	127	0	0
7411-6DCM29	Location 3 Whitemans Creek	Agricultural	Field and Pasture Crops	539732	4774352	1545	30	127	0	0
7411-6DCM29	Location 4 Whitemans Creek	Agricultural	Field and Pasture Crops	540062	4773830	1545	30	127	0	0
7520-8H6Q4N	Whiteman's Creek	Agricultural	Tobacco	538479	4773246	1640	60	270	0	0
7835-78PKXV	Whitemans Creek	Agricultural	Field and Pasture Crops	540721	4773594	955	30	78	0	0
8315-869NKJ	Horners Creek	Agricultural	Field and Pasture Crops	533917	4781415	1443	50	198	10	2182

MOECC Permit Number	Source	Purpose	Specific Use	Easting (m)	Northing (m)	Maximum Daily Permitted Taking (m^3/day)	Number of Permitted Days per Year	Mean Annual Permitted Taking (m^3/day)	Mean Reported Daily Demand (m^3/day)	Maximum Reported Daily Demand (m^3/day)
8655-6BGSP6	Horner Creek	Agricultural	Tobacco	538669	4776161	1999	35	192	0	0
99-P-1008	Ponds	Agricultural	Other - Agricultural	530000	4780800	7855	9	194	0	0
99-P-1082	Horner Creek	Agricultural	Tobacco	530410	4787920	2046	30	168	0	0
99-P-1122	Pond	Agricultural	Other - Agricultural	529523	4785289	1227	10	34	0	0
99-P-1125	Pond	Agricultural	Other - Agricultural	532070	4786409	1227	10	34	0	0

Appendix C Active Groundwater Permits in Whitemans Creek Subwatershed

MOECC Permit Number	Source	Purpose	Specific Use	Easting (m)	Northing (m)	Maximum Daily Permitted Taking (m³/day)	Number of Permitted Days per Year	Mean Annual Permitted Taking (m³/day)	Mean Reported Daily Demand (m³/day)	Maximum Reported Daily Demand (m³/day)
0042-8GRREW	Home Farm Well	Agricultural	Tobacco	547050	4770650	5040	24	331	124	4800
00-P-2055	Dugout pond	Agricultural	Other - Agricultural	538262	4773563	955	0	0	0	0
00-P-2255	Dugout pond	Agricultural	Other - Agricultural	548443	4773518	2720	25	186	0	0
00-P-2339	Well Points	Agricultural	Field and Pasture Crops	547153	4770544	3816	40	418	20	3180
00-P-2372	Dugout pond	Agricultural	Tobacco	544607	4771512	2292	24	151	27	736
00-P-2458	Dugout pond	Agricultural	Other - Agricultural	545596	4778594	1364	15	56	0	0
00-P-2517	dugout pond	Agricultural	Other - Agricultural	547575	4774297	546	0	0	0	0
00-P-2518	dugout pond	Agricultural	Other - Agricultural	547783	4773505	546	0	0	0	0
00-P-2684	Dugout pond	Agricultural	Other - Agricultural	544114	4772213	2180	0	0	10	1966
00-P-2751	one dugout pond	Agricultural	Tobacco	545471	4770536	2180	0	0	0	0
00-P-2751	three quarry ponds	Agricultural	Tobacco	545869	4769989	2180	0	0	0	0
00-P-2764	well	Commercial	Golf Course Irrigation	544173	4774858	102	0	0	0	0
00-P-2764	Dugout pond	Commercial	Golf Course Irrigation	544049	4775087	1718	0	0	2	168
0188-9X7KYD	Pond	Agricultural	Tobacco	538811	4772117	982	90	242	0	0
01-P-2070	sandpoint	Agricultural	Field and Pasture Crops	548170	4770886	1637	0	0	0	0
0303-83LPN8	West Pond	Agricultural	Field and Pasture Crops	528666	4788076	951	16	42	18	8768
0534-9NDPJE	Pond	Agricultural	Field and Pasture Crops	540601	4774303	3764	180	1856	60	3494
0550-6BTRD6	Well WWR 1305235	Agricultural	Field and Pasture Crops	533014	4777874	196	312	168	8	144
0550-6BTRD6	Well WWR 1304883	Agricultural	Field and Pasture Crops	533059	4777871	524	312	448	20	38
0550-6BTRD6	Well WWR 1304499	Agricultural	Field and Pasture Crops	533078	4777889	131	312	112	9	44
0550-6BTRD6	Pond	Agricultural	Field and Pasture Crops	533271	4777715	3208	10	88	0	0

MOECC Permit Number	Source	Purpose	Specific Use	Easting (m)	Northing (m)	Maximum Daily Permitted Taking (m³/day)	Number of Permitted Days per Year	Mean Annual Permitted Taking (m³/day)	Mean Reported Daily Demand (m³/day)	Maximum Reported Daily Demand (m³/day)
0786-9EGSNK	Pond	Agricultural	Field and Pasture Crops	542967	4774142	912	180	450	0	0
1066-6H5J49	Dugout Pond	Agricultural	Field and Pasture Crops	536390	4777569	1079	10	30	0	0
1071-5Y2MU3	Pond	Agricultural	Field and Pasture Crops	546079	4771004	3764	180	1856	0	0
1123-9NNN3B	Norwich Well 2 (Tag A011226)	Water Supply	Municipal	532640	4759396	1633	365	1633	0	0
1125-9L9Q27	Pond #1	Agricultural	Field and Pasture Crops	545471	4770536	3800	30	312	0	0
1125-9L9Q27	Pond #2	Agricultural	Field and Pasture Crops	545132	4771123	3800	30	312	87	2880
1125-9L9Q27	Pond #3	Agricultural	Field and Pasture Crops	546108	4770536	3800	30	312	26	2880
1167-5YVFZ2	Dugout Pond	Agricultural	Tobacco	540969	4770453	1637	50	224	3	360
1344-6AJNNR	Pond	Agricultural	Tobacco	539959	4776053	2946	90	726	7	1022
1523-8NQL6U	Pond #2	Agricultural	Sod Farm	533894	4778190	1013	180	499	10	608
1523-8NQL6U	Well #3	Agricultural	Sod Farm	533389	4778888	1310	180	646	0	0
2301-9D5M9J	Pond	Agricultural	Tobacco	549693	4774364	1296	40	142	294	955
2351-8S6PBV	Dugout Pond	Agricultural	Field and Pasture Crops	549589	4774455	2592	35	249	294	1728
2486-856GX2	Pond A	Agricultural	Field and Pasture Crops	545565	4769761	2350	45	290	192	3276
2486-856GX2	Pond B	Agricultural	Field and Pasture Crops	545683	4769725	2350	45	290	58	2304
2486-856GX2	Pond C	Agricultural	Field and Pasture Crops	545903	4769968	2350	45	290	0	0
2526-8LRLRH	Well 1	Commercial	Golf Course Irrigation	543598	4776353	102	214	60	0	0
2526-8LRLRH	Ponds 1 and 2	Commercial	Golf Course Irrigation	543615	4776355	1718	214	1008	68	583
2715-5Z6QVP	TW1-01	Commercial	Other - Commercial	532087	4786336	131	365	131	0	0
2725-8HMPXS	Art Da Silva Princeton	Agricultural	Field and Pasture Crops	538433	4778513	2448	20	134	54	8700
2743-6FUJ5L	Dugout Pond	Agricultural	Field and Pasture Crops	536753	4778857	931	6	15	0	0
2767-6APJF9	Pond	Agricultural	Tobacco	543073	4774080	999	180	493	0	0
3066-9CKH6G	Dugout Pond	Agricultural	Tobacco	536466	4775533	3475	35	333	0	0
3101-9L5J95	Well 1	Agricultural	Other - Agricultural	549126	4775562	818	149	334	0	0
3101-9L5J95	Well 2	Agricultural	Other - Agricultural	549096	4775571	818	149	334	0	0

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3101-9L5J95	Well 3	Agricultural	Other - Agricultural	549111	4775582	818	149	334	0	0
3101-9L5J95	Well 4	Agricultural	Other - Agricultural	549130	4775591	818	149	334	0	0
3168-9ZZPLW	Pond	Agricultural	Tobacco	541278	4772419	888	15	36	0	0
3243-642M69	Pond	Agricultural	Tobacco	538281	4771345	2488	90	613	33	5178
3257-9PMLN8	Pond	Agricultural	Field and Pasture Crops	546851	4769542	3764	180	1856	44	3456
3300-68ESHK	Pond	Agricultural	Field and Pasture Crops	542769	4776661	3764	180	1856	0	0
3411-64SLMD	Pond 1	Agricultural	Field and Pasture Crops	548475	4773541	1364	10	37	0	0
3411-64SLMD	Pond 2	Agricultural	Fruit Orchards	548144	4773454	219	10	6	0	0
3411-64SLMD	Pond 3	Agricultural	Market Gardens / Flowers	548151	4773460	131	12	4	0	0
3411-64SLMD	Well	Agricultural	Fruit Orchards	548169	4773753	219	10	6	0	0
3468-9PNPGA	6 Sandpoints	Agricultural	Tobacco	552165	4775780	2589	40	284	0	0
3502-7V8R6S	Dugout Pond	Agricultural	Field and Pasture Crops	545525	4771836	982	30	81	0	0
3538-62FNDS	Pond	Agricultural	Field and Pasture Crops	547759	4777528	2177	14	84	0	0
3730-9KRNC8	Middle Pond	Agricultural	Sod Farm	544781	4774763	6378	180	3145	194	4449
3730-9KRNC8	West Pond	Agricultural	Sod Farm	543756	4775003	6408	180	3160	127	4637
3730-9KRNC8	East Pond	Agricultural	Sod Farm	545080	4774979	6378	180	3145	2055	3666
3863-7GFR3N	Pond	Agricultural	Field and Pasture Crops	544917	4775897	2184	90	539	0	0
4182-975J6G	Dugout Pond	Agricultural	Other - Agricultural	539695	4770919	2046	180	1009	275	2046
4205-9MHPAE	James Pond #1	Agricultural	Field and Pasture Crops	547673	4774220	546	30	45	480	480
4205-9MHPAE	James Pond #2	Agricultural	Field and Pasture Crops	547822	4773487	546	30	45	480	480
4211-7UGL6P	Guido Pond	Agricultural	Field and Pasture Crops	542989	4775974	2455	180	1211	25	2402
4355-8JFQJL	Well "One" (WWR #39996)	Agricultural	Other - Agricultural	548436	4775248	630	40	69	8	375
4471-9Y8JS6	Casing	Agricultural	Field and Pasture Crops	543819	4773666	2620	120	861	37	5178
4471-9Y8JS6	Pond	Agricultural	Field and Pasture Crops	544053	4773602	1310	12	43	0	0
4504-5XZKJ6	Dugout Pond	Agricultural	Tobacco	538400	4778552	591	20	32	0	0
4505-6LSMZX	Dugout pond	Agricultural	Tobacco	537550	4775321	1114	150	458	0	0

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4506-5WZSJD	Wellpoints (3) 150 IGPM from all sources combined	Agricultural	Field and Pasture Crops	543628	4772241	409	60	67	0	0
4547-69FMNG	Pond	Agricultural	Field and Pasture Crops	542117	4774753	2146	12	71	0	0
4647-9XHHLL	Pond	Agricultural	Tobacco	544520	4773032	1090	25	75	0	0
4672-9SZJWX	Dugout Pond (on farm)	Agricultural	Tobacco	539401	4775195	200	3	2	0	0
4704-6EMHSP	Pond	Agricultural	Field and Pasture Crops	537603	4772082	1250	4	14	2	625
5005-6QZLV4	Pond #1	Agricultural	Tobacco	540473	4777189	913	20	50	0	0
5087-9QJR28	Pond	Agricultural	Tobacco	538290	4771238	2488	90	613	0	0
5128-8Q8J96	Irrigation Pond	Agricultural	Sod Farm	535554	4778758	240	180	118	2	192
5156-9Q3HZH	Well	Agricultural	Field and Pasture Crops	547360	4776021	1309	120	430	0	0
5156-9Q3HZH	Pond	Agricultural	Field and Pasture Crops	547392	4775945	3928	120	1291	96	9494
5278-7BTL2D	Madero Pond	Agricultural	Field and Pasture Crops	526550	4784000	1488	30	122	5	819
5342-9BLMDB	Bedrock Well	Agricultural	Nursery	542420	4773932	216	180	107	0	0
5342-9BLMDB	Pond	Agricultural	Nursery	542392	4773899	688	120	226	6	458
5382-6CRQBW	Dugout Pond	Agricultural	Sod Farm	540665	4775585	1181	30	97	0	0
5388-9RNQ88	Pond 1 (Lot 18)	Agricultural	Field and Pasture Crops	532790	4786694	2455	60	404	0	0
5388-9RNQ88	Pond 2 (Lot 17)	Agricultural	Field and Pasture Crops	533450	4787025	2455	60	404	0	0
5488-7VBQMC	pond	Agricultural	Field and Pasture Crops	533505	4782573	2455	50	336	4	458
5546-5ZSJ5M	Pond 2. Lot 17	Agricultural	Tobacco	533443	4787033	2455	60	404	10	1079
5812-8PRLZF	Pond	Agricultural	Field and Pasture Crops	545930	4773526	2376	42	273	24	792
5815-5Z5L66	Pond	Agricultural	Field and Pasture Crops	542327	4776194	3764	180	1856	0	0
5836-9EANY5	Pond	Agricultural	Field and Pasture Crops	546614	4769558	3494	90	862	2325	28390
63-P-0711	Dugout Pond	Agricultural	Field and Pasture Crops	544417	4775975	1080	0	0	4	764
63-P-1123	Dugout pond	Agricultural	Tobacco	539044	4772860	2771	150	1139	0	0
6420-9EYK9K	Pond #1	Agricultural	Field and Pasture Crops	544923	4775902	912	180	450	0	0
6635-9XEM7J	Pond	Agricultural	Other - Agricultural	540448	4774656	1522	120	500	0	0

MOECC Permit Number	Source	Purpose	Specific Use	Easting (m)	Northing (m)	Maximum Daily Permitted Taking (m³/day)	Number of Permitted Days per Year	Mean Annual Permitted Taking (m³/day)	Mean Reported Daily Demand (m³/day)	Maximum Reported Daily Demand (m³/day)
66-P-0534	Dugout Pond	Agricultural	Tobacco	539556	4776318	1308	0	0	0	0
6728-9FMJXV	Dugout pond	Agricultural	Field and Pasture Crops	547119	4776127	3928	120	1291	0	0
6733-8WXQXF	Pond	Agricultural	Field and Pasture Crops	526076	4784164	5237	30	430	444	2500
6782-98DHDL	Pond 1 (Lot: 18, Conc: 1)	Agricultural	Other - Agricultural	535256	4779757	2318	20	127	40	2318
6782-98DHDL	Pond 2 (Lot: 17,Conc:1)	Agricultural	Other - Agricultural	535416	4779730	2318	20	127	12	1855
6881-6DCLKL	Dugout Pond	Agricultural	Tobacco	539150	4775110	1020	20	56	0	0
69-P-0199	Dugout pond	Agricultural	Other - Agricultural	540476	4772932	1364	0	0	0	0
69-P-0203	Dugout pond	Agricultural	Tobacco	545254	4775626	999	0	0	0	0
69-P-0374	Excavation Pit	Agricultural	Other - Agricultural	553183	4774740	3805	0	0	0	0
7104-9CLK8A	South Pond	Agricultural	Other - Agricultural	529304	4788559	2040	150	838	31	405
7104-9CLK8A	North Pond	Agricultural	Other - Agricultural	528999	4789790	1224	90	302	0	0
7287-A57RWG	VanDeWalle 8th	Agricultural	Field and Pasture Crops	544892	4770554	1264	180	623	91	4150
7377-8JXJFS	Pond	Agricultural	Field and Pasture Crops	550740	4775473	2864	20	157	48	2500
73-P-0097	Dugout Pond	Agricultural	Other - Agricultural	531006	4784951	1092	5	15	0	0
7454-8WYLSF	Franken Pond	Agricultural	Field and Pasture Crops	542297	4776525	3764	153	1578	101	1964
7467-84BQEE	Well 4	Water Supply	Municipal	527587	4790760	327	365	327	6	126
7467-84BQEE	Well 4A	Water Supply	Municipal	527587	4790765	327	365	327	84	230
7467-84BQEE	Well 5	Water Supply	Municipal	527515	4790696	243	365	243	15	122
7506-5TXH8B	Dugout Pond #1	Agricultural	Tobacco	538709	4772821	3840	120	1262	0	0
7506-5TXH8B	Dugout Pond #2	Agricultural	Tobacco	538494	4776870	3840	120	1262	0	0
7607-63RPKH	Pond	Agricultural	Field and Pasture Crops	546614	4769558	5237	210	3013	78	4368
7680-64CJKY	Pond	Agricultural	Sod Farm	533461	4778832	3475	180	1714	671	9926
7680-64CJKY	Well #1	Agricultural	Sod Farm	533395	4778824	1310	180	646	314	1094
7680-64CJKY	Well #2	Agricultural	Sod Farm	533420	4778827	1310	180	646	158	1094
77-P-2000	Pond	Agricultural	Other - Agricultural	545446	4771840	982	0	0	0	0
7847-62ENT9	Pond	Agricultural	Field and Pasture Crops	545894	4770754	3273	180	1614	103	3276

MOECC Permit Number	Source	Purpose	Specific Use	Easting (m)	Northing (m)	Maximum Daily Permitted Taking (m³/day)	Number of Permitted Days per Year	Mean Annual Permitted Taking (m³/day)	Mean Reported Daily Demand (m³/day)	Maximum Reported Daily Demand (m³/day)
79-P-2024	Pond	Agricultural	Other - Agricultural	538545	4777869	916	0	0	0	0
8025-82TRZT	Dugout Pond	Agricultural	Field and Pasture Crops	537332	4775409	952	24	63	8	834
8120-7VBQVQ	old	Agricultural	Field and Pasture Crops	534524	4780464	3273	50	448	15	1718
8120-7VBQVQ	new	Agricultural	Field and Pasture Crops	534287	4781034	3273	50	448	2	1527
8142-642JS2	Pond	Agricultural	Field and Pasture Crops	536591	4776571	3090	180	1524	0	0
8242-8KDKUR	Pond 1	Agricultural	Tobacco	539911	4775827	1950	30	160	137	1850
8242-8KDKUR	Pond 2	Agricultural	Tobacco	540092	4775484	1950	30	160	210	1850
8242-8KDKUR	Pond 3	Agricultural	Tobacco	540568	4775908	1950	30	160	216	1850
8242-8KDKUR	Pond 4	Agricultural	Tobacco	540510	4775321	1950	30	160	192	1850
8242-8KDKUR	Pond 5	Agricultural	Tobacco	540365	4775223	1950	30	160	178	1850
8314-65JLCU	Dugout Pond	Agricultural	Tender Fruit	537586	4772671	128	120	42	0	0
8340-8L2KYR	Pond	Agricultural	Field and Pasture Crops	547827	4773453	952	24	63	4	467
8545-A48Q8C	P52 (TW 1/05) [A026040]	Water Supply	Municipal	550782	4777852	1296	365	1296	57	744
8545-A48Q8C	P51 (PW 1/12) [A002048]	Water Supply	Municipal	550768	4777831	1310	365	1310	17	1077
8545-A48Q8C	P53 (PW 2/12) [A002049]	Water Supply	Municipal	550782	4777834	1310	365	1310	17	473
8545-A48Q8C	P54 (PW 4/12) [A002052]	Water Supply	Municipal	550746	4777821	1310	365	1310	47	371
8565-95RL8P	Pond	Agricultural	Other - Agricultural	546798	4770069	5042	90	1243	78	1890
8587-8GPKDT	Wilson Farm Well	Agricultural	Tobacco	547250	4770150	5040	24	331	154	4800
8618-8JJNN9	Pond 1	Agricultural	Other - Agricultural	541233	4775178	2043	150	840	145	2043
8618-8JJNN9	Pond 2	Agricultural	Other - Agricultural	541106	4774871	2043	150	840	45	1321
8643-9ZZQER	Pond	Agricultural	Tobacco	541054	4770810	1780	15	73	0	0
8655-6BGSP6	Pond	Agricultural	Tobacco	537904	4776109	1999	35	192	0	0
8770-82HQU7	Dugout pond	Agricultural	Field and Pasture Crops	550184	4774187	2619	100	718	103	2316
88-P-2077	Wells(PW1, PW2, PW3, PW4, PW5)	Agricultural	Other - Agricultural	546832	4770289	3272	0	0	0	0

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93-P-2049	Pond	Agricultural	Field and Pasture Crops	541646	4775323	1364	30	112	0	0
99-P-1097	Dugout pond	Agricultural	Tobacco	529736	4786634	1364	10	37	0	0
99-P-2127	Dugouts	Agricultural	Other - Agricultural	540621	4771906	2128	0	0	0	0
99-P-2139	Dugout	Agricultural	Tobacco	552840	4774269	1091	0	0	0	0
99-P-2142	Well	Agricultural	Tobacco	549631	4773202	546	0	0	0	0
99-P-2154	Well	Agricultural	Other - Agricultural	547033	4769638	2	0	0	0	0

Appendix D Local Area Drawdown Threshold Evaluation

D.1 Introduction

The Tier 3 Risk Assessment requires the delineation of a 'local area' for every municipal water supply intake within the study watersheds. The local area for a groundwater supply well is defined as the combination of the following areas (Ontario Ministry of Environment, 2011):

i) the cone of influence of the municipal supply well;
ii) the cones of influence resulting from other water takings where those cones of influence intersect that of the municipal supply well; and
iii) the areas where a reduction in recharge would have a measureable impact on the cone of influence of the municipal supply well.

Although the cone of depression can extend outward for large distances away from a well, the magnitude of the drawdown decreases exponentially with distance. At large distances, it can be difficult to distinguish the effect of pumping from natural variation in groundwater levels. The level of precision at which the cone of influence is ultimately reported must, therefore, take into consideration factors including: model precision, seasonal fluctuations in water levels, and water-level measurement error and uncertainty. It is therefore necessary to establish a 'drawdown threshold' to serve as a practical means of delineating the lateral extent of a cone of influence in which drawdowns exceeding the threshold may be significant and detectable while predicted drawdowns below the threshold would be less significant, more difficult to detect and, therefore, would be considered to be outside the cone of influence.

The Bright and Bethel Road municipal wellfields are the only sources of municipal groundwater supply in the subwatershed. It is assumed that, due to their separation (~25 km), each wellfield will have its own distinct Local Area and therefore, the drawdown thresholds were evaluated separately.

D.2 Seasonal Water-Level Fluctuations

Previous Tier 3 studies have identified season variation in water levels as a reasonable standard for selecting the drawdown threshold (e.g., Earthfx, 2014a; Matrix Solutions, 2017). The analysis presented in this report uses transient data from groundwater monitoring wells within the study area (well locations shown in Figure E1) to estimate seasonal water-level fluctuations. The groundwater monitoring wells are discussed in more detail below and include Provincial Groundwater Monitoring Network (PGMN) wells and municipal monitoring wells. To evaluate seasonal water-level fluctuations in the vicinity of the municipal wellfields, two different methods were employed and compared. These methods considered:

1. the annual measured range in water levels; and
2. the seasonal range in water levels based on a semi-quantitative interpretation of hydrographs for each monitoring well, whereby a typical range between adjacent seasonal highs and lows was estimated visually.

The measured range in water levels was the preferred method where data were available, however it was sensitive to anomalous data such as large, daily water level fluctuations from variable groundwater pumping, or offsets caused by a change in measurement location relative to the datum. An example of each method used to interpret the hydrograph for well TW2/11, located in the Bethel wellfield, is presented in Figure E2.

The hydrograph in Figure E2 exhibits both daily and seasonal fluctuations in water level. Daily water level changes of up to several meters can be seen (Figure E2a), however this type of behaviour is more likely related to instantaneous pumping rates, rather than seasonal trends. Closer inspection of the hydrograph reveals more typical seasonal trends in water levels on the order of 0.5 m (Figure E2b). In this case, the semi-quantitative interpretation method is preferred because it allows for professional judgement to be used to ignore anomalous data.

D.2.1 Bright Municipal Wellfield

Water level fluctuations in the vicinity of the Bright municipal wellfield were characterized by PGMN well W0000478-1 and municipal monitor MW1 (see Figure E1 inset). PGMN well W0000478-1 is located 5 km to the south of the wellfield and is screened in the Waterloo Moraine Aquifer, the same aquifer unit as the municipal wells. Municipal monitor MW1 is located in the Bright municipal wellfield, 20 m from Well 4A and 85 m from Well 5. It has a shallow monitoring interval, screened in the Tavistock Till, and a lower monitoring interval, screened in the Waterloo Moraine Aquifer.

Hydrographs for the PGMN and municipal monitors are presented in Figure E3 and Figure E4, respectively. Information for each well, including the average annual seasonal water level fluctuations are summarized in Table E1. All hydrographs represent a daily water level observation and exhibit a smooth characteristic seasonal response. The average annual measured range in the PGMN well is 0.92 m. Municipal monitor MW1 ranges from 3.13 m in the shallow monitoring interval and 1.65 m in the deeper interval. There was no difference between the average annual measured range in water levels and the average annual interpreted water levels for monitoring wells considered in the analyses of the Bright municipal wellfield.

MW1-Deep is considered to be more representative of the Bright wellfield source aquifer than MW1-Shallow because it is screened across the same aquifer unit as the municipal wells. Water levels in MW1, however, are likely influenced by the seasonality of the municipal pumping due to the close proximity of the measurement to the production wells. The measured range in water levels in the municipal monitor may therefore represent an overestimation of the natural range. While it is likely that W0000478-1 provides the best representation of natural water-level variability, it is difficult to discern the relationship between water levels in the PGMN monitor and the levels in the Bright wellfield area. A 1-m drawdown was selected as a reasonable drawdown threshold by using MW1-Deep and W0000478-1 as upper and lower bounds, respectively.

D.2.2 Bethel Road Municipal Wellfield

Water level fluctuations in the Bethel municipal wellfield were characterized by PGMN well W0000477-1 and municipal monitors TW2/11, SMW5/12, SMW6/12, and MW3/04 (see Figure E1 inset). It is important to note that only municipal monitors with greater than two years of data were considered in the analysis. While other transient monitors exist, their periods of record were too short to make distinctions about seasonal water level variability. PGMN well W0000477-1 is located 9 km to the southwest and is screened in the same aquifer unit as the municipal wells, the Waterloo Moraine Aquifer. Municipal monitors TW2/11 and SMW6/12 are located amongst the production well cluster while SMW5/12 and MW3/04 are located approximately 60 m and 350 m to the west of the wellfield, respectively. The wells are screened in the Waterloo Moraine Aquifer and the Sand Plain/Outwash Aquifer (See Table E1), which are believed to be in reasonably good connection with one another in the vicinity of the wellfield.

Groundwater level hydrographs for the PGMN and municipal monitors are presented in Figure E2 and Figure E5 through Figure E8. PGMN monitor W0000477-1 represents daily water level measurements and has an average annual range of 1.56 m. The municipal monitors collect high frequency measurements, either hourly or every 10 minutes. The high frequency measurements are more susceptible to variable pumping rates and consequently, the hydrographs exhibit many large, short duration spikes in water levels. A pump test completed in April of 2013 (IWC, 2014) may explain the large water level fluctuations in some of the monitors observed during this time period. The largest range in the average annual range in water level was measured at municipal monitors TW2/11 and MW3/04-3 at 4.59 and 3.87 m, respectively. The remaining four monitors all experienced an average range in water level of 1 m or less.

A semi-qualitative interpretation of the seasonal trend (see Figure E2b) was used for the Bethel wellfield analysis. The results from the interpretive analysis suggest that the seasonal water level fluctuation in the Bethel wellfield area is approximately 0.5 m; this result was consistent across all municipal monitors. .

It is reasonable to assume that the municipal pumping has no impact on the water levels at PGMN well W0000477-1. However, it is difficult to quantify how well the seasonal water level behaviour observed in this well represents the natural conditions near the Bethel Road municipal wellfield. In contrast to the analysis of the Bright municipal wellfield, pumping from the Bethel production wells is not expected to have significantly biased the observed seasonal response in the groundwater levels because there is no evident seasonality in the pumping rate. As such, the municipal monitors are considered to be the best representation of the natural seasonal water level variability for the Bethel wellfield area. The local seasonal fluctuation of 0.5 m was believed to be an appropriate limit for delineating the drawdown threshold for the cone of influence.

D.3 Summary and Conclusions

This section summarized the analyses performed to identify appropriate drawdown thresholds to be used in the in the Whitemans Creek subwatershed Tier 3 Risk Assessment scenario. Drawdown thresholds of 1 m and 0.5 m were determined for the Bright and Bethel wellfields, respectively. These drawdown thresholds will be used to delineate the wellhead protection areas and the Local Area for the municipal supply wells.

D.4 References

International Water Consultants Ltd. (IWC). 2014. County of Brant – Paris North Bethel well field construction of PW 4/12 and well field testing. 15 p.

D.5 Tables

Table E1: Summary of monitoring wells used for seasonal water level analysis

Monitor Name	Monitor Type	Collection Frequency	Screened Unit	Easting (m)	Northing (m)	Data Period		Average Annual Measured Range in Water Level (m)	Average Interpreted Range in Water Level (m)
						Start Date	End Date		
Bright Municipal Wellfield									
W0000478-1	PGMN Well	Daily	Waterloo Moraine Aquifer	529065	4785860	10/23/2008	9/16/2015	0.92	0.92
MW1-Shallow	Municipal Monitor	Daily	Tavistock Coarse Till	527582	4790748	06/3/2005	12/3/2014	3.13	3.13
MW1-Deep	Municipal Monitor	Daily	Waterloo Moraine Aquifer	527582	4790748	06/3/2005	12/3/2014	1.65	1.65
Bethel Municipal Wellfield									
W0000477-1	PGMN Well	Daily	Waterloo Moraine Aquifer	542577	4773875	10/23/2008	9/21/2015	1.56	1.56
TW2/11	Municipal Monitor	Hourly, 10 minute	Waterloo Moraine Aquifer	550745	4777822	10/19/2012	7/3/2015	4.59	0.52
SMW5/12	Municipal Monitor	Hourly	Sand Plain/Outwash Aquifer	550683	4777838	10/19/2012	6/16/2015	0.88	0.50
SMW6/12	Municipal Monitor	Hourly, 10 minute	Sand Plain/Outwash Aquifer	550783	4777844	10/19/2012	7/3/2015	1.00	0.50
MW3/04-1	Municipal Monitor	Hourly	Waterloo Moraine Aquifer	550428	4777722	10/19/2012	7/3/2015	0.70	0.60
MW3/04-2	Municipal Monitor	Hourly	Waterloo Moraine Aquifer	550428	4777722	10/19/2012	7/3/2015	0.69	0.60
MW3/04-3	Municipal Monitor	Hourly	Sand Plain/Outwash Aquifer	550428	4777722	10/19/2012	7/3/2015	3.87	0.50

D.6 Figures

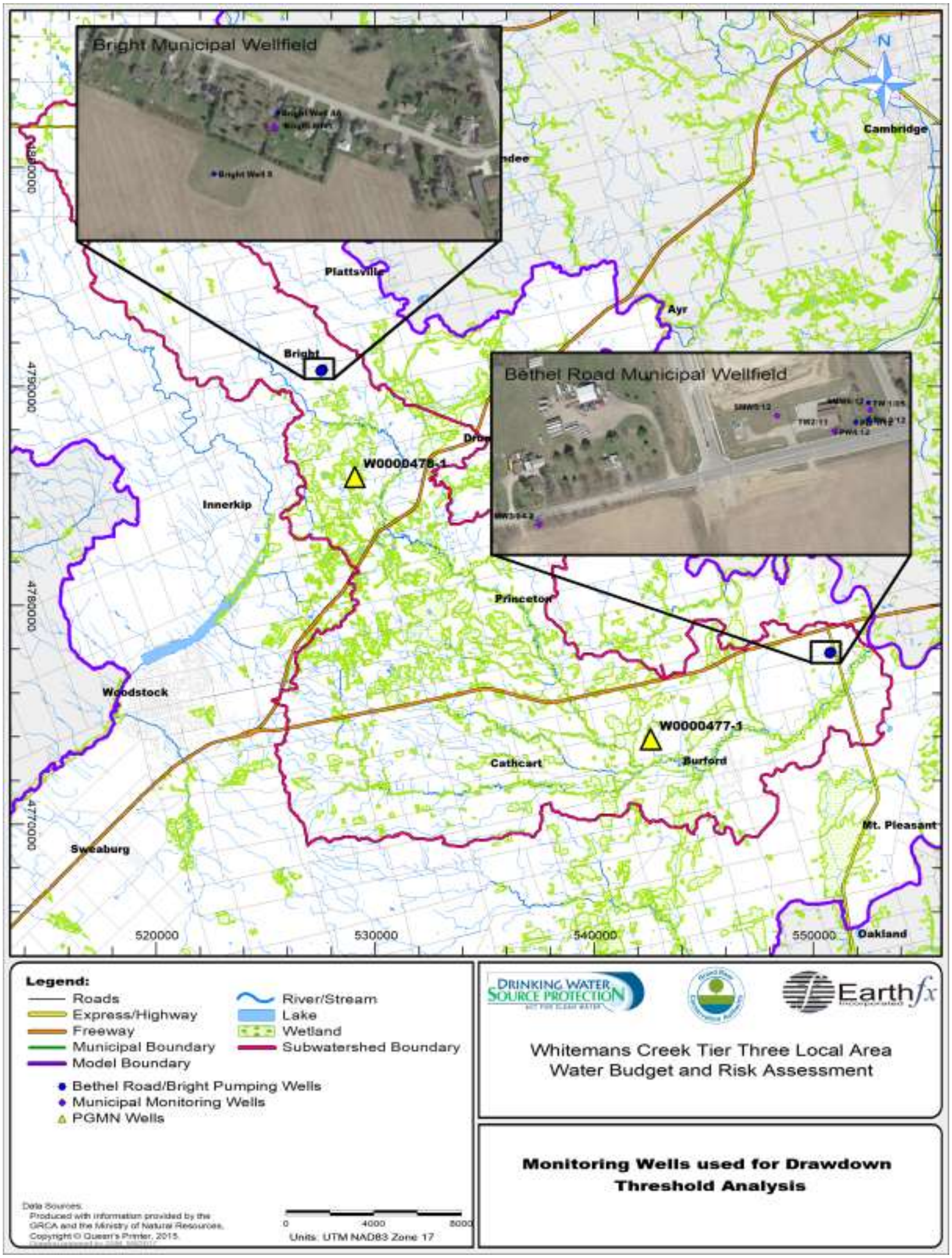

Figure E1: Location of monitoring wells used in the drawdown threshold analysis.

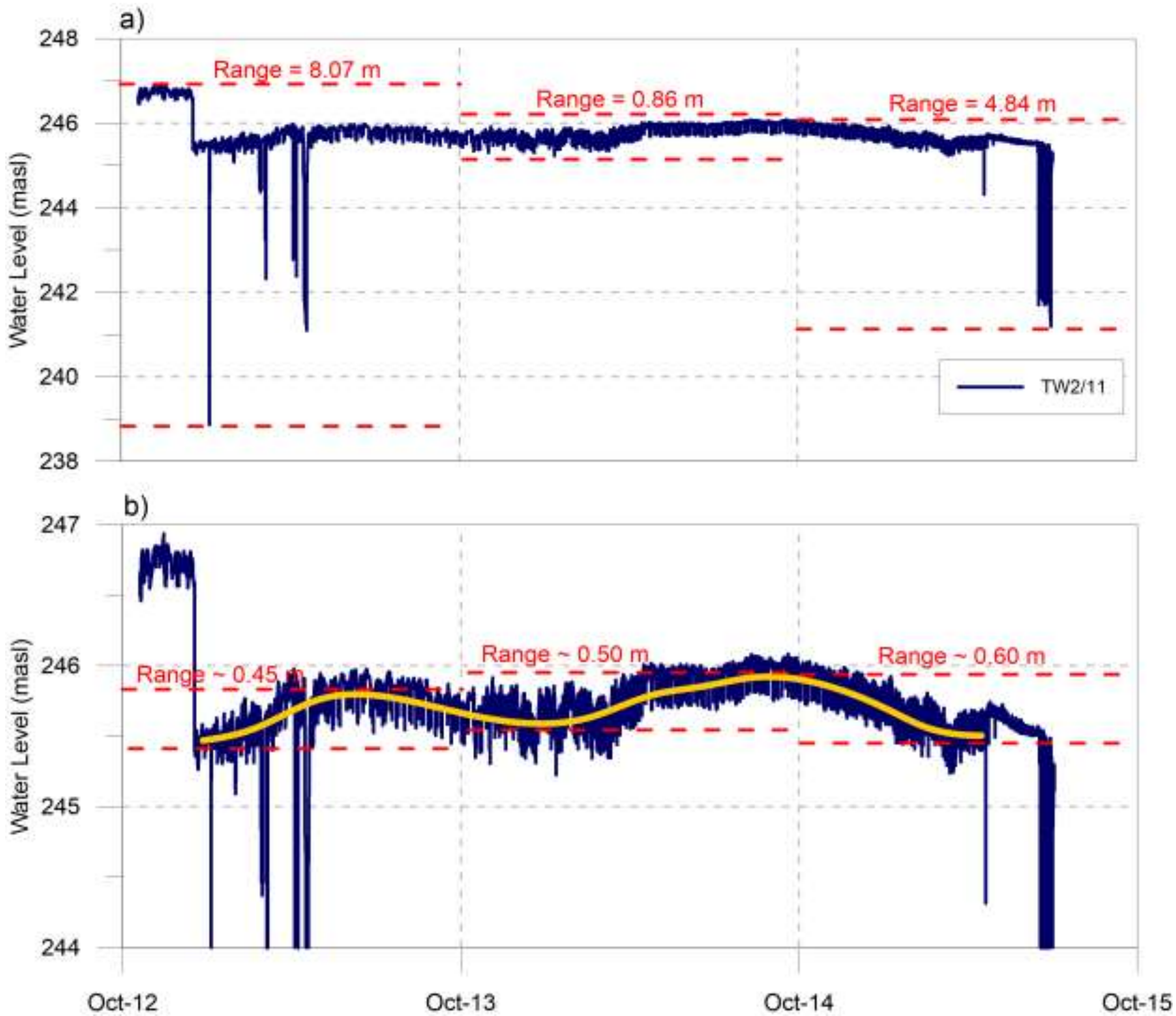

Figure E2: Example of the two methods used to estimate the seasonal water level fluctuations: a) the annual measured range in water level; and b) the interpreted range in water level represented by the yellow line.

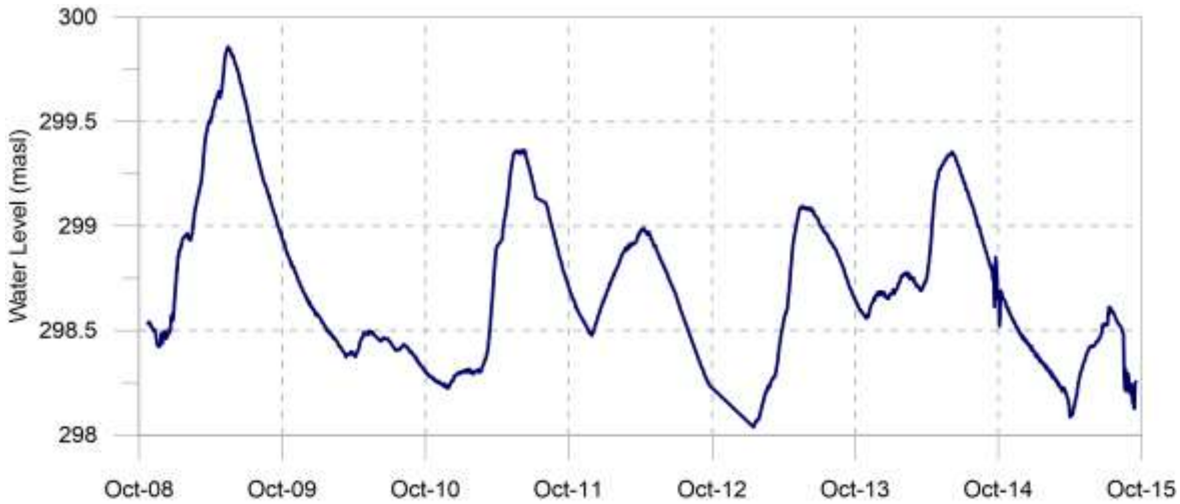

Figure E3: Hydrograph for PGMN Well W0000478-1 (October 2008 to October 2015).

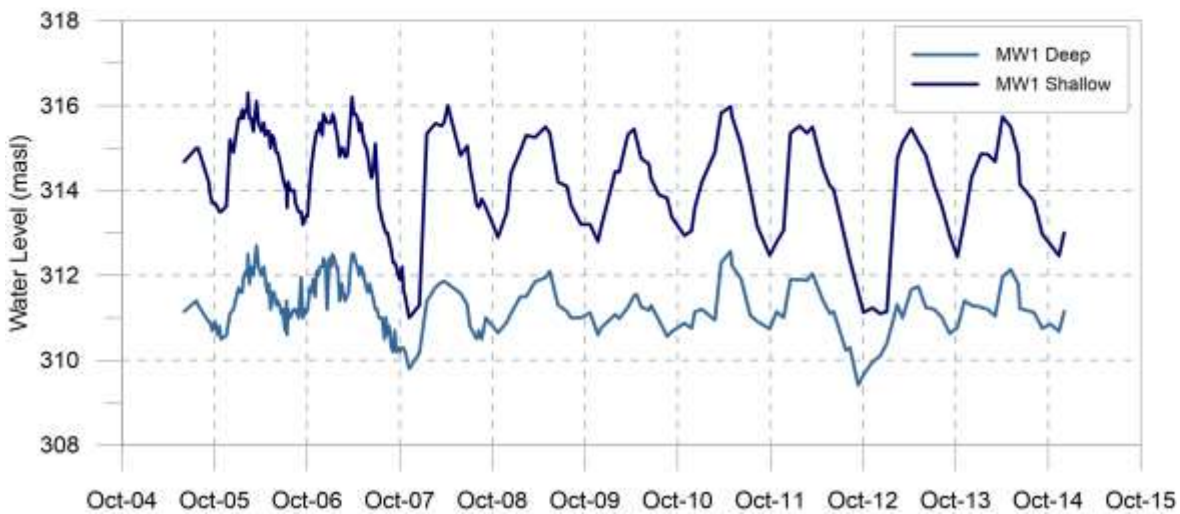

Figure E4: Hydrographs for Bright MW-11 (October 2004 to October 2015).

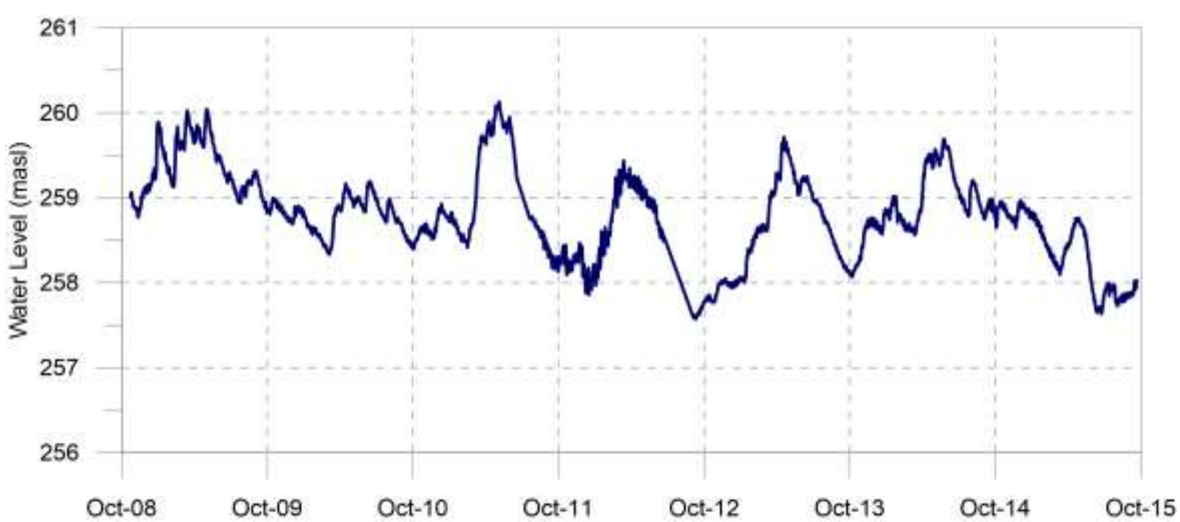

Figure E5: Hydrograph for PGMN Well W0000477-1.

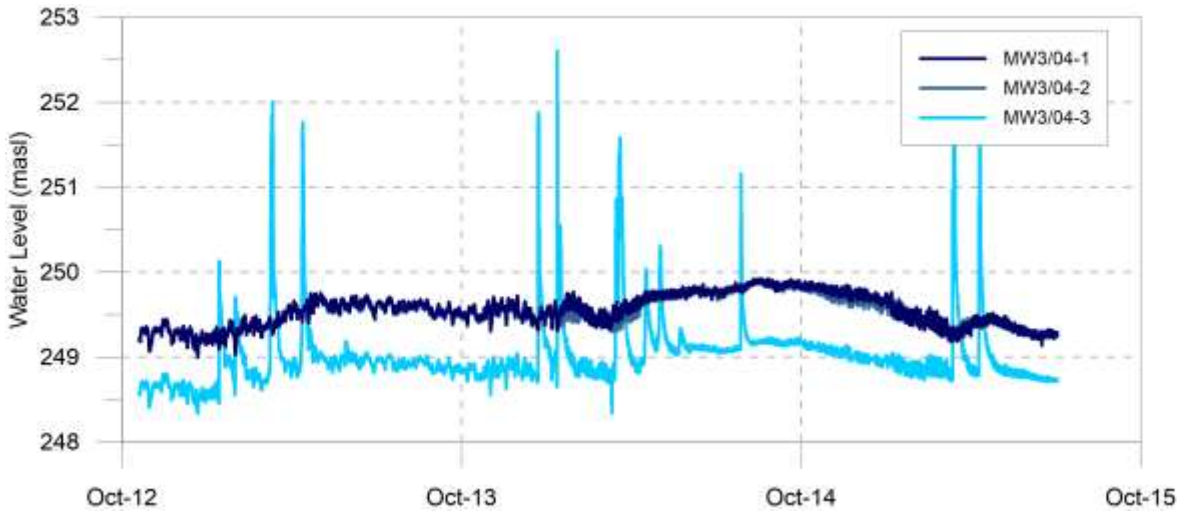

Figure E6: Hydrographs for Bethel MW3/04.

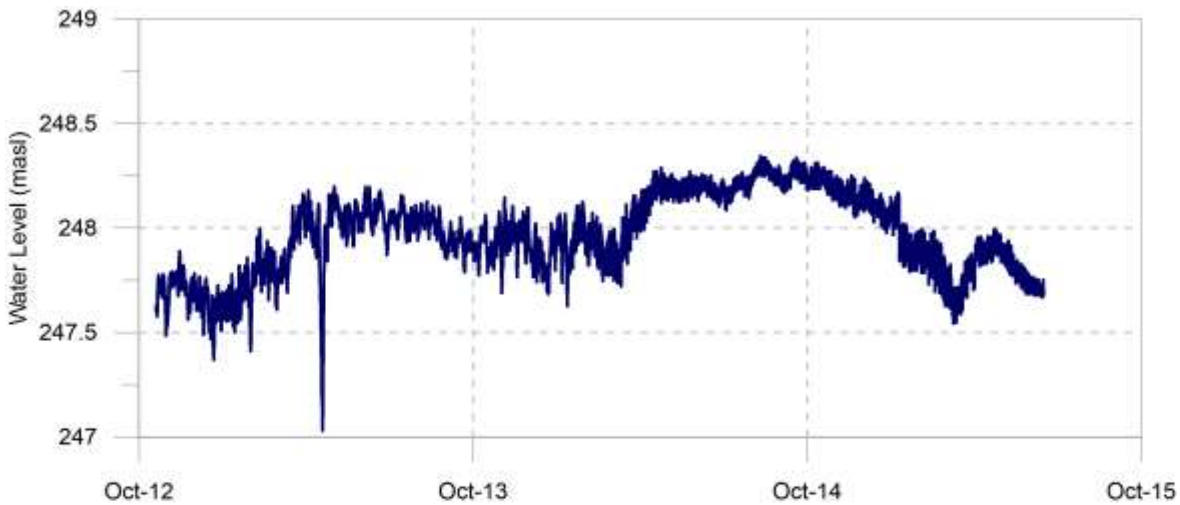

Figure E7: Hydrograph for Bethel SMW5/12.

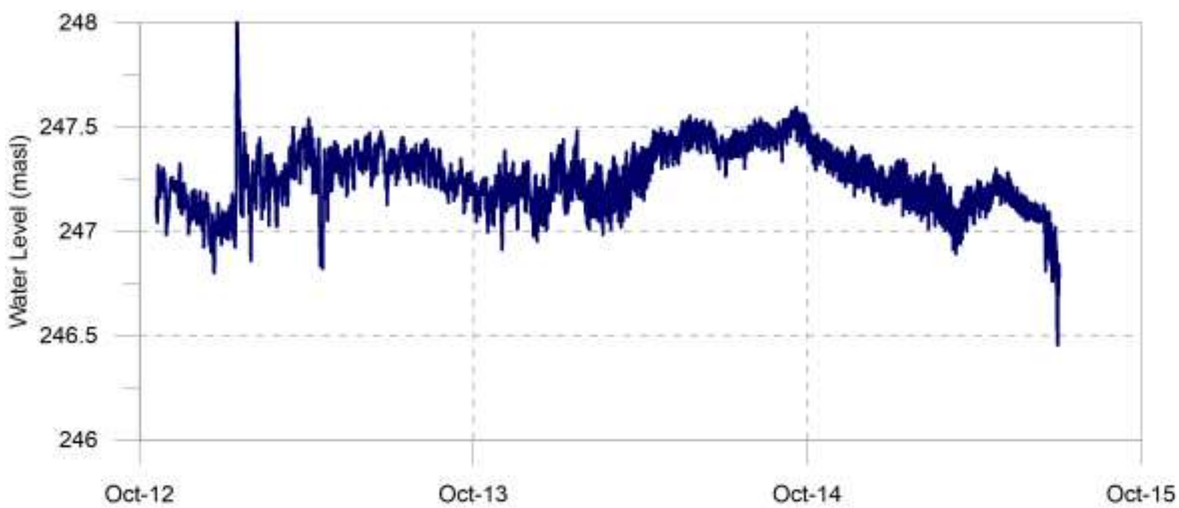

Figure E8: Hydrographs for Bethel SMW6/12.