ASSESSING VULNERABILITY OF DRINKING WATER SOURCES

FIGURES

TABLES

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).

D1.1 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).

D1.2 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*);
- 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*).

D1.3 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.

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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:

Technical Bulletin: Groundwater Vulnerability

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

Technical Bulletin: Groundwater Vulnerability

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

Technical Bulletin: Groundwater Vulnerability

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

Technical Bulletin: Groundwater Vulnerability

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
ACT FOR CLEAN WATER

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 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.

Technical Bulletin: Delineation of Significant Groundwater Recharge Areas

- 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.

Technical Bulletin: Delineation of Significant Groundwater Recharge Areas

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).

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

- 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.

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

- 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

Technical Bulletin: Climate Change Summary

> 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 ANALYSIS

D2.1 Wellhead Protection Areas (WHPAs)

As described in **Chapter 4** of the Assessment Report, there are 21 Well Head Protection Areas (WHPAs) for six groundwater-based municipal drinking water systems within the TRSPA. They service the following communities:

- Palgrave-Caledon East (Palgrave 3 wells, Caledon East 3 wells);
- Kleinburg (2 wells);
- Nobleton (3 wells);
- King City (2 wells);
- Whitchurch-Stouffville (5 wells); and
- Uxville (2 wells).

The groundwater vulnerability analysis for WHPAs was completed by consultants on behalf of TRCA's municipal partners and then peer reviewed by a team of external experts. The methodologies applied were documented in the reports listed in **Table D2-1**, and the results are presented in **Chapter 4** of the Assessment Report and are not described further in this Appendix.

D2.2 Highly Vulnerable Aquifers (HVAs)

The Groundwater Vulnerability Analysis undertaken for the Assessment Report involved determining relative vulnerability (high, medium or low) of aquifers over the entire TRSPA. It should be noted that the WHPA groundwater vulnerability assessments take precedence over the more regional HVA analysis within the WHPA zones in the development of policies under the Source Protection Plan. Mapping of threats within Highly Vulnerable Aquifer areas and determining risk scores is presented in **Chapter 4** of the Assessment Report while water quantity vulnerability is dealt with in **Chapter 3**.

This analysis identifies the susceptibility of aquifers to surface or near-surface sources of contamination. The underlying assumption in this analysis is that the vulnerability of the aquifer decreases as the time of travel to the aquifer increases. Relative vulnerability scores are used as input to the Water Quality Risk Assessment.

As outlined in the *Guidance Module and Technical Rules* (MOE, 2006; MOE, 2009) regarding groundwater vulnerability analyses, there are a number of available approaches to estimate groundwater vulnerability. The latest *Technical Rules* (MOE, 2009) list the following methods that can be used to assess groundwater vulnerability. Methods 3 and 4 below generally utilize three-dimensional groundwater flow models:

1. Intrinsic Susceptibility Index (ISI) – a score or index value is given to each well (e.g., MOECC Water Well Information System (WWIS)). The index or score at each well is then interpolated between wells to produce a vulnerability map. This takes into account water table and/or water level information, AVI does not;

Table D2-1: Wellhead Protection Area Reports

Regional Municipality	Component	Wells	Consultant: Study Title: Study Date
Peel	WHPA A-D Delineation & Vulnerability Scoring	Caledon East Wells 3, 4 and 4A Palgrave Wells 2, 3 and 4	**EarthFx Incorporated:** **August 2008** (SWAT analysis) - *Addendum Report: Wellhead Protection Area Study and Surface to Well Advection Time Analysis for Palgrave Well 4 Located within the Toronto and Region Conservation Authority Watersheds* (Earthfx 2008b*)* **February 2008** (SWAT analysis) - *Surface to Well Advection Time Analysis Wellhead Protection Areas for Municipal Residential Groundwater Systems Located within the Toronto and Region Conservation Authority Watersheds* (Earthfx, 2008a) **May 2007** (ISI analysis) - *Wellhead Protection Area Study for Municipal Residential Groundwater Systems Located within the Toronto and Region Conservation Authority Watersheds* (Earthfx, 2007a) **December 2015** (CE4 and 4A) - Caledon East Wellhead Protection Area Delineation Wells CE4 and CE4A (Matrix 2015) **August 2018** (Well 4A) - Vulnerability Assessment and Vulnerability Scoring for Caledon East Well 4A (Matrix 2018)
York	WHPA A-D Delineation & Vulnerability Scoring	King City 3 & 4 Kleinberg 3 & 4 Nobleton 2, 3 & 5 Stouffville 1, 2, 3, 5 & 6	**EarthFx Incorporated:** **November 2007** - *Vulnerability Assessment and Scoring of Wellhead Protection Areas Regional Municipality of York (Earthfx, 2007b)* **October 2008** - *Vulnerability Assessment and Scoring of Wellhead Protection Areas Regional Municipality of York (Earthfx, 2008c)* **November 2009** - *Updated Vulnerability Assessment and Scoring Wellhead Protection Areas Region of York (Earthfx, 2009)*
Durham	WHPA A-D Delineation & Vulnerability Scoring	Uxville Wells 1 & 2	**AECOM** **September 2009** - *Groundwater Modeling and WHPA delineation – Uxville Water Supply System (AECOM, 2009)* **Gartner Lee Limited** **September 2007** - *Durham Region Wellhead Protection Groundwater Studies* (Gartner Lee, 2007)

2. Aquifer Vulnerability Index (AVI) – score or index value based on mapping products (e.g., depth to aquifer, soil type and thickness, etc.) that reflects relative amount of protection provided by physical features that overlie the aquifer;
3. Surface to Aquifer Advection Time (SAAT); and
4. Surface to Well Advection Time (SWAT).

These methods can be used to identify vulnerable areas and determine relative vulnerability within the vulnerable areas. The results reflect the intrinsic vulnerability of the vulnerable areas and are independent of contaminant characteristics. The maps produced provide relative indications of vulnerability to be used to focus groundwater protection strategies to areas of greatest risk. This information should not be used to assess actual susceptibility for groundwater contamination on a specific property. The Source Water Protection program expects that a continuous improvement process will occur in areas with greatest risk and vulnerability.

The HVA mapping for the TRSPA has been prepared utilizing method 2 (AVI). This appendix includes a general description of relative aquifer vulnerability within the study area, briefly discusses results from previous ISI mapping for the area, and then more fully describes the AVI methods and maps that were generated for the CTC Source Protection Region (SPR). This appendix also includes discussions regarding man-made pathways that can affect aquifer vulnerability and uncertainty regarding input data and methodology as it relates to this HVA analysis.

The results of this aquifer vulnerability mapping/scoring are to be carried forward to the water quality risk analysis where the vulnerability scoring presented here is multiplied by hazard scoring for various contaminants to give a risk score.

D2.2.1 General Study Area Relative Aquifer Vulnerability

A brief description of the aquifer units present in the study area was provided in **Chapter 3** of the Assessment Report along with a description of the different hydraulic settings where municipal drinking water supplies are obtained from groundwater. The following section provides a relative ranking of aquifer vulnerability within the CTC SPR using the geologic model prepared for TRCA's Tier 1 water budget (TRCA, 2010). The different hydraulic settings and their relative vulnerability listed from highest to lowest are described in detail below.

Type 1 Setting (High Vulnerability)

Type 1 settings include coarse grained sediments that occur at or near the surface. This includes the Oak Ridges Moraine aquifer complex (or equivalent sediments) including hummocky Halton Till deposits, which enhance recharge. Where the Halton Till confines the pinching Oak Ridges Aquifer, vertical hydraulic gradients tend to be upwards so the aquifer is not as vulnerable in these areas. Also included in this setting are shallow coarser sediments that occur above the escarpment along moraines, outwash channels and infilling bedrock valleys.

Type 2 Setting (Medium Vulnerability)

This setting is similar to Type 1 except that the aquifers are overlain by aquitard material regardless of the integrity of the aquitard. Aquitard integrity and vertical hydraulic gradients can increase or lessen the vulnerability, respectively.

Type 3 and 4 Setting (Low Vulnerability)

This setting includes deep sedimentary aquifers overlain by aquitard material (Type 3 - Thorncliffe and Scarborough Aquifers) and rock aquifers overlain by rock aquitards (Type 4).

Test 1 - Historical Issues

The above descriptions and classifications involve many assumptions and simplifications. One key assumption is that all potential aquitard materials (silt, clay, till) provide the same degree of protection to the underlying aquifers. The classification system also relies on existing mapping and water well descriptions of potential aquitard materials. However, because the subsurface cannot be examined directly, it is not possible to determine if the aquitard materials provide adequate protection everywhere. Aquitard integrity may be compromised by various features and processes such as fractures, sand bodies, geochemical dissolution and erosion (Cherry et al., 2007). It is also acknowledged that wells can become contaminated for reasons other than geologic deposit integrity; for example improper seals surrounding well casing can allow contaminants to rapidly travel to well screens along the annulus.

Some insight regarding aquifer vulnerability can be gleamed in this analysis in the broader CTC SPR where the stratigraphy and formation thickness is similar, by looking at historical contamination issues that have occurred. Various “ground truthing” tests were done in this analysis to confirm the rigor of the results as follows:

- Historical municipal well contamination cases (located in the greater CTC Source Water Protection area: TRSPA or CVSPA);
- Municipal well chloride concentration trends (located in the greater CTC Source Water Protection area: TRSPA or CVSPA); and
- Provincial Groundwater Monitoring Network (PGMN) chemistry trends.

As an example, the TRCA PGMN well locations with elevated chloride concentrations, may indicate migration of road salt to the underlying aquifers. Many of the locations with elevated or increasing chloride concentrations are in areas where silt and or sand are mapped at surface. It should also be noted that some of the monitors situated in sands of the Oak Ridges Moraine Aquifer Complex do not exhibit increasing chloride concentrations, particularly in protected areas such as the Claremont Conservation Area.

D2.2.2 Relative Aquifer Vulnerability

The most vulnerable aquifer settings situated within the study area occur where sand and gravel deposits occur at or near the ground surface (Type 1). Generally, supply wells that are situated in this setting tend to exhibit rising chloride levels, indicating anthropogenic influence from contaminants introduced at the ground surface. This conclusion is consistent with other studies that have recently been conducted within the CTC study area.

The Type 2 vulnerability setting includes shallow aquifers with an overlying thickness of aquitard material including silt, clay or till. Many municipal wells located in the CTC SPR that are in this setting exhibit rising chloride levels indicating contamination introduced at the ground surface is migrating within the subsurface to well intakes. Historical issues (e.g., King City) also suggest that in areas mapped as till overlying an aquifer that contaminants can still migrate to depth and reach the underlying aquifer. While these areas have been suggested to contain relatively moderate susceptibility to contamination, it should be kept in mind that aquitards within the study area (and elsewhere) do not provide absolute protection. This conclusion is supported by others who have worked in the study area.

Care should be taken when studying and utilizing groundwater vulnerability mapping. Areas mapped as moderate to low vulnerability do not suggest that they are fully protected, only that potential contaminants may take longer to reach aquifers at depth. Further discussion regarding aquifer vulnerability within part of the study area can be found within Howard and Beck (1986), Gerber and Howard (1996; 2002) and Gerber *et al.* (2001).

D2.2.3 Intrinsic Susceptibility Index (ISI - Wells)

The groundwater intrinsic susceptibility index (ISI) approach has been applied and documented over the entire TRSPA. This method was adopted as a general standard in the guidance documents for the Provincial Groundwater Protection Studies Program beginning in 2001 and represents the minimum standard for most Source Protection Areas in Ontario. Further discussion and details on limitations of the methodology is provided in OMMAH (2004) and MOE (2006).

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. The input data for this method is the Water Well Information System (WWIS), which is maintained by the Ministry of the Environment and Climate Change. In Ontario, drillers must submit a water well record to the Ministry of the Environment and Climate Change for every water well they construct. This information is input into a database, including well information and a summary of the geologic units encountered.

The ISI is calculated as the sum of the product of the thickness of each geologic unit overlying the first aquifer encountered in a water well with a corresponding K-factor for the overlying unit. The K-factor (**Table D2-2**) is a dimensionless number related to vertical hydraulic conductivity where a low number represents materials with a higher hydraulic conductivity and a higher K-factor represents soil units with a relatively lower hydraulic conductivity. 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). A high score represents low vulnerability, and a low score represents high vulnerability. The single GSC soil classifications and their associated K-factors are included in the **Table D2-3** and **Table D2-4**.

The ISI method requires that uppermost aquifer be at least partially saturated. Therefore, the calculation incorporates information on the water table in each well; specifically the location of the “water encountered” field in the WWIS. In the ISI method, 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.

To produce the aquifer vulnerability map, the individual values for wells in the WWIS database are calculated, and then interpolated in a grid pattern across the aquifer area (100 m x 100 m for the TRSPA). It should be noted that the methodology specifics described above can be modified to reflect study area characteristics. In this method index values less than 30 are high (vulnerability score=6); between 30 and 80 is medium (vulnerability score=4); and greater than 80 is low (vulnerability score=2). Estimates of aquifer vulnerability utilizing the ISI method have been completed for the TRSPA to fulfill requirements of the *Oak Ridges Moraine Conservation Plan* (ORMCP)(OMMAH, 2004).

Table D2-2: 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 D2-3: GSC classification and K-factors (from OMMAH, 2004)

Table B. Geological Materials of the Oak Ridges Moraine
(Based on the MOE well records, and after the GSC conversion)

Description	K Number	Aquifer
clay, silty clay	6	No
clay, silty clay, topsoil	6	No
clay, silty clay, with muck, peat, wood frags.	6	No
clay, silty clay, with rhythmic/graded bedding	6	No
covered, missing, previously bored	3	No
diamicton: cl to cl/si matrix	5	No
diamicton: cl to cl/si with gr/sa/si/cl interbeds	5	No
diamicton: cl to cl/si, stoney	5	No
diamicton: cl to cl/si, topsoil	5	No
diamicton: cl to cl/si, with muck, peat, wood frags.	5	No
diamicton: si to sa/si matrix	5	No
diamicton: si to sa/si with gr/sa/si/cl interbeds	5	No
diamicton: si to sa/si with muck, peat, wood frags.	5	No
diamicton: si to sa/si, stoney	5	No
diamicton: si to sa/si, topsoil	5	No
diamicton: si/sa to sa matrix	5	No
diamicton: si/sa to sa with gr/sa/si/cl interbeds	5	No
diamicton: si/sa to sa with muck, peat, wood frags.	5	No
diamicton: si/sa to sa, stoney	5	No
diamicton: texture unknown	5	No
dolomite	2	Yes
fill (incl topsoil, waste)	3	No
granite (poss. bedrock, prob. boulder)		No
gravel, gravelly sand	1	Yes
gravel, gravelly sand, topsoil	2	Yes
gravel, gravelly sand, with muck, peat, wood frags.	2	Yes
gravel, gravelly sand, with rhythmic/graded bedding	1	Yes
interbedded limestone/shale	2	No
limestone	1	Yes
miscellaneous; no obvious material code	3	No
organic	3	No
organic, topsoil	3	No
potential bedrock	3	Yes
rock	3	Yes
sand, silty sand	2	Yes
sand, silty sand, topsoil	3	Yes
sand, silty sand, with muck, peat, wood frags.	3	Yes
sand, silty sand, with rhythmic/graded bedding	3	Yes
sandstone	5	No
shale	8	No
silt, sandy silt, clayey silt	4	No
silt, sandy silt, clayey silt, topsoil	4	No
silt, sandy silt, clayey silt, with muck, peat, wood frags.	4	No
silt, sandy silt, clayey silt, with rhythmic/graded bedding	4	No

Table D2-4: Representative K-factors for various geologic materials from SWP Guidance Module 3 (MOE, 2006)

Geological Material	Representative K-Factor (dimensionless)*	Hydraulic Conductivity (m/s) @75% range**	Highest Hydraulic Conductivity (m/s)
gravel weathered dolomite/limestone (weathered) karst permeable basalt	1	1.00E-01 1.00E-06 1.00E-03 1.00E-03	0.1
Sand	2	0.01	1.00E-02
peat (organics) silty sand weathered clay (<5m below surface) shrinking/fractured & aggregated clay weathered shale	3	1.00E-03 1.00E-04 1.00E-04*** 1.00E-04*** 1.00E-05 1.00E-05***	1.00E-03
Silt loess limestone/dolomite	4	1.00E-06 1.00E-06 1.00E-06	1.00E-06
weathered/fractured till diamicton (sandy, silty) diamicton (silty, clayey) sandstone	5	1.00E-07 1.00E-07*** 1.00E-08*** 1.00E-07	1.00E-07
clay till clay (unweathered marine)	8	1.00E-09*** 1.00E-10	1.00E-09
unfractured igneous and metamorphic rock	9	1.00E-13	1.00E-13

* Representative K-Factors are relative numbers and do not correspond directly to the exponent or index of the observed hydraulic conductivity for the geological material in the group.
** Correspondence with descriptors of observed hydraulic conductivities presented in Freeze & Cherry 1979, Prentice-Hall. Derived using the length of the line to determine the 75% value and rounding to the highest K-Value.
*** Estimated value based on field studies in Ontario

Problems associated with this approach are primarily related to the quality of the data in the MOECC water well record database. The objective of well drillers is to install a well that will yield an adequate water supply for their clients, not to describe geologic units. The interpolation method also introduces errors in areas where topography changes over a short distance. For example, two wells may be located on the tableland on either side of a river valley. The calculated ISI between two such points will be incorrect because since the aquitard thickness will be lower and the water table will be at or close to ground surface in river valley. TRCA staff have experienced challenges in using the existing ISI mapping in the review of development applications because of these fundamental issues in the methodology. Therefore, a more rigorous method was developed for source water protection purposes, as described below.

D2.2.4 Aquifer Vulnerability Index (AVI - Hydrostratigraphic Layers)

A second vulnerability analysis method involves the application of the Aquifer Vulnerability Index (AVI) method to three-dimensional interpreted hydrogeologic layers, instead of applying it to information from individual boreholes and then interpolating between boreholes. A three-dimensional hydrostratigraphic interpretation was prepared to complete TRCA's Tier 1 water budget (TRCA, 2010). The information from the numerical modelling that was utilized in the AVI analysis included:

- Three-dimensional hydrostratigraphic interpretation for each model layer (aquifers and aquitards);
- Hydraulic conductivity (K) distribution for each model layer; and
- Observed and simulated water table and hydraulic head distribution for each aquifer to confirm that all sediments that are greater than 2 m thick are saturated.

Vulnerability scores were produced for each aquifer and then combined into one map for the TRSPA. These aquifers included:

- Lake Iroquois and Late Stage Lacustrine sand and gravel deposits (model layer L1);
- Oak Ridges aquifer or equivalent (model layer L3);
- Thorncliffe aquifer (model layer L5); and
- Scarborough aquifer (model layer L7).

For the TRSPA, the bedrock is largely shale with groundwater yield and quality concerns largely precluding the use of groundwater within bedrock being used for a drinking supply. The regional Aquifer Vulnerability Mapping being utilized by the TRSPA utilizes this AVI methodology. The areas of low, moderate, and high aquifer vulnerability are shown on **Figure D2-1**, while the highly vulnerable aquifers with scoring (Vulnerability Score = 6) are presented on **Figure D2-2**.

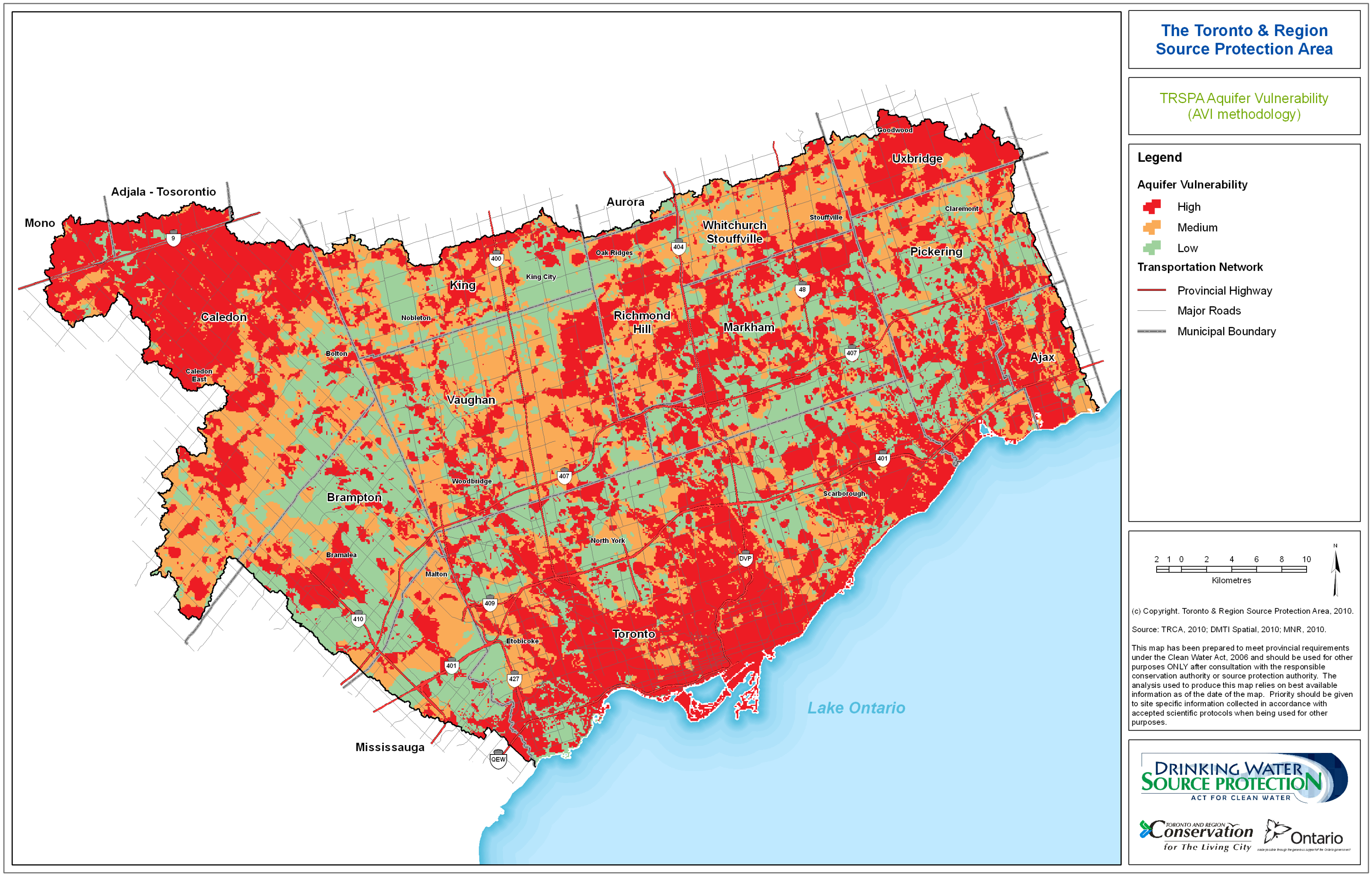

Figure D2-1: TRSPA Aquifer Vulnerability Mapping (AVI methodology)

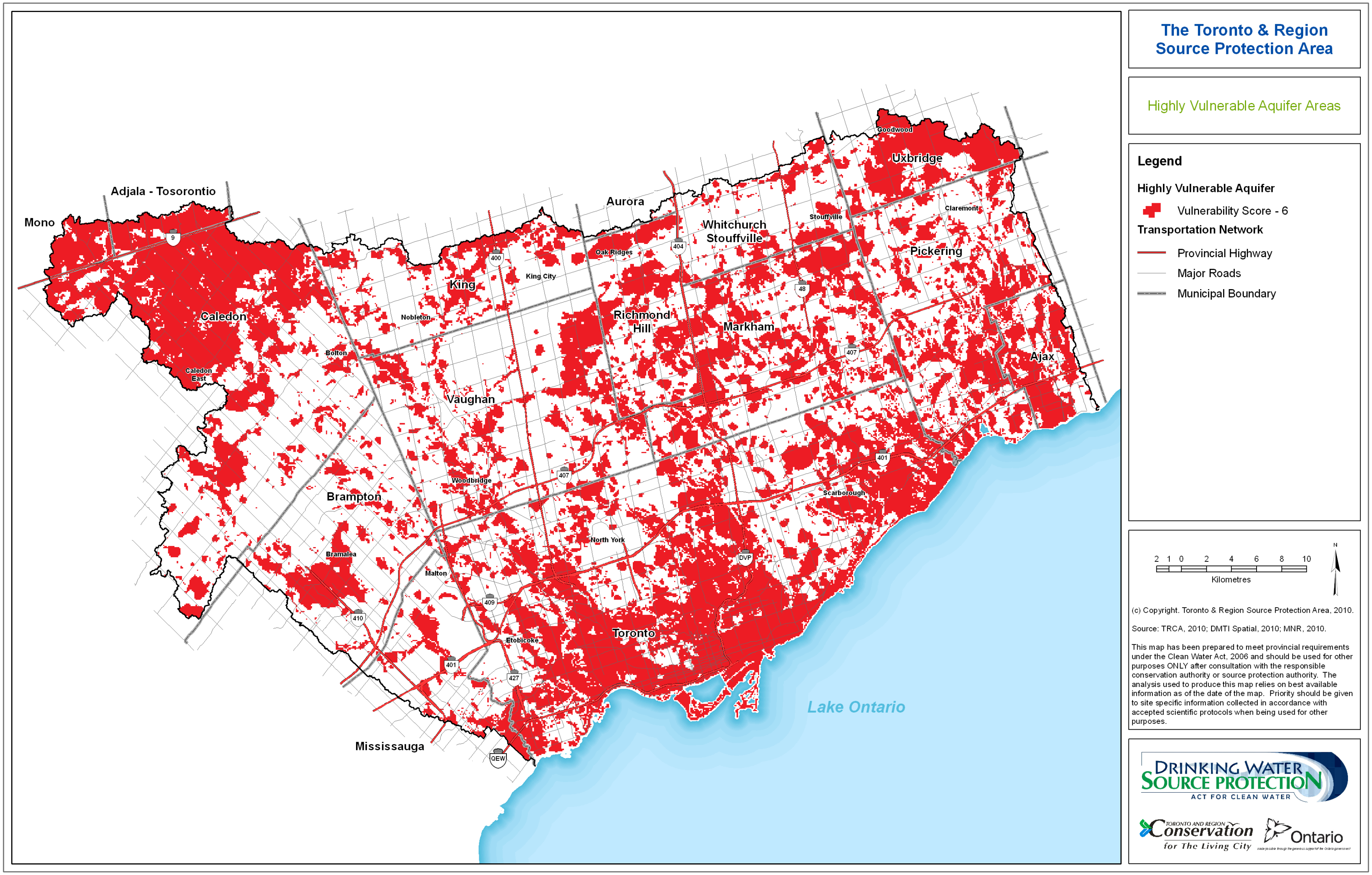

Figure D2-2: TRSPA Highly Vulnerable Aquifers with Scoring (AVI Methodology)

D2.2.5 Numerical Groundwater Flow Models (SAAT, WAAT)

A three-dimensional numerical groundwater flow model exists within the study area. This model was developed for other aspects of the Source Water Protection program namely the water budget analyses as mentioned previously. Some of the components of these models (e.g., three-dimensional hydrostratigraphy) have been used to produce aquifer vulnerability estimates on a regional basis utilizing the AVI method discussed previously.

It is anticipated that this more detailed analysis could be conducted if deemed necessary. Such an analysis would more fully incorporate the interpreted hydrostratigraphic units, observed and simulated estimates of water table and potentiometric surfaces, vertical hydraulic gradients and horizontal flow within the flow system. The index methodologies (ISI, AVI) represent simplified and assumed vertical flow components only and do not incorporate horizontal flow that may impact aquifer vulnerability. An analysis utilizing groundwater flow models would estimate contaminant travel times from the ground surface to the aquifer (SAAT) or, more conservatively, from years would represent High Vulnerability (Vulnerability Score = 6), 5-25 years Medium Vulnerability (Vulnerability Score = 4), and >25 years would represent Low Vulnerability (Vulnerability Score = 2).

D2.2.6 Constructed Preferential Pathways

Technical Rules 39-41 (Part IV.1) state that the vulnerability of an aquifer (Vulnerability Score) can be increased due to the presence of anthropogenic transport pathways. Such pathways could include, but not necessarily limited to:

- Improperly abandoned or sealed water wells and boreholes;
- Buried infrastructure such as sewer and water pipes; and
- Pits and quarries.

The locations of all documented boreholes and wells within the study area are shown on **Figure D2-3**. Depending on many factors, including well construction and/or abandonment procedures, any of these locations could theoretically constitute an anthropogenic pathway. Determination of whether or not this is actually the case would be an enormous undertaking.

Pits and quarries mapped by the Ontario Geological Survey (OGS, 2003) located within the study area are shown on **Figure D2-4**. To determine if these facilities constitute an anthropogenic pathway, details such as excavation depth and stratigraphy encountered would need to be known. Such detail is unavailable at this point in time for all of the pits and quarries shown. Buried infrastructure such as sewer, water and utility lines and associated trenching/tunnelling could also form pathways that could increase the vulnerability of aquifer units. Similar to pits and quarries, details regarding construction procedures and stratigraphy encountered would need to be known to assess whether these constitute pathways that could enhance aquifer vulnerability.

Increasing the estimated aquifer vulnerability due to anthropogenic pathways has been undertaken within the study area for this regional aquifer vulnerability analysis; for more details see **Section D4**.

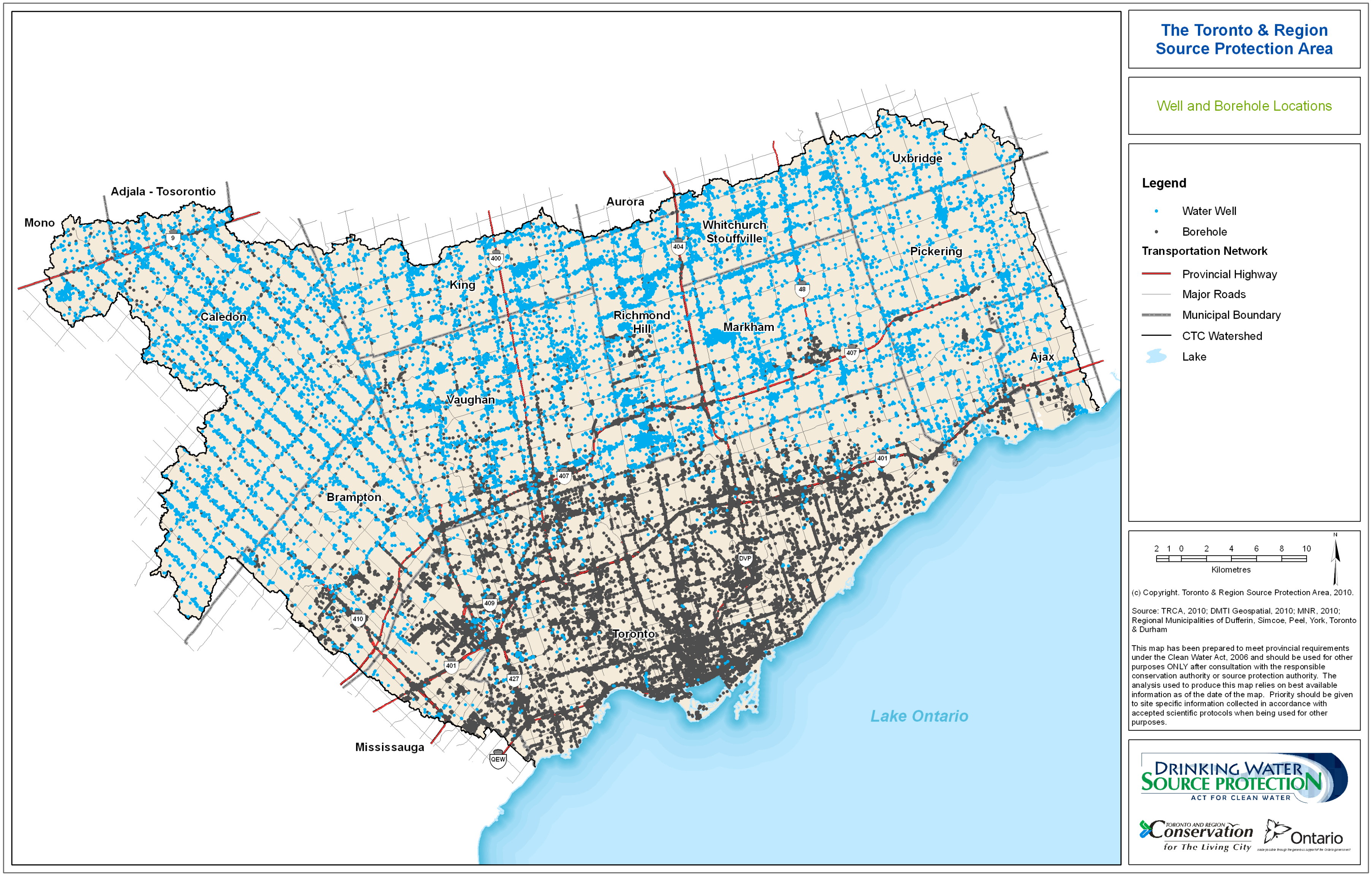

Figure D2-3: Well and Borehole Locations

Figure D2-4: Locations of Pits and Quarries (from OGS, 2003)

D2.2.7 Uncertainty

Our knowledge of the subsurface will always be uncertain. In a book on groundwater vulnerability assessments (National Research Council, 1993), the following two laws are proposed governing groundwater vulnerability:

- "All ground water is vulnerable"; and
- "Uncertainty is inherent in all vulnerability assessments".

Further information and guidance along the same theme is provided in Jaroslav and Zoporozec (1994).

There are a number of components of this aquifer vulnerability analysis that inherently have considerable uncertainty. One of the largest areas of uncertainty relates to the variable quality of the input information, particularly as it relates to geological descriptions within the database. Some areas have reliable geologic information in the subsurface and some areas simply do not. The lower quality geologic 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 three-dimensional geologic interpretation as more information is collected.

The AVI method utilized relies on hydraulic conductivity estimates contained within the numerical groundwater flow models for Tier 1 water budget analyses. While suitable numerical groundwater flow model calibration has been achieved by successively refining recharge and hydraulic conductivity estimates within these steady state models, 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. Sand is assumed to offer less aquifer protection than silt, which is considered to offer less aquifer protection than clay and till. 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 index method, are often fractured or contain other secondary permeability structures that can enhance the hydraulic conductivity of the unit. These secondary permeability features may allow rapid migration of contaminants to underlying aquifers. Fracture delineation and quantification is difficult at best. Even the vulnerability assessment within the WHPAs utilizing particle traces does not specifically incorporate the possible effects of discrete fracture and/or till sand seam contaminant transport. This is known to occur in the broader CTC study area as described earlier where certain areas with till overlying an aquifer have historical contamination problems (e.g., King City). This places an emphasis on always testing the vulnerability mapping results with water quality data from monitoring networks.

The AVI method relates an aquifer vulnerability score to a Vulnerability Score representing high, medium and low vulnerability. None of this is measurable. While the above discussion regarding uncertainty may cause concern, the results of the AVI analysis do provide results that make sense when assessing relative vulnerability. As mentioned above, uncertainty is reduced by continual refinement of the input information (geology and hydraulic conductivity) as more information is received. Uncertainty is reduced and greater confidence in the mapping is achieved as the results of this regional mapping are compared to vulnerability mapping within WHPAs, comparison to GUDI studies, comparison to monitoring data (groundwater quality), and comparison to 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.

D2.2.8 Data and Knowledge Gaps

The identified data and knowledge gaps regarding vulnerable area requirements are listed in **Table D2-5**.

Table D2-5: Data and Knowledge Gaps Identified for Vulnerable Areas

Identified Data and Knowledge Gaps			
Vulnerable Areas with Scoring			
Component	**Data Set Name or Source**	**Data Gap Problem**	**Comment**
IPZ-3 delineation/scoring	Lake based assimilation studies	In progress	Lake Ontario IPZ collaborative study initiative
Knowledge Gaps			
Development of methodology and tools to provide spills response analysis, which will involve all pathways including overland flow, stream travel and groundwater flow including the unsaturated zone transport.			
More detailed scrutiny of significant recharge areas as it relates to drinking water systems			
More detailed scrutiny of highly vulnerable aquifers specifically shallow aquifer deposits			

Although numerous steps were taken to exclude WWIS data of lower reliability, the uncertainty associated with several of the components of the WWIS (location accuracy, reliability of geologic log, measurement of water level, etc.) represent a significant limitation in the assessment. There is also natural variability in the hydraulic conductivity, which is not captured in the analysis.

D2.2.9 HVA Analysis Digital Input File List

The following files are from the TRSPA MODFLOW model that was used for the TRSPA Tier 1 water budget analysis. Some of the files below were used for the CTC HVA analysis as described in the text. All files were provided by EJ Wexler of Earthfx Inc on September 14, 2009. All files are VIEWLOG grid files UTM Zone 17 NAD83.

<u>Geologic Surfaces (Top surface; metres above sea level - mASL)</u>

RECENT DEPOSITS.GRD – recent deposits, (Layer 1)

HALTON V5.GRD – Halton Aquitard (Layer 2)

ORC V5.GRD – Oak Ridges Aquifer (Layer 3)

NEWMARKET V5.GRD – Newmarket Aquitard (Layer 4)

THORNCLIFFE V5.GRD – Thorncliffe Aquifer (Layer 5)

SUNNYBROOK V5.GRD – Sunnybrook Aquitard (Layer 6)

SCARBOROUGH V5.GRD – Scarborough Aquifer (Layer 7)

BEDROCK V5.GRD – Weathered Bedrock (Layer 8)

MODFLOW Surfaces (Tops; masl)

RECENT DEPOSITS.GRD

Adjusted Top of Layer 2_2.grd

Adjusted Top of Layer 3.grd

Adjusted Top of Layer 4_2.grd

Adjusted Top of Layer 5.grd

Adjusted Top of Layer 6.grd

Adjusted Top of Layer 7.grd

Adjusted Top of Layer 8.grd

Adjusted Bottom of Layer 8.grd

Horizontal Hydraulic Conductivity (m/s)

HYCOND1.grd – Layer 1

HYCOND2.grd – Layer 2

HYCOND3.grd – Layer 3

HYCOND4.grd – Layer 4

HYCOND5.grd – Layer 5

HYCOND6.grd – Layer 6

HYCOND7.grd – Layer 7

HYCOND8.grd – Layer 8

Observed Water Levels (masl)

Waterlevel_ORM_outlierRemoved_AK.grd – Oak Ridges Aquifer

Waterlevel_Thorncliffe_outlierRemoved_AK.grd – Thorncliffe Aquifer

Waterlevel_SCAR_outlierRemoved_AK.grd – Scarborough Aquifer

WL_Static_ORAC.grd – Oak Ridges Aquifer - observed

WL_Static_TAC.grd – Thorncliffe Aquifer - observed

WL_Static_SAC.grd – Scarborough Aquifer - observed

Simulated Water Levels (masl)

EastModel-sim-heads-L1.grd – Layer 1

EastModel-sim-heads-L2.grd – Layer 1

EastModel-sim-heads-L3.grd – Layer 1

EastModel-sim-heads-L4.grd – Layer 1

EastMode-sim-heads-L5.grd – Layer 1

EastModel-sim-heads-L6.grd – Layer 1

EastModel-sim-heads-L7.grd – Layer 1

EastModel-sim-heads-L8.grd – Layer 1

Recharge (mm/yr)

Avg_GWI_TRCA.grd

MODFLOW Vertical Conductance

VC12.grd – Layer 1 to Layer 2

VC23.grd – Layer 2 to Layer 3

VC34.grd – Layer 3 to Layer 4

VC45.grd – Layer 4 to Layer 5

VC56.grd – Layer 5 to Layer 6

VC67.grd – Layer 6 to Layer 7

VC78.grd – Layer 7 to Layer 8

MODFLOW Simulated Vertical Flux

TRCA-vert-flux-01.grd – flux from Layer 1

TRCA-vert-flux-02.grd – flux from Layer 2

TRCA-vert-flux-03.grd – flux from Layer 3

TRCA-vert-flux-04.grd – flux from Layer 4

TRCA-vert-flux-05.grd – flux from Layer 5

TRCA-vert-flux-06.grd – flux from Layer 6

TRCA-vert-flux-07.grd – flux from Layer 7

Other VIEWLOG Files

Ibound Layer8.grd

TRCA 100 m.NOD - VIEWLOG grid information file

D2.3 Significant Groundwater Recharge Areas (SGRAs)

D2.3.1 Methods of Analysis

Per *Technical Rules 44 (1) and 44 (2),* as part of the Water Supply Estimation, significant groundwater recharge areas (SGRAs) are to be delineated for each watershed. The rules 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:

Method #1: Delineation based on OGS quaternary soils mapping. Can be combined with topographic mapping to identify upland areas.

Method #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; and

Step 3: Identify SGRAs as areas having a recharge rate greater than 115% of the average annual recharge rate for the watershed.

Method #3: Rule 44 (2):

Step 1: Same as Method 2 above;

Step 2: Same as Method 2 above; and

Step 3: Identify SGRAs as areas having a recharge rate greater than 55% of the water surplus.

The first three methods apply to areas with limited groundwater data. (*Technical Rules 44 (1) and 44 (2))* were selected for delineating the SGRAs in TRSPA because they can be applied directly to the results of the PRMS 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 (Q_R) 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. Because evapotranspiration (ET) is such a difficult number to verify, the uncertainty of this method is considered higher than Method 44 (1).

The shaded areas on **Figure D2-5** show the areas of high volume recharge using *Rule 44 (1)*. The colour scale shows the magnitude of the threshold value within each major watershed, which spanned a wide range, from 93 to 178 mm/yr. As can be expected, a significant part of the TRSPA would be flagged as SGRAs with this watershed average approach. This makes sense as the areas generally coincide with surficial geology classes associated with the Oak Ridges Moraine deposits, exposed Lower Sediment sands, Iroquois Beach deposits, and alluvium, although not always. For example, the low threshold in the Etobicoke and Mimico watersheds resulted in even the upland areas covered by Halton Till being labelled as SGRAs.

TRSPA staff endorses the use of *Rule 44 (1)* because the thresholds that result are more defensible, in that there are more measurable parameters than *Rule 44 (2)* in which surplus is calculated by subtracting evapotranspiration (difficult to measure) from precipitation and assuming that recharge is 55% of surplus.

With *Rule 44 (1)* being the preferred approach, the issue then becomes the selection of an appropriate boundary for the calculation of the threshold. In an effort to deal with edge-matching issues and to address problems such as SGRAs being defined by less than 100 mm/year recharge, TRCA's staff recommended that the average recharge be calculated based on the jurisdictional average (threshold of 165 mm/year), as shown on **Figure D2-6**. The jurisdictional threshold captures the areas historically documented as important for recharge, correlates well with the provincial surficial geology maps and address internal boundary issues. It is also consistent with the methodology used in CLOCA to the east, and CVC to the west. The final mapping with the Tier 3 results is presented on **Figure D2-7.**

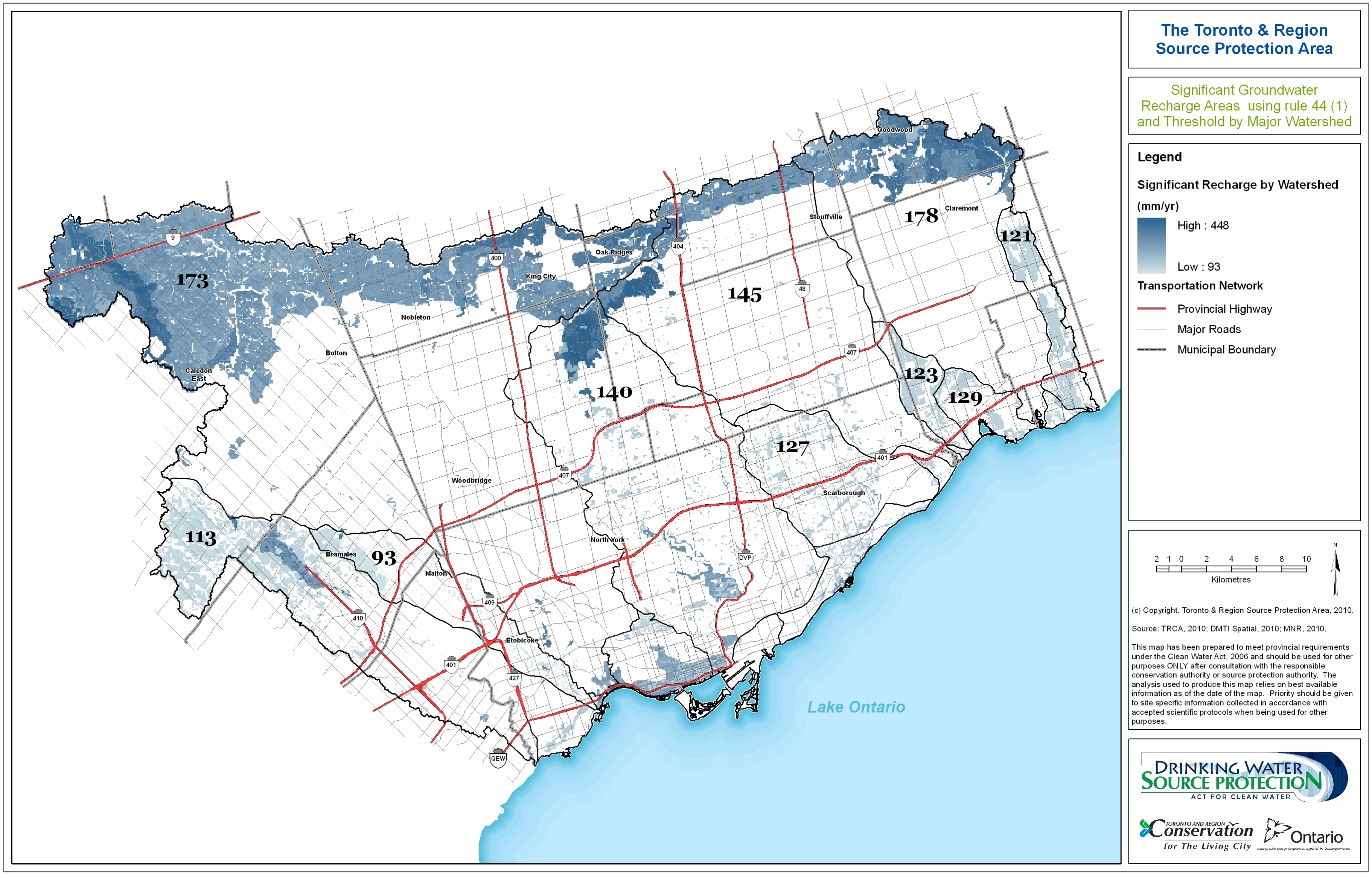

Figure D2-5: SGRAs using Rule 44 (1) and Threshold by Major Watershed

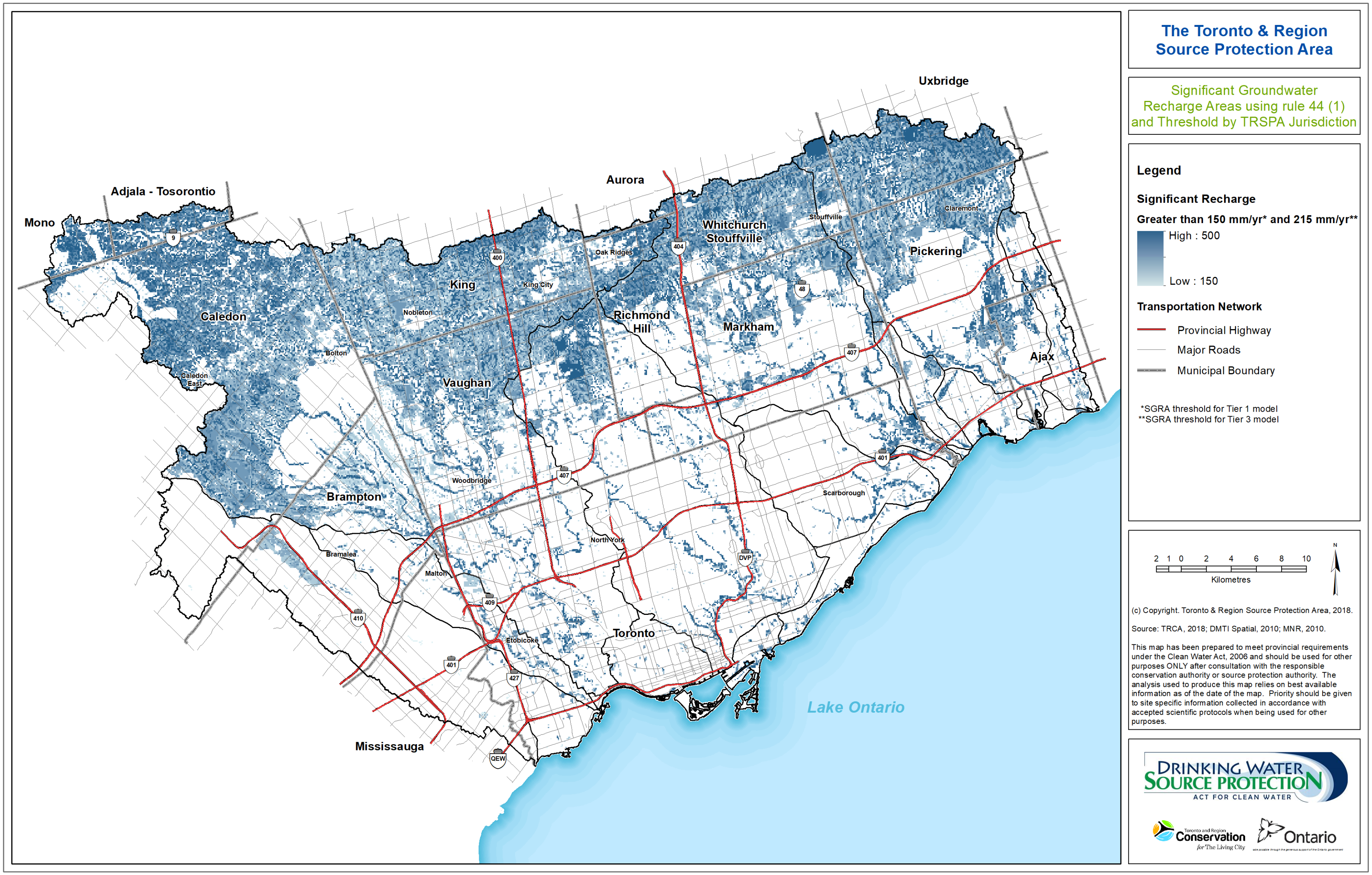

Figure D2-6: SGRAs using Rule 44 (1) and Threshold by TRSPA Jurisdiction

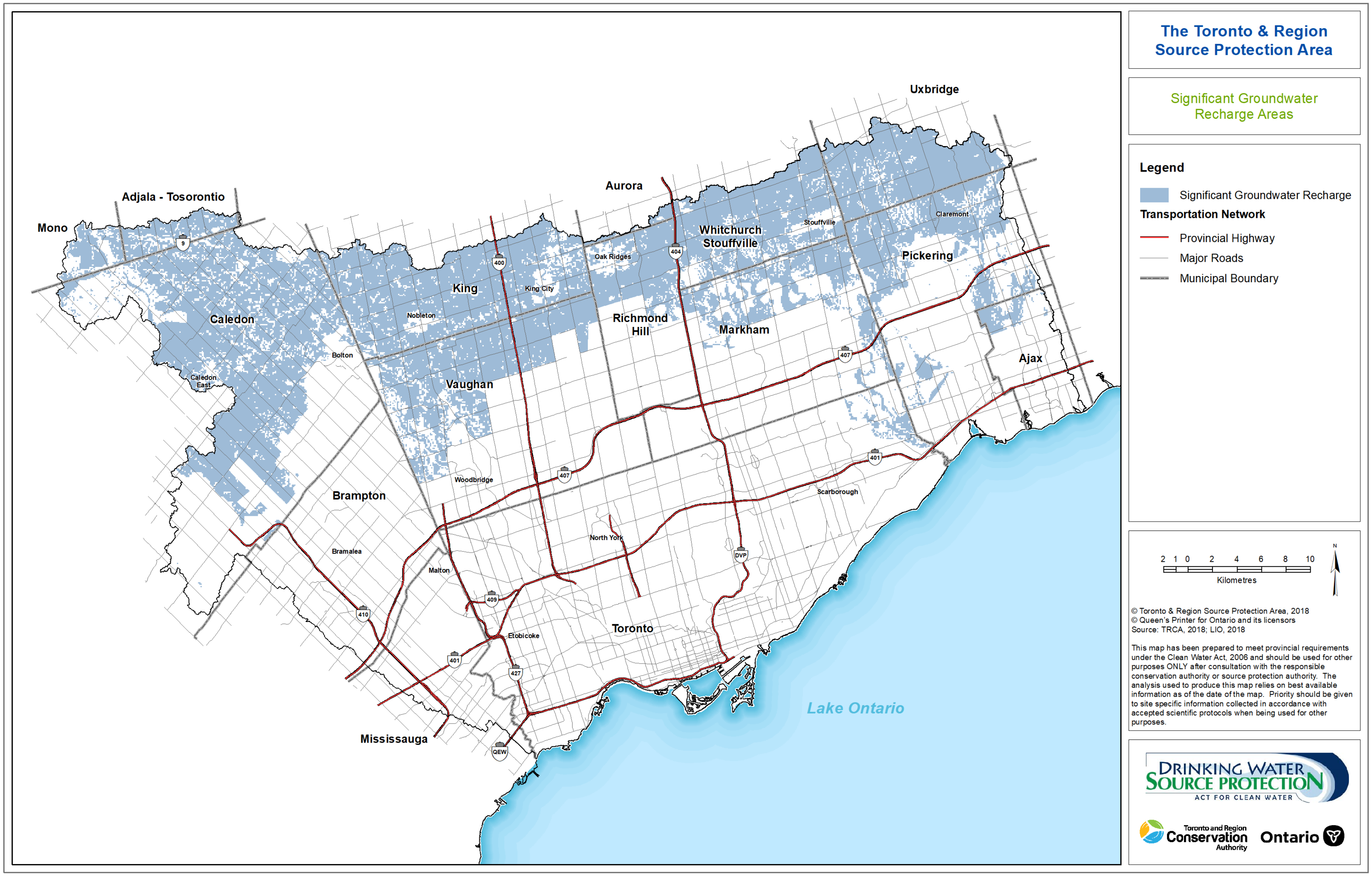

Figure D2-7: Final SGRAs from Tier 3 Water Budget

To produce the final map shown in the main body of this Assessment Report, TRCA staff clipped out the areas that were not upgradient of the known municipally serviced areas from Lake Ontario. This was to satisfy *Rule 45* that states that SGRAs must be hydraulically connected to a groundwater system (municipal or private).

As discussed in **Chapter 3** of the main body of this report, the Tier 3 Water Budget projects for York Region (Earthfx, 2013) resulted in redefined SGRAs for the TRSPA. The same evaluation processes were used for the new model output. The SGRAs from the Tier 1 work that are located outside of the Tier 3 model domain have been added in to the final map.

In 2017, TRCA staff became aware that the York Tier 3 water budget parameter mapping (i.e., precipitation, evapotranspiration, runoff, and recharge) provided by the consultant were not estimated from a standard 30-year climate normal simulation using the fully integrated surface water - groundwater model (GSFLOW). Instead, they were obtained from a shorter modelling period using the surface water module (PRMS) alone. Therefore, TRCA arranged for GSFLOW model outputs for the Oct 1, 1983 to Sept 30, 2013 period using the known existing pumping rates and existing land use. The revised outputs are considered to be the best available representation of current average annual conditions.

It is important to note that, while the analyses were restricted to the TRSPA, the SGRAs include areas outside of the TRSPA watersheds that contribute to streamflow within the study area. Lateral groundwater movement between catchments is significant, and in particular, lateral inflows from outside the TRSPA watersheds form an important component of the flow system, both from a water volume and SGRA protection perspective.

D2.3.2 Limitations: Data and Method

This report does not exhaustively address all possible conditions that may exist in the study area. Computer models are a simplification of the real world, built from limited and potentially erroneous data, so their results should be considered with care and independently verified. It should be recognized that the passage of time affects the information provided in this report. Environmental conditions can change. Computer simulations are based upon information that existed at the time the data and model was formulated.

D2.3.3 Uncertainty Assessment

Uncertainty is inherent in the water budget estimation process. The accuracy of estimates relies on the:

- 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.

Overall, the issues related to uncertainty, data and knowledge gaps are complex and highly qualitative. There is a degree of uncertainty associated with every aspect of the water budget analyses. However, it is reasonable to expect a low level of uncertainty in areas where data density is high, where hydrogeologic studies have been conducted, and where numerical models have been developed. It is recognized, that all hydrogeologic analyses have an intrinsic level of uncertainty because one can never have enough data to fully know how conditions vary in the subsurface.

D2.4 Vulnerability in Intake Protection Zones (IPZ-1 and IPZ-2s)

D2.4.1 Methods of Analysis

The TRSPA surface water vulnerability analysis was conducted as part of a broader Lake Ontario collaborative of municipalities with intakes along the north and western shores of Lake Ontario *(the Lake Ontario Vulnerability Assessment Surface Water, Phase 1 and Phase 2, 2008)*. Technical studies are being conducted in two general areas of analysis.

For Great Lakes intakes, three vulnerability zones 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 where a spill of a contaminant might reach the intake before the plant operator can respond. In TRPSA, the IPZ-2 is based on estimating distance a contaminant might move in 2 hours along the water surface calculated from the water intake crib outwards under 10 year storm wind conditions. The IPZ-2 has the following components:
    - *In-Lake and alongshore (in-water) extent:*

      The in-water 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 time of travel (TOT) of 2-hours.
    - *Landward and up-tributary (upland) extent:*

      The upland component consists of the contributing area of watercourses located within the alongshore extent of the IPZ-2 (as determined above). The upstream limit of the IPZ-2 for each tributary within this zone is calculated using the residual time of the 2-hour TOT at the watercourse mouth and a standard “full bank” high flow event. The contributing areas off-bank in the main tributary and associated tributary branches downstream of this limit are determined as the Conservation Authority Regulated Limit, or the administratively set limit of 120 m, whichever is greater and includes constructed pathways such as storm sewersheds, drains and other surface water conveyances in addition to natural drainage.

  In general, sources of information for the upland and watershed IPZ-2 components include the TRCA Watershed Characterization Report, Canadian Hydrographic Service streamflow data, and other conservation authority watershed data and reports and municipal stormshed network mapping.

- IPZ-3 – In the Great Lakes, this zone is calculated as the area that may contribute contaminants to the intake based on modelling potential spills or releases from a specific facility on the shore or from rivers or creeks. Because the IPZ-3 analysis specifically identifies significant drinking water threats, the methodology for this analysis is presented separately in **Appendix E6**.

A schematic of the methodology for generation of IPZ-1 and 2 is included on **Figure D2-8.** These zones are then subject to an inventory of potential contaminant threat sources.

The IPZ-2 delineations are created 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 team must also assess 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.

D2.4.2 IPZ Delineations

Baird conducted numerical modeling in support of IPZ delineation for three (3) water treatment plants (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 data set 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 nearshore. 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 D2-8**. These zones are then subject to an inventory of potential contaminant threat sources.

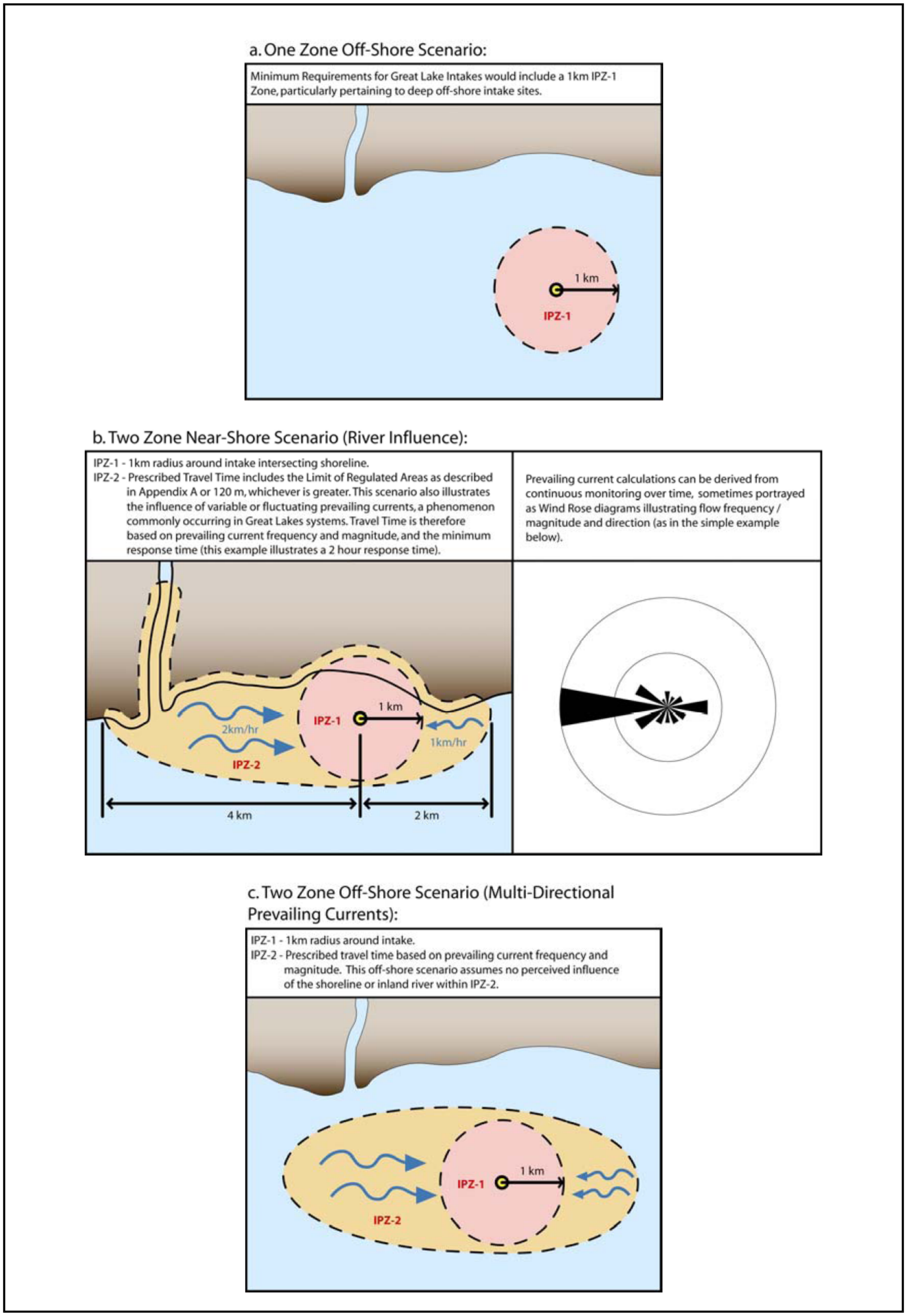

Figure D2-8: IPZ Delineation (from MOE, 2006)

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, at three WTP locations in the Durham Region 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.

D2.4.3 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.

D2.4.4 Limitations: Data Gaps and Methods

Numerical modeling undertaken in support of IPZ delineation during this phase of the project provides preliminary delineation of the IPZ-2 considering the hydrodynamic processes in the lake.

The key limitations of the modeling are as follows:

- The models used in this phase of the work are uncalibrated. A comparative validation of the model against available measured current and temperature data is recommended in order to evaluate the uncertainties associated with the numerical modeling results. Until this is done, it is not possible to say whether the results are conservative or not;

- Event based simulations were carried out in this phase of work for two events (east wind and west wind) of 3.5 day duration only. These are considered to be test runs and do not represent the full range of conditions that the intakes are exposed to. The time frames of these events were limited to the availability of the POM data, which covered a period from 2002 to 2006. Therefore, wind events that may have occurred prior to 2002 cannot be modeled using this methodology;
- Cross-section data for the rivers was limited to the information (if any) supplied in the NOAA National Geophysical Data Centre (NGDC) hydrographic dataset. Due to lack of any additional upstream bathymetry, it has been assumed that the upstream river cross-sections are the same as the river mouth. Actual river cross-section data should be collected and used in Phase 2 to better define the velocities in the river and the IPZ-2 limits;
- In this phase of the study, only gauged tributaries were defined in the model and flows at the mouth of the rivers were represented by 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;
- IPZ delineation was derived from lake hydrodynamics. The dispersion of contaminant plumes through natural diffusion movements as a result of density currents was not considered in this phase of work; and
- A conservative approach was taken in the reverse particle tracking. Particles were released at the surface where currents are stronger. Although this is a conservative approach, we cannot be certain if the model results are conservative, until the model is calibrated (as discussed above). In the next phase of the work, the particles will be released at the intake depth, closer to the lakebed.

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. To complete a more comprehensive Module 4 assessment, data gaps identified in **Table D2-5** must 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 D2-6**.

Table D2-6: Summary of Data that are Undergoing Refinement

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
Zones 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

D2.4.5 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.

- Overland flow and drainage patterns are based on topographical information;
- Stormsheds were assumed on the basis that large urban areas are drained by storm sewer networks;
- 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;
- Residual time method was used in delineating upland IPZ-2 boundaries. See Case A in **Appendix 3.2** for method description and procedure;
- Where regulated limit is not provided the assumed upland extent for shoreline components and tributary watercourses is 120 m; and
- Transportation corridors are assumed to connect directly to vulnerability pathways.

There was an abundance of data collected for this study from the participating conservation authorities, the region, the WTP, and other public databases.

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D3 MOECC 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,

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D4 TRANSPORT PATHWAY ADJUSTMENT STUDY

D4.1 Introduction

The assessment reports for the three authorities of the CTC SPR (Credit Valley Source Protection Authority (CVSPA), 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 (WHPA) 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** of this report.

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):*

- Aquifer Vulnerability Index (AVI);
- Intrinsic Susceptibility Index (ISI); and
- 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:

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

The CTC SPC 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 SPR 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 SPC 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**.

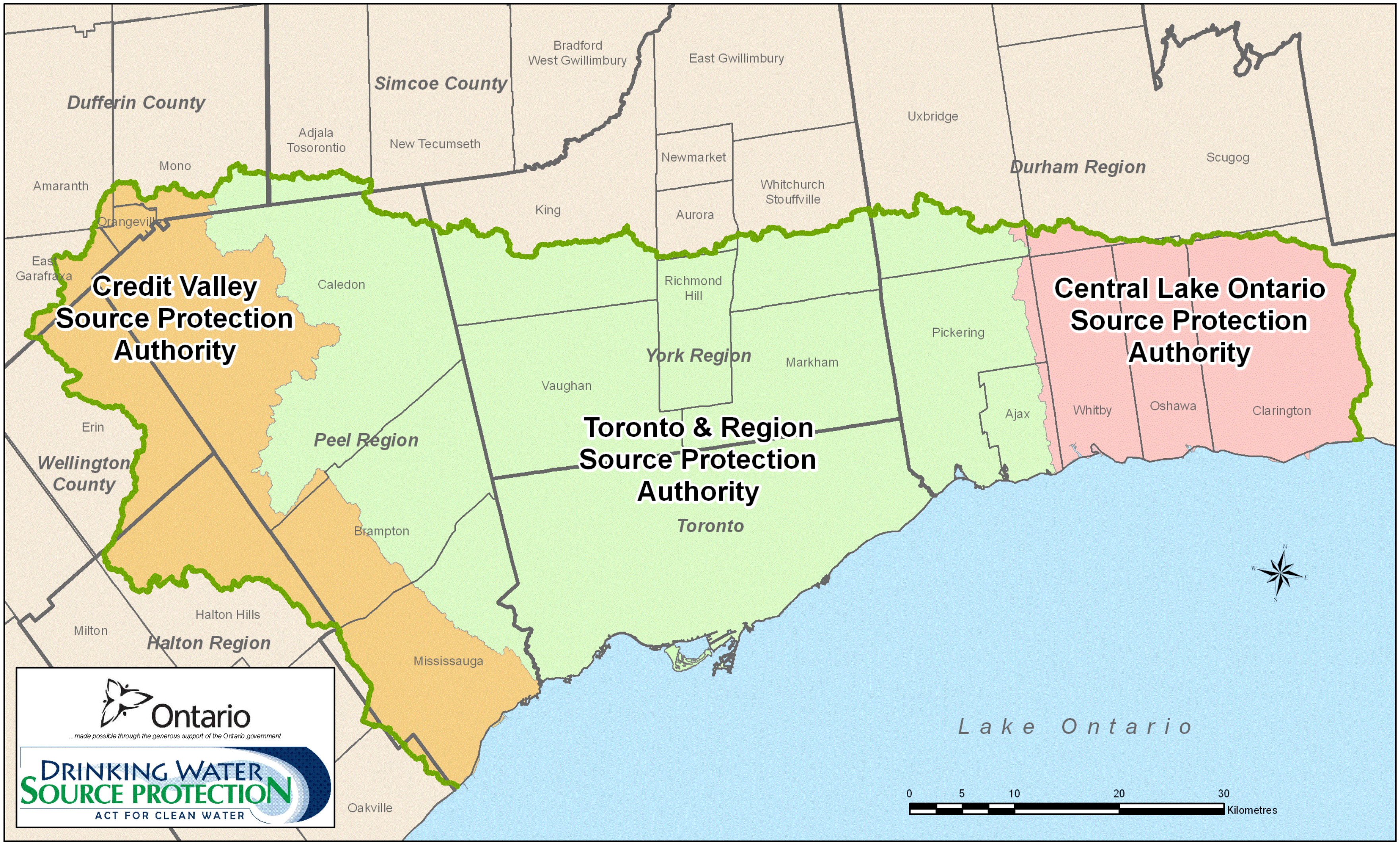


Figure D4-1: CTC Source Protection Region

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 **Table D4-1** 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.

D4.2 Available Methodologies

D4.2.1 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.

D4.2.2 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 D4-2: 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 available in digital format (septic locations outside of the WHPAs), 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';
- Large pipes (horizontal pathway); and
- 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 they 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.

D4.2.3 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".

D4.2.4 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.

D4.2.5 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 SPR 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.
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 assessment reports 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 3/3A, 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** (CE-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 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.
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 30m) vulnerability was increased by one category. These results were excluded from the assessment reports because of inconsistency between WHPAs.

Table D4-4: 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 East (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 East (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 East (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

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 East (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	Groundwater vulnerability analysis of SWAT times, unsaturated zone travel times (UZAT) were set equal to zero.	Not Applicable	Not Applicable
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 utility.	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 East (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 East (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
	Comments	Not Applicable	Not Applicable	Most buildings in Georgetown and Acton appear to be one to two stories with outdoor parking. Accordingly, there is not 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.

D4.3 Methodology Used by CTC Source Protection Region

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)).

D4.3.1 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. **ORMGP 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.

D4.3.2 Detailed Considerations of Pathways

<u>Pits and Quarries</u>

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.

<u>Full jurisdiction vulnerability/ HVA Delineation</u>

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 3/3A 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.

D4.3.3 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 be 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 East 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

D4.3.4 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

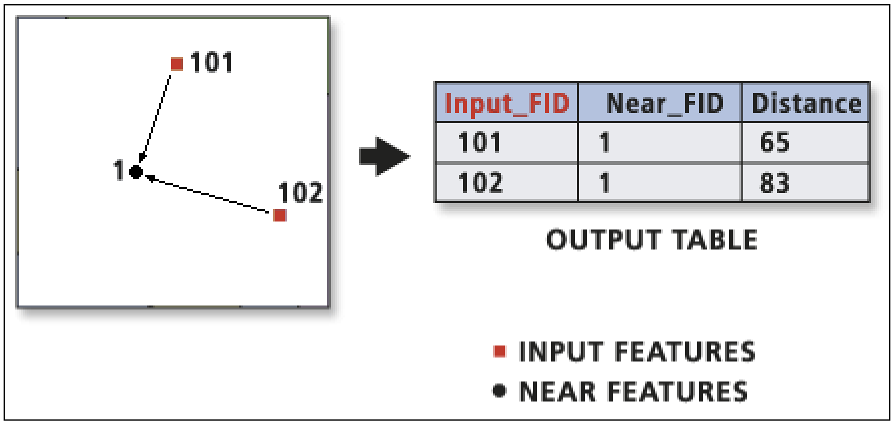
- Age of the boreholes as staff believes that there is no direct correlation between the age of the borehole and its impact as a potential pathway. Additionally, new properly constructed borehole could become a pathway in the future; and
- Municipal and monitoring wells as preferential pathways because 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.

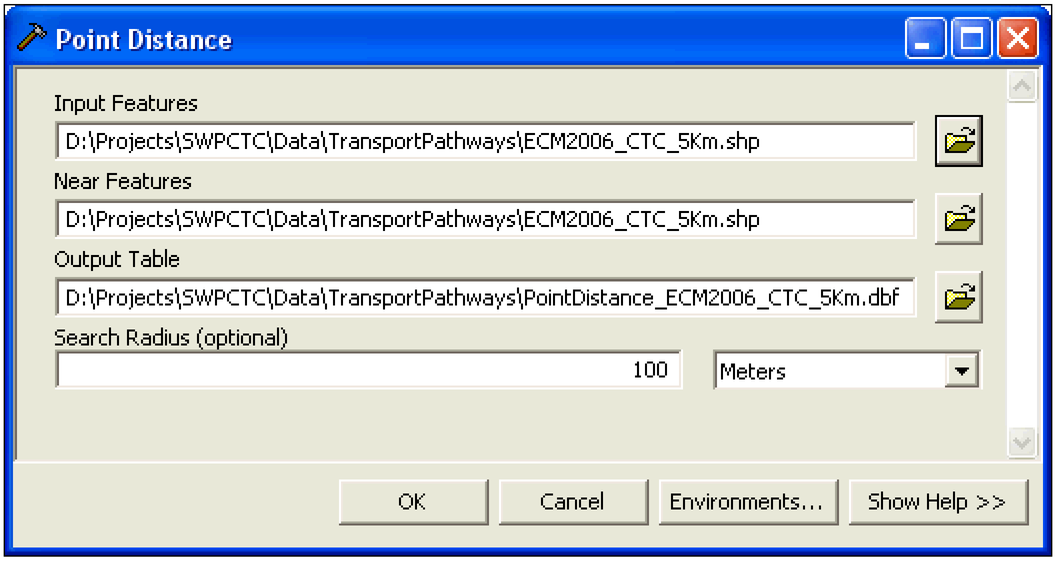
Point Distance Density Methodology

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 ORMGP) 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).
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))

D4.4 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.

D4.4.1 High Vulnerability Aquifer (HVA)

Figure D4-2 shows the CTC - High Vulnerability Aquifers 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 ORMGP 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 D4-5**).

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 SPR	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 SPR	1,923,190,000	1,929,870,000	6,680000	0.35

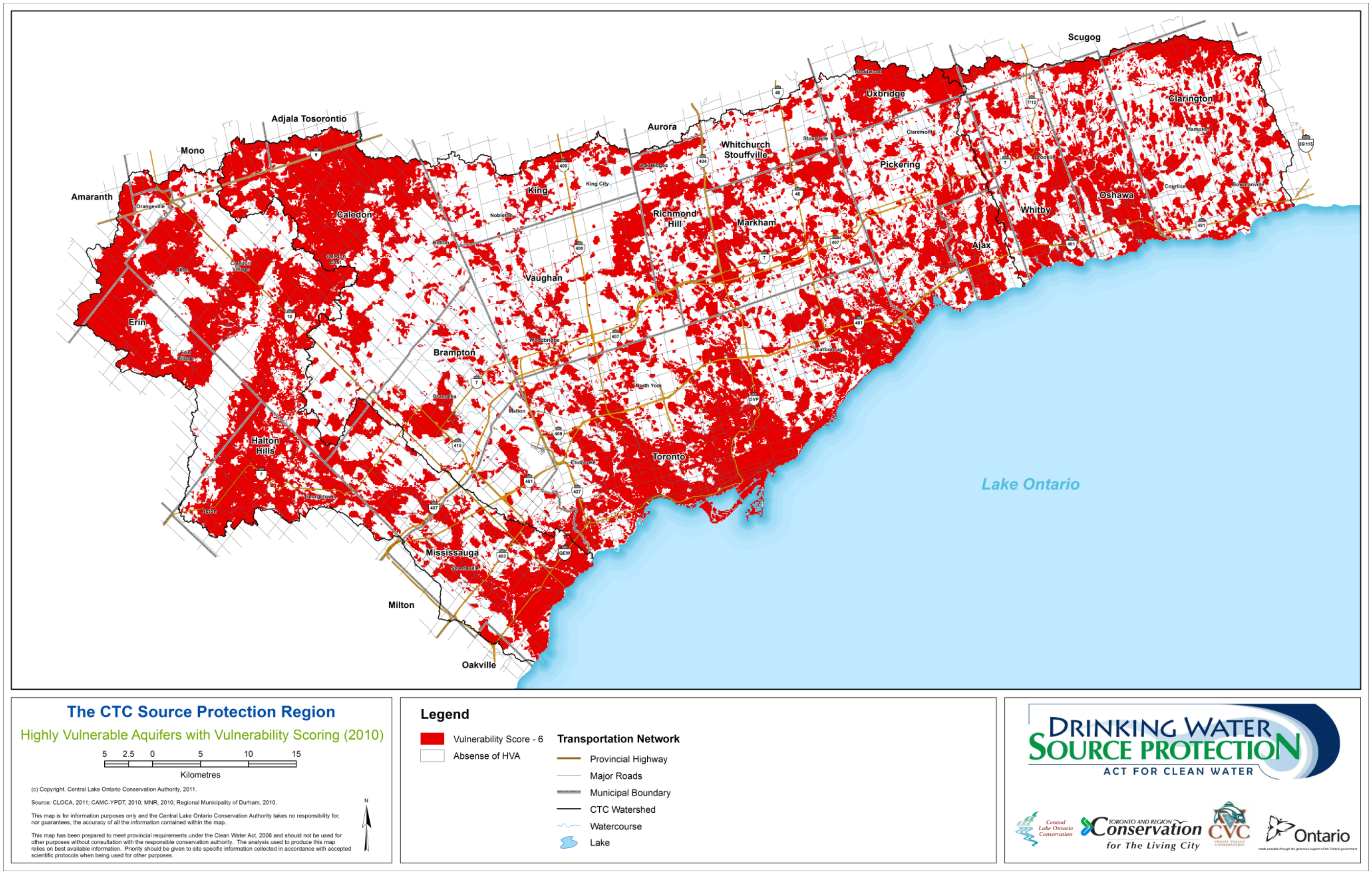


Figure D4-2: CTC SPR - High Vulnerability Aquifers without Pathways adjustment (2010)

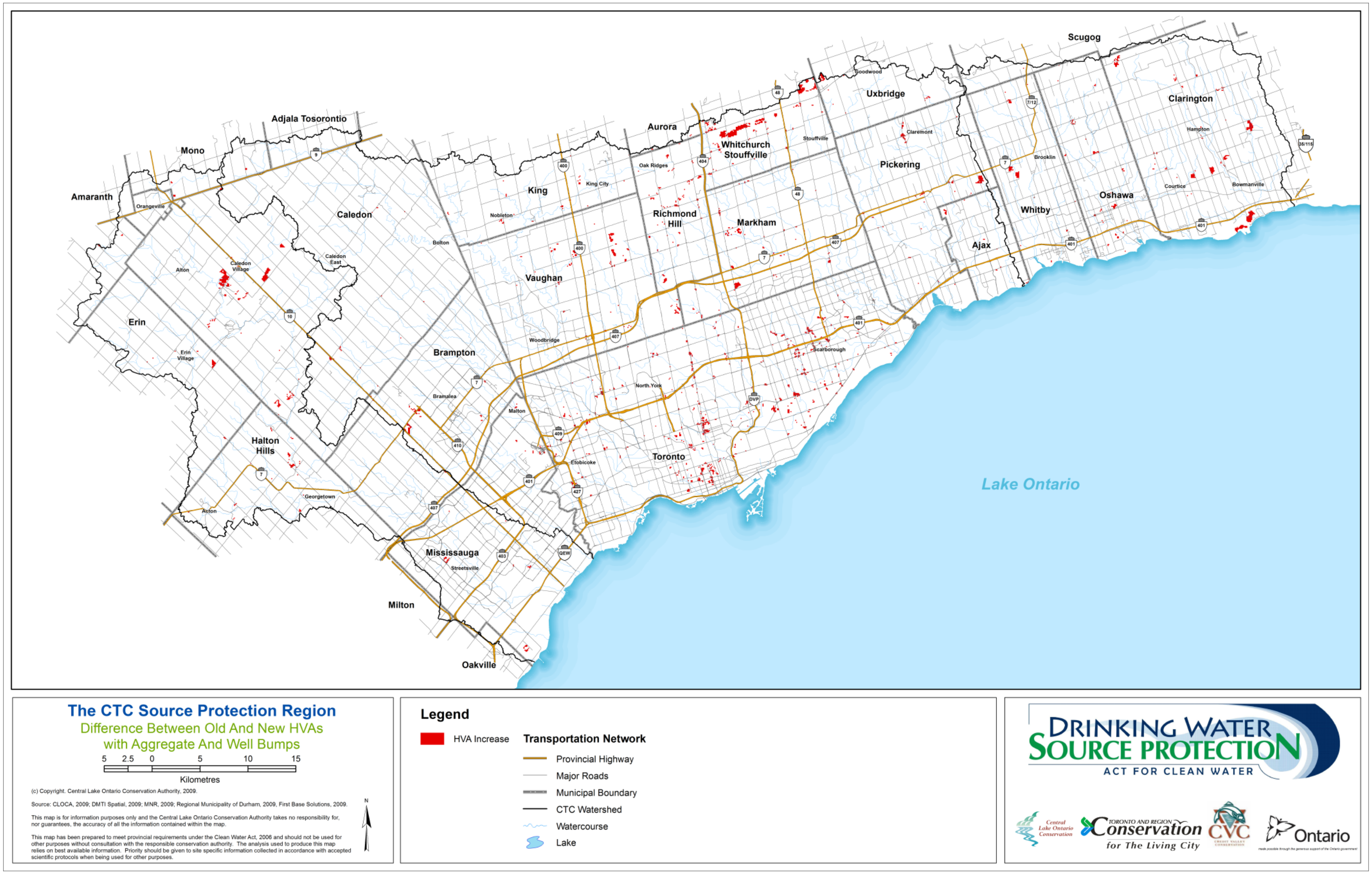


Figure D4-3: High Vulnerability Aquifer Differences (Pit/quarries and Clusters boreholes) 2011

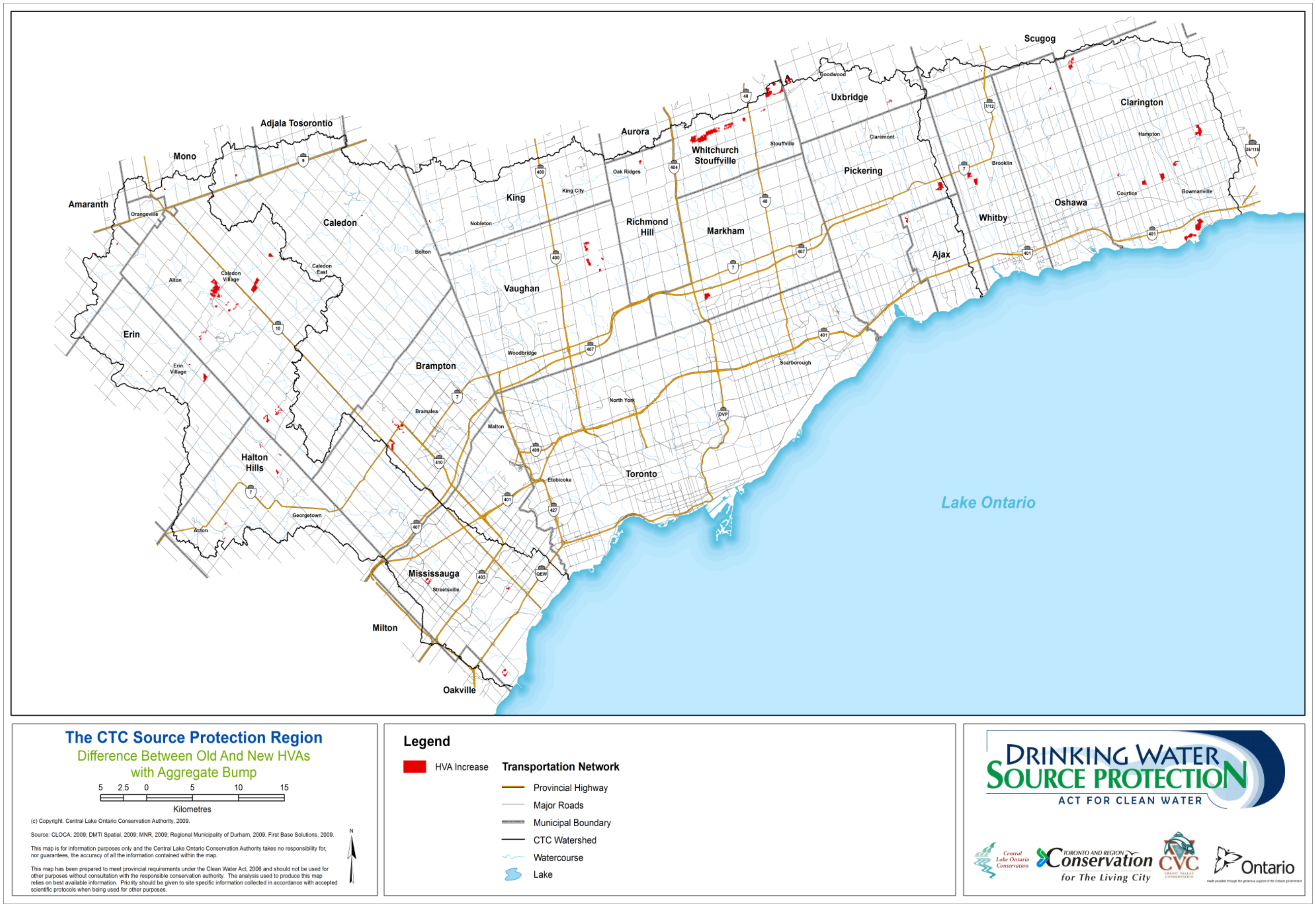


Figure D4-4: Highly Vulnerable Aquifer Differences (only Pit/quarries) 2011

D4.4.2 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**).

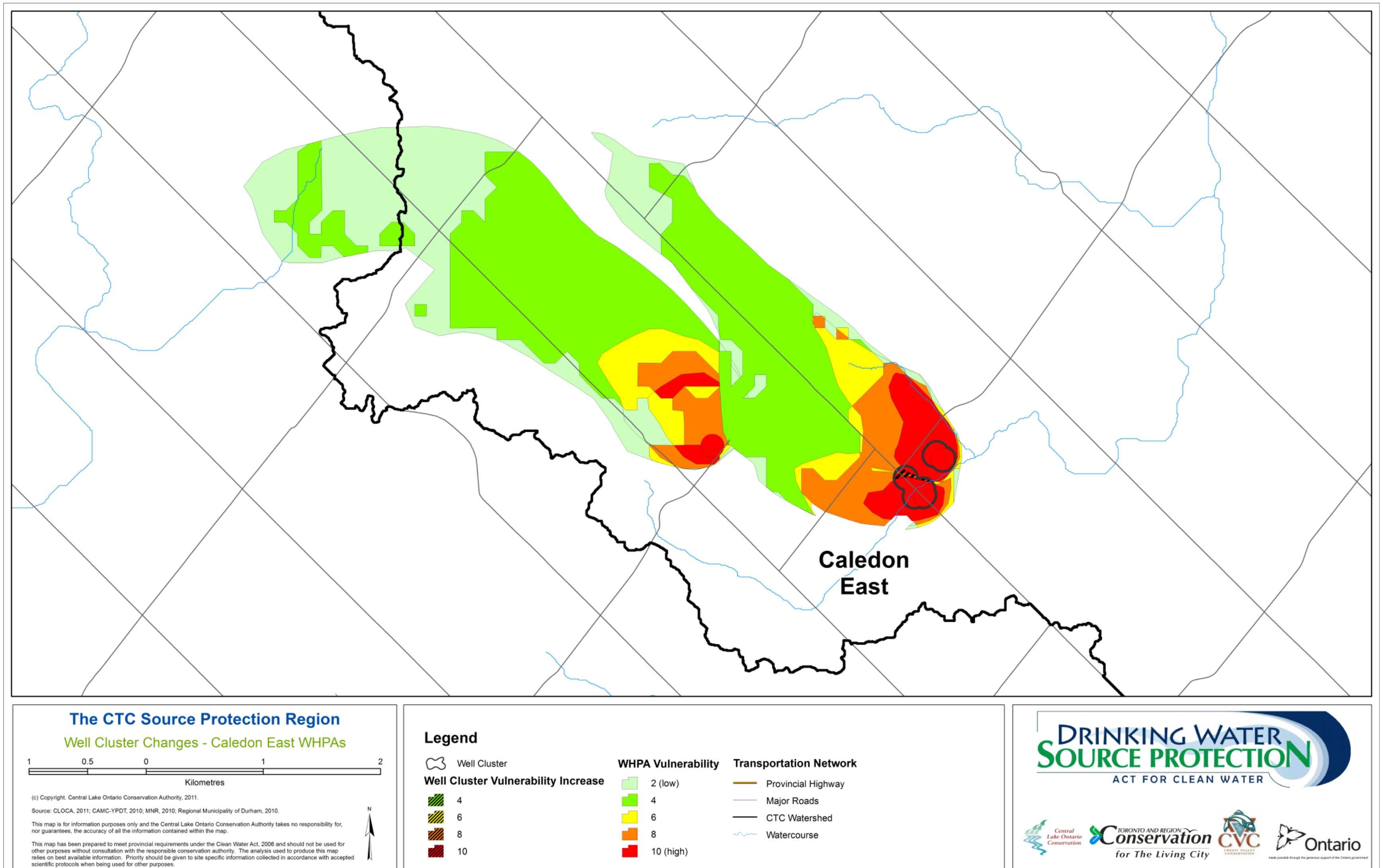


Figure D4-5: Borehole Cluster Changes Caledon East (TRSPA-Peel)

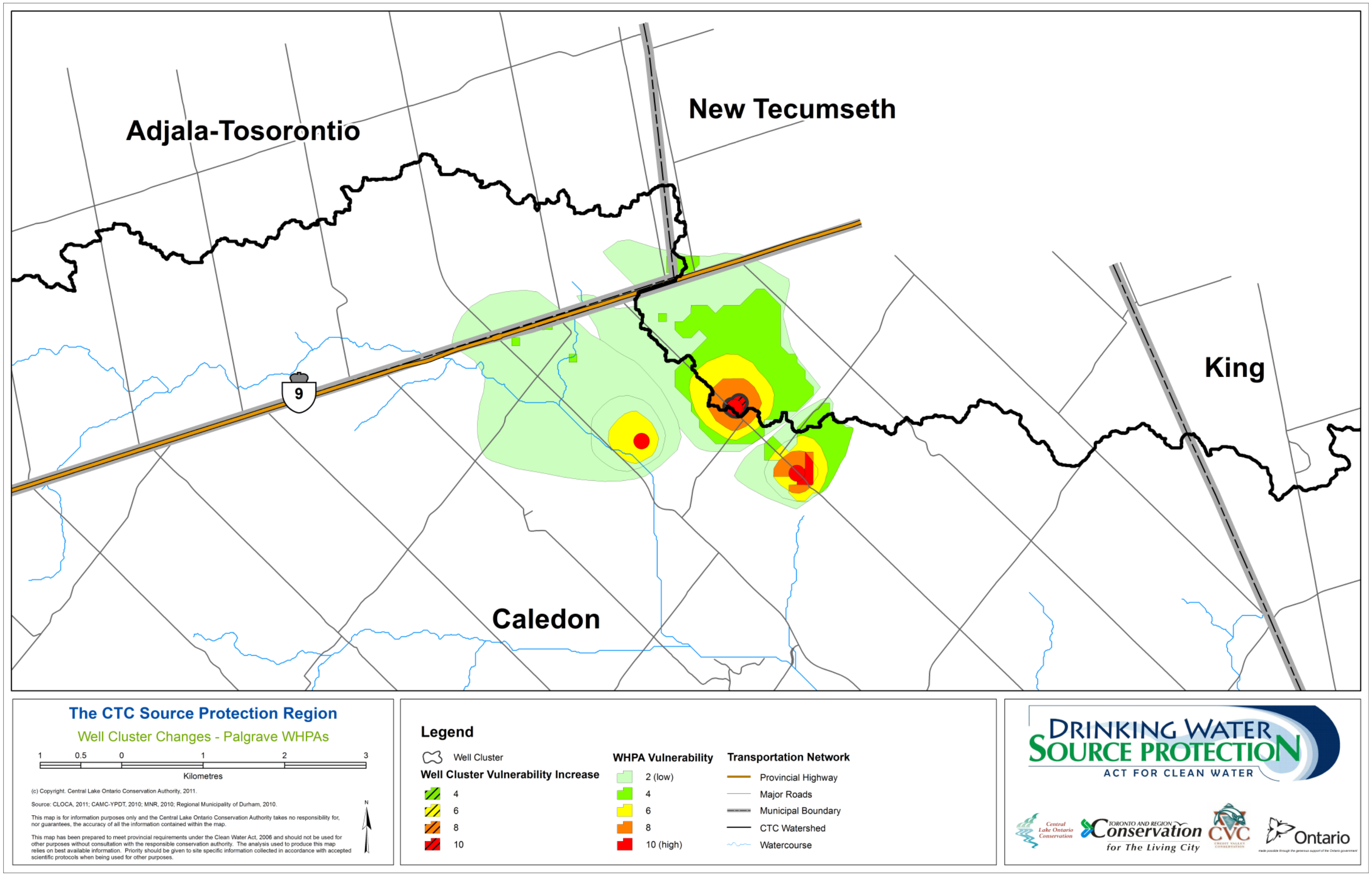


Figure D4-6: Borehole Cluster Changes Palgrave (TRSPA-Peel)

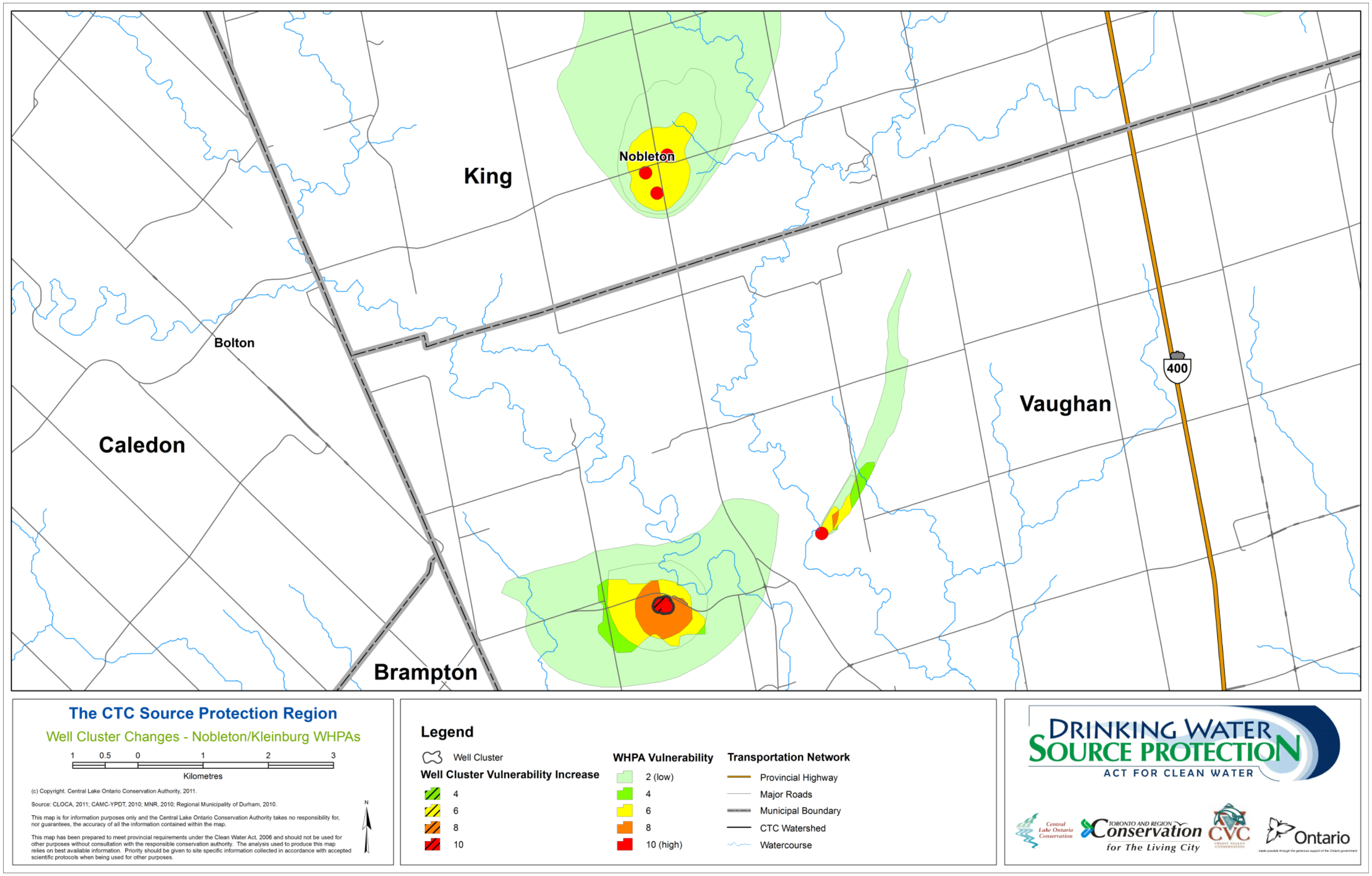


Figure D4-7: Borehole Cluster Changes Kleinburg (TRSPA-York)

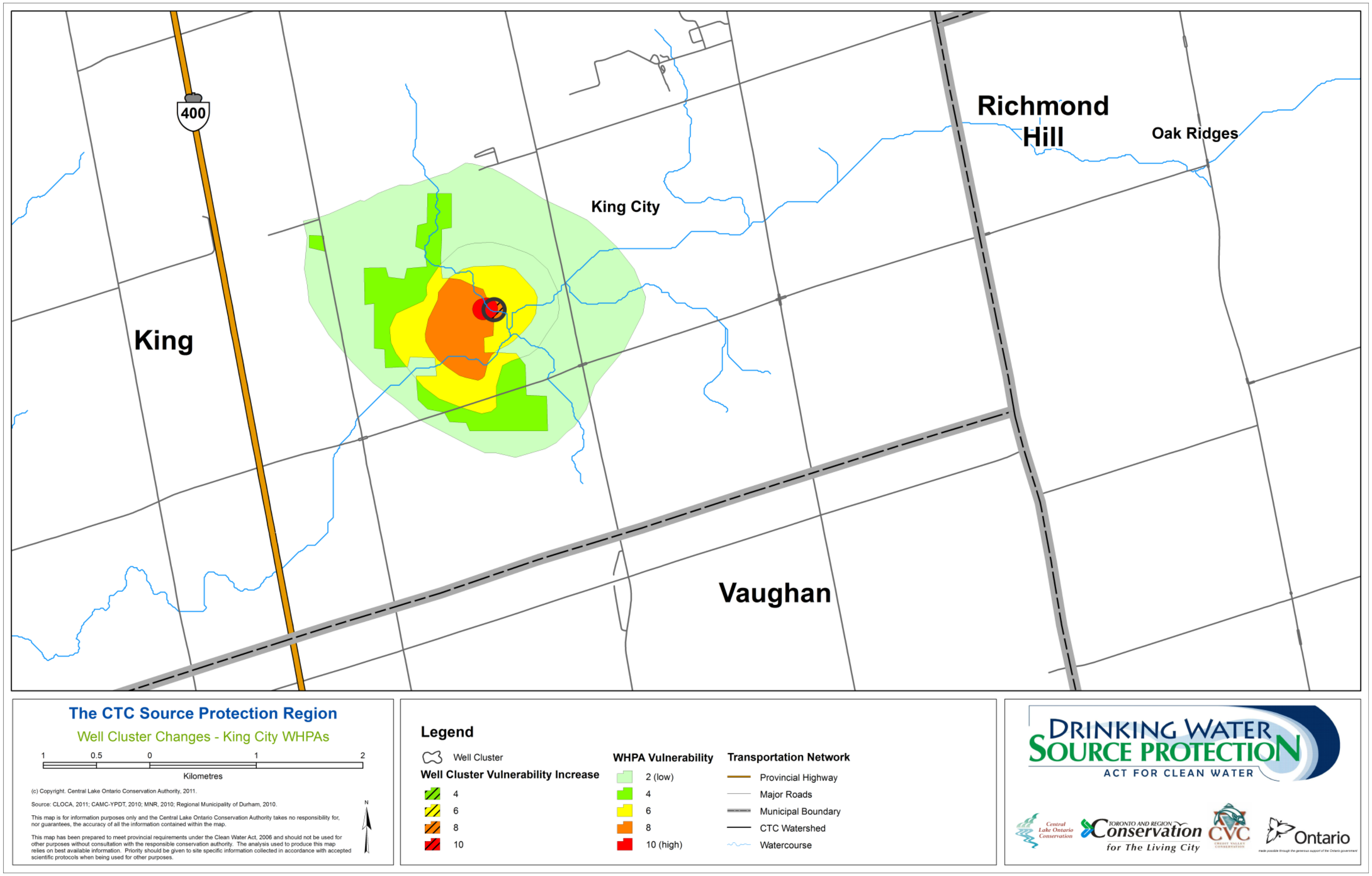


Figure D4-8: Borehole Cluster Changes King City (TRSPA-York)

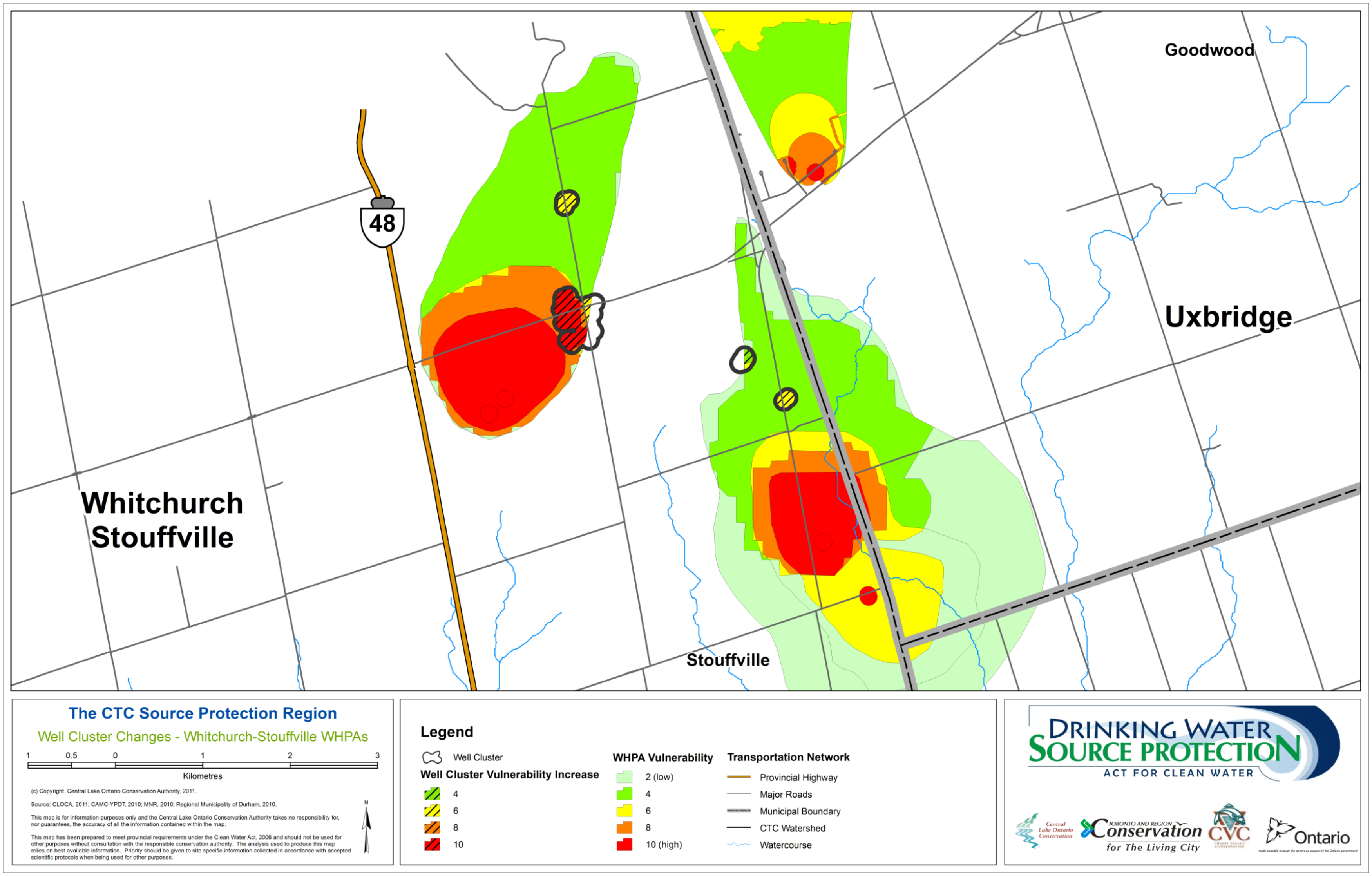


Figure D4-9: Borehole Cluster Changes Whitchurch-Stouffville (TRSPA-York)

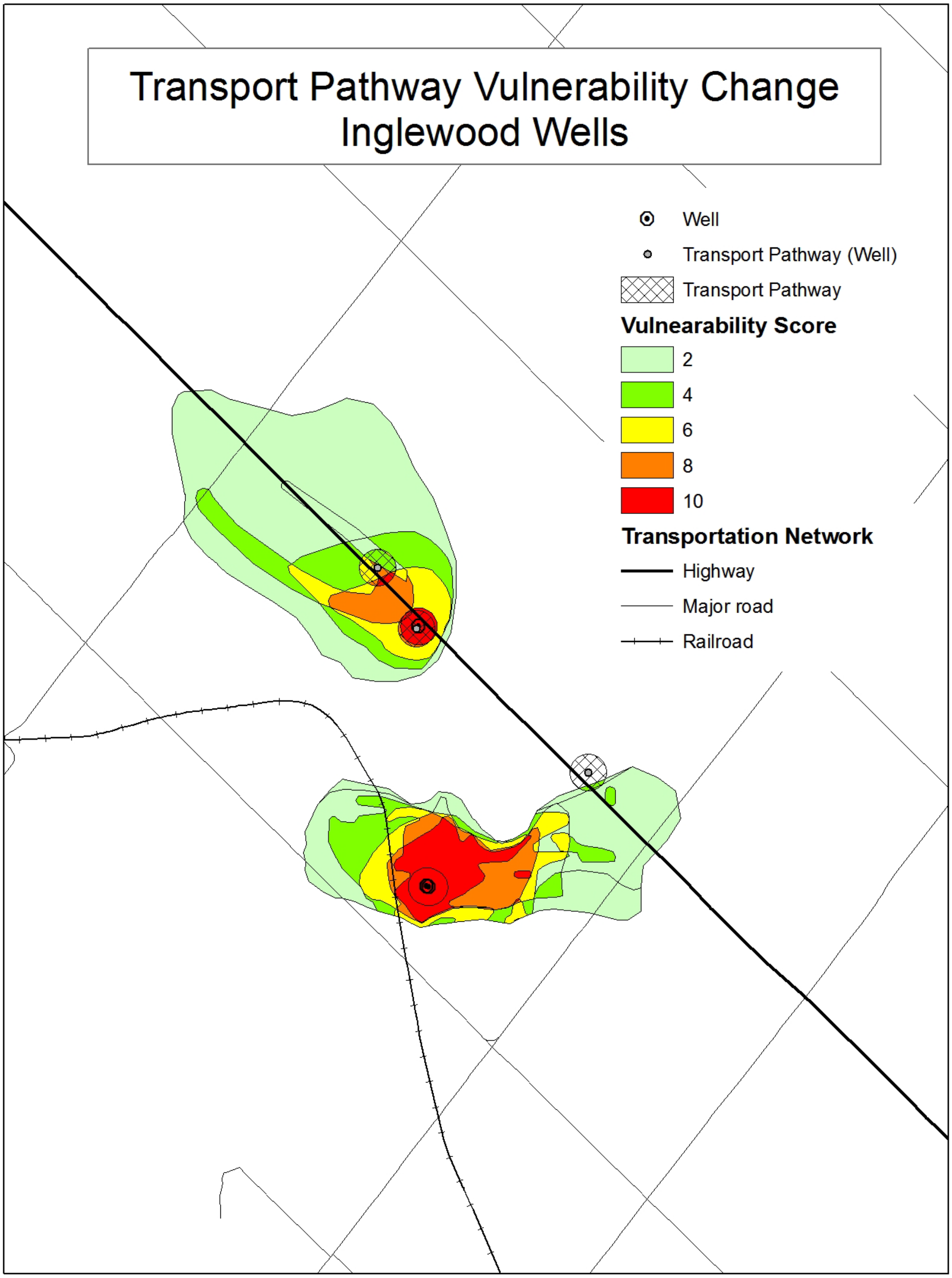


Figure D4-10: Borehole Cluster Changes Inglewood (CVSPA-Peel)

D4.4.3 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 reports.

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.

D4.4.4 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.

D4.5 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 **Table D4-5**). The total area increased to high vulnerability for pits/quarries only is 0.35% or 6,680,000 m^2 (0.0006 ha) (see **Table D4-6**). 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 lead 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.

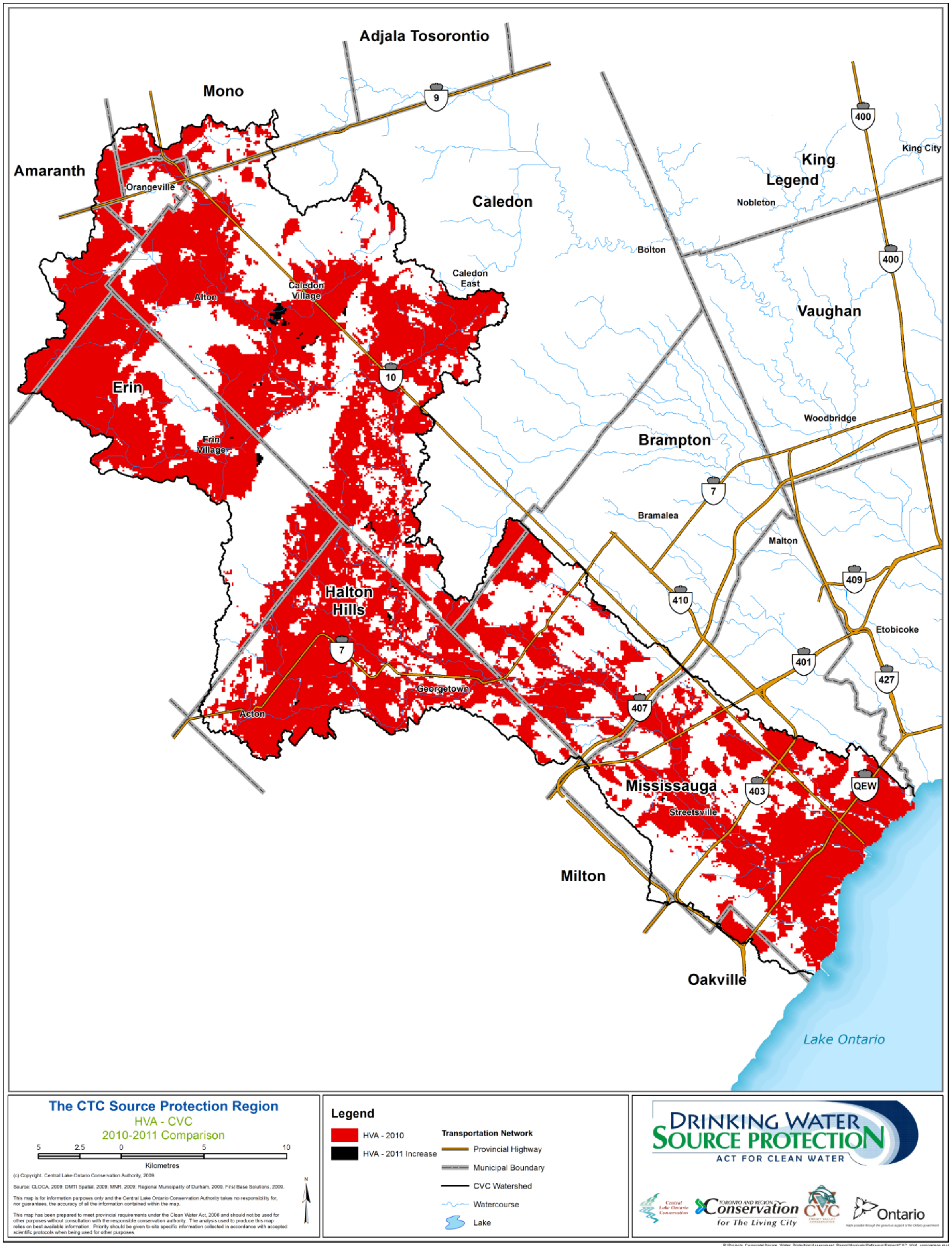


Figure D4-11: CVSPA - High Vulnerability Aquifer Differences (Pit/quarries)

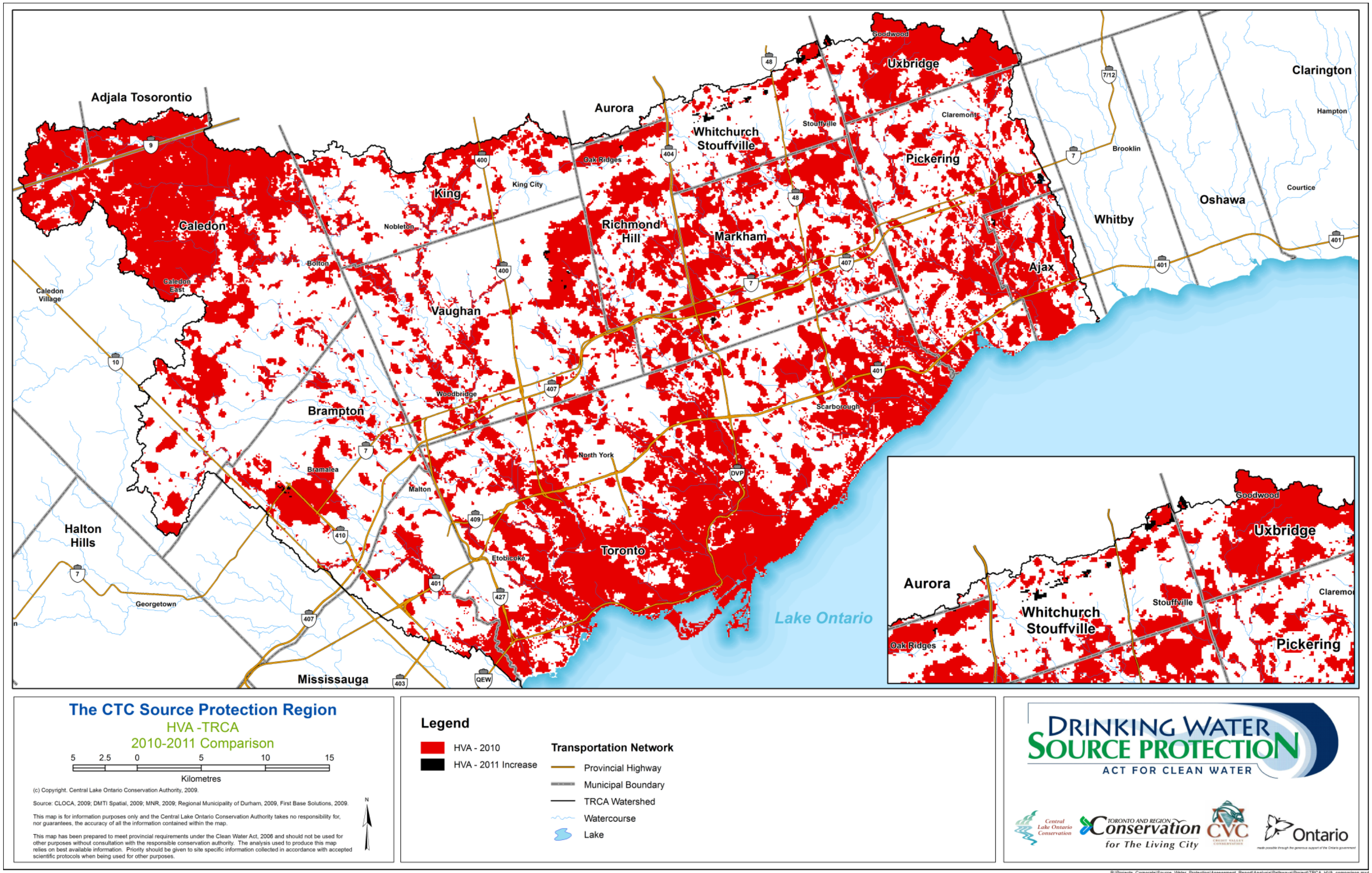


Figure D4-12: TRSPA - High Vulnerability Aquifer Differences (Pit/quarries)

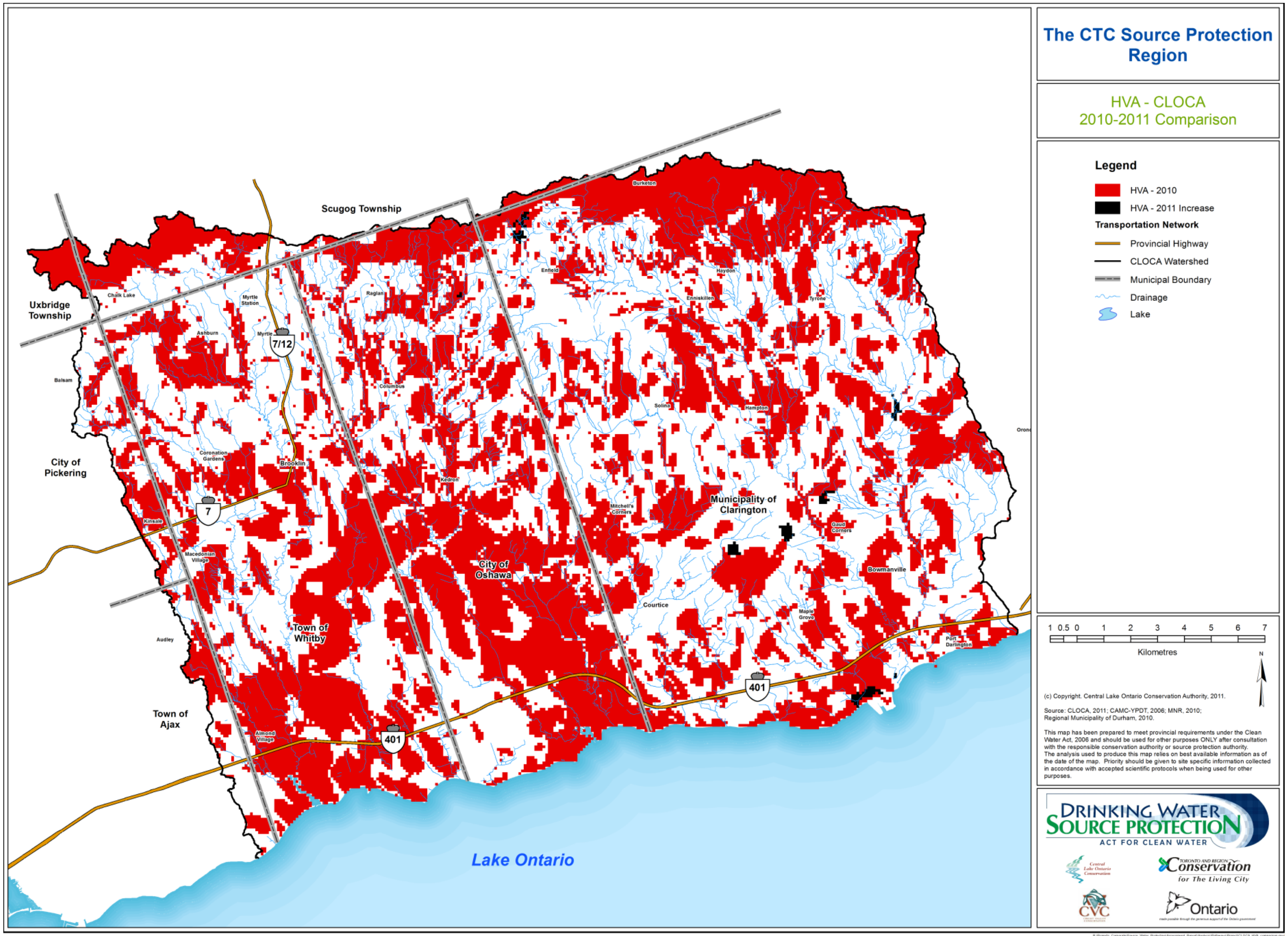


Figure D4-13: CLOSPA - High Vulnerability Aquifer Differences (Pit/quarries)

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