Assessing Vulnerability of Drinking Water Sources

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D1 MOECC-TECHNICAL BULLETINS

This section focuses on the detailed methodologies used to develop the vulnerability analysis component of the Assessment Report (**Chapter 4**). The four vulnerable areas covered include:

- Wellhead Protection Areas (WHPA);
- Highly Vulnerable Aquifers (HVA);
- Significant Groundwater Recharge Areas (SGRA); and
- Intake Protection Zones (IPZ-1 & 2's).

Objectives

The objective of the groundwater vulnerability analysis is to identify areas that may be more susceptible to contamination than the surrounding area. These vulnerable areas may be associated with municipal drinking water wells (WHPAs), intakes (IPZ-1 and IPZ-2's), or the broader landscape (HVAs, SGRAs).

Technical Rules

The following *Technical Rules (2009, 2013 & 2017)* describe the requirements for vulnerability analysis:

- Part I.2 Assessment report contents (*Rule 5*);
- Part I.4 Determining level of uncertainty (*Rules 13-15*);
- Part IV Groundwater Vulnerability Assessment (*Rules 37-41*);
- Part V Delineation of Vulnerable Areas: Highly Vulnerable Aquifers, Significant Groundwater Recharge Areas, and Wellhead Protection Areas (*Rules 42-53*) – not applicable in CLOSPA;
- Part VI Delineation of Vulnerable Areas: Surface Water Intake Protection Zones (*Rules 55-75*);
- Part VII Vulnerability: Highly Vulnerable Aquifers and Wellhead Protection Areas (*Rules 79-85*); and
- Part VIII Vulnerability: Surface Water Intake Protection Zones (*Rules 86-96*).

Technical Bulletins

To provide additional clarification and direction, the MOECC released the following technical memos regarding vulnerability analysis:

- Groundwater Vulnerability (June 2010);
- Delineation of Significant Groundwater Recharge Areas (April 2009);
- Water Budget and Water Quantity Risk Assessment Tier 2 Subwatershed Stress Assessment Groundwater Drought Scenarios (July 2009); and
- Climate Change and Director's Technical Rules (August 2009).

These four technical bulletins are below:

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Technical Bulletin: Groundwater Vulnerability

Date: June 2010

The *Clean Water Act, 2006* requires the source protection committee (SPC) prepare an Assessment Report for each source protection area they represent, in accordance with the regulations, the Director's technical rules and the approved terms of reference for that source protection area.

For groundwater in a source protection area (SPA), there are four steps to assigning vulnerability scores to each of the groundwater-based vulnerable areas. First, a groundwater vulnerability assessment is completed to document the vertical vulnerability (sometimes referred to as the intrinsic groundwater vulnerability) and map it across the entire SPA. Second, the three types of vulnerable areas are delineated using a variety of tools outlined in the rules. The third step is to overlie the groundwater vulnerability mapping and the vulnerable area delineation and to create a vulnerability scoring map. In some cases there is both a regional based vulnerability score and a locally based vulnerability score. The fourth step is to refine the vulnerability score to reflect transport pathways, if any, which may circumvent the normal infiltration of water from the surface to an aquifer at depth in the ground.

The three groundwater-based vulnerable areas are:

- highly vulnerable aquifers (HVAs),
- significant groundwater recharge areas (SGRAs), and
- wellhead protection areas (WHPAs).

This technical bulletin provides clarification to source protection committees on some of the specific processes under the technical rules for the assessment report. Requirements for conducting the various aspects of assigning vulnerability scores in the groundwater-based vulnerable areas are set out in Parts IV, V and VII of the technical rules.

Technical Bulletin: Groundwater Vulnerability

1. GROUNDWATER VULNERABILTY

The vertical, or intrinsic, vulnerability of groundwater within a source protection area shall be assessed as directed in Part IV. This aspect of groundwater vulnerability considers the relative protective capacity of the overlying materials above an aquifer with respect to a potential chemical or pathogen threat from the surface. The groundwater vulnerability is used, in combination with the delineation of the vulnerable areas, to assign a vulnerability score to the 3 groundwater based vulnerable areas.

Part IV.1, Rule 37 specifies the methods applied to determine groundwater vulnerability. These include: 37(1) intrinsic susceptibility index (ISI); (2) aquifer vulnerability index (AVI); (3) surface to aquifer advective time (SAAT); or (4) surface to well advective time (SWAT). Of these methods, the ISI and AVI evaluate the effectiveness of protective layers and look only at the relative protection provided to the underlying aquifer. The SAAT and SWAT methods evaluate the additional protection provided by the unsaturated and saturated zones and by quantifying, through modeling, the time it takes for water to travel from ground surface to the aquifer or to the well. The ISI and AVI effectively represent shallow aquifer systems, but are more conservative when evaluating deeper drinking water sources in that they ignore many processes, including advection, that impact the flow of water to the source (well or aquifer).

For these reasons, ISI and AVI methods are generally used when assigning groundwater vulnerability on a wider (SPA) scale. SPCs use one of these methods to assign a groundwater vulnerability score for their SPA and to delineate HVAs. Some SPCs are using the SAAT or SWAT methods (or other director approved methods) to assign groundwater vulnerability at a local scale (for example in a WHPA). When mapping the HVAs, the SPC can only generate one HVA map and must describe which groundwater vulnerability methods were used to delineate HVAs in different areas. For example, if AVI was used in one municipality, SAAT in another, then ISI for the rest of the SPA, then the map would show one set of HVAs based on the patchwork of different methods. The AR must also clearly identify what method was used where. As set out later in this bulletin, the SPC can have a second groundwater vulnerability map for the deeper aquifer if a deeper groundwater vulnerability was assigned in the WHPA.

Surface to Aquifer Advective Time (SAAT) and Surface to Well Advective Time (SWAT)

When using SAAT or SWAT to assess the vulnerability of an aquifer to surficial or shallow contaminants, the results are assigned a category of relative vulnerability based upon Rule 38 (2) which reads:

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38(2) where a method described in subrule 37 (3) or (4) was used to assess vulnerability;

(a) areas of high vulnerability are those areas with results that are less than 5 years;

(b) areas of medium vulnerability are those areas with results that are greater than or equal to 5 years but less than or equal to 25 years;

(c) areas of low vulnerability are those areas with results that are greater than 25 years;

These SAAT and SWAT methods typically portray the length of time that it takes a given particle of water within the subsurface to travel to a well or aquifer within which a well is located. Where this is determined through reverse particle tracking in a computer model simulation, there may be particles which do not ever reach the surface. When assigning the groundwater vulnerability to areas represented by such particles the area will be deemed as low vulnerability as per rule 38(2)(c), which represents advective travel times of greater than 25 years.

2. VULNERABLE AREAS AND VULNERABILITY SCORING

Highly Vulnerable Aquifers and WHPAs

Under Part V.1, Technical Rule 43 specifies that the delineation of highly vulnerable aquifers (HVAs) is based on the mapping of area(s) of high groundwater vulnerability in accordance with Part IV, including the underlying subsurface areas.

In a situation where the municipal drinking water supply well draws from a deeper confined or semi-confined aquifer with a delineated WHPA and there exists a shallower aquifer within this WHPA, the groundwater vulnerability may be assessed for both the municipal and shallow aquifers as per Rule 38.1 which reads:

"In respect of a wellhead protection area that has been delineated for a drinking water system mentioned in clause 15 (2) (e) of the Act, different groundwater vulnerability scores may be assigned to the shallow and deep aquifer if the well that is part of the drinking water system draws water from the deep aquifer."

In the case where the shallow and deep aquifer groundwater vulnerability has been determined, then the vulnerability score for the WHPA is assigned based on the deep aquifer groundwater vulnerability, and would have a lower vulnerability score than the overlying aquifer. When this approach is taken, the AR must contain two different groundwater vulnerability maps, one for the shallow aquifer(s) and one for the deeper aquifer(s) in the WHPA(s). In addition, an HVA map must be included and be based on the shallower aquifer groundwater vulnerability. Therefore, you would have the groundwater vulnerability map for the full SPA, the local groundwater vulnerability map for the

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WHPA(s), an HVA map delineated and scored based on the shallow aquifer vulnerability, and WHPA maps with the scoring based on the deeper aquifer groundwater vulnerability.

3. DELINEATION OF WHPAS

Part V provides specific details on the delineation of vulnerable areas, including WHPAs. Several points of clarification are warranted around the delineation of WHPAs, as noted in the following sections.

WHPA-B within WHPA-A

Part V.3 of the Technical Rules states that a WHPA is created by combining the surface and subsurface areas within all of:

47. (1) WHPA-A – an area centred on the well with an outer boundary identified by a radius of 100 metres
(2) WHPA-B – an area within which the time of travel to a well is less than or equal to two years but excluding WHPA-A
(3) WHPA-C – an area within which the time of travel to a well is less than or equal to five years but greater than two years.
(4) WHPA-D – an area within which the time of travel to a well is less than or equal to twenty-five years but greater than 5 years.

In the case where WHPA-B falls entirely within WHPA-A, wherein the two year time of travel is less than or equal to 100 metres from the well, there would be no WHPA-B and WHPA-A would be adjacent to WHPA-C.

WHPA-C and WHPA-C1

Part V.3 of the Technical Rules indicates that a WHPA-C1, being within which the time of travel to the well is less than or equal to ten years but greater than 2 years, may be used in lieu of WHPA-C when:

48. Despite rule 47, where a zone representing a ten year time of travel was delineated for the well in a report prepared prior to April 30, 2005 and a five year time of travel has not been delineated for the well in a report prepared after that date.

For clarification, where a 5 year time of travel zone was delineated prior to April 30, 2005, it shall be used as WHPA-C and the Assessment Report should not include a 10 year time of travel WHPA-C1 for a well where a WHPA-C has been delineated.

WHPA-E and WHPA-F

For groundwater well supplies which are subject to these rules and are considered groundwater under the direct influence of surface water (GUDI), the Technical Rules require the delineation of additional WHPAs to consider the

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vulnerability of well water supplies with respect to the transport of potential contaminants along surface water pathways that influence the GUDI well. These areas are specified in the rules as:

47(5). area WHPA-E, being the area delineated in accordance with the rules in Part VI that apply to the delineation of an IPZ-2, as if an intake for the system were located:
(a) at the point of interaction between the groundwater that is the source of raw water supply for the well and the surface water body that is directly influencing that groundwater; or
(b) at the point in the surface water body influencing the raw water supply for the well that is closest in proximity to the well, if the point of interaction described in (a) is not known.

47(6) area WHPA-F, being the area delineated in accordance with the rules in Part VI that apply to the delineation of an IPZ-3, as if an intake for the system were located in the surface water body influencing the well at the point closest in proximity to the well.

For clarification, the Intake Protection Zone (IPZ) methodology used in delineating WHPA-E and WHPA-F shall be consistent with the classification of the water body associated with the GUDI well. For example, if the GUDI well was influenced by a great lake, the IPZ delineation would be consistent with the approach in Part VI that applies to great lakes intakes.

For GUDI wells, it is important to note that the Technical Rules provide three criteria which must exist in order to require WHPA-E and WHPA-F delineations, since without a WHPA-E you cannot have a WHPA-F (see rule 50(1)). These criteria are stipulated in the following rule:

49. Despite subrules 47(5) and 47(6), area WHPA-E shall only be added to a wellhead protection area where:
1. the well obtains water from a raw water supply that is groundwater under the direct influence of surface water as determined in accordance with subsection 2 (2) of O. Reg. 170/03 (Drinking Water Systems) made under the Safe Drinking Water Act, 2002;
2. a determination has not been made under subsection 2 (3) of O. Reg. 170/03 (Drinking Water Systems) that subsection 2 (2) of that regulation does not apply; and
3. the interaction between surface water and groundwater has the effect of decreasing the time of travel of water to the well when compared to the time it would take water to travel to the well if the raw water supply for the well was not under the direct influence of surface water.

For clarification, 49 (1) and (2) infer that the well is registered under O. Reg. 170/03 as a groundwater source under the direct influence of surface water. In

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addition, 49 (3) specifies that the GUDI influence must result in a reduced time of travel to the well via the surface water body and influence on the groundwater supply when compared to the typical travel pathway of infiltration and subsurface flow paths. As an example, where a relatively shallow and aerially small wetland area exists within a WHPA that has resulted in the well supply being designated as GUDI but where the water in the surface water body doesn't flow but merely infiltrates to the subsurface as any other surface water might, there is no significant circumvention of the path of flow to the well via the surface water body and condition (3) would not be met resulting in no required WHPA-E.

DRINKING WATER SOURCE PROTECTION
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Technical Bulletin: Delineation of Significant Groundwater Recharge Areas

Date: April 2009

Ontario Ministry of Natural Resources

Ontario Ministry of the Environment

The Clean Water Act requires the Source Protection Committee to prepare an Assessment Report for each source protection area they represent, in accordance with the regulations, the Director's Technical Rules and the approved terms of reference for that source protection area.

As part of the Assessment Report, committees must identify four types of vulnerable areas within each Source Protection Area. These include wellhead protection areas, intake protection zones, highly vulnerable aquifers, and Significant Groundwater Recharge Areas (SGRAs). Once these areas are delineated, the rules require that vulnerability scores be assigned within these areas.

This technical bulletin provides clarification to Source Protection Committees on the process of identifying and delineating SGRAs under the recently released Technical Rules for the Assessment Report. Requirements for assigning vulnerability scores to the SGRAs are set out in Part VII.2 of the Technical Rules and are not addressed in this bulletin.

SGRAs are delineated through the development of water budgets as per the

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Technical Bulletin: Delineation of Significant Groundwater Recharge Areas

Technical Rules. The Technical Rules allow the Source Protection Committees to use a number of methods to identify and delineate the SGRAs as set out below.

Part V.2 of the Technical Rules states,

44. Subject to rule 45, an area is a significant groundwater recharge area if,

(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

(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.

To help Source Protection Committees determine what methodology to apply, the following guidance is provided:

Rule 44 (1):

- The method outlined in this technical rule was developed for areas where the recharge rates within the source protection areas are homogenous. This method can assist in distinguishing between high versus low recharge even when narrow ranges in recharge rates exist across an area.
- The method outlined in the technical rule is dependent on scale. This means that considerable differences can occur in the delineation of SGRAs depending on the scale (e.g. subwatershed/watershed/source protection area/region) at which this method is applied.

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- If the method outlined in the technical rule is applied at smaller spatial scales it will likely lead to greater variation in SGRA delineation between adjacent areas and a much higher likelihood of boundary issues occurring between the different areas where it is applied.

Rule 44 (2):

- The method outlined in the technical rule was developed for areas where the recharge rates are heterogeneous throughout the watershed.
- This method is less dependent on scale. This means that it can be applied across a broader range of spatial scales (e.g. subwatershed/watershed/source protection area/region) with fewer differences occurring in SGRA delineation between the scales.

Rule 45

- The Clean Water Act defines drinking water systems as having the same meaning as defined under the Safe Drinking Water Act (SDWA). The SDWA defines a drinking water system as "any system of works, excluding plumbing, that is established for the purpose of providing users of the system with drinking water…" This means that any system that provides drinking water, whether it is regulated under the SDWA or not, is a drinking water system for this rule. This includes domestic wells and intakes.
- Rule 45 is an exception rule. It states that you can not delineate an SGRA as per rule 44 unless there is a hydrological connection to a surface water body or aquifer that is a source of drinking water for a drinking water system as defined under the SDWA. Therefore, it excludes any area that does not provide drinking water to someone.
- Using available information, drinking water systems are to be overlaid onto the delineated SGRA per rule 44. Using this information, knowledge of the area and professional judgement establish whether there is a hydrologic connection to a surface water body or aquifer. A groundwater recharge area is only 'significant' for the purposes of the Clean Water Act if it has a hydrologic connection to a drinking water system.

Rule 46

- This rule provides the flexibility to apply engineering judgement to refine SGRAs delineated as per rules 44 and 45. The province expects the technical experts (e.g. P.Eng, P.Geo, etc.) and peer reviewers to use professional judgement in the assessment, delineation, and review of SGRAs.
- In applying professional judgement, consideration must be given to the physiographic/geologic setting to which the SGRA methods are applied. If refinement in spatial scale is desired for delineating SGRAs then it is likely more appropriate to subdivide a Source Protection Area by physiographic/geologic region rather than subwatershed. When moving to this scale, additional work will be required to address edge mapping and to ensure there is a logical flow between the different physiographic regions.

Water Budget and Risk Assessment Technical Guidance, March 2007

- The province recognizes that the delineation of SGRAs to date has been primarily based on the technical guidance and requests that all Source Protection Committees review the methods used to ensure consistency with the Technical Rules.

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Technical Bulletin: Water Budget and Water Quantity Risk Assessment - Tier 2 Subwatershed Stress Assessment - Groundwater Drought Scenarios

Date: July 2009

Ontario Ministry of Natural Resources

Ontario Ministry of the Environment

The Clean Water Act requires Source Protection Committees (SPCs) to prepare an assessment report for each source protection area it represents, in accordance with the regulations, the Director's Technical Rules and the approved terms of reference for that source protection area.

As part of the assessment report, SPCs must identify four types of vulnerable areas within each source protection area. These include wellhead protection areas (WHPAs), intake protection zones (IPZs), highly vulnerable aquifers (HVAs), and significant groundwater recharge areas (SGRAs) for types I, II and III drinking water systems. The SPCs must also assess risks to water quality and quantity for these drinking water systems. The water quality and quantity risk assessments complete the assessment report.

In order to evaluate the risks to water quantity, the SPC must evaluate the ability of the water supply to meet the community's drinking water needs following a tiered water budget analysis. This is called a stress assessment. This tiered approach uses water budget models in which the local water supply, water

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Technical Bulletin: Water Budget and Water Quantity Risk Assessment - Tier 2 Subwatershed Stress Assessment - Groundwater Drought Scenarios

demands and the needs of the aquatic ecosystem will be compared through a process of successively more detailed and focused level of technical complexity, more refined information derived from water budgeting work and refined geographical scale. The water quantity risk assessment will also evaluate the potential hydrologic stress that could arise from future water needs and periods of drought.

The water budget and quantity risk assessment framework requires that drought scenarios be considered beginning at Tier 2.

This technical bulletin provides clarification to SPCs on the process of evaluating drought scenarios in the groundwater component of water budgets that are being developed for the water quantity risk assessment in order to assign Tier 2 subwatershed stress levels.

Definitions

"ten year drought period" means the continuous ten year period for which precipitation records exist with the lowest mean annual precipitation.

"two year drought period" means:

(a) in relation to an assessment of surface water quantity, the continuous two year period for which precipitation records exist with the lowest mean annual precipitation, and

(b) in relation to an assessment of groundwater quantity, a simulated two year period with no groundwater recharge.

Explanation of the Rules:

Technical Rule 35(2)(e) and Rule 35(2)(f)

- Rule 35(2)(f) specifies that a stress level can only be assigned as moderate if either of the circumstances listed in rule 35(2)(e) are triggered for both the two year and ten year drought scenarios. The two year drought analysis includes scenarios D (existing system – two year drought) and E (existing system – future two year drought). The ten year drought analysis includes scenarios G (existing system – ten year drought) and H (existing system – future ten year drought).

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- The above implies that if the simulations of both scenarios D and G or both scenarios E and H results in either of the following circumstances in Rule 35(2)(e) described below, then the stress level of the subwatershed should be assigned as moderate:

  Circumstance 1: the groundwater in the vicinity of the well was not at level sufficient for the normal operation of the well or

  Circumstance 2: the operation of a well pump was terminated because of an insufficient quantity of water being supplied to the well.

Technical Rule 35(3)

- Rule 35(3) specifies that if neither of the drought scenarios results in either of the above circumstances at the well, then the subwatershed stress level should be assigned as low.

Clarification of the Rules:

- The two year drought, unlike the ten year drought, has two separate methods; one for assessing surface water and one for assessing groundwater. The two year drought assessment for surface water is based on historical climate records; however the drought assessment for groundwater must be completed using zero recharge for a two year period, as per the definition.
- The intent of the rules are to provide, at first, a simple, conservative (e.g. zero recharge), two year drought scenario as a screening tool for groundwater that would not require a more thorough assessment of historical climate records and would include the use of the calibrated model in transient conditions, thereby saving time and effort.
- It is recognized that using zero recharge for the two year groundwater drought scenario provides a screening assessment that looks at the extreme "worst case" scenario that may produce greater levels of drawdown than the assessment of the ten year drought scenario.

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- Following the Rule 35(2)(f), the two year drought scenarios should be undertaken first. If neither of the two year drought scenarios D and E triggered a circumstance in 35(2)(e) then there is no requirement to undertake a further assessment of a ten year drought scenario. As stated in Rule 35(3), the subwatershed stress level should then be assigned as low.

- If either or both of the two year drought scenario(s) did trigger a circumstance in 35(2)(e) then a further assessment is required using a more representative ten year drought scenario that requires the assessment of climate data, estimation of monthly recharge rates, and the use of actual pumping rates in a transient groundwater model, which are the scenarios G and H.

- Professional judgement is needed to assess the drought scenarios when the historical climate period of record is relatively short (e.g. less than 20 years) and does not encompass a typical drought period (e.g. 1960's or late 1990's). In this situation using the two year drought scenario for groundwater (as opposed to the ten year drought scenario) may be more appropriate as a conservative estimate of drought conditions. In these circumstances, the team should select the most representative nearby climate station outside of the watershed with a longer term climate record.

- Historical observations of drought impacts to surface water and groundwater in the watershed are very important to verify the results of the drought scenarios. As an example, operator records of water levels, where available, can help to verify simulated water level fluctuations.

Technical Bulletin: Water Budget and Water Quantity Risk Assessment - Tier 2 Subwatershed Stress Assessment - Groundwater Drought Scenarios

Questions

Question 1. Does the two year groundwater drought scenario need to be simulated if the ten year groundwater drought scenario is already complete?

Question 2. Can the two year and ten year groundwater drought scenarios be simultaneously evaluated using a transient model?

Question 3. Can the two year groundwater drought scenario use a continuous two year period for which records exist with the lowest mean annual precipitation rather than using zero recharge?

Question 4 Can the two year or ten year groundwater drought scenarios be evaluated using a steady state model?

Answers to Questions:

Question 1:Does the two year groundwater drought scenario need to be simulated if the ten year groundwater drought scenario is already complete?

If the ten year drought scenario has been completed and neither of the scenarios G and H triggered a circumstance in Rule 35(2)(e), then the stress level is assigned as low according to Rule 35(3) and therefore the two year drought scenario does not need to be run. If either of the ten year drought scenarios does trigger a circumstance in 35(2)(e) then you must still show that the two year drought scenario also triggers a circumstance in 35(2)(e) before you can assign the stress level as moderate.

Given the level of effort for the ten year versus two year drought scenarios, we recommend that the two year be run first, and if neither of the two year scenarios trigger a circumstance in 35(2)(e), then you are not required to do the more complex modelling required for the ten year drought scenario.

Question 2:Can the two year and ten year groundwater drought scenarios be simultaneously evaluated using a transient model?

In cases where the groundwater flow model has already been used to simulate a long-term transient period (i.e., 40 years), the results of those simulations can be considered to be indicative of droughts of any time period (e.g., two year, ten year).

Simulating the two year and ten year drought scenarios simultaneously in transient mode and extracting the maximum groundwater drawdown estimates from the entire period of record (typically 30+ years) meets the intent of rule 35(2)(f) and 35(2)(g).

- From recent review of Tier 2 Water Budget reports it has become apparent that in the process of developing the requisite complex groundwater and surface water models it may be a straightforward process, in some cases, to run the groundwater model in full transient mode.
- Full transient mode simulation means that the entire historical climate period of record and variable pumping rates can be incorporated into a transient groundwater model capable of simulating varying groundwater levels.
- Full transient mode simulation allows for a more realistic (e.g. actual assessment of historical data) assessment of drought rather than using the conservative zero recharge for the two year drought scenario.
- The model developed in this manner enables water levels to be simulated at any location, during any time period or interval, throughout the entire period of record.

Question 3:**Can the two year groundwater drought scenario use a continuous two year period for which climate records exist with the lowest mean annual precipitation rather than using zero recharge?**

The two year groundwater drought scenario can not use a continuous two year period for which climate records exist with the lowest mean annual precipitation rather than using zero recharge. The two-year scenario with zero recharge is intended to be a screening scenario. A transient simulation using just two years of reduced recharge based on historical records may not appropriately simulate the longer term impacts of an actual drought.

Technical Bulletin: Water Budget and Water Quantity Risk Assessment - Tier 2 Subwatershed Stress Assessment - Groundwater Drought Scenarios

Question 4: Can the two year or ten year groundwater drought scenarios be evaluated using a steady state model?

The drought scenarios must be simulated using a transient model. The transient model will account for changes in storage under varying recharge and pumping rates.

Notable Points:

- There is inherent uncertainty in the simulated drought water levels using regional groundwater models. However, as long as the water level drawdown in comparison to the available drawdown at the wells is acceptable, then there is confidence that the drought scenario will not impact the aquifer and the well will be able to continue to pump the allocated rate.
- The results of the simulation of the drought scenario and the assignment of subwatershed stress levels should be reviewed with the peer review team for the respective source protection area.

DRINKING WATER SOURCE PROTECTION
ACT FOR CLEAN WATER

Technical Bulletin: Climate Change and the Director's Technical Rules

Date: Updated August 2009

Ontario Ministry of the Environment

Regulation regarding the content of the assessment report became law in November 2008. In the section outlining other information to be included in an assessment report, the following clause has been included to address climate change:

> *Part II.2 – Assessment Report Contents*
>
> *9.(2)(e) with respect to the assessment of the climate of the source protection area undertaken in accordance with Part III.1, the effects that projected changes in the climate over the following 25 years will have on the conclusions reached in the assessment report and a list of the information sources underlying those projected changes;*

In addition, the Director's Technical Rules (rules), established in December 2008, contain a clause pertaining to climate change:

> *Part III.1 – Conceptual Water Budget*
>
> *19. A conceptual water budget shall include an assessment of the following elements,*
>
> *(13) The climate of the area, including historical trends and existing projections*

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Technical Bulletin: Climate Change Summary

related to changes in the climate of the area.

As a result of the regulation's release, a number of questions regarding the purpose and intent of these requirements have been raised. There is also some uncertainty about whether new work is necessary to meet the obligation raised by the regulation and rules. The purpose of this bulletin is to provide guidance.

These regulation and rules require that the assessment report contain a summary of the existing climate change knowledge and climate data available to source protection committees (SPCs) and their interpretation of how it could impact the conclusions in the assessment reports. The intent is for SPCs to work with the Conservation Authority and other partners to gather available knowledge.

The regulation and rules were intended to be an information gathering exercise for currently available data.

- Some source protection areas have partners that have advanced further than others in their study of climate change and know that the changes in the local climate will impact their water quality and water quantity. If climate change projections or modelling are already completed, this information should be included in the conceptual water budget as required by rule 19(13). If these data indicate to a SPC that there may be water shortages in the next 25 years, and this is different than the area's current assessment report findings, then that would be information to include in the summary.
- Some SPCs do not have future climate projections available. In this case, their summary would include a declaration that there is no climate change data or analysis available. If no climate change information specific to the source protection area is available, then the summary could still include an analysis of impacts on the conclusions of the assessment report. This could be based on the broad predictions in climate trends for the whole of Ontario and would consist of a wide exploration of the potential impacts on the conclusions of the assessment report. This is not mandatory, but is allowed under the rules. Once more information becomes available in the future, this exploration can be revisited with better capability and in greater detail.
- SPCs may also want to include data on flooding and extreme storm events and their potential impact on water quality and vulnerable areas. Many

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areas in the province have experienced more frequent flooding in recent years than would be expected from historic weather patterns. If possible, it would be beneficial to consider the potential effects of this on the conclusions of the assessment report.

This climate change clause within the regulation does not oblige SPCs to undertake any new climate change analysis or projections. The Ministry anticipates that it will build a foundation of climate change science and knowledge as it relates to source protection. More information about the Source Protection Program's plan ahead for climate change should be available this year through a discussion paper posted through the Environmental Registry.

D2 VULNERABILITY OF DRINKING WATER SOURCES

D2.1 Highly Vulnerable Aquifers (HVAs)

The relative vulnerability of groundwater to contamination (sometimes termed intrinsic vulnerability) is then determined within each of these areas. Vulnerability is equated to travel times of contaminants from surface where if contaminants are estimated to be able to reach an aquifer or well in a shorter time period, then that aquifer or well is deemed to be more vulnerable. For the delineation of HVAs the *Technical Rules, 2009* require:

a) Assessment and delineation of groundwater vulnerability (*Part IV.1, Rules 37 and 38*);

b) Delineating highly vulnerable aquifers (*Part V.1*, *Rule 43*);

c) Assign vulnerability scores. highly vulnerable aquifers outside of a WHPA are given a score of 6 (*Part VII.1, Rule 79*);

d) Determining impact of anthropogenic transport pathways (*Part IV.1, Rules 39 and 40*);

e) Determining level of uncertainty as high or low (*Part I.4, Rules 13-15*);

f) Threats and issues within HVA only (High Vulnerability area with score of 6) (*Part X and XI*); and

g) Risk Score = Hazard Rating (range from a low of 1 to a high of 10) x vulnerability (*Part X and XI*). A risk score greater than 80 is a significant threat, 60 to 79 is a moderate threat and 40 to 59 is a low threat. An HVA can never contain a significant threat according to the proposed risk scoring system contained within the Technical Rules.

Assessment

The analysis and delineation of aquifer vulnerability includes many assumptions. A key assumption is that all potential aquitard materials (silt, clay, till) provide some protection to underlying aquifers. It also relies on existing mapping and water well descriptions of potential aquitard material being valid. In reality, aquitards are not always homogeneous in hydraulic properties or protective capability. Aquitard integrity as a protective layer can be compromised by various features and processes such as fractures, sand bodies, geochemical dissolution, and erosion (Cherry *et al*., 2006).

The various hydrogeologic settings, from which municipal systems obtain supplies within the CVSPA, were initially ranked in terms of their relative vulnerability. This allows for a general appreciation of their relative susceptibility.

The input data, information sources and assumptions used in the creation of the numerical model are documented in Section 3, while detailed discussions on the HVA analysis are presented in the report *SPC Accepted Groundwater Quality Vulnerability Analysis, Highly Vulnerable Aquifer Delineation* (CTC Source Protection Region, May 2010). This report contains the foundation technical data and information upon which the summary below has been based.

The AVI Delineation Report was extensively peer reviewed by a panel of municipal and provincial representatives, private consultants, and the CVC prior to acceptance by the CTC Source Protection Committee (SPC), and inclusion in the Assessment Report.

This methodology represents a modification of the basic AVI method in that it utilizes the geologic surfaces (overburden, soil types, and thicknesses) generated by a computer model, instead of creating interpolative surfaces premised on point-sourced raw data available in the provincial Water Well Information System (WWIS). This modification has received approval from the MOECC.

The data and information obtained from the modeling are:

- Three – dimensional hydrostratigraphic interpretation for each model layer (aquifer and aquitards) – thickness of geologic formations;
- Hydraulic conductivity (K) distribution for each model layer; and
- Observed and simulated water table and hydraulic head distribution from each aquifer.

The stratigraphic layers produced by FEFLOW, for the analysis are summarized on **Table D2-1** and shown conceptually in **Figure D2-1**. The aerial plan of the section is also shown in **Figure D2-1** for ease of reference.

K-factor - a dimensionless number related to the vertical hydraulic conductivity of geologic material.

The K distribution describes the ease with which water flows through subsurface material and are based on estimates of vertical and horizontal flows in the geological layers. More transmissive rock types (e.g., aquifer) have higher K value than a less transmissive (e.g., aquitard) ones. K values are then translated into "K-factors" for derivation of the AVI. A listing of the K values and K-factors associated with various geological materials is presented in **Table D2-2** and **Table D2-3** a chart showing the concept of AVI indexing is also presented as **Figure D2-2**.

The Geological Survey of Canada has developed a classification scheme that reduces the three soil material descriptions contained within the MOECC water well record database into a single classification (Russell *et al.*, 1998).

The K values for the Halton Till have been further refined since the Tier 2 study, through other work undertaken for the CVC (2008/2009 North West Brampton Study), and the updated K distribution for the till has been used in this analysis.

The AVI is generally calculated by assessing the K-factors and the thickness of each type of geological material sequentially overlying the surficial aquifers at a location. A more transmissive rock type (e.g., aquifer) would be assigned a higher K value than a less transmissive (e.g., aquitard).

The AVI score for a particular geologic material is the product of its K-factor and thickness. The scores for each material at a particular location are then summated to obtain an overall AVI score for the overburden. A higher AVI score implies greater permeability in the material above an aquifer, and hence less protection. This further implies a higher susceptibility / vulnerability of the aquifer to surface influences.

The overall model set-up, and computations undertaken for the AVI methodology is summarized in **Table D2-4**.

Table D2-1: FEFLOW Hydrostratigraphic Layers - Aquifer Units are Bolded

CVSPA			
L		**Feflow Model Layer**	
1	Top	Surficial sediments & Stratified drift	
2	Top	Upper Till Aquitard	Halton, Wentworth & Newmarket Tills (includes Port Stanley outside Buried Valleys)
3	Top	Upper Aquifer	Ice-Contact Drift, MIS and ORM equivalent
4	Top	Intermediate Till Aquitard	Port Stanley, Tavistock & Northern (Catfish Creek) Tills
5	Top	Lower Sediments	Thorncliffe equivalent Sunnybrook equivalent Scarborough sands equivalent
6	Top	Weathered Bedrock	Contact Zone - upper 3-5m of weathered bedrock outside valleys
7		Guelph/Amabel Aquifer	Guelph/Amabel Formations
8		Cabot Head Aquitard	Cabot Head Formation
9		Manitoulin/Whirlpool Aquifer	Manitoulin/Whirlpool Formations
10		Queenston 1 Aquitard	Queenston Formation
11		Queenston 2 Aquitard	
12		Georgian Bay Aquitard	Georgian Bay Formation
13		Bottom of Model	

Table D2-2: Lumping of K values into K factors – CVSPA HVA Analysis

K-factor Classification		
K_v (m/s)		**K-factor**
min	**max**	
1.00E-05		1
1.00E-06	9.99E-06	3
1.00E-07	9.99E-07	4
	9.99E-08	5
Note: modified from Table D3		

Table D2-3: Generic K-Factors (from OMMAH, 2004).

Table A. Generic K-Numbers

Soil Type	K-number
gravel weathered limestone/dolomite permeable basalt	1
sand	2
peat (organics) silty sand weathered clay (<5 m below surface) fractured igneous & metamorphic rock	3
silt limestone/dolomite	4
till (diamicton) sandstone	5
clay (unweathered marine) shale	8
unfractured igneous & metamorphic rock	9

Source: Ministry of the Environment, November 2001. Groundwater Studies 2001/2002. Technical Terms of Reference

Table D2-4: AVI Computations

Step	Task
1	Create isopachs (layer thickness) of groundwater flow model layers
2a	Create K layers by multiplying K for each layer cell by an anisotropy value L2 - Halton Till - multiply K x 0.3 to give K L4 - Newmarket - multiply K x 0.2 to give K L6 - Sunnybrook - multiply K x 0.2 to give K
3a	Assign K-factor to each cell in each layer according to Table D-2
4	Layer thickness x K-factor = "layer score"
5	Sum "layer score" for layers above aquifer (aquifer layers - L3, L5, L7) = Aquifer Vulnerability Index (AVI)
6	Clip AVI to where aquifer is >2m thick (assumed present)
7	Assign Vulnerability Score AVI < 30 = High Vulnerability (Vulnerability Score = 6) AVI = 30 to 80 = Medium Vulnerability (Vulnerability Score = 4) AVI > 80 = Low Vulnerability (Vulnerability Score = 2)
7a	Shallow sediments - add areas where L1 >2m thick and K-factor = 1 as HVA
8	Combine L1, L3, L5, L7 vulnerability scores into one map (6=high; 4=med; 2=low) Note that Vulnerability Scores are for uppermost aquifer
9	Final map - clip all surfaces to the SPA watershed boundary
10 11 12 13 14	Check - compare vulnerability mapping to surficial geology Check - compare vulnerability mapping to SGRA mapping Check - compare to vulnerability calculated for within WHPAs Note that WHPA vulnerability mapping takes precedence Check - compare to vulnerability mapping utilizing simulated vertical flux estimates Check – compare to vulnerability utilizing particle tracing (groundwater flow models)
15 16	Possible - reduce Vulnerability Score where vertical hydraulic gradients are upward Possible - increase vulnerability if details of anthropogenic pathways are known and warrant an increase in vulnerability
Note: Aquifers occur in groundwater flow models layers L1, L3, L5 and L7.	

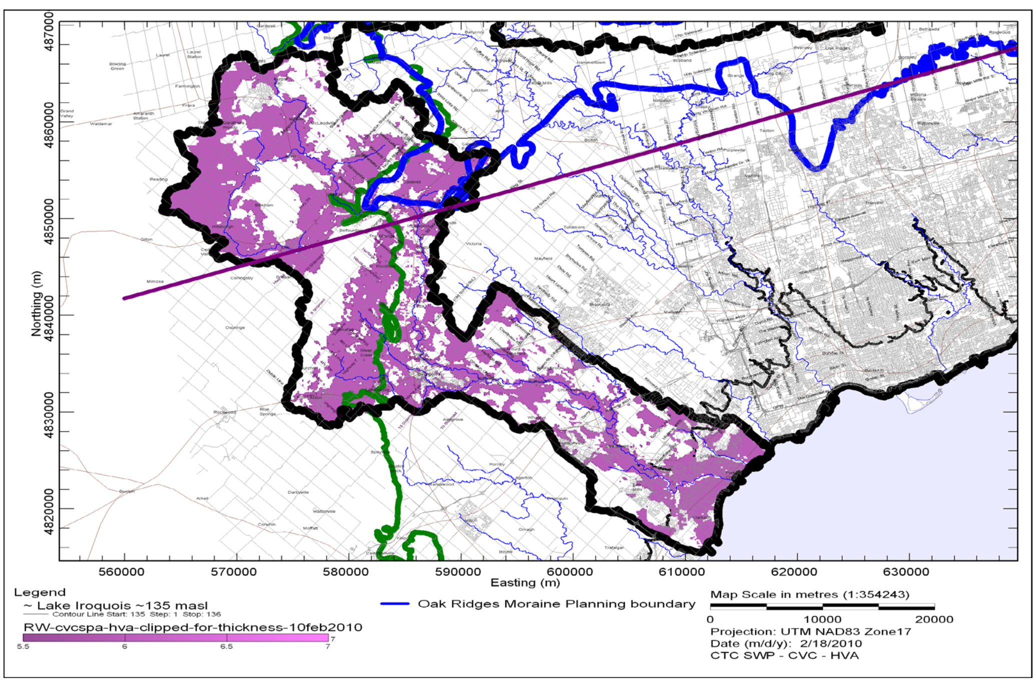

Figure D2-1: Stratigraphic Layers Produced by FEFLOW

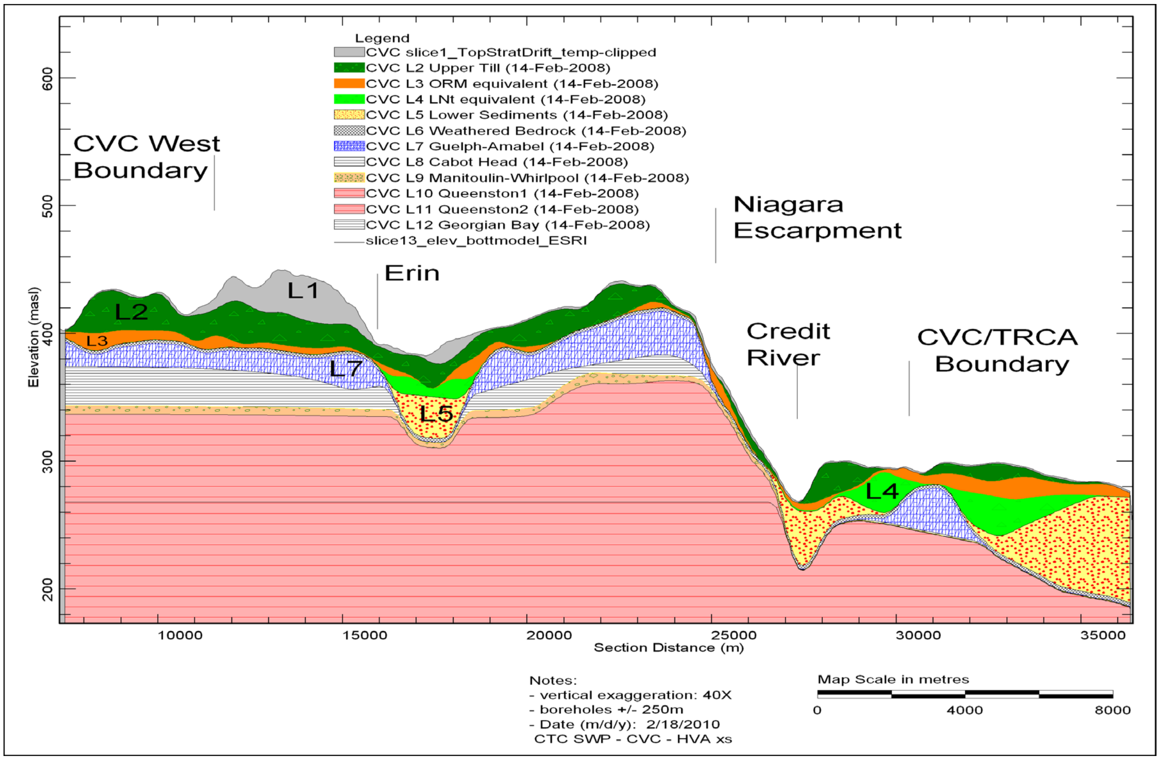

Figure D2-2: Geological Section through the CVSPA

The major aquifer units in CVSPA occur in FEFLOW layers L1, L3, L5 and L7 (**Table D2-1** and **Figure D2-3**), and are identified them as follows:

- Surficial stratified sediments - L1;
- Upper aquifer largely comprised of ice-contact drift, Oak Ridges Moraine/ Mackinaw Interstadial equivalent - (L3);
- Lower sediments (Thorncliffe equivalent, Sunnybrook equivalent, Scarborough Sands equivalent) - L5 and;
- The Amabel Formation (L7- bedrock aquifer).

In the analysis, they were considered as being vulnerable only where:

- Surficial deposits of sand and gravel (L1) are greater than 2 m in thickness; and
- L3, L5 or L7 deposits occur at or near the surface.

Lower permeability geologic materials such as clay, silt and till are assumed to function as aquitards that offer some degree of protection to underlying aquifers (sand and gravel). These include:

- Upper Till (Halton Till) - L2;
- Intermediate Till (Port Stanley, Tavistock and Northern Tills) - L4; and
- Weathered bedrock (upper 3 - 5 m of weathered bedrock outside valleys) - L6.

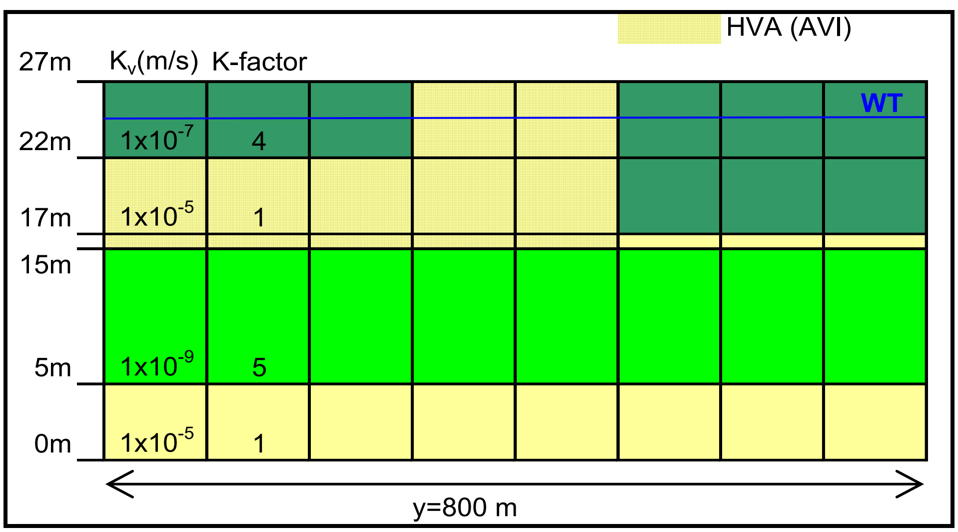

Figure D2-3: Schematic Showing how FEFLOW Model Layers, K_v and K-Factor Components

WT – Water Table, AVI = Summation of (Thickness of strata x K factor for that strata) AVI above the most surficial aquifers at locations throughout CVSPA

Uncertainty

An uncertainty assessment was undertaken to review the factors affecting/influencing the validity of the outputs, and an assessment of their effect on the accuracy levels.

Intrinsic vulnerability is based on the density of data, the accuracy and currency of the surface geology mapping, and interpretations and assumptions made in the development of three-dimensional (3-D) models. Through its involvement in the York Peel Durham Toronto groundwater study team, the CTC has made significant advances in its understanding of the hydrogeological system over the last decade, adding new high integrity data sources, and refining existing data. This knowledge has given the study team an increased level of confidence in the results of the analyses. Uncertainty associated with the AVI analysis is summarized in **Table D2-5** and is discussed below.

Table D2-5: Uncertainty in AVI Delineation

Parameter	High	Low
The distribution, variability, quality, and relevance of data.		X
The ability of the methods and models used to accurately reflect the flow processes in the hydrological system.	X	
The quality assurance and quality control procedures applied.		X
The extent and level of calibration and validation achieved for models used or calculations or general assessments completed.		X
The accuracy to which the groundwater vulnerability categories effectively assess the relative vulnerability of the underlying hydrogeological features.		X

One of the largest areas of uncertainty relates to the quality of the input information – some areas have reliable geologic information in the subsurface while others do not. The lower quality information (e.g., MOECC water well records) has been used to interpret areas between higher quality information (e.g., cored boreholes logged by a professional geologist). Uncertainty is reduced by continual refinement of the 3-D geologic interpretation as more information is collected.

The AVI method utilized relies on hydraulic conductivity estimates contained within the model numerical groundwater flow models which have been used for the Tier 2 water budget analyses. While suitable numerical groundwater flow model calibration has been achieved by successively refining recharge and hydraulic conductivity estimates, the preferred calibrated scenario is probably not unique. Again, uncertainty can be reduced by incorporating further aquifer testing results into the continued refinement of the numerical model calibration as these data become available.

The AVI method reclassifies hydraulic conductivity information into a K-factor, which represents relative hydraulic behaviour of the subsurface materials. This index method is a relative comparison of aquifer protection and does not provide estimates of contaminant travel times. In reality, till deposits, which are assumed to offer some degree of aquifer protection in this method, are often fractured or contain other secondary permeability structures that can enhance the hydraulic conductivity of the unit - which in turn may allow rapid migration of contaminants to underlying aquifers. Fracture delineation and quantification is difficult at best. This places an emphasis on always testing the vulnerability mapping results with water quality data from monitoring networks.

The results of the AVI analysis do make sense when assessing relative vulnerability. Uncertainty is reduced by continual refinement of the input information (geology and hydraulic conductivity) as more information is received. Greater confidence in the mapping is achieved as the results of this regional mapping are compared to vulnerability mapping within WHPAs, and through comparison to GUDI studies, monitoring data (groundwater quality) and other geologic and hydrogeologic information as it becomes available. This continual testing process will lead to continual refinement and improvement in the input data and interpretation which will in turn reduce the uncertainty in the mapping.

D2.2 Significant Groundwater Recharge Areas (SGRAS)

Technical Rules 44 (1) and 44 (2) provide provincial directive as to how to delineate those areas that provide the highest volume of recharge per unit area of the watershed. The rules list five different methods, as summarized below:

1. Delineation based on OGS quaternary soils mapping. Can be combined with topographic mapping to identify upland areas;
2. *Rule 44 (1)*: Step 1: Determine annual water budget surplus using a simple method (e.g., Penman or Thornthwaite). Step 2: Consider slope, surficial geology, and land cover. Step 3: Identify SGRAs as areas having a recharge rate greater than 115% of the average annual recharge rate for the watershed;
3. *Rule 44 (2)*: Steps (1) and (2) same as Method 2 above. Step 3: Identify SGRAs as areas having a recharge rate greater than 55% of the water surplus;
4. Steps 1 through 3 are same as Method 2 except that estimates of recharge are based on the results of the numerical surface water and groundwater models; and
5. Steps 1 through 3 are same as Method 3 except that estimates of surplus (P-AET) are based on the results of the numerical surface water and groundwater models.

The first three methods apply to areas with limited groundwater data. Director's Rules 44 (1) and 44 (2) were selected for delineating the SGRA in CVSPA because they can be applied directly to the results of the FEFLOW model which calculates annual surplus and annual average recharge over each 25 m cell. The primary difference between the rules is the thresholds assigned. *Technical Rule 44 (1)* uses a factor of 1.15 times the annual groundwater recharge (QR) while *Rule 44 (2)* sets the threshold at 0.55 of the surplus.

Rule 44 (2) requires calculating the surplus as total observed precipitation minus the total AET (which includes interception and depression storage losses). Values of 0.55 times the surplus represent a simplified estimate of the average split between infiltration and runoff. Since evapotranspiration (ET) is such a difficult number to nail down, the uncertainty of this method is considered higher than Method 44 (1).

With *Rule 44 (1)* being the preferred approach, the issue then becomes the selection of an appropriate boundary for SGRA threshold. In an effort to deal with edge-matching issues (within CVSPA) which causes inconsistent results for significance for contiguous areas, various natural boundaries were used in an attempt to refine and select the appropriate threshold.

In selecting the area to be defined as the "the whole of the related SGRA", three alternate methods were tested using *Rule 44(1)*:

- Scenario 1 – using "three zones" upper, middle, and lower watershed area regional recharge rates;
- Scenario 2 - using subwatershed level recharge rates for each of the 22 subwatersheds; and
- Scenario 3 - computation using watershed-wide recharge rates for the entire CVSPA.

In summary the outcome of each scenario was:

- Scenario 1 – Three thresholds ranging from 170 to 300 mm/yr;
- Scenario 2 – 22 thresholds ranging from 36 mm/yr to 397mm/yr; and
- Scenario 3 – One threshold: 230 mm/yr.

A review of the results showed that the three-zone and subwatershed approaches produced undesirable results as they yielded inconsistencies across boundaries (physiographic in scenario 1, subwatershed in scenario 2), due to the average recharge rate being different for neighbouring zones/subwatersheds.

Having discontinuities in SGRA boundaries would be difficult to reconcile or justify on a scientific (stratigraphic, hydrogeological, etc.) basis.

As a result, the watershed level scenario (Scenario 3) was determined to provide the most defensible basis for SGRA delineation. Scenarios 1 and 2 show high volume recharge aquifers and are presented in the *SPC Accepted Integrated Water Budget Report – Tier 2. Credit Valley Source Protection Area* (AquaResource Inc., 2009).

Tier 3 Refinements to SGRAs in Subwatershed 19

The recharge distribution calculated in the Tier 3 assessment for Subwatershed 19 was refined from that established in the Tier 2 assessment; as such, the SGRA mapping for Subwatershed 19 was updated.

The SGRA threshold established in the Tier 2 assessment (of 230 mm/yr.) was used to protect groundwater recharge areas across the broader watershed. To account for uncertainty associated with the HSP-F recharge results in the Tier 3 assessment, recharge rates greater than 225 mm/yr. were used to delineate the SGRAs for the Tier 3 assessment. Professional judgment was used to remove potential groundwater discharge areas (areas where the model simulated water table is less than 2 m below ground surface) from the SGRA mapping. The 2-metre threshold was chosen to account for seasonal water level fluctuations not captured by the steady state model.

Potential groundwater discharge locations were removed, and the locations of private and municipal drinking water wells were added to identify areas where the SGRAs contribute to domestic drinking water sources. Municipal capture zones are also overlain to further identify those areas contributing to municipal groundwater supplies. Based on the analyses, several groundwater recharge areas were no longer considered as SGRAs as they do not appear to contribute to domestic or municipal groundwater supplies. In addition, small, isolated areas less than or equal to 1 hectare (10,000 m^2) were removed to simplify the implementation of this mapping in the planning process.

SGRAs include large portions of the Orangeville Moraine to the west and east and areas where coarse-grained sediments are mapped at surface. Within the urban areas, there are few SGRAs as the urban areas have a high percentage of impervious cover associated with roads, buildings, paved areas, etc.

Tier 3 Refinements to SGRAs in Subwatersheds 10 and 11

The recharge distribution calculated in the Tier 3 assessment for subwatershed 10 and 11 was refined from that established in the Tier 2 assessment and the SGRA mapping for subwatershed 10 and 11 was updated.

The SGRA threshold established in the Tier 2 assessment (230 mm/yr) was used in this assessment. However, a consistent surface water model for recharge development over both watersheds was refined in the Tier 3 assessment; this was particularly important as the cross-boundary flows between the two watersheds are a significant portion of the water balance. As such, the SGRA mapping was updated through the Tier 3 assessment.

The MIKE SHE surface water model produces a surface of spatially distributed groundwater recharge estimates based primarily on surficial soils, topography and land use cover. MIKE SHE also limits recharge where the water table is shallow, as it typically is within groundwater discharge zones (i.e., streams and wetlands).

The locations of private and municipal drinking water wells were used to identify areas where the SGRAs contribute to domestic drinking water sources. The WHPA-Q1 (developed through the Tier 3 study) was also overlain to further identify those areas that may contribute to municipal groundwater supplies. Based on this analysis, several of the previously identified recharge areas were no longer considered SGRAs, since they did not appear to contribute to domestic or municipal groundwater supplies. In addition, small, isolated areas (less than or equal to 40,000 m^2) were removed to create mapping that focuses the delineated SGRAs to larger geologic and physiographic features that are considered more representative of mapped surficial geology features. This modification simplifies the mapping to make it more practical and workable for planning purposes.

The SGRAs include portions of the upland regions. Large portions of Acton urban areas are included as SGRAs due to higher recharge rates within these areas where deposits of sand and gravel are mapped at surface. Within the Georgetown urban areas, there are few SGRAs as these areas have a high percentage of impervious cover associated with roads, buildings, paved areas, etc.

Differences in mapped SGRA locations in common areas reflect the refined analysis in the Tier 3 assessment. The most important refinement relates to the interpolation of climate data. In the Tier 3 analysis, the addition of more local climate stations (e.g., Georgetown) provides a more representative estimate of precipitation and temperature. The Tier 2 study used more distant stations (e.g., Pearson Airport). Further, the Tier 3 study was able to represent additional detail in surficial geology using a more detailed model mesh as compared to that of the Tier 2 assessment. The Tier 2 groundwater recharge rates were predicted using the HSP-F model. This model has a simplified representation of the groundwater system as an infinite sink with little feedback to the surface water system. In contrast, the MIKE SHE model represents structure, properties, and processes in the subsurface, and provides a dynamic limit and feedback to the surface water system, therefore providing a more physical representation of recharge.

SGRA Delineation - Uncertainty

The SGRA map was developed using best information available at the time.

Uncertainty is inherent in the water budget estimation process, and is related to:

- Quantity and quality of the input data (e.g., related to streamflow, climate, groundwater well records);
- Conceptual understanding of the watersheds; and
- Modelling calculation methodology.

The calibrated groundwater model meets the requirements of the Tier 2 Water Budget Framework (MOE, 2007) by simulating both groundwater potentiometric levels and groundwater discharge rates that are generally consistent with those observed within the watershed. The model was developed and calibrated to be representative of watershed scale conditions and there may be situations where the model predictions are not representative of local scale conditions. These situations may be due to the either the model characterization or the level of calibration at those locations.

Uncertainties associated with the SGRA delineation are:

- Recharge Rate Distribution - the model is shown to adequately represent observed groundwater discharge as estimated from stream gauges at the outlet of many of the subwatersheds. As a result, the total groundwater recharge within each subwatershed is thought to be well represented by the model.
- Lower Watershed - estimating hydrologic water budget parameters with a high level of certainty for the lower watershed, particularly in the Halton Till, is difficult in the absence of quality monitoring data. The estimated groundwater recharge rates are very sensitive to the estimated runoff and evapotranspiration rates which represent the largest components of the water budget. The estimated groundwater recharge rates in some of the lower watershed is low and this is subject to the methods in which the hydrologic model represents interflow, seasonality, and evapotranspiration.
- Infrastructure - tile drains, storm water sewers, sanitary sewers and water distribution infrastructure are not represented in the model, and therefore, their effects on the water budget are not currently examined.
- Buried Bedrock Valleys - uncertainties with respect to the extent and infill of some key bedrock valleys (e.g., Georgetown area) is high. This has a local effect on model calibration and potentially on local predictions of groundwater flow direction and magnitude.
- Calibration Residuals and Cross-Boundary Flow - the calibrated groundwater flow model exhibits trends of high calibration residuals along some of the model boundaries and this may result in an over-estimate of cross-boundary flows in some conditions.
- Boundary Conditions - the model’s boundary conditions are close to the subwatershed boundaries in some areas, and this may have a minor local impact on model predictions.

D2.3 Municipal Water Quality - Wellhead Protection Areas (WHPAs)

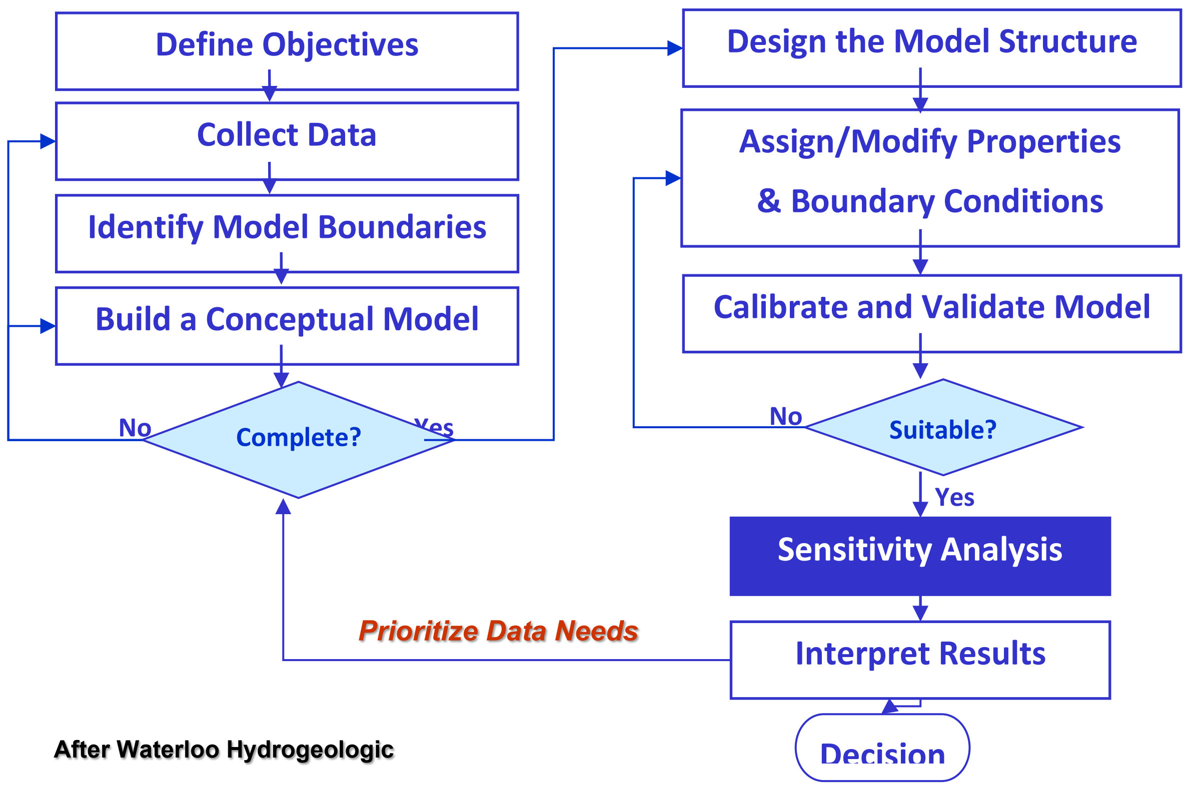

Figure D2-4: Numerical Modelling Process

D2.1.1 Dufferin County – Town of Orangeville

Geological Setting

Table D2-6: Orangeville Municipal Wells – Depths, Aquifer Setting and GUDI Status

Well	Depth (m)	Aquifer	Type	Classification
Well 2A	38.7	Guelph/Amabel	Semi-confined	GUDI
Well 5/5A	17.7	Overburden	Unconfined	GUDI w effective in-situ filtration
Well 6	48.8	Guelph/Amabel	Semi-confined	Groundwater
Well 7	47.2	Guelph/Amabel	Semi-confined	Groundwater
Well 8B/8C	76.2	Guelph/Amabel	Semi-confined	GUDI
Well 9A/9B	17.4	Guelph/Amabel	Semi-confined	GUDI w effective in-situ filtration
Well 10	60.9	Overburden	Unconfined	GUDI w effective in-situ filtration
Well 11	54.8	Guelph/Amabel	Confined	Groundwater
Well 12	49.4	Guelph/Amabel	Semi-confined	GUDI w effective in-situ filtration

WHPA Delineation

Model Selection

MODFLOW is a three-dimensional, saturated, finite difference groundwater modelling code developed by the USGS (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996). MODFLOW simulates the flow of groundwater through porous media through the calculation of a series of partial-differential equations that describe the relationship between flow, pressure, and the properties of the porous media.

MODFLOW was used in this project to simulate groundwater flows and pressures in the Orangeville, Mono, and Amaranth areas. Hydrogeologic and geologic information regarding groundwater flow, groundwater-surface water interactions, and information regarding the material properties of the aquifers/aquitards in the area were assembled and used to generate the conceptual groundwater flow model in the area. This conceptual understanding was then translated into the numerical representation necessary for MODFLOW.

Input Parameters

Hydraulic Conductivity

The hydraulic conductivity distribution in each model layer was assigned based on the properties of the aquifer or aquitard they represent. **Table D2-7** outlines the range of hydraulic conductivity and transmissivity values estimated from aquifer testing data for bedrock (BR) and overburden (OB) aquifers and the modelled hydraulic conductivity and transmissivity values.

Table D2-7: Field Based and Modeled Hydraulic Conductivity and Transmissivity Values

Well Tested	Aquifer	Hydraulic Conductivity (m/s)		Transmissivity (m^2/d)		Reference for Reported/ Estimated Conductivity Values
		Field Estimates	Modelled Values	Field Estimates	Modelled Values	
Well 2A	BR	7.17E-05	5.50E-05	140	151	Crowley Groundwater Ltd., 1979.
Well 2A	BR	2.20E-05		43		Trow, Dames and Moore, 1991.
Well 5	OB	1.58E-03	4.00E-03	835	2600	Trow, Dames and Moore, 1991.
Well 5/5A	OB	2.69E-03		1416		Mayhew, G.H., 1978.
Well 5/5A	OB	3.33E-03		1755		
Well 5A	OB	1.96E-03		1035		Trow, Dames and Moore, 1991.
Well 6	BR	1.58E-04	5.50E-05	355	152	Trow, Dames and Moore, 1991.
Well 7	BR	3.59E-05	5.50E-05	75	151	Trow, Dames and Moore, 1991.
Well 7	BR	8.27E-05		173		Gartner Lee, 1998.
Well 7	BR	5.17E-05		108		Terraqua Investigations, 1995.
Well 8A/ 8B	BR	8.16E-06	5.50E-05	43	152	Wilson Associates, 1989.
Well 8C	BR	8.28E-06		46		
Well 9A	BR	5.20E-04	9.00E-05	409	126	Burnside, 1993.
Well 9B	BR	1.24E-03		461		
Well 10	OB	1.42E-03	4.00E-04	711 to 717	726	Wilson Associates, 1993.
Well 11	BR	1.84E-05	5.50E-05	48	138	Gartner Lee, 1998.
Well 12	BR	1.19E-03	5.50E-05	2678	151	Burnside and Gartner Lee, 2004
	BR	8.41E-05		189		Franklin Geotechnical, 1989.
Pullen	BR	3.50E-04	5.50E-05	900	134	Terraprobe, 2006b.
	BR	7.00E-04		210		Terraqua Investigations, 1995.
Coles 1	OB	3.42E-05	4.00E-05	65	86	Wilson Associates, 1989.
Coles 2	OB	1.37E-05		26		Terraqua Investigations, 1995.
Cardinal Woods 1	BR	1.07E-04	5.50E-05	369	108	Burnside, 2000.
	BR	1.19E-04		410		
	BR	1.53E-05		53		Terraqua Investigations, 1995.
Cardinal Woods 2	BR	8.04E-05	5.50E-05	278	108	Burnside, 2000.
	BR	1.70E-04		586		
	BR	9.84E-06		34		Terraqua Investigations, 1995.
Cardinal Woods 4 (Brett Farm)	BR	7.76E-05	5.50E-05	n/a	108	Burnside, 2000.
	BR	1.13E-06		n/a		Burnside, 2000.
	BR	3.00E-04		n/a		Terraqua Investigations, 1995.

The modelled hydraulic conductivity and transmissivity values lie within the range of field measured values for the majority of the municipal wells. Wells 8B, 8C, 12, and the Pullen Well lie in close proximity to one another and all extract water from the Amabel Formation aquifer.

The model calibration started with a hydraulic conductivity at the upper limit of the range of field-based conductivities; however, the model-predicted drawdown in the pumping wells was significantly lower than observed during the transient calibration to the three-well pumping test in this area (i.e., calibration to pumping in Wells 12, 8C, and Pullen).

The hydraulic conductivity of the area in the model was lowered, and higher hydraulic conductivity zones were added around Pullen and Well 12, however, the observed drawdown in Pullen, Well 12, and Well 8C in the transient calibration could not be reproduced by the model with these elevated conductivity values. Lowering the hydraulic conductivity of the bedrock aquifer to values estimated by Terraqua Investigations (1995; 210 m^2/d at Pullen) and Franklin Geotechnical (1989; 151 m^2/day at Well 12) produced an excellent calibration to the three-well pumping test (see AquaResource *et al*., 2008 for details). Hydraulic conductivity estimates of Terraprobe (2006) and Burnside and Gartner Lee (2004) are believed to over-predict the transmissivity of the bedrock, whereas transmissivity values estimated in earlier studies are interpreted to be more representative of the local conditions in the vicinity of these wellfields. The calibration to steady-state and transient water levels provides additional confidence in the model in this area.

The model simulates a saturated thickness at Wells 5/5A of approximately 7.7 m, which translates to a transmissivity of 2,700 m^2/d at the well. Field test values assume a saturated thickness of 5 m (transmissivity of approximately 1,700 m^2/d). The high conductivity zone ($4x10^{-3}$ m/s) is restricted to an isolated area around the well (geologically interpreted to be an outwash feature), and the field values may represent this zone and the surrounding aquifer properties (producing a lower transmissivity estimate). The hydraulic conductivity of this zone was reduced in the lower hydraulic conductivity sensitivity analysis scenario (discussed below), and under this scenario the transmissivity (1,700 m^2/d) falls within the range of the field estimated values.

Effective Porosity

Tracer tests provide the best means for estimating effective porosity in fractured rock as these tests integrate the influence from both the connected matrix and fracture porosity features. The estimated effective bedrock porosity impacts the size of delineated time-of-travel capture zones (e.g., the 2-year, 5-year, and 25-year time-of-travel) because the calculated linear velocity is inversely proportional to the specified "effective" porosity value. Consequently, it is typical to use a lower estimate of effective porosity when delineating capture zones for WHPAs to ensure that those areas are conservatively large enough to account for uncertainty in the parameter estimates.

Flow and porosity data were collected as part of a bedrock hydrogeological study in nearby Cambridge, Ontario. These studies included the use of televiewer logs, flow profiles, tracer tests, and packer tests to identify flow horizons and estimate porosity in the Guelph and Amabel Formation bedrock (bedrock production aquifers in the Orangeville area). The studies concluded that fractures are the most important features in contributing to the overall transmissivity of the bedrock aquifer, but areas with higher concentrations of vuggy, or secondary porosity, also provide localized higher transmissivity zones.

Four tracer tests were conducted in Cambridge, Ontario (Beak Consultants *et al*., 1995; Lotowater, 1997), and analysis of the tracer test results estimated the effective porosity range for use in a groundwater flow to be 0.07% to 11% (Duke Engineering and Services Inc., 1998). AquaResource reviewed the tracer test results and estimated the most representative effective porosity for use in the Orangeville and Mono capture zone delineation was 3.9%, based on the distance and length of time over which the tracer tests in Cambridge were conducted. Duke Engineering and Services Inc. (1998) also conducted numerical and analytical modelling using a dual porosity code (SWIFT-II) to show that effective porosity of 3% provided a reasonable approximation of dual porosity at the spatial and temporal scale of typical capture zones. Based on the results of the tracer tests, and dual porosity modelling, the range of bedrock porosities representative of the Orangeville area is outlined in **Table D2-8**.

Table D2-8: Modelled Porosity Values

Lithology	Effective Porosity (%)		
	Base Case	Low	High
Competent Bedrock Aquifer	3	1	9
Weathered Guelph and Amabel Formation Bedrock	5	3	10
Bedrock Aquitard	7	5	10
Overburden Aquifers/ Aquitards	25	15	35

Boundary Conditions

Boundary conditions applied in the groundwater flow model were chosen to approximate the regional groundwater flow patterns and to approximate the major groundwater fluxes within the study area. Boundary conditions applied in the model include groundwater recharge (provided from the HSP-F model), flow into and out of surface water features (streams, rivers, lakes), groundwater pumping wells, and flow into and out of the model along its perimeter (**Figure D2-5**).

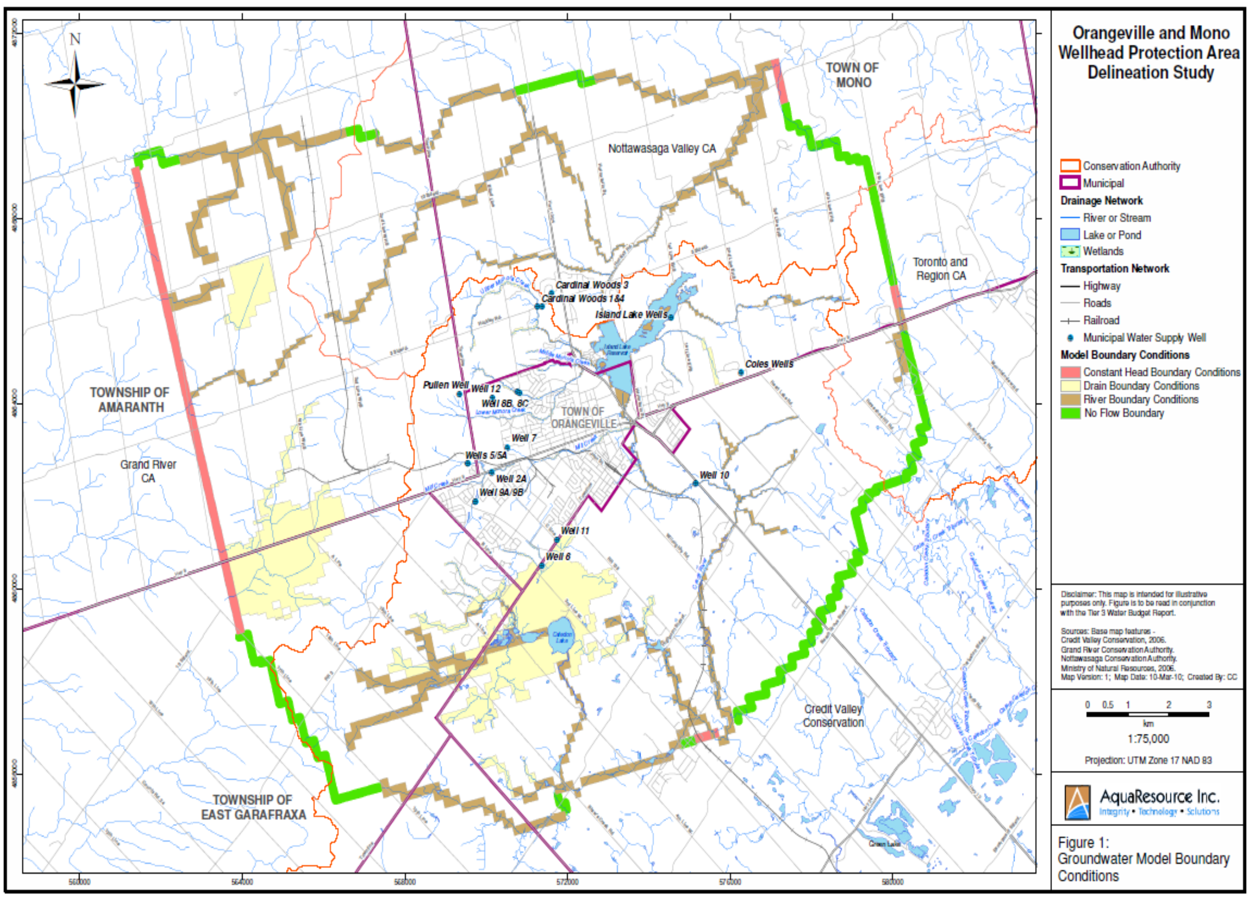

Figure D2-5: Groundwater Model (MODFLOW) Boundary Conditions

Specified head boundary conditions are commonly used to simulate areas where aquifer potentials are expected to remain at a constant level such as the flow of water into or out of the model domain. Specified or constant head boundary conditions were applied at locations along the perimeter of the groundwater flow model where groundwater was interpreted, from observed water levels, to flow into or out of the model domain.

Specified flux boundary conditions are boundary conditions for which a flux value is assigned to specific model cells. These boundary conditions were used to represent groundwater extraction wells and recharge to the groundwater system.

No-flow boundaries are another type of specified flux boundary where the rate of lateral flow across the boundary is assumed equal to zero. They were used to represent groundwater divides in the northern, southern, and eastern portions of the model domain. The location of these divides was based on a regional scale potentiometric surface mapped based on hydraulic head measurements in Ministry of the Environment and Climate Change's (MOECC) water well records.

Head dependent boundary conditions are boundaries where a flux across a boundary is calculated given a value of head assigned to specific model cells. The flux is dependent on the difference between a specified head and the calculated heads in the surrounding model cells. These head-dependent flow boundary conditions include river and drain boundary conditions that were applied in the model to represent discharge of water into or out of surface water features such as rivers, creeks, and wetlands.

Municipal Pumping Wells

The Orangeville capture zones were delineated at a rate that was determined to be the maximum future average annual groundwater demand that can be sustained by the wells. The rates were run to steady-state and the model predicted drawdown at each well was compared to the available drawdown (relative to current water level elevations in the wells and the safe operating water level elevation) to ensure the wells could pump long term at these elevated rates.

The model was run iteratively in an attempt to partition the required long-term pumping across the municipal wells, such that the wells could sustain the elevated pumping rates, and there was minimal impact on surface water features. The capture zone delineation rates are the outcome of this exercise; the model predicted drawdown at each municipal well is within the safe available drawdown. These rates are estimated maximum average annual rates that could be sustained by the wells. Higher daily pumping rates may be temporarily experienced by the wells; however, they cannot be sustained over the long term. As such, these maximum average annual (future) water demand values were used to delineate the capture zones for the Orangeville wells.

The permitted pumping rates for the Town of Mono are also significantly higher than the 2008 average rates. The capture zone delineation rates were determined in consultation with the Town of Mono, who noted that there are limitations on growth in the town due to the *Greenbelt Act*, and as such, only a few additional subdivisions can be added to the town. The increase in population in areas designated in the Town of Mono Official Plan was used to estimate the future demand from the Town of Mono supply wells. Based on the Official Plan, Town of Mono staff estimated an additional 175 dwellings would be added in the Cardinal Woods area and 300 dwellings in the Purple Hill area (supply from Island Lake Wells). Each dwelling was estimated to require 0.75 m^3/day of water. This equated to a long-term capture zone delineation rate of 392 m^3/d for the Cardinal Woods wellfield, 116 m^3/d from the Coles wellfield, and 347 m^3/d from the Island Lake wellfield.

The WHPAs for the Cardinal Woods wellfield were delineated using two different pumping scenarios to reflect conditions of the town's PTTW which does not allow Wells 1, 3, and 4 to pump at the same time. The first scenario simulated only Well 3 as active, and the second scenario simulated Wells 1 and 4 as active and Well 3 inactive. The model scenarios were configured this way to delineate the maximum capture area that would result from the two operating schemes.

It is expected that the Pullen Well will be used to service a rural residential community located near the well, and based on the number of dwellings proposed, and an estimated demand per dwelling, the average day rate of 220 m^3/d is estimated to be taken from the well into the future. As the well is not yet permitted, each of the model scenarios were run twice: once with the Pullen Well actively pumping (220 m^3/d), and once with the Pullen Well inactive (no pumping). Running the model twice ensures the capture zones for the nearby Orangeville Wells are conservative and account for the impact of the Pullen Well under the two potential future scenarios.

Recharge

Groundwater recharge specified across the top surface of the groundwater flow model was estimated using a calibrated HSP-F surface water model, also developed in the Tier 3 assessment (AquaResource *et al*., 2008).

Model calibration

The calibration of the model was assessed using several criteria which included calibration to over 1,100 steady-state head values reported in MOECC water well records (from 1960 to present day) as well as the range of hydraulic heads reported in Town of Orangeville monitoring wells. The aim was to minimize the difference between the model-predicted and model-calculated heads. Calibration statistics are as follows:

- *Normalized root mean squared* (NRMS) error = 3.4% for higher quality wells (i.e., monitoring wells; 3.5% for MOECC wells). This percentage value allows the goodness-of-fit in one model to be compared with another model, regardless of the scale. Typically, a model is considered representative when the NRMS is less than 10% (Spitz and Moreno, 1996).
- *Root mean squared* (RMS) error = 3.0 m for higher quality wells (and 6.8 m for MOECC wells). The RMS is similar to a standard deviation providing a measure of the degree of scatter about the 1:1 best-fit line. The measure indicates that the majority statistical population of predicted water levels would fall within 3.0 m of the observed value for the monitoring wells and within 7.2 m for MOECC wells. Water levels associated with the MOECC water well information system are collected over decades and reflective of the snapshot in time when they are collected. As such, water levels may vary seasonally by 2 to 5 m, depending on the geologic environment and the location and elevation reliability of these wells.
- *Mean Error* = -1.6 m for higher quality wells and -0.7 m for MOECC wells. The mean error is a measure of whether, on average, predicted water levels are higher or lower than those observed (ideally it should be close to 0). This statistic indicates that on average, the simulated water levels are lower than the observed values by 1.6 m.

- *Mean Absolute Error* = 2.2 m for higher quality wells and 5.1 m for MOECC wells. The mean absolute error is a measure of the average deviation between observed and simulated water levels. The value of 2.2 to 5.1 m is less than the population statistic (RMS) and within the range of the expected error considering the data sources. The model was also calibrated to drawdown in three municipal wells (Orangeville Well 12, Well 8C, and the Pullen Well in Amaranth) during a 44-day pumping test involving three municipal wells (see Tier 3 Water Budget and Local Area Risk Assessment report for additional information).

Sensitivity Analysis

Sensitivity analyses are performed to determine the impact of uncertainty in parameter estimates on the results of the modelling. A set of sensitivity scenarios was designed to assess the impact of parameter uncertainty on the delineated WHPAs. The scenarios focused on the uncertainty associated with: 1) hydraulic conductivities and recharge, 2) porosity, and 3) alternate conceptual models for the overburden and bedrock conductivity zones. The sensitivity analysis involved adjusting the base case model parameters in the calibrated model while maintaining the calibration and evaluating the change in particle tracking results used to delineate the WHPAs. The size and extent of the resulting zones were then assessed relative to the base case calibrated model and the other sensitivity scenarios. Seven scenarios were created as outlined in **Table D2-9**.

Table D2-9: Sensitivity Scenarios

Scenario	Recharge	Hydraulic Conductivity	Porosity (%)			
			Guelph / Amabel		Bedrock Aquitard	Over-burden
			Weathered	Competent		
Base case	Base case	Base case	5	3	7	20
1. High Conductivity and Recharge	Increased by 25%	Increased by 50%	5	3	7	20
2. Low Conductivity and Recharge	Decreased by 25%	Decreased by 50%	5	3	7	20
3. Low Porosity	Base case	Base case	3	1	5	15
4. High Porosity	Base case	Base case	10	9	10	35
5. Valley	Extend lower aquifer northward from Well 10 to Island Lake to account for buried bedrock valley uncertainty. (Base case recharge and hydraulic conductivity distribution)					
6. Bedrock	Modify extent of hydraulic conductivity representing the Eramosa Fm aquitard southeast of Wells 9A/9B towards Wells 6, and 11. (Base case recharge and hydraulic conductivity distribution)					

Each scenario was run twice; initially with the Pullen Well and Cardinal Woods Well 3 active (Cardinal Woods Wells 1 and 4 inactive), and second, with Cardinal Woods Wells 1 and 4 active, and Cardinal Woods 3 and the Pullen Well inactive. This was done to produce conservative capture zones that are representative of all future potential pumping conditions. Results are shown in **Table D2-10**.

The first two sensitivity cases involved increasing and decreasing the hydraulic conductivity and recharge applied in the model. The hydraulic conductivity of the Amabel Formation was changed from 5.5×10^{-5} to 8.3×10^{-5} m/s in the higher hydraulic conductivity and recharge scenario, and to 3.7x10^{-5} m/s in the lower hydraulic conductivity and recharge scenario. The recharge applied to the Orangeville Moraine area was 320 mm/yr. in the base case scenario and was adjusted to 400 mm/yr. and 256 mm/yr. in the higher and lower hydraulic conductivity and recharge scenarios, respectively.

The third and fourth sensitivity cases involved increasing and decreasing the modelled porosity for the overburden and bedrock units. The base case porosity for the competent Amabel Formation bedrock was changed from 3% in the base case model to 1% and 9% in the low and high porosity sensitivity scenarios, respectively.

The fifth sensitivity scenario included carrying the higher conductivity zone representing coarse-grained buried bedrock valley infill from Well 10 northwards toward Island Lake. Review of sparse borehole data in the area suggests that the bedrock shallows in this area and overburden is fine-grained; however, due to uncertainty associated with the location and lithologic information, a higher hydraulic conductivity zone was carried northward towards Island Lake to assess the uncertainty in this area.

The sixth sensitivity scenario involved modifying the extents of the hydraulic conductivity zone representing the Eramosa Formation bedrock. Lithologic information associated with higher quality borehole logs at Wells 9A/B and Wells 6 and 11 indicates the aquitard pinches out between Well 9A/9B and Wells 6 and 11; however, the location of this contact is poorly understood. The hydraulic head difference between the upper and lower bedrock aquifers helped to constrain this location, but a sensitivity analysis was conducted to determine the potential change in particle flowpaths in the vicinity of these wellfields.

Results

Table D2-10: Results - Sensitivity Scenarios

Scenario	Wellfield	NRMS (MOE Wells)	NRMS (High Quality)
Base Case	All Wellfields	3.53%	4.42%
1. High K, recharge	All Wellfields	3.81%	4.72%
2. Low K, recharge	All Wellfields	3.62%	5.23%
3. Low Porosity	All Wellfields	3.53%	4.42%
4. High Porosity	All Wellfields	3.53%	4.42%
5. Valley Infill	Well 10, Coles Wells	3.53%	4.56%
6. Bedrock Aquitard	Wells 2, 9A/9B, 11, 6.	3.60%	4.54%

The 25-year time-of-travel pathlines delineated in the sensitivity scenarios are comparable to the 25-year pathlines derived from the base case scenario. The pathlines for the higher hydraulic conductivity and higher recharge scenario is similar to the 25-year pathlines derived in the base case model, and while the model calibration is poorer than the base case, it is within an acceptable statistical range. The lower hydraulic conductivity pathlines are also very similar to the pathlines delineated in the base case model, with the capture zones extending wider and broader than the pathlines in the base case model, especially around Wells 6 and 11, and Wells 8B and 8C.

As predicted, changes to bedrock and overburden porosity led to considerable changes in particle pathline length, especially in the early time-of-travel capture zones (2-year and 5-year. Increases in effective porosity led to smaller time-of-travel capture zones, while decreases in the porosity led to longer and larger capture zones. Effective porosity values do not affect the simulated groundwater flow direction but are used in the velocity calculation and for particle tracking; as such, the changes to the effective porosity values did not change the model calibration statistics.

The uncertainty associated with the modelled hydraulic conductivity distribution northwest of Well 10 was also examined in the sensitivity analysis. The resultant particles extended in a more northerly direction; however, the overall shape and extent was comparable to that of the base case model.

The uncertainty associated with the confining bedrock aquitard between Wells 6 and 11, and the wellfields to the northwest was also tested as a sensitivity scenario. The resulting capture zones are very similar to the base case capture zones.

Hydrostratigraphic and Model Layers – Orangeville, Mono and Amaranth

The numerical model comprises nine hydrostratigraphic layers, based on the 11 hydrostratigraphic layers defined through the conceptual and stratigraphic modelling (**Table D2-11**). The two uppermost hydrostratigraphic units include thin surficial layers of sand and gravel, or clay and till beds, and were relatively thin in most areas, and predominately unsaturated within the study area.

Table D2-11: Hydrostratigraphic Layers (assumed to be saturated) in the Headwaters Area

Model Layer	Hydrostratigraphic Unit	General Lithology
1	Upper Aquitard and Intermediate Aquifer	Coarse-grained outwash sand deposits associated with the Orangeville Moraine; Newmarket Till, glaciolacustrine clays, Singhampton Moraine
2	Lower Aquitard	Tavistock Till, Port Stanley Till, Catfish Creek Till (/ Northern Till)
3	Lower Aquifer	Sand and gravel overlying fractured bedrock
4	Bedrock Aquifer	Contact zone aquifer
5	Bedrock Aquifer	Guelph Formation
6	Bedrock Aquitard	Eramosa Member of the Amabel Formation
7	Bedrock Aquifer	Amabel Formation (Colpoy Member)
8	Bedrock Aquitard	Clinton - Cataract Group
9	Bedrock Aquitard	Queenston Formation

Table D2-12: Municipal Pump Rates

		Pumping Rates (m^3/day)		
Well	Depth (m)	Permitted Rates	2008 Average Day Demand	WHPA Delineation
Well 2A	38.7	864	286	440
Well 5/5A	17.7	6000	3359	3500
Well 6	48.8	3456	1358	1800
Well 7	47.2	1309	755	1142
Well 8B/8C	76.2	655	478	554
Well 9A/9B	17.4	878	559	732
Well 10	60.9	1395	121	1118
Well 11	54.8	1309	939	1082
Well 12	49.4	1309	781	1082

Vulnerability Assessment - AVI Methodology

Criteria used to define the top of the aquifer based on the reasoning that this information would be the most accurately recorded in the database are:

1. Bedrock wells - the top of bedrock is considered the top of aquifer. This conservative assumption accounts for the fractured nature of bedrock aquifers and the relatively high flow rates through primary flow paths; and
2. Overburden wells - the location of the top of the screen indicates the top of aquifer. If no screen information was recorded, then the depth of the well is used to define the top of the aquifer. This reflects the fact that for overburden wells, drilling ceases at the point where a productive aquifer is encountered.

Based on the above criteria, the water well database was analyzed, and the appropriate data was extracted to allow for the calculation of the AVI.

The AVI is a product created by: assigning a “K” (aquifer hydraulic conductivity) factor to the material of each geologic stratum recorded in the well drilling log; multiplying this number by the thickness of each stratum; and summing the total value for all strata above the aquifer of interest. Values for K used in this study are based on guidance provide by the MOECC. The above calculation is applied to each well in the study area, as shown in **Figure D2-6** below.

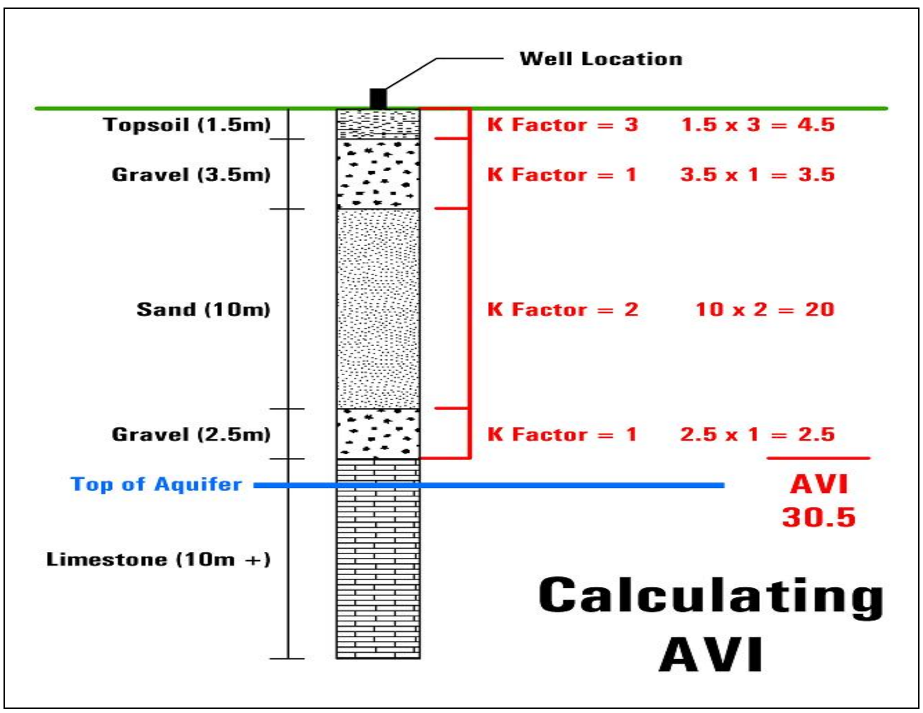

Figure D2-6: AVI Indexing Methodology

An analysis of the distribution of the well point shows that wells are mainly located in areas that are not or have not been municipally serviced. There is a general absence of data points within the municipal boundaries of the Town of Orangeville as this area has been historically serviced with municipally supplied water services. Areas of high well density are associated with subdivisions that have been developed on private services. Despite the absence of high well densities within the municipal boundaries of Orangeville it is anticipated that the "averaging impact" of interpolating over a large area will produce a reasonable assessment of vulnerability. The distribution of wells in areas denoted as high vulnerability is high. This indicates that the assessment of high vulnerability is based on data points and therefore is more reliable than an assessment based solely on interpolations.

It was assumed that the information contained in the water well database provided the best record of variations in the overburden materials as well as the bedrock and hence was the best descriptor of the geologic conditions existing within aquifers in the study area. In order to incorporate additional known variations in geology, information from the Ministry of Northern Development and Mines (MNDM) surficial geology of Southern Ontario was employed. The surficial geology was used to add data points in areas where bedrock was known to outcrop or to be present close to the surface. Well points that fell within these areas were used to generate average values for the entire area and these updated areas were subsequently used as part of the AVI calculation.

All values generated by the above processes were then interpolated to create an AVI surface for the area of interest. Various interpolation methods were evaluated including kriging, spline, radial-bias-function, and nearest neighbour. Statistical reports on the performance of each interpolator were evaluated, and all resulting surfaces were compared to the values of the original sample points (wells) and other geologic and topographic data.

The first method of interpolation attempted was kriging. Kriging being a statistical-interpolator is the most advanced interpolation method available, but was unable to provide acceptable results based on the sample values and distribution. ArcGIS Geostatistical Analyst was used for the analysis, but an acceptable semi-variogram model was not achievable based on AVI values (it should be noted that when the same sample points were tested using values such as static water level and well elevation, the kriging method produced good results).

Radial-Bias-Function produced good results when compared against the values in the sample points and how closely it agreed with topography and geologic features defined in other datasets. ANUDEM interpolator was also evaluated and performed slightly better than the Radial-Bias-Function when compared against the supporting datasets and requirements for cartographic representation. The analysis for AVI was therefore completed using this interpolator. Following this, post processing was performed on the results to produce a vector polygon dataset, with some post processing edits being applied to remove data outliers of 5 ha in size or less.

WHPA-E Delineation

The Technical Rules (August 2009) require that the WHPA-E be delineated via methods approved to delineate the Intake Protection Zone 2 (IPZ-2) for a surface water intake.

Calculation Procedure

The WHPA-E is based on a 2-hour travel time upstream of the GUDI well "intake" and for the purposes of this study was assumed to represent bankfull flow conditions within the determined stream or water body. In order to determine the extent of this zone, a Hydraulic Model was created using HEC-RAS to evaluate the channel velocity during bankfull conditions.

Stream bed cross-section geometry was determined from a Digital Terrain Mapping (DTM) that was obtained for the study area with cross-section locations taken roughly every 50 to 100 m upstream of the GUDI "intake". The terrain model was created from photogrammetric acquired elevation data in 2008. ArcGIS and HecGeo-Ras were used to determine the channel geometry including the flow length for each section of the main channel as well as the left and right overbanks. Manning's "n" values for the main channel and overbanks were determined based on aerial photography. This information was imported into Hec-Ras and modeled using a steady state, sub-critical flow regime. A downstream boundary condition of normal depth was assumed with a bed slope of 0.002.

Bankfull conditions were determined for each reach by iterating the channel discharge within HEC-RAS until a majority of sections were at bankfull depth. This was completed for each flow change location within the watercourse starting at the downstream end at the intake and working upwards. For reaches which seem to have greater bankfull capacity than reach immediately downstream, the channel discharge from the upstream reach was assumed to be equal to that of the reach immediately downstream.

Once the appropriate channel discharge had been established for each reach within the watercourse, the channel velocity for each cross section was determined using Hec-Ras. The travel time for each cross section was then determined as the distance between cross-sections divided by the channel velocity for that cross section. The travel time for each section was then added beginning at the GUDI well intake and moving upstream until the total travel time was equal to 2 hours. This represents the limit of the WHPA-E. The lateral extent of the zone was defined by using the regulatory or flood limit as the boundary for this zone. Where this data was missing a 120 m offset from the channel was used to define the lateral extent of the WHPA-E.

Design Assumptions

For reaches which contain large online ponds (>0.5 ha) the WHPA-E was assumed to end at the pond outlet as the hydraulic residence time within the pond would be greater than 2 hours. For reaches which were less than 2.0 km in length it was assumed that the WHPA-E would encompass the entire reach. For minor tributaries where the point of confluence at the main channel is less than 2-hours from the well, the entire tributary was assumed to be within the WHPA-E.

Vulnerability Scoring

The *Technical Rules: Assessment Report* (*Clean Water Act, 2006*) outline that the vulnerability score for a WHPA-E is determined based on the same principles as an IPZ-2 which is defined based on professional judgment as a product of area vulnerability (V_a) and source vulnerability (V_s) factors. Within the current study area vulnerability and source vulnerability were developed using the following methodology.

Area Vulnerability

Area vulnerability was determined from surficial geology, slope, and land use within the delineated WHPA-E. Each factor was rated as either vulnerable or not vulnerable and assigned a score of 1 or 0, respectively. Scores were summed at the end of the analysis and based on total score of 1, 2, or 3, the area vulnerability was ranked as 7, 8 or 9.

The surficial geology of the area is considered as the overburden sediments, which affect how much infiltration occurs and how much water becomes runoff. When the surficial geology consisted of predominantly course-grained sediments it was assigned a score of 1. Surficial units consisting predominantly of fine-grained sediments were assigned a score of 0.

Land use within the WHPA-E was considered for the vulnerability of the area as the activities within the area can cause a greater chance of contamination. Agricultural, residential, industrial land uses were assigned a score of 1. Natural areas which have limited anthropogenic activities within them were assigned a score of 0.

The slope of the capture area can affect the vulnerability as the greater the slope the quicker contaminants will travel over the ground flow towards the source. **Table D2-13** outlines the factors used to determine the area vulnerability factor for the Orangeville wells' WHPA-Es.

Table D2-13: Area Vulnerability Factor (Va) Derivation

Wellfield	Factors		Score	V_a
Well 2A	Surficial Geology	Course glaciolucustrine /ice contact stratified drift	1	8
	Slope	1.3%	0	
	Land Use	Residential	1	
			2 of 3	
Wells 5/5A	Surficial Geology	Glaciofluvial/ice contact stratified drift	1	7
	Slope	1.6%	0	
	Land Use	Natural some agriculture	0	
			1 of 3	
Wells 9A/9B	Surficial Geology	Ice contact stratified drift	1	8
	Slope	1.5%	0	
	Land Use	Residential	1	
			2 of 3	
Wells 8B/8C & 12	Surficial Geology	Glaciofluvial/ice contact stratified drift	1	8
	Slope	2.5 – 0.3 %	0	
	Land Use	Residential/Natural/ Agricultural	1	
			2 of 3	
Well 10	Surficial Geology	Till/Glaciofluvial/ice contact drift	0	8
	Slope	6.7 – 2.8 %	1	
	Land Use	Natural/ Agricultural/ Industrial	1	
			2 of 3	

Source Vulnerability

Source vulnerability was determined based on the intake type, the depth of the well and the dimensions of the associated water body, and the inferred potential for dilution of contaminants within that body.

All of the Orangeville wells are associated to a Type C intake. The source vulnerability factor for an intake Type C is 0.9 to 1.0. To determine the exact number, the well depth and associated water body, and potential for dilution were considered.

Wells that were less than 15 m deep were regarded as vulnerable and given a score of 1, those greater than 15 m deep were scored as 0 for less vulnerable.

The dimensions of each water body and the potential for dilution of contaminants were examined. A water body with a large capacity for dilution was rated as low vulnerability and scored as 0, while a water body with low potential for dilution was rated as 1. These numbers were summed to produce the overall source vulnerability, which was determined as a summed score of 1 representing a source vulnerability of 0.9, and a summed score of 2 representing a source vulnerability of 1.0. **Table D2-14** outlines the factors used to determine the source vulnerability factor for the WHPA-Es.

Table D2-14: Source Vulnerability Factor (Vs) Derivation

Wellfield	Factors		Score	Vs
Well 2A	Well Depth	38.7 m	0	0.9
	Water Body	Creek	1	
			1 of 2	
Wells 5/5A	Well Depth	17.7 m	0	0.9
	Water Body	Creek (intermittent)	1	
			1 of 2	
Wells 9A/9B	Well Depth	17.4 m	0	0.9
	Water Body	Creek	1	
			1 of 2	
Wells 8B/8C	Well Depth	39.7 m / 42.9 m	0	0.9
	Water Body	Creek	1	
			1 of 2	
Well 10	Well Depth	23.5 m	0	0.9
	Water Body	Credit River / wetland	0	
			0 of 2	
Well 12	Well Depth	49.4 m	0	0.9
	Water Body	Creek	1	
			1 of 2	

Vulnerability Score

To determine the vulnerability score, the area vulnerability factor is multiplied by the source vulnerability factor. This results in a vulnerability score as shown in **Table D2-15**.

Table D2-15: WHPA–E Vulnerability Scores

Wellfield	Area Vulnerability Factor	Source Vulnerability Factor	Final Score Vulnerability Score
Well 2A	8	0.9	7.2
Well 5/5A	7	0.9	6.3
Well 8B/8C	8	0.9	7.2
Well 9A/9B	8	0.9	7.2
Well 10	8	0.9	7.2
Well 12	8	0.9	7.2

Uncertainty

Groundwater Flow Model

The model was calibrated successfully to both steady state and transient conditions which significantly reduces the uncertainty of the model. Based on the stated NRMS error of 3.4% to 3.5% and the number of data points used for the calibration of the model it can be concluded that the model is a good representation of the hydrogeological understanding of the aquifer system in Orangeville.

The sensitivity analysis performed for the delineation of the capture zones has also served to improve the reliability of the model by presenting a more conservative estimate of the shape and orientation of the capture zones. It can be concluded that based on the methodology and background professional assumptions that the calibrated model represents a low level of uncertainty in the predicted results.

Despite the low uncertainty of the model results, it is also known that there is a general uncertainty in the water well database that was used for the calibration of the model. For the Tier 3 study quality checks were performed on the data and only wells rated as high reliability by the MOECC were included in the study. Additionally, borehole records from test boreholes completed under the supervision of Burnside were also included in the model. This additional data is anticipated to have improved the uncertainty of the base data. The remaining uncertainty in the database is due to the nature of the occurrence of the data being mapped, which are underground features that are not easily verifiable. This uncertainty would be persistent through any methodology selected for the delineation of WHPAs or the computation of vulnerability. The uncertainty of the database can therefore be assumed to be a professional uncertainty associated with evaluation of parameters that are for the most part in the subsurface and subject to individual interpretations.

Uncertainty of WHPA-E Delineation

Information used for the delineation of the WHPA-E included flood plain extent mapping and high-definition terrain modeling. Cross-sectional analysis was completed using surface water modelling and GIS. The analysis associated with the delineation of the WHPA-E was conducted using methodology outlined in the MOECC's *Draft Guidance Module 5–Surface Water Vulnerability* (December 2006). The cross-sectional analysis was based on the high definition terrain model for the area which had a resolution of 1 m for the vertical. This terrain model provided detailed information for the analysis, which was also verified by field visits. Professional judgment was used to estimate additional parameters necessary for the computation of stream flow in the study area. The field visits also helped with the verification of these assumptions. Considering the level of detail available for analysis and delineations there is low level of uncertainty assigned to the WHPA-E.

Uncertainty of Aquifer Vulnerability

The main uncertainty in the AVI mapping is associated to the quality and quantity of the data used to interpret the geologic and numerical model layers. The main source of information used in the AVI mapping was the MNRF water well database. This database has a high amount of uncertainty associated to it.

In light of the known high level of uncertainty in this data, Burnside incorporated several measures into the data analysis in order to reduce the uncertainty associated with the use of this data. The measures implemented by Burnside have been outlined in a previous section of this report and include; the elimination of some wells based on method of construction, the inclusion of updated data from the groundwater management studies and the cross checking with surficial geology data. It is anticipated that these measures would result in a reduction of uncertainty in the analyses undertaken.

It is also noted that the AVI was developed by an interpolation of local data into a regional setting. The interpolation is based on the assumption that the feature being interpolated is in fact continuous over the region of the interpolation. Based on the absence of adequate data points regionally (the original reason for the interpolation) it cannot be verified that the interpolation is in fact correct for areas with no data points. This absence of control points regionally serves to increase the uncertainty of the AVI calculation.

Within the Town of Orangeville's well fields, the distribution of data points for the AVI calculation is varied. Data is more available within the WHPA-A for each of the wells. With a high data density within the WHPA-A it is assumed that the uncertainty of the AVI calculations in this zone are reduced. Outside of the WHPA-A, data availability is typically reduced. Within the WHPA-B for Well 6 and 11 there is a significant collection of well points associated with private wells developed as part of a sub-division. The presence of these points indicates that the uncertainty associated with the AVI for this zone is reduced. It is also noted that Wells 2, 5, 7 and 9 show a fair distribution of wells within the WHPA-B where uncertainty would be reduced.

Local variations of geology within the WHPAs of each well are not accounted for in the areas where there is insufficient data coverage. There is an absence of data points in other areas of the WHPA outside of the areas noted above. The absence of these data points does not allow for detailed local analyses to be conducted over the entire extent of the WHPAs. Based on the available information the regional data is assumed to provide the best representation of the aquifer and its vulnerability. It is possible that detailed investigations in the future may provide information useful in determining vulnerability on a local scale. However, based on currently available data the uncertainty related to calculating vulnerability over the entire WHPA remains high.

D2.1.2 Dufferin County – Town of Mono

Geological Setting

Table D2-16: Mono Municipal Wells – Depths, Aquifer Setting and GUDI Status

Wellfield & Wells	Depth (m)	Aquifer	Type	Classification
Cardinal Woods				
MW1	59.6	Bedrock - Amabel Limestone	Semi-confined	GUDI
MW3	65.9	Bedrock - Amabel Limestone	Semi-confined	Groundwater
MW4	36.1	Bedrock - Amabel Limestone/Shale	Semi-confined	GUDI
Island Lake				
Well PW 06-2	50.3	Overburden - Fine Sand	Confined	Groundwater
Well 1 (TW1)	57.3	Overburden - Sand and Gravel	Confined	Groundwater
Well 2 (PW1)	58.8	Overburden - Sand and Gravel	Confined	Groundwater
Coles				
Well 1	25.1	Overburden - Fine Sand and Silt	Confined	Groundwater
Well 2	25.1	Overburden - Fine Sand and Silt	Confined	Groundwater

WHPA A-D Delineation

Table D2-17: Municipal Pump Rate – Mono

Well	Pumping Rates (m^3/day)		
	Permitted Rates	2008 Average Day Demand	WHPA Delineation
Cardinal Woods MW1	817	8	196
Cardinal Woods MW3	1571	240	392
Cardinal Woods MW4	753	0	196
Island Lake Well 1 (TW-1)	820	118	347
Island Lake Well 2 (PW-1)	1966	5	
Coles Well 1 / 2	655	82	116

WHPA-E Delineation

Area Vulnerability

Area vulnerability was determined from surficial geology, slope, and land use within the delineated WHPA-E. Each factor was rated as either vulnerable or not vulnerable and assigned a score of 1 or 0, respectively. Scores were summed at the end of the analysis and based on total score of 1, 2, or 3, the area vulnerability was ranked as 7, 8 or 9.

The surficial geology of the area is considered as the overburden sediments, which affect how much infiltration occurs and how much water becomes runoff. When the surficial geology consisted of predominantly course grained sediments it was assigned a score of 1. Surficial units consisting predominantly of fine-grained sediments were assigned a score of 0.

Land use within the WHPA-E was considered for the vulnerability of the area as the activities within the area can cause a greater chance of contamination. Agricultural, residential, and industrial land uses were assigned a score of one. Natural areas with limited anthropogenic activities were assigned a score of 0.

The slope of the capture area can affect the vulnerability as the greater the slope the quicker contaminants will travel over the ground flow towards the source. **Table D2-18** outlines the factors used to determine the area vulnerability factor for the Cardinal Woods MW1 and MW4 WHPA-Es.

Table D2-18: Area Vulnerability Factor (Va) Derivation

Well	Factors		Score	V_a
MW1 and MW4	Surficial Geology	Ice contact stratified drift deposits (course grained)	0	7
	Slope	9.1 % - 0.4 %	1	
	Land Use	Natural, some residential	0	
			1 out of 3	

Source Vulnerability

The closest watercourse to the wells is Monora Creek. This watercourse is a Type C intake. The source vulnerability factor for an Intake Type C is 0.9 to 1.0. To determine the exact number, the well depth and associated water body, and potential for dilution were considered. Wells that were less than 15 m deep were regarded as vulnerable and given a score of 1, those greater than 15 m deep were scored as 0 for less vulnerable.

The dimensions of each water body and the potential for dilution of contaminants were examined. A water body with a large capacity for dilution was rated as low vulnerability and scored as 0, while a water body with low potential for dilution was rated as 1. These numbers were summed to produce the overall source vulnerability, which was determined as a summed score of 1 representing a source vulnerability of 0.9, and a summed score of 2 representing a source vulnerability of 1.0. **Table D2-19** outlines the factors used to determine the source vulnerability factor for the Cardinal Woods MW1 and MW4 WHPA-E.

Table D2-19: Source Vulnerability Factor (Va) Derivation

Well	Factors		Score	V_s
MW1	Well Depth	MW1 - 60 m	0	0.9
	Water Body	Creek and wetland (high potential for dilution)	0	
			0 of 2	
MW4	Well Depth	36.1 m	0	0.9
	Water Body	Creek and wetland (high potential for dilution)	0	
			0 of 2	

Vulnerability Score

To determine the vulnerability score, the area vulnerability factor is multiplied by the source vulnerability factor. This results in a vulnerability score as provided in **Table D2-20**.

Table D2-20: WHPA–E Vulnerability Scores

Well	Area Vulnerability Factor	Source Vulnerability Factor	Final Vulnerability Score
MW1	7	0.9	6.3
MW4	7	0.9	6.3

D2.1.3 Wellington County – Town of Erin

Geologic/Hydrogeologic Setting

Table D2-21: Erin Municipal Wells – Depths, Aquifer Setting.

Well	Aquifer	Total Depth (m)	Maximum Permitted Rate (m^3/day)	2009 Average Pumping Rate (m^3/day)	Forecast Water Usage (WHPA Delineations)
Erin - E7	bedrock	43	2,160	500	1,009
Erin - E8	bedrock	46	1,964	449	568
Hillsburgh - H3	bedrock	57.9	653.8	118	175
Hillsburgh - H2	bedrock	88	982	77	175
Bel Erin - BE1 & BE2	overburden	11.3-16.2	655.2	Not operational	655.2

Groundwater Recharge

It is noted that there is a high level of recharge throughout much of the town, resulting in a significant contribution of groundwater to baseflow in the West Credit River and the tributaries of the Eramosa River and Blue Springs Creek of the Grand River watershed. Recharge rates of 250-300 mm can be expected in many of the high recharge areas. The average recharge throughout the town is estimated to be 160-200 mm.

Many of these recharge areas are also local topographically high relief areas. Water that recharges or infiltrates to the water table in these areas will follow the path of least resistance through the groundwater flow system. If there is an extensive low permeability till unit underlying the sand and gravel, then groundwater will largely not move to depth and likely discharge as baseflow to a local surface water feature. If there is a good hydraulic connection to the deeper groundwater system, then much of the water is likely to move to the lower aquifer system. This is more evident in the interpretation of the local and deep groundwater flow system.

Groundwater Flow

Groundwater flow is generally north to south, which follows the general topographic relief of the town with local areas of groundwater flow influenced by the local topographic lows of major surface water features. These areas typically create local groundwater discharge where the topographic lows intersect the water table. Water level elevations ranged from about 475 mAMSL, in the northern portion of the town, north of Hillsburgh, to 360 mAMSL in the southern boundary of the town, near Crewsons corner.

Water level elevation contours were also mapped for the bedrock aquifer system to interpret groundwater flow. Water levels in the bedrock generally mimic the water table contours, although they are typically lower by 10-20 metres. Water levels in the bedrock range 470 mAMSL in the northern portion of the town to 350 mAMSL in the southern portion of the town. Regional groundwater flow in the bedrock is generally northwest to southeast. Locally, there is groundwater flow easterly out of the town in the deep bedrock valley east of Erin.

Groundwater Flow Model Development

The Town of Erin Groundwater Model (2003) was used in the County of Wellington study (2006) to delineate WHPAs for Erin and Hillsburgh municipal wells.

The County of Wellington study updated the Erin Groundwater Model to model 50-day, 2-year, 10-year and 25-year time of travel capture zones for each municipal supply well. Capture zones were modelled using forecasted pumping rates that accounted for future growth in Erin and Hillsburgh. As part of an updated study for the County of Wellington, under the Phase 1 Source Water Protection Funding Program by MOECC, 5-year capture zones were later simulated.

Erin Groundwater Flow Model

A steady-state three-dimensional MODFLOW model was developed to simulate the groundwater flow and stream discharge within an area encompassing much of the West Credit River watershed and the Town of Erin. MODPATH was used, in conjunction with MODFLOW, to predict wellhead capture. The steady-state model was calibrated using water level data from the MOECC water well database and stream flow measurements available throughout most of the model area. Once the model was calibrated, it was used to predict the stream discharge and drawdown of the various land use scenarios and capture zones of the well fields.

The model is mostly bounded laterally by regional groundwater boundaries of the study area. **Figure D2-7** shows the modeled area. The model covers a relatively large area, extending radially about 6 to 10 km from the Town of Erin. Regional boundaries are lines, which can be plotted on a map, where groundwater flow does not cross (i.e., no flow boundaries). The model is bounded by regional discharge areas (e.g., Credit River) and groundwater flow lines. To take the advantage of the natural regional flow boundaries, the lateral extent of the model was established beyond the boundaries of the West Credit River subwatershed and the Town of Erin.

The only boundary of the model that is a groundwater flow boundary is the area north and northeast of Hillsburgh, the upgradient area of the regional groundwater flow system. Vertically, the model is bounded by topography at the top, and the base of the bedrock aquifer at the bottom. Four geologic layers were used in the model, as described in **Appendix A**. The overburden layers consist of an upper aquifer and two underlying till units. The lower sand and gravel and bedrock unit were modelled as one aquifer unit, as they are typically hydraulically connected. The bedrock aquifer was assumed to be 25 metres thick.

Parameters and Boundary Conditions

The model utilizes boundary conditions to simulate flow in and out of the aquifer system. The boundary conditions used in the model were:

- Recharge;
- Rivers;
- No-flow; and
- Wells.

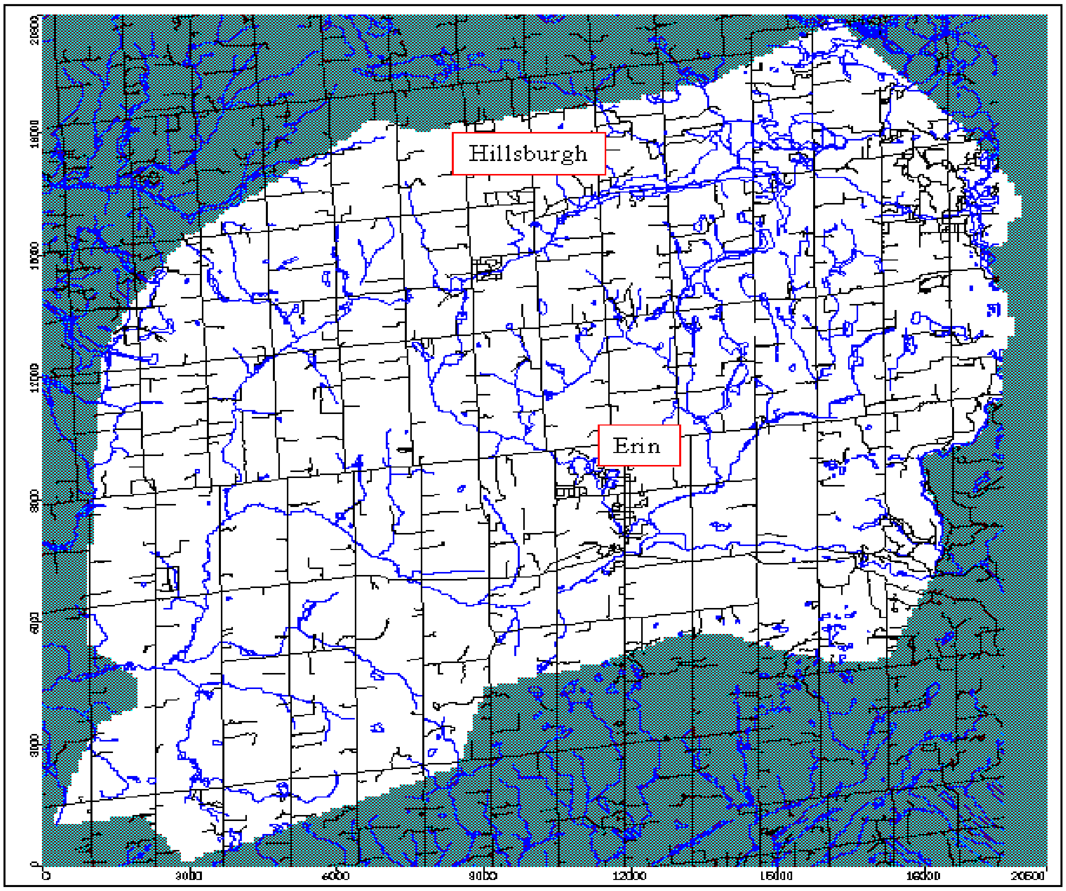

Figure D2-7: Erin Groundwater Model Plan Extent

These conditions were applied to represent the natural flow boundaries of the aquifer. Since the model considers steady-state flow, flow entering the aquifer equals flow exiting the aquifer. An estimate of flow out of the system is known because of baseflow estimates of the streams in the area. The recharge of the area ranges from 100 to 400 mm/year. All streams, except the Credit River, within the study area are represented in the model by a river boundary condition. It is appropriate to apply river boundary conditions where streams are small, and the river sediments are estimated to be lower than the connecting aquifer system. The Credit River is represented by a constant head boundary. The main input parameter for the river boundary conditions is surface elevations. Surface elevations were referenced from the DEM and topographic maps. Besides flow to streams, the only other groundwater removal from the aquifer comes from groundwater extraction wells. Information from Permits to Take Water and pumping rates, where known, were used as boundary conditions for pumping wells.

Aquifer Parameters

There are three aquifer parameters of concern:

- Hydraulic conductivity;
- Porosity; and
- Geometry.

Hydraulic conductivity is a hydraulic parameter that dictates how fast or how slow groundwater moves through soil or rock and is primarily a function of the permeability of the geologic material. Groundwater tends to move readily through sand and gravel (i.e., aquifers) and less so through silt and clay (i.e., aquitards). Porosity describes the percentage of void space within a soil. Void spaces are the regions between soil particles or fractures in rock through which groundwater travels. Aquifer geometry describes the thickness and shape of a groundwater system.

The hydraulic conductivity field applied in the model is broken up into two distinct units – aquifer units and aquitard units. The values of the hydraulic conductivity zones within each unit were determined through model calibration discussed below.

Total porosity is a measure of the void space of a soil, whereas effective porosity is a measure of the pore spaces that are inter-connected. Effective porosity is used by MODPATH in the determination of the groundwater movement. The impacts of porosity on the model predictions are discussed further in the following section.

Model Results

The model was calibrated to steady-state flow conditions. The steady-state model was calibrated to observed water level data from the MOECC database and surface calibration points (389 locations). The model was also calibrated to stream flow data. To achieve calibration, hydraulic conductivity values were adjusted until simulated heads matched the observed. Recharge was also adjusted slightly during calibration.

For the calibration the simulations of typical pumping rates were used for pumping wells within the model area. Except for a 20% loss, all the groundwater pumped is assumed to flow back to the shallow groundwater system through septic systems. Rainfall runoff on impervious surfaces is assumed to not enter the groundwater system.

According to the industry standards, the criteria for a satisfactory groundwater flow calibration are:

1. The points of calculated heads versus observed plot closely follow a 45° line;
2. Mean error is close to zero; and
3. The scaled RMS is less than 10%.

The scaled RMS is calculated by RMS error of the residuals (maximum observed head – minimum observed head).

Zones of Capture

With the model calibrated to existing conditions, the capture zones for the Erin and Hillsburgh wells were determined by activating the pumping wells at their typical pumping rates plus an additional 40% to account for estimated growth over the next 20 years (based on Official Plan estimates). Using MODPATH, groundwater particles are released at the pumping wells and backward tracked in the direction of their recharge area. The time-related capture zones that are subsequently derived from this analysis represent a two-dimensional (2-D) projection of the particle outlines to ground surface.

Bel-Erin Flow Model

The Bel-Erin municipal water supply wells lie within the footprint of the Erin Groundwater Model. In order to develop capture zones (and delineate the WHPAs) for the Bel-Erin water supply wells, which were not included in the original study, the Erin Groundwater Model was refined in the vicinity of wells BE1 and BE2. The following summarizes the basic refinements completed:

- The finite difference grid was refined to provide improved definition of the local tributary of the West Credit River which runs from west to east along the north side of the Bel-Erin wells. The grid resolution in the vicinity of the wells was increased, with a final spacing of approximately 5 metres. Following refinement of the numerical grid, the elevations along the surface water feature were defined to provide improved representation of the topographic gradient along this drainage feature.
- A bedrock valley trends in a southwesterly to northeasterly direction through the area of the Bel-Erin wells. While this valley was present in the original Erin Groundwater Model, its depth and lateral extents were considered to be under-represented based on a more detailed examination of the well logs in this area of the model. The numerical model was therefore updated to reflect the presence of this bedrock valley and provides a more contiguous valley through this area of the model. Although the Bel-Erin wells are shallow overburden wells, the location of the bedrock contact and potential connection to the bedrock aquifer can potentially influence where the water is obtained during the pumping of the wells. The refined bedrock valley has been incorporated into the model.
- A series of large springs are located to the southwest of the Bel-Erin wells, which partially drain the adjacent Erinbrook subdivision. Water from the springs is used as part of an aquaculture operation, west of the Bel-Erin wells, and eventually discharge to the nearby tributary of the West Credit River. These springs are routinely monitored and flow at a much higher rate than the permitted pumping rate for the Bel-Erin wells, on the order of 25 L/sec. These springs were simulated using MODFLOW's drain boundary condition, and in addition to groundwater elevations, estimates of average spring discharge were considered in the model calibration process. This was a key aspect of the calibration as the springs have a considerable influence on the local shallow groundwater flow system.
- The number of layers in the MODFLOW model was increased from four to seven. One of the new layers represents a zone of weathering (conceptualized as approximately 2 metres thick) at the bedrock surface. The hydraulic conductivity of this layer was

assigned at $1x10^{-4}$ m/s, which is greater than the underlying limestone bedrock which was assigned at $2.3x10^{-5}$ m/s in the original groundwater model. This zone of weathering is inferred to be connected to the shallow groundwater zone and the springs which discharge on the north side of the Erin Brook Estates subdivision noted earlier. The remaining two layers were introduced to increase the vertical discretization of the model in the vicinity of the Bel-Erin wells, allowing a discrete numerical layer across the screened interval of the supply wells (approximately 5 metres in thickness); and

- The general stratigraphy in the model remains the same as that developed for the Erin Groundwater Model: an upper aquifer which is underlain by till, which in turn overlies the bedrock. In the vicinity of the Bel-Erin wells, the sand and gravel aquifer is generally coarser, and of higher permeability. Further, there are inferred to be local areas where the till is absent, such that the sand and gravel aquifer directly overlies the bedrock.

Following its update to reflect additional detail in the Bel-Erin area, the MODFLOW model was calibrated to steady state conditions by comparing the simulated groundwater elevations to static water levels in the MOECC well record database, as well as simulated spring discharge rates and groundwater elevations in the Erin Brook Estates subdivision area to the south of the Bel-Erin wells to those estimates from field measurements. The general statistics for the calibrated model are considered reasonable over the regional scale of the available information: the regional residual mean was 0.6 m; the absolute mean difference was 5.5 m, and the normalized root mean square was 6.6%. In addition to the above, the simulated groundwater discharge rate at the springs (26 L/s), compared reasonably well with that estimated from field measurements (which, over the period from 1999 through 2007 had an overall range from 8.2 to 78 L/s, with a typical range from 20 to 40 L/s).

Through the modelling process, the principal data gaps identified in the Bel-Erin area included uncertainty related to the degree of hydraulic interaction between the surface water feature to the north of the Bel-Erin wells and the sand and gravel aquifer in which the wells derive their supply. Another data gap was the relative proportion of groundwater contribution from the south in comparison to that which may be derived from the west along the river valley (i.e., limitations in the spatial distribution of monitoring wells which could constrain the direction of groundwater flow to the south / southwest of the well field).

Capture Zone Delineation

With the model calibrated to existing conditions, the capture zones for the Bel-Erin wells were determined by activating the pumping wells at their forecast rates and using MODPATH where groundwater particles are released at the pumping wells and backward-tracked in the direction of their recharge area. The permitted pumping rate was used for these wells, the rate is not that high and if the wells were used operationally by the town, the primary purpose would be to aid in balancing the distribution of water throughout Erin, as the other wells are located in the northwest.

The time-related capture zones that are subsequently derived from this analysis represent a two-dimensional (2-D) projection of the particle outlines to ground surface. Generally, the capture zone extends in a southerly direction from the wells to the higher topography recharge areas to the south. Although, there is also a contribution that is simulated from the area of the surface water course to the north of the wells. The time of travel estimated from this surface water feature to the Bel-Erin wells is less than two years.

Vulnerability Assessment - ISI Methodology

The ISI method does not provide estimates of potential contaminant travel time but produces a numerical score representing relative vulnerability for water wells based on the soil type and thickness above the aquifer, and the static water level in the well. Note that the scoring can also be applied to interpreted hydrostratigraphic layers. The values at each well are then interpolated between locations over the aquifer area. A high score represents low vulnerability, and a low score represents high vulnerability.

The methodology was honed to overcome inaccuracies in the water well database that forms the base of the computations. It also sought to revise the method of interpolation of the data in order to improve the spatial validity of the results. The primary datasets used in this support role were the Ministry of Northern Development and Mines Surficial Geology of Southern Ontario and the Ministry of Natural Resources and Forestry (MNRF) Ontario Base Data.

The original intrinsic susceptibility index (ISI) mapping was done as part of the Wellington Groundwater Protection Strategy (Golder, 2006), and the maps were originally generated using the approach specified by the MOE (MOE, 2006). The updated ISI mapping was done in accordance with the Technical Rules (MOE, 2009).

The county-wide ISI mapping was generated following a modified version of the approach specified in the MOECC *Technical Terms of Reference* (MOE, 2001). While the index scores at individual wells were calculated using the basic concept specified by the MOECC (i.e., a score representing the summed product of the thickness of the soil units and soil type – where GSC codes and an associated numerical protection value table are provided to reflect each soil type), the principal difference applied in the county-wide study was that vulnerability (ISI) maps were produced for "individual" aquifers rather than only the uppermost aquifer.

As a result, county-wide vulnerability maps were generated for:

i) The uppermost (shallow) aquifer (sands and gravels less than 15 m below ground surface);

ii) A deep overburden aquifer (overburden sands and gravels at depths greater than 15 metres below ground surface); and

iii) The bedrock aquifer.

Only wells encountering a specific aquifer were used in creating the map. The original vulnerability mapping was interpreted across the entire county and provided a regional trend in the vulnerability of the aquifers. The limitations associated with the sparse spatial distribution and varied quality of the data, and the semi-quantitative approach to classifying high, medium, and low vulnerability, must be recognized in utilizing results. Confirmation of the vulnerability of a specific area to contamination would require more detailed, site-specific investigations.

As part of this study the local areas around the municipal wells were updated as part of a more subjective review based on local knowledge of the hydrogeology. This removed some of the high "bulls-eyes" that were based on anomalous data (e.g., in the middle of a field, or no correlation to wells in close proximity) that did not fit with the current interpretation of the hydrogeologic system.

For the Erin and Hillsburgh wells, the bedrock ISI is used. The bedrock aquifer (Guelph-Amabel Formation) is a major aquifer in this area with some protection offered by low hydraulic conductivity layers overlying it, and a conservative approach has been adopted whereby the top of bedrock is used to determine the vulnerability of the bedrock aquifer. The Bel-Erin wells, located farther south than the other municipal wells, are located in a shallow overburden aquifer and the overburden ISI mapping was used for these wells.

The ISI method also incorporates information on water levels in aquifers, specifically the location of the water table. In determining the first aquifer at depth, the ISI method requires that the sand or gravel unit is saturated, or partially saturated in the case of an unconfined aquifer. ISI requires that the uppermost aquifer be at least partially saturated. If the water table is located less than 4 m above the top of the aquifer, then the aquifer is considered to be unconfined. For unconfined aquifers, the ISI index value is calculated from ground surface to the water table. For confined aquifers, the ISI value is calculated from ground surface to the top of the aquifer. In general, sand and gravel thicknesses greater than 2 m are considered to be aquifers.

The ISI is calculated as the sum of the product of the thickness of each geologic unit overlying an aquifer with a corresponding K-factor. The single GSC soil classifications and their associated K-factors are reported in **Table D2-1** and **Table D2-3,** respectively.

Uncertainty

The uncertainty in capture zone delineation in this study was addressed by the use of two correction factors; an expansion of the capture zone by 5 degrees from the centerline, and an increase of 20% from the centerline of the capture zone.

Erin Wells

The Erin wells show a low uncertainty ranking in all categories. One area near Well E8 shows a high vulnerability score base on the vulnerability mapping. While the mapping is considered to be reasonable, based on the geologic information, it is noted the water quality of the well shows no evidence of surface sources of contamination in spite of being near surface water and not having a great thickness of overburden. The well has had no elevated concentrations of nitrate, chloride or sodium and exhibits no increasing trend over the more than 15 years of pumping. When the well cycles on for only part of each day and is then taken off, water levels typically recover to above ground surface. So, although there is a highly vulnerable area near the well, which is probably correct, the well does not exhibit any indication of impacts from surface sources of contamination.

Hillsburgh Wells

The Hillsburgh wells are similar to the Erin wells, with a low uncertainty ranking in all categories. The vulnerability scoring appears to be reasonable based on the known geologic conditions in the area. The wells do not show any evidence of contamination from surface sources. There is a low uncertainty ranking in the vulnerability scoring, but the vulnerability scoring may be high in some areas based on all factors being considered. However, to err on the side of caution it is concluded that the vulnerability scoring is appropriate.

Bel-Erin Wells

The model refinement for the Bel-Erin wells was substantial and it is believed that the representation is reasonably accurate. However, the model simulations were sensitive to subtleties in representation of the spring flows (e.g., elevation) to the south-west of the well field. Considerable refinement was necessary to obtain a reasonable calibration to water levels and flows in the springs. Only slight changes in model parameters and local conditions around the springs, caused a considerable change in the capture zone, with portions of it extending "up the valley" to the west of the wells. It is believed that the present capture zone is a reasonable representation of the true capture zone, as it follows the expected flow path based on the groundwater flow system. However, there has not been a long-term pumping test at the rate used in the capture zone simulations so there is still uncertainty.

In spite of the potential high uncertainty associated with the representation in the model, there is low uncertainty with respect to whether the vulnerability scoring accurately reflects the underlying hydrogeologic features. Since the entire area is highly vulnerable and the scoring represents the highest vulnerability possible for each WHPA zone, there is little uncertainty associated with the vulnerability.

D2.1.4 Region of Halton – Acton and Georgetown

WHPA A-D Delineation

The previous WHPA A-D delineations for the municipal wells of Acton and Georgetown were premised on technical work completed in 2009. The delineation has since been revised using the groundwater model developed for the Tier 3 water budget study for Acton and Georgetown.

The Tier 3 Water Budget study began in 2010, with an initial objective of addressing data gaps identified through previous studies. These gaps were reduced through an extensive field program which entailed borehole development and seismic surveying. This program yielded high quality data that allowed for a vastly improved understanding of the geology within the localized area, particularly with respect to the hydrogeological conditions influencing the municipal well fields. The availability of new datasets has prompted several key revisions to the conceptual and numerical groundwater models that form the basis for the methodology of WHPA delineations.

Capture Zone Delineation methodology

Groundwater flow models are used to simulate the velocity and trajectory of groundwater through overburden and bedrock and are developed to represent the "real world" groundwater flow system as well as possible. Results from these flow models can then be used to delineate capture zones by using particle tracking techniques that estimate the path and trajectory of hypothetical particles of water for defined time periods, and thus can be used to estimate the land areas within which groundwater may migrate towards a well.

The capture zone delineation methodology includes several components:

- Application of a calibrated groundwater flow model;
- Selection of appropriate municipal pumping rates;
- Selection of appropriate porosity values; and
- Numerical particle tracking techniques.

Groundwater Flow Model

The model was developed using the finite-element FEFLOW software code and was calibrated to steady-state groundwater levels and stream-flow observations. The simulated steady-state conditions represented average water levels and pumping rates in 2005 through 2009.

Groundwater recharge specified across the top surface of the groundwater flow model was estimated with a calibrated integrated groundwater-surface water model that was also developed in the Tier 3 assessment with the MIKESHE software program. Since the Tier 3 groundwater flow model represents the best available groundwater flow parameters for the Acton and Georgetown areas, it was chosen for the delineation of the capture zones and WHPAs for the Groundwater Vulnerability Assessment and Water Quality Threats Assessment.

The calibrated Tier 3 steady-state groundwater flow model was used for the particle tracking analysis, which was used initially to delineate base case time of travel (TOT) capture zones. The model extent is shown in **Figure D2-8**. Five plausible alternative model scenarios were then identified as part of a sensitivity analysis and then used to simulate the future pumping rates and delineate combined TOT capture zones and WHPAs. The steady-state flow solution was considered suitable for the delineation of capture zones and WHPAs as they are based on long term hydrogeologic conditions.

Municipal Pump Rates

WHPA delineations were completed under steady-state conditions to represent long term average conditions for the study area and are shown in **Table D2-22**. The rates used for the delineations are the same as those defined for the steady-state risk scenarios of the Tier 3 assessment.

The Tier 3 steady-state model calibration used the average pumping rates for the 2005 through 2009 pumping period for each Acton and Georgetown well. **Table D2-22** shows both the permitted water taking rates and the simulated rates. The permitted maximum annual average daily taking were used as they best represent long term average conditions and preliminary modelling indicated that these rates would not exceed available drawdown in all wells under steady-state conditions. The rates to be simulated are consistent with current Acton and Georgetown Permits to Take Water (PTTW).

The *Technical Rules* (MOE, 2009) specify that WHPA rates not exceed the approved treatment capacity under the region's Municipal Drinking Water License (MDWL). The MDWL limits capacity at the Georgetown Water Treatment Plant (WTP) to 12,960 m^3/day. The Prospect Park WTP has an authorized capacity of 2,270 m^3/day. The Georgetown WTP processes water takings from Cedarvale 1A, 3A, 4 and 4A only. The Prospect Park WTP processes water takings from Prospect Park Wells 1 and 2 only. Water takings from all other Acton and Georgetown supply wells are not processed through the WTPs but are treated/filtered/disinfected at the well's pumphouse before release to the distribution system. Thus, WHPA rates for the Cedarvale wellfield do not exceed the Georgetown WTP limit, and rates for Prospect Park do not exceed the Prospect Park WTP limit.

The maximum annual average daily taking at the Cedarvale wellfield is 5,790 m^3/day (the middle approved rate per Condition 3.3b of the Georgetown PTTW). This value is less than the authorized Cedarvale WTP capacity. The maximum annual average daily taking and the maximum daily taking at the Prospect Park well field are blended rates that account for the special condition of the Acton PTTW. The special condition limits takings at Prospect Park to 2,273 m^3/day from June 1 to September 30; and 1,137 m^3/day from October 1 to May 31 of each calendar year. The corresponding average annual daily taking rate is 1,517 m^3/day, which is 31% less than the Prospect Park WTP capacity.

Table D2-22: Summary of Municipal Pumping Rates for Capture Zone Delineation

Well	Permitted Rates § (m^3/day)			Municipal Drinking Water License WTP Capacity λ (m^3/day)	Sustainable Halton Average Demand Estimate (m^3/day)	Rate for WHPA-B/C/D Delineation (m^3/day)	Comments
	Maximum Daily Taking at Well	Maximum Annual Average Daily Taking	Maximum Daily Taking at Wellfield				
Fourth Line Well A	1,309	1,309	1,309	N/A	1,309	1,309	
Davidson Well 1	1,250	2,500	2,500	N/A	2,100	2,500	Two wells are represented by one boundary node in model. In Column 6, 2,500 m^3/day is pumped but 400 m^3/d is used to supplement local ponds.
Davidson Well 2	1,250			N/A			
Prospect Park Well 1	2,273	1,517*	1,517*	2,270	3,000	1,517	Two wells are represented by one boundary node in model.
Prospect Park Well 2	2,273						
Total Acton	***8,355***	***5,326***	***5,326***		***6,409***	**5,326**	
Lindsay Court Well 9	6,545	6,545	6,545	N/A	7,500	6,545	
Princess Anne Well 5	4,582	6,800	13,091	N/A	6,800	3,400	Maximum annual average daily taking divided equally among wells based on historical and planned extraction patterns.
Princess Anne Well 6	13,091			N/A		3,400	
Cedarvale Well 1A	2,618	5,790	14,404	12,960	5,790	1,447.5	Maximum annual average daily taking divided equally among wells based on historical and planned extraction patterns.
Cedarvale Well 3A	3,931					1,447.5	
Cedarvale Well 4	7,855					1,447.5	
Cedarvale Well 4A	5,891					1,447.5	
Total Georgetown	***44,513***	***19,135***	***34,040***		**20,090**	**19,135**	

§ - Values per PTTW 7801-825PBJ for the Georgetown Municipal Water Supply, and PTTW 6281-7WFQB3 for the Acton Municipal Water Supply

∗ - Blended rate given maximum daily taking of 2,273 m^3/d for June 1 to September 30; and 1,137 m^3/d for October 1 to May 30 of each calendar year

λ - Refers to capacity at: the Prospect Park Water Treatment Plant, which has a limiting effect on water takings at the Prospect Park well field; and the Georgetown Water Treatment Plant, which has a limiting effect on water takings at the Cedarvale wellfield, per MOE Technical Rules.

The Sustainable Halton Master Planning process ascribed demand to the existing wells based on a process that included using historical observations, tests, and operational insights as well as a previous version of the groundwater flow model.

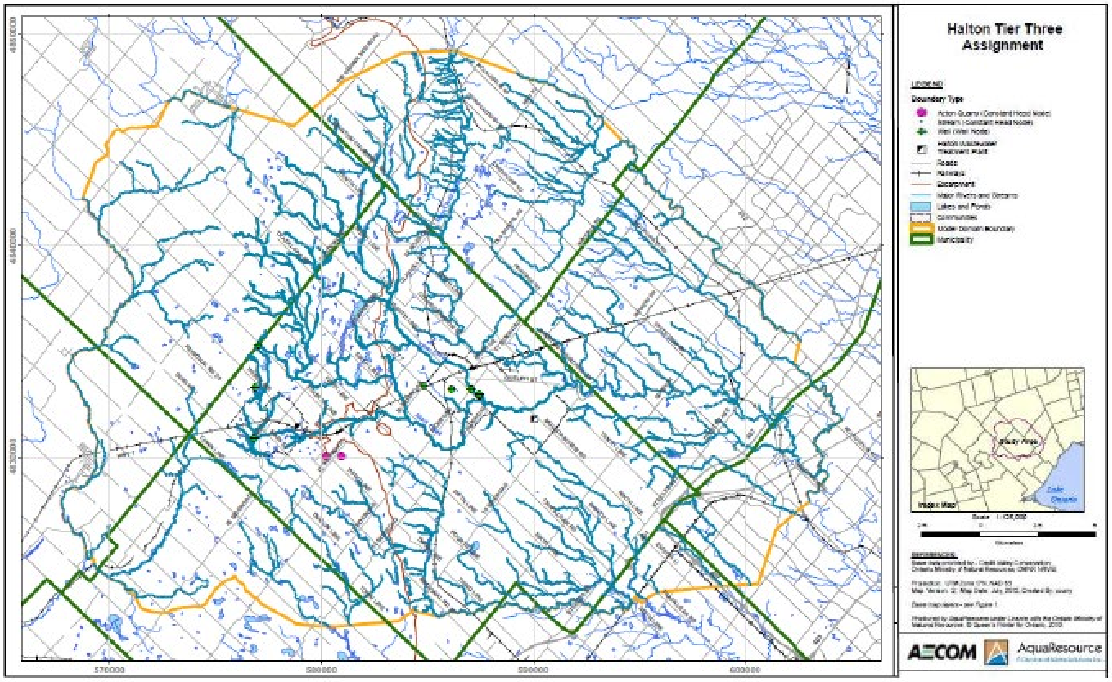

Figure D2-8: Halton Hills Model Extents and Conditions along Model Boundary

Particle Tracking

The Tier 3 groundwater flow model was used to estimate capture zones based on forward and reverse particle tracking within the FEFLOW model. Particle tracking is carried out by releasing hypothetical particles of water into the 3D and using an algorithm to compute the path that those particles would travel. For backward particle tracking, particles are released and tracked backwards in time through the saturated groundwater flow field to the water table, whereas for forward particle tracking particles are tracked forward in time to the location where groundwater discharges from the model (e.g., a pumping well).

Particle tracking uses an approximation of the 3D velocity field. It is possible for errors to be introduced into the solution in areas of coarse mesh discretization as well as in areas of high contrast in hydraulic conductivity. Several considerations were incorporated into the development of the FEFLOW model to minimize particle tracking errors where possible, including:

- The size of finite elements near and including pumping wells was reduced;
- The size of finite elements near rivers and streams was reduced; and
- The overburden aquitards were subdivided into three layers to minimize numerical smoothing of groundwater velocities within the aquitard due to the large velocity contrasts expected between it and the adjacent units and allowing for the predominantly vertical flow through the aquitard to be reflected in computed pathlines.

Capture zones were delineated using a combination of backward and forward particle tracking. For backward particle tracking, particles were released at multiple levels within all screened layers along the well, and also in the layers above and below the screen. At each level, approximately 100 particles were released in three circles around each well at distances from the well determined by the size of the surrounding finite elements. The distances ranged from 15 to 270 m with the average being 90 m around the municipal wells. Particle tracks were calculated to steady-state with time markers at 2-year, 5-year, 10-year and 25-year periods.

Forward particles were released at the water table on a 100 m grid spacing across the model area and tracked forward in time until the particles reached a municipal well or a groundwater discharge location. Forward particle traces that stopped within a 25 m radius of a municipal well were considered to be captured by the well, and the TOT for the particle trace was recorded.

TOT capture zones were delineated to encompass the areas that surround all backward particle tracking pathlines and forward particle tracking points that arrive at a well during a specific period of time based on all scenarios. For example, the 2-year TOT capture zone was delineated for each municipal well by drawing a polygon around the 2-year particle pathlines (from backward tracking), and the start locations for the particles that reached the well in 2-years or less (from forward tracking). The 5-year and 25-year capture zones were delineated in the same manner. Where capture zones were in proximity to each other and the capture zones intersected, the resultant time of travel capture zones were merged into one polygon.

Porosity

Groundwater flow models provide estimates of the Darcy flux (flow rate of groundwater per unit cross-sectional area) through the porous medium. To estimate the linear groundwater velocity, this flux is divided by the “effective” porosity of the porous medium. Effective porosity differs from the total porosity and is typically smaller than the total porosity. While a porous medium may have a high proportion of pore space, many of those pores may not be connected, particularly in the case of fractured bedrock aquifers, and as a result, those unconnected pores do not act as pathways for groundwater to travel. The effective porosity represents the fraction of pore space that is connected and thereby provides a path for groundwater to travel from one point to another.

Porosity is difficult to measure over a large scale and standard observations (water levels) provide little or no insight to quantify or constrain its value. Further, the porosity value applied for capture zone delineation is intended to represent an “effective” porosity that would represent what a “typical” contaminant would experience. While the effective porosity for overburden geologic units can be confidently estimated within a factor of 2, the same cannot be said for a bedrock unit. The “effective” porosity specified for bedrock units is an aggregate value that represents both primary (matrix ~10%) and secondary (fracture ~0.001%) porosity, and fracture connectivity. As a result, there is considerable uncertainty in the appropriate porosity value for bedrock aquifers. This uncertainty has a significant impact on the TOT capture zones delineated for bedrock aquifers because the calculated velocity is inversely proportional to the specified “effective” porosity value. Consequently, it is typical to use a lower estimate of effective porosity when delineating capture zones for WHPAs to ensure that the areas are conservatively large enough to account for uncertainty in the parameter estimates.

Table D2-23 provides a summary of the effective porosity values used in the 2010 delineation study (EarthFx, 2010), values used in neighbouring Tier 3 studies currently in progress, and the values used for Halton Tier 3 study model calibration. In each study, the porosity values have been estimated from literature values. For the overburden, the range in the effective porosity is likely to be relatively small, from 0.10 to 0.30. For bedrock the range is likely to be larger.

Table D2-23: Modelled Porosity

Unit	Halton	Guelph	Orangeville	Halton	Halton
	Vulnerability Study (EarthFx, 2010)	Vulnerability Study (AquaResource, 2010)	Tier Three Study (AquaResource, 2011c)	Draft Calibrated Transient Porosity Tier Three Study (AECOM and AquaResource, 2011b)	Base Case Vulnerability Update
Bedrock Aquifer	0.1	0.01	0.01	0.01	0.01
Bedrock Aquitard	0.1	0.01	0.07	0.01	0.01
Contact Zone (fractured bedrock)	0.1	0.03	0.05	0.05	0.05
Overburden	0.25	0.20	0.25	0.20	0.20

The bedrock porosity used in the Guelph and Orangeville Tier 3 projects is based on a tracer study completed in Cambridge in dolostone of the Guelph Formation (AquaResource, 2011). Information in the Region of Waterloo estimates the range of effective porosity based on tracer studies to range over four orders of magnitude.

As there are little data to constrain the bedrock values, the base case porosity values were reduced in the sensitivity scenarios to a point where the 2-year TOT capture zone is equal to the steady-state capture zone for the majority of particles originating from streams nearest the wells. This was used as a guide to the upper limit of the capture zone area.

Sensitivity Analysis and Uncertainty for Capture Zones

There is a degree of uncertainty with all groundwater flow models, and as such when making predictions with groundwater models, the uncertainty associated with the model input parameters and conceptualization needs to be examined. One method for exploring uncertainty is to complete a sensitivity analysis.

The primary objective of the sensitivity analysis is to evaluate scenarios using plausible alternative representations of the groundwater flow system. These alternative representations are plausible if they use parameter sets that are consistent with the conceptual model and provide a similar representation (calibration) of the available monitoring data as the base case calibrated model. The scenarios can then be used to identify the maximum areal extent of capture zones given the uncertainty in the model and build this understanding in the WHPA delineations.

A sensitivity analysis was completed to quantify how uncertainty associated with various model input parameters (e.g., effective porosity, hydraulic conductivity, etc.) influences the TOT capture zones and WHPA delineations. Five scenarios were conducted to examine the impact of uncertainty in hydraulic conductivity, porosity, and alternative conceptual models within the area.

Table D2-24 summarizes the sensitivity scenarios and the rationale for scenario selection. The overall rationale is to simulate larger capture zones than presented in the base case by modifying parameters in a direction that will increase capture zone size. A secondary objective is to complete scenarios to understand the range of capture zone sizes smaller than the base case. **Table D2-24** also presents the initial change in parameters that was tested for each scenario.

However, based on the initial sensitivity runs, larger or smaller changes in the parameters were made within the parameter range based on the conceptual model (AECOM and AquaResource, 2011b) to evaluate the range of parameters that would maintain model calibration.

Table D2-25 summarizes the results of the sensitivity analysis including the range of parameters tested, final parameters used for the scenario, and head calibration comparison to the base case. Head residuals for all high-quality wells and the simulated change in drawdown at each well are shown in the table.

The sensitivity analysis model simulations used the same calibration observations and pumping rates as were used to calibrate the base case model (AECOM and AquaResource, 2011c). However, only change in residuals at the high-quality wells are presented for comparison as most of these wells are located in the vicinity of the wellfields, the focus area of the study.

In Scenario 5, the continuity of the buried valley through Limehouse was tested by increasing hydraulic conductivity in the overburden and contact zone. Depth to bedrock has good control at this location based on AECOM drilling (AECOM, 2011). The increased conductivity simulations did not result in flow paths from the west side of Limehouse from either pit or quarry area to the north or south (Acton Quarry) of Black Creek to any of the municipal wells. In previous capture zone and WHPA analysis (EarthFx, 2010) this bedrock control data was not available and the previous conceptualization showed these areas west of Limehouse and north and south of Black Creek as being in the Georgetown well capture zones. The current conceptualization and model scenarios suggest that these areas are not sources of water for the Georgetown wells. Therefore, Scenario 5 focused on parameters with the potential to influence capture zones.

Table D2-24: Sensitivity Scenarios for Capture Zone and WHPA delineations

Scenario	Base Parameter Value	Initial Value to Tested	Comments/Rationale
Increase production aquifer K value and adjust recharge values	Calibrated value	One order of magnitude higher K, recharge +/-10% or more	Maximum change will be made considering calibration/other parameters may be adjusted to compensate. The order of magnitude change is based on the range of available pump tests results. However, this is a starting point for parameter adjustments. We will attempt larger changes to conductivity zones to better demonstrate the plausible range in size of capture zones warranted by the calibration.
Decrease production aquifer K value and adjust recharge values	Calibrated value	One order of magnitude smaller K, recharge +/- 10% or more	Maximum change will be made considering calibration/other parameters may be adjusted to compensate. The order of magnitude change is based on the range of available pump tests results. However, this is a starting point for parameter adjustments. We will attempt larger changes to conductivity zones to better demonstrate the plausible range in size of capture zones warranted by the calibration.
Decrease overburden and bedrock porosity	Existing value (Table 3)	Test range: Overburden 0.1 to 0.3. Bedrock and Contact Zone 0.01 to 1e-10	Expect larger capture zones areas with lower effective porosity. Range of porosity used to understand the range.
Decreased leakage from Beeney Creek	Calibrated value	Decrease by 10%+	Maximum change will be made considering calibration/other parameters may be adjusted to compensate. This rate is based on the assumption that model calibration will degrade significantly with a larger reduction. Larger reductions will be attempted if warranted by calibration data. Seasonal variation from MIKE SHE simulations shows that monthly leakage could be as low as 50%, or as high as 200% of the average annual volume of simulated leakage (AECOM and AquaResource 2011b; Figure 3-29). Where supported by calibration data, leakage rates can be varied within this range.
Acton-Georgetown Buried Valley Continuity	Calibrated value	Make aquifer units more continuous	Changes will be made within constraint of maintaining calibration. Expect observation data limits plausible changes in Limehouse area.

Notes: K - Hydraulic Conductivity

Table D2-25: Sensitivity Scenario Results

Scenario	Parameter	Minimum Factor (Change) Tested Compared to Base Case	Maximum Factor (Change) Tested Compared to Base Case	Final Scenario Factor (Change) Parameters for Capture Zone Delineation	Final Change in Head Residuals Compared to Base Case (m)*	Observations
Scenario 1- Production Aquifer and Recharge	Hydraulic Conductivity at Municipal Well	$10^{0.5}$	$10^{1.0}$		N/A	Increase one order of magnitude in K for all well production aquifers leads to large pumping well head residuals, which cannot be compensated by a decreased 20% recharge. Increase half order of magnitude in K for all well production aquifers leads to large pumping well head residuals, which cannot be compensated by a decreased 20% recharge. Large decreased recharge (> 4%) causes negative flow at gauges located along Beeney Creek. Increase half order of magnitude in K for seven wells and keep rest of them unchanged with a decreased 4% recharge works.
	Global Recharge	0.8	1.2	0.96		
	Fourth Line			1	-0.1	
	Davidson			$10^{0.5}$	-0.2	
	Prospect Park			$10^{0.5}$	0	
	Lindsay Court			1	-0.5	
	Princess Anne 5			1	+1.1	
	Princess Anne 6			$10^{0.5}$	+1.1	
	Cedarvale			$10^{0.5}$	0 to +0.2	
Scenario 2- Production Aquifer and Recharge	Hydraulic Conductivity at Municipal Well	$10^{-1.0}$	$10^{-0.5}$		N/A	Decrease one order of magnitude in K for all wells leads to large pumping well head residuals, which cannot be compensated by an increased 20% recharge. Decrease half order of magnitude in K for all wells leads to large pumping well head residuals, which cannot be compensated by an increased 20% recharge. Large increased recharge (> 4%) causes a large head residual at Fourth Line well. Decrease half order of magnitude in K for seven wells and keep rest of them unchanged with an increased 4% recharge works.
	Global Recharge	0.8	1.2	1.04		
	Fourth Line			1	+0.1	
	Davidson			$10^{-0.5}$	+0.1	
	Prospect Park			$10^{-0.5}$	0	
	Lindsay Court			1	-0.3	
	Princess Anne 5			1	+1.4	
	Princess Anne 6			$10^{-0.5}$	+ 1.4	
	Cedarvale			$10^{-0.5}$	+0.2 to +0.4	

Scenario 3- Overburden and Bedrock Porosity	Overburden Porosity			0.1	0	Change in porosity does not influence steady-state calibration heads or stream flows only groundwater flow velocity for which there are no observations.
	Bedrock/Contact Zone Porosity			1.0E-10		
Scenario 4- Beeney Creek Leakage	Stream Bed Hydraulic Conductivity at Beeney Creek	$10^{-1.0}$	$10^{-0.5}$	$10^{-1.0}$	N/A	Decreased leakage was completed by decreasing the stream bottom conductivity (one order of magnitude lower, kZone 1 and kZone 6 at the Beeney Creek were renamed as kZone 1001 and dkZone 6001), as shown on Figure 2. Decrease one order of magnitude in K along Beeney Creek results in a decreased leakage of 23.33% from Beeney Creek (Figure 2).
	Lindsay Court				-1.8	
	Princess Anne				-1.3 to -1.4	
	Cedarvale				-0.2	
Scenario 5- Buried Valley Continuity between Lindsay Court and Georgetown	Hydraulic Conductivity Between Lindsay Court and Princess Anne Wellfields	$10^{-1.0}$	$10^{-2.0}$	$10^{-2.0}$	N/A	Change both kZones 2522 and 2559 results in large residuals at the Cedarvale wells (three of them are close to 4 m). Change kZone 2559 hydraulic conductivity value to keep the valley continuity (Figure 3).
	Lindsay Court				-0.4	
	Princess Anne				+1.2	
	Cedarvale				+0.1 to +0.3	

Updated Capture Zones & Wellhead Protection Areas

Base case and combined TOT capture zones were delineated using the methods described above. The particle tracking results from all scenarios provide the plausible range of flow paths and TOT capture zones sizes that are used to delineate the WHPAs.

WHPAs were delineated based on a range of the largest and smallest capture zones from the suite of particle tracks from all scenarios described above. Professional judgment was used to extend the width or length of some WHPAs to account for geologic or conceptual uncertainty. The capture zones show the forward and backward particle tracking results of the calibrated base case model and the five scenarios used to delineate the composite capture zones and WHPAs. The composite TOT capture zones polygons are overlain on the particles in each scenario and were used to delineate the WHPAs.

By using multiple scenarios, the forward and backward particle tracking results reflect the key uncertainties in the capture zones, results will be more meaningful than a single run, and provide results that are consistent with the level of conceptual understanding afforded by the available field data.

Vulnerability Assessment – SWAT Methodology

Surface to Well Advective Travel Times (SWAT) consists of two components, the vertical travel time through the unsaturated zone above the water table (Unsaturated Zone Advective Time - UZAT) and the travel time from the water table to the well through the saturated zone (Water table to Well Advective Time - WWAT).

The classification is based on actual travel times from the surface to the well as follows:

a) Areas of high vulnerability are those areas with travel times less than 5 years;

b) Areas of medium vulnerability are those areas with travel times greater than or equal to 5 years but less than or equal to 25 years; and

c) Areas of low vulnerability are those areas with travel times greater than 25 years.

Determining vertical time of travel through the unsaturated zone is highly complex and depends on the unsaturated hydraulic conductivity of the soil, soil moisture, and tensions (i.e., negative pressure-heads) in the unsaturated zone. Unsaturated hydraulic conductivity and pressure-head can be related to moisture content through characteristic curves developed for each soil type. Unfortunately, the data on unsaturated soil properties is very limited and calculation of unsaturated travel times would be highly uncertain.

UZAT Analysis

As an alternative to complex unsaturated flow calculations, Guidance Module 3 (MOE, 2006) suggests a simplified method wherein the annual rate of groundwater recharge is assumed to be an approximation for the average rate of moisture movement through the unsaturated zone. Accordingly, UZAT values can be estimated as:

$$UZAT = \frac{d_{wt} \cdot \theta_m}{q_z} \quad \text{(Eq. 1)}$$

where: UZAT = advective time of travel through the unsaturated zone

d_{wt} = depth to the water table

θ_m = mobile moisture content

q_z = infiltration rate

Infiltration rates were obtained from the groundwater recharge values computed by the PRMS model. Depth to water table was estimated by subtracting the interpolated water-table surface from land surface elevation. Guidance Module 3 (MOE, 2006) suggests values for mobile moisture content based on soil type. As an example, assuming an infiltration rate of 320 millimetres per year for a sand with a θ m of 0.10 and a depth to water table of 10 m, the UZAT would equal 3.2 years. A loam soil with a recharge rate of 160 mm/year would have a UZAT of 20.8 years, and a clay soil with a recharge rate of 10 mm/year would have a UZAT of 40 years.

Based on the computations, estimated UZAT times are very low within the stream valleys and in the immediate vicinity of the wellfields (expect for the Lindsay Court well) but there are large areas with UZAT times over 25-years west of the Acton Wells and surrounding the Princess Anne and Cedarvale wells.

It should be noted that the estimation method for UZAT values is reasonable when considering a contaminant that is leached by precipitation, such as road salt or agricultural pesticides or fertilizers. Surface releases of contaminated fluids (e.g., a spill from a wastewater lagoon or a leaky storage tank), however, can locally saturate the soil and move downward through a sandy or sandy-silt soil in orders of magnitude less time (i.e., hours or days rather than years).

Therefore, it is thought that if the contaminants of concern in a particular area are likely to be released by spills and leaks rather than leaching, it is a reasonable assumption to omit UZAT times from the SWAT analysis. Accordingly, the SWAT times calculated for the study area were based on the WWAT values only.

WWAT Analysis

WWAT values were determined by releasing virtual particles from cells in the uppermost active groundwater model layer (i.e., the layer containing the water table) within a buffer around the 25-year time of travel zone. The particles were forward-tracked from the water table to their point of discharge, either a stream, lake/wetland, or well. The times-of-travel for particles ending up in the municipal wells are assigned back to the originating cell.

WHPA-E Delineation

All of Acton's wells, and the Cedarvale wells in Georgetown, are GUDI (per subsection 2 (2) of O. Reg. 170/03) and require the delineation of the WHPA-E. Details on GUDI status of the Acton and Georgetown wells are presented in **Table D2-26**.

Table D2-26: GUDI Status – Acton and Georgetown

Well Fields	Well	Status
Acton	All Wells	GUDI
Georgetown	Cedarvale 1A, 3A, 4A	GUDI
	Princess Anne 5 & 6	Groundwater
	Lindsay Court 9	Groundwater

The WHPA-E was delineated with a setback was drawn to either side of the stream and around the perimeter of the nearby wetland which included the maximum of either the Regulation Limit or the 120 m buffer from the high water mark of the surface water body. The sewersheds for storm sewers in Georgetown were outlined based on aerial photographs and the digital elevation model and included in the WHPA-E.

The key task in delineating the WHPA-Fs was to extend the area of concern to the ends of all tributary streams to Silver Creek setbacks, based on the 120 m limit or Regulation Limit were drawn. The WHPA-Fs were outside of the urban area and stormwater sewersheds were not found. Mapping of setbacks from the high water mark of the surface water bodies were determined using mapping tools in the Manifold GIS software using digital mapping data supplied by MNRF, CVC, and the Region of Halton.

Data Sources

The stream network and lake and wetland outlines used in delineating the WHPA-Es were determined based on digital mapping by the MNRF included in the Water Virtual Flow – Seamless Provincial Data Set and the Water Poly Segment data layers housed in the Ontario Land Information Warehouse. Setbacks from the high water mark of the surface water bodies were determined using mapping tools in the Manifold GIS software.

Digital mapping of Regulation Limits, defined as the "area delineated on a map or series of maps filed at the head office of a conservation authority in accordance with a regulation made under subclause 28(1)(c) of the *Conservation Authorities Act* and subsection 4(4) of O. Reg. 97/04 (Content of Conservation Authority Regulations under Subsection 28(1) of the *Act*: Development, Interference with Wetlands and Alterations to Shorelines and Watercourses) made under that *Act*" were obtained from CVC.

Digital mapping of storm sewersheds for Acton were provided by the Region of Halton. Similar maps were not available for the Georgetown area, but approximate areas were estimated.

Acton and Georgetown (Cedarvale) Two-hour time of travel derivations

To derive the two-hour time of travel upstream of the intersection point, upstream flow velocities were estimated using a comparative technique developed by Annable (1996) and applying to all gauges in the study area (**Table D2-27**).

Annable (1996) computed a discharge-velocity relationship for the Black Creek at Acton given by:

$$v = 0.9107\ Q^{0.4524}$$

The same relation was used to estimate bank full flow velocity in the stream segments upstream of the Davidson wells (see Leopold and Maddock, 1955).

Table D2-27: Acton and Georgetown (Cedarvale) Two-hour Time of Travel

Tributary	Contributing Area (km^2)	Proportional Contribution	Estimated Bank Full Discharge (m^3/s)	Estimated Bank Full Velocity (m/s)	2-Hour Travel Distance (m)
Acton Tributary					
02HB024 (downstream gauge)	18.9	1.000	2.230	1.413	
Upstream of Davidson Well	2.18	0.115	0.257	0.493	3548
Upstream of 4th Line Well	2.00	0.106	0.236	0.474	3412
Fairy Lake - North Tributary	9.90	0.524	1.168	0.977	7035
Fairy Lake - Northwest Tributary	1.20	0.063	0.142	0.376	2708
Fairy Lake - West-Northwest Tributary	0.66	0.035	0.078	0.287	2066
Fairy Lake - West Tributary	3.10	0.164	0.366	0.578	4160
Fairy Lake - East Tributary	3.90	0.206	0.460	0.641	4615
Cedarvale Tributary					
02HB008 (downstream gauge)	127	1.000	12.71	1.627	
Upstream of Cedarvale Wells	37	0.29	3.70	0.81	5850

Vulnerability Scoring

Area vulnerability and source vulnerability were developed using the following methodology:

- Area vulnerability - calculated based on surficial geology, slope and land use within the delineated WHPA-E; and
- Source vulnerability - calculated based on the depth of the well and the dimensions of the associated water body and the inferred potential for dilution of contaminants within that body.

The area vulnerability factor considers:

- Percentage of the area of the IPZ-2 or IPZ-3 that is composed of land;
- Land cover, soil type, permeability of the land and the slope of any setbacks; and
- Hydrological and hydrogeological conditions in the area that contributes water to the area through transport pathways.

Base scores of 8 were assigned to each WHPA-E. These scores were modified upward or downward by one point depending on the ability of the area to generate runoff that could transport contaminants to the nearby stream where it could then infiltrate and adversely affect the well and the presence of other contaminant pathways.

Source vulnerability factors varied from 0.9 to 1 for a Type C intake and from 0.8 to 1.0 for Type D intakes. Assigning values took into account:

- Depth of the well below land surface, of the surface water body from the well; and
- The number of recorded drinking water issues related to the well that source. Final values were assigned based on professional judgment.

It should be noted that there is an error in the report *Vulnerability Analysis for the Georgetown and Acton Well fields, Final Report* (EarthFx Inc., February 2010), with respect the assignment of vulnerability score in the transport pathway analysis. The correct vulnerability assessment has been used in this Assessment Report.

Uncertainty

The vulnerability assessment is a combination of several components, each with their own uncertainty associated to them. These are discussed below.

- The distribution, variability, quality and relevance of data used;
- Interpretations related to aquifer confinement;
- The extent and level of calibration achieved for model used;
- Time of travel delineation; and
- Vulnerability mapping.

Data Distribution

The degree of confidence related to the TOT and vulnerability scoring analyses depends on data density. From a regional perspective, there is good coverage of MOECC WWIS data to the west of the Niagara Escarpment but poorer coverage to the east. This is fortunate because the TOT zones extend to the west at Georgetown and to the northwest at Acton. The higher quality data is focussed close into the wellfields which coincide with the areas of highest vulnerability.

The intrinsic biases in the MOECC WWIS well log data is another source of uncertainty. In general, well owners only drill as deep as necessary, often completing the borehole in the top of the first aquifer encountered. This has resulted in a general tendency to accurately record the extent of low permeability materials overlying the aquifers, but the wells provide limited information on the total thickness of the aquifer or on the properties of deeper aquifers and aquitards. Other biases, such as the lack of geologic training for drillers and the poor sampling techniques associated with water well drilling methods, also add to the level of uncertainty.

Uncertainty Related to Aquifer Confinement

Uncertainty in the TOT and WWAT results for the municipal wells in the deep overburden and shallow bedrock might be considered high, because of a lack of sufficient well data to accurately map the discontinuous till units. Gaps in the confinement provided by the tills would allow more rapid travel of contaminants to the deeper wells than the model may have predicted. Additional seismic and borehole drilling was conducted as part of the Tier 3 water budget study. A better representation of the geology along with a reduction in uncertainty will be forthcoming as these new data are interpreted.

Groundwater Model Calibration and TOT Uncertainty

There are inherent limits in the level of confidence associated with all numerical modelling due to the quality of the input data as well as the simplifying assumptions made during model development. While the numerical model produced good matches to the observed water levels and baseflows, the ability of the flow model to exactly reproduce local flow patterns is not as certain. Intrinsic errors in the WWIS data used to map the water table and potentiometric surfaces imply that we can never know the true water levels and flow patterns to a high level of certainty. Subtle variations in the flow directions near the wells, caused by local variation in aquitard or aquifer thickness, aquifer, and aquitard hydraulic conductivity values, and/or recharge rates can lead to significant changes in the flow paths of the particles. Unfortunately, available geologic data are limited and, therefore, the level of uncertainty in defining the three-dimensional flow patterns and determining TOT zones to a high level of precision is impossible. As Halton Region continues to expand their monitoring network and obtain additional high-quality data within the TOT zones, the level of certainty associated with the TOT delineation will increase.

There are additional factors that increase the uncertainty in calculating travel times. For example, the times of travel scale linearly with the porosity of the formations and are highly sensitive to the values assumed. Porosity values are not used in the flow model and are, therefore, not part of the normal model calibration process. No specific measurements of porosity were available for this study, so values for the various formations were estimated based on published values (e.g., Freeze and Cherry, 1979). To be conservative, we used values that were lower for the till aquitard layers (assuming that the tills behave as fractured media), thus resulting in greater velocities and therefore shorter travel times.

Vulnerability Mapping Uncertainty

The WWAT component of the SWAT method is based on assessing true travel times using locally determined hydraulic properties that have been adjusted and refined through model calibration. The model that the WWAT analyses was based on was developed using recognized hydrogeologic and hydraulic principles and have been calibrated to match the observed heads and, more importantly, the model was calibrated to best match the observed directions of flow by carefully representing factors that influence flow patterns such as local variations in aquifer properties, recharge rates, aquifer and aquitard thickness and continuity as well as the effects of pumping from nearby wells and the influence of streams. However, as indicated by the discussions above, it is difficult to quantitatively assess the certainty of the TOT zones in an unbiased way and it is even more difficult to assess uncertainty in the WWAT values within the TOT zones.

Data from other sources, such as isotope data (for age-dating the water), geochemical data, and water quality indicators can provide some corroboration of the calculated travel times. As an example, high chloride and nitrate levels, where present, often indicate contamination from surface sources such as road salt, agriculture, and un-serviced residential development and therefore, are indicative of relatively short travel times. The presence of tritium in the water can also indicate short travel times. The absence of these indicators, however, only confirms that the travel times are greater than the period of time in which pumping at the well has induced flow towards the wells.

Uncertainty – WHPA E

As the delineation of the WHPA-Es is primarily a mapping exercise the degree of uncertainty is relatively low. The only factor contributing to uncertainty is the calculation of velocities. Flow volumes were inferred from catchment area/bank full flow volume relationships by Annable extrapolated from downstream gauge measurements. Velocity was inferred using velocity-discharge relations for the gauge.

Although there may be uncertainty associated with the method, in most cases, the WHPA-Es delineated extended to the end of the streams and most likely took in most potential contaminant source areas.

With respect to the vulnerability factors and source vulnerability factors, the uncertainty arises, in part, due to the lack of specific methodology regarding:

- Factors to be considered;
- Scoring of individual factors; and
- Assignment of relative weights to the composite scores.

Uncertainty in the scoring for the deeper municipal wells with apparent confinement also results from lack of sufficient well data to accurately map the discontinuous till units. Gaps in the confinement, particularly in stream reaches where the shallow tills may have been have eroded away, could allow rapid travel of contaminants to the deeper wells.

D2.1.5 Region of Peel – Town of Caledon

Geological Setting

Table D2-28: Region of Peel Municipal Wells – Depths, Aquifer Setting

Well Field	Well ID	Depth (m)	Screen Interval (m below ground)	Formation Screened
Cheltenham	CHEL1	51.6	44.8 – 51.0	sand, gravel (confined)
	CHEL2	51.8	45.0 – 51.3	sand, gravel (confined)
Inglewood	ING2	9.4	6.0 – 7.9	sand (confined)
	ING3	54.7	48.9 – 54.7	sand, gravel (confined)
	ING4	60.0	53.5 – 58.5	sand, gravel (confined)
Caledon Village	CV3	36.1	29.0 – 35.1	sand, gravel (confined)
	CV4	75.9	61.3 – 75.9	sand (confined)
	AL3	22.2	15.3 – 20.8	sand, gravel (unconfined)
	AL4A	17.6	12.7-14.7	Sand, gravel (unconfined)

Model Development - YPDT Groundwater Management Study

The conceptual model and numerical model were first compared with the regional groundwater flow model developed as part of the YPDT Groundwater Management Study. The comparison entailed review of cross-section interpretations, model input and results files. Specifically, comparisons were made at the boundaries between the models to ensure consistency in the science utilized:

1. Geologic and hydrogeologic boundaries such as water levels;
2. Bedrock topography;
3. Interpretations of Lower Sediments;
4. Evaluation of geometry and fluxes;
5. Refinement of stream networks; and
6. Groundwater recharge.

The regional conceptual models were generally consistent with minor modifications being completed. The YPDT study bedrock topography and Lower Sediment subdivisions were used as the base case for evaluating the change in capture zones with an alternative regional conceptualization of the depth and infill of buried bedrock valleys. Perennial stream networks were found to be consistent within the two models.

Local Area Refinements

1. Cross Sections - In the Alton area, seven cross-sections were generated. An additional five cross-sections were drawn in Caledon Village, five in Cheltenham, and eight in Inglewood. The cross-section lines were drawn to include as many water wells as possible within the previously delineated wellhead protection areas, and attention was paid to intersect high quality boreholes and former test wells on the section.

Once the cross-section lines were drawn, overburden geologic/ hydrostratigraphic interpretations were made in AquaMapper, a GIS-based software extension that is used for generating and interpreting cross-sections. The AquaMapper tool was linked to the YPDT database, which houses water well records from the MOECC, as well as the Region of Peel's observation well information. Using this database, cross-section profiles were drawn illustrating borehole details, including lithology (GSC codes, or Material 1, 2, and 3 descriptors), water level elevations, and screen locations. Using these profiles, the overburden geologic/ hydrostratigraphic interconnections were interpreted and the elevations at interpreted boreholes were populated to an interpretation table in the database.

Once the cross-sections were interpreted, the overburden model surfaces were interpolated using the local level stratigraphic picks stored in the database, as well as the cross-section picks from the regional CVC Water Budget model. The bedrock surface defined by the YPDT study model was considered suitable for use in this study. An additional top of bedrock surface interpretation was created using bedrock wells and deep overburden wells (without other valley control points) as part of the CVC Water Budget initiatives. These two alternate bedrock surfaces were used to simulate the sensitivity of simulations to a change in the interpreted bedrock valley configuration.

2. Model Boundary Conditions - Boundary conditions are assigned to represent the model's interaction with the area outside the model domain. Boundary conditions specify locations where groundwater flows into or out of the model domain, by specifying a head or flux. Therefore, selecting appropriate boundary conditions for a model is critical to ensuring the groundwater flow model is defensible and properly simulates the physical system conditions with minimum bias in the areas of interest.

Model Perimeter

Type I (constant head) boundaries were applied in some areas along the perimeter of the model where groundwater is entering or leaving the model domain. The specified head applied was based on observed water levels in the area and adjusted through calibration of the regional model (AquaResource, 2006).

The specified head boundaries in the CVC model were reviewed for consistency with the model predicted heads in the YPDT study model. Examination of the YPDT study model predicted heads and heads prescribed in the CVC model along the Subwatershed 13 model boundary near Caledon East showed consistency in most units. At few locations, the specified heads were either higher or lower than predicted in the YPDT, but at the overwhelming majority of locations the difference was considered acceptable given the variation in topography and the match to calibration data in the CVC's regional watershed-scale model.

Model Calibration Targets

Field observations available to support calibration of the groundwater model include Peel groundwater level monitoring data and static water levels as reported in MOECC Water Well Records, and baseflow values reported by the Water Survey of Canada (WSC) or the CVC.

Water levels associated with water wells stored within the MOECC database were a secondary source of calibration targets having less reliable water level measurements and less detailed geologic descriptions. But they do provide better spatial coverage for estimating water levels throughout the study area. All of the wells in the June 2006 YPDT database update were used as regional calibration points, but a buffer area around each wellhead was used to select wells that were close to the wellhead. This included wells of location quality 1 through 9 with all wells having equal weight in the calibration statistics.

The third calibration data set used was continuous streamflow values recorded at WSC gauges. Baseflow estimates were assumed to be representative of groundwater discharge contributions. An estimated baseflow range was calculated at each WSC gauge using a baseflow separation technique.

Peel Water Resources Management Model (PWRMM19)

In 2019, The Regional Municipality of Peel (Peel Region), in collaboration with the Oak Ridges Moraine Groundwater Program (ORMGP) and Credit Valley Conservation (CVC) initiated the development of a regional-scale numerical model of the groundwater and surface water flow systems in Peel Region. Phase 1 of this Project includes the development of a steady-state groundwater flow model for Peel Region and vicinity. The first application of the model is to delineate wellhead protection areas (WHPA) for the Alton Wellfield. The following text is taken from EarthFx and Geocamp (2019). The reader is referred to this report for context and additional detail.

For Phase 1, steady-state conditions were assumed in order to approximate long-term average conditions in the groundwater flow system. The groundwater flow model used in this study was built using the USGS MODFLOW-NWT v1.0.7 computer code (Niswonger et al., 2011).

- **Model Extent:** The southern boundary was taken along the shoreline of Lake Ontario. The eastern and western boundaries were mainly set along the centrelines of the Humber River and Sixteen-Mile Creek (Oakville Creek); respectively. The northern boundary followed major watershed topographic divides and was extended northward to account for groundwater discharge to the Hockley Valley area. The model boundary encompasses approximately 2700 square kilometres (km2).
- **Model Discretization**: The PWRMM19 uses square cells 90 m across the study area. Numerical model layers were used to represent the integrated hydrostratigraphic layers.
- **Model Boundary Conditions**: Boundary conditions were specified for cells along lines corresponding to the physical boundaries of the groundwater flow system. Three general types of boundary conditions were used in the groundwater flow model: constant head, no-flow, and head-dependent discharge boundaries.
- **Groundwater Recharge Estimation**: The U.S. Geological Survey (USGS) Precipitation-Runoff Modelling System (PRMS) was selected to represent the hydrologic processes in

the study area. The PRMS submodel was run on a daily basis for a 10-year period to calculate the average daily amount of recharge supplied to the groundwater system.

- **Simulated Groundwater Takings**: Groundwater pumping was estimated based on reported takings associated with the Permit to Take Water (PTTW). Groundwater takings were represented in the MODFLOW model using the WEL7 module in MODFLOW-NWT. Wells were assigned to the proper hydrostratigraphic unit based on the well depth and well screen setting, where available.
- **Groundwater Parameter Distribution**: Initial estimates for hydraulic conductivity were made based on previous hydrogeologic investigations and modelling studies. Layer 1 hydraulic conductivities were assigned based on the surficial geology. Uniform hydraulic properties were initially assigned to each of the hydrostratigraphic units.
- **Groundwater Head Calibration**: Calibration of the steady-state groundwater submodel was conducted by adjusting the hydraulic properties assigned to the aquifers and aquitards until a good match was achieved between the simulated and observed water levels. Static water levels from the MECP Water Well Information System served as a primary target for the regional-scale calibration and had good regional coverage. Targets for the local calibration in the Alton area included a combination of high-quality Peel Region monitoring well data, MECP Provincial Groundwater Monitoring Network (PGMN) data, MECP static water levels, and data from other wells with continuous or longer-term measurements.
- **Baseflow/Discharge Calibration**: Simulated groundwater discharge to streams and groundwater discharge to land surface in the riparian areas are routed downstream using the SFR2 model. Simulated values were compared against the average of estimated baseflow at the Environment Canada (EC) Water Survey of Canada stream gauges. Baseflow separation was conducted using the modified UKIH method, devised by National Water Research Institute and Meteorological Service of Canada (Piggott et al., 2005). Baseflow was assumed to be dominated by groundwater discharge. Good agreement was seen at the gauges within the study area.

Table D2-29: Summary of Calibration Targets within Local Calibration Areas

Target Type	Dataset Name	Number of Points	Description
Static Water Levels	ORMGP Database(s)	1129	Static water levels reported in the ORMGP database for the region of Peel wellhead areas within CVC. Wells of location quality 1 to 9.
Water Levels	Early Warning Wells/ Monitoring/ Observation Wells	45	Range of observed water levels.
	Drive Point Piezometers	37	Range of observed water levels.
Baseflow	HYDAT / Water Survey Canada Stream Gauge	5	Minimum and maximum estimates of average annual baseflow at HYDAT Gauges.

WHPA A-D Delineation

Table D2-30: Municipal Pump Rates – Region of Peel, Town of Caledon

Well	Town of Caledon Pumping Rate (m^3/day); PTTW maximum unless otherwise noted
Alton Well 3 & Well 4A	1047[1]
Inglewood Well 2	1296
Inglewood Well 3	1296[2]
Inglewood Well 4	1296[2]
Caledon Village Well 3	1964
Caledon Village Well 4	3273
Cheltenham Wells 1 & 2	1468

[1] Based on PTTW Daily Maximum water taking, Alton Wells 3 and 4A can pump alternately to a maximum of 1047 m^3/day.
[2] ING3 and ING4 are not permitted to pump simultaneously.

WHPA-E Delineation

Table D2-31: GUDI Status – Town of Caledon Municipal Wells

Well Fields	Well	Status
Cheltenham	1	Groundwater *
	2	Groundwater*
Inglewood	2	No study, assumed GUDI
	3	Groundwater **
	4	Groundwater ***
Caledon Village	3	GUDI with adequate in situ filtration**
	4	GUDI with adequate in situ filtration**
Alton	3	GUDI with adequate in situ filtration**
	4A	No study, assumed GUDI with adequate in situ filtration**

* R.J. Burnside & Associates, 2002
** Stantec Consulting Inc., 2002 a,b,c
*** Matrix Solutions Inc., 2017

Calculation Procedure

The WHPA-E is based on a 2-hour travel time upstream of the GUDI well “intake” and for the purposes of this study was assumed to represent bankfull flow conditions within the determined stream or water body. In order to determine the extent of this zone, a Hydraulic Model was created using HEC-RAS to evaluate the channel velocity during bankfull conditions.

Stream bed cross-section geometry was determined from a Digital Terrain Mapping (DTM) that was obtained for the study area with cross-section locations taken roughly every 50 to 100 m upstream of the GUDI “intake”. The terrain model was created from photogrammetric acquired elevation data in 2008. ArcGIS and HecGeo-Ras were used to determine the channel geometry including the flow length for each section of the main channel as well as the left and right overbanks. Manning’s “n” values for the main channel and overbanks were determined based on aerial photography. This information was imported into HEC-RAS and modeled using a steady state, sub-critical flow regime. A downstream boundary condition of normal depth was assumed with a bed slope of 0.002.

Bankfull conditions were determined for each reach by iterating the channel discharge within HEC-RAS until a majority of sections were at bankfull depth. This was completed for each flow change location within the watercourse starting at the downstream end at the "intake" and working upwards. For reaches which seem to have greater bankfull capacity than reach immediately downstream, the channel discharge from the upstream reach was assumed to be equal to that of the reach immediately downstream.

Once the appropriate channel discharge had been established for each reach within the watercourse, the channel velocity for each cross section was determined using HEC-RAS. The travel time for each cross section was then determined as the distance between cross-sections divided by the channel velocity for that cross section. The travel time for each section was then added beginning at the GUDI well "intake" and moving upstream until the total travel time was equal to 2-hours. This represents the limit of the WHPA-E. The lateral extent of the zone was defined by using the regulatory or flood limit as the boundary for this zone. Where this data was missing a 120 m offset from the channel, the Conservation Authority regulation limit was used to define the lateral extent of the WHPA-E.

In the case of the WHPA-E delineation for Alton Well 4A (EarthFx and Geocamp, 2019), slopes were calculated for each of 133 channel segments and varied from 0.003 to 0.017. On-line ponds and lakes were assumed to each be at least one reach segment with a single flow velocity.

Design Assumptions

For reaches which contain large online ponds (>0.5 ha) the WHPA-E was assumed to end at the pond outlet as the hydraulic residence time within the pond would be greater than 2-hours. For reaches which were less than 2.0 km in length it was assumed that the WHPA-E would encompass the entire reach. For minor tributaries where the point of confluence at the main channel is less than 2 hours from the well, the entire tributary was assumed to be within the WHPA-E.

Vulnerability Scoring

Area Vulnerability

Area vulnerability was determined from the following factors, surficial geology, slope and land use within the delineated WHPA-E. Each factor was rated as either vulnerable or not vulnerable and assigned a score of 1 or 0, respectively. Scores were summed at the end of the analysis and based on total score of 1, 2, or 3, the area vulnerability was ranked as 7, 8 or 9.

The surficial geology of the area is considered as the overburden sediments, which affect how much infiltration occurs and how much water becomes runoff. When the surficial geology consisted of predominantly course grained sediments it was assigned a score of 1. Surficial units consisting predominantly of fine-grained sediments were assigned a score of 0.

Land use within the WHPA-E was considered for the vulnerability of the area as the activities within the area can cause a greater chance of contamination. Agricultural, residential, and industrial land uses were assigned a score of one. Natural areas with limited anthropogenic activities were assigned a score of 0.

The slope of the capture area can affect the vulnerability as the greater the slope the quicker contaminants will travel over the ground flow towards the source. **Table D2-32** outlines the factors used to determine the area vulnerability factor for the WHPA-Es for the Town of Caledon's GUDI Wells.

Table D2-32: WHPA – E Area Vulnerability Factor (V_a) Derivation –Town of Caledon

Well	Factors		Score	V_a
Alton Wells 3 & 4A	Surficial Geology	Glaciofluvial/alluvial/organics	1	8
	Slope	5%	0	
	Land Use	Residential, agricultural	1	
			2 of 3	
Caledon Village Well 3	Surficial Geology	Glaciofluvial deposits	1	8
	Slope	~0%	0	
	Land Use	Aggregate extraction	1	
			2 of 3	
Caledon Village Well 4	Surficial Geology	Glaciofluvial, organics	1	7
	Slope	~3%	0	
	Land Use	Natural some agricultural	0	
			1 of 3	
Inglewood Well 2	Surficial Geology	Till, alluvial, ice contact stratified drift	0	8
	Slope	~5.2%	1	
	Land Use	Residential, natural	1	
			2 of 3	

Source Vulnerability

Source vulnerability was determined based on the intake type, the depth of the well and the dimensions of the associated water body, and the inferred potential for dilution of contaminants within that body.

All of the Caledon's wells are associated to a Type C intake. The source vulnerability factor for an intake Type C is 0.9 to 1.0. To determine the exact number, the well depth and associated water body, and potential for dilution were considered. Wells that were less than 15 m deep were regarded as vulnerable and given a score of 1, those greater than 15 m deep were scored as 0 for less vulnerable.

The dimensions of each water body and the potential for dilution of contaminants were examined, a water body with a large capacity for dilution was rated as low vulnerability and scored as 0 while a water body with low potential for dilution was rated as 1. These numbers were summed to produce the overall source vulnerability, which was determined as a summed score of 1 representing a source vulnerability of 0.9, and a summed score of 2 representing a source vulnerability of 1.0. **Table D2-33** outlines the factors used to determine the source vulnerability factor for the Town of Caledon's GUDI Wells.

Table D2-33: WHPA – E Source Vulnerability Factor (V_s) Derivation – Town of Caledon
Vulnerability Score

Well	Factors		Score	Vs
Alton Wells 3 & 4A	Intake Type	C	1.0	
	Well Depth	22.2 m and 17.6 m	0	1.0
	Water Body	Creek	1	
			2 of 2	
Caledon Village Well 3	Intake Type	D		
	Well Depth	36.1 m	0	0.8
	Water Body	Gravel pit ponds	0	
			0 of 2	
Caledon Village Well 4	Intake Type	C		
	Well Depth	75.9 m	0	0.9
	Water Body	Credit River	0	
			0 of 2	
Inglewood Well 2	Intake Type	C		0.9
	Well Depth	9.4	1	
	Water Body	Credit River	0	
			1 of 2	

To determine the vulnerability score, the area vulnerability factor is multiplied by the source vulnerability factor. This results in a vulnerability score as shown in **Table D2-34.**

Table D2-34: WHPA–E Vulnerability Scores for Wells in the Town of Caledon

Well	Area Vulnerability Factor	Source Vulnerability Factor	Vulnerability Score
Alton Wells 3 & 4A	8	1.0	8.0
Caledon Village Well 3	8	0.9	6.4
Caledon Village Well 4	7	0.9	6.3
Inglewood Well 2	8	0.9	7.2

D2.4 Municipal Water Quality - Intake Protection Zones (IPZ-1 and IPZ-2s)

For Great Lakes intakes, three vulnerability zones (IPZ) are required:

- The IPZ-1 is set at a minimum 1 km radius about the intake; its radius can be increased and considered to be the most vulnerable. An increase in radius of IPZ-1 results from special or unique conditions or other environmental situations that in good judgment, suggest that this most vulnerable zone be increased in order to properly address the identified situations and/or conditions.

- IPZ-2 – This zone represents the area, both on land and in water, where a spill of a contaminant might reach the intake before the plant operator can respond. In CVSPA, the IPZ-2 is based on estimating the distance a contaminant might move in 2-hours along the water surface, calculated from the water intake crib outwards under wind conditions that reflect a 1-year return period to the east, and a 3-year return period to the west. The IPZ-2 has the following components:
    - In-Lake and alongshore (in-water) extent:

        - The in-lake component of the IPZ-2 can be calculated using numerical or hydrodynamic modeling to define the local water movement for a range of conditions. Inputs to the models may include but are not limited to: wind and wave data; bathymetry data; water quality parameters at the intake; and an administratively set TOT of 2-hours. This component is extended to the shoreline at an angle perpendicular to the model.
    - Upland extent:
        - This component has two sub-components; setbacks and transport pathways. The setbacks are determined as the Conservation Authority Regulated Limit or the administratively set limit of 120 m from a watercourse or waterbody, whichever is greater. The transport pathways component includes areas that are drained by stormsewers and watercourses. The upper limit of this latter component is determined based on the 2-hr TOT of a particle within the transport pathway, beginning at the water surface over the intake. A modeled "bank full" flow event was assumed to complete the 2-hour TOT analysis.
- IPZ-3 – A number of spill scenarios were modelled as part of the Lake Ontario Collaborative project to determine if certain land-based activities could pose a potential drinking water threat to these intakes. Any scenario that identifies conditions under which a contaminant could exceed a threshold in the raw water is identified as a significant drinking water threat. The delineated IPZ-3 is shown as a line between the source of the spill and the intake, following the flow direction predicted by the model.

A schematic of the methodology for generation of IPZ-1 and IPZ-2 from a WTP in the Central Lake Ontario Source Protection Area is included as an example on **Figure D2-9**. These zones are then subject to an inventory of potential contaminant threat sources.

The IPZ-2s and IPZ-3s are drawn based on complex hydrodynamic models. The discussion of the models and approach used to determine the IPZ-2 areas are found in the *Lake Ontario Vulnerability Assessment Surface Water, Phase 1 and Phase 2*, 2008. The models consider several criteria, including currents, wind direction and speed, bathymetry, and loadings from surface water features. The study has also assessed the transport pathways within the IPZs that could allow contaminants to reach an intake at a quicker rate. Such pathways include storm sewer systems, drainage ditches, or tiled field drains. The work to delineate IPZ-3 has been completed as a new phase of the Lake Ontario Collaborative study and is included in this update to the Assessment Report.

IPZ Delineations

Baird conducted numerical modeling in support of IPZ delineation for three (3) WTPs. Hydrodynamic processes on the Great Lakes are in most cases three-dimensional (3-D) with currents at the lakebed often flowing in the opposite direction from currents at the surface. The currents also vary temporally and are highly dependent on wind conditions. Field data, where it exists, defines the current patterns for the duration of the dataset only at the specific instrument location. It is useful in providing current information for a specific time and location, but it does not define the current patterns throughout the IPZ for the full range of conditions.

Numerical modeling calibrated against field measurements is a recommended scientific approach to defining the IPZ-2. It allows for the evaluation and understanding of the flow patterns around the intake under a range of conditions.

Two numerical models were selected for use in this study: the Danish Hydraulic Institute (DHI) MIKE-3 model was used to define the hydrodynamic conditions for western Lake Ontario and in the vicinity of the intakes while National Oceanic and Atmospheric Administration's (NOAA) lake wide Princeton Ocean Model (POM) was used to provide the boundary conditions and external forcing mechanisms for the MIKE-3 model.

DHI's MIKE-3 can simulate unsteady 3-D flows in lakes, rivers and oceans taking into consideration density variations, bathymetry and external forcing functions including meteorology, tides, current velocity, and surface elevation. The model has the ability to define several levels of nesting in order to provide the resolution necessary at specific locations within the computational domain. For this study, the MIKE-3 model was used to evaluate hydrodynamic conditions in the lake and around the intakes for selected wind events. Model grid resolutions used for this study ranged from 2,430 m to 10 m.

The version of the POM developed and used by NOAA for the Great Lakes Operational Forecast System (GLOFS) to forecast water levels, currents and temperatures on Lake Ontario was used to define the boundary conditions for the MIKE-3 model including spatial wind fields, air temperature, surface elevation, and water temperatures. The Lake Ontario Operational Forecast System (LOOFS) is run with a 5 km grid and 20 layers in the vertical. This grid setup is too coarse for defining the IPZ-2 and does not extend into the near shore. The model output does however describe the large-scale hydrodynamic processes in the lake.

A schematic of the methodology for generation of IPZ-1s and 2s is included on **Figure D2-10**. These zones are then subject to an inventory of potential contaminant threat sources.

The model runs were event based, that is, the numerical model was run for historical wind events that occurred between 2002 and 2006. The simulation periods chosen for the runs were limited to this time period due to the availability of LOOFS results. Two wind events in 2003 were identified based on an analysis of data from Pearson International Airport; one represented a strong east wind, the other, a strong west wind. These represent the two dominant wind directions that occur in western Lake Ontario. Test runs were also carried out, to examine the impact of north winds particularly as it pertains to the potential for contaminants to be transported from shore to the intakes. Based on the time series data for Pearson Airport, the east event is less than a 1-year return period event. The west event is approximately a 3-year return period event. The POM data, which includes a spatially varied wind field developed from multiple wind stations, shows peak winds during both events, of 75 km/hr., which is closer to a 5-year return period event.

Local tributaries were defined in the model and a 2-year return period flow was used in all runs. It is important to note that in this phase of the study only gauged tributaries were defined in the model and the flows at the mouths of the rivers were based on the gauged data. Adjustment to the gauged river flows to represent conditions at the river mouth, and inclusion of non-gauged rivers is recommended in the next phase of work once hydrological data becomes available.

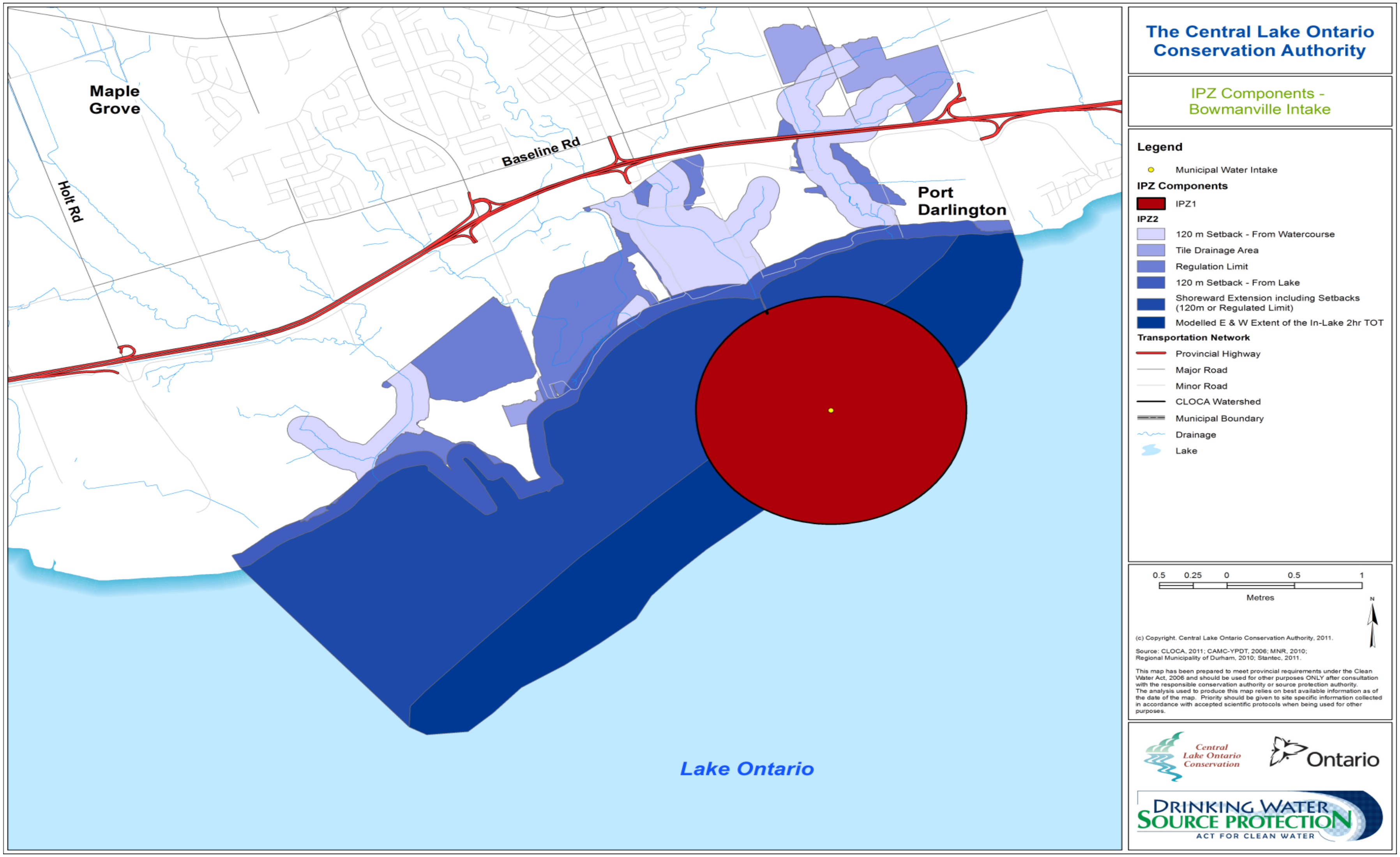

Figure D2-9: Schematic

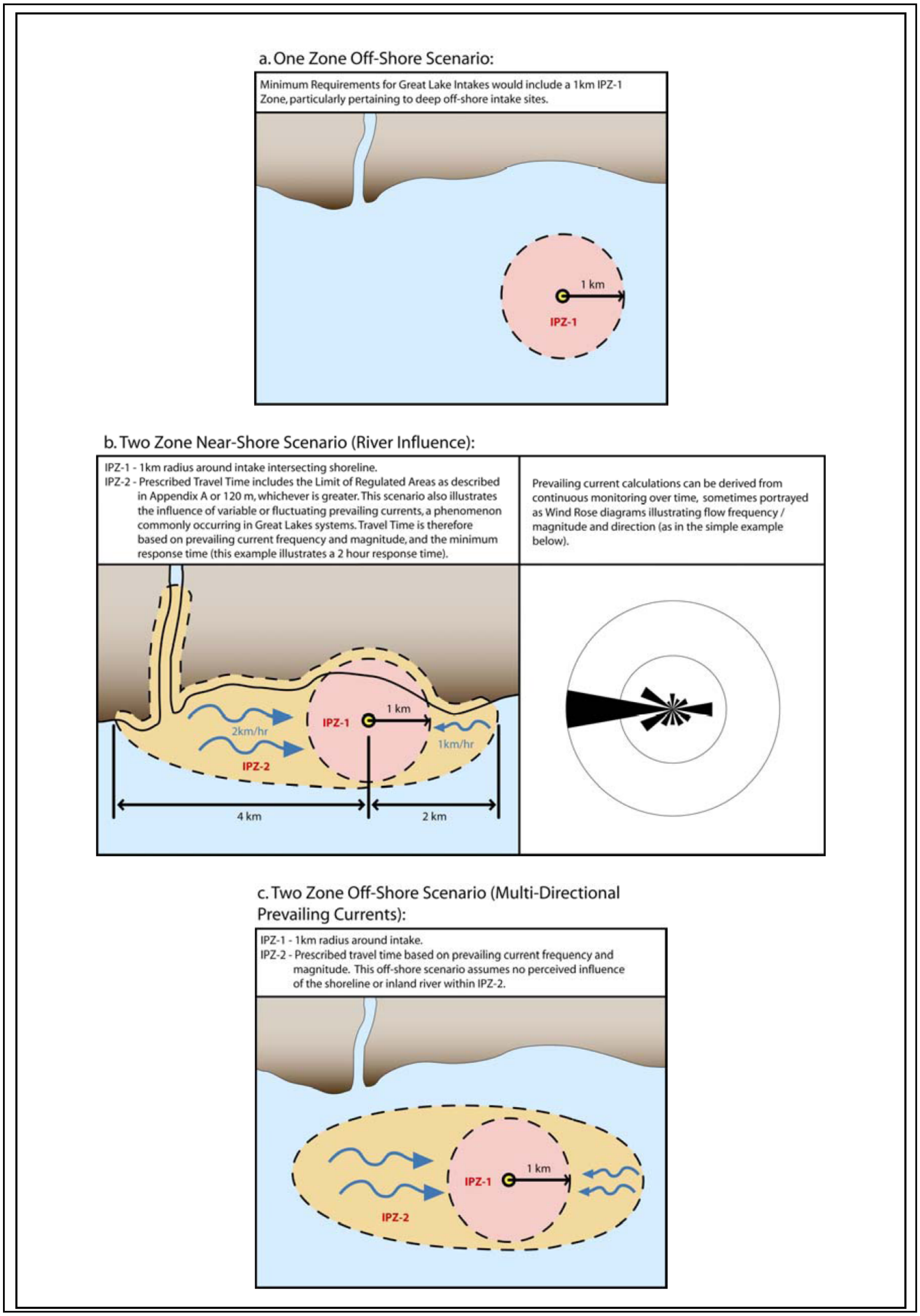

Figure D2-10: IPZ Delineation (figure from Ontario Ministry of the Environment, 2006)

IPZ Delineations Results

The model results showed that nearshore current patterns are strongly correlated to wind direction; a similar response was evident throughout the lake. Current patterns within the lake are 3-D; encompassing reverse currents, upwelling, and downwelling, which are physical phenomena that occur. The intakes were generally located far enough offshore that they were not influenced by shoreline structures, and adjacent tributaries did not influence current patterns around the intakes under a 2-year flow event. The results from the numerical modeling activities indicate that current patterns are most strongly influenced by wind conditions.

Reverse particle tracking was utilized to delineate the preliminary in-lake IPZ-2 for each intake. The particle model is driven with the simulated hydrodynamics from the MIKE-3 model and run in reverse mode with the particles tracking the paths by which the currents would have transported neutrally buoyant particles to the intakes.

For each intake, the reverse particle tracking was run for the east and west events, described previously. These events each had durations of 3.5 days. The reverse particle tracking represents a location from which a particle could reach the intake within the 2-hour shut down time defined by the WTP operators. The location of the particles varies with the release time within the 3.5-day event. A conservative approach was taken for the preliminary delineation and the particles were released at the surface, rather than at the intake depth. This is conservative because the surface currents have greater speeds than the currents at depth.

Intake Protection Zone -2 (IPZ-2) Delineation – Arthur P. Kennedy (formerly Lakeview) and Lorne Park WTPs

The sources of information and data includes municipalities, conservation authorities, and other organizations stretching from Niagara in the western region of Lake Ontario, to Kingston in the east; past studies and reports; Canadian Hydrographic Service stream flow data; conservation authority watershed data and reports; and municipal storm sewer network mapping.

Methodology and Procedure – IPZ-2

The IPZ-2 is based on a two-hour time of travel (TOT) distance from the intake, and was delineated via two major components:

- In-lake and alongshore (in-lake) extent; and
- Up-tributary (upland) components.

The in-lake component was calculated using a 2-dimensional hydrodynamic model and a numerical forecasting model, which was used to set boundary conditions. These models were driven by five-year storm wind conditions to define the local water movement for a range of conditions. Inputs to the models may include but are not limited to:

- Wind and wave data;
- Bathymetry data;
- Current velocities; and

- An administratively set TOT to the intake of 2-hours.

The up-tributary component has two sub-components – setbacks and transport pathways. The setbacks are determined as the Conservation Authority Regulated Limit or the administratively set limit of 120 m from a watercourse or waterbody, whichever is greater. Where the subwatershed boundaries indicated overland flow travelling away from the watercourse, the setbacks were modified.

Lorne Park WTP

The intake is located approximately 1.2 km offshore. Particle tracking indicates that the IPZ-2 does not extend to the Credit River, but it has been extended to the river mouth (northeast), and to the shoreline (southwest) to provide a measure of conservativeness based on estimated wave action and the expected contaminant plume movement. Based on the modeled in-lake IPZ-2, the upland component of the IPZ-2 begins at the Credit River and follows stormshed boundaries to a western extent of Meadow Wood Lane.

The watercourses that were included in the up-tributary components of the IPZ-2 are:

- Credit River;
- Sheridan Creek;
- Birchwood Creek;
- Lornewood Creek;
- Moore Creek;
- Tecumseh Creek; and
- Turtle Creek.

Arthur P. Kennedy WTP

The intake is located 2 km from shore, and the IPZ-2 extends approximately 3.2 km northeast of the intake and 2.9 km southwest of the intake. Based on the modeled in-lake IPZ-2, the western extent of the Arthur P. Kennedy IPZ-2 is at the Credit River. A conservative up-tributary extent was determined utilizing storm sewer network information provided by the City of Mississauga (Mississauga, 2006), and residual TOT as derived via the methodology, as sufficient data was not available to determine stream flow velocities in the watercourse.

The up-tributary IPZ-2 was extended to the limit of CN railway line located north of Lakeshore Road East and follows the stormshed boundaries east to the Etobicoke Creek.

The watercourses that were considered part of the delineated stormsheds include:

- Credit River;
- Etobicoke Creek;
- Cooksville Creek;
- Applewood Creek; and
- Serson Creek.

East of Etobicoke Creek, in the City of Toronto storm sewer data was unavailable. In this case the administratively set limit of 120 m was applied along the Lake Ontario shoreline.

The northeast area (about 6.7 km^2 in size) of the IPZ-2 extends into the TRSPA. Particle tracking indicates that the IPZ-2 does not extend to the shoreline, but it has been extended to shore to provide a measure of conservativeness based on estimated wave action and the expected contaminant plume movement. The south-western extent of the IPZ-2 for the R.L. Clark intake owned and operated by the City of Toronto (in the TRSPA) abuts both the IPZ-1 and 2 of the Arthur P. Kennedy WTP intake.

Upland Extent of IPZ-2 - Tributary Flow

The *Technical Rules* recommends that stream velocity at bank full stage be used to determine the extent upstream in tributaries that the IPZ-2 extends. A tributary analysis was conducted for water courses that discharge to the alongshore extent of the in-water IPZ-2 to determine the distance to be delineated upstream. Influencing reaches for watercourses contributing to the IPZ-2 were based on 2-year storm velocities within a two-hour TOT to the intake. The velocities were derived using the HEC-RAS model and were provided by CVC and TRCA.

The tributaries and calculated up-tributary distances for Arthur P. Kennedy and Lorne Park WTPs based on residual TOT (i.e., 2-hour TOT subtract in-lake TOT to WTP) are listed in **Table D2-35** and **Table D2-36**, respectively.

Table D2-35: Tributary Analysis Summary – Arthur P. Kennedy WTP

Tributary	Residual Time of Travel (TOT) (Minutes)	Calculated Up-Tributary Distance (m)
Credit River	34.0	256
Cooksville Creek	39.4	5231
Serson Creek	42.5	3629
Applewood Creek	21.8	2485
Etobicoke Creek	8.1	988

Table D2-36: Tributary Analysis Summary – Lorne Park WTP

Tributary	Residual Time of Travel (TOT) (Minutes)	Calculated Up-Tributary Distance (m)
Sheridan Creek	46.8	5401
Turtle Creek	50.0	9300*
Birchwood Creek	61.6	8799*
Moore Creek	54.0	6156*
Lornewood Creek	45.1	3884*
Tecumseh Creek	36.0	4752*
Credit River	3.9	291

* Creeks are shorter than the calculated up-tributary distance. Therefore, they are included in their entirety.

Note that for Cooksville Creek, Serson Creek (Arthur P. Kennedy) and Birchwood Creek (Lorne Park), there was not enough velocity data (stations) to consume the entire residual TOT. Therefore, the velocity recorded at the last station was assumed to provide the residual TOT.

A setback of 120 m or the area of the Regulation Limit, whichever is greater, was applied to each watercourse. Where the subwatershed boundaries indicated overland flow travelling away from the watercourse, the setbacks were modified.

Transport Pathways

Transport pathways within the IPZ-2s could potentially allow contaminants to reach an intake at a quicker rate. Infrastructure and operations experts determined the preferential pathways and point sources of pollutants by reviewing WTP operations information, storm and sewer outfall data, current land uses and area characterization, and other anthropogenic influences on the study area.

In this study, the transport pathways component includes areas that are drained by storm sewers and watercourses. The upper limit of this latter component is determined based on the 2-hr TOT of a particle within the transport pathway, beginning at the watercourse mouth.

The analysis to determine the upland component of the IPZ-2 delineation considered:

- The contributing area of watercourses located in the along shore extent of the IPZ-2; and
- Storm sewer information from the City of Mississauga.

Per the requirements of the *Technical Rules*, a modeled “bank full” flow event was assumed to complete the 2-hr TOT analysis. To meet this criterion, the streamflow assessment was undertaken using the flow model HEC-RAS to derive 2-year storm velocities on the watercourses. This work was undertaken by CVC and TRCA.

Storm sewer networks, including storm sewer outfall locations, were available for the Region of Peel. Storm sewers that outlet into the IPZ-2 were included as transport pathways within the upland delineation of the IPZ-2 to meet the 2-hour time of travel criteria for delineation of the IPZ-2 as per *Technical Rule* (66). The IPZ-2 does not include the entire storm sewer network. Further, if a storm sewer outlets to the exterior of the delineated IPZ-2, then it was not included as a transport pathway within the IPZ-2.

Catchment area extents were estimated using the networks, residual TOT at the outfall mouths, and watershed boundaries. In general, storm sewers were included in their entirety; however, were truncated based on estimated residual TOT and 1.0 m/s velocity in pipe, closer to the northern extents of the up-tributary delineations.

Vulnerability Assessment

The vulnerability score (V), is derived by using an equation which comprises the product of an area vulnerability factor (Vf_z) and source vulnerability factor (Vf_s), in keeping with *Technical Rule 87*:

$$V = Vf_z \times Vf_s$$

The area vulnerability factors (Vf_z) are assigned to each IPZ according to their susceptibility to becoming contaminated and depend on varying factors, such as the surrounding environmental conditions, the percentage of the area that is land and how water flows through the area. As indicated earlier, transport pathways are also accounted for.

Vf_z is always assigned as 10 for the IPZ-1, while the IPZ-2 is assigned a value ranging between 7 and 9 (*Technical Rule 88*). For Type A intakes, AVf_s is assigned a value ranging between 0.5 and 0.7 (*Technical Rule 95*).

Area Vulnerability Factor

The area vulnerability factor for IPZ-1 was prescribed by the *Technical Rules*. The area vulnerability factor for IPZ-2 was assigned a whole number ranging from 7 to 9, based upon consideration of the following sub factors:

a. Percentage of area that is land within the IPZ-2;
b. Land cover, soil type, and permeability; and
c. Transport pathways within the IPZ-2 upland environment.

To quantify these factors a decision matrix was developed using ranges of characteristics for each of the three sub factors. The sub factors were assumed to have equal importance, and therefore, were weighted equally. **Table D2-37** provides the decision matrix created by Stantec to calculate the area vulnerability factor.

Table D2-37: Area Vulnerability Factor Decision Matrix

Sub Factor		Criteria: 7	Criteria: 8	Criteria: 9	Sub Factor Score
% Land		< 33%	33% to 66%	> 66%	Based on areas calculated within the IPZ-2
Land Characteristics	Land cover	Mainly forested	Agriculture and/or mixed vegetated, & developed	Mainly developed	Each sub factor assigned a score based on environmental conditions $= \frac{(cover + soil + perm + slope)}{4}$
	Soil Group	Group A	Groups B & C	Group D	
	Permeability	> 66%	33% to 66%	< 33%	
	% Slope	< 2%	2% to 5%	> 5%	
Transport Pathways		Limited presence of transport pathways	Mainly tile drainage and ditches	Mainly storm sewer	Each sub factor assigned a score based upon the characteristics of the IPZ-2

Group A – Low Runoff Potential (sands and gravels)
Groups B & C – Moderate Runoff Potential (sandy and silty loam soils)
Group D – High Runoff Potential (clay; soils in permanent high water table; shallow soils over nearly impervious material)

To calculate the area vulnerability factor score the following equation was used based upon the results:

$$\text{Area Vulnerability Factor} = \frac{(\%\,land + land\ characteristics + transport\ pathways)}{3}$$

To satisfy the components for each sub factor and populate the decision matrix, the characteristics of the upland area were evaluated based on the following criteria:

- The percent land criterion was based upon the assumption that a higher percentage of area that is land within an IPZ-2 may indicate a higher potential for runoff and drainage to the source water. This may be a coarse indicator of the availability of land-based activities and transport pathways that may contribute contaminants to source water in the vulnerable zone. Consequently, the score increases with a higher percentage of land in the zone. The percent land criterion was divided into equal ranges of percentage (< 33%, 34 to 66%, > 66%);

- The land characteristics sub factor had four components: land cover, soil type, permeability, and percent slope, and was generally based on drainage characteristics that would promote good drainage, average drainage, or poor drainage. An area that was a highly developed area, with lower permeability, and higher slope may encourage faster runoff to the source water, and therefore, have been assigned a higher score. Conversely, an area with high soil permeability, low slope, and high percentage of forested areas may represent a lower score; and

- The transport pathways sub factor may represent the ability to drain the land portion of the IPZ-2 (and potentially a contaminant spill) to the source water. A high score may reflect an upland IPZ-2 environment with a high density of storm sewers, and numerous outfalls from anthropogenic sources that may convey contaminants to source water rather quickly.

Source Vulnerability Factor

For Type A (Great Lakes) intakes a score must be assigned a value of 0.5 to 0.7 rounded to the nearest tenth. The following sub factors are required to be considered:

a. The depth of the intake from the water surface;
b. The distance of the intake from land; and
c. The number of recorded drinking water issues related to the intake.

The method of evaluating the sub factors was not prescribed in the *Technical Rules* and therefore to quantify these factors a decision matrix was developed using ranges of characteristics for each of the three sub factors. The criteria for the sub factors were developed using a number of resources.

The criteria to determine the depth of intake was derived from the MOECC Design Guidelines for Drinking Water Systems (MOE, 2008). These guidelines state that the minimum submergence of an intake crib, measured from the top of the intake structure to minimum recorded water levels, should be 3 m, wherever possible.

The criteria for the length of intake from shore to the intake crib was not based upon MOECC Design Guidelines as the guidelines do not prescribe a minimum or recommended distance from shore. In the absence of local requirements, information that the State of Michigan used as part of its Source Water Protection Program (MDEQ, 2004) was reviewed. This resource assigns a high level of vulnerability to intake lengths that are less than 300 m. This was implemented in the decision matrix by applying a score of 0.7 for intakes less than 300 m in length. An intake length that was greater than 500 m was used to determine a score of 0.5. Local hydrodynamic conditions and the location of the wave breaking zone in reference to the intake location were also considered for this sub factor. If the intake was located within the wave breaking zone, regardless of intake length, the score could not be 0.5 because there is modeled evidence of the potential for water column mixing. It was reasonable to assume an increase in intake susceptibility to contamination and therefore, a higher source vulnerability rating was assigned.

The recorded water quality issues were based on a comparison of available raw water quality data to the Ontario Drinking Water Quality Standards (ODWQS), review of watershed characterization report concerns, and WTP operation and municipal staff concerns.

Table D2-38 provides the decision matrix that was used to calculate the source vulnerability factor.

Table D2-38: Source Vulnerability Factor Decision Matrix

Sub Factor	Criteria			Sub Factor Score
	0.5	0.6	0.7	
Intake Characteristics Depth	> 6.1 m	3.1 m to 6.0 m	0 m to 3.0 m	Choose score based on intake characteristics
Intake Characteristics Offshore length	> 500 m	300 m to 500 m	< 300 m	Choose score based on intake characteristics
Recorded Water Quality Issues	Minimal number of parameter results measured above ODWQS. No additional concerns.	Some parameter results measured above ODWQS along with operator concerns. Watershed characterization reported concerns.	Several parameter results measured above ODWQS. Operator and/or municipal staff confirmation of raw water quality concerns.	Choose most appropriate score based upon information received

The three sub factors presented in **Table D.33** were assumed to have equal importance and were therefore weighted equally. To calculate the source vulnerability factor score the following equation was used:

$$\text{Source Vulnerability Factor} = \frac{(\textit{offshore length} + \textit{depth} + \textit{water quality})}{3}$$

Arthur P. Kennedy WTP

The natural characteristics driving the area vulnerability estimation within the IPZ-2 area include the slope of the upland environment, the influencing tributary watercourses and lake processes.

The study area is low-lying, gently sloping, and highly urbanized. Tributary watercourses are generally degraded and in places abutted by older neighbourhoods, which may feature out-of-date storm and CSO outfalls to the Cooksville and Etobicoke creeks and the Credit River.

The G.E. Booth WWTP outfall located east of the Arthur P. Kennedy WTP intake is a potential contaminant source (operator interview). The WWTP effluent is discharged into Lake Ontario through a 1,400 m diffuser, which allows for effluent discharge along a selected length of the pipe (KMK, 2004). This reduces single point effluent loads. The total phosphorus and ammonia plumes modeled directly overlap the Arthur P. Kennedy IPZ-1 and IPZ-2 (KMK, 2004).

Anthropogenic pathways in the IPZ-2 area include transportation routes, CSOs, storm sewers, and WWTP discharges. Within the area, storm sewers are a concern due to the high density of urban development in Mississauga. The South Peel area has a large number of high-density transportation routes. Culverts and watercourse crossings have the potential to convey spills and highway runoff into the source water.

Vulnerability Factors

Based on the above considerations, the vulnerability scoring was undertaken as follows:

IPZ-1 Vf_z is assigned a value of 10 in accordance with the *Technical Rules*, 2009.

IPZ-2 Vf_z is determined to be 9 based on natural and anthropogenic characteristics of the upland and in-water environment. The vulnerability score summary for Arthur P. Kennedy WTP is presented in **Table D2-39**.

Table D2-39: Vulnerability Score Summary – Arthur P. Kennedy WTP Intake

Intake Type	Area Vulnerability Factor (Vf_z)		Source Vulnerability Modifying Factor (Vf_s)	Vulnerability Score[1] (V)	
	IPZ-1	IPZ-2		IPZ-1	IPZ-2
Great Lakes	10	9 HIGH	0.5 LOW	5 LOW	4.5 LOW

Lorne Park WTP

Natural characteristics, driving the area vulnerability estimation, within the IPZ-2 area include the slope of the upland environment, the influencing tributary watercourses, and general lake processes.

The study area is low-lying, gently sloping, and highly urbanized. Tributary watercourses are generally degraded and abutted by older neighbourhoods that typically feature out of date storm sewer and CSO outfalls. The Credit River is the largest such watercourse in the area, but several other smaller creeks that serve as municipal drains exist further to the west of the Credit River.

The G.E. Booth WWTP located in the eastern section of the study area has been identified as a potential contaminant pathway (operator interview). Effluent from the WWTP was modeled by KMK Consultants Limited (KMK, 2004). The modeled ammonia plume overlaps the Lorne Park WTP IPZ-2.

Anthropogenic pathways in the IPZ-2 area include transportation routes, CSOs, storm sewers, and WWTP discharges. Within the area, storm sewers are a concern due to high-density urban development in Mississauga and therefore the increased potential for runoff and delivery into the lake.

Combined sewer overflows have been identified in the upland components of the IPZ-2. The CSOs in the area are located primarily in Port Credit along the Credit River. The operator interview addressed CSO influences maintaining that within Mississauga the sewer network is largely separate and that CSOs are of a low concern.

The South Peel area has a large concentration of high-density transportation routes. The QEW is the major transportation route within the study area, although many other high traffic routes exist.

Vulnerability Factor s

Based on the above considerations, the vulnerability scoring was undertaken as follows:

IPZ-1 Vf_z is assigned a value of 10 in accordance with the *Technical Rules*, *2009*.

IPZ-2 Vf_z is determined to be 9 based on natural and anthropogenic characteristics of the upland and in-water environment. The vulnerability score summary for Lorne Park WTP is presented in **Table D2-40**.

Table D2-40: Vulnerability Score Summary – Lorne Park WTP Intake

Intake Type	Area Vulnerability Factor (Vf_z)		Source Vulnerability Modifying Factor (Vf_s)	Vulnerability Score[1] (V)	
	IPZ-1	IPZ-2		IPZ-1	IPZ-2
Great Lakes	10	9 HIGH	0.5 LOW	5 LOW	4.5 LOW

Uncertainty

An analysis of uncertainty, characterized by "high" or "low" is required for the delineation of the IPZs and the vulnerability assessment. The following factors were considered in the uncertainty analysis:

- Distribution, variability, quality and relevance of data;
- Ability of methods and models used to accurately reflect the flow processes in the hydrological system;
- Quality assurance and quality control procedures applied;
- Extent and level of calibration and validation achieved for models used, calculations or general assessments completed; and
- Accuracy to which the area vulnerability factor and the source vulnerability factor effectively assesses the relative vulnerability of the hydrological features.

Arthur P. Kennedy – IPZ-2

Delineation Uncertainty

There are two delineation components that require an uncertainty analysis, the hydrodynamic modeling and methodology for the delineation of the in-water portion and extension to shore, and the methodology employed to delineate the upland portion.

Hydrodynamic In-water Modeling

The uncertainty level is high for IPZ-2 delineation due to the general lack of data to calibrate the model suites and the limited data inputs used to drive the model and reach steady state conditions. More data is required to run a variety of scenarios to effectively conceptualize water movement in the study area. In addition, there is high uncertainty with the delineation to shore. The in-water modeling did not indicate a connection to shore; however due to the uncertainties with the model an extension was made.

Upland Methodology

Credit River, Cooksville Creek, Serson Creek, Applewood Creek and Etobicoke Creek were included in the upland delineation. Velocity data was provided by CVC for Credit River, Cooksville Creek, Serson Creek and Applewood Creek, and from the TRCA for Etobicoke Creek. The 2-year HEC-RAS model velocities and the residual TOT at the creek mouth were used in the calculation of the up-tributary extents. Due to the conservative nature of the HEC-RAS data the up-tributary delineations have a moderate level of uncertainty.

Storm sewer networks were available and were included in the upland delineation for the Arthur P. Kennedy WTP study area. Catchment area extents were not provided and therefore were estimated. Velocities were not available for the storm sewers. There is low uncertainty as to which storm networks should be included, but high uncertainty as to the extent of the network that should be included.

Vulnerability Scoring Uncertainty

Data used in the delineation of the upland IPZ-2 and vulnerability assessment for the Arthur P. Kennedy WTP was evaluated based upon quality, and relevance of the information.

Quality

The available data used to determine the vulnerability scores were provided by provincial and municipal sources, CVC and by the TRCA. A high level of confidence in the quality of the data was established based on the assumption that adequate quality control programs are in place for the sources.

Relevance

Available datasets for the area factor analysis were relevant. The % area that is land was determined using the Water Poly Segment (WPS) datasets available from the Ministry of Natural Resources and Forestry. The impervious land cover and land cover type was determined using SOLRIS (2009) information. Slope was determined using Ontario Base Mapping contours. Storm sewers were analyzed for the transport pathway portion of the area vulnerability analysis. Storm sewer networks were obtained from the Region of Peel and all the datasets used were relevant to the study area.

QA/QC measures were applied to each component of the vulnerability factor analysis. Vulnerability factors were reviewed throughout the analysis process and as such the confidence in the data and the calculations used in the vulnerability analysis was high resulting in a low uncertainty rating.

The revised uncertainty for the delineation and vulnerability scores for the Arthur P. Kennedy WTP are summarized in **Table D2-41**.

Table D2-41: Uncertainty Level Ratings – Arthur P. Kennedy WTP IPZ -2

IPZ Delineation	In-Water	HIGH
	Upland	MODERATE
	Overall	HIGH
Vulnerability Score		LOW
Combined Rating		**HIGH**

Lorne Park – IPZ-2

Delineation Uncertainty

There are two delineation components that require an uncertainty analysis, the hydrodynamic modeling and methodology for the delineation of the in-water portion and extension to shore, and the methodology employed to delineate the upland portion.

Hydrodynamic In-water Modeling

The uncertainty level is high for IPZ-2 delineation due to the general lack of data to calibrate the model suites and the limited data inputs used to drive the model and reach steady state conditions. More data is required to run a variety of scenarios to effectively conceptualize water movement in the study area. In addition, there is high uncertainty with the delineation to shore. The in-water modeling did not indicate a connection to shore; however due to the uncertainties with the model an extension to shore was made.

Upland Methodology

Sheridan Creek, Turtle Creek, Birchwood Creek, Moore Creek, Lornewood Creek, Tecumseh Creek and Credit River were included in the upland delineation. HEC-RAS data was provided by CVC for Sheridan Creek, Birchwood Creek, Lornewood Creek and Credit River. Velocities were unavailable for Turtle Creek, Moore Creek and Tecumseh Creek. The average velocity of the nearest creek was used in the up-tributary calculations for these three creeks. Due to the conservative nature of the HEC-RAS data and the assumed velocities used for Turtle Creek, Moore Creek and Tecumseh Creek, the up-tributary delineations have a moderate level of uncertainty.

Storm sewer networks were available and were included in the upland delineation for the Lorne Park WTP study area. Catchment area extents were not provided and therefore were estimated. Velocities were not available for the storm sewers. There is low uncertainty as to which storm networks should be included; however, there is high uncertainty as to the extent of the network that should be included.

Vulnerability Scoring Uncertainty

Data used in the delineation of the upland IPZ-2 and vulnerability assessment for the Lorne Park WTP was evaluated based upon quality, and relevance of the information.

Quality

The available data used to determine the vulnerability scores were provided by provincial and municipal sources, and CVC. A high level of confidence in the quality of the data was established based on the assumption that adequate quality control programs are in place for the sources.

Relevance

Available datasets for the area factor analysis were relevant. The % area that is land was determined using the Water Poly Segment (WPS) datasets available from the Ministry of Natural Resources and Forestry. The impervious land cover and land cover type was determined using SOLRIS (2009) information. Slope was determined using Ontario Base Mapping contours. Storm sewers were analyzed for the transport pathway portion of the area vulnerability analysis. Storm sewer networks were obtained from the Region of Peel and all the datasets used were relevant to the study area.

QA/QC measures were applied to each component of the vulnerability factor analysis. Vulnerability factors were reviewed throughout the analysis process and as such the confidence in the data and the calculations used in the vulnerability analysis was high resulting in a low uncertainty rating.

Uncertainty Level Summary

The revised uncertainty for the delineation and vulnerability scores for the Lorne Park WTP are summarized in **Table D2-42**.

Table D2-42: Uncertainty Level Ratings – Lorne Park WTP IPZ -2

IPZ Delineation	In-Water	HIGH
	Upland	MODERATE
	Overall	HIGH
Vulnerability Score		LOW
Combined Rating		**HIGH**

Data Gaps and Methods

In general, the quality and quantity of data available from readily available public domain data sources are sufficient to characterize the intake and setting, undertake preliminary delineation of IPZ-2, and conduct qualitative vulnerability analyses for zone and source factors. There are no gaps in data essential to completing a preliminary scoping IPZ and vulnerability assessment analysis. In order to complete a more comprehensive analysis, data gaps identified in **Table D2-43** should be addressed. To indicate the relative importance of identified data gaps, priority ratings of high, moderate, and low have been assigned to each data gap listed in **Table D2-43**.

Assumptions

In an effort to fulfill the gaps in the IPZ-2 delineation area characterizations, and vulnerability zones assumptions had to be made. By doing so, an area representing locations where contaminants and vulnerabilities exist that have the potential to affect the WTP and its intake was developed. Below is a list of the assumptions that were made in deriving the upland extents of the landward IPZ-2:

1. Overland flow and drainage patterns are based on topographical information;

2. Stormsheds were assumed on the basis that large urban areas are drained by storm sewer networks;
3. Projection of alongshore extent of IPZ-2 is assumed to provide some upland IPZ-2 extents. The level of modelling uncertainty is high and thus onshore and tributary outfall components are not explicitly represented;
4. Residual time method was used in delineating upland IPZ-2 boundaries;
5. Where regulated limit is not provided the assumed upland extent for shoreline components and tributary watercourses is 120 m; and
6. Transportation corridors are assumed to connect directly to vulnerability pathways.

Table D2-43: Data Gaps

Vulnerability Deliverable	Data Set Name	Priority	Comment
IPZ-2 Delineation	Sewershed	Moderate	Refine the boundary conditions for the model. Needed to improve the accuracy of IPZ-2 delineation
	Stream properties	High	Refine the boundary conditions for the model. Needed to improve the accuracy of IPZ-2 delineation
Intake and Area Characterization	Raw water quality data (DWSP and DWIS data)	High	Determine the characteristics of the raw water. Needed to fulfill characterization requirements outlined Intake and Area in Module 4
	Sediment quality data	Low	Determine the threat from lakebed sediment. Needed to fulfill characterization requirements outlined in Module 4
Zone Vulnerability Score	Outfall data (storm water outfalls, combined sewer outfalls and overflows)	High	Determine threat from outfalls. Needed to improve understanding of preferential pathways and zone vulnerability score

References

Annable, W.K. (1996). Database of morphologic characteristics of watercourses in Southern Ontario: Ontario Ministry of Natural Resources report, 212 pp.

Beak Consultants Ltd., Raven Beck Environmental Ltd., and Waterloo Hydrogeologic. (1995). Delineation of the Capture Zones for Middleton Street Well Field, Cambridge, Ontario. Report prepared for the Regional Municipality of Waterloo, April 1995.

Burnside and Gartner Lee. (2004). Interactions Between Pumping of Pullen, Transmetro and Dudgeon Wellfields and Upper Branch of Lower Monora Creek. Unpublished report. February 2004. File M-1355.5.

Cherry, J.A., Parker, B.L., Bradbury, K.R., Gotkowitz, M.B., Eaton, T.T., Hart, D.J., and Borchardt, M.A. (2007). *Contaminant Transport through Aquitards: Technical Guidance for Aquitard Assessment*. AWWA Research Foundation, 270 p.

Duke Engineering and Services Inc. (1998). Numerical and Analytical Modelling to Guide Selection of Bedrock Transport Porosity for Use in Cambridge Capture Zone Modelling. Report submitted to the Regional Municipality of Waterloo, September 1998.

Duke Engineering and Services Inc. (1998b). Cambridge Capture Zone Modelling Project – Final Report. Prepared for the Regional Municipality of Waterloo, November 1998.

Earthfx Incorporated, 2010, Water balance analysis of the Lake Simcoe basin using the Precipitation-Runoff Modelling System (PRMS): prepared for the South Georgian Bay Lake Simcoe Source Protection Region, October 2010.

Freeze, R.A., and Cherry, J.A. (1979). *Groundwater*. Upper Saddle River, NJ: Prentice-Hall Inc.

Harbaugh, A.W., and McDonald, M.G. (1996). User's documentation for MODFLOW-96, an update to the U.S. Geological Survey modular finite-difference ground-water flow model: U.S. Geological Survey Open File Report 91-484. 358 p.

KMK consultants Limited (KMK). (2004). Lakeview Wastewater Treatment Plant Effluent Modeling; Prepared for the Regional Municipality of Peel. November 2004.

Leopold, L.B. and Maddock, T. Jr., 1953, The hydraulic geometry of stream channels and some physiographic implications: USGS Professional Paper 252, 57 pp.

Lotowater. (1997). Study of the Hydrogeology of the Cambridge Area. Report to the Regional Municipality of Waterloo.

Matrix Solutions Inc. (Matrix). (2017). *Inglewood Wellhead Protection Area Delineation Wells ING3 and ING4, Peel Region*. February 2017. Waterloo, ON: Matrix Solutions Inc.

Matrix Solutions Inc. (Matrix). (2018). *Vulnerability Assessment and Vulnerability Scoring for Inglewood Well 4, Region of Peel*. August 2018. Guelph, ON: Matrix Solutions Inc.

McDonald, M.G. and A.H. Harbaugh, 1988. A modular three-dimensional finite-difference ground water flow model. In techniques of water-resources investigations of the United States Geological Survey, Book 6, Chapter A1.

MDEQ. 2004. Michigan Department of Environmental Quality Water Bureau. State of Michigan Source Water Assessment Program Report, December 2004.

Ministry of the Environment. (2001). Groundwater Studies 2001/2002. Technical Terms of Reference.

Ministry of Municipal Affairs and Housing (OMMAH). (2004). *Oak Ridges Moraine Aquifer Vulnerability Mapping*. Accompanying Document to the Reference Map for Ontario Regulation 140/02 (Oak Ridges Moraine Conservation Plan). March 2004.

Mississauga. (2006). City of Mississauga Storm Sewer Network 2006.

Russell, H.A., Brennand, T.A., Logan, C., and Sharpe, D.R. (1998). Standardization and assessment of geological descriptions from water well records, Greater Toronto and Oak Ridges Moraine Areas, southern Ontario. *Current Research 1998-E*, Ottawa: ON, Geological Survey of Canada, p 89-102.

Spitz, K. and Moreno, J. (1996). A practical guide to groundwater and solute transport modeling. Wiley Interscience. New York.

Terraprobe. (2006a). Hydrogeologic Investigations, Proposed Hamount and Valleygrove Development, Amaranth. File 1-01-0450.

Terraprobe. (2006b). Results of Additional Field Investigations proposed Hamount Valleygrove Developments, Township of Amaranth, Letter to Carmen Navaleza, Harbourview Investments. File No. 1-01-0450.

D3 MOE APPROVAL FOR MODIFIED SWAT ANALYSIS

York Region

Environmental Services

April 1, 2009

Mr. Ian Smith,
Director, Source Protection Programs Branch
Ontario Ministry of the Environment
2 St. Clair Avenue West, 8th Floor
Toronto, ON M4V 1L5

Dear Mr. Smith:

Re: Request for Approval of Water Table to Well Advection Time (WWAT) as Suitable Vulnerability Assessment Method for York Region's Municipal Wells

The following letter is to request your approval of the use of "Water Table to Well Advection Time (WWAT)" as a suitable groundwater vulnerability assessment method, under Section 37 (Part IV.1) of the Technical Rules: Assessment Report, made under the Clean Water Act, 2006.

At the outset of the Vulnerability work, York Region's consultants proposed to develop Surface to Well Advection Time (SWAT) mapping for the Region's Wellhead Protection Areas (WHPAs), by combining numerically-modelled WWAT mapping and manually calculated Unsaturated Zone Advection Times (UZATs). The UZATs would be based on the suggested method found in Appendix 3 of Ministry of the Environment's Assessment Report: Draft Guidance Module 3. However, as the study progressed, a decision was made to proceed with the vulnerability work based solely on the WWAT approach for the following reasons:

1. The UZAT estimations would have a high degree of uncertainty associated with them, due to the numerous variables that UZAT is dependent upon and the limited data available for these variables;
2. Where potential sources of contamination lie below ground surface, either within the unsaturated zone or at the water table (such as underground storage tanks), the WWAT approach may actually provide a more realistic representation of the vulnerability of the water supply; and
3. Where potential sources of contamination are located at ground surface, the WWAT approach would provide a conservative estimation of the travel time of potential contaminants to the well, which would be favourable from the perspective of protecting our municipal well supplies.

The vulnerability assessment of York Region's 37 active municipal wells, based on the WWAT approach, is now complete. We are presently seeking your consideration for the use of the

The Regional Municipality of York, 17250 Yonge Street, Newmarket, Ontario L3Y 6Z1
Tel: 905-895-1200, 1-877-464-9675, Fax: 905-830-6927
Internet: www.york.ca

April 1, 2009 2
Request for Approval of WWAT

WWAT approach as "a method that in the opinion of the Director is equivalent or better than the methods permitted by subrules (1) through (4)" of Section 37 of the Technical Rules.

If you have any questions, please contact Tammy Silverstone, Program Coordinator, Water Resources, at 905-830-4444 extension 5027.

Sincerely,

Tammy Silverstone, P.Eng., M.Eng.
Program Coordinator, Water Resources

TS/sc

Copy to: Wendy Kemp, Manager, Water Resources, York Region

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D4 TRANSPORT PATHWAY ADJUSTMENT STUDY

Introduction

The assessment reports for the three authorities of the CTC SPR (Credit Valley Source Protection Authority (CVSPA), Toronto and Region Source Protection Authority (TRSPA), and Central Lake Ontario Source Protection Authority (CLOSPA)), were completed in accordance with the *Clean Water Act, 2006 and Technical Rules (MOE, Nov 2009)*. The CTC source protection authorities identified gaps in their assessment reports where the data required were not available in time to meet the submission deadlines. One of the gaps identified is related to *Technical Rules 39 to 41* where groundwater vulnerability scores may be increased as a result of man-made pathways that serve to circumvent the natural environment's protective layers.

These 'transport pathways' may allow for contaminating chemicals from anthropogenic activities to reach an aquifer in a shorter time frame than would normally occur as they have the potential to compromise the natural vulnerability afforded by the geology. These pathways include structures such as abandoned or improperly maintained wells, pits and quarries, and sanitary and storm sewage systems. While some SPR study teams chose to increase the vulnerability score wherever these structures exist, the CTC technical team recognized that all structures could not be treated equally and should be further examined.

The potential impact on the aquifer is highly dependent on details associated with the specific location and each structure such as the local geology, the method of well construction of the structure, and the proximity of the structure to the aquifer. Thus, it was decided that vulnerability as determined using approved methodologies would not be increased until additional data could be collected, and a series of logical considerations completed to screen out sites/structures that would more likely warrant an increase in vulnerability score.

The CTC SPR technical team analyzed the question and developed a standard methodology to effectively and consistently deal with assessing various anthropogenic pathways and to estimate their impact on groundwater vulnerability on a case-by-case basis. The methodology has been developed and applied to the current scores of groundwater vulnerability as delineated in the assessment reports for the three SPAs. A revision of the vulnerability for pathways generally results in an increase to the vulnerable areas currently mapped as Highly Vulnerable Aquifers (HVAs), Significant Groundwater Recharge Areas (SGRAs) and Well Head Protection Areas (WHPAs) for areas with medium or low scores.

The managed lands, imperviousness and threat enumeration maps and analyses will also require revision as a result of these changes as these analyses are required in areas with specific vulnerability scores. These updates to the vulnerability mapping based on the anthropogenic pathway vulnerability assessment will be included in updated assessment reports.

This document is intended as a supporting document for selected methodologies for considering the effect of transport pathways on the vulnerability of an area. Data availability was considered as part of this analysis.

D4.1.1 Objective

The primary objective of this study is to review and update the Groundwater Vulnerability Analyses for the CTC SPR (CVSPA, TRSPA, and CLOSPA). The *Technical Rules Part IV.1 (39 to 41) Vulnerability Assessment and Delineation, Groundwater, (MOE, Nov 2009)* and *Clean Water Act, 2006* allows for an increase in vulnerability scoring for an aquifer due to the presence of transport pathways (anthropogenic in origin), see **Section D4.2.1**.

D4.1.2 Study Area

The CTC SPR is comprised of the CVSPA, TRSPA, and CLOSPA. A map showing the geographic extent of the study area is shown on **Figure D4-1.**

D4.1.3 Scope of Work

The Groundwater Vulnerability Analysis applied within the CTC SPR currently includes three approved methods to assess groundwater vulnerability, *Technical Rules (37 & 38):*

a) Aquifer Vulnerability Index (AVI);
b) Intrinsic Susceptibility Index (ISI); and
c) Surface to Well Advection Time (SWAT).

As part of the groundwater vulnerability analysis three vulnerable areas were delineated using one or more of the above groundwater vulnerability assessment methods. These vulnerable areas include:

1. Highly Vulnerability Aquifer (HVA);
2. Significant Groundwater Recharge Area (SGRA); and
3. Well Head Protection Area (WHPA).

The CTC selected an Aquifer Vulnerability Index (AVI) approach for Highly Vulnerability Aquifer (HVA) and Significant Groundwater Recharge areas (SGRA). This approach uses the interpreted products of geological and numerical models (three dimensional geologic layers). The AVI method does not estimate potential contaminant travel time or the behavior of specific contaminants. Rather, it produces a numerical index representing the relative vulnerability of an aquifer, based on the type and thickness of the soil above. A more detailed description of the methodology used to delineate the AVI is found in *Gerber (2010)*.

The vulnerability approaches for the various CTC WHPAs ranged and were based on complex hydrogeologic models (reverse particle tracking), local Aquifer Vulnerability Index (AVI), local Intrinsic Susceptibility Index (ISI), and local modified Surface to Well Advection Time (SWAT) as outlined in the SWAT approach estimates potential contaminant travel time from the ground surface to the well intake. The CTC applied a modified SWAT (UZAT + WWAT) in several of its WHPAs and assumed a zero time-of-travel in the unsaturated zone (UZAT), as approved by the MOECC Director as per the *Technical Rule 38(3).* A more detailed description of methodologies used to delineate the WHPAs using this approach can be found in Burnside (2010) and EarthFx Inc. (2010) as summarized in **Table D4-1**, **Table D4-2**, and **Table D4-3**.

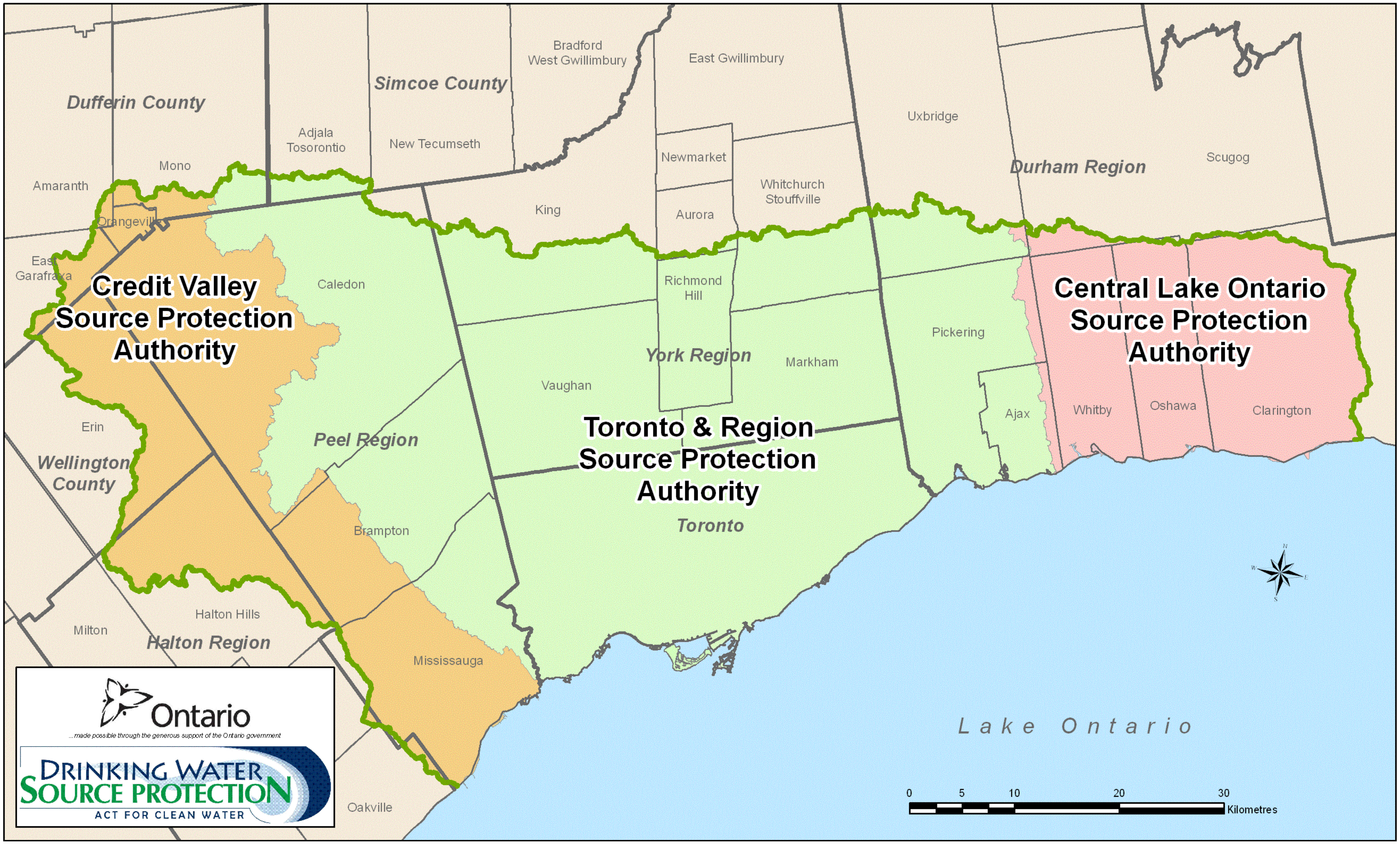


Figure D4-1: CTC Source Protection Region

An ISI approach is similar to an AVI approach except the ISI considers also the static water level in the well. The ISI method requires that the uppermost aquifer be at least partially saturated (MOE, 2006).

The SWAT approach estimates potential contaminant travel time from the ground surface to the well intake. The CTC applied a modified SWAT (UZAT + WWAT) in several of its WHPAs and assumed a zero time-of-travel in the unsaturated zone (UZAT), as approved by the MOECC Director as per the *Technical Rule 38(3).* A more detailed description of methodologies used to delineate the WHPAs using this approach can be found in Burnside (2010) and EarthFx Inc. (2010).

Table D4-1: Groundwater Vulnerability Assessment Methods Applied in CTC Vulnerable Areas.

<table>
<tr><th>Vulnerable Areas</th><th colspan="2">CVSPA</th><th colspan="2">TRSPA</th><th>CLOSPA</th></tr>
<tr><td>HVA</td><td colspan="5" rowspan="2">Regional Aquifer Vulnerability Index (AVI)</td></tr>
<tr><td>SGRA</td></tr>
<tr><td rowspan="4">WHPA</td><td>Dufferin</td><td>Local Aquifer Vulnerability Index (AVI)</td><td>York</td><td>Local Surface to Well Advection Time (SWAT) (UZAT =0)</td><td rowspan="4">Not Applicable</td></tr>
<tr><td>Wellington</td><td>Local Intrinsic Susceptibility Index (ISI)</td><td rowspan="2">Durham</td><td rowspan="2">Local Intrinsic Susceptibility Index (ISI)</td></tr>
<tr><td>Halton</td><td>Local Surface to Well Advection Time (SWAT) (UZAT =0)</td></tr>
<tr><td>Peel</td><td>Local Surface to Well Advection Time (SWAT) (UZAT =0)</td><td>Peel</td><td>Local Surface to Well Advection Time (SWAT) (UZAT =0)</td></tr>
</table>

The relative vulnerability within each of these areas has been characterized as high (score 6), medium (score 4), or low (score 2) for AVI and scores 2 to 10 in WHPAs. In this context, the categorization is intended to reflect the susceptibility of the aquifer(s) in the vulnerable areas to surface (or near surface) sources of contamination. This follow-up study seeks to review the estimated groundwater vulnerability and intrinsic vulnerability scores and adjust the vulnerability scores as necessary to account for transport pathways. The structures listed in Error! Reference source not found. will be considered as transport pathways within this study. For the purpose of *Rule (13) (1)*, an analysis of uncertainty classified as high or low is also required.

Three separate products are expected out of this process:

1. A revised vulnerability map for the full CTC jurisdiction using the AVI (Aquifer Vulnerability Index) methodology;
2. A revised CTC HVA (High Vulnerability Aquifer) map showing the additional areas added to the HVA delineation as a result of modifications to the full CTC vulnerability map; and
3. WHPA updated vulnerability maps where the well specific aquifer is assessed and updated within WHPAs A-D.

It should be noted that this task was scoped as a desktop exercise. Ground truthing exercises were not feasible within the time frame for completion. Additionally, the cost associated with such work in the broader landscape would be exorbitant and an inefficient use of funds at this time given the more pressing drinking water concerns within the CTC SPR.

Available Methodologies

D4.1.4 Technical Rules, Nov 2009, and Guidance, 2006

The vulnerability of an aquifer may be increased by any land use activity or structure that disturbs a formation above the aquifer that acts as a protective layer, or which artificially enhances flow to the aquifer. Within a zone of vulnerability, transport pathways such as abandoned wells or quarries can eliminate partially or entirely, the protective layers above the aquifers and form a direct conduit between the ground surface and the aquifer. Such structures significantly increase locally the vulnerability of the zone, and this should be reflected in the vulnerability assessment of the area.

Following the Aquifer Vulnerability Index (AVI) approach, areas of high vulnerability are usually associated with shallow and unconfined aquifers. This document focuses on deeper or confined aquifers and activities that could disturb overlying protective soils, thereby rendering these aquifers to be more vulnerable by potentially allowing contaminants to get to the groundwater faster.

The following section describes how the vulnerability may be modified in an area due to the existence of transport pathways in the Director's Rules. In particular *Rules 39 to 41* define the framework for rating transport pathways.

Vulnerability increase, transport pathways:

Rule (39): Where the vulnerability of an area identified as low in accordance with Rule 38 is increased because of the presence of a transport pathway that is anthropogenic in origin, the area shall be identified as an area of medium or high vulnerability, high corresponding to greater vulnerability.

Rule (40): Where the vulnerability of an area identified as medium in accordance with Rule 38 is increased because of the presence of a transport pathway that is anthropogenic in origin, the area shall be identified as an area of high vulnerability.

Rule (41): When determining whether the vulnerability of an area is increased for the purpose of rules 39 and 40 and the degree of the increase, the following factors shall be considered:

(1) Hydrogeological conditions;
(2) The type and design of any transport pathways;
(3) The cumulative impact of any transport pathways; and
(4) The extent of any assumptions used in the assessment of the vulnerability of the groundwater.

Assessment Report: Draft Guidance Modules, Source Protection Technical Studies, Module 3 - Appendix 5: Groundwater Vulnerability Analysis October 2006,

Guidance on determining when it is appropriate to use a transport pathway adjustment and selecting the appropriate adjustment is provided in *Appendix 5 - Module 3: Groundwater Vulnerability Analysis, Provincial Guidance Modules,* (MOE, 2006). This provincial guidance was later replaced by the Director's Rules but reflects the accepted approaches to the adjustment of vulnerability. Vulnerability adjustments may be increased one or more categories and is based on professional judgment.

The procedure to account for these pathways in the water quality risk assessment scoring involved the following steps:

- Collection of Transport Pathways Inventory – an inventory of the transport pathways was compiled;

- Determining the Appropriate Score Modifier - the transport pathways inventory was reviewed and assessed to determine whether there was adequate data to justify an adjustment and if so what the appropriate modifier value should be. The bypassing of the natural protection of an aquifer will essentially increase the vulnerability index for that aquifer. Where an aquifer is already determined to be of high intrinsic vulnerability, no further increase is possible; and
- Modifying the Transport Pathway Adjustment based on Risk Management Activities – the score modifier may be subsequently reduced if risk management activities (e.g., proper abandonment of boreholes) have been undertaken to mitigate the impact of the transport pathway. This step requires 'ground-truthing' and is out of scope for this study though some site-specific information may become available during public consultation.

D4.1.5 Transport Pathway Inventory

The following provides a general overview of the contents of the available pathways data inventory while reference should be made to **Table D4-2**.

Table D 4-2: Transport Preferential Pathways of Concern

TRANSPORT PATHWAYS - Groundwater	
Where human-made pathways * present the risk of augmenting the transmission of drinking water contaminants into aquifer sources.	
Vertical	▪ Water Wells, existing and abandoned
	▪ Gas and Oil Wells
	▪ Exploration Holes or Wells
Horizontal	▪ Pits and Quarries
	▪ Mines
	▪ Large Diameter Pipes (Trunk Sewers, Gas or Oil Pipes)
	▪ Septic Systems
	▪ Sanitary and Storm Sewage Systems

* Such pathways could include, but not necessarily be limited to.

Modified from: Module 5: Issues Evaluation and Threats Inventory, Provincial Guidance Modules, (MOE, 2006), www.ene.gov.on.ca/en/water/cleanwater/cwa-guidance.php

CTC staff only considered the pathways on the above list as the most common pathways. Digital maps showing the location and distribution of these transport pathways where available were obtained and reviewed. Many of the target data were found to either not be available in digital format (septic locations outside of the WHPAs), were incomplete regarding the data required to determine the feature's impact on aquifer vulnerability (e.g., the varying depth of a trunk sewer along its full path), or of poor quality (privately owned water well data). As well, some pathways are not known to exist in the CTC (mines). Additionally, some pathways were already considered and incorporated in the CTC WHPA vulnerability analyses where site specific data were available. After reviewing all the available data, CTC staff decided to consider only the following pathways:

AVI

- All boreholes (wells, gas, and oil, exploratory and geotechnical) that are ‘clustered’; and
- Pits and quarries.

WHPAs

- All boreholes (wells, gas, and oil, exploratory and geotechnical) that are ‘clustered’; and
- Large pipes (horizontal pathway).

Note: Pits and quarries, were already considered

Septic, and sanitary and storm sewage systems were considered in the WHPAs in the assessment of threats analysis. Private septic systems were not considered for this AVI pathways work given that these ‘structures’ are shallow. Therefore, the Aquifer Vulnerability Index (AVI) approach generally picks up high vulnerability scores in shallow and unconfined aquifers.

Geothermal wells and excavations (ponds, etc.) were not considered in this analysis, but may be considered in future iterations of the Assessment Report as suggested by municipal representatives. Data for these potential pathways were not available for this study.

D4.1.6 Determining the Appropriate Score Modifier

According to the Directors Rules, to account for the presence (and potential impact) of transport pathways on groundwater quality, the intrinsic vulnerability determined from the intrinsic groundwater vulnerability assessment may be increased by the assessment team to reflect (in a relative manner) an increase in the vulnerability of the aquifer(s) of interest. The increase in the intrinsic vulnerability is generally increased one step (e.g., from low to moderate or from moderate to high), except in extreme cases where the transport pathway is considered to increase the intrinsic vulnerability of the aquifer from low to high. In this case (e.g., a pit or quarry which completely breaches any low permeability layers overlying a deeper aquifer) an increase from low to high vulnerability may be considered. After modifying the intrinsic vulnerability, the vulnerability score must be recalculated. The resultant vulnerability score would then reflect the enhanced vulnerability due to the assessed presence of preferential pathways.

Factors that should be considered in evaluating the need for, the magnitude of, and the spatial footprint applicable for the adjustment value include:

Geology: Depending on the geology and hydrogeological conditions, transport pathways may have a significant influence on groundwater vulnerability. In areas already identified as high aquifer vulnerability, transport pathways would provide no further risk to the water quality of the aquifer. In these cases, no additional modifier can be applied. Conversely, in areas where natural groundwater protection is reflected in a medium or low vulnerability classification, artificial pathways through (or partially through) the natural protective layers may increase the vulnerability to a medium (or high) classification.

Nature and design of a transport pathway: The physical characteristics of the transport pathway must be considered to determine if the transport pathway extends to the water table or breaches protective layers (e.g., low permeability soils or bedrock strata) above the aquifer(s) of interest. For example, where the transport pathway is not deep enough to penetrate the natural protective layers above the aquifer, an adjustment to the original score may not be necessary. Conversely, where the transport pathway completely penetrates the overlying layers (e.g., an improperly abandoned or poorly constructed well) then an adjustment (increase) in the intrinsic vulnerability may be warranted on a local basis. The extent (or area) associated with the adjustment should be based on the physical characteristics (dimensions) of the transport pathway and the local hydrogeological conditions (e.g., the transport pathway may serve to connect flow in shallow and intermediate depth aquifers with deeper aquifers). In other words, while specific parcels of land may not have a transport pathway present within their immediate footprint, their vulnerability score could be subject to adjustment based on transport pathways on adjacent (or nearby) parcels.

Likelihood of the occurrence of transport pathways: The spatial distribution and density of the transport pathways in the vulnerable areas should be considered. The spatial distribution will provide general guidance as to the areal extent across which the vulnerability modifier should be applied, while the density of the transport pathways provides a general indication of the likelihood of a transport pathway providing a connection between a surface (or near surface) source of contamination and the aquifer of interest. Where the density of transport pathways is relatively high (e.g., a cluster of private wells in the same area), then the likelihood of a connection is also relatively high and this should be considered in assigning the intrinsic vulnerability modifier (e.g., high density clusters may warrant an increase in vulnerability ranking, while single wells or lower density clusters may not be considered as warranting an increase).

Notwithstanding the above, consideration must be given to the assumptions made in completing the intrinsic vulnerability assessment. Where conservative assumptions have already been applied in mapping the intrinsic vulnerability, additional adjustments for transport pathways may not be warranted or justifiable. For example, where the vulnerability indices may have been calculated conservatively by omitting the upper few metres or more of the geological strata (e.g., in several CTC WHPAs, the upper unsaturated zone was set at zero, i.e., treated as if they provide no protection). This conservatism suggests that a further adjustment to the vulnerability score may not be warranted.

Independent of the above considerations, the resultant vulnerability ranking cannot be increased above "high".

D4.1.7 Modifying the Transport Pathway Adjustment based on Risk Management Activities

Where the intrinsic vulnerability ranking and resultant vulnerability scores have been adjusted these adjustments can be reduced, or even eliminated, to account for risk management activities such as the proper abandonment of unused boreholes or infilling of an excavation or pit. Site specific information is required for such re-adjustments.

The adjustment associated with risk management activities completed may only reduce or remove the original vulnerability ranking modifier and therefore return the vulnerability ranking to its original value. Note that while best management practices applied to particular land use activities (e.g., double-walled tanks for chemical storage, soil conditioning, etc.) may affect the likelihood of a chemical release, they may not be considered as valid risk management activities for reducing the transport pathway modifier. This work is out of scope for this project and may be considered in the implementation of the Source Protection Plan policies.

D4.1.8 Other Jurisdictional Approaches

The municipalities of Dufferin, Wellington, Halton, Peel, York, and Durham completed the Groundwater Vulnerability Analysis in their respective WHPA areas. The reports included various vulnerability methodologies and pathways considerations. **Table D4-3** and **Table D4-4** summarize assumptions and criterions approaches within WHPAs in the CTC SPR.

Table D4-3: Consideration of Pathways in the Vulnerability Assessment in CTC Well Head Protection Areas (WHPAs)

	Municipality		Wells		Methods	Pathways Considered		Comments
Municipal Wells in the CVSPA								
BURNSIDE	**Dufferin**	Orangeville	12	2A, 5/5A, 7, 9A/9B, 6, 11, 8B, 8C, 12, 10	Local AVI	Yes	Pits and quarries, Surface utilities and wells	There were no **aggregate** operations identified within the WHPAs. **Surfaces utilities** were considered; however, there are no utilities located within their WHPAs. A review of **water well** records from the MOECC water well database was conducted to identify wells within the WHPAs. The wells located in these zones were then ranked based on their risk to the supply aquifer. The risk posed by a well is based on the date of construction (hence degree of confidence in its ground level seal) and completion depth in terms of proximity to the aquifer of concern. The survey resulted in the identification of 433 water wells within the WHPAs and classified 269 of the wells as high-risk wells. Vulnerability increased by one category. These results were excluded from the assessment reports because of inconsistency between WHPAs.
		Mono	8	Cardinal Woods (MW-1, MW-3, MW-4) Coles (1 & 2), Island Lake (PW-1, PW-2-06, TW-1)			Pits and quarries, Surface utilities and wells	There were no **aggregate** operations identified within the WHPAs. **Surface utilities** the depth of excavation for the construction of utilities were determined and the risk that the utilities pose on the municipal supply aquifer. Since the aquifers used by the municipal supply wells are generally protected by an upper aquitard, the risk posed by utilities is low. Surface utilities were considered; however, the vulnerability was NOT increased. A review of **water well** records from the MOECC water well database was conducted to identify wells within the WHPAs. The wells located in these zones were then ranked based on their risk to the supply aquifer. The risk posed by a well is based on the date of construction (hence degree of confidence in its ground level seal) and completion depth in terms of proximity to the aquifer of concern. The survey resulted in the identification of 69 water wells within the WHPAs and classified 42 of the wells as high-risk wells. Vulnerability increased by one category. These results were excluded from the assessment reports because of inconsistency between WHPAs.
		Amaranth	1	Pullen Well			Pits and quarries, Surface utilities and wells	There were no **aggregate** operations identified within the WHPAs. **Surfaces utilities** were considered; however, there are no utilities located within their WHPAs. A review of **water well** records from the MOECC water well database was conducted to identify wells within the WHPAs. The wells located in these zones were then ranked based on their risk to the supply aquifer. The risk posed by a well is based on the date of construction (hence degree of confidence in its ground level seal) and completion depth in terms of proximity to the aquifer of concern. The survey resulted in the identification of 9 water wells within the WHPAs and classified 5 of the wells as high-risk wells. Vulnerability increased by one category. These results were excluded from the assessment reports because of inconsistency between WHPAs.
GOLDER BLACKPORT &	**Wellington**	Erin	5	Erin Village (E7 & E8) Hillsburgh Village (H2 & H3) Bel Erin	Local ISI	No	Pits/ quarries and surface utilities	**Pits/ quarries**, and **surface utilities** were considered; however, no transport pathways were identified within the Erin and Hillsburgh and Bel-Erin WHPAs and as such the vulnerability was not adjusted. It is noted that private wells were not considered in the transport pathway assessment at this time.

	Municipality		**Wells**		**Methods**	**Pathways Considered**		**Comments**
Municipal Wells in the CVSPA								
EARTHFX	**Halton**	Acton	5	4th Line, Davidson (1 & 2), Prospect Park (1 & 2)	Local SWAT-MODFLOW	Yes	Pits and quarries, and clusters wells before 1990	SWAT – UZAT equal zero (Unsaturated Zone removed for the consideration of vulnerability). **Pits and quarries** vulnerability was increased by one category. **Surface Utilities** were not considered. **Clusters of deep wells** (greater than 20 m below the recorded static elevation) and wells that were installed after 1990 were identified. The vulnerability score within the area outlined by the well locations was increased from low to medium. These results were excluded from the assessment reports because of inconsistency between WHPAs.
		Georgetown	7	Lindsay Court (9), Princess Anne (5 & 6), Cedarvale Park (1-A, 3-A, 4 & 4-A)				SWAT – UZAT equal zero (Unsaturated Zone removed for the consideration of vulnerability). **Pits and quarries** vulnerability was increased by one category. **Surface Utilities** were not considered. **Clusters of deep water wells** (greater than 20 m below the recorded static elevation) and wells that were installed after 1990 were identified. The vulnerability score within the area outlined by the well locations was increased from low to medium. These results were excluded from the ARs because of inconsistency between WHPAs.
BURNSIDE	**Peel**	Caledon	8	Alton (3 & 4), Caledon Village (3 & 4), Inglewood (2 & 3), Cheltenham (PW-1/PW-2)	Local SWAT-FEFLOW	Yes	Pits and quarries (Caledon Village 3/, Alton 3 & 4), Surface utilities (Alton 3 & 4), septic systems (Alton, Cheltenham, Caledon Village, Inglewood), single wells before 2002 (buffer 30m)	SWAT - UZAT equal zero (Unsaturated Zone removed for the consideration of vulnerability). Vulnerability was increased because of **pits and quarries** and proximity to water system by one category. **Surface utilities** were considered. Vulnerability increased by one category. Since **septic systems** only penetrate the upper few metres of the ground, they will only provide preferential pathways when they penetrate the water table of an unconfined aquifer system. The wells that utilize an unconfined overburden aquifer include Alton 3, Alton 4. These results were excluded from the assessment reports because of they are covered in the threats enumeration. **Single water wells** constructed before 2002 were considered and a buffer of 30 m radius around the wells was applied and the vulnerability of that area was increased by one category. These results were excluded from the assessment reports because of inconsistency between WHPAs.
	TRSPA – WHPAs							
BURNSIDE	**Peel**	Caledon East	3	Well (2, 3 & 4)	Local SWAT-MODFLOW	Yes	Pits and quarries, large sewage (Caledon E-2), septic systems, single wells before 2002 (buffer 30m)	SWAT – UZAT equal zero (Unsaturated Zone removed for the consideration of vulnerability). **Pits and quarries** were considered; however, there are no pits and quarries located within their WHPAs. **Large sewage** was considered. Vulnerability increased by one category. **Septic systems** were considered; however, there are no septic systems located within their WHPAs. These results were excluded from the ARs because of they are covered in the threats enumeration. **Single water wells** constructed before 2002 were considered and a buffer of 30 m radius around the wells was applied and the vulnerability of that area was increased by one category. These results were excluded from the assessment reports because of inconsistency between WHPAs.

	Municipality		Wells		Methods	Pathways Considered		Comments
Municipal Wells in the CVSPA								
BURNSIDE	**Peel**	Palgrave	3	Well (2, 3 & 4)	Local SWAT-MODFLOW	Yes	Pits and quarries, surface utilities (Palgrave 2) Septic Systems (Palgrave) single wells before 2002(buffer 30m)	SWAT – UZAT equal zero (Unsaturated Zone removed for the consideration of vulnerability). **Pits and quarries** were considered; however, there are no pits/quarries located within their WHPAs. **Surface utilities** were considered. Vulnerability increased by one category. Since **septic systems** only penetrate the upper few metres of the ground, they will only provide preferential pathways when they penetrate the water table of an unconfined aquifer system. The wells that utilize an unconfined overburden aquifer include Palgrave 2. **Single water wells** constructed before 2002 were considered and a buffer of 30 m radius around the wells was applied and the vulnerability of that area was increased by one category. These results were excluded from the assessment reports because of inconsistency between WHPAs.
EARTHFX	**York**	Nobleton	3	Wells 2, 3 & 4	Local SWAT - MODFLOW	No	Pits and quarries and wells	SWAT – UZAT equal zero (Unsaturated Zone removed for the consideration of vulnerability). **Pits and quarries and wells** were considered; however, no specific data were found on improperly decommissioned wells or on pits and quarries.
		Kleinburg	3	Wells 2, 3 & 4				
		King City	2	Wells 3 & 4				
		Whitchurch-Stouffville	5	Stouffville (1,2, 3, 5 & 6)				
AECOM	**Durham**	Uxville	2	Wells 1 & 2	Local ISI	Yes	Pit (W-1 & 2), sewage line (W-1 & 2 Buffer 26m) and old cluster water wells (W-1 & 2 Buffer 30m)	Vulnerability increased by one category because of **pit, sewage line** (buffer 26 m) and **old cluster water wells** (buffer 30 m) vulnerability was increased by one category. These results were excluded from the assessment reports because of inconsistency between WHPAs.

Table D 4-4: Summary of Approaches to Consideration of Pathways in the Vulnerability Assessment on Well Head Protection Areas (WHPAs)

Pathways	Steps	Pathways Approaches in Well Head Protection Areas (WHPAs)					
		Burnside (Local AVI)	Blackport &Golder (Local ISI)	Earthfx (SWAT)	Burnside (SWAT)	Earthfx (SWAT)	AECOM (local ISI)
		Dufferin (CVSPA)	Wellington (CVSPA)	Halton (CVSPA) York (TRSPA)	Peel (CVSPA - TRSPA)	York (TRSPA)	Durham (TRSPA)
		Orangeville (12 wells), Mono (8 wells) & Amaranth (1 well)	Erin (5 wells)	Acton (5 wells) & Georgetown (7 wells) Nobleton (3 wells), Kleinburg (3 wells), King City (2) & Whitchurch-Stouffville (5 wells)	Caledon (8 wells), Caledon E (3 wells) & Palgrave (3 wells)	Nobleton (wells 2, 3, & 4), Kleinburg (wells 2,3, &4), King City (wells 3&4), Stouffville (wells ½, 3, 5, &6)	Uxville (2 wells)
Water Wells	Assumptions	Local AVI	▪ No transport pathways were identified within the Erin and Hillsburgh and Bel-Erin WHPAs and as such the vulnerability was not adjusted. ▪ Private wells were not considered in the transport pathway assessment	Groundwater vulnerability analysis of SWAT times, unsaturated zone travel times (UZAT) were set equal to zero (the available data on unsaturated soil properties is very limited and calculation of unsaturated travel times would be highly uncertainty). Therefore, only deep wells that may leak or have improperly abandoned were considered Pathways in WHPAs. The vulnerability rating within the areas outlined by the old deep well cluster locations (before 1990) was increased from low to medium or medium to high. Final vulnerability scores were modified accordingly.	Groundwater vulnerability analysis of SWAT times, unsaturated zone travel times (UZAT) were set equal to zero. Therefore, only deep wells that may leak or have improperly abandoned were considered Pathways in WHPAs. Construction and condition of each individual well was not known and considered. To determine the risk of each individual well a site inspection of the well would be required.	No transport pathways were identified. No specific data were found on improperly decommissioned wells or on pits and quarries that have breached the confining units. It is recommended that York Region begin a program to locate, catalogue, and properly decommission its abandoned wells.	Parcels not served by the municipal infrastructure that may have wells.
	Criteria	A review of water well records from the MOE water well database was conducted to identify wells within the WHPAs. The wells located in these zones were then ranked based on their risk to the supply aquifer. The risk posed by a well is based on the date of construction (hence degree of confidence in its ground level seal) and completion depth in terms of proximity to the aquifer of concern.	Not applicable	Wells that had a depth greater than 20 m below the recorded static elevation. Wells that were installed after 1990, when Ontario Regulation 903 (Wells) under the Ontario Water Resources Act), set out minimum standards for the construction and proper decommissioning of all types of wells, were assumed to be less likely to have failures of the casing or annular seals.	Wells are within the delineated WHPA-A to D and the mapped vulnerability is medium or low. The well intersects an interpreted water supply aquifer or the bottom of the well extends to within 3 m of the interpreted top of the water supply aquifer or the water supply aquifer is unconfined. Wells were constructed before 2002 (all wells constructed after 2002 should have been constructed under the standards of O. Reg. 903 and therefore a lower risk).	Not applicable	Buffer around the wells in the WHPA older than 10 years and that extend to, through, or within 3 m above the top of the municipal aquifer. In this case, the top of the municipal aquifer was conservatively assumed to be 40 m bgs.

Pathways	Steps	Pathways Approaches in Well Head Protection Areas (WHPAs)					
		Burnside (Local AVI)	**Blackport &Golder (Local ISI)**	**Earthfx (SWAT)**	**Burnside (SWAT)**	**Earthfx (SWAT)**	**AECOM (local ISI)**
		Dufferin (CVSPA)	**Wellington (CVSPA)**	**Halton (CVSPA) York (TRSPA)**	**Peel (CVSPA - TRSPA)**	**York (TRSPA)**	**Durham (TRSPA)**
		Orangeville (12 wells), Mono (8 wells) & Amaranth (1 well)	**Erin (5 wells)**	**Acton (5 wells) & Georgetown (7 wells) Nobleton (3 wells), Kleinburg (3 wells), King City (2) & Whitchurch-Stouffville (5 wells)**	**Caledon (8 wells), Caledon E (3 wells) & Palgrave (3 wells)**	**Nobleton (wells 2, 3, & 4), Kleinburg (wells 2,3, &4), King City (wells 3&4), Stouffville (wells ½, 3, 5, &6)**	**Uxville (2 wells)**
Water Wells	Buffer	Not applied	Not applicable	Not applied	A 30 m radius around the well was increased by one category. A 30 m radius has been chosen based on the recommended setback distance from contamination sources in the Ontario Regulation 903 as amended. This distance has also been incorporated in the Ontario Building Code.	Not applicable	Delineation of a 30 m buffer around the wells in the WHPA older than 10 years and that extend to, through, or within 3 m above the top of the municipal aquifer.
	Comments	Orangeville - 433 water wells identified, 269 of the wells as high-risk wells. Vulnerability increased by one category. Mono - 69 water wells identified, and 42 classified as high-risk wells. Vulnerability increased by one category. Amaranth - The survey resulted in the identification of 9 water wells within the WHPAs and classified 5 of the wells as high-risk wells. Vulnerability increased by one category.	Not applicable	Unsaturated zone travel times (UZAT) were set equal to zero. Therefore, constructed pathways that could possibly reduce unsaturated zone travel times would not result in an increase in the vulnerability scores already assigned. It is more likely that older wells, rather than wells constructed after 1990, would be improperly decommissioned. vulnerability will still require land-use planning and water quality monitoring.	Groundwater vulnerability analysis of SWAT times, unsaturated zone travel times (UZAT) were set equal to zero. Therefore, only deep wells that may leak or have improperly abandoned were considered pathways in WHPAs. For transport pathways located in areas not considered to discharge to the municipal well, no initial WWAT (Water Table to Well Advection Time) was provided, and no update was performed. Based on their exact point of discharge, the transport pathways may represent a concern to other water resource users or features to which they discharge.		The local ISI mapping shows results similar to the regional interpretation of ISI. This is consistent with the local interpretation of the borehole data, which indicates a partial protection by Halton Till, with partially unprotected conditions at the northern part of the WHPA.

Pathways	Steps	Pathways Approaches in Well Head Protection Areas (WHPAs)					
		Burnside (Local AVI)	Blackport &Golder (Local ISI)	Earthfx (SWAT)	Burnside (SWAT)	Earthfx (SWAT)	AECOM (local ISI)
		Dufferin (CVSPA)	Wellington (CVSPA)	Halton (CVSPA) York (TRSPA)	Peel (CVSPA - TRSPA)	York (TRSPA)	Durham (TRSPA)
		Orangeville (12 wells), Mono (8 wells) & Amaranth (1 well)	Erin (5 wells)	Acton (5 wells) & Georgetown (7 wells) Nobleton (3 wells), Kleinburg (3 wells), King City (2) & Whitchurch-Stouffville (5 wells)	Caledon (8 wells), Caledon E (3 wells) & Palgrave (3 wells)	Nobleton (wells 2, 3, & 4), Kleinburg (wells 2,3, &4), King City (wells 3&4), Stouffville (wells ½, 3, 5, &6)	Uxville (2 wells)
Aggregate Operation	Assumptions	There were no aggregate operations identified within the WHPAs	Pits and quarries were considered; however, they were not identified within the WHPAs	Groundwater vulnerability analysis of SWAT times, unsaturated zone travel times (UZAT) were set equal to zero. The vulnerability score within the area outlined by the gravel pits and quarries were increased by one category.	Groundwater vulnerability analysis of SWAT times, unsaturated zone travel times (UZAT) were set equal to zero. The constructed pathway is considered to increase the vulnerability of the aquifer from low to high.	Pits and quarries were considered; however, they were not identified within the WHPAs.	Vulnerability was increased because of pits from medium to high.
	Criteria	Not Applicable	Not Applicable	Pits and quarries that extend to or below the water table.	Pits and quarries that extend to or below the water table.		
	Buffer	Not Applicable	Not Applicable	Not applied	Not applied		Not Applied
	Comments	Not Applicable	Not Applicable	The gravel pits may be above the water table and, although the decrease in unsaturated flow times was already accounted for, the removal of overburden also creates a condition where smaller spills may not be sufficiently attenuated (through mechanisms such as adsorption or residual saturation). Dewatering for the limestone quarry would likely cause local inward gradients during most of the year but the quarry could act as a pathway for contaminants to the deeper aquifers at other times of the year.	The removal of the overburden has resulted in the opening up of the underlying overburden and perhaps bedrock layers. This opening up will have resulted in a loss of the protective layers overlying the aquifer across the entire footprint of the gravel pit. When pits or quarries are completely breach any low permeability layers overlying a deeper aquifer. The constructed pathway is considered to increase the vulnerability of the aquifer from low to high.		Vulnerability was increased because of pits from medium to high. The local ISI mapping shows results similar to the regional interpretation of ISI.
Septic Systems	Assumptions	Not considered	Not considered	Not considered	Septic systems are assumed to be used at all rural homes and buildings within villages that do not have municipal sanitary sewage system.	Not considered	Not considered
	Criteria	Not Applicable	Not Applicable	Not Applicable	Penetrate the water table of an unconfined aquifer system.	Not Applicable	Not Applicable
	Buffer	Not Applicable	Not Applicable	Not Applicable	Not applied	Not Applicable	Not Applicable
	Comments	Not Applicable	Not Applicable	Not Applicable	Groundwater vulnerability analysis of SWAT times, unsaturated zone travel times (UZAT) were set equal to zero.	Not Applicable	Not Applicable

Pathways	Steps	Pathways Approaches in Well Head Protection Areas (WHPAs)					
		Burnside (Local AVI)	Blackport &Golder (Local ISI)	Earthfx (SWAT)	Burnside (SWAT)	Earthfx (SWAT)	AECOM (local ISI)
		Dufferin (CVSPA)	Wellington (CVSPA)	Halton (CVSPA) York (TRSPA)	Peel (CVSPA - TRSPA)	York (TRSPA)	Durham (TRSPA)
		Orangeville (12 wells), Mono (8 wells) & Amaranth (1 well)	Erin (5 wells)	Acton (5 wells) & Georgetown (7 wells) Nobleton (3 wells), Kleinburg (3 wells), King City (2) & Whitchurch-Stouffville (5 wells)	Caledon (8 wells), Caledon E (3 wells) & Palgrave (3 wells)	Nobleton (wells 2, 3, & 4), Kleinburg (wells 2,3, &4), King City (wells 3&4), Stouffville (wells ½, 3, 5, &6)	Uxville (2 wells)
Trunk Sewers (Storm)	Assumptions	The depth of excavation for the utilities were determined and the risk that the utilities pose on the municipal supply aquifer. Since the aquifers used by the municipal supply wells are generally protected by an upper aquitard, the risk posed by utilities is low.	Surface utilities were considered; however, they were not identified within the WHPAs.	Not considered	Groundwater vulnerability analysis of SWAT times, unsaturated zone travel times (UZAT) were set equal to zero.	Not considered	The proposed road right-of-way for Phase I and Phase II was determined to be 20 m and 23 m respectively. A single buffer for both phases was created using a width of 26 m to ensure complete capture of the storm-sanitary sewage.
	Criteria	Vulnerability was NOT increased.	Not Applicable	Not Applicable	Depth of installation on unconfined aquifer. Construction and condition of each individual utilities.	Not Applicable	Not Applicable
	Buffer	Not Applicable	Not Applicable	Not Applicable	Not applied	Not Applicable	A single buffer for both phases was created using a width of 26 m to ensure complete capture of the storm-sanitary sewage.

Pathways	Steps	Pathways Approaches in Well Head Protection Areas (WHPAs)					
		Burnside (Local AVI)	Blackport &Golder (Local ISI)	Earthfx (SWAT)	Burnside (SWAT)	Earthfx (SWAT)	AECOM (local ISI)
		Dufferin (CVSPA)	Wellington (CVSPA)	Halton (CVSPA) York (TRSPA)	Peel (CVSPA - TRSPA)	York (TRSPA)	Durham (TRSPA)
		Orangeville (12 wells), Mono (8 wells) & Amaranth (1 well)	Erin (5 wells)	Acton (5 wells) & Georgetown (7 wells) Nobleton (3 wells), Kleinburg (3 wells), King City (2) & Whitchurch-Stouffville (5 wells)	Caledon (8 wells), Caledon E (3 wells) & Palgrave (3 wells)	Nobleton (wells 2, 3, & 4), Kleinburg (wells 2,3, &4), King City (wells 3&4), Stouffville (wells ½, 3, 5, &6)	Uxville (2 wells)
	Comments	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	The geological interpretation of the area shows that the thickness of aquitard material is enough to provide protection even when excavated for municipal infrastructure (approximately 5 m). The local ISI mapping shows results similar to the regional interpretation of ISI. This is consistent with the local interpretation of the borehole data.

Pathways	Steps	Pathways Approaches in Well Head Protection Areas (WHPAs)					
		Burnside (Local AVI)	**Blackport &Golder (Local ISI)**	**Earthfx (SWAT)**	**Burnside (SWAT)**	**Earthfx (SWAT)**	**AECOM (local ISI)**
		Dufferin (CVSPA)	**Wellington (CVSPA)**	**Halton (CVSPA) York (TRSPA)**	**Peel (CVSPA - TRSPA)**	**York (TRSPA)**	**Durham (TRSPA)**
		Orangeville (12 wells), Mono (8 wells) & Amaranth (1 well)	**Erin (5 wells)**	**Acton (5 wells) & Georgetown (7 wells) Nobleton (3 wells), Kleinburg (3 wells), King City (2) & Whitchurch-Stouffville (5 wells)**	**Caledon (8 wells), Caledon E (3 wells) & Palgrave (3 wells)**	**Nobleton (wells 2, 3, & 4), Kleinburg (wells 2,3, &4), King City (wells 3&4), Stouffville (wells ½, 3, 5, &6)**	**Uxville (2 wells)**
Sanitary Sewage	Assumptions	Wells located in the deep overburden and bedrock aquifers are not affected by the presence of underground utilities. Well 5/5A are located in an unconfined overburden aquifer however there are no utilities located within their WHPAs.	Surface utilities were considered; however, they were not identified within the WHPAs.	Not considered	Groundwater vulnerability analysis of SWAT times, unsaturated zone travel times (UZAT) were set equal to zero.	Not considered	CAD drawings outlining the proposed location of the storm-sanitary sewage for the two phases of the commercial developments were used to create buffer zones for the analysis.
	Criteria	Vulnerability was NOT increased.	Not Applicable	Not Applicable	Depth of installation on unconfined aquifer. Proximity to the supply well. Construction and condition of each individual utilities.	Not Applicable	Single buffer for both phases was created using a width of 26 m to ensure complete capture of the storm-sanitary sewage.
	Buffer	Not Applicable	Not Applicable	Not Applicable	Not applied	Not Applicable	A single buffer with a width of 26 m to ensure complete capture of the storm-sanitary sewage.
	Comments	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	The local ISI mapping shows results similar to the ISI. This is consistent with the local interpretation of the borehole data.
Deep Excavations / Foundation	Assumptions	Not considered	Not considered	Groundwater vulnerability analysis of SWAT times, unsaturated zone travel times (UZAT) were set equal to zero.	Not considered	Not considered	Not considered
	Criteria	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
	Buffer	Not Applicable	Not Applicable	Not applied	Not Applicable	Not Applicable	Not Applicable

Pathways	Steps	Pathways Approaches in Well Head Protection Areas (WHPAs)					
		Burnside (Local AVI)	**Blackport &Golder (Local ISI)**	**Earthfx (SWAT)**	**Burnside (SWAT)**	**Earthfx (SWAT)**	**AECOM (local ISI)**
		Dufferin (CVSPA)	**Wellington (CVSPA)**	**Halton (CVSPA) York (TRSPA)**	**Peel (CVSPA - TRSPA)**	**York (TRSPA)**	**Durham (TRSPA)**
		Orangeville (12 wells), Mono (8 wells) & Amaranth (1 well)	**Erin (5 wells)**	**Acton (5 wells) & Georgetown (7 wells) Nobleton (3 wells), Kleinburg (3 wells), King City (2) & Whitchurch-Stouffville (5 wells)**	**Caledon (8 wells), Caledon E (3 wells) & Palgrave (3 wells)**	**Nobleton (wells 2, 3, & 4), Kleinburg (wells 2,3, &4), King City (wells 3&4), Stouffville (wells ½, 3, 5, &6)**	**Uxville (2 wells)**
	Comments	Not Applicable	Not Applicable	Most buildings in Georgetown and Acton appear to be one to two stories with outdoor parking. Accordingly, there is no likely to be a risk due to clusters of buildings with deep excavations.	Not Applicable	Not Applicable	The cut and fill for the creation of the industrial park increase vulnerability, but no map of the cut and fill was available.

Methodology Used by CTC SPR

The general factors that should be considered in the evaluation for the need for an adjustment are described in **Section D4.2.1** and include:

- Hydrogeological conditions;
- Type and design of any transport pathways;
- The cumulative impact of any transport pathways; and
- The extent of any assumptions used in the assessment of the vulnerability of the groundwater (TR (41)).

D4.1.9 Collecting Data

Data compilation: Relevant available datasets were reviewed by CVSPA, TRSPA and CLOSPA GIS staff. The data sources are described below:

1. **MOECC WWIS:** to attempt to identify older and unused domestic water wells. The Ontario Ministry of the Environment and Climate Change has recently been collecting water well records for wells that have been properly abandoned. Reconciliation of abandonment records with the original water well record has not been conducted to date.
2. **YPDT database:** to identify other types of boreholes (oil and gas and geotechnical boreholes). This database includes the WWIS records but has also records from the MNDM-OGS and other agencies and covers the CTC area. A more complete inventory was possible with a review of this dataset. As well, this dataset identifies the aquifer associated with the well intakes.
3. **MNRF:** pits and quarries data. In order to determine whether these facilities constitute an anthropogenic pathway, details such as excavation depth and maximum permit excavation depth, stratigraphy encountered, and water levels were examined.
4. **Municipalities:** buried infrastructure such as large diameter pipes (truck sewers, gas or oil pipes) could also form pathways that could increase the vulnerability of aquifer units. Similar to pits and quarries, details regarding construction procedures and stratigraphy encountered were gathered to assess whether these constitute pathways that could enhance aquifer vulnerability.

D4.1.10 Detailed Considerations of Pathways

__Pits and Quarries__

Based on the vulnerability approaches for the various CTC WHPAs used to determine original vulnerability, and the conservatism therein, the CTC technical team agreed to increase vulnerability one level for pits and quarries within both the WHPAs and the full jurisdiction HVA delineation.

__Full jurisdiction vulnerability/ HVA Delineation__

Vulnerability was increased by one category (low to medium or medium to high) for pits and quarries to be consistent with the modifier approach used in the WHPAs.

No buffer was added to the quarry footprint as it is assumed that a buffer is already considered within the boundary of the site. The minimum extraction setback distance (areas where extraction is not permitted) is fifteen metres (15 m) from the boundary of the site, and thirty metres (30 m) from highways, residential land, and water bodies (e.g., wetlands), *(Aggregate Resources Provincial Standards Ontario, 1997)*.

WHPAs:

Vulnerability was not increased because the quarries have already been considered in these analyses both in the time of travel and as a pathway.

- **Halton**: Aggregate operations were identified in the WHPAs of Acton and Georgetown. The vulnerability score within the area outlined by pits and quarries were increased by one step (low to medium or medium to high) as the pits may be above the water table;
- **Peel:** Aggregate operations were identified in the WHPAs of Caledon Village 3 and Alton 3 and 4. The vulnerability was increased by one step (low to medium or medium to high) as all protective sediments overlying the water table have been removed;
- **Durham:** Aggregate operations were identified in the WHPAs of MW1 and MW2. The pit is mostly located within the already highly vulnerable area. Therefore, the vulnerability was increased only in the area of medium vulnerability intersected by the pit; and
- **Dufferin, Wellington and York:** There were no aggregate operations identified within the WHPAs.

D4.1.11 Large Diameter Pipes (Trunk Sewers, Gas or Oil Pipes)

Various consultants adjusted the vulnerability for large pipes in WHPAs using depth of the installation in unconfined aquifers as the deciding criteria. Large diameter pipes located within high vulnerability (AVI, ISI and SWAT (with UZAT set to zero) were not considered for this analysis.

Full jurisdiction vulnerability/ HVA Delineation

The CTC team collected data on the location of deep (≥3 m) large diameter pipes (≥60 cm) that are located within the study area. There are numerous pipes that meet the initial criteria with a range in attribute data provided, such as the substrate fill material, the size of the pipe excavation channel or the buffer. The impact of the pipe as a pathway would have to be determined based on the intersection of the pipe with each aquifer along its path. Specific depth information (z coordinates) was not digitally available. An initial screening of the data revealed that it is beyond the scope and ability of the team to assess the impact of large pipes in an equitable and defensible manner without detailed GIS analyses that was out of scope for this study. Large diameter pipes thus, are not considered in this study for the AVI analysis.

WHPAs:

- **CVSPA:** The Dufferin and Wellington WHPA vulnerability was already assessed, and no adjustment was made for large pipes. The aquifers used by the municipal supply wells are generally protected by an upper aquitard or there are no utilities located within the WHPAs, the risk posed by utilities is low. Vulnerability was therefore not increased at all.

  In Halton, no pathways adjustment was reported by the consultants. The CTC team requested and was provided data on the location of sewers system (>50 cm diameter, > 2m deep) that are located within the study area. The data, however, was not adequate to determine if the pipes penetrate the saturated zone and warranted consideration as preferential pathways. Large pipes, therefore, were not considered for adjustment of vulnerability in this study.

The WHPAs in Peel vulnerability have already been assessed for adjustment associated with large pipes (Alton 3 and 4). Vulnerability was increased one category.

- **TRSPA**: The vulnerability of the WHPAs has already been assessed for adjustment associated with large pipes, increased one step.

  The WHPAs in Peel vulnerability have already been assessed for adjustment associated with large pipes (Caledon E 2 & 3, and Palgrave 3). Vulnerability was increased one category.

  No adjustment was required in York Region as the region used the modified SWAT approach (Unsaturated Zone removed for the consideration of vulnerability) and considered this approach conservative enough to address the potential for large pipes to act as 'pathways'.

  In Durham**,** vulnerability has already been assessed for adjustment associate with storm-sanitary sewage.

- **CLOSPA**: Not applicable – no WHPAs

D4.1.12 Borehole Density

The CTC team did not consider:

- Boreholes located within high vulnerability areas: AVI, ISI and SWAT (with UZAT set to zero) in the analysis;
- Single boreholes with no boreholes within 100 m distance;
- Boreholes made to a depth of less than 3.0 m.

  Rationale: Shallow Works O. Reg. 903, 1990

  1.1(1) A test hole or dewatering well that is made to a depth of less than 3.0 metres below the ground surface is exempt from sections 36 to 50 of the Act and from the Regulation

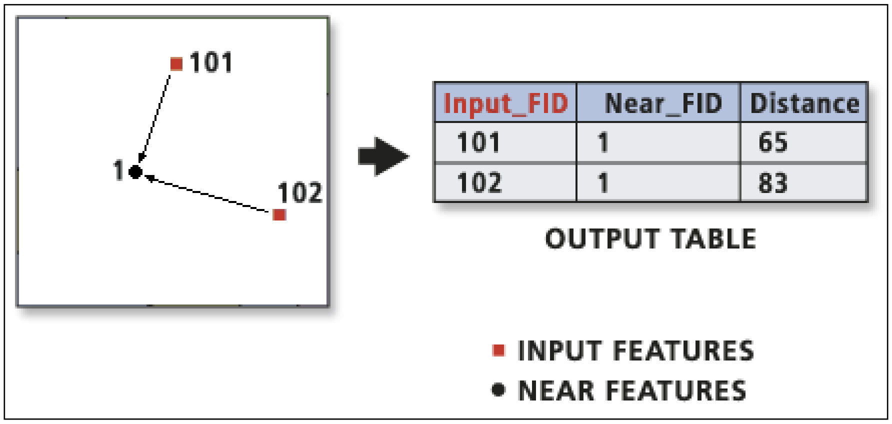
- Age of the boreholes as staff believes that there is no direct correlation between the age of the borehole and its impact as a potential pathway. Additionally, new properly constructed borehole could become a pathway in the future; and
- Municipal and monitoring wells as preferential pathways because these wells are always upgraded, inspected, and maintained by municipalities to meet O. Reg. 903, 1990. Also, municipalities have regular inspections by MOECC Drinking Water Inspectors who inspect municipal and monitoring wells for compliance with O. Reg. 903. MOECC inspection includes active pumping well and monitoring wells.

<u>**Clustered Boreholes**</u>

The CTC staff tested two methods for calculating the borehole density within the area including Kernel and Point Distance Density. The method that CTC team selected to use was the point distance density as the most defensible. The methodology point density approach is further described below:

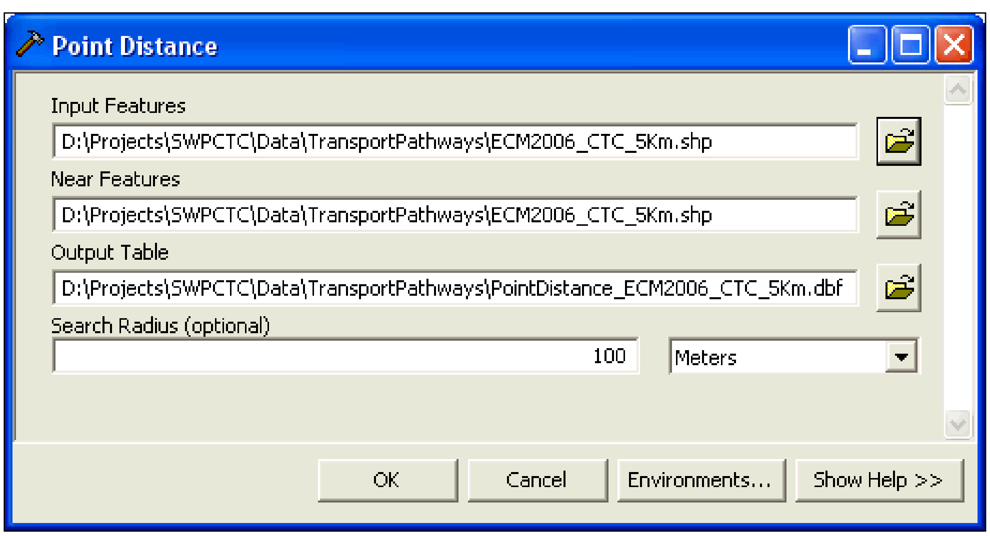
Point Distance Density Methodology

This approach determines the distances between point features.



Since the criteria for an adjustment in vulnerability scores is based on a number of boreholes (6+) in a given area (100 m radius), the Point Distance tool is closer to what we need, (Silverman, 1986):

- Use the borehole feature class (provided by CAMC-YPDT) for both the ***Input Features*** and ***Near Features*** inputs;
- Use a search radius of 100 m (based on the cell size of the HVA raster);
- Open the resulting table and summarize based on ***Input FID*** - This gives us a COUNT of boreholes within the 100 m radius;
- Join the summary table back to the original FID;
- Select points (boreholes) that have a COUNT of 6 or more;
- Create grid from the select points with a value of 2 (the adjusted value for HVA grid cells);
- Add this grid to the HVA grid (resulting grid has values of 2, 4, 6 & 8 - the value of 8 is where HVA will be already 6/high and get adjusted further);
- Re-class the resulting grid to remove 8's and re-class them as 6 (resulting grid has values of 2, 4 & 6); and
- The software will automatically adjust the HVA grid cell that shares the largest common area (clustered boreholes of 6 or more) with the density grid by increase the vulnerability by one category.



Full jurisdiction vulnerability/ HVA Delineation

For the AVI/ISI areas outside of the WHPA, the CTC team decided to look at depth and density as the key consideration for vulnerability adjustment. This will be irrespective of water supply aquifer (given that the concern is not only the municipal aquifer). The CTC will review:

1. All the boreholes regardless of depth or aquifer;
2. Boreholes located in AVI score 2 and 4;
3. Boreholes deeper than 3 m (shallow works rules);
4. Where there exists a cluster of 6 boreholes within 100 m radius on a 100 m grid; and
5. Increase the vulnerability of the area from step 4) by one category.

WHPA:

The CTC team selected a modified Genivar *(South Georgian Bay-Lake Simcoe SPR Proposed Assessment Report, 2010)* approach regarding clusters where the water supply aquifer, depth and borehole density are the key considerations for potential impact with the WHPA as follows:

1) Identify the municipal aquifer from the database;
2) Select out boreholes in WHPA A-D (groundwater WHPAs only);
3) Complete the point distance analysis for all areas within the WHPA; and
   (a) Select boreholes that intersect the target aquifer and any formation below the target aquifer;
   (b) Exclude all boreholes above the target aquifer or located outside of the WHPA area (INCLUDE all WHPAs A-D plus a 100 m buffer on the outside of the WHPA area) and exclude any municipal and municipal monitoring boreholes from the subset data;
   (c) Run the cluster analysis on the borehole subset;
   (d) Select all borehole that have a point distance total of 6 or more;

Note: The methodology is correct but for the GIS implementation, set the threshold at 5 as the point distance tool (summary) ignores the original boreholes in the count.

   (e) Buffer the resulting selection from step d) by 100 m; and
   (f) Screen out clusters that are already scored as HIGH (see table below: AVI, ISI and SWAT); and

4) Increase the vulnerability of the area from step f) by one category (low to medium or medium to high) - use the scores from the table below.

Table 2(a): Wellhead Protection Area Vulnerability Scores – ISI or AVI

Groundwater Vulnerability Category for the Area	Location Within a Well Head Protection Area					
	WHPA-A	WHPA-AA	WHPA-B	WHPA-C	WHPA-C1	WHPA-D
High	10	10	10	8	8	6
Medium	10	8	8	6	6	4
Low	10	6	6	4	4	2

Table 2(b): Wellhead Protection Vulnerability Scores – SAAT or SWAT

Groundwater Vulnerability Category for the Area	Location Within a Well Head Protection Area					
	WHPA-A	WHPA-AA	WHPA-B	WHPA-C	WHPA-C1	WHPA-D
High	10	10	10	8	8	6
Medium	10	8	8	6	6	4
Low	10	6	6	2	2	2

Taken from Technical Rules, Nov 2009 (Rule (83))

Results

The following section will discuss the results after assessing various anthropogenic pathways and their impact on the full jurisdiction vulnerability and the resulting HVA delineation and WHPAs in the CTC.

D4.1.13 High Vulnerability Aquifer (HVA)

Figure D4-2 shows the CTC - High Vulnerability Aquifer without Pathways adjustment (2010), **Figure D4-3** shows the High Vulnerability Aquifer Differences (Pit/quarries and Clusters boreholes) 2011, and **Figure D4-4** shows the High Vulnerability Aquifer Differences (only Pit/quarries) 2011. **Table D4-5** and **Table D4-6** presents the statistics for the changes to the HVAs resulting from vulnerability adjustment for pathways for pits/quarries and clusters and pits and quarries only, respectively. As shown, the changes to the HVA afforded by the pathways adjustment are minor. Data uncertainty associated with the borehole cluster analysis was a key concern as staff applied the methodology. While several efforts were made to raise the level of accuracy though the application of several QA/QC routines and checks (assisted by the CAMC-YPDT staff), the issue of borehole location, depth, and screen elevations errors as well as record duplication resulted in questions regarding the defensibility of adjusting the vulnerability scores. The data associated with pits and quarries on the other hand were adequate and staff agreed it was defensible to adjust vulnerability for these structures consistent with the WHPAs (see **Figure D4-4**).

Table D4-5: Increase in HVA areas with pathways adjustment for clusters and pits/quarries (2011)

SPA	2010 (m^2)	2011 (m^2)	Difference (m^2)	Increase (%)
CVSPA	540,970,000	544,510,000	3,540,000	0.65
TRSPA	1,080,340,000	1,085,520,000	5,180,000	0.48
CLOSPA	301,880,000	304,660,000	3,5400,000	0.91
CTC	**1,923,190,000**	**1,934,690,000**	**12,260,000**	**0.64**

Table D4-6: Increase in HVA areas with pathways adjustment for pits and quarries only (2011)

SPA	2010 (m^2)	2011 (m^2)	Difference (m^2)	Increase (%)
CVSPA	540,970,000	542,830,000	1,860,000	0.34
TRSPA	1,080,340,000	1,083,720,000	3,380,000	0.31
CLOSPA	301,880,000	303,320,000	1,440,000	0.48
CTC	**1,923,190,000**	**1,929,870,000**	**6,680,000**	**0.35**

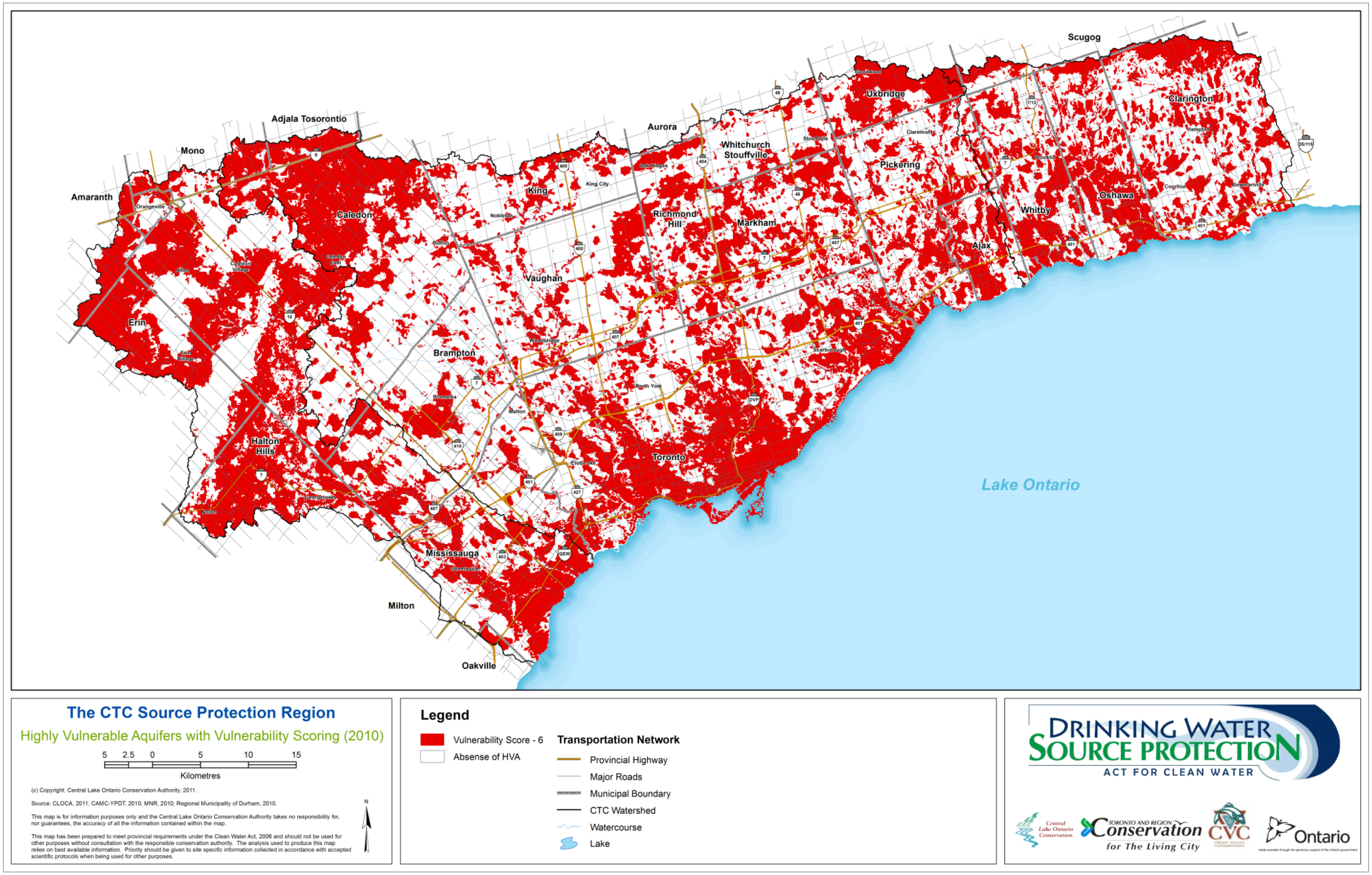


Figure D4-2: CTC - High Vulnerability Aquifer without Pathways adjustment (2010)

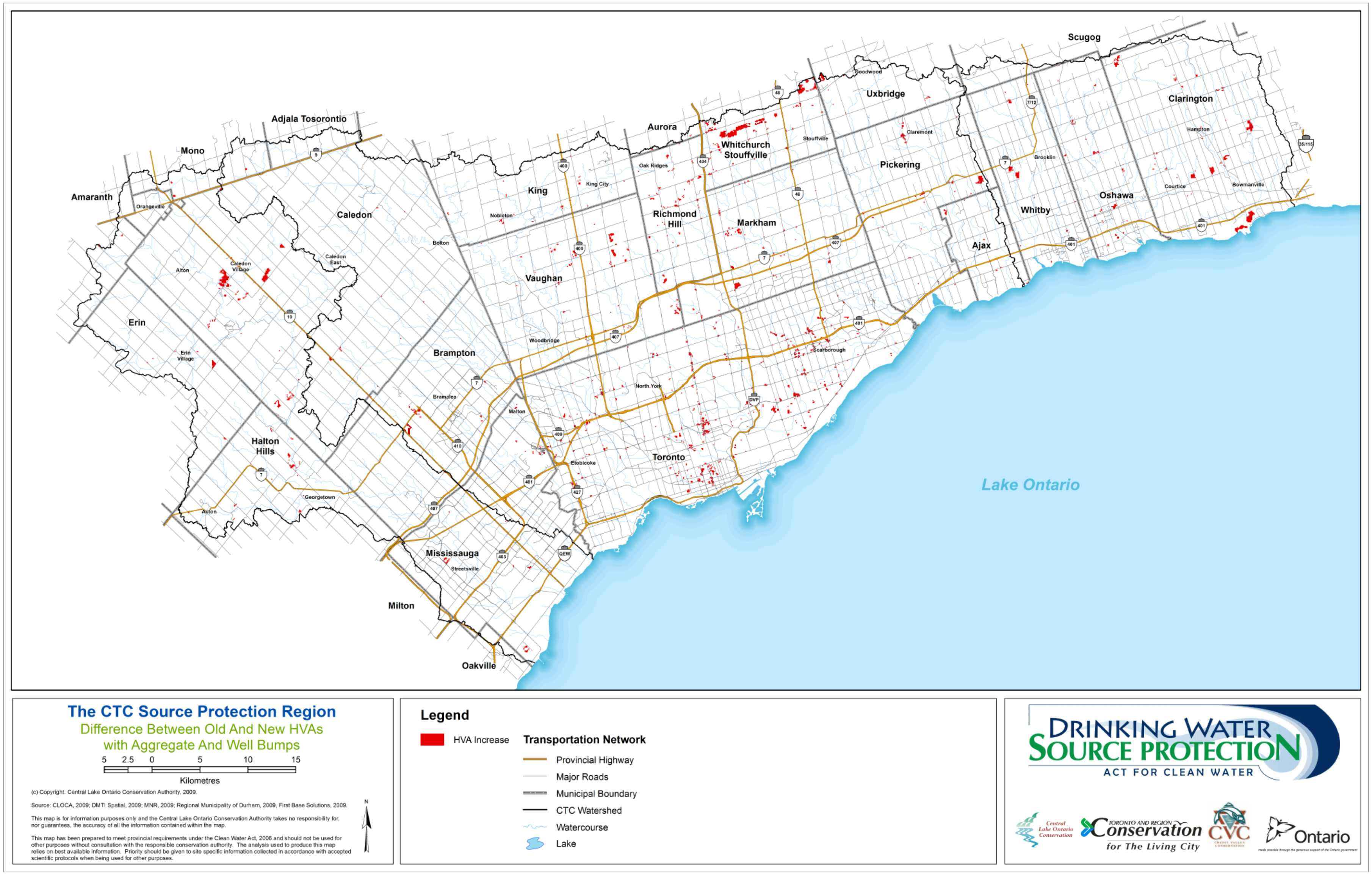


Figure D4-3: High Vulnerability Aquifer Differences (Pit/quarries and Clusters boreholes) 2011

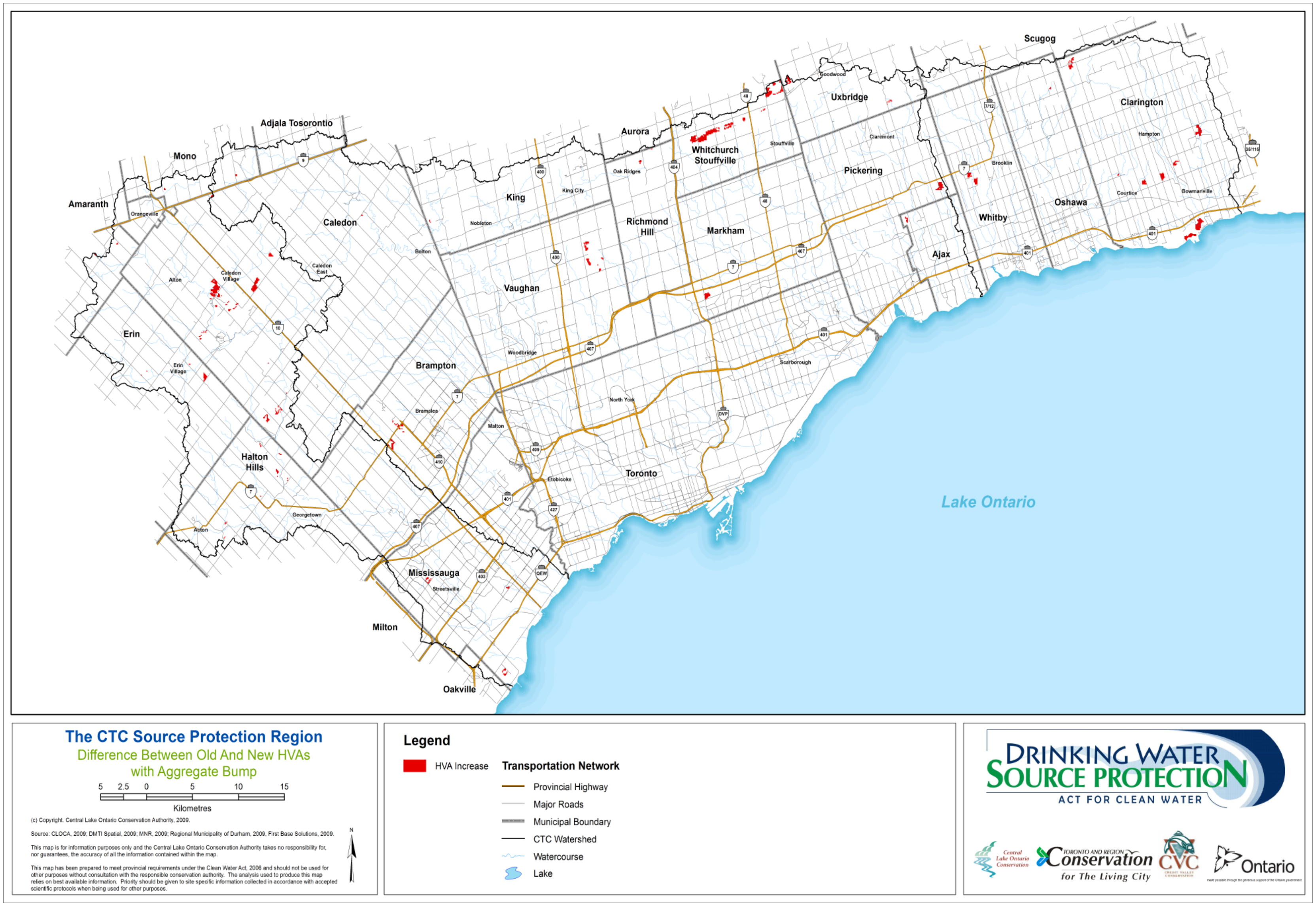


Figure D4-4: Highly Vulnerable Aquifer Differences (only Pit/quarries) 2011

D4.1.14 Well Head Protection Areas (WHPA)

Toronto and Region Source Protection Area (TRSPA)

The increase in vulnerability mapping was completed for all TRSPA (13 WHPAs – see **Figure D4-5** and **Figure D4-9** as a test case for the application of the CTC pathways methodology in the WHPAs. As discussed earlier the vulnerability adjustment was completed for cluster boreholes only given that other structures were already accounted for in the WHPA delineation and vulnerability scoring process as outlined in the assessment reports. For the borehole cluster analysis, WHPAs were treated differently to the AVI/HVA areas. Only clusters in the municipal aquifer within the WHPAs (A-D) were subject to adjustment. This required staff to 'mark' all the boreholes in the database to the aquifer that the water is being drawn from and screen out all other boreholes within the WHPA. Boreholes were assigned an aquifer by cross referencing the borehole to the geological model. It should be noted that though this process was useful in the completion of the vulnerability adjustment, it assumes that the geologic model is without error and that the well screen data are correct, ultimately introducing another component of uncertainty. Nevertheless, the analysis was completed to support or refute a decision regarding an additional adjustment for vulnerability within the WHPAs.

All the WHPAs were mapped. Statistics, however, were only prepared for the most impacted of the TRSPA WHPAs for the purposes of this report. The most notable vulnerability increase resulting from borehole clusters analysis in the TRSPA is in Whitchurch-Stouffville. Increase in vulnerability within Whitchurch-Stouffville is minor (4.59 % or 291,607 m^2 – **Figure D4-9**).

Credit Valley Source Protection Area (CVSPA)

The mapping was not completed in the report for each of the individual CVSPA (24 WHPAs). An example (Inglewood) was deemed adequate for the purposes of this report. Increase in vulnerability within Inglewood afforded by the borehole clusters was minor (2.34 % or 66,773 m^2 – see **Figure D4-10**).

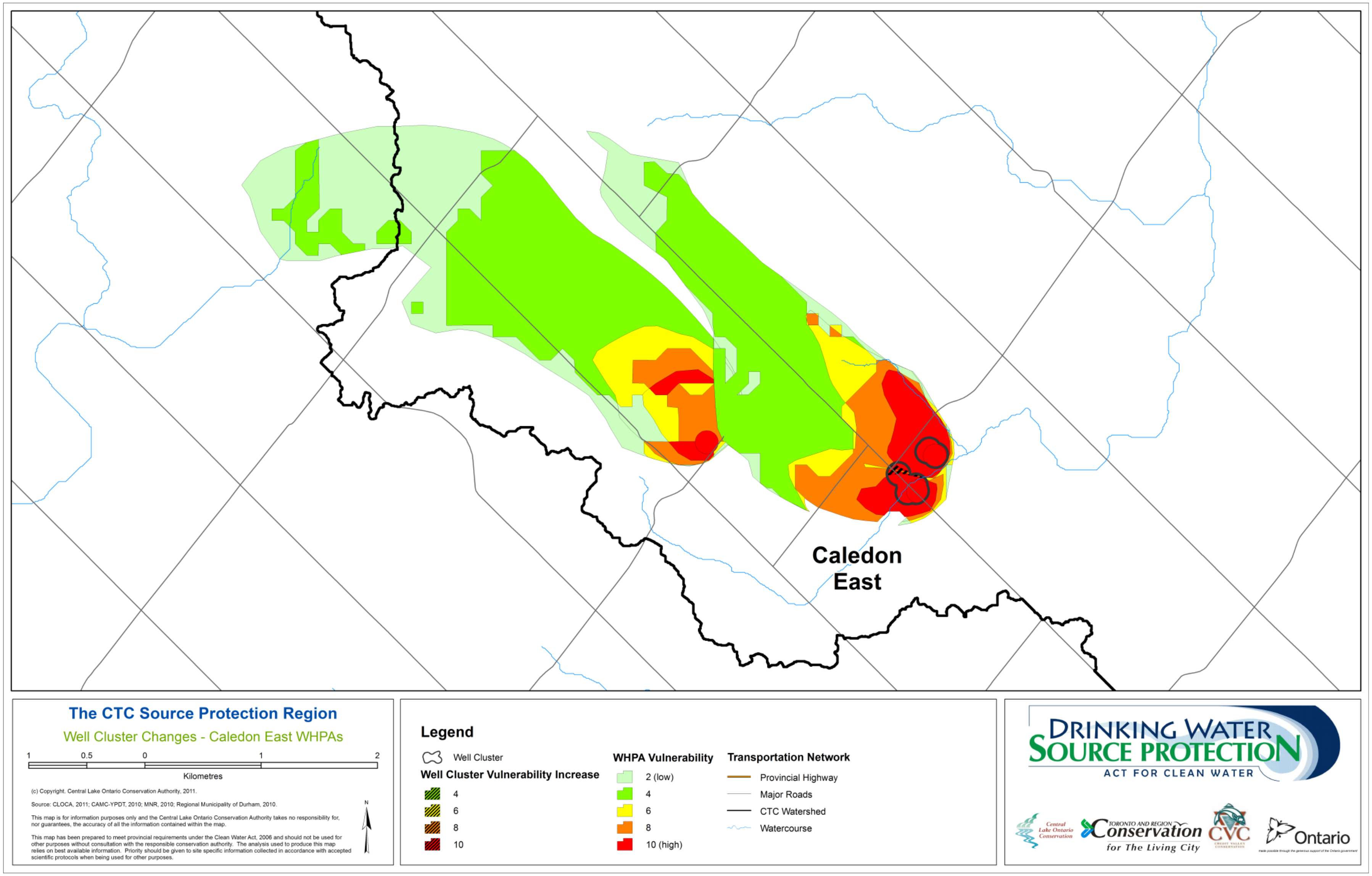


Figure D4-5: Borehole Cluster Changes Caledon East (TRSPA-Peel)

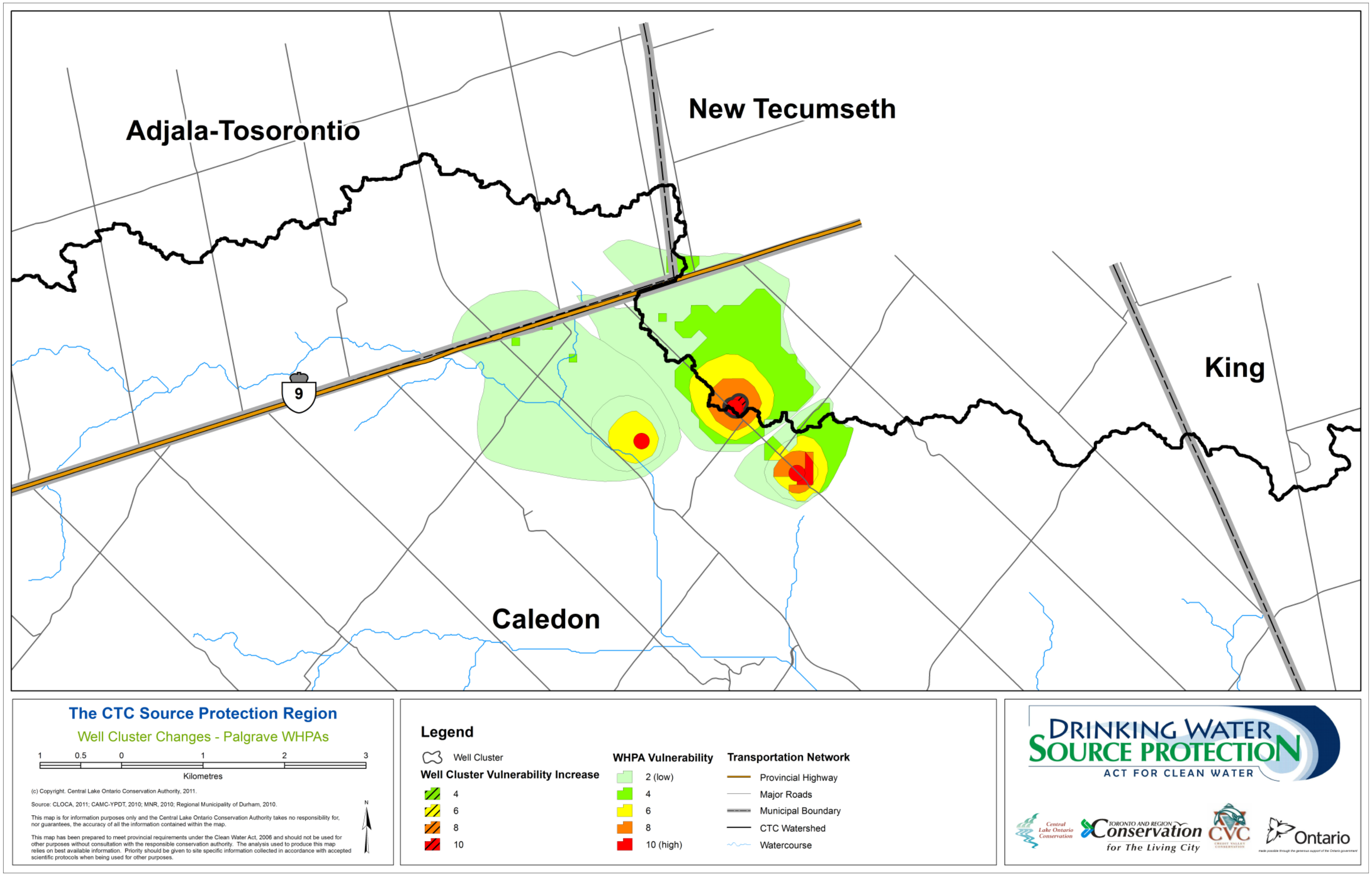


Figure D4-6: Borehole Cluster Changes Palgrave (TRSPA-Peel)

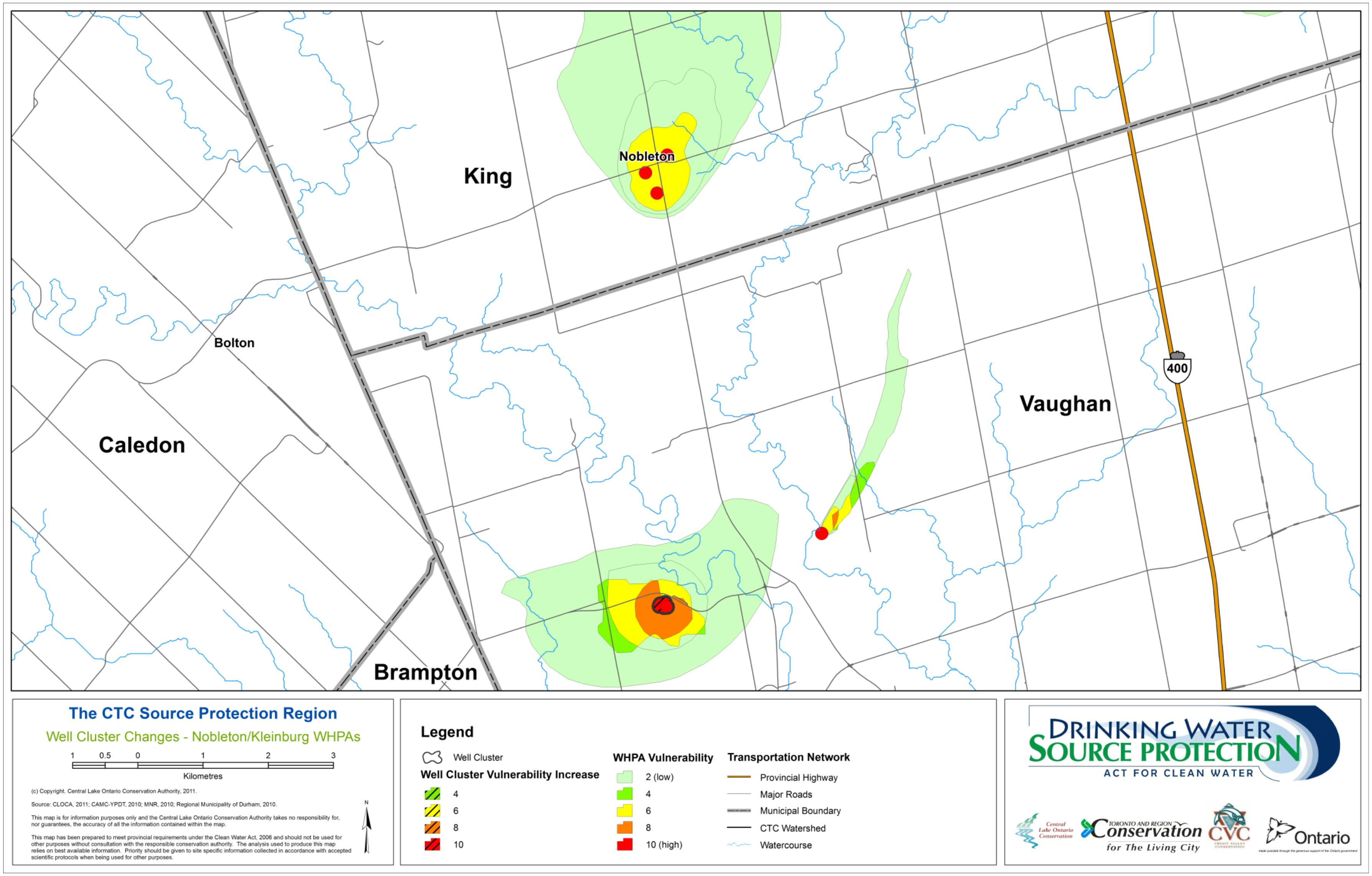


Figure D4-7: Borehole Cluster Changes Kleinburg (TRSPA-York)

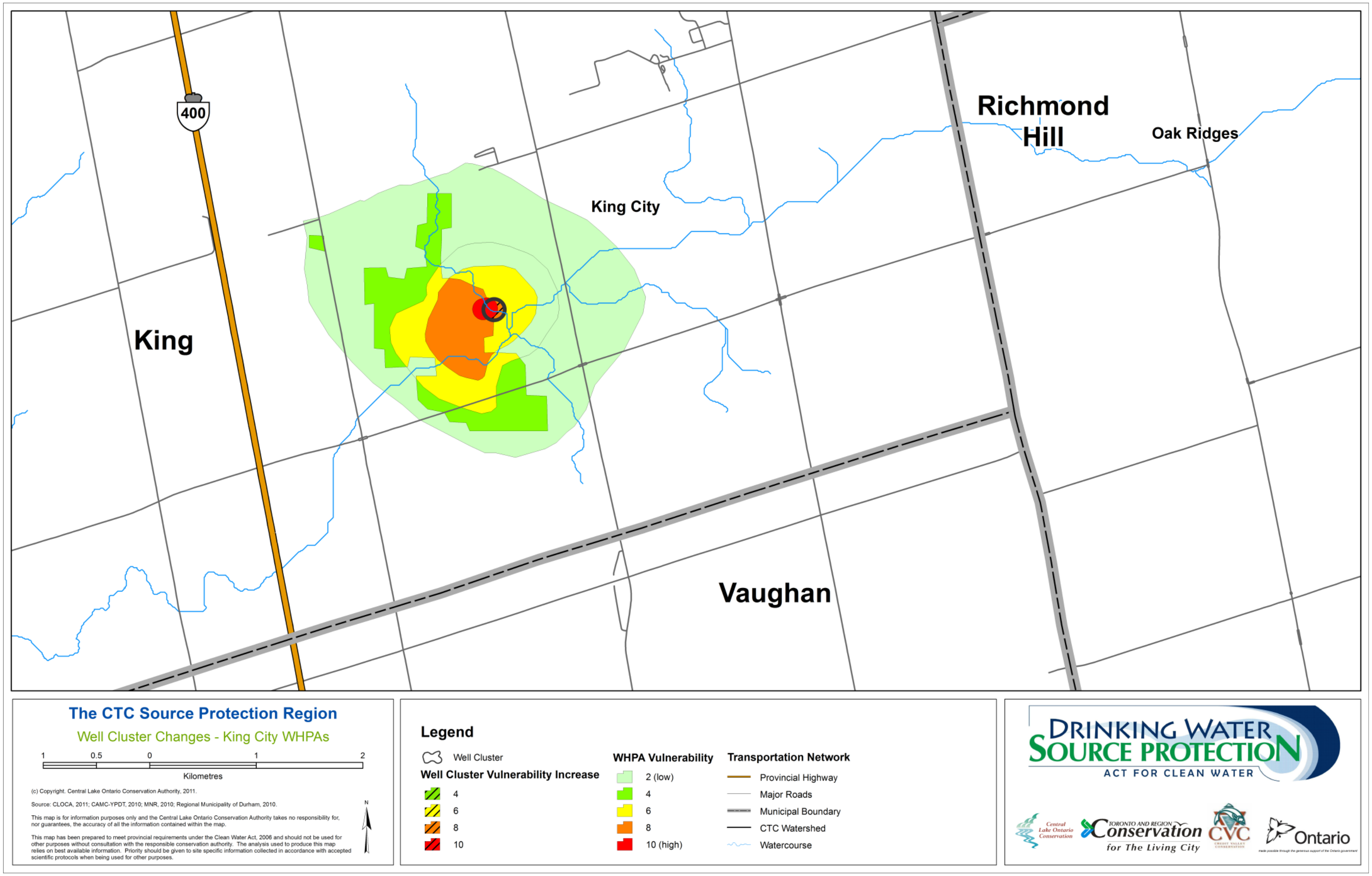


Figure D4-8: Borehole Cluster Changes King City (TRSPA-York)

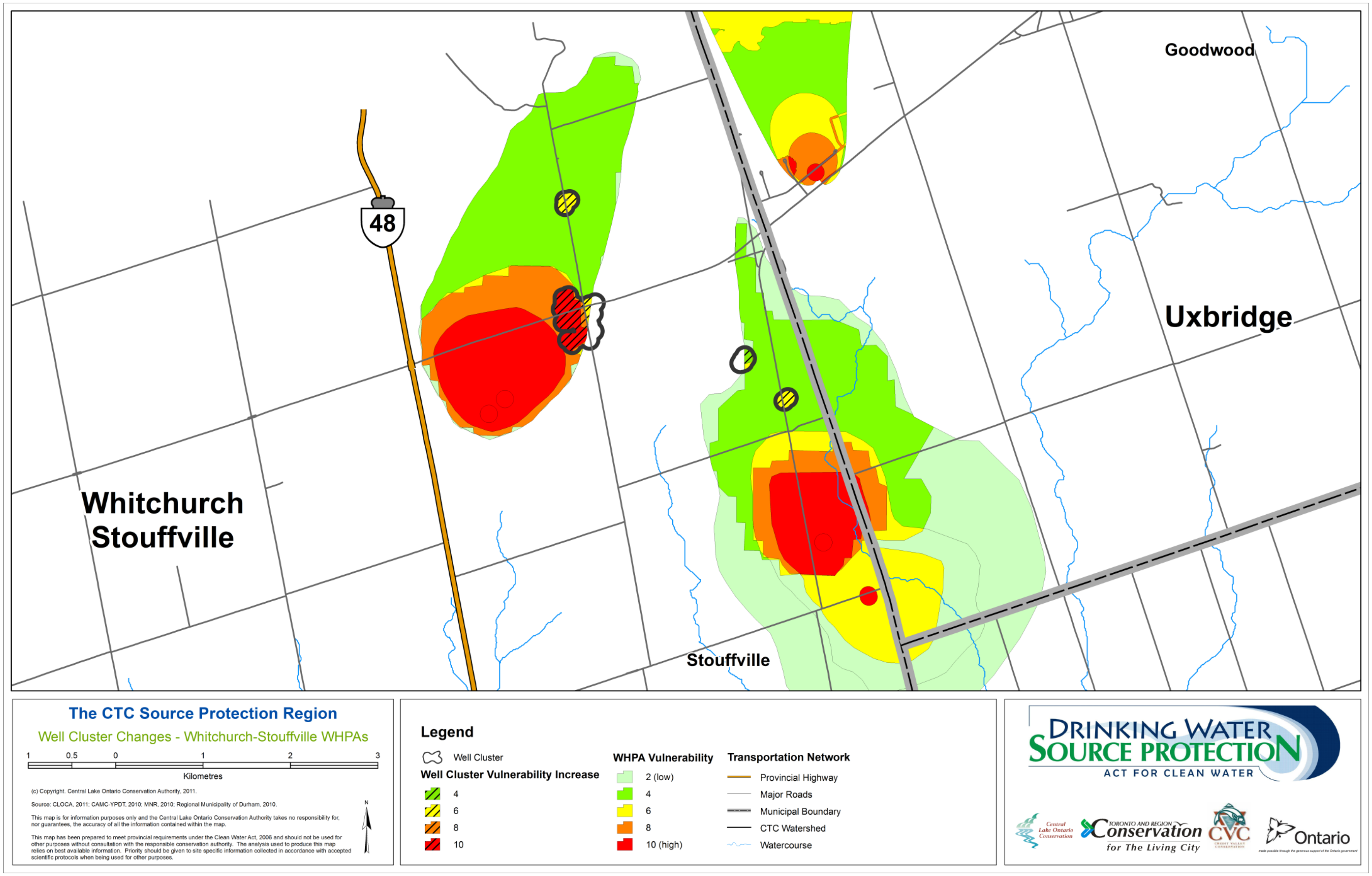


Figure D4-9: Borehole Cluster Changes Whitchurch-Stouffville (TRSPA-York)

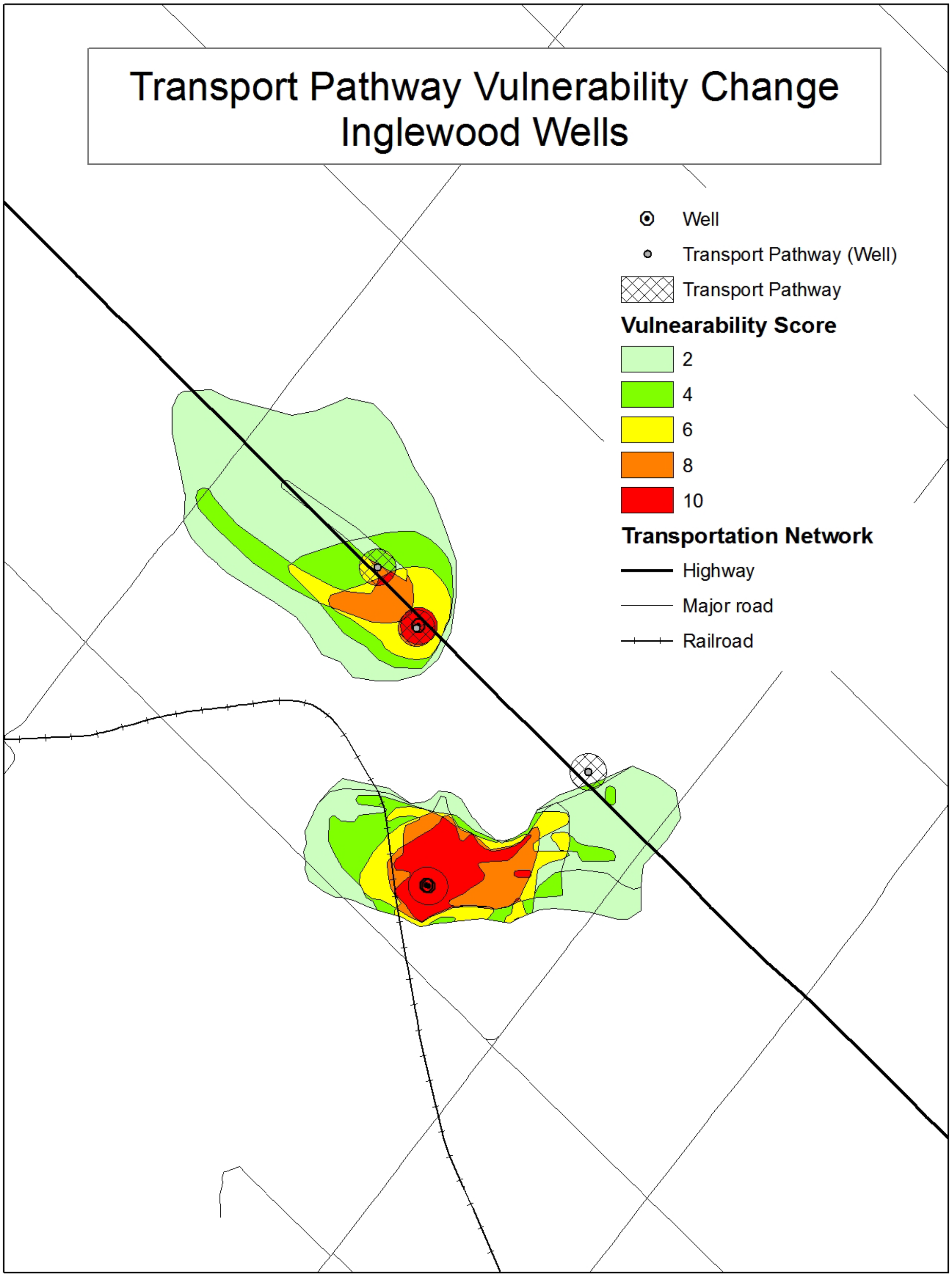


Figure D4-10: Borehole Cluster Changes Inglewood (CVSPA-Peel)

D4.1.15 Gap Analysis and Limitations

CTC staff identified several data gaps in the implementation of this study. A number of datasets related to the selected pathways structures were unavailable, incomplete or inaccurate.

- Large diameter pipes (specific depth information (z coordinates) was not available);
- Data related to geothermal installations; and
- Data related to deep excavations (other than pits/quarries).

It is recommended that additional pathway and attribute data be collected for a future iteration of the assessment report.

There were several limitations of note in the study. CTC staff were required to complete the transport pathways analysis and standardize where possible various approaches used in the WHPAs by various consultants within a certain timeframe and within a certain budget.

- Time (the updated assessment report timelines dictate that a desktop exercise was the most feasible approach);
- Many of the required attribute data were unavailable/problematic and too costly to acquire or correct at this time; and
- Cost (a detailed exercise would have proved expensive, and a more detailed study was not justifiable of cost).

The key limitation to note here is that where regional analyses are necessary to be used as ‘flags’, site specific data takes primacy over regional desktop analyses. Where site specific data is available it should be used.

D4.1.16 Uncertainty Assessment

The *Technical Rules (13) (1)* require that an analysis of uncertainty be completed for all components of the vulnerability assessment on a regional scale. Factors that need to be considered in evaluating the level of confidence in the groundwater vulnerability assessment include:

- Errors/uncertainty in the data;
- The distribution, variability, quality and relevance of data available such as borehole record errors (location, depth, screen locations) and borehole record duplication (several screens);
- The level of QA/QC procedures applied in reviewing/filtering/revising the data used to construct the models and methods;
- The extent (and level) of calibration and validation achieved for any numerical models;
- Inherent uncertainty in the geologic models to assign boreholes to the aquifer formation;
- Engineering solutions may not be considered;
- Inherent uncertainty in the models used to determine vulnerability and scoring (for high, medium and low);
- Borehole density tool limitations;
- Assumptions made in the cluster analysis;
- Ground-truthing (out of scope for this study); and
- Some transport pathways (large diameter pipes, geothermal installations, and deep excavations) may not be considered in this study, but they could be in the future.

All groundwater is inherently vulnerable to some degree. A vulnerability analysis is completed to identify areas that are most vulnerable. In doing so, many components are utilized that each individually have a component of uncertainty; the geologic models used, and the assumptions used in their construction, the hydraulic properties that are estimated, the data that is used to construct the models and perform the cluster analyses, and the scale at which these analyses are done. For each component the CTC staff and the SPC have erred on the side of caution by selecting the most conservative approach.

The CTC team approached this transport pathways exercise in that same vein recognizing the uncertainty and limitations of the datasets used. The available databases all have limitations regarding the quality e.g., the Water Well Information System (WWIS) database is limited regarding records (incomplete or inaccurate) and cannot be used with good confidence to estimate whether a well is properly located, constructed or decommissioned. Some of the other datasets used in this exercise were not created for the purpose of determining their potential environmental impact and thus do not contain the fields necessary for them to be assessed.

Conclusions and Recommendations

This document provides a description of the methodology and results of a study to adjust the groundwater vulnerability presented in the CTC assessment reports for transport pathways per *Technical Rules* (39-41).

Vulnerability analyses were completed for the full CTC jurisdiction to delineate the Highly Vulnerability Aquifers (HVAs) using the Aquifer Vulnerability Index (AVI) method and through separately prescribed methodologies, the WHPAs in the CTC SPR. Vulnerability adjustments were included for some structures in the WHPAs.

Staff collected and reviewed several pathways datasets from various sources to determine pathways that were feasible to consider in the adjustment of vulnerability and selected pits and quarries and boreholes (water wells, oil and gas, exploratory boreholes, etc.) for the HVA pathways adjustment analysis. While the team recognized that there are other structures that could represent a pathway, these data were not available in a format that could be applied through a desktop exercise. It is recommended that additional data be collected for use in a future update maps in the Assessment Report.

It is recommended that the data uncertainty and data gap issues be addressed prior to the next update of the Assessment Report and revisions considered at that time.

HVAs

The vulnerability products supporting the delineation of the HVAs were assessed for pits and quarries and clustered wells. The total area increased to high vulnerability in the HVA, in CTC because of pit and quarries and cluster analysis is 0.64 % or 12,260,000 m^2 (0.0012 ha) (see Error! Reference source not found.). The total area increased to high vulnerability for pits/quarries only is 0.35% or 6,680,000 m^2 (0.0006 ha) (see Error! Reference source not found.). Staff believe that the high uncertainty associated with the borehole cluster analysis and the minor change observed in the results do not support the adjustment of vulnerability nor revision of the management land, imperviousness, and threats enumeration products. The areas of increase vulnerability by SPR are clearly illustrated in **Figure D4-11** to **Figure D4-13**.

It is recommended that the vulnerability scores be adjusted one level for pits/quarries only in the full jurisdiction vulnerability and resulting HVA delineation.

WHPAs

The total area increased to high vulnerability in the Inglewood (CVSPA) and Whitchurch-Stouffville (TRSPA) WHPAs because of cluster analysis is 2.34% and 4.59% or 291,607 m^2 (0.0291 ha) respectively.

Pits and quarries, trunk sewers and large diameter pipes were already considered as part of the WHPAs delineation as outlined in the assessment reports and in this report. Staff believes that this approach is adequately conservative.

The high uncertainty associated with the borehole cluster analysis and the minor changes observed in the WHPA vulnerability led staff to conclude that the adjustment of the vulnerability and revision of dependent products (management land, imperviousness, and threats enumeration) is not defensible or justifiable. Additionally, several clusters extend outside of the WHPA areas and/or of CTC jurisdiction. It is uncertain how these pathways would be handled. The existing WHPA vulnerability scores and the methodologies employed are considered conservative enough for protection of the municipal aquifers.

It is recommended that no additional revisions be made to WHPAs vulnerability scores for pathways (cluster boreholes) at this time.

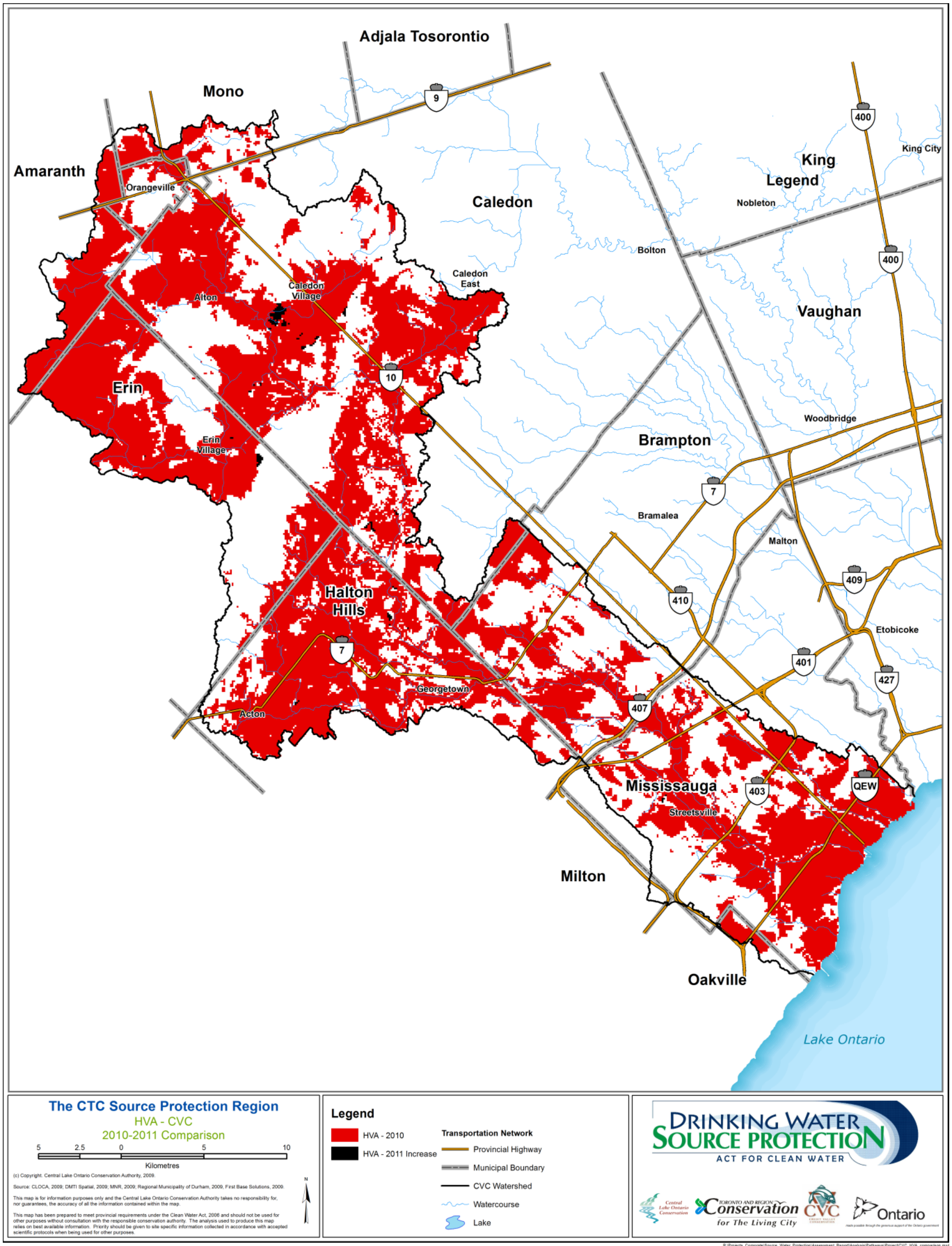


Figure D4-11: CVSPA - High Vulnerability Aquifer Differences (Pit/quarries)

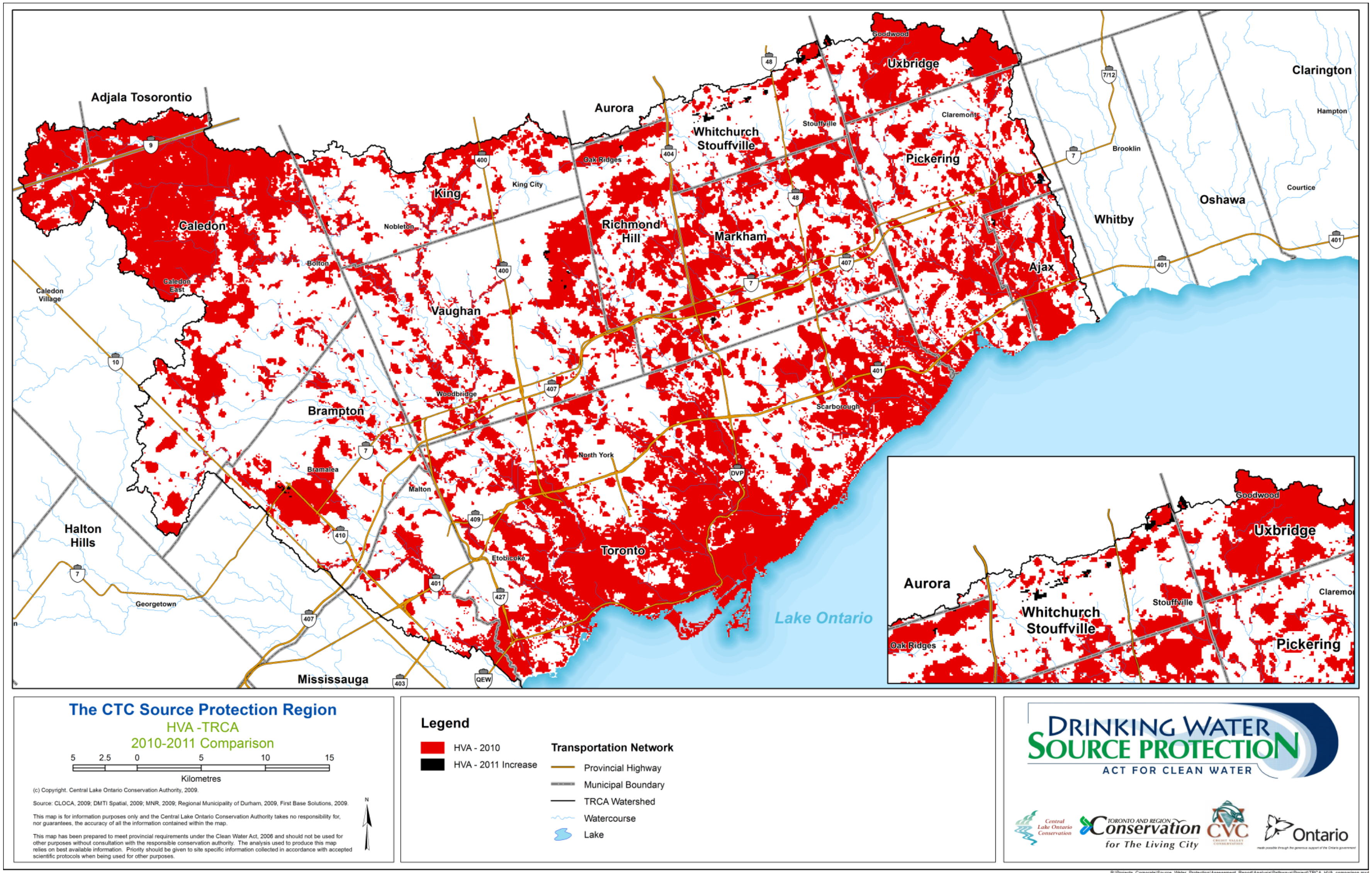


Figure D4-12: TRSPA - High Vulnerability Aquifer Differences (Pit/quarries)

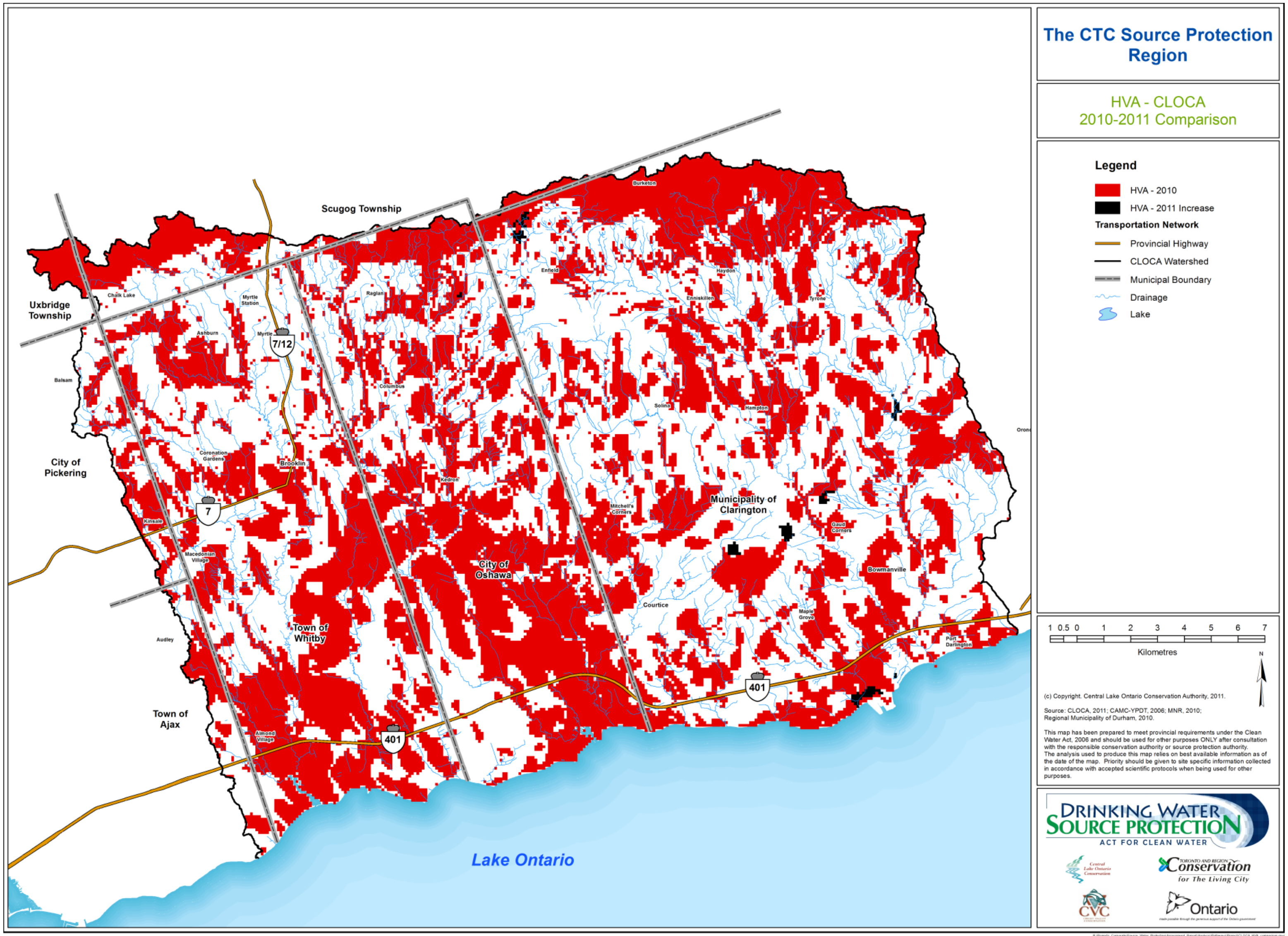


Figure D4-13: CLOSPA - High Vulnerability Aquifer Differences (Pit/quarries)

References

AECOM. (2009). *Groundwater Vulnerability Assessment – Township of Uxbridge – Uxbridge Industrial Park in Uxville.*

AquaResource Inc. (2008a). *Region of Peel, Wellhead Protection Area Delineations and Vulnerability Assessments for Alton 1-2 Standby Wells, Cheltenham PW1/PW2 Amended PTTW, and Caledon Village Proposed Well 5 (TW2-05), AquaResource Inc.*

AquaResource Inc. (2008b). Reg*ional Municipality of Peel, Surface to Aquifer and Surface to Well Advection Time Wellhead Protection Areas in Credit Valley Watershed, Caledon Village Wells 3 and 4, Inglewood Wells 1, 2 and 3, Cheltenham PW1/PW2 and Alton Wells 3 and 4.*

Blackport Hydrogeologic and Golder. (2010). *WHPA Delineation and Vulnerability Assessment Town of Erin.*

Burnside. (2010). *Groundwater Vulnerability Assessment, Town of Amaranth.*

Burnside. (2010). *Groundwater Vulnerability Assessment, Town of Mono.*

Burnside. (2010). *Groundwater Vulnerability Assessment, Town of Orangeville.*

Burnside. (2010). *Transport Pathways Update to Groundwater Vulnerability Region of Peel.*

EarthFx Inc. (2010). *Vulnerability Analysis for the Georgetown Acton Wellfields.*

EarthFx Inc. (2008). *Wellhead Protection Area Study and Surface to Well Advection Time Analysis for Palgrave 4 Located within the Toronto Region Conservation Authority Watersheds, Regional Municipality of Peel.*

EarthFx Inc. (2008c). *Vulnerability Assessment and Scoring of Wellhead Protection Areas Regional Municipality of York.*

EarthFx Inc. (2007). *Wellhead Protection Areas – Caledon East Wells 2, 3 and 4 and Palgrave Wells 2 and 3, EarthFx Inc.*

EarthFx Inc. (2006). *Groundwater Modelling of the Oak Ridges Moraine Area. CAMC-YPDT Technical Report #01-06.*

Gerber, R. (2010). *Highly Vulnerability Aquifer Delineation* CTC SWP Region, May 2010.

Golder. (2006). *The County of Wellington Groundwater Study.*

Jagger Hims Limited. (2004b). *Supplemental Assessment of Groundwater Interference, Proposed Phase 2, Uxbridge Industrial Park, Pat Lots 14 and 15, Concession 1, Township of Uxbridge.*

Lake Erie Source Protection Committee. (2010). *Proposed Assessment Report: Lake Erie Source Protection Region,* Stantec.

Ministry of Natural Resources (MNR). (1997). Aggregate Resources Provincial Standards Ontario.

Ministry of Environment (MOE). (2009). Ontario Ministry of the Environment, Technical Rules: Assessment Report, Clean Water Act, 2006, Nov 2009: *Part IV: Vulnerability Assessment and Delineation, Groundwater.*

Ministry of Environment (MOE). (2006). Ontario Ministry of the Environment, Assessment Report: Draft Guidance Modules, Source Protection Technical Studies, *Module 3 - Appendix 5: Groundwater Vulnerability Analysis October 2006,* www.ene.gov.on.ca/en/water/cleanwater/cwa-guidance.php.

Ministry of Environment (MOE). (2006). Ontario Ministry of the Environment, Assessment Report: Draft Guidance Modules, Source Protection Technical Studies: *Module 5: Issues Evaluation and Threats Inventory October 2006,* www.ene.gov.on.ca/en/water/cleanwater/cwa-guidance.php

Ministry of Environment (MOE). (1992). *Building Code Act, 1992 - O. Reg. 350/06 (Part 8 Sewage Systems - Septic, Sanitary and Storm Sewage Systems).*

Ministry of Environment (MOE). (1990). *Ontario Water Resources Act - R.R.O. 1990, Reg. 903 (Wells).*

Silverman, B. W., 1986, *Density Estimation for Statistics and Data Analysis*, New York, Chapman and Hall.

South Georgian Bay-Lake Simcoe Source Protection Committee. (2010). *Proposed Assessment Report: South Georgian Bay-Lake Simcoe Source Protection Region,* Genivar.

Thames-Sydenham and Region. (2009). *Proposed Approach to Consideration of Transport Pathways in the Vulnerability Assessment of Groundwater Based Vulnerable Areas Version 0.2.*

Waterloo Hydrogeologic Inc. (WHI) (2005). *Municipal Groundwater Supply Vulnerability Pilot Study for Palgrave No. 4, Regional Municipality of Peel, Final Report.*