VULNERABILITY ANALYSIS

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) – not applicable in CLOSPA;
- Highly Vulnerable Aquifers (HVA); and
- 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 & 2's), or the broader landscape (HVAs).

D1.2 TECHNICAL RULES

The following *Technical Rules* describe the requirements for vulnerability analysis:

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

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); and
- Climate Change and Director's Technical Rules (August, 2009).

These three technical bulletins are below:

DRINKING WATER
SOURCE PROTECTION
ACT FOR CLEAN WATER

Technical Bulletin: Groundwater Vulnerability

Date: June 2010

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

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

The three groundwater-based vulnerable areas are:

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

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

Technical Bulletin: Groundwater Vulnerability

1. GROUNDWATER VULNERABILTY

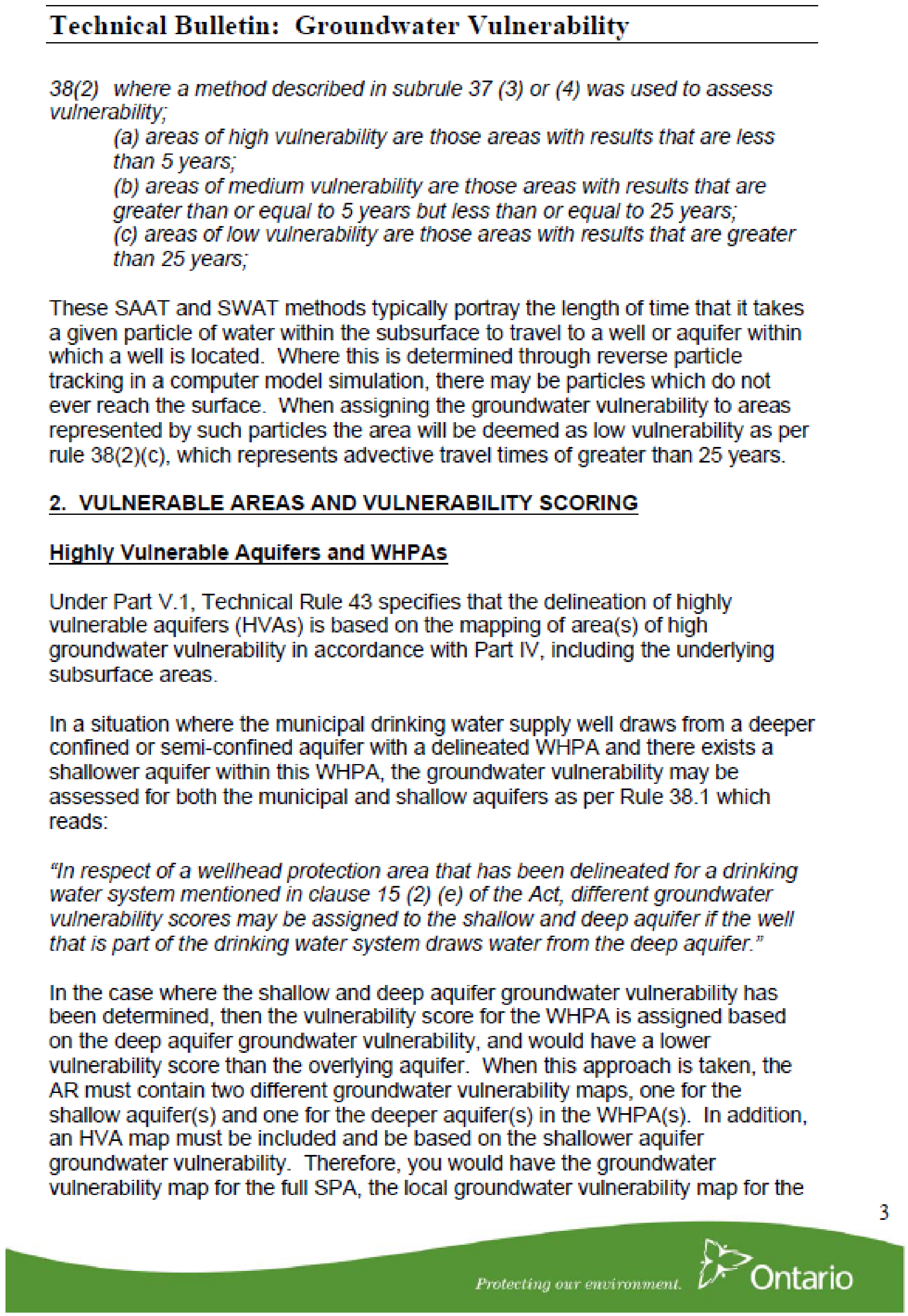
The vertical, or intrinsic, vulnerability of groundwater within a source protection area shall be assessed as directed in Part IV. This aspect of groundwater vulnerability considers the relative protective capacity of the overlying materials above an aquifer with respect to a potential chemical or pathogen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

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

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

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

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



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

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

3. DELINEATION OF WHPAS

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

WHPA-B within WHPA-A

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

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

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

WHPA-C and WHPA-C1

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

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

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

WHPA-E and WHPA-F

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

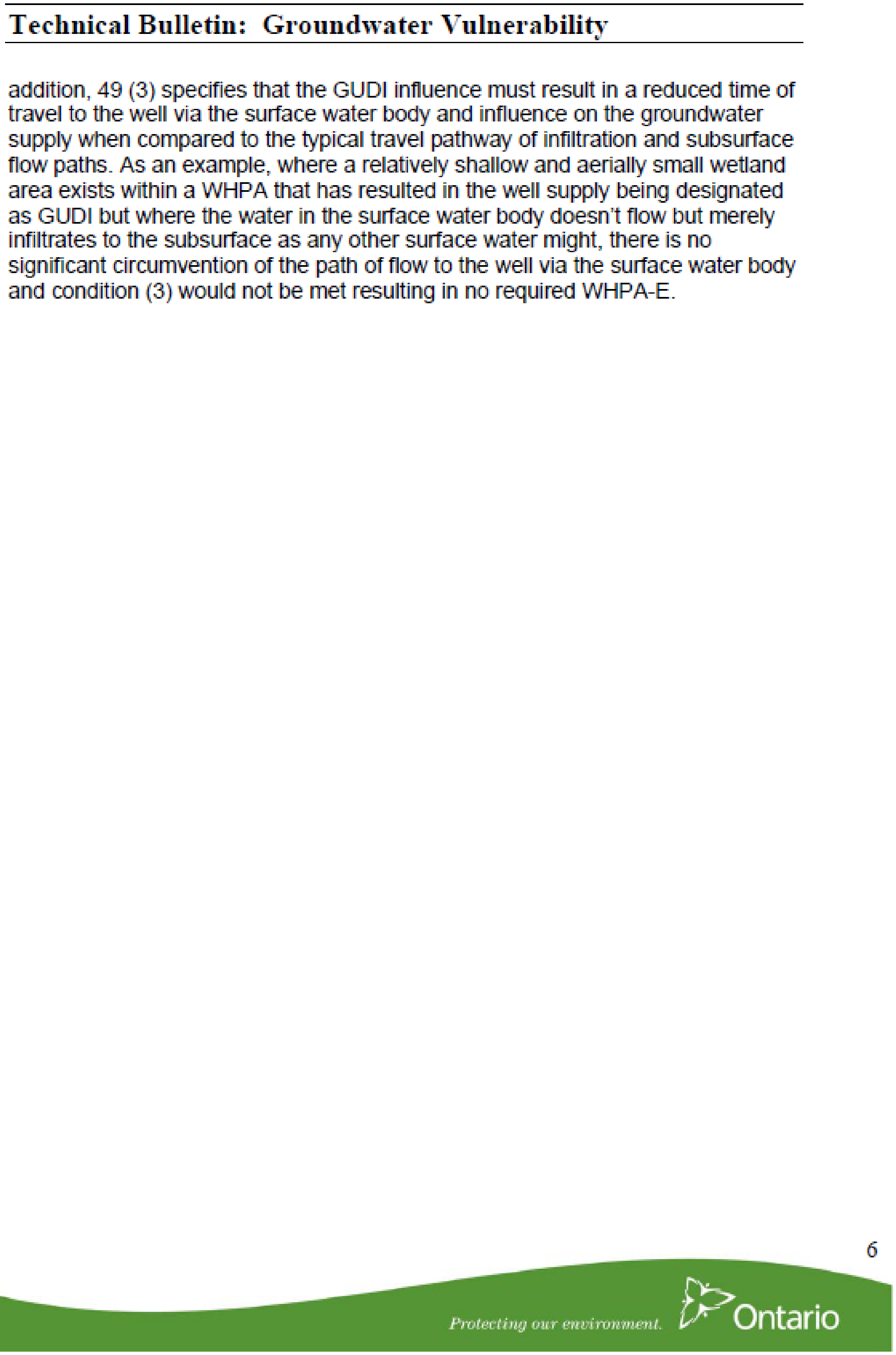
47(6) area WHPA-F, being the area delineated in accordance with the rules in Part VI that apply to the delineation of an IPZ-3, as if an intake for the system were located in the surface water body influencing the well at the point closest in proximity to the well.

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.

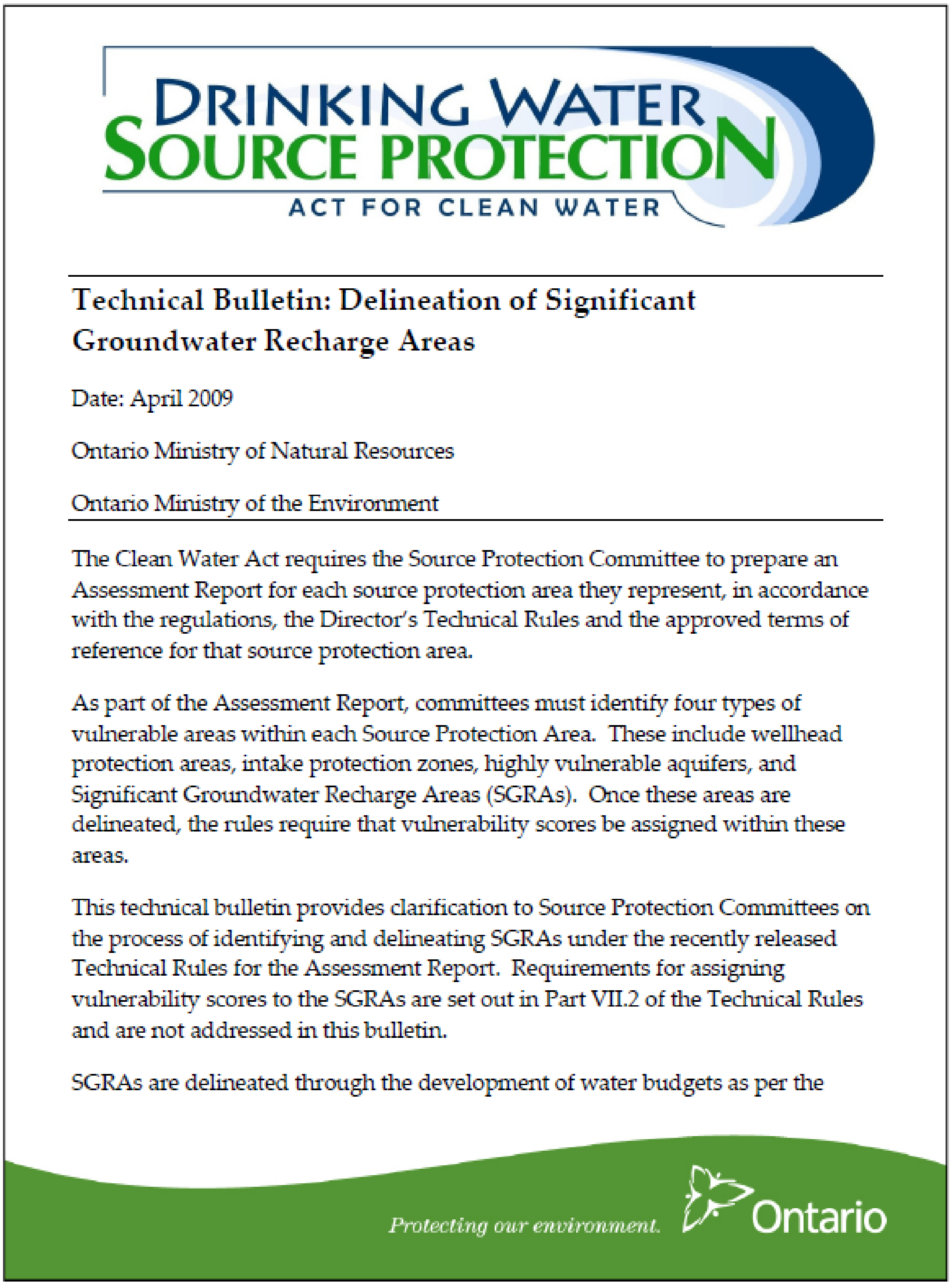
For GUDI wells, it is important to note that the Technical Rules provide three criteria which must exist in order to require WHPA-E and WHPA-F delineations, since without a WHPA-E you cannot have a WHPA-F (see rule 50(1)). These criteria are stipulated in the following rule:

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



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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PIBS 7576e

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.

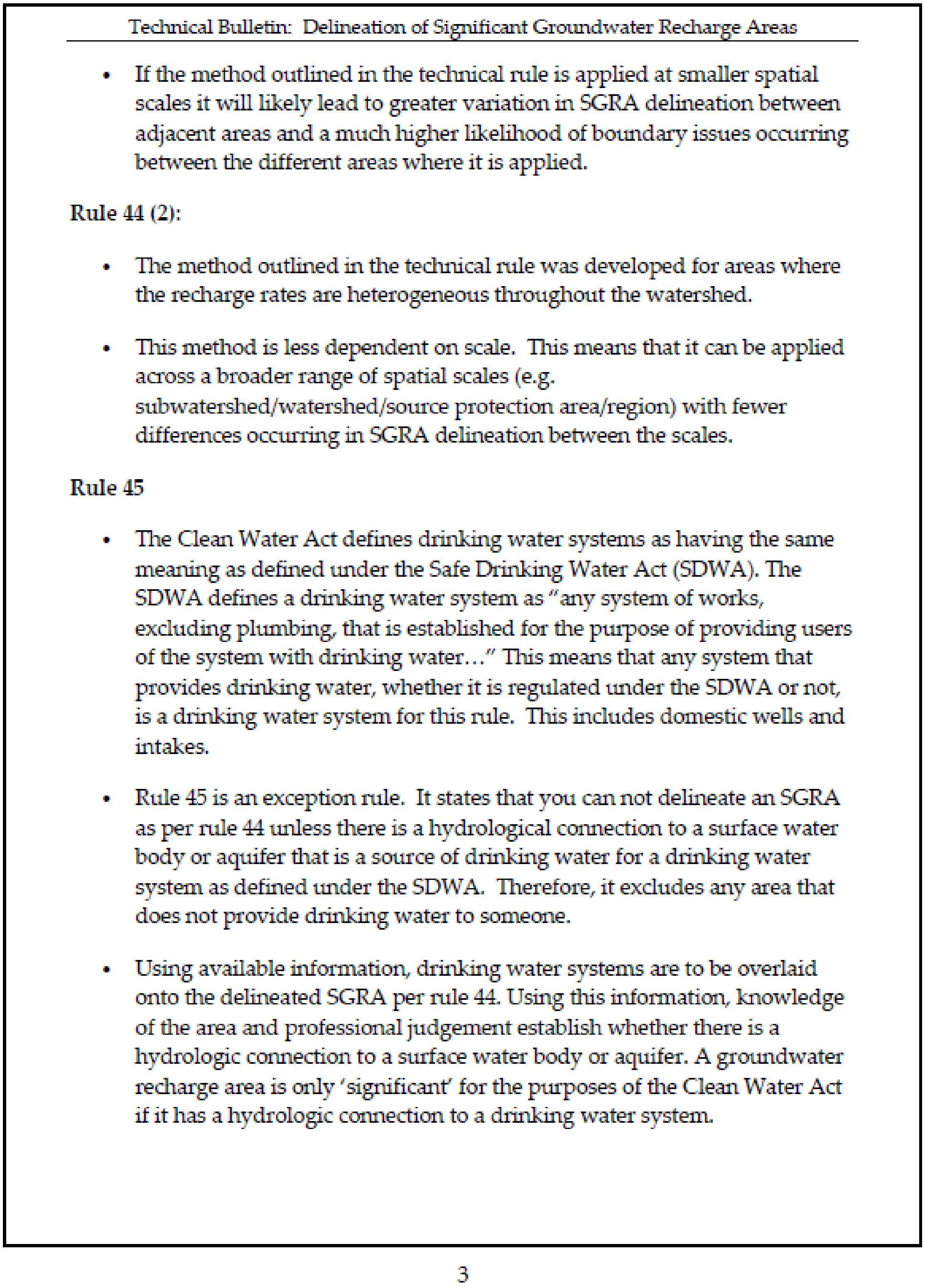
Part V.2 of the Technical Rules states,

> *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.



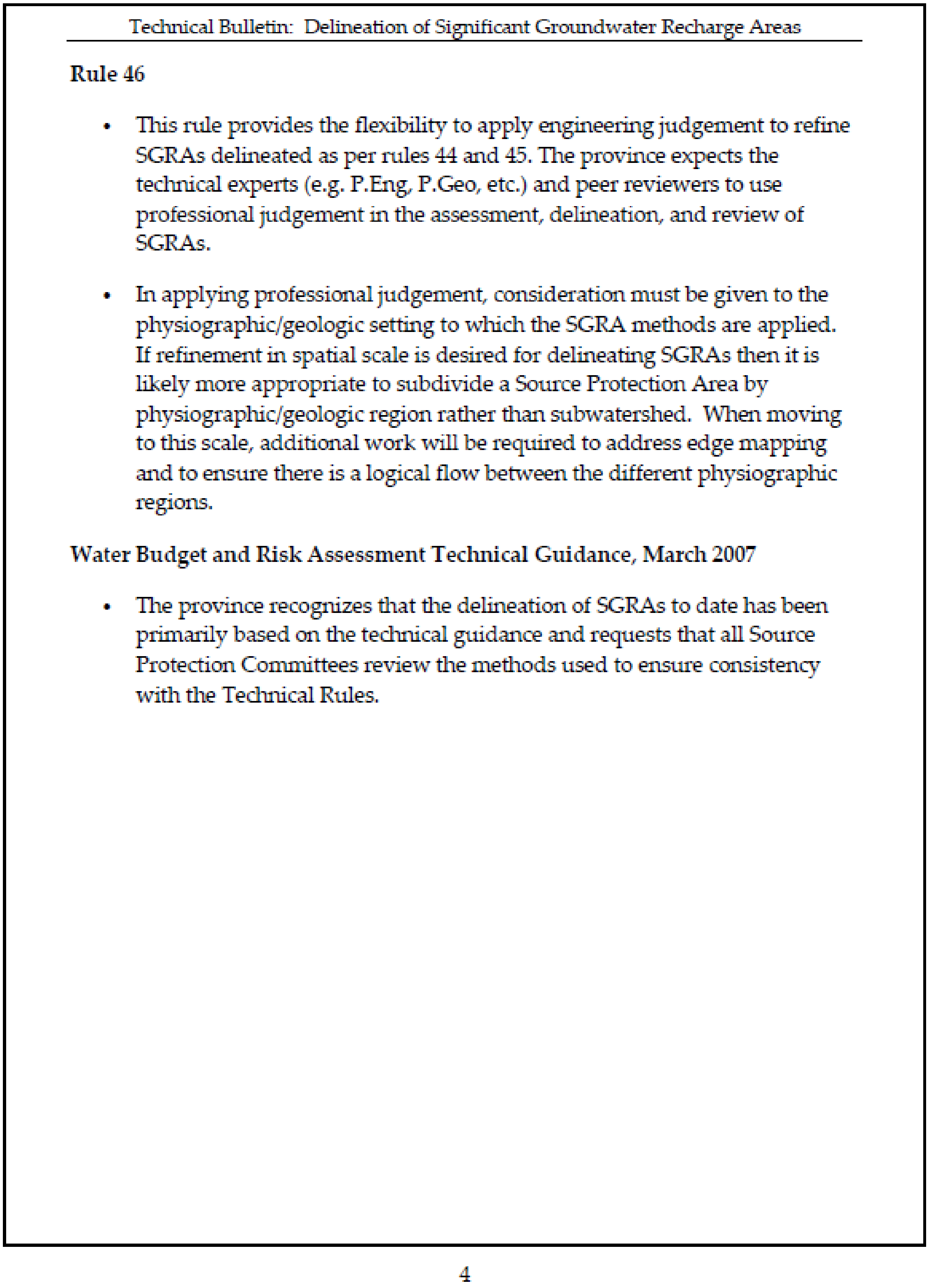
- If the method outlined in the technical rule is applied at smaller spatial scales it will likely lead to greater variation in SGRA delineation between adjacent areas and a much higher likelihood of boundary issues occurring between the different areas where it is applied.

Rule 44 (2):

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

Rule 45

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



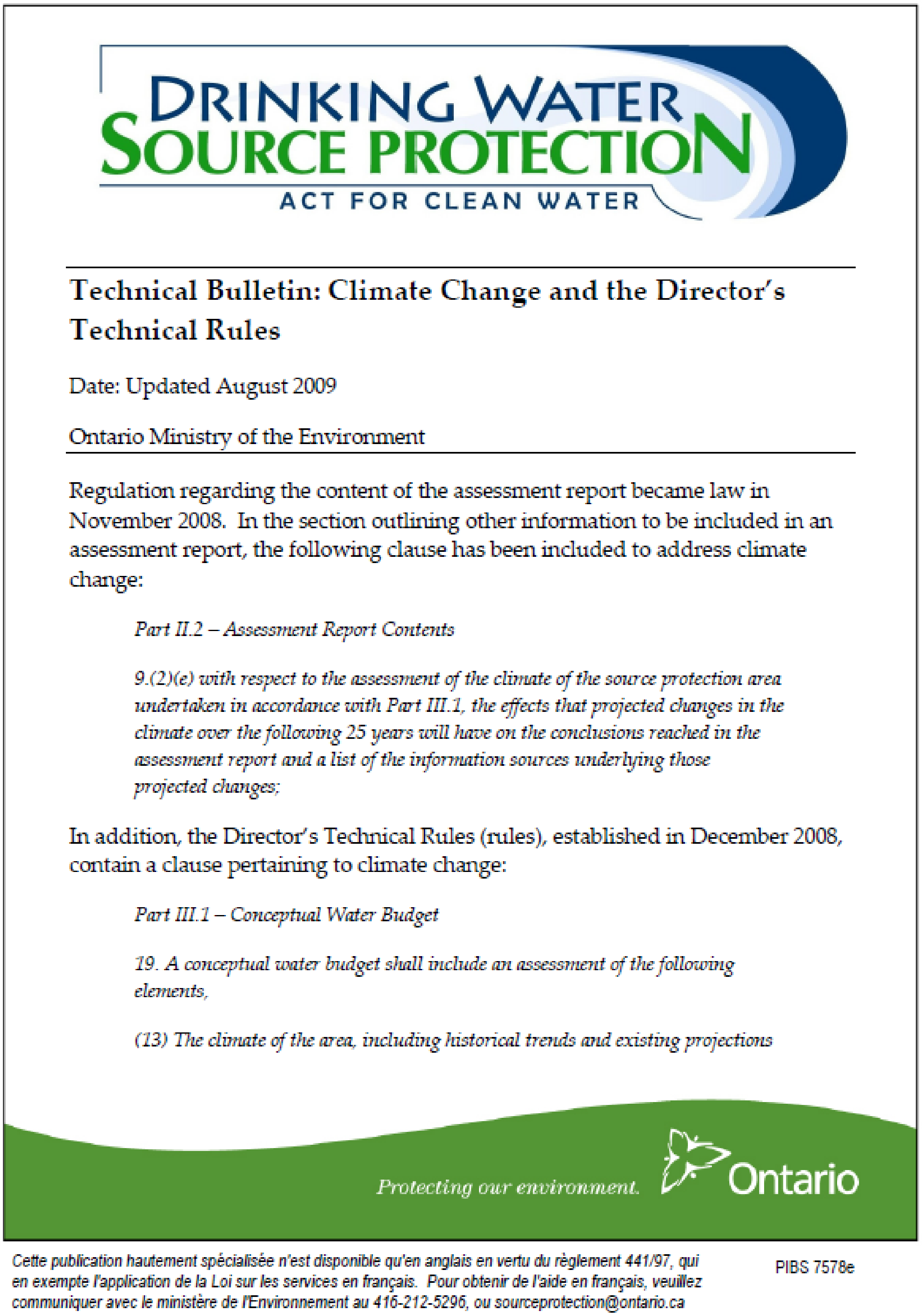
Rule 46

- This rule provides the flexibility to apply engineering judgement to refine SGRAs delineated as per rules 44 and 45. The province expects the technical experts (e.g. P.Eng, P.Geo, etc.) and peer reviewers to use professional judgement in the assessment, delineation, and review of SGRAs.

- In applying professional judgement, consideration must be given to the physiographic/geologic setting to which the SGRA methods are applied. If refinement in spatial scale is desired for delineating SGRAs then it is likely more appropriate to subdivide a Source Protection Area by physiographic/geologic region rather than subwatershed. When moving to this scale, additional work will be required to address edge mapping and to ensure there is a logical flow between the different physiographic regions.

Water Budget and Risk Assessment Technical Guidance, March 2007

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



DRINKING WATER
SOURCE PROTECTION
ACT FOR CLEAN WATER

Technical Bulletin: 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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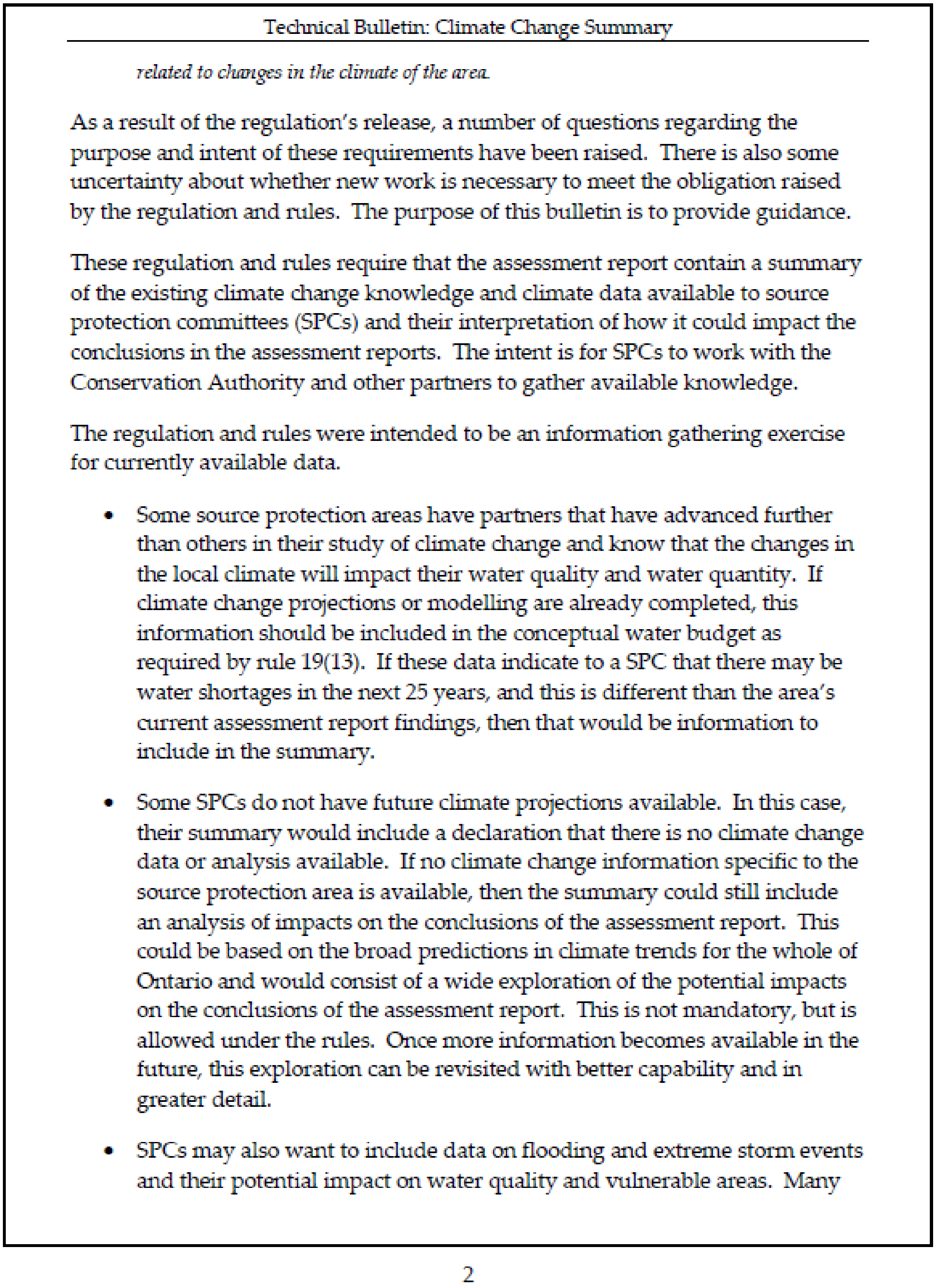


related to changes in the climate of the area.

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.

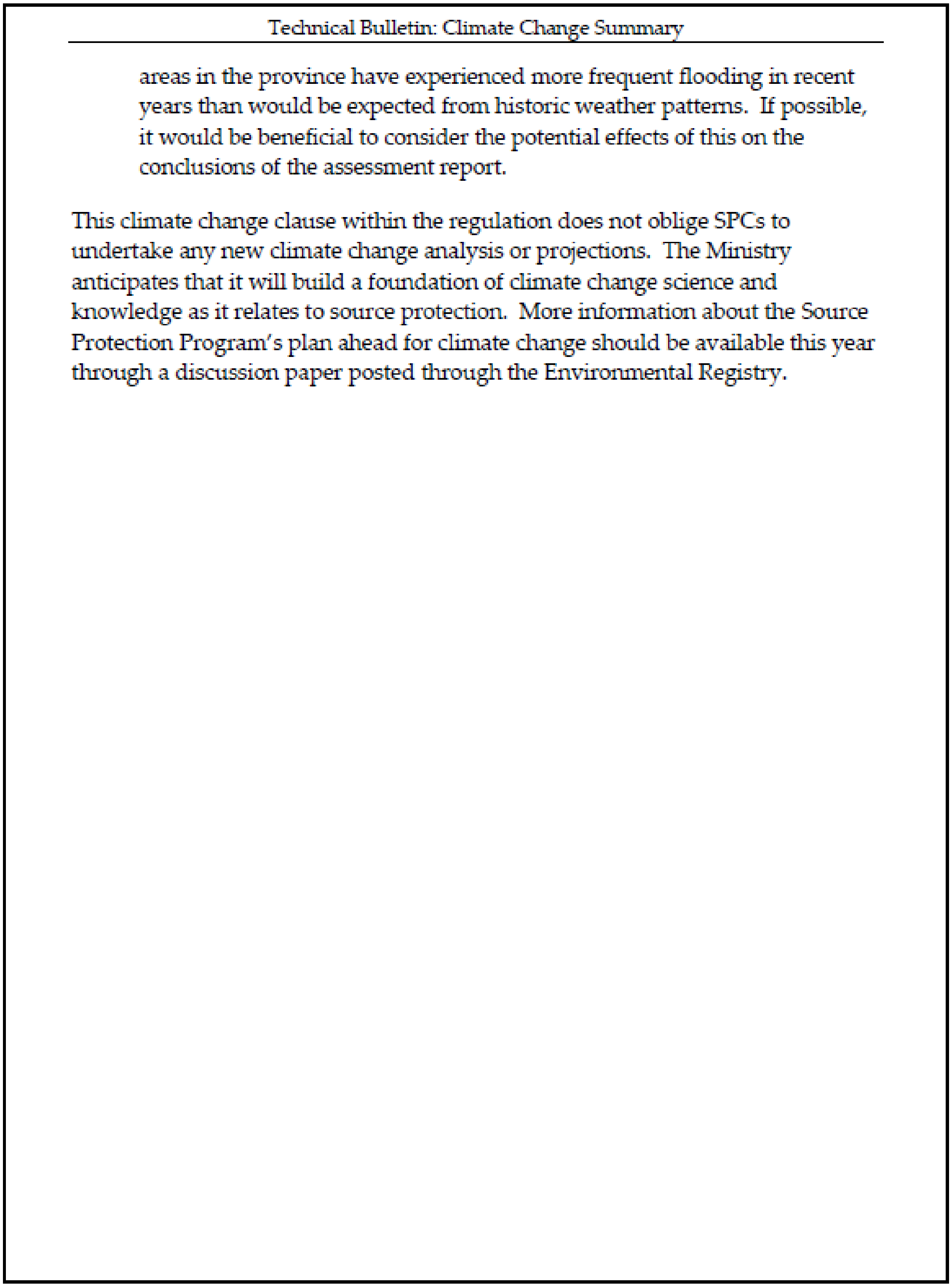
These regulation and rules require that the assessment report contain a summary of the existing climate change knowledge and climate data available to source protection committees (SPCs) and their interpretation of how it could impact the conclusions in the assessment reports. The intent is for SPCs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

This chapter focuses on the Groundwater Quality Vulnerability Analysis component of the Assessment report. In this analysis, vulnerable areas are delineated including:

- Wellhead protection areas (WHPAs) – not applicable to CLOSPA;
- Highly vulnerable aquifers (HVAs); and
- Significant groundwater recharges areas (SGRAs).

The relative vulnerability of groundwater to contamination (sometimes termed intrinsic vulnerability) is then determined within each of these areas. Vulnerability is equated to travel times of contaminants from surface where if contaminants are estimated to be able to reach an aquifer or well in a shorter time period, then that aquifer or well is deemed to be more vulnerable. This chapter focuses on the delineation of HVAs following the *Technical Rules.* WHPA (not applicable to CLOSPA) and SGRA analyses are documented elsewhere. The listing of tasks and *Technical Rules* (see **Figure D2-1**) relative to the HVA analysis include:

a) Assessment and delineation of groundwater vulnerability (*Part IV.1, Rules 37 and 38*);
b) Delineating highly vulnerable aquifers (*Part V.1, Rule 43*);
c) Assign vulnerability scores. Highly vulnerable aquifers outside of a WHPA (not applicable to CLOSPA) are given a score of 6 (*Part VII.1, Rule 79*);
d) Determining impact of anthropogenic transport pathways (*Part IV.1, Rules 39 and 40*);
e) Determining level of uncertainty as high or low (*Part I.4, Rules 13-15*);
f) Threats and issues within HVA only (high vulnerability area with score of 6) (*Part X and XI*); and
g) Risk Score = Hazard Rating (range from a low of 1 to a high of 10) x vulnerability (*Part X and XI*). A risk score greater than 80 is a significant threat, 60 to 79 is a moderate threat and 40 to 59 is a low threat. An HVA can never contain a significant threat according to the proposed risk scoring system contained within the *Technical Rules*.

Tasks f) and g) above are not included as part of this document and are described in **Chapter 5** (**Drinking Water Threats Assessment**) of this Assessment Report.

A brief description of the physical system to be analyzed is provided in **Chapter 2** (**Watershed Characterization**).

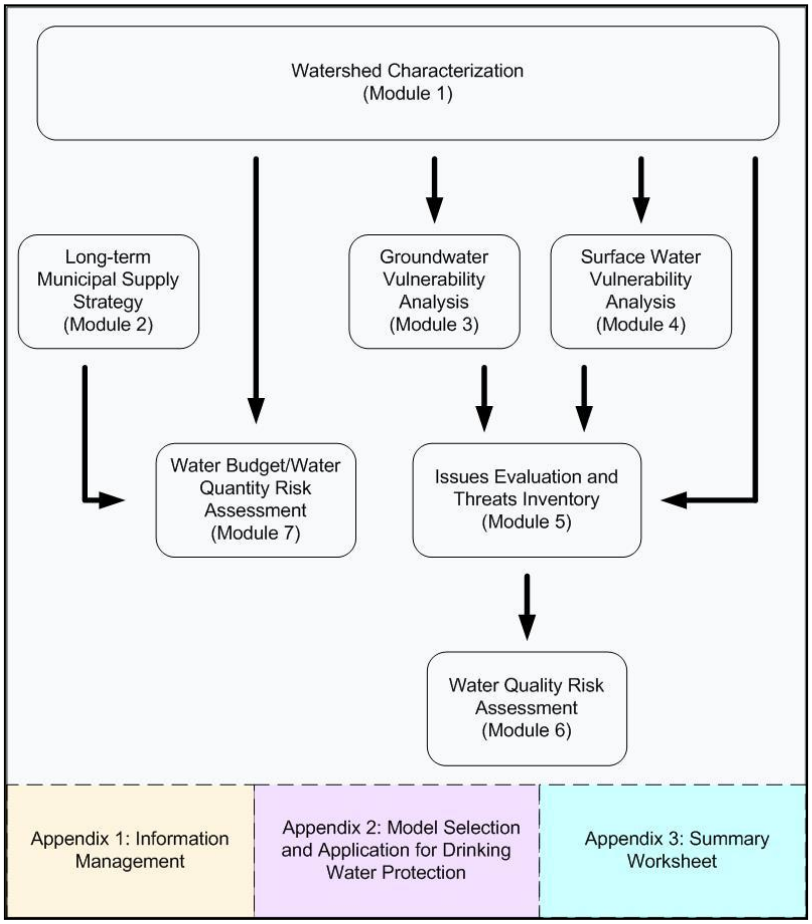


Figure D2-1: Assessment Report Modules which have now been Captured in the *Technical Rules, 2009*

Figure from Guidelines Ontario Ministry of the Environment (2006).

D2.1.1 Background – CLOSPA Hydrostratigraphic Overview

The purpose of this chapter is to delineate highly vulnerable aquifers. Where a detailed description of the hydrostratigraphic framework for the study area is provided in the Water Budget **Chapter 3** of this report, this section will briefly describe the interpretation of the aquifer systems that occur within the study area as a basis for the vulnerability analysis.

Three-dimensional hydrostratigraphic interpretation or interpretation of aquifers and aquitards, within the study area has been on-going and refined over a number of years. Within the CLOSPA jurisdiction, a regional interpretation was prepared and built into a regional numerical groundwater flow model (MODFLOW) for the Oak Ridges Moraine Groundwater Program (EarthFx Inc., 2006). This interpretation was subsequently refined and utilized for water budget analyses (EarthFx Inc., 2008b). The interpretations used for the preparation of the drinking water source protection (SWP) water budget documents (EarthFx Inc., 2008b) was utilized for this aquifer vulnerability analysis.

Initial refinements of the two interpretations have been conducted. It was determined that the regional conceptual models were generally consistent with minor modifications. Differences largely relate to interpreted bedrock valley systems and associated sedimentary infill, with the interpretations of these structures being based on sparse information. Refinement and synchronization of the three-dimensional hydrostratigraphic interpretations is on-going as new information is obtained.

In the study area there are generally three aquifers situated within Quaternary-aged, unlithified sediments. These aquifers include, from shallowest/youngest to deepest/oldest, the Oak Ridges aquifer complex, the Thorncliffe aquifer complex and the Scarborough aquifer complex. A hydrogeologic cross section illustrating the interpreted hydrostratigraphy is shown on **Table D2-1** and **Figure D2-2.**

Layer	East Model CLOSPA- MODFLOW Model Layer	Aquifer
1	Recent Deposits –Weathered Till	✓
2	Halton Till Complex	
3	Oak Ridges Moraine/ Mackinaw Interstadial Aquifer complex	✓
	Unconformity	
4	Newmarket Till	
5	Thorncliffe Aquifer Complex	✓
6	Sunnybrook Drift	
7	Scarborough Aquifer Complex	✓
8	Weathered Bedrock	
	Unweathered Bedrock - bottom of model from EarthFx Inc., 2008	

Table D2-1: Summary of Hydrostratigraphic Interpretation Nomenclature. Aquifer units are shaded.

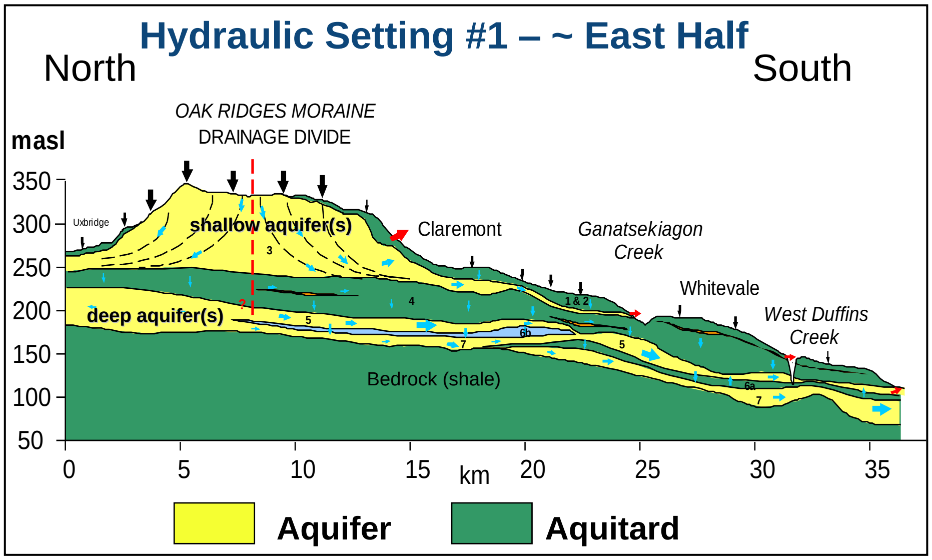


Figure D2-2: East Cross Section (Figure modified from Gerber and Howard, 2002).

Numbers refer to CLOSPA Hydrostratigraphic Units shown on **Table D-1**.

D2.1.2 Aquifers and Municipal Supplies

None of the aquifer systems described above is utilized for municipal supplies from groundwater within the study area. All municipal supplies within the CLOSPA area are "sourced" from Lake Ontario.

Even as there are no municipal water supply wells located in the study area and the focus of the *Clean Water Act*, *2006* is on municipal supplies, the aquifers described above are utilized for private water supply purposes and need to be addressed in this aquifer vulnerability analysis.

Thickness (isopach maps) of the various aquifers described above are presented in **Chapter 3** (**Water Budget**) should the reader be interested in the extent of these aquifer systems.

D2.1.3 Aquifer Vulnerability Analysis

The Groundwater Vulnerability Analysis undertaken in this document basically involves determining relative vulnerability (high, medium or low) of aquifers on a regional basis or over the entire SPA. The other two vulnerable zones from a groundwater perspective, WHPAs and SGRAs, are delineated and described in detail elsewhere. While the reader is reminded that there are no Well Head Protection Areas (municipal wells) located in the study area, where WHPA groundwater vulnerability assessments are done (not applicable to CLOSPA), they take precedence over this 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 5** (**Drinking Water Threats Assessment**) of this document. Water quantity vulnerability is dealt with in **Chapter 3 (Water Budget and Stress Assessment**).

This analysis can basically be considered as 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* regarding groundwater vulnerability analyses, there are a number of available approaches to estimate groundwater vulnerability. The latest *Technical Rules* list the following methods to assess groundwater vulnerability:

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 considers the soil, sediment or rock type and thickness above an aquifer and the static water level in the well. The index or score at each well is then interpolated between wells to produce a vulnerability map;
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).

One of the main differences between the AVI and ISI methods involves the identification of the uppermost aquifer. The AVI method assumes that surficial sand and gravel materials of sufficient thickness are defined as an aquifer. The ISI method requires that the uppermost aquifer be at least partially saturated, with saturation defined by the presence of aquifer material below the regional water table. Unsaturated granular materials lying above the regional shallow water table are then assumed to provide some degree of protection (MOE, 2006). Methods 3 and 4 above generally utilize three-dimensional groundwater flow models.

The above 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 Drinking Water Source Protection program expects that a continuous improvement process will occur in areas with greatest risk and vulnerability.

The HVA mapping for the CLOSPA has been prepared utilizing method 2 (AVI). This appendix will start with a general description of relative aquifer vulnerability within the study area, briefly discuss results from previous ISI mapping previously done for the area, and then more fully describe the AVI methods and maps that were generated for the CTC Source Protection Region (SPR). This appendix will also include discussions regarding anthropogenic pathways that can affect aquifer vulnerability and uncertainty regarding input data and methodology as it relates to this HVA analysis.

D2.2 HIGHLY VULNERABLE AQUIFERS (HVAS)

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 areas was provided and the different hydraulic settings where municipal supplies from groundwater are obtained were introduced in **Chapter 3** (**Water Budget and Stress Assessment**, **Table 3.1**). The following section utilizes this information and provides a relative ranking of aquifer vulnerability within the CTC SPR.

Within the study area, the hydraulic settings and their relative vulnerability listed from highest to lowest would include the following type areas.

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 Complex, 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 (Type 3 - Thorncliffe aquifer complex and Scarborough aquifer complex) overlain by aquitard material and rock aquifers overlain by rock aquitards (Type 4).

In general, vulnerability can increase depending on nature of overlying aquitards. Also for these settings, vulnerability can decrease if upward vertical gradients are present, although it must be noted that some contaminants, such as non-aqueous phase liquids (NAPL), can migrate according to gravity regardless of the predominant direction of groundwater flow.

Private water wells in the CLOSPA study area occur in all of these various settings.

D2.2.2 Intrinsic Susceptibility Index (ISI - Wells)

The groundwater intrinsic susceptibility index (ISI) approach has been applied over much of the Source Protection Area as this method was adopted as a general standard in the guidance documents for the Provincial Groundwater Protection Studies Program completed since 2001. Further, the ISI approach is expected to be a minimum standard for most Source Protection Areas. Further discussion and details on limitations of the methodology is provided in OMMAH (2004) and MOE (2006) (see **Figure D2-2**).

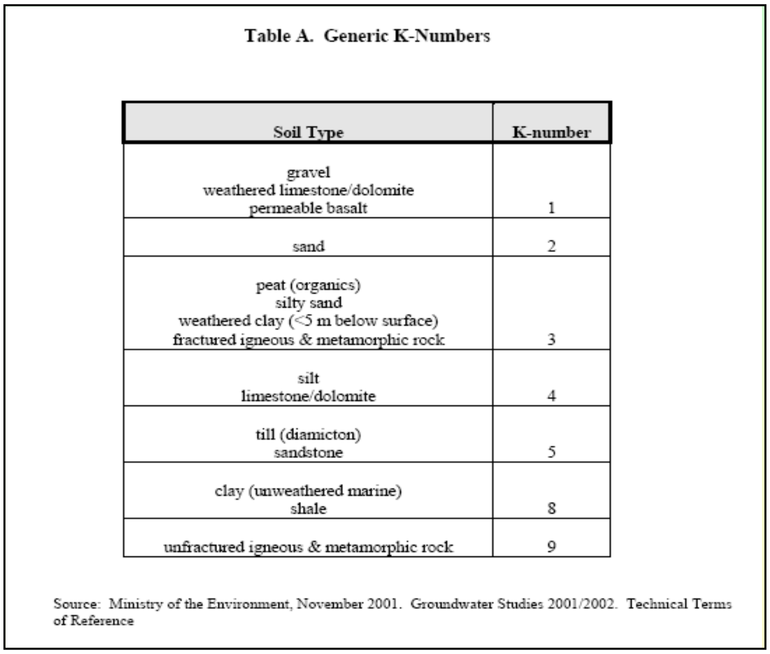


Table A. Generic K-Numbers

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 D2-2: Generic K-Factors (from OMMAH, 2004)

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

The ISI is calculated as the sum of the product of the thickness of each geologic unit overlying an aquifer with a corresponding K-factor. The K-factor 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). The single GSC soil classifications and their associated K-factors are included in **Table D2-3** and **Table D2-4**.

The ISI method also incorporates information on water levels in aquifers, specifically the location of the water table. In determining the first aquifer at depth, the ISI method requires that the sand or gravel unit is saturated, or partially saturated in the case of an unconfined aquifer. The study team may, however, as was done in this analysis confirm that the aquifers are indeed saturated with available water level data. ISI requires that the uppermost aquifer be at least partially saturated. For unconfined aquifers, the ISI index value is calculated from ground surface to the water table. 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 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.

It should be noted that the methodology specifics described above can be modified to reflect study area characteristics. In this method index values <30 = HIGH (vulnerability score =6); 30-80 = MEDIUM (vulnerability score = 4); and >80 = LOW (vulnerability score = 2). Estimates of aquifer vulnerability utilizing the ISI method have been completed for the Oak Ridges Moraine Conservation Plan (ORMCP) area (OMMAH, 2004). The estimates have been expanded outside the ORMCP over much of the CTC study area. This approach generally leads to patchiness and has inconsistent output or output that is often difficult to explain when comparing to observations such as surficial geology mapping. A reason for this is that the input contained in the MOECC water well record database is inconsistent. For example, the objective of a well driller is to install a well that will yield an adequate water supply. Once complete, the driller must submit a water well record to the Ontario Ministry of the Environment and Climate Change, including well information along with a summary of the geologic units encountered. The main purpose of the well record is not to describe geologic units, or the driller may not be experienced in describing geologic units encountered, yet geologic information is what is used in the ISI method to estimate aquifer or well vulnerability on a borehole basis. Another potential problem is conflicting geologic information recorded on nearby water well records. This may or may not actually be the case.

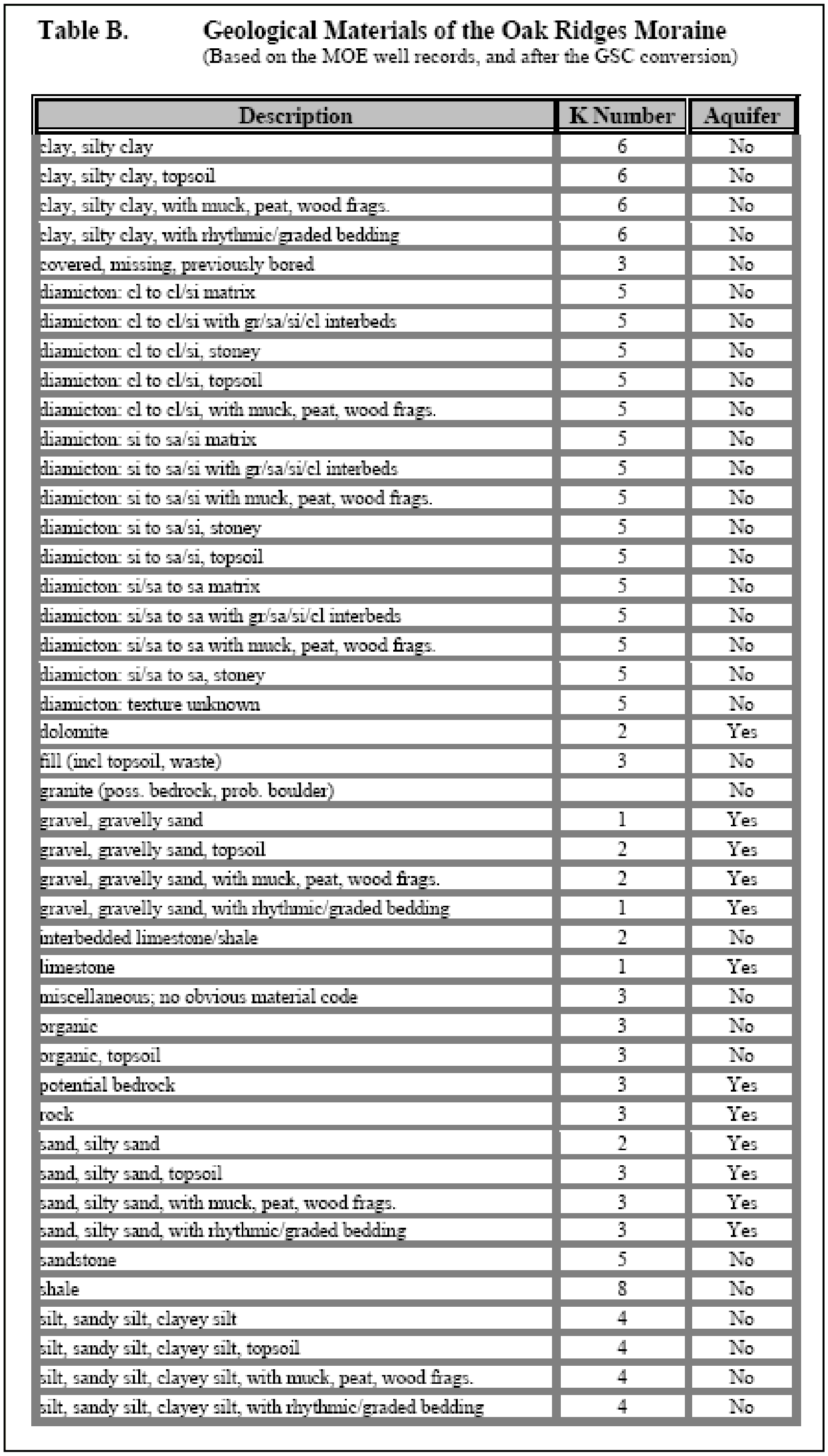
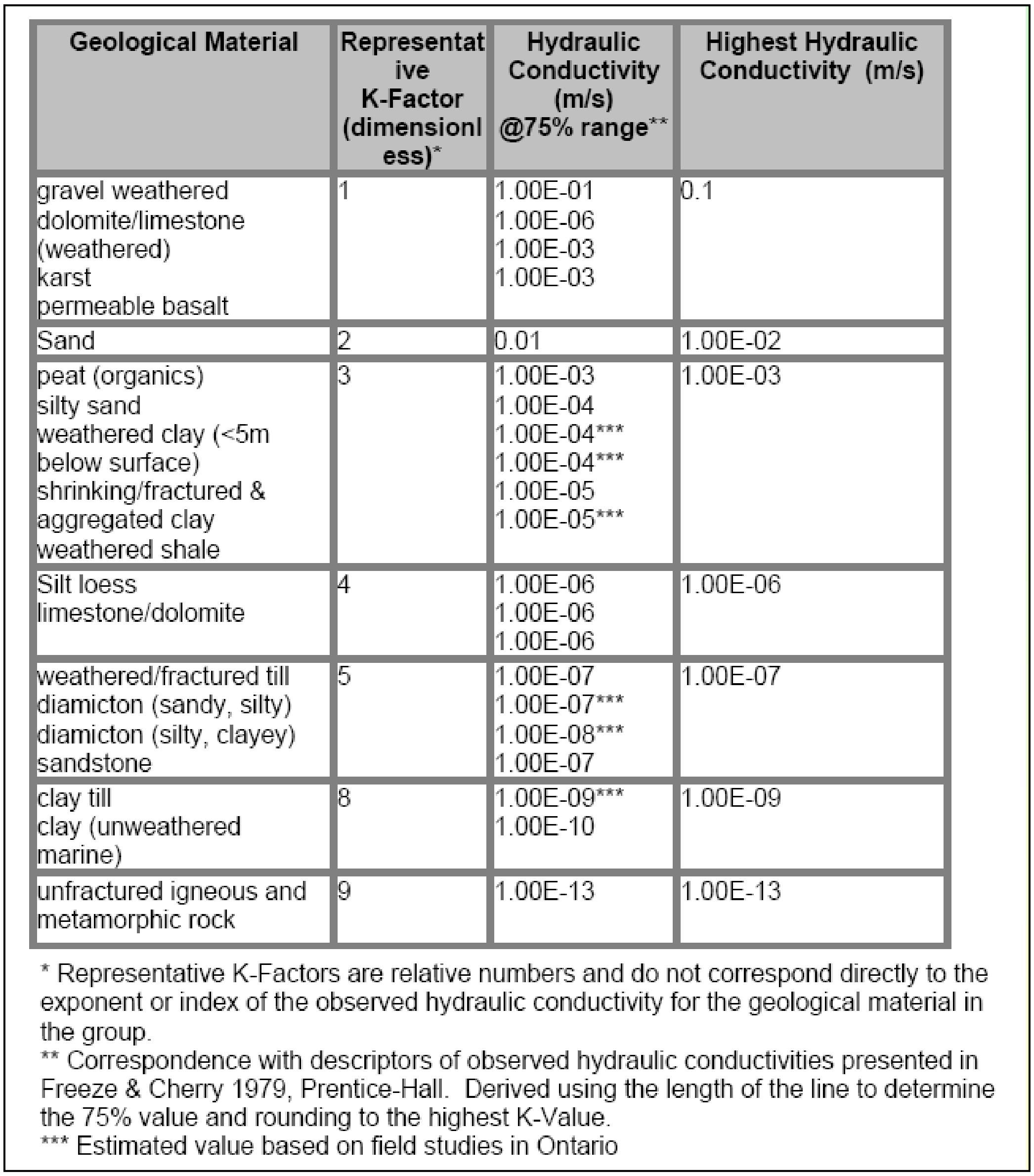


Table B. Geological Materials of the Oak Ridges Moraine
(Based on the MOE well records, and after the GSC conversion)

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 D2-3: GSC Classification and K-factors (from OMMAH, 2004)



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

Table D2-4: Representative K-factors for Various Geologic Materials. From SWP Guidance Module 3 (MOE, 2006)

D2.2.3 Aquifer Vulnerability Index (AVI - Hydrostratigraphic Layers)

Another vulnerability analysis method conducted for the CLOSPA Source Protection Authority (SPA) area is to apply the AVI method to three-dimensional interpreted hydrogeologic layers, instead of applying it to information from individual boreholes and then interpolating between boreholes. Three-dimensional hydrostratigraphic interpretations have been utilized in numerical groundwater flow models (CLOSPA – MODFLOW) that were used for the Tier 1 water budget analyses (EarthFx Inc., 2008b).

The indexing method does not necessarily incorporate water level information and may assume sand and gravel of sufficient thickness constitutes an aquifer. AVI only includes an analysis of geologic stratum above the aquifer. Index or numerical score reflects the relative amount of protection by the physical features that overlie the aquifer and are assigned to:

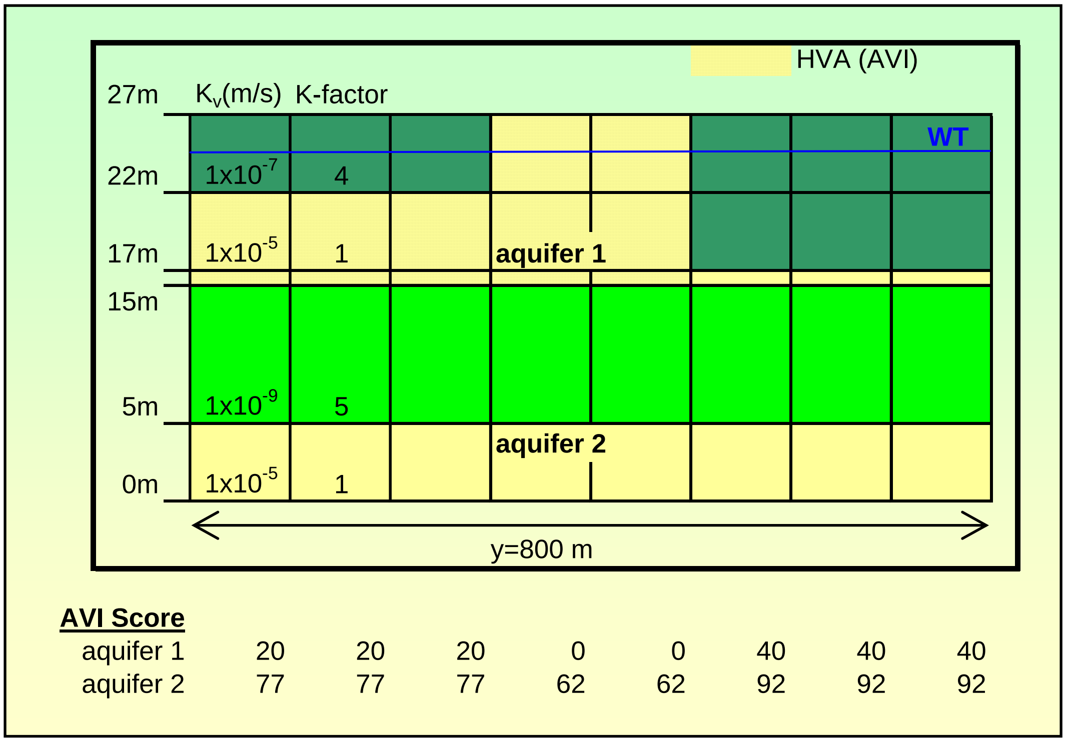
- Three-dimensional hydrostratigraphic interpretation for each model layer (aquifers and aquitards);
- Hydraulic conductivity (K) distribution for each model layer; and
- Observed and simulated water table and hydraulic head distribution for each aquifer to confirm that all sediments that are greater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

The methodology utilized for the CLOSPA aquifer vulnerability mapping is summarized in **Table D2-5** and **Table D2-6.** Vulnerability scores were produced for each aquifer and then combined into one map for the CLOSPA. For the CLOSPA, aquifer units occur within surficial Lake Iroquois and Late Stage Lacustrine sand and gravel deposits (L1), within the Oak Ridges Moraine/Mackinaw Interstadial aquifer complex (L3), the Thorncliffe aquifer complex (TAC), and the Scarborough aquifer complex (L7). For the CLOSPA jurisdiction, 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 relationship between hydraulic conductivity (K) and K-factors used for this study (**Table D2-6**) deviates from that provided in the Provincial Guidance (**Table D2-4)**. The deviation is dictated by the range of estimated K values that occur within the study area. The two tables are consistent for lower permeability deposits, but deviate when dealing with higher permeability deposits. The K values used in calibrated groundwater flow models within the study area are summarized in this appendix. **Table D2-6** and **Table D2-4** are similar in that vertical hydraulic conductivity between $1x10^{-6}$ and $1x10^{-7}$ m/s are given a K-factor of 4 and values $< 1x10^{-7}$ m/s are given a K-factor of 5 or higher. Within the study area the aquifer deposits are interpreted to have a hydraulic conductivity of $1x10^{-5}$ m/s or higher. In this analysis, these deposits are given a K-factor of 1. Hydraulic conductivity values between $1x10^{-6}$ and $1x10^{-5}$ m/s (considered consistent with silt deposits which are prevalent throughout the study area) were given a K-factor of 3.

Within the study area significant variability and reliability in the shallow water level information necessary to define the water table exists. There can also be significant range in seasonal variability of the water table. For example, the water table in surficial till deposits can range over 4 to 5 m annually. The water level information was utilized to check that any unit classified as an aquifer (sand and gravel deposits greater than 2 m thick) was saturated or partially saturated. An unconfined aquifer that outcrops at surface is classified as an area of high aquifer vulnerability in that the unsaturated sand and gravel is not assumed to provide protection to the aquifer below the water table.

Example aquifer vulnerability calculations utilizing the AVI methodology described above are illustrated on **Figure D2-2.** In this example the area in question is discretized horizontally into cells 100x100m in size, similar to that of the CTC SPR. There are two aquifers present within the example and the aquifer vulnerability is calculated for each aquifer. For each aquifer the AVI is shown below the cross section for each cell. For ‘aquifer 1’ on the left hand side of the diagram, the overlying till deposit is 5 m thick, has a K-factor of 4 and an AVI value of 20. Vulnerability index values less than 30 correspond to areas of High Aquifer Vulnerability and are given a vulnerability score of 6. The areas of ‘aquifer 1’ with High Aquifer Vulnerability are shown with a dotted pattern. Note that where the aquifer outcrops that the unsaturated part of the aquifer is assumed to offer no protection to the part of the aquifer below the water table. Also note that ‘aquifer 2’ only contains areas of medium vulnerability (AVI score of 30 to 80) and high vulnerability (AVI score >80). The final HVA map would be a composite for the two aquifers where the highest vulnerability score for any aquifer (this would occur for the shallowest aquifer) is mapped. The regional Aquifer Vulnerability Mapping being utilized by the CTC SPR for areas outside the WHPAs utilizes the AVI methodology described above.



AVI Score								
aquifer 1	20	20	20	0	0	40	40	40
aquifer 2	77	77	77	62	62	92	92	92

Figure D2-3: Example AVI Scoring, WT = Water Table

The estimated areas of high aquifer vulnerability (AVI <30; vulnerability score = 6) on a regional basis are shown on **Figure D2-3**. Close inspection of the highly vulnerable aquifer mapping reveals many small patches estimated to be highly vulnerable. Much of this patchiness is attributed to surficial sand and gravel sediments in Layer 1 that according to the methodology are classified as local aquifers. It is recommended to the Source Protection Committee (SPC) that the occurrence of smaller isolated areas be considered when developing policies regarding the management of highly vulnerable aquifers. For example, any polygon classified as highly vulnerable and having an area less than 1 km^2 may be removed from the mapping or joined with other local isolated polygons.

The regional Aquifer Vulnerability Mapping being utilized by the CLOSPA utilizes this AVI methodology. The estimated areas of High Vulnerability (vulnerability score = 6) are shown on **Figure D2-4** and **Figure D2-5.**

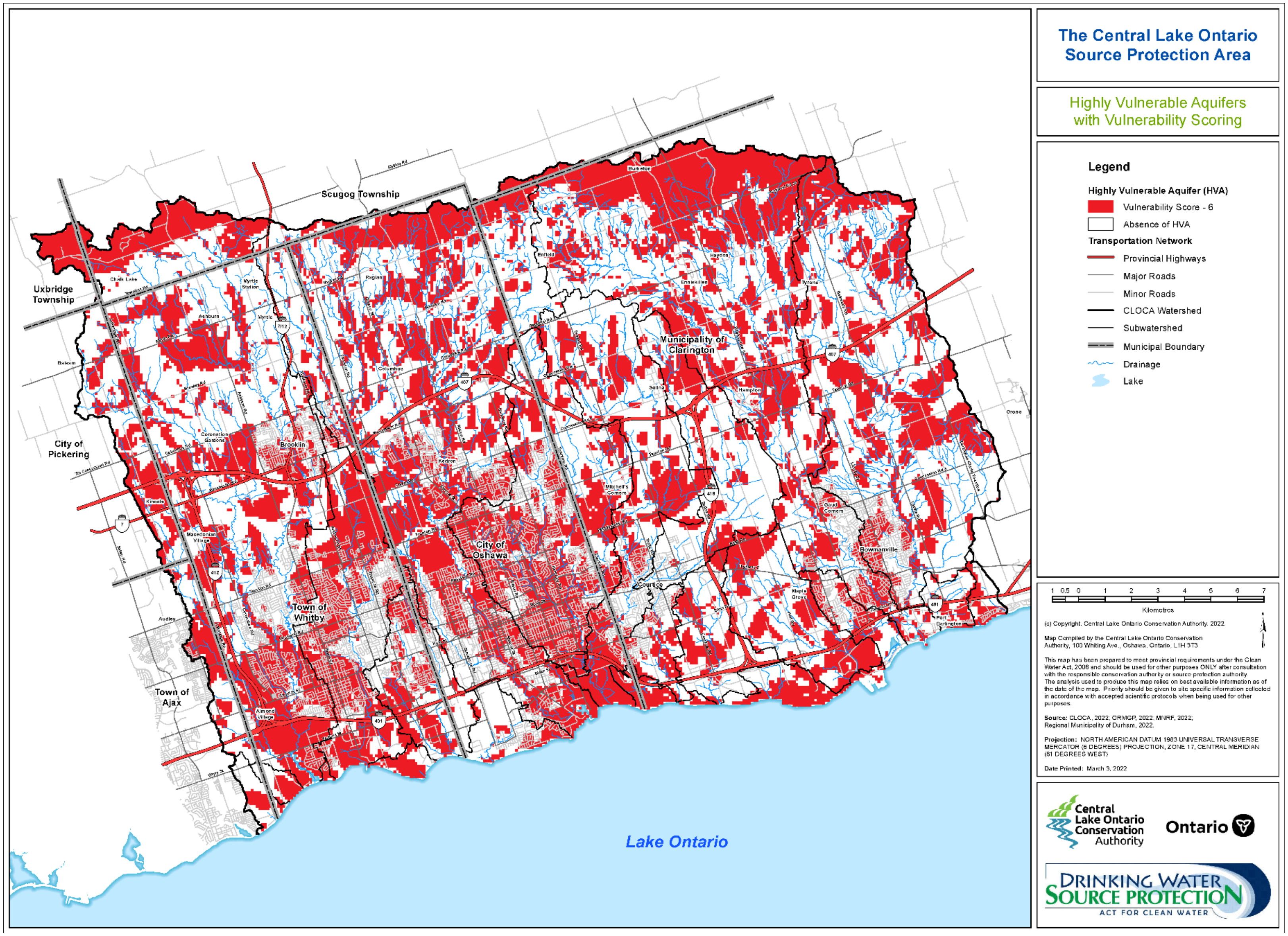
Step	Task
1	Create isopachs (layer thickness) of groundwater flow model layers
2a	Create K layers by multiplying K for each layer cell by an anisotropy value L2 - Halton Till - multiply K x 0.3 to give K L4 - Newmarket - multiply K x 0.2 to give K L6 - Sunnybrook - multiply K x 0.2 to give K
3a	Assign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

Table D2-5: CLOSPA SPA AVI Methodology

K-factor Classification		
K_v (m/s)		K-factor
min	max	
1.00E-05		1
1.00E-06	9.99E-06	3
1.00E-07	9.99E-07	4
	9.99E-08	5

Note: modified from Table C3.

Table D2-6: K-Factor Classification



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Map Compiled by the Central Lake Ontario Conservation Authority, 100 Whiting Ave., Oshawa, Ontario, L1H 3T3

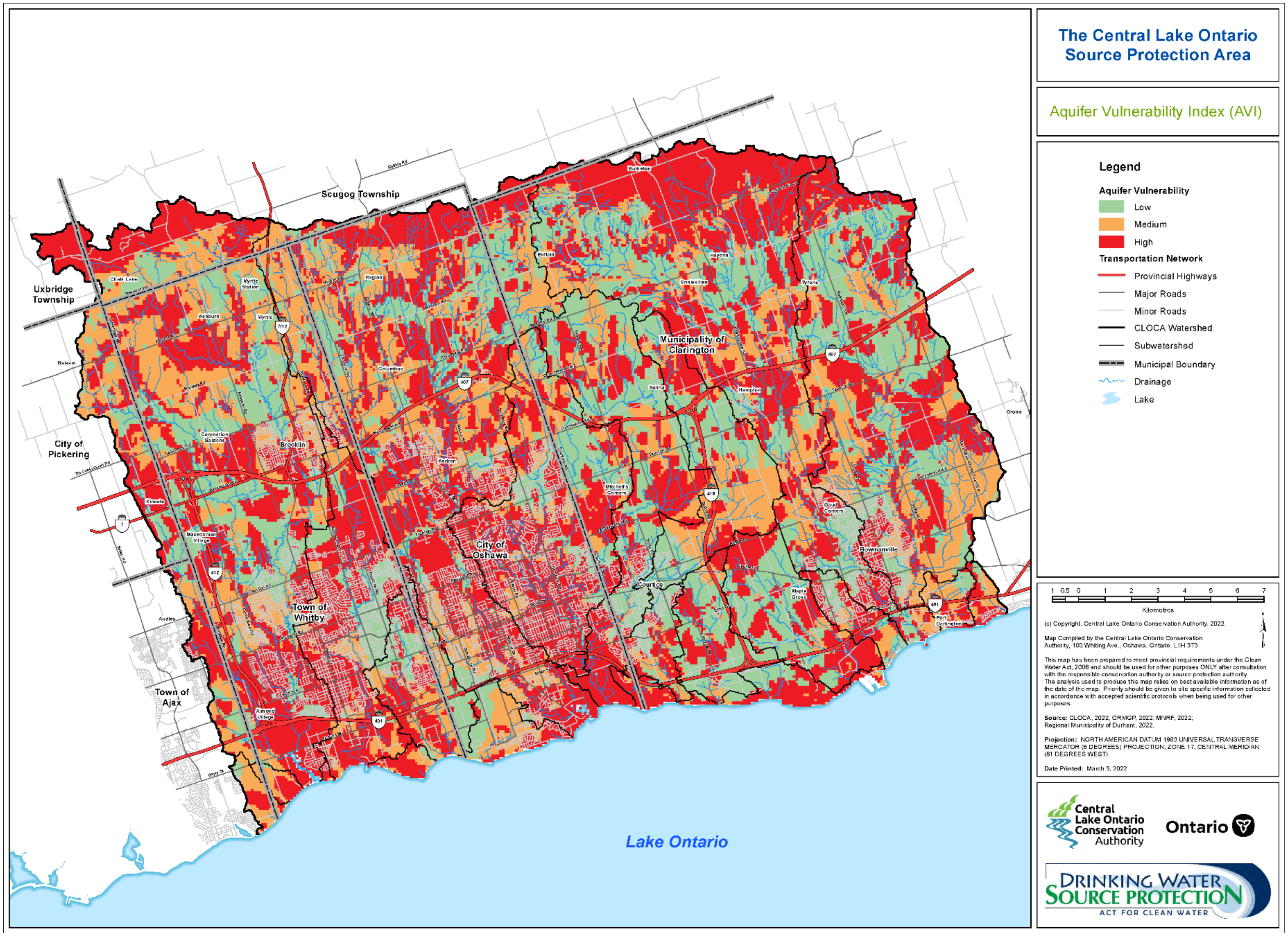
This map has been prepared to meet provincial requirements under the Clean Water Act, 2006 and should be used for other purposes ONLY after consultation with the responsible conservation authority or source protection authority. The analysis used to produce this map relies on best available information as of the date of the map. Priority should be given to site specific information collected in accordance with accepted scientific protocols when being used for other purposes.

Source: CLOCA, 2022; ORMGP, 2022; MNRF, 2022; Regional Municipality of Durham, 2022.

Projection: NORTH AMERICAN DATUM 1983 UNIVERSAL TRANSVERSE MERCATOR (6 DEGREES) PROJECTION, ZONE 17, CENTRAL MERIDIAN (81 DEGREES WEST)

Date Printed: March 3, 2022

Figure D2-4: Highly Vulnerable Aquifer with Vulnerability Scoring (Score 6 - High)



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Date Printed: March 3, 2022

Figure D2-5: Aquifer Vulnerability Index (AVI) (Score 6, 4 and 2 of High, Medium and Low)

D2.2.4 Numerical Groundwater Flow Models (SAAT, WAAT)

A three-dimensional numerical groundwater flow model exists within the study area, the CLOSPA watersheds (East Model - MODFLOW). This model has been utilized for other aspects of the Drinking Water Source Protection program namely the water budget analyses as mentioned previously (Earthfx Inc., 2008b). Some of the components of these models (e.g., three-dimensional hydrostratigraphy and hydraulic conductivity estimates) 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 the water table to the aquifer (WAAT) (**Figure D2-6**). An estimated travel time of 0 to 5 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).

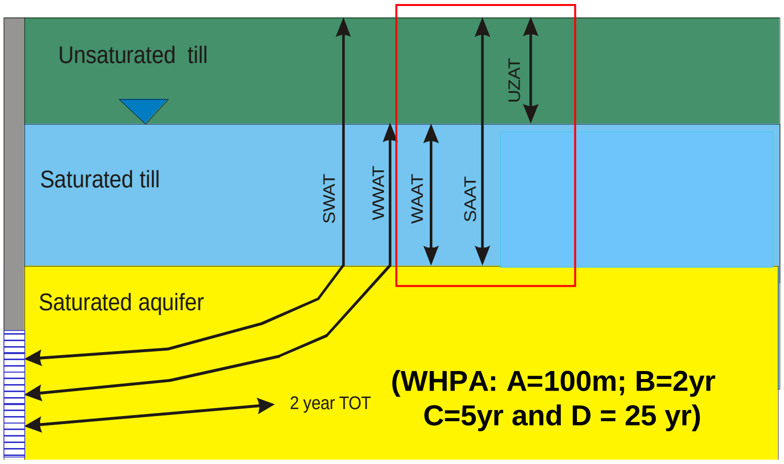


Figure D2-6: SWAT-WWAT-WAAT-SAAT-UZAT Analysis Schematic

D2.2.6 Aquifer Vulnerability Analysis Discussion

The areas of high aquifer vulnerability (vulnerability score = 6) for the CLOSPA estimated using the AVI methodology (**Table D2-5**) were described earlier and presented on **Figure D2-3.** The vulnerability scoring for the whole study area is shown in **Figure D2-4**. The areas delineated as having high vulnerability contain aquifers at the surface or at depth that are deemed to have little to no natural protection. In this analysis, lower permeability geologic materials, such as clay, silt and till, are assumed to function as aquitards that offer some degree of protection to underlying aquifers (sand and gravel). Specifically, these areas consist of:

- Surficial deposits of sand and gravel (L1) that are greater than 2 m thick (late stage lacustrine deposits);

- Oak Ridges Moraine aquifer complex or equivalent (L3) deposits that occur at or near the surface;
- Thorncliffe aquifer complex or Lower Sediment deposits (L5) that occur at or near the ground surface; or
- Scarborough aquifer complex (L7, CLOSPA) deposits that occur at or near the surface.

Profile and plan depictions of the estimated high aquifer vulnerability areas for the CLOSPA are shown on **Figure D2-7** and **Figure D2-8.** The eastern portion of the CLOSPA area along the cross section is estimated to be an area of high vulnerability. In this area the Oak Ridges Moraine aquifer complex (L3) occurs at the ground surface. Patches of high aquifer vulnerability to the west of this area represent areas where thin Halton Till overlies the Oak Ridges Moraine aquifer complex (L3). Areas of high vulnerability within the Thorncliffe aquifer complex (L5) and the Scarborough aquifer complex (L7) are not shown on the section but occur south of the Glacial Lake Iroquois shoreline where these deeper aquifers are close to the ground surface.

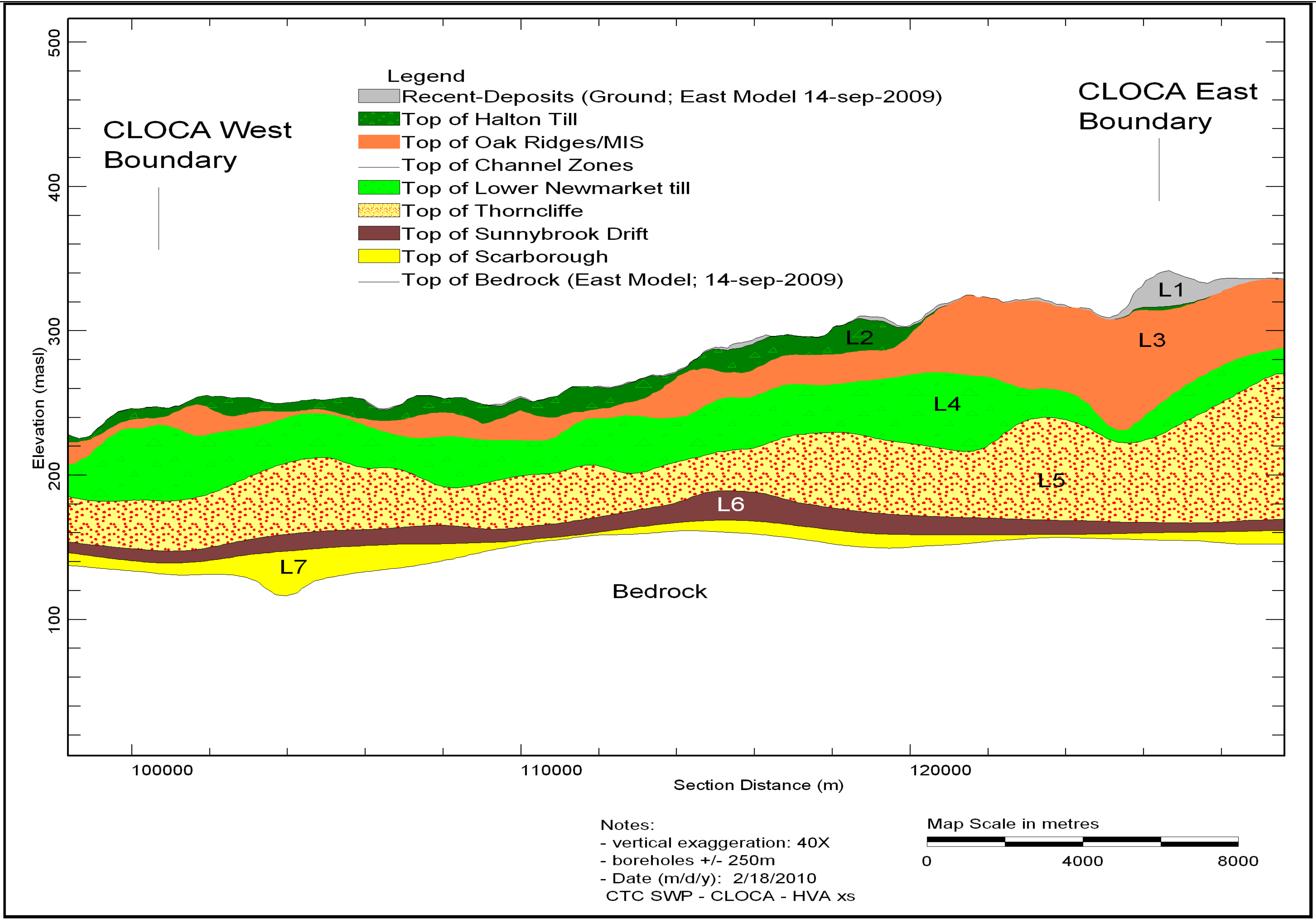


Figure D2-7: CLOCA HVA Cross Section (Profile)

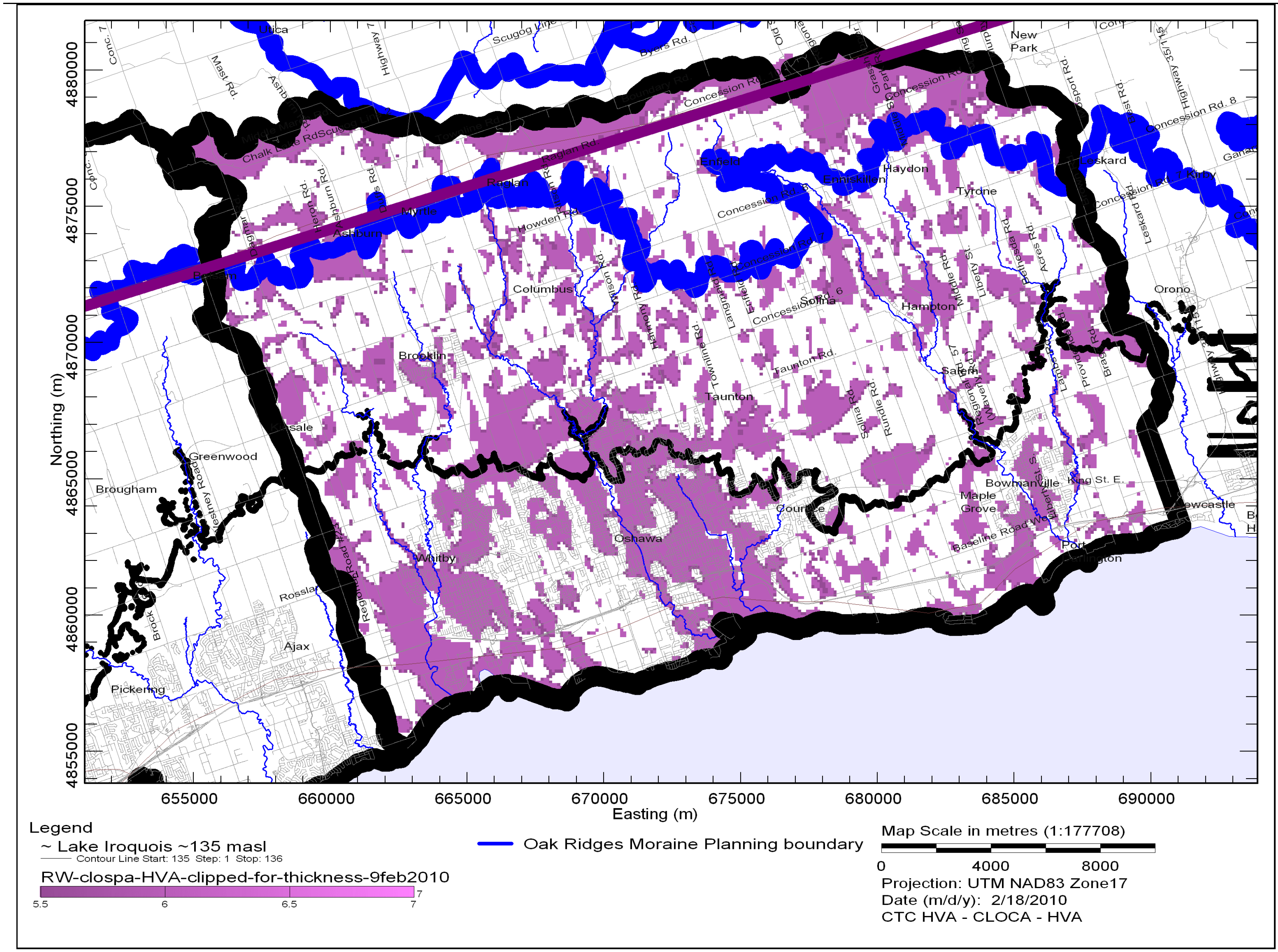
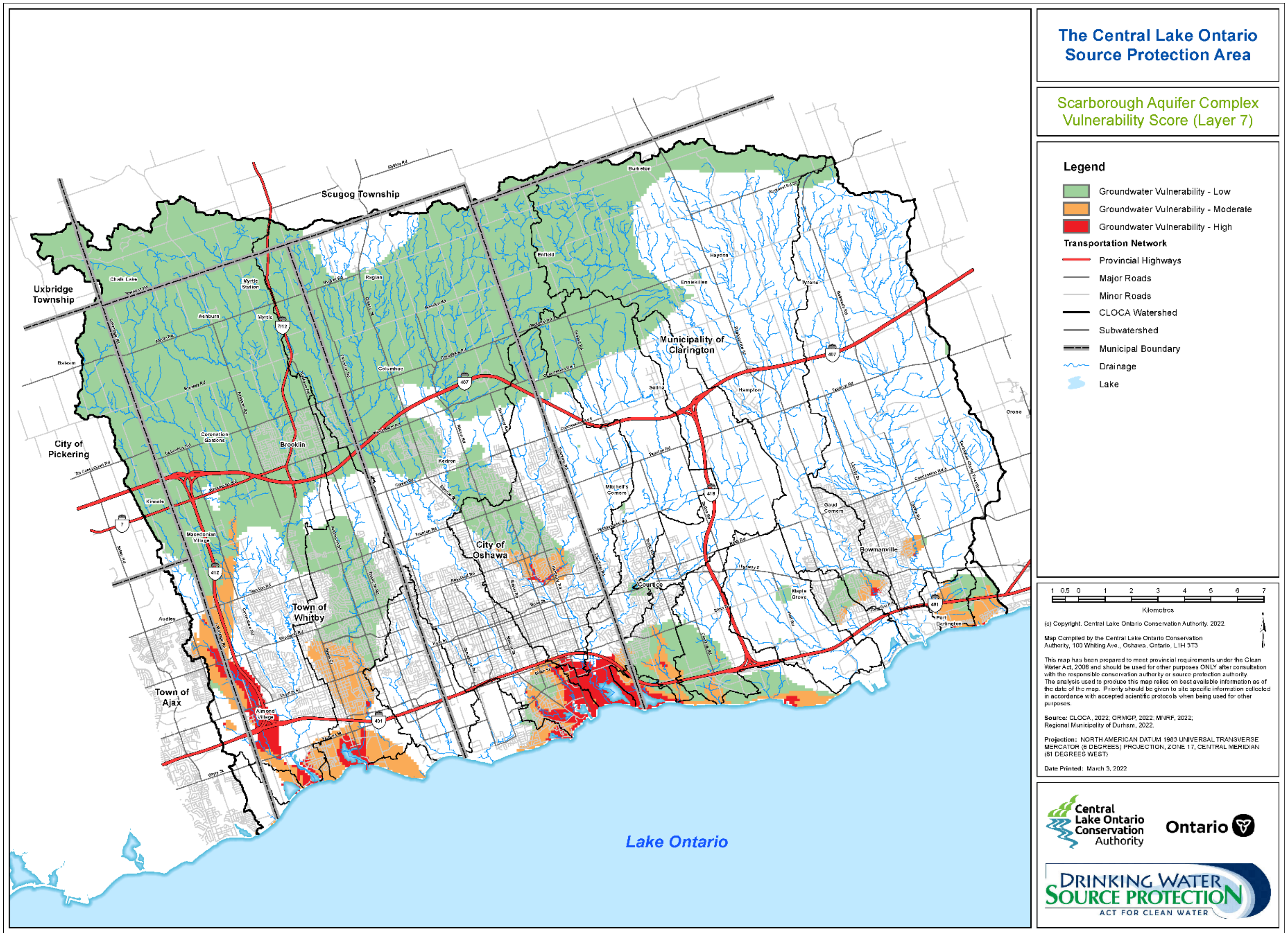


Figure D2-8: CLOSPA HVA Cross Section Location (Plan)

As mentioned previously, the CLOSPA aquifer vulnerability mapping shown on **Figure D2-4** is a composite map made from the vulnerability scoring for each of the aquifers present within the study area (L1, L3, L5 and L7). The highest score from any of the aquifers is the final score shown on the composite map. The highest score will occur for the shallowest aquifer present. Areas without an underlying aquifer are given a minimum vulnerability score of 2 as per the *Technical Rules.* The vulnerability scoring for each aquifer is shown on (**Figures D2-9** through **Figure D2-11**).

Figure D2-9 illustrates the vulnerability scoring for the deepest aquifer within the study area (Layer 7: the Scarborough Formation). The highest vulnerability scores for this aquifer occur where it is overlain by thin sediments south of the Lake Iroquois shoreline. A similar pattern occurs for aquifers contained within model layer 5 representing the Thorncliffe aquifer complex (**Figure D2-10**). The highest vulnerability areas for layer 3 Oak Ridges Moraine/Mackinaw Interstadial deposits (or equivalent) occur where these deposits outcrop at surface or have a thin cap of till (**Figure D2-11**). Layer 1 high vulnerability areas include thicker (>2m) areas of lacustrine sand and gravel within the CLOSPA study area (**Figure D2-12**)

The aquifer vulnerability mapping presented in this document (utilizing the AVI method) represents a first attempt at a consistent interpretation for the study area, and is heavily dependent on the interpreted subsurface geology. **Table D2-5** lists a number of steps (10-16) that should be utilized to check any aquifer vulnerability mapping against other sources of information and/or estimation. Vulnerability mapping should also always be tested with chemistry data from municipal supply and monitoring wells. In other words, any aquifer vulnerability mapping should always be tested with all information regarding what is known about the flow system. The following sections analyse or test the current vulnerability mapping to other observations regarding the flow system within the study area. Any future updated or refined mapping should also be subject to similar testing.



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Source: CLOCA, 2022; ORMGP, 2022; MNRF, 2022; Regional Municipality of Durham, 2022.

Projection: NORTH AMERICAN DATUM 1983 UNIVERSAL TRANSVERSE MERCATOR (6 DEGREES) PROJECTION, ZONE 17, CENTRAL MERIDIAN (81 DEGREES WEST)

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Figure D2-9: Scarborough Aquifer Complex Vulnerability Score (Layer 7)

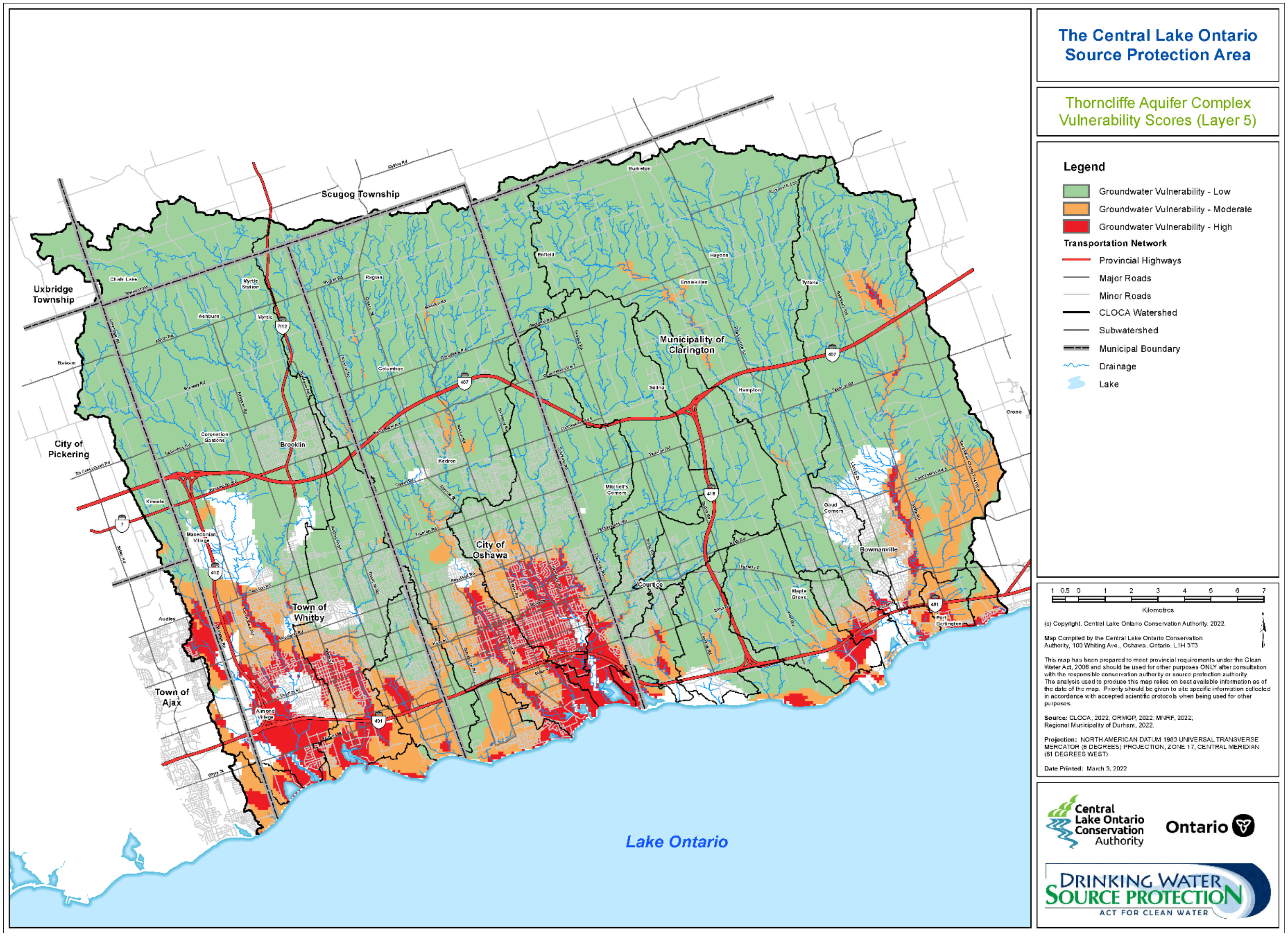

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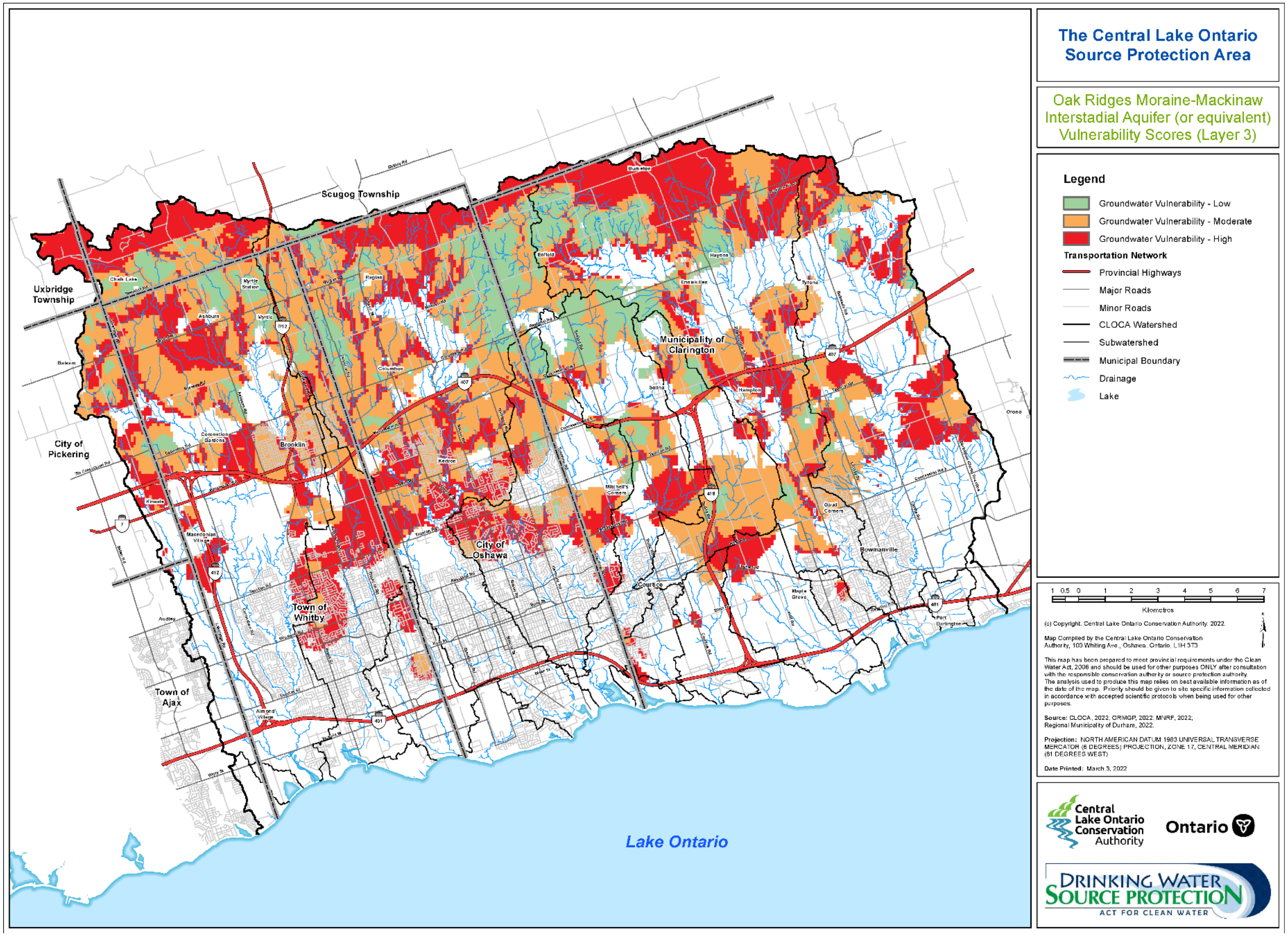
Figure D2-10: Thorncliffe Aquifer Complex Vulnerability Scores (Layer 5)



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Projection: NORTH AMERICAN DATUM 1983 UNIVERSAL TRANSVERSE MERCATOR (6 DEGREES) PROJECTION, ZONE 17, CENTRAL MERIDIAN (81 DEGREES WEST)

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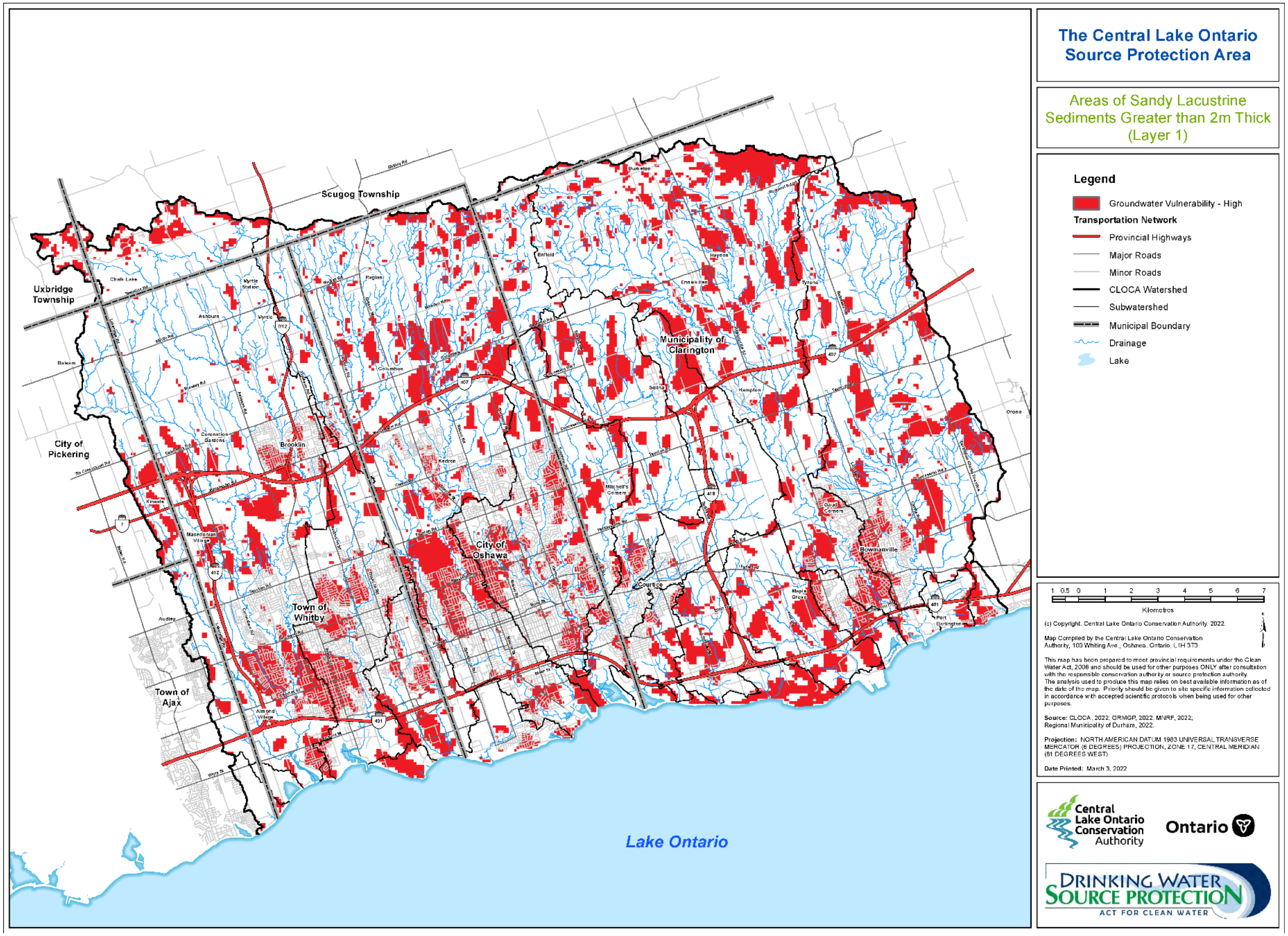
Figure D2-11: Oak Ridges Moraine-Mackinaw Interstadial Aquifer (or equivalent) Vulnerability Scores (Layer 3)



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Source: CLOCA, 2022; ORMGP, 2022; MNRF, 2022; Regional Municipality of Durham, 2022.

Projection: NORTH AMERICAN DATUM 1983 UNIVERSAL TRANSVERSE MERCATOR (6 DEGREES) PROJECTION, ZONE 17, CENTRAL MERIDIAN (81 DEGREES WEST)

Date Printed: March 3, 2022

Figure D2-12: Areas of Sandy Lacustrine Sediments Greater than 2 m thick (Layer1)

Test 1 – Surficial Geology Mapping

One test of the aquifer vulnerability mapping is to compare the areas of sand and gravel from surficial geology mapping (see **Figure 3.7, Chapter 3** of this report) to those areas mapped as highly vulnerable aquifers. The presence of sand and gravel at surface may represent areas where aquifers outcrop at surface and would be most vulnerable to surface sources of contamination. For the most part the areas delineated as highly vulnerable conform to areas mapped as coarser geologic materials (sand and gravel). Surficial sand and gravel areas not estimated as highly vulnerable are where these deposits are interpreted in the current geological model to be less than 2 m thick.

Test 2 - Historical Contamination Issues

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

Some insight regarding aquifer vulnerability can be obtained by looking at historical contamination issues that have occurred within the study area. It is 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.

Historically residents within the study area have obtained their water supply from a number of sources including wells, streams, and lakes. Streams and lakes were also used as areas to dump human waste. In the 1800s, the lack of adequate waste water and drinking water treatment led to many problems with diseases such as cholera and typhoid in populated areas along the Lake Ontario shoreline. The adoption of public health and treatment facilities utilizing water obtained from Lake Ontario had largely eradicated this disease problem by 1915. Historical records were not available for the CLOSPA study area at the time of this study. Historical data in the CTC Region was generally associated with municipal wells and there are no municipal wells located in CLOSPA. These data which were available for the greater CTC SPR, however, provided a sense of accuracy/validity of the approach used for the whole region including CLOSPA and the associated results.

Test 3 – PGMN Chemistry

The Provincial Groundwater Monitoring Network (PGMN) operated by the MOECC and partner conservation authorities measure water levels and chemistry at numerous locations largely situated away from municipal pumping centres. Data from this network can also be used to test the regional aquifer vulnerability mapping. The locations of PGMN wells within the study area and whether the wells exhibit elevated chloride concentrations are shown on **Figure 2.10, Chapter 2**. All of the wells interpreted to have elevated chlorides plot in or along the edge of areas mapped as having high aquifer vulnerability. It should be noted that some of the wells plot within areas of high vulnerability yet do not exhibit elevated chlorides. Again, in these situations one would need to consult the vulnerability designation for the aquifer that the well is installed in. 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. These wells are situated away from roads or other sources of contamination.

D2.2.7 Relative Aquifer Vulnerability

The most vulnerable aquifer settings situated within the CTC study area occur where sand and gravel deposits occur at or near the ground surface. Municipal supply wells that are situated in this setting all exhibit rising chloride levels, indicative of anthropogenic influence from contaminants introduced at the ground surface. Though there are no municipal wells to assess within the study area, this conclusion drawn from the study of wells within the greater CTC SPR is valid for any aquifer vulnerability study and worthy of mention here.

The cited conclusion is consistent with other studies that have recently been conducted within the CTC study area. For example, in the CVC Tier 2 water budget work, AquaResource Inc. (2008b) state "In many areas, overburden overlying the Amabel Formation is thin making the aquifer susceptible to surficial sources of contamination." Further on page 22, "Similarly, the Orangeville Moraine, and Paris Moraine (with its associated meltwater deposits) above the Escarpment also act as productive overburden aquifers for private well users, however the unconfined nature of the sands and gravels leaves them susceptible to surficial contamination."

The type 2 vulnerability setting includes shallow aquifers with an overlying thickness of aquitard material including silt, clay or till. Many municipal wells 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. The following quote emanates from work related to groundwater supplies within Halton Region:

> Halton Till overlying aquifer settings are considered to be relatively less vulnerable however contaminants often do reach the underlying aquifers, they are just retarded by the till. For example, at Georgetown the bedrock valley aquifer systems are overlain by surficial Halton Till. All of the Georgetown municipal wells have increasing concentrations of sodium and chloride suggesting that surficial contamination can migrate through the till to the underlying aquifers." (Holysh, 1997).

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).

D2.2.8 Uncertainty

Life is uncertain, and our knowledge of the subsurface more so. 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."
- "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.

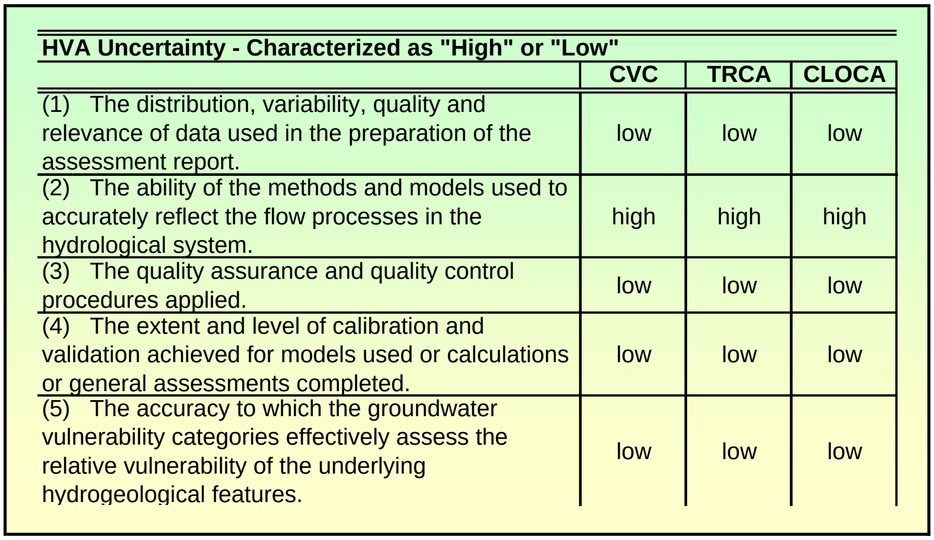
The AVI method reclassifies hydraulic conductivity information into a K-factor, which represents relative hydraulic behaviour of the subsurface materials. Sand is assumed to offer less aquifer protection than silt, which is considered to offer less aquifer protection than clay and till. This index method 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.

While the level of uncertainty cannot be quantified, an attempt to qualify the uncertainty is included in **Table D2-7.** The Provincial SWP Guidance Modules (MOE, 2006) suggests some general factors where it would be reasonable to expect a low uncertainty rating. These factors include:

- Areas where data density is high or the quality of the data is high;
- Areas where previous hydrogeological studies have been completed to confirm the regional scale mapping;
- Areas where independent evidence exists that supports the vulnerability assessment; and
- Areas where calibrated numerical flow models exist and subsequent verification studies.

The study area is subject to all of the above factors which lead to many of the low uncertainty ratings included in **Table D2-7**. The high uncertainty ratings for (2) in **Table D2-7** relates to the inability of any model to accurately reflect the potential for contaminant transport along fractures and other secondary permeability features when the delineation of such features on a local and regional scale is difficult at best. This places an emphasis on monitoring groundwater quality over the long term (e.g., municipal sentry wells). Also for the study area the level of uncertainty is reduced by checking the vulnerability mapping versus other sources of knowledge regarding the flow system. It should be remembered that the aquifer vulnerability mapping presented in this document represents a regional treatment and that site specific information takes precedence over this regional assessment. The SWP program also incorporates a continuous improvement process as part of future planning cycles to upgrade mapping and assessments as more information and knowledge is gained. This increase in knowledge often occurs by incorporating the results of site specific investigations.



HVA Uncertainty - Characterized as "High" or "Low"

	CVC	TRCA	CLOCA
(1) The distribution, variability, quality and relevance of data used in the preparation of the assessment report.	low	low	low
(2) The ability of the methods and models used to accurately reflect the flow processes in the hydrological system.	high	high	high
(3) The quality assurance and quality control procedures applied.	low	low	low
(4) The extent and level of calibration and validation achieved for models used or calculations or general assessments completed.	low	low	low
(5) The accuracy to which the groundwater vulnerability categories effectively assess the relative vulnerability of the underlying hydrogeological features.	low	low	low

Table D2-7: Uncertainty Characterization

D2.2.9 Summary

This document has described the estimation of Highly Vulnerable Aquifers within the CLOSPA with some reference to work conducted for the full CTC SPR. Regional aquifer vulnerability indices have been estimated utilizing the AVI methodology. These index values have been transformed into vulnerability scores where high vulnerability areas are given a score of six, moderate vulnerability areas are given a score of four and low vulnerability areas are given a vulnerability score of two. These vulnerability scores will be used in the Threats and Issues component of the Assessment Report where risk is estimated for any threats and issues that exist within vulnerable areas.

The AVI methodology has been described earlier in **Chapter 4** (as well as in this appendix document), and was preceded by a general description of aquifer vulnerability within the CLOSPA and a brief presentation on existing vulnerability mapping utilizing the ISI method. The AVI method utilized interpreted hydrostratigraphic layers (aquifers and aquitards) and hydraulic conductivity estimates from three-dimensional numerical groundwater flow models. These models have been used for other components of the Assessment Report including Tier 1 water budget assessments.

Uncertainty exists with the methodology as it does for any assessment involving subsurface architecture and associated hydraulic and chemical processes. The main source of uncertainty relates to the variable quality of the existing database. The understanding of the subsurface increases as new information is incorporated. This new information may lead to refinement of the interpreted subsurface behaviour of water, or conceptual model, which will in turn affect assessments based on this conceptual model. It is expected that the vulnerability mapping presented here will be continually tested with new information as it becomes available and will also be tested against the conclusions of other hydrogeologic studies as they are prepared. The potential complexity of contaminant transport through the subsurface makes prediction difficult at best. This places great emphasis on monitoring networks that allow for measurement of various chemical and tracer concentrations over time. It is vital that the estimates of aquifer vulnerability presented here be consistent with the results obtained from the monitoring network.

D2.2.10 Data and Knowledge Gaps

Identified data and knowledge gaps regarding vulnerable area requirements are listed in **Table D2-8.**

Identified Data and Knowledge Gaps
Vulnerable Areas with Scoring
Knowledge Gaps
• Need more detailed scrutiny of significant recharge areas as they relate to drinking water systems • Need more detailed scrutiny of highly vulnerable aquifers, specifically shallow aquifer deposits

Table D2-8: Data and Knowledge Gaps Identified for Vulnerable Areas

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. A further examination of transport pathways was done, see **Section D3**. Pits and quarries were ultimately the only transport pathway where there was sufficient data to adjust the aquifer vulnerability.

D2.3 SIGNIFICANT GROUNDWATER RECHARGE AREAS (SGRAS)

As part of Ontario's Source Protection Program, Significant Groundwater Recharge Areas (SGRAs) must be delineated across watershed regions and these areas should be considered vulnerable from a water quality and quantity perspective. According to the Technical Rules, SGRAs should be delineated and mapped to identify and subsequently protect all drinking water sources across the broader landscape, without specific focus on municipal supplies.

The Technical Experts Committee put forth a series of recommendations to protect drinking water at the source. One of the recommendations (no. 66) was to map SGRAs across the broader landscape, and that these areas should be considered vulnerable from both a water quality and quantity perspective. The Committee noted that land use changes, such as urbanization within the SGRAs, can restrict the quantity of water migrating downward to subsurface aquifers, and from a quality perspective, SGRAs can be vulnerable to long term contaminant loadings (such as sodium from road salt application). Groundwater recharge is an integral part of understanding the flow system within a watershed, and therefore it is important to consider significant recharge areas. Recharge is the process whereby water moves from the ground surface through the unsaturated zone, to the underlying water table. As there is no standard scientific method for delineating recharge areas, mapping the spatial distribution of recharge areas across a watershed is difficult for a number of reasons (adapted from Holysh, 2007):

- Recharge occurs to some degree almost everywhere which makes it difficult to establish cut-offs that determine what is 'significant' and what is insignificant;
- There are seldom natural breaks between areas of high recharge and areas of low recharge;
- It is also difficult to represent the transient nature of recharge in a meaningful way on a map, as land use changes such as urbanization or agricultural field tile drainage have the potential to greatly impact the recharge rate across a given area; and
- It is difficult to accurately measure recharge rates, and there is no standard methodology at the moment that outlines how to deal with significant recharge areas.

A Tier 1 water budget has been completed for the whole of the CLOSPA and no further water budget work is being undertaken for drinking water source protection purposes. The water budget models used were U.S. Geological Survey (USGS) Precipitation-Runoff Modelling System (PRMS) and USGS MODFLOW (groundwater). The models were based on analysis of conditions for 25-meter by 25-meter grid cells (PRMS) and 100 meter by 100 meter grid cells (MODFLOW). Both of these models and the results for the study area were peer reviewed as part of the Tier 1 Water Budget process.

The PRMS model results (recharge grid) were used to determine the location of the significant groundwater recharge areas (SGRAs). The PRMS model provided estimates of precipitation, interception, evaporation, potential and actual evapotranspiration, snow melt, run-off, infiltration, interflow, and groundwater recharge. All physical properties, including land-use classes, were represented on a 25-meter cell grid covering the study area. The MODFLOW model was developed as part of the Oak Ridges Moraine groundwater model.

The model estimated groundwater items such as the exchange of water between shallow and deeper aquifers, lateral inflows and outflows from the catchments, and groundwater discharge to streams. The groundwater model was also used (reverse particle tracking) to confirm significant groundwater recharge areas (SGRA). The groundwater model was calibrated based on measured groundwater potentials and estimated baseflows.

D2.3.1 Methods of Analysis - Significant Recharge Areas

As part of the Water Budget analysis, significant recharge areas were to be delineated for each watershed. The first step in this task is to delineate those areas that provide the highest volume of recharge per unit area of the watershed. These areas are identified as Significant Groundwater Recharge Areas (SGRA). *Technical Rule (V)* provides the following options for the delineation of SGRA:

> *Rule (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 evaporation for the whole of the related groundwater recharge area from the annual precipitation for the whole of the related groundwater recharge area.
>
> *Rule (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 the source of a drinking water for a drinking water system.
>
> *Rule (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.

The PRMS model results were used to determine the location of the significant groundwater recharge areas (SGRAs). The PRMS model provided estimates of precipitation, interception, evaporation, potential and actual evapotranspiration, snowmelt, runoff, infiltration, interflow, and groundwater recharge. All physical properties, including land-use classes, were represented on a 25-metre cell grid covering the study area.

To better represent the linkage, a model, based on the U.S. Geological Survey's MODFLOW was used. This groundwater model was developed as part of the Oak Ridges Moraine groundwater model. The model estimated groundwater items such as the exchange of water between shallow and deeper aquifers, lateral inflows and outflows from the catchments, and groundwater discharge to streams. The groundwater model was also used (reverse particle tracking) to confirm significant groundwater recharge areas (SGRA). The groundwater model was calibrated based on measured groundwater potentials and estimated baseflows.

An important finding was that preliminary SGRAs outside of the CLOCA watersheds contribute to streamflow within the study area. This lateral groundwater flow below surface watershed boundaries is an important component of the flow system. Particularly notable is that groundwater recharge northeast of CLOCA flows in deep aquifers under Soper Creek before discharging to surface in Bowmanville Creek.

To confirm the location of the High Volume Recharge Areas (HVRAs), CLOCA conducted single point stream temperature measurements to identify cold water fisheries. Generally, CLOCA watersheds are classified as cold to cool water systems with a few warm water streams (CLOCA, 2007). CLOCA (2007) further identified the occurrence of brook trout (*Salvelinus fontinalis*), a species primarily confined to coldwater fish habitat. Brook trout were found in coldwater streams originating from the Oak Ridges Moraine and in the Black Creek watershed in the vicinity of the Iroquois Beach deposits (**Figure** D2-13).

An aerial thermography survey was flown over the Oak Ridges Moraine in February 1994 by the MNRF. Data were interpreted to identify areas of open water which would indicate high volumes of groundwater seepage (Dyke *et al*., 1997). A portion of the map, covering the northern part of the CLOCA area, is shown in **Figure** D2-13. These locations, which also correlate well with the brook trout occurrences, were selected as starting points for backward particle tracking with the USGS MODPATH code. Particle tracks indicate that the source of the water is likely from the SGRA on the Oak Ridges Moraine. The coverage of the aerial thermography data is limited and CLOCA (2007) noted that, aside from this information, the location of springs and seepage areas are not generally well mapped within the study area.

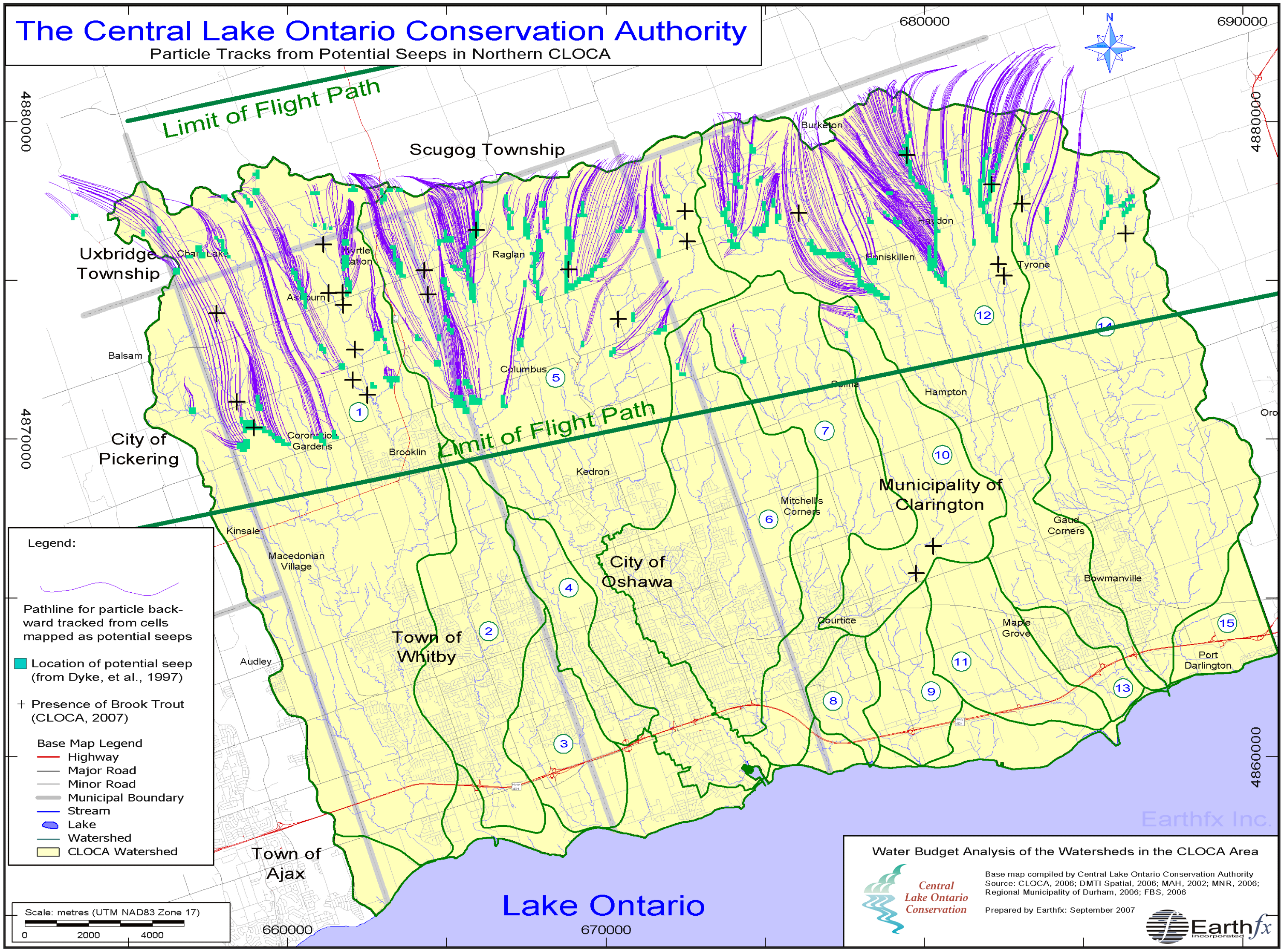


Figure D2-13: Backward Particle Tracking from Potential Seeps and Springs in the ORM

Another confirmatory analysis was undertaken by selecting locations of high groundwater discharge to streams as determined by the numerical groundwater model and identifying where this area where the recharge was occurring. This backward tracking was conducted from all cells that had a discharge greater than 1 litre per second per 100 metre grid cell (**Figure D2-14** and **Figure D2-15**). The areas identified as high recharge corresponded well with the HVRAs identified in the northern parts of the source protection area.

CLOCA performed three options for delineation of the whole of the related groundwater recharge area. The Threshold Criteria for annual recharge (in millimetre per year) were calculated as follows:

Scenario 1 - Threshold Criteria calculated for individual major watersheds that drain to Lake Ontario ranged from 114 to 246 mm/yr. The SGRA areas (**Figure D2-16**) generally coincide with the Oak Ridges Moraine deposits, exposed sands, and Iroquois Beach deposits, although not always. For example, in the Bowmanville Creek watershed the Iroquois Beach deposits do not show as SGRAs although it is known that there is important recharge occurring in these deposits and a number of private drinking water wells that depend upon this recharge. A large proportion of the headwaters of Bowmanville Creek are in the Oak Ridges Moraine and therefore the Threshold Criteria for this watershed is dominated by the recharge rate there, which masks the importance of local recharge occurring in the Lake Iroquois deposits.

Scenario 2 – Threshold Criteria calculated for three physiographic regions running horizontally through CLOCA as shown in **Figure D2-17.** The Threshold Criteria range from 149 to 390 mm/yr. With this approach several key recharge areas in the Oak Ridges Moraine do not show up as SGRAs. These are important known recharge areas for the aquifers that supply private wells as well as providing baseflow for watersheds south of the moraine. In contrast using this approach, there are SGRAs identified in the middle zones that are not significant to drinking water supplies and baseflow to the watershed.

Scenario 3 - Threshold Criteria of 182 mm/yr calculated for the whole of the CLOCA (**Figure D2-18**). The SGRAs delineated with this approach are consistent with the surficial geology, soils data, as well as other analyses and information (reverse particle tracking, flow path analysis, historical reporting and model results). The Oak Ridges Moraine consistently shows up as well as key outwash deposits in the north east. Additionally, several particle tracks from points of discharge in some of the small watersheds in the eastern part of the study area originate on the Iroquois Beach deposits where many private drinking water systems are located. This underlines the need to preserve recharge on the beach. Though all approaches highlight portions of the Oak Ridges Moraine, other approaches as described above produce inconsistent results for these beach deposits.

As mentioned, to confirm that the SGRAs are associated with significant groundwater discharge areas in CLOCA, the following additional analyses were performed:

- Key groundwater-dependent hydrological functions (e.g., key groundwater springs or areas of upwelling (coincident with cold water fisheries) that must be preserved were identified;
- Particle tracking analyses of these features/processes were conducted by placing virtual particles beneath the springs/upwelling; and
- The virtual particles were tracked as they travelled backwards to their point of entry to at the water table.

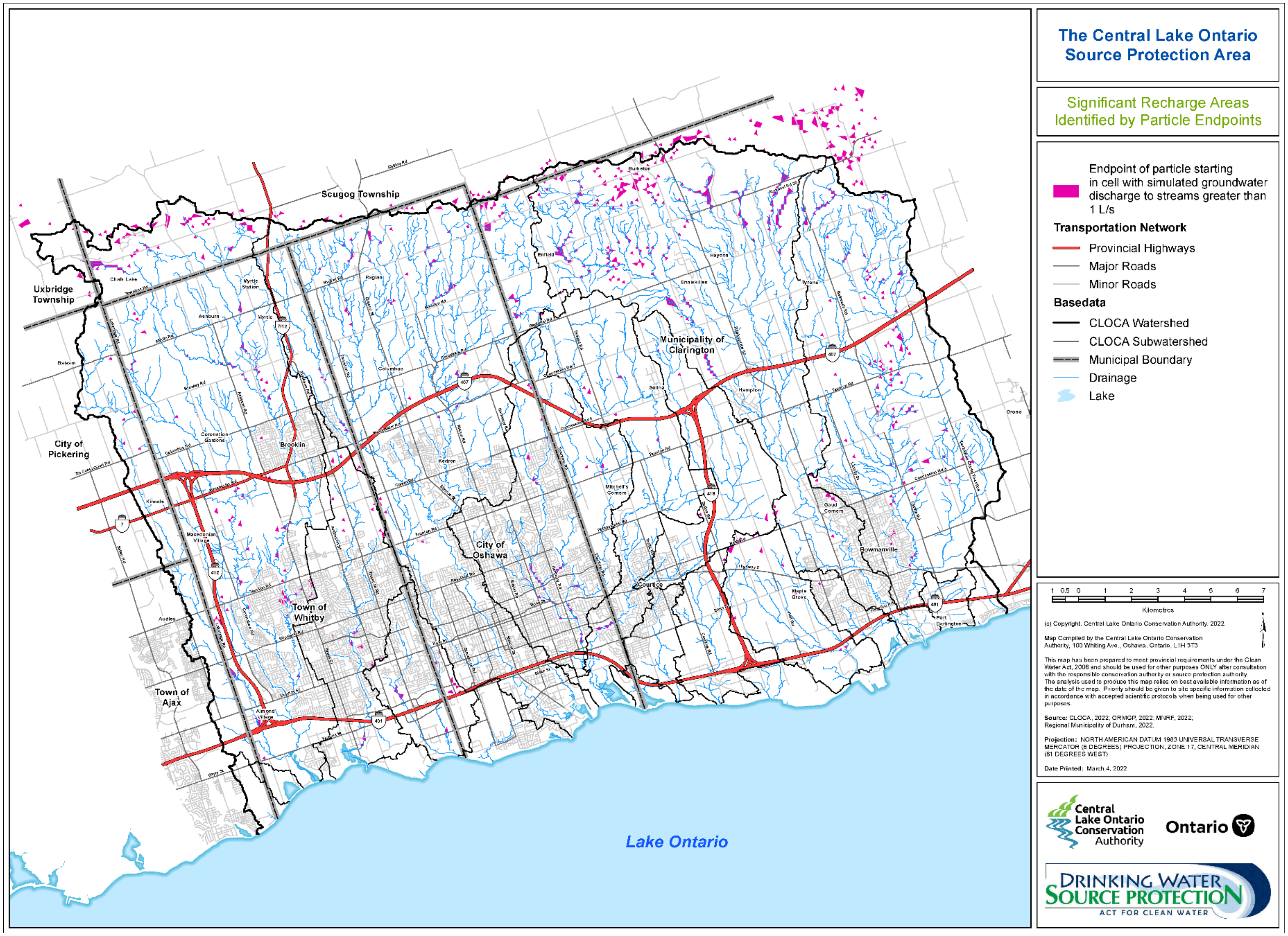


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Figure D2-14: Reverse Tracking from High Groundwater Discharge Area

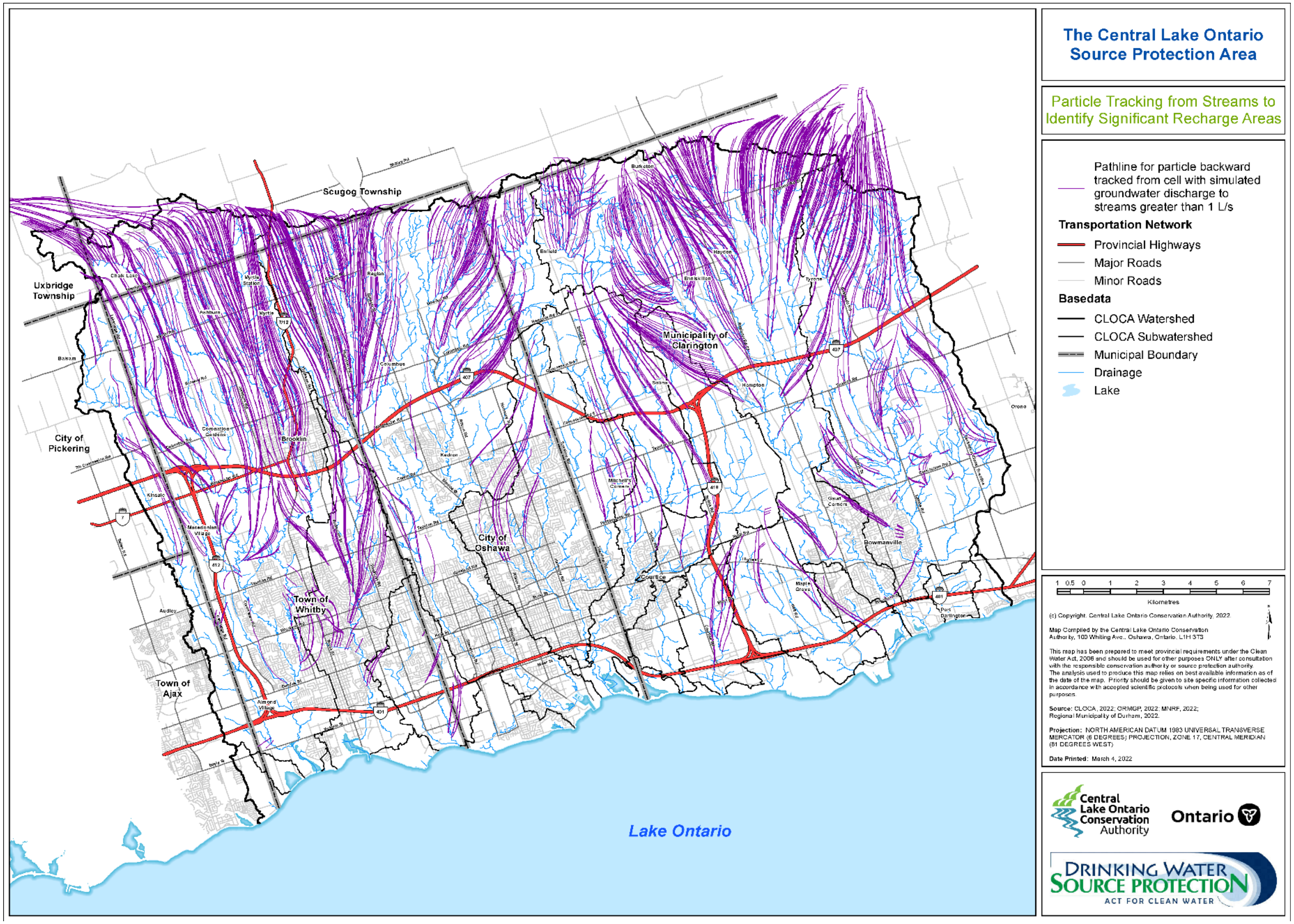

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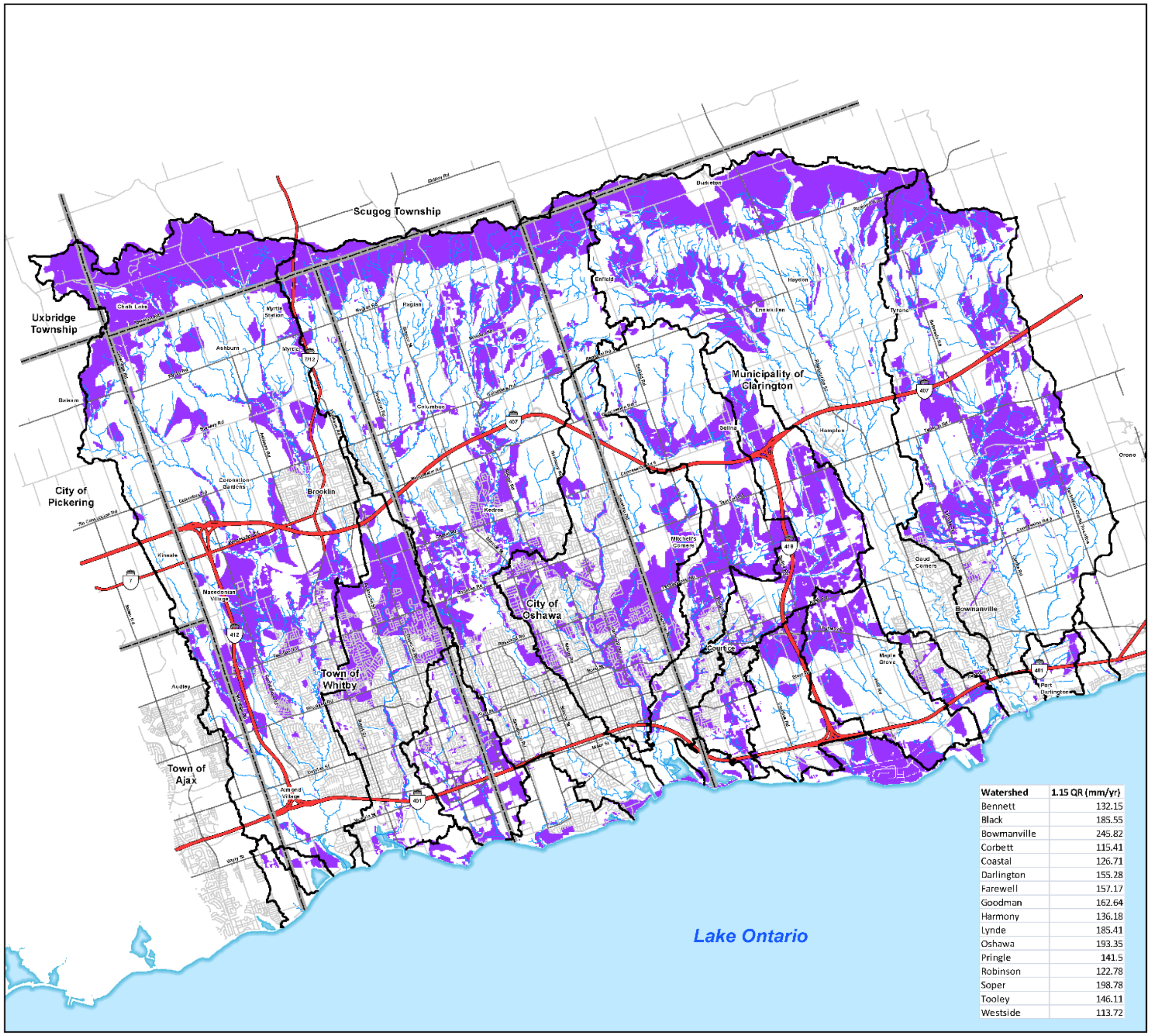
Figure D2-15: High Volume Recharge Area Identified by Backward Tracking from Cells with Simulated Groundwater Discharge to Streams Greater than 1 L/s



Watershed	1.15 QR (mm/yr)
Bennett	132.15
Black	185.55
Bowmanville	245.82
Corbett	115.41
Coastal	126.71
Darlington	155.28
Farewell	157.17
Goodman	162.64
Harmony	136.18
Lynde	185.41
Oshawa	193.35
Pringle	141.5
Robinson	122.78
Soper	198.78
Tooley	146.11
Westside	113.72

The Central Lake Ontario Source Protection Area

High Recharge by Watershed

High Recharge by Watershed
- ■ >= 1.15 QR (mm/yr)

Transportation Network
- Provincial Highways
- Major Roads
- Minor Roads

Basedata
- CLOCA Watershed
- CLOCA Subwatershed
- Municipal Boundary
- Drainage
- Lake

1 0.5 0 1 2 3 4 5 6 7
Kilometres

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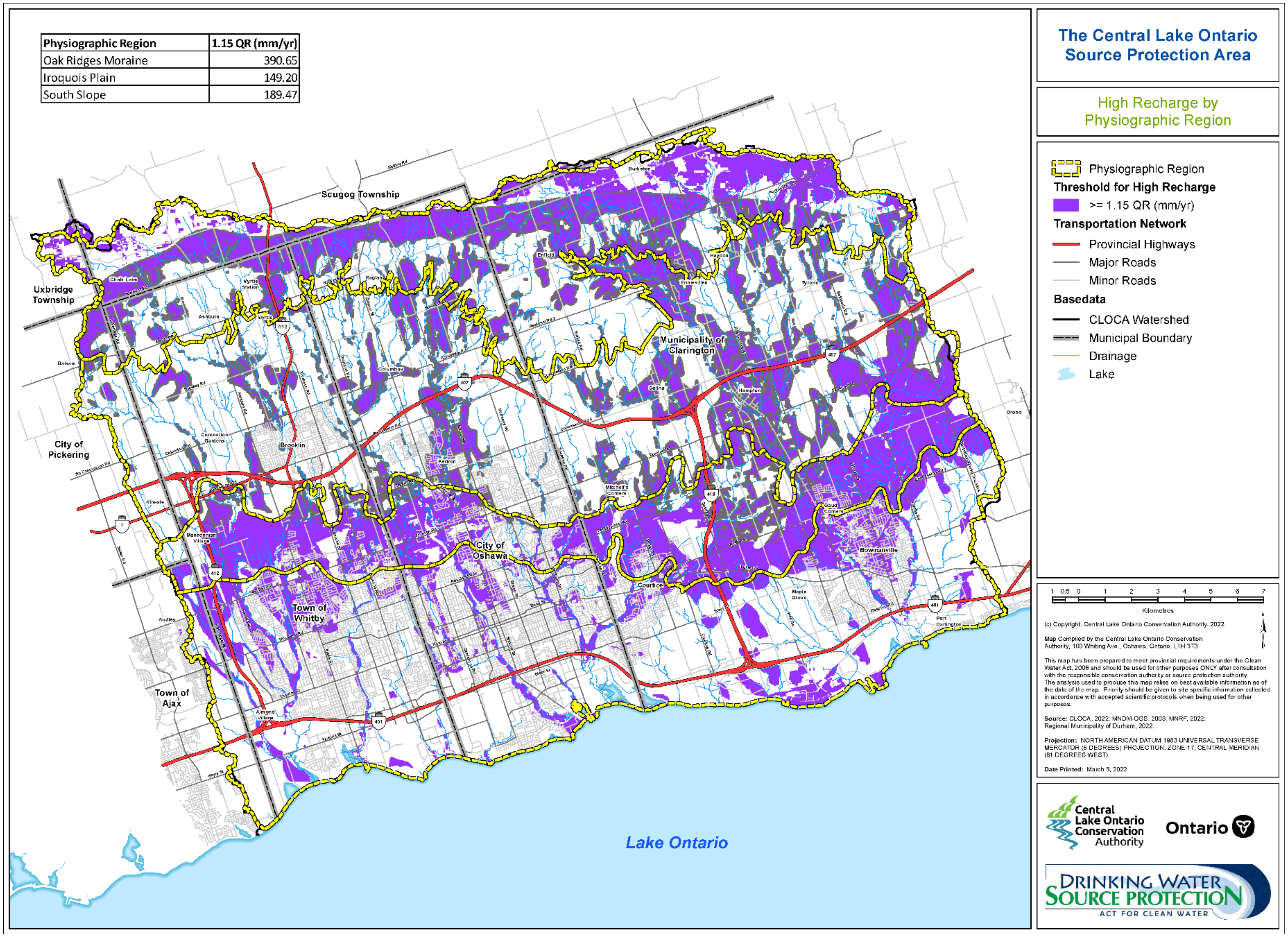
Figure D2-16: High Volume Recharge Areas by Watershed



Physiographic Region	1.15 QR (mm/yr)
Oak Ridges Moraine	390.65
Iroquois Plain	149.20
South Slope	189.47

The Central Lake Ontario Source Protection Area

High Recharge by Physiographic Region

Physiographic Region

Threshold for High Recharge

>= 1.15 QR (mm/yr)

Transportation Network

Provincial Highways

Major Roads

Minor Roads

Basedata

CLOCA Watershed

Municipal Boundary

Drainage

Lake

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Central Lake Ontario Conservation Authority

Ontario

DRINKING WATER SOURCE PROTECTION

ACT FOR CLEAN WATER

Figure D2-17: High Volume Recharge Areas by Physiographic Region

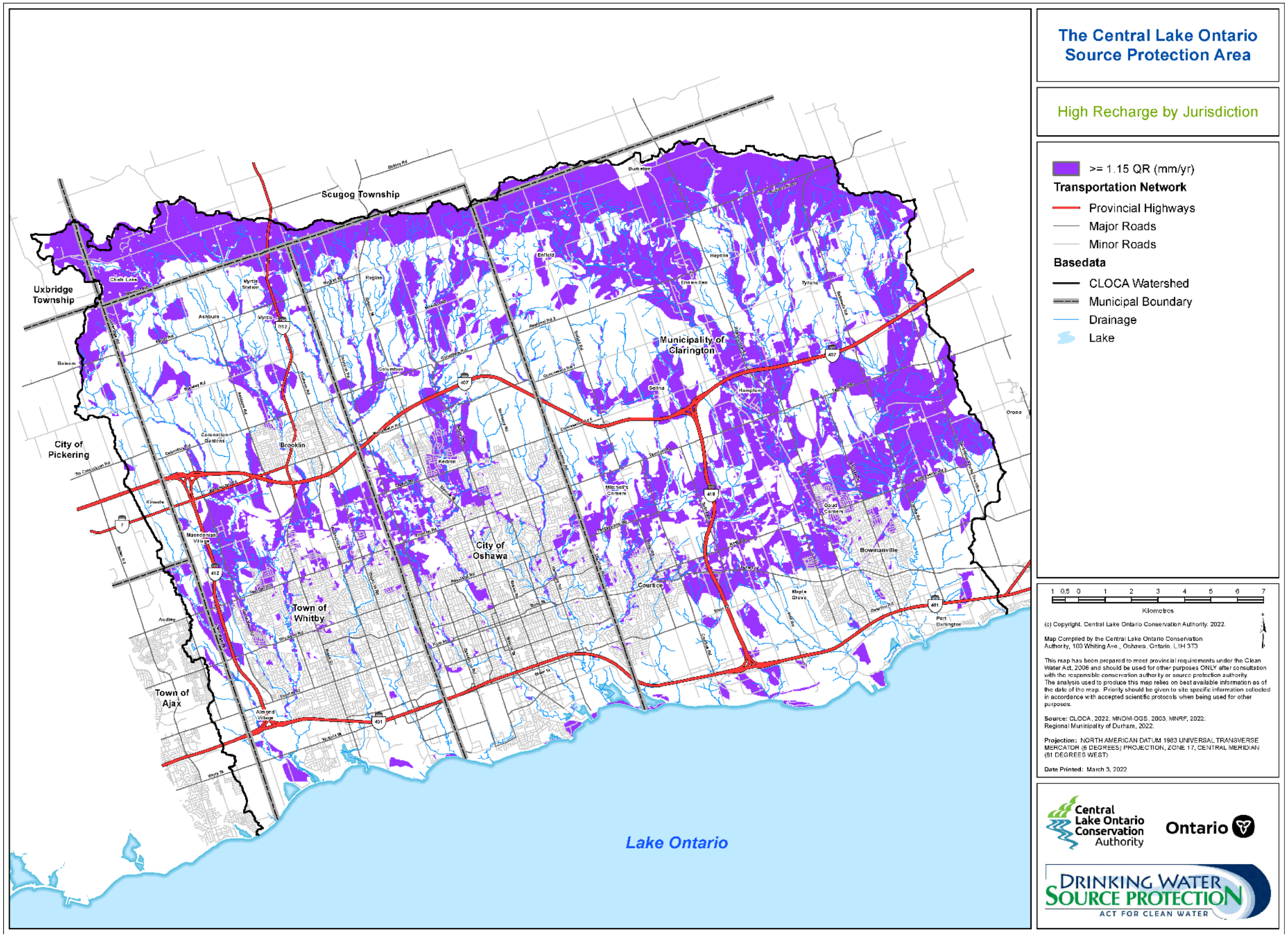

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Figure D2-18: High Volume Recharge Areas by Jurisdiction

The Threshold Criteria used to calculate the SGRA for the whole source protection area (**Figure D2-19**) was decided upon for the following reasons:

1. The jurisdictional threshold appears to capture all the areas historically documented as important for recharge;
2. It correlates well with the provincial surficial geology maps and reverse particle track analyses conducted for the study area; and
3. It identifies the beach deposits in the east part of the source protection area that are connected with local private drinking water supplies and which provides the important and large amount of recharge to the small eastern watersheds (Tooley, Darlington, Westside).

Further, to comply with *Technical Rule (45),* areas where there are no groundwater supplies, e.g., municipalities serviced by Lake Ontario-based supplies, were "clipped" to remove them. Therefore, the preliminary significant groundwater recharge areas located in these municipally serviced areas covering Whitby, Oshawa and Bowmanville were removed in the CLOCA study area. SGRAs located in the Brooklin serviced area were not removed as there are private drinking water systems located down-gradient of the SGRAs in the area that may be dependent. The clipped map was then labelled SGRA as the finalized map under the CWA.

Explanatory Note

> *This report has been prepared to meet provincial requirements under the Clean Water Act, 2006 and should not be used for other purposes without consultation with the responsible conservation authority. The water budget follows a tiered process to screen the areas to identify where there is potential water quantity stress. These potentially stressed areas that are associated with mandated drinking water supplies are then studied in more detail. The process is designed so that each successive tier in the analysis (up to and including Tier 3), becomes more complex, requiring increased sophisticated analysis and data. As a result, with each successive tier the certainty in the findings of the analysis is increased.*
>
> *The analysis used to produce this report was based on best information available at the time. Priority should be given to site specific information collected in accordance with accepted scientific protocols when being used for other decision-making purposes, such as determining the impact of a specific water taking.*

D2.3.2 Limitations: Data and Methods

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.

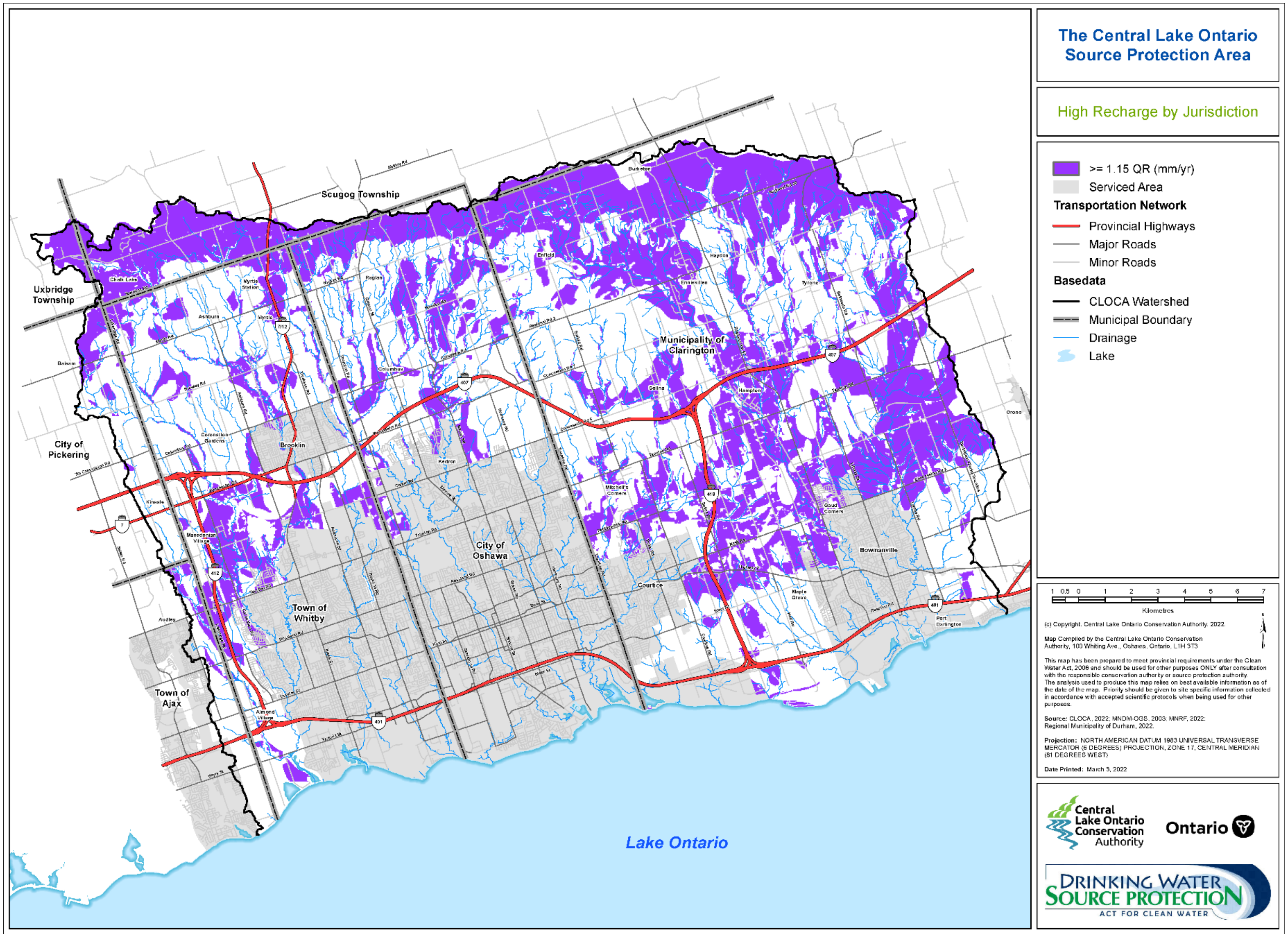

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Figure D2-19: Clipping Significant Groundwater Recharge Area (as defined under the *Clean Water Act, 2006*)

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 INTAKE PROTECTION ZONES (IPZS)

D2.4.1 Methods of Analysis

The CLOSPA 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. Technical studies are being conducted in two general areas of analysis. The intake protection zone delineation was conducted by a consultant team consisting of Stantec Consulting Ltd. 2008, 2010 and 2011; IPZs-3 delineation was conducted under a separate cover. The purpose of these zones is to present an area within which contaminant threat sources (Threats) are to be inventoried in subsequent phases of the project. To assist in illustrating the various IPZ elements and their extents, **Figure D2-20** shows the IPZ components for the Bowmanville water treatment plant (WTP) intake.

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

- The IPZ-1 is set at a minimum one (1) kilometre radius about the intake; its radius can be increased and considered to be the most vulnerable. An increase in radius of IPZ-1 results from special or unique conditions or other environmental situations that in good judgment suggest that this most vulnerable zone be increased in order to properly address the identified situations and/or conditions.
- IPZ-2 – This zone represents the area, both on land and in water, where a spill of a contaminant might reach the intake before the plant operator can respond. In CLOPSA, the IPZ-2 is based on estimating the distance a contaminant might move in two (2) hours along the water surface, calculated from the water intake crib outwards under wind conditions that reflect a 1 year return period to the east and a three year return period to the west. The IPZ-2 has the following components:
  - In-lake and alongshore (in-water) extent:
    - The in-lake component of the IPZ-2 can be calculated using numerical or hydrodynamic modelling 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 two (2) hours. This component is extended to the shoreline at an angle perpendicular to the model.
  - Upland extent:
    - This component has two sub-components; setbacks and transport pathways. The setbacks are determined as; the Conservation Authority Regulated Limit or the administratively set limit of 120 metres from a watercourse or waterbody, whichever is greater. The transport pathways component includes areas that are drained by storm sewers and watercourses. The upper limit of this latter component is determined based on the two (2) hour TOT of a particle within the transport

pathway, beginning at the water surface over the intake. A modelled "bank full" flow event was assumed to complete the two (2) hours TOT analysis. In CLOSPA, modelled flow conditions were selected based on the absence of streamflow monitoring stations on the tributaries that are in close proximity to the confluence with the lake. The hydrologic (flow) models were designed for the purposes of planning and floodplain delineation and are therefore considered to yield conservative results.

  - In general, sources of information for the upland and watershed IPZ-2 components include the CLOCA Module 1 – Watershed Characterization Reports, Canadian Hydrographic Service streamflow data, other CA 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 during an extreme storm event conditions, such as a 100-year storm event. A 100-year storm is a rainfall event that statistically has a one percent chance of occurring in any given year. Any scenario that identifies conditions under which a contaminant could exceed a threshold in the raw water is identified as a significant drinking threat. The delineated IPZ-3 is shown as a line between the source of the spill and the intake following the flow direction predicted by the model.

A schematic of the methodology for generation of IPZ-1s and 2s is included on **Figure D2-21**. These zones are then subject to an inventory of potential contaminant threat sources.

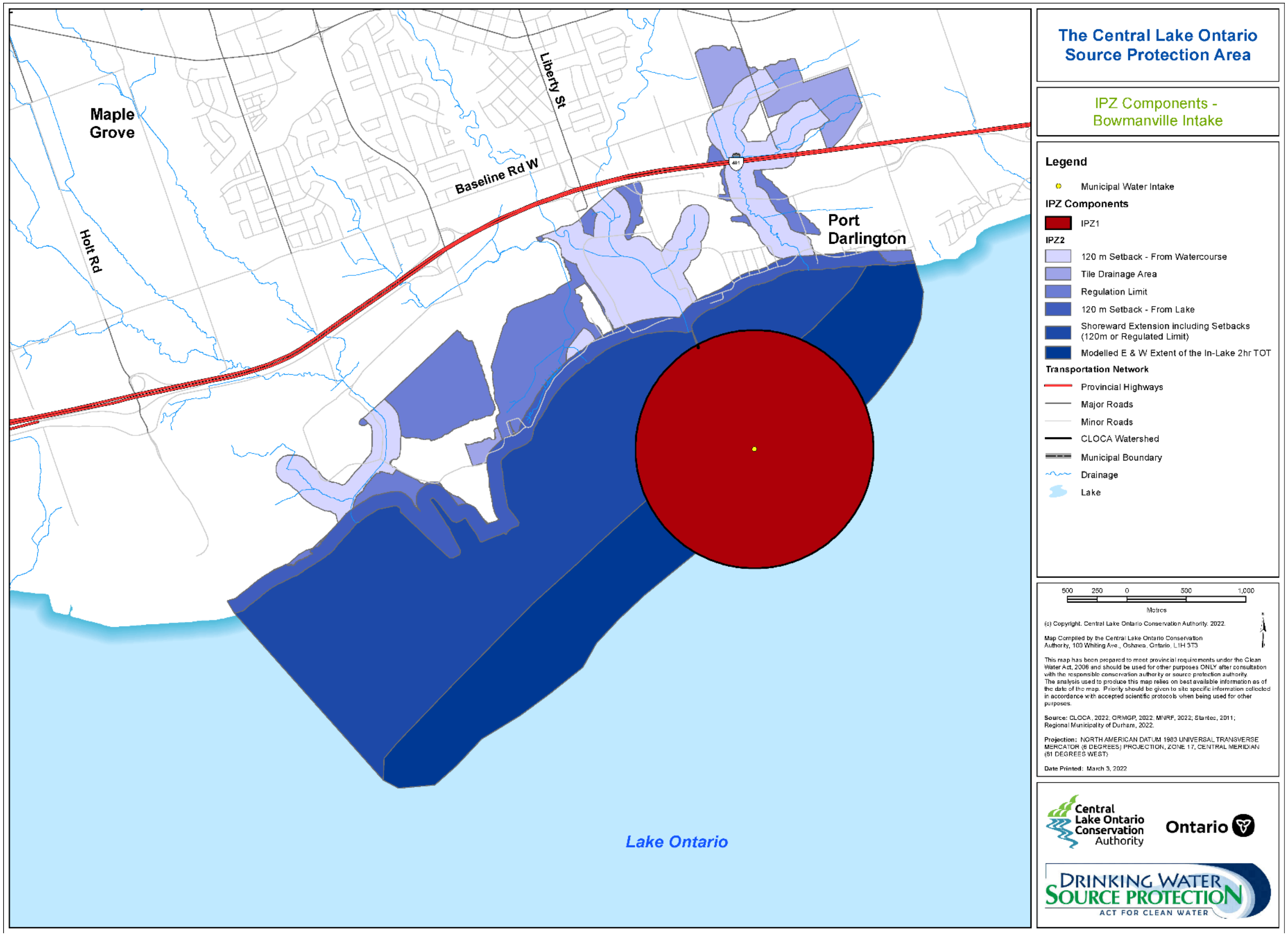

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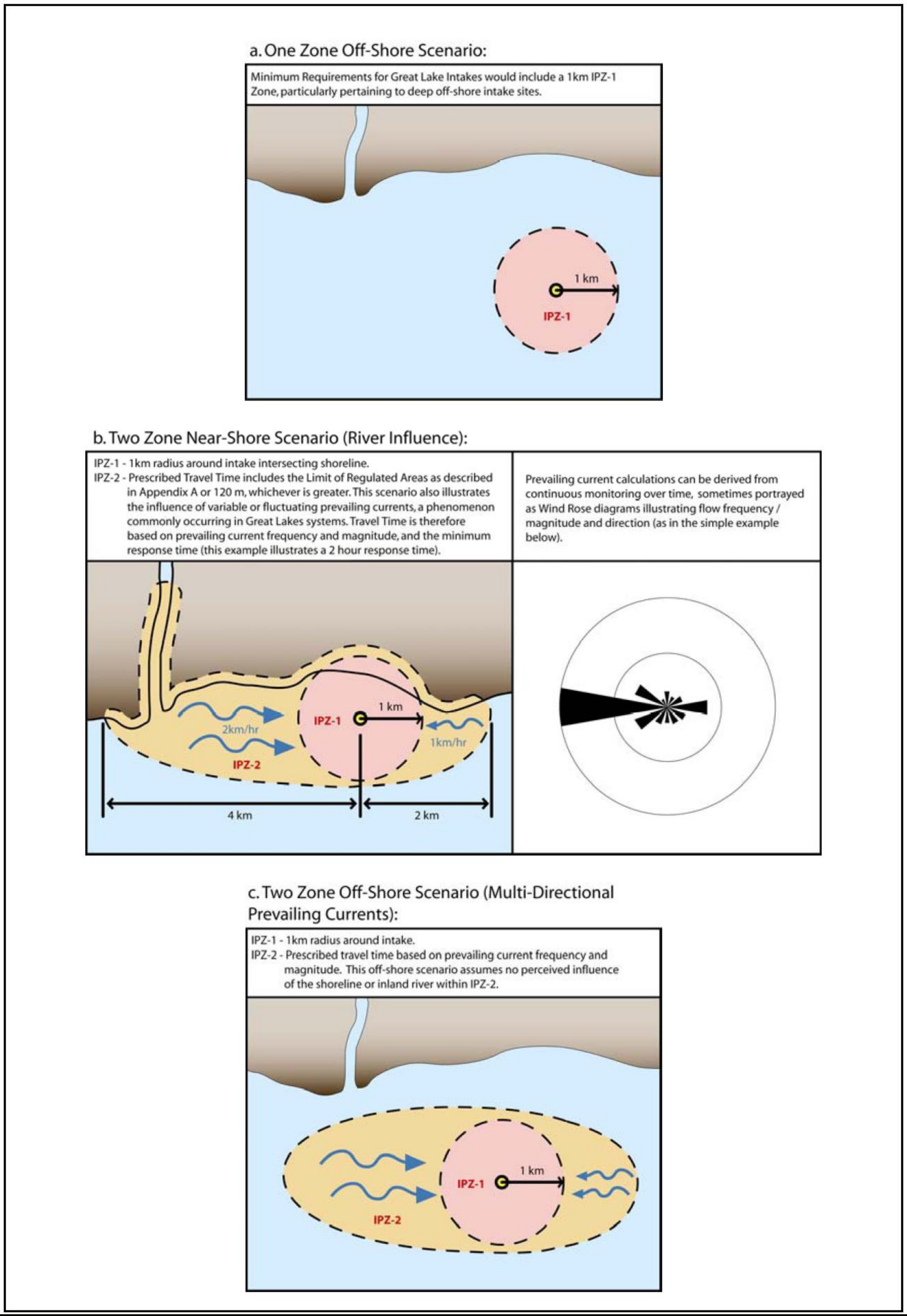
Figure D2-20: IPZ Components, Bowmanville Intake



a. One Zone Off-Shore Scenario:

Minimum Requirements for Great Lake Intakes would include a 1km IPZ-1 Zone, particularly pertaining to deep off-shore intake sites.

b. Two Zone Near-Shore Scenario (River Influence):

IPZ-1 - 1km radius around intake intersecting shoreline.
IPZ-2 - Prescribed Travel Time includes the Limit of Regulated Areas as described in Appendix A or 120 m, whichever is greater. This scenario also illustrates the influence of variable or fluctuating prevailing currents, a phenomenon commonly occurring in Great Lakes systems. Travel Time is therefore based on prevailing current frequency and magnitude, and the minimum response time (this example illustrates a 2 hour response time).

Prevailing current calculations can be derived from continuous monitoring over time, sometimes portrayed as Wind Rose diagrams illustrating flow frequency / magnitude and direction (as in the simple example below).

c. Two Zone Off-Shore Scenario (Multi-Directional Prevailing Currents):

IPZ-1 - 1km radius around intake.
IPZ-2 - Prescribed travel time based on prevailing current frequency and magnitude. This off-shore scenario assumes no perceived influence of the shoreline or inland river within IPZ-2.

Figure D2-21: IPZ Delineation (figure from Ontario Ministry of the Environment, 2006)

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

D2.4.2 IPZ Delineations

Baird conducted numerical modelling in support of IPZ delineation for three (3) WTPs. Hydrodynamic processes on the Great Lakes are in most cases three-dimensional (3-D) with currents at the lakebed often flowing in the opposite direction from currents at the surface. The currents also vary temporally and are highly dependent on wind conditions. Field data, where it exists, defines the current patterns for the duration of the 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 modelling 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. The 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 metres to 10 metres.

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 were 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 five (5) kilometres grid and twenty (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.

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 one (1) year return period event. The west event is approximately a three (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 five (5) year return period event.

Local tributaries were defined in the model and a two (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 was completed in the IPZ-3 work discussed in **Appendix E**.

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 two (2) year flow event. The results from the numerical modelling 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-hours shutdown 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.

IPZ-1 Delineations for Whitby, Oshawa, and Bowmanville WTP

The IPZ-1 was set for Whitby, Oshawa and Bowmanville plants at a minimum 1 kilometre radius about the intake.

IPZ-2 Delineations for Whitby, Oshawa, and Bowmanville WTP

Whitby WTP In-Lake IPZ-2

The intake is located 1.7 kilometres from shore. Currents in this area are predominantly parallel to the lakebed contours. Additional particle tracking runs were undertaken for this intake to evaluate the effects of offshore winds on the currents. The in-lake IPZ-2 extends approximately 2.4 kilometres northeast of the intake and 3 kilometres southwest of the intake. Although the particle tracking indicates that the IPZ-2 does not extend to shore, it has been extended from the outer extents of the in-water modelling to the shoreline at an angle perpendicular to the model, to be conservative.

Whitby WTP Upland IPZ-2

The limits of the upland component of the IPZ-2 are near Cranberry Marsh at the western extent, and to Thickson Road at the eastern extent of the Ajax WTP IPZ-2. The administratively set limit of 120 metres or the Regulation Limit (whichever is greater) was applied to each watercourse, Cranberry Marsh, Whitby Harbour, and Lynde Marsh. The distance up each tributary that is included was calculated using the velocities and distances provided within hydraulic models. Hydraulic models were available for Lynde and Pringle Creeks. For the remaining tributaries, where a hydraulic model was not available, an estimated velocity was used. A summary of the tributary analysis for the Whitby intake is presented in **Table D2-9**. Storm sewers were also considered in the analysis of the upland component. Catchment areas were estimated for the residual time of travel at the outlets. Two large catchment areas are included, one of the areas is bound by Seaboard Gate to the west, Victoria Street to the north and Gordon Street to the east, the second area stretches to approximately 200 metres north of the Hwy-401 and is bound by Brock Street to the east and Henry Street to the west.

Tributary	Calculated Upstream Distance (m)
Lynde	901
Pringle	344
Creek North of Harbour	2012*
Hanson Pipe Creek	2423*
Creek East of Hanson Pipe	1526*

Table D2-9: Summary of the Whitby Intake Tributary Analysis

*Actual creek lengths are shorter than the calculated distance. Therefore, the entire watercourse is included in the delineation.

Oshawa WTP In-Lake IPZ-2

There are two intakes for this WTP, located approximately 150 metres apart. Based on information provided by the operators both intakes are used equally and there is no primary intake, and the east intake was chosen to be modelled and is representative of both intakes due to their close proximity. The intake is located 924 metres from shore. Currents in this area are predominantly parallel to shore and the in-water IPZ-2 extends approximately 2 kilometres northeast of the intake and 4.7 kilometres southwest of the intake. It is estimated that the IPZ for the west intake would extend approximately 150 metres further to the west. Although the particle tracking indicates that the IPZ-2 does not extend to shore, it has been extended from the outer extents of the in-water modelling to the shoreline at an angle perpendicular to the model to be conservative. Further analysis should be undertaken early in Phase 2 to evaluate the potential for the IPZ-2 to reach the river mouth, as this has implications for the scope of the Phase 2 studies.

Oshawa WTP Upland IPZ-2

The limits of the Oshawa WTP upland IPZ-2 are Thickson Road, at the western limit, and Oshawa Harbour at the eastern limit. The administratively set limit of 120 metres or the Regulation Limit (whichever is greater) was applied to each watercourse, Pumphouse Marsh, and the Oshawa Harbour. The distance up each tributary that is included was calculated using the velocities and distances provided within hydraulic models. Hydraulic models were available for Corbett and Oshawa creeks. The hydraulic model for Oshawa Creek was not used as the 2-hours TOT expires within the harbour. For the remaining tributaries, where a hydraulic model was not available, an estimated velocity was used. A summary of the tributary analysis for the East and West Oshawa intakes is presented in **Table D2-10** and **Table D2-11**, respectively. Storm sewers were also considered in the analysis of the upland component. Velocities for storm sewers were not available so a sufficiently high velocity was assumed to include the entire network. The contributing storm sewer catchment areas stretch from the intake, west to Boundary Road and end south of Hwy-401.

Tributary	Calculated Upstream Distance (m)
Corbett Creek	74
Creek East of Corbett Creek	1500*
Creek East of Lakefront Park	3100*
Oshawa Creek	Entire Harbour

Table D2-10: Summary of the Oshawa East Intake Tributary Analysis

*Actual creek lengths are shorter than the calculated distance. Therefore, the entire watercourse is included in the delineation.

Tributary	Calculated Upstream Distance (m)
Corbett Creek	75
Creek East of Corbett Creek	1570*
Creek East of Lakefront Park	3100*
Oshawa Creek	Entire Harbour

Table D2-11: Summary of the Oshawa West Intake Tributary Analysis

*Actual creek lengths are shorter than the calculated distance. Therefore, the entire watercourse is included in the delineation.

Bowmanville WTP In-Lake IPZ-2

The intake is located 1.3 kilometres from shore. Currents in this area are predominantly parallel to the lakebed contours. The in-lake IPZ-2 extends approximately 2.4 kilometres northeast of the intake and 3.8 kilometres southwest of the intake. Although the particle tracking indicates that the IPZ-2 does not extend to shore, it has been extended from the outer extents of the in-water modelling to the shoreline at an angle perpendicular to the model to be conservative. Further analysis should be undertaken early in Phase 2 to evaluate the potential for the IPZ-2 to reach the river mouth, as this has implications for the scope of the Phase 2 studies.

Bowmanville WTP Upland IPZ-2

The limits of the Bowmanville WTP upland IPZ-2 are Holt Road (if it were extended to the lake) at the western limit and Bennett Road at the eastern limit. The administratively set limit of 120 metres or the Regulation Limit (whichever is greater) was applied to each watercourse and Bowmanville Marsh. The distance up each tributary that is included was calculated using the velocities and distances provided within hydraulic models. Hydraulic models were available for all creeks within the study area, however, only partial information was available for Bennett Creek. A summary of the tributary analysis for the Bowmanville intake is presented in **Table D2-12.** Storm sewer networks were obtained, however, there are no outlets or networks within the study area. A tile-drained catchment is included as part of this upland IPZ-2, the catchment is bound by Haines Road to the west, Bennett Road to the east, Hwy-401 to the south, and Hwy 2 to the north.

Tributary	Calculated Upstream Distance (m)
Darlington Creek	1127
Westside Creek	238
Bowmanville Creek	1565
Soper Creek	1412
Bennett Creek	2248

Table D2-12: Summary of the Bowmanville Intake Tributary Analysis

D2.4.4 IPZ Zone Vulnerability

The vulnerability score (V), as defined in the *Technical Rules (88)* and *(89)*, is a numerical expression of the susceptibility of the intake to contaminants. It is based on attributes of the intake (length and depth), type of water body, physical characteristics of the environment it is situated in, and the influences affecting intake water. It is essentially qualitative, based upon low, medium or high scores assigned to the contributing factors. Vulnerability scores are derived for each intake protection zone.

V is derived from the formula that is provided in Module 4, where:

$$V = Vfz \times Vfs$$

Vfz is the zone vulnerability factor relating to each zone; and

Vfs is the source vulnerability modifying factor relating to the location of the intake and influences affecting it.

The formula does not consider specific contaminants, their respective properties, or behaviours. The V and assigned scores of its respective factors, Vfz and Vfs, do not have units.

The *Technical Rules* outline vulnerability scoring for intakes in all types of surface water sources, however, the following discussions will be limited to the Great Lakes. Vulnerability scores for Great Lakes intakes are derived for the IPZ-1 and IPZ-2 *(*MOE, 2006*).* A summary of Great Lakes intakes vulnerability scores and factors is presented in **Table D2-13**.

Vulnerability Score for Great Lakes Intakes					
Intake Type	Zone Vulnerability Factor (Vf_z)		Source Vulnerability Modifying Factor (Vf_S)	Vulnerability Score (V)	
	IPZ-1	IPZ-2		IPZ-1	IPZ-2
Great Lakes	10	7 to 9	0.5 to 0.7	5 to 7	3.5 to 6.3

Table D2-13: Vulnerability Score for Great Lakes Intakes

Vulnerability scores established for each intake are then assigned a ranking of vulnerability based on the following criteria:

- Low Vulnerability ($V \leq 5$);
- Moderate Vulnerability ($5 < V \leq 6$); and
- High Vulnerability ($V > 6$)

A summary of vulnerability scores is presented for all the intakes in subsequent WTP-specific chapters of this report.

Zone Vulnerability Factor

A Vfz score is assigned to each IPZ and relates to features and processes in the local environment that may impact the intake. The value for the Zone Vulnerability Factor that is assigned to IPZ-1 is prescribed by the *Technical Rules* and is fixed at a value of ten (10) (it is fixed due to inherent vulnerability of close proximity to intakes). The value assigned to IPZ-2 is determined based on a matrix that considers three sub-factors; percentage of land, land characteristics and transport pathways. Each subfactor is considered equally when determining the final value, which will be a whole number between 7 and 9. The matrix is presented in **Table D2-14**.

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

Table D2-14: Zone Vulnerability Factor Decision Matrix

Source Vulnerability Modifying Factor

A Vfs score is assigned to the intake. For Great Lakes intakes the Vfs scores can range from 0.5 to 0.7, representing low, moderate, and high vulnerability. Methods for determining the Vfs were not included in the *Technical Rules* instead, various resources were consulted to develop a matrix that was used to quantify the factor. The three subfactors included in the matrix are weighted equally as it is assumed that they are of equal importance (see **Table D2-15**).

Subfactor	Criteria			Subfactor Score
	0.5	0.6	0.7	
Intake depth	> 6.1m	3.1 to 6.0m	0 to 3.0m	Choose score based on intake characteristics
Intake length from shore	> 500m	300 to 500m	< 300m	Choose score based on intake characteristics
Recorded water quality issues	Minimal number of parameter results measured above ODWQS - No additional concerns	Some parameter results measured above ODWQS along with operator concerns –Watershed characterization reported concerns	Several parameter results measured above ODWQS -Operator and/or municipal staff confirmation of raw water quality concerns	Choose the most appropriate score based upon information received

Table D2-15: Source Vulnerability Factor Decision Matrix

Related Source Vulnerability Considerations

The MOECC guidelines for the *Design of Water Treatment Works (MOE, 1982)* prescribe that the preferred submergence for raw water intakes is ten (10) metres however; three (3) metres or more is satisfactory. It does not recommend a preferred distance from shore.

For the purposes of comparison, this report has included State of Michigan surface water intake categorization criteria, in an effort to provide additional resources for qualifying selected intake vulnerability scores. The State of Michigan intake categories do not directly apply to Canadian Great Lakes WTP intakes, but it is assumed that Great Lakes intakes will have comparable vulnerability when viewed exclusively from the perspectives of distance offshore and depth parameters.

The State of Michigan, as part of its *Source Water Protection Program (MDEQ, 2004),* categorizes surface water intakes in four (4) ways according to the distance offshore and depth to intake: near shore, shallow-water intakes; near shore, deep-water intakes; offshore, shallow-water intakes; and offshore, deep-water intakes. This classification system has been applied to the intakes in this study in order to provide a more detailed qualitative description of the source vulnerability modifying factor outlined in Module 4. The Michigan categories for Great Lakes intakes are discussed in detail in Appendix 5.1 of that report.

D2.4.5 Limitations: Data Gaps and Methods

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

The key limitations of the modelling are as follows:

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

- IPZ-2 in-water 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.
- A conservative approach was taken in the reverse particle tracking for the in-water modelling of IPZ-2. Particles were released at the surface where currents are stronger. Although this is a conservative approach, the level of conservativeness in the model results is unknown. This uncertainty could be further refined with future modelling that would include the release of particles at intake depth.
- The upland (tributary) portion of the IPZ-2 was delineated with the use of HEC-RAS hydraulic modelling. The HEC-RAS hydraulic model provided was created for the purposes of floodplain mapping and was based on un-calibrated flow data. The low flow channels dimensions used in the models (which are typically representative of the 2-year flow) were interpolated from several measured sections. As such the values for the 2-year simulations are extremely conservative. Due to the conservative nature of the HEC-RAS data and assumptions made for tributaries in CLOSPA, the up-tributary delineations have a moderate level of uncertainty.

In general, the quality and quantity of data available from readily available public domain data sources and from conservation authorities and municipalities are sufficient to characterize the intake and setting, undertake a conservative delineation of IPZ-2, and conduct qualitative vulnerability analyses for zone and source factors.

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D3 TRANSPORT PATHWAYS ADJUSTMENT STUDY

D3.1 INTRODUCTION

The assessment reports for the three authorities of the CTC Source Protection Region (SPR) (Credit Valley Source Protection Authority (CVSPA), Toronto and Region Source Protection Authority (TRSPA), and Central Lake Ontario Source Protection Authority (CLOSPA)), were completed in accordance with the *Clean Water Act, 2006* and *Technical Rules.* 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 – 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) 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 prior to the preparation of the Source Protection Plan.

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. The approved approach and results will be incorporated into the respective SPA updated assessment reports upon approval by the CTC Ad Hoc Technical Committee and the CTC Source Protection Committee. The SPA reports will then be updated accordingly. The deadline for submission of the updated assessment report is June 2011 (including a 30 day period for public consultation).

D3.1.1 Objective

The *Technical Rules Part IV.1 (39 to 41) Vulnerability Assessment and Delineation, Groundwater, (2009)* (*Clean Water Act, 2006)* allows for an increase in vulnerability scoring for an aquifer due to the presence of transport pathways (anthropogenic in origin).

The primary objective of this study is to review and update the Groundwater Vulnerability Analyses for the CTC SPR (CVSPA, TRSPA, and CLOSPA).

This study builds on the results of earlier work and compiles additional information towards completion of the updated assessment reports for the CTC SPR (CVSPA, TRSPA, and CLOSPA), June 2011.

D3.1.2 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 D3-1**.

D3.1.3 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 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 behaviour of specific contaminants. Rather, it produces a numerical index representing the relative vulnerability of an aquifer, based on the type and thickness of the soil above. A more detailed description of the methodology used to delineate the AVI is found in Gerber (2010).

The vulnerability approaches for the various CTC WHPAs ranged and was 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.

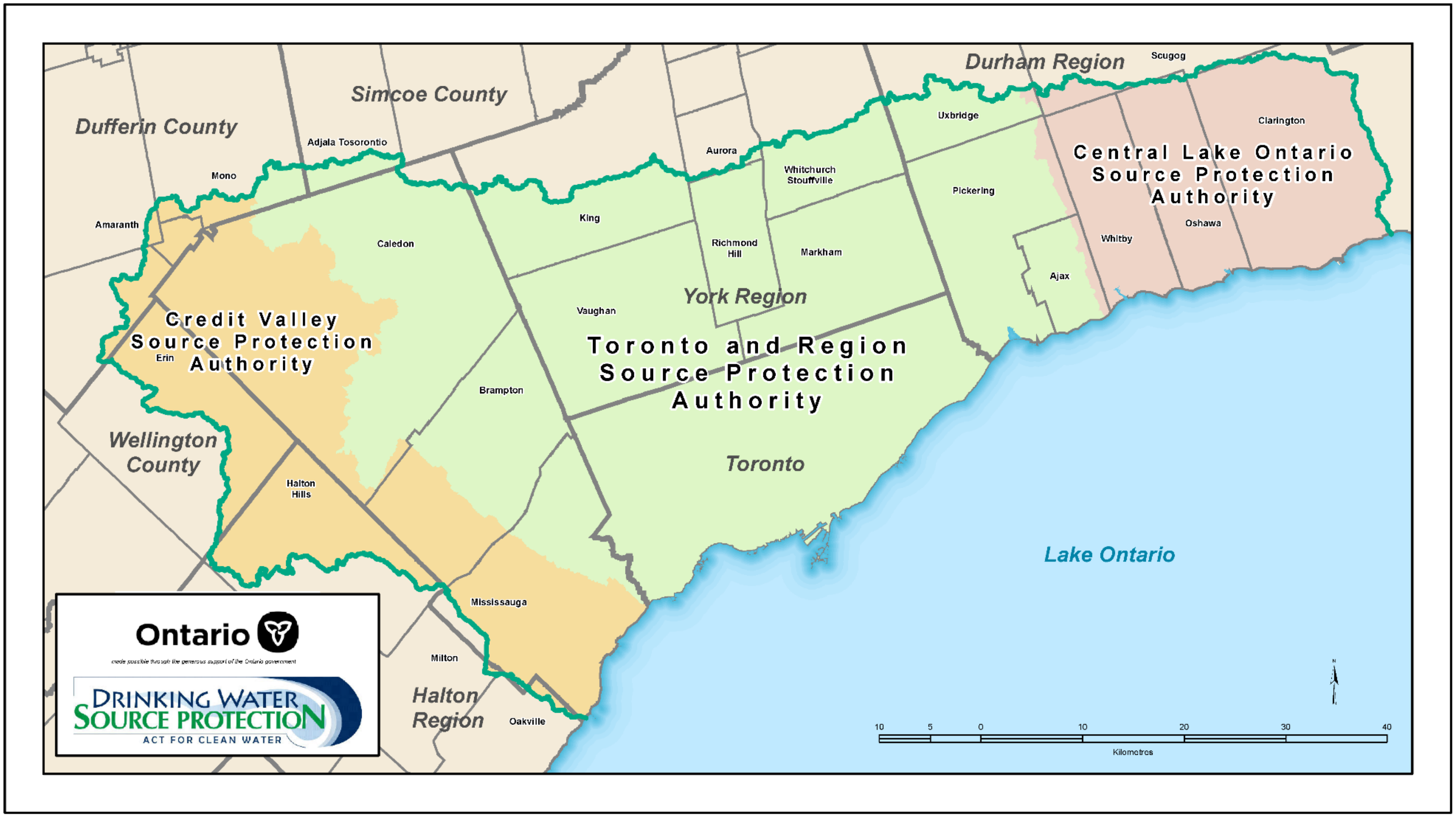


Figure D3-1: CTC Source Protectoin Region

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), (see **Table D3-1**). 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.

CTC Vulnerable Areas	**CVSPA**		**TRSPA**		**CLOSPA**
HVA	Regional Aquifer Vulnerability Index (AVI)				
SGRA					
WHPA	**Dufferin**	Local Aquifer Vulnerability Index (AVI)	**York**	Local Surface to Well Advection Time (SWAT) (UZAT =0)	Not Applicable
	Wellington	Local Intrinsic Susceptibility Index (ISI)	**Durham**	Local Intrinsic Susceptibility Index (ISI)	
	Halton	Local Surface to Well Advection Time (SWAT) (UZAT =0)			
	Peel	Local Surface to Well Advection Time (SWAT) (UZAT =0)	**Peel**	Local Surface to Well Advection Time (SWAT) (UZAT =0)	

Table D3-1: Groundwater Vulnerability Assessment Methods Applied in CTC Vulnerable Areas

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 D3-2** 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 inefficient use of funds at this time given the more pressing drinking water concerns within the CTC SPR.

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.

Table D3-2: Transport Preferential Pathways of Concern

D3.2 AVAILABLE METHODOLOGIES

D3.2.1 Technical Rules 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.
- 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.

D3.2.2 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 D-17**.

Modified from: Module 5: Issues Evaluation and Threats Inventory, Provincial Guidance Modules, (MOE, 2006).

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

AVI

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

WHPAs

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

Note: Pits and quarries, were already considered

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

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

D3.2.3 Determining the Appropriate Score Modifier

According to the *Technical 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 score cannot be increased above 10 points for WHPAs or 6 points for HVAs. These are the maximum scores for these areas. In particular, this applies to WHPA Zone A, and to DNAPL threats within WHPA Zones B and C where maximum vulnerability scores of 10 have already been assigned.

D3.2.4 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.

D3.2.5 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 D3-3** and **Table D3-4** summarize assumptions and criterions approaches within WHPAs in the CTC SPR.

Table D3-3: Consideration of Pathways in the Vulnerability Assessment in CTC Well Head Protection Areas (WHPAs)

	CVSPA - WHPAs							
	Municipality		**Wells**		**Methods**	**Pathways Considered**		**Comments**
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)	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.

	CVSPA - WHPAs							
	Municipality		**Wells**		**Methods**	**Pathways Considered**		**Comments**
				Bel Erin				
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							
	Municipalities		**Wells**		**Methods**	**Pathways Considered**		**Comments**
BURNSIDE	**Peel**	Caledon E	3	Well (2, 3 & 4)	Local SWAT-MODFLOW	Yes	**Pits and quarries, large sewage** (Caledon E-2), **septic systems**, **single wells before 2002** (buffer 30m)	SWAT – UZAT equal zero (Unsaturated Zone removed for the consideration of vulnerability). **Pits and quarries** were considered; however, there are no pits and quarries located within their WHPAs. **Large sewage** was considered. Vulnerability increased by one category. **Septic systems** were considered; however, there are no septic systems located within their WHPAs. These results were excluded from the 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.
		Palgrave	3	Well (2, 3 & 4)			**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	Well (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	Well (2, 3 & 4)				
		King City	2	Well (3 & 4)				
		Whitchurch-Stouffville	5	Stouffville (1/2, 3, 5 & 6)				
AECOM	**Durham**	Uxville	2	Well (1 & 2)	Local ISI	Yes	**Pit** (W-1 & 2), **sewage line** (W-1 & 2 Buffer 26m) and **old cluster water wells** (W-1 & 2 Buffer 30m)	Vulnerability increased by one category because of **pit, sewage line** (buffer 26 m) and **old cluster water wells** (buffer 30 m) vulnerability was increased by one category. These results were excluded from the assessment reports because of inconsistency between WHPAs.

Pathways	Steps	Burnside (Local AVI)	Blackport &Golder (Local ISI)	Earthfx (SWAT)
		Dufferin (CVSPA)	Wellington (CVSPA)	Halton (CVSPA) York (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)
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. It is noted that private wells were not considered in the transport pathway assessment. ▪ 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.
	Criteria	▪ 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.		▪ 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.
	Buffer	▪ Not applied		▪ Not applied
	Comments	▪ Orangeville - 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. ▪ Mono - 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. ▪ 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.		▪ 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, constructed pathways that could possibly reduce unsaturated zone travel times, such as pipeline bedding and excavations above the water table, would not result in an increase in the vulnerability scores already assigned. The focus, therefore, was on identifying those constructed pathways that could reduce travel times in the saturated zone (below water table). ▪ It is more likely that older wells, rather than wells constructed after 1990, would be improperly decommissioned. Because of uncertainty in these assessments, as discussed further below, the results of the ToT and WWAT (Water Table to Well Advection Time) analyses should best be viewed as a tool for identifying the higher risk areas that should receive priority for contaminant risk assessment, improved water quality monitoring and decommissioning of abandoned wells. Areas identified as moderate and low vulnerability will still require land-use planning and water quality monitoring.

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 from by one category.
	Criteria			▪ Pits and quarries that extend to or below the water table.
	Buffer			▪ Not applied
	Comments			▪ 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.
Septic System	**Assumptions**	▪ Not considered	▪ Not considered	▪ Not considered
	Criteria			
	Buffer			
	Comments			
Storm-Water Trunk Sewer	**Assumptions**	▪ Utilities that may act as transport pathways (storm-water trunk sewers and sanitary infrastructure). 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. Vulnerability was NOT increased.	▪ Surface utilities were considered, however, they were not identified within the WHPAs.	▪ Not considered
	Criteria			
	Buffer			
	Comments			
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. Vulnerability was NOT increased.	▪ Surface utilities were considered, however, they were not identified within the WHPAs.	▪ Not considered
	Criteria			
	Buffer			
	Comments			

Deep Excavation (Parking garages and basements for multi-story buildings)	**Assumptions**	▪ Not considered	▪ Not considered	▪ 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).
	Criteria			
	Buffer			▪ Not applied
	Comments			▪ Most buildings in Georgetown and Acton appear to be one to two stories with outdoor parking. Accordingly, there is no likely to be a risk due to clusters of buildings with deep excavations.

Table D3-4: Summary of Approaches to Consideration of Pathways in the Vulnerability Assessment on Well Head Protection Areas (WHPAs)

Pathways	**Steps**	**Burnside (SWAT)**	**EarthFx (SWAT)**	**AECOM (local ISI)**
		Peel (CVSPA - TRSPA)	**York (TRSPA)**	**Durham (TRSPA)**
		Caledon (8 wells), **Caledon E (3 wells) & Palgrave (3 wells)**	**Nobleton (wells 2, 3, & 4), Kleinburg (wells 2,3, &4), King City (wells 3&4), Stouffville (wells ½, 3, 5, & 6)**	**Uxville (2 wells)**
Water Wells	**Assumptions**	▪ 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 or 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	▪ 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).		▪ Locations where well clusters were identified. ▪ 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. In this case, the top of the municipal aquifer was conservatively assumed to be 40 m bgs.
	Buffer	▪ 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.		▪ 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	▪ 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. The locations of these pathways were not included in any further analysis within the current study. In the current analysis it was assumed that these pathways where present would allow water particles to directly access the water table within the areas that do not discharge to the municipal well. Based on the simulations provided by the groundwater models it was determined that water particles originating in these areas do not discharge to the wells of concern and therefore these transport pathways do not provide a pathway for contaminants to get to the wells. 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.
Aggregate Operation	**Assumptions**	▪ 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	▪ Pits and quarries that extend to or below the water table.		
	Buffer	▪ Not applied		▪ Not Applied
	Comments	▪ 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. 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.
Septic System	**Assumptions**	▪ 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	▪ Penetrate the water table of an unconfined aquifer system.		
	Buffer	▪ Not applied		
	Comments	▪ Groundwater vulnerability analysis of SWAT times, unsaturated zone travel times (UZAT) were set equal to zero.		

Storm-Water Trunk Sewer	**Assumptions**	▪ Groundwater vulnerability analysis of SWAT times, unsaturated zone travel times (UZAT) were set equal to zero.	▪ Not considered	
	Criteria	▪ Depth of installation on unconfined aquifer. ▪ Construction and condition of the each individual utilities.		▪ 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. In order to ensure that the buffers were representative of the local area, they had to be wider than the estimated road right-of-way for each of the phases. 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.
	Buffer	▪ Not applied		▪ A single buffer for both phases was created using a width of 26 m to ensure complete capture of the storm-sanitary sewage.
	Comments			▪ 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, which indicates a partial protection by Halton Till, with partially unprotected conditions at the northern part of the WHPA.
Sanitary Sewage	**Assumptions**	▪ Groundwater vulnerability analysis of SWAT times, unsaturated zone travel times (UZAT) were set equal to zero.	▪ Not considered	
	Criteria	▪ Depth of installation on unconfined aquifer. ▪ Proximity to the supply well. ▪ Construction and condition of the each individual utilities.		▪ 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. In order to ensure that the buffers were representative of the local area, they had to be wider than the estimated road right-of-way for each of the phases. 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.
	Buffer	▪ Not applied		▪ A single buffer for both phases was created using a width of 26 m to ensure complete capture of the storm-sanitary sewage.
	Comments			▪ 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, which indicates a partial protection by Halton Till, with partially unprotected conditions at the northern part of the WHPA.

Deep Excavation (Parking garages and basements for multi-story buildings)	**Assumptions**	▪ Not considered	▪ Not considered	▪ Another consideration during the vulnerability increase interpretation is related to the cut and fill of the ground surface for the installation of the industrial park. This cut and fill was carried out in two phases. The modification of the ground surface could result in increased vulnerability where it was cut and decreases in the filled areas. A map indicating the areas that were cut and filled is not available. According to the Jagger Hims (2004b) report, the cut and fill of the topography would not breach the overlying till sediments that partially protect the aquifer. However, the fact that the surface was modified has to be taken into account when determining the vulnerability. AECOM recommends that the whole WHPA be considered as moderate uncertainty in the vulnerability analysis, in order to account for the possible change to the vulnerability scoring of the areas.
	Criteria			
	Buffer			
	Comments			
	Criteria			
	Buffer			
	Comments			

D3.3 METHODOLOGY USED BY CTC SPR

The general factors that should be considered in the evaluation for the need for an adjustment are described in **Section D3.2.1**, and guidance documents 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 *(Technical Rule (41)).*

D3.3.1 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. **Oak Ridges Moraine Groundwater Program (formerly YPDT) database:** to identify other types of boreholes (oil and gas and geotechnical boreholes). This database includes the WWIS records but has also records from the MNDM-OGS and other agencies and covers the CTC area. A more complete inventory was possible with a review of this dataset. As well, this dataset identifies the aquifer associated with the well intakes;
3. **MNRF:** pits and quarries data. In order to determine whether these facilities constitute an anthropogenic pathway, details such as excavation depth and maximum permit excavation depth, stratigraphy encountered, and water levels were examined; and
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.

D3.3.2 Detailed Considerations of Pathways

Pits and Quarries

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

Full jurisdiction vulnerability/ HVA Delineation

The 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)*.

WHPA

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.

D3.3.3 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. The 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 the 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). The vulnerability was increased in one category.

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

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

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

D3.3.4 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

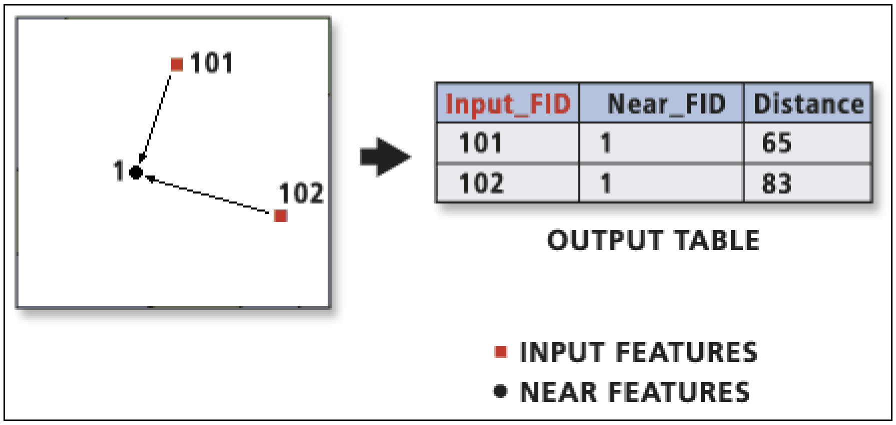
- The age of the boreholes as staff believes that there is no direct correlation between the age of the borehole and its impact as a potential pathway. Additionally, a new properly constructed borehole could become a pathway in the future; and
- Municipal and monitoring wells as preferential pathways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

Clustered Boreholes

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

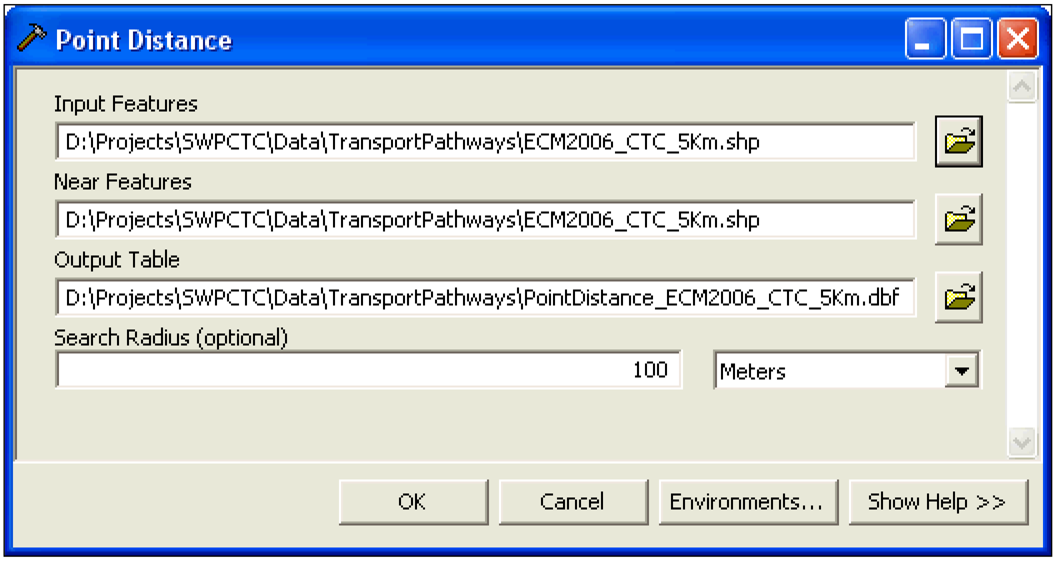
This approach determines the distances between point features.



Input_FID	Near_FID	Distance
101	1	65
102	1	83

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 increasing the vulnerability by one category.



Input Features
D:\Projects\SWPCTC\Data\TransportPathways\ECM2006_CTC_5Km.shp
Near Features
D:\Projects\SWPCTC\Data\TransportPathways\ECM2006_CTC_5Km.shp
Output Table
D:\Projects\SWPCTC\Data\TransportPathways\PointDistance_ECM2006_CTC_5Km.dbf
Search Radius (optional)
100 Meters

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 the 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.

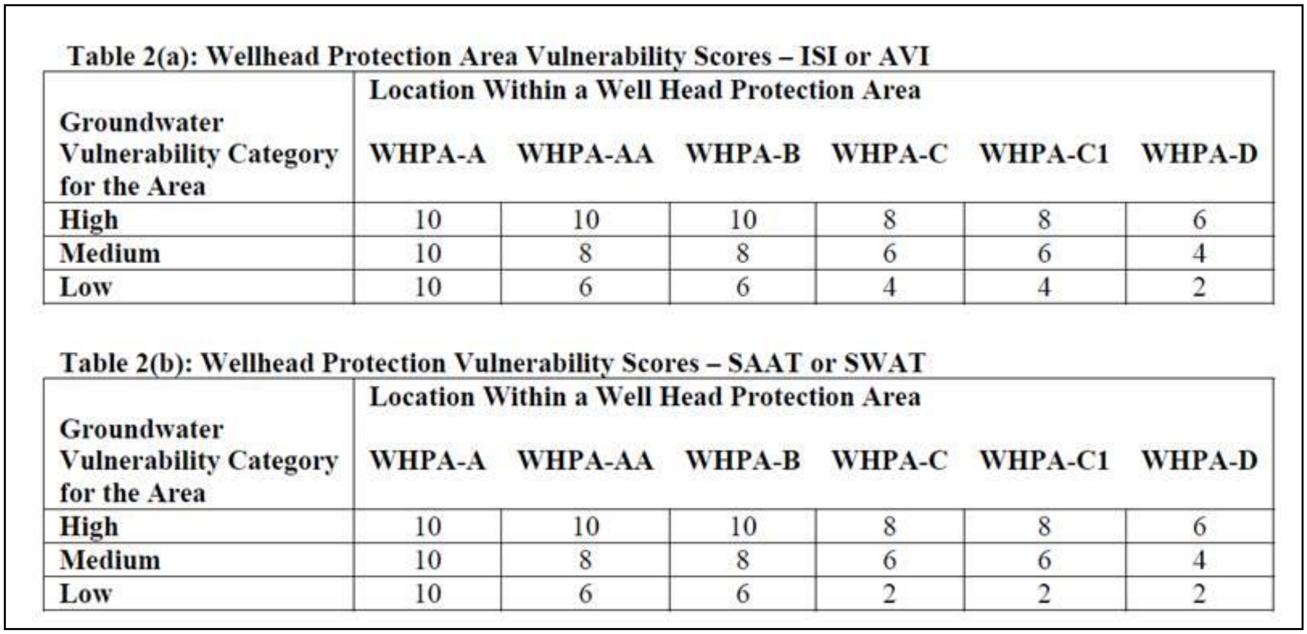


Table 2(a): Wellhead Protection Area Vulnerability Scores – ISI or AVI

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, 2009 (Rule (83))*

D3.4 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.

D3.4.1 High Vulnerability Aquifer (HVA)

Figure D3-2 shows the CTC - High Vulnerability Aquifer without Pathways adjustment (2010), **Figure D3-3** shows the High Vulnerability Aquifer Differences (Pit/quarries and Clusters boreholes) 2011, and **Figure D3-4** shows the High Vulnerability Aquifer Differences (only Pit/quarries) 2011. **Table D3-5** and **Table D3-6** present 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 through 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 D3-4**).

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

Table D3-5: 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	542,830,000	1,860,000	0.34
TRSPA	1,080,340,000	1,083,720,000	3,380,000	0.31
CLOSPA	301,880,000	303,320,000	1,440,000	0.48
CTC	1,923,190,000	1,929,870,000	6,680000	0.35

Table D3-6: Increase in HVA Areas with Pathways Adjustment for Pits and Quarries Only (2011)

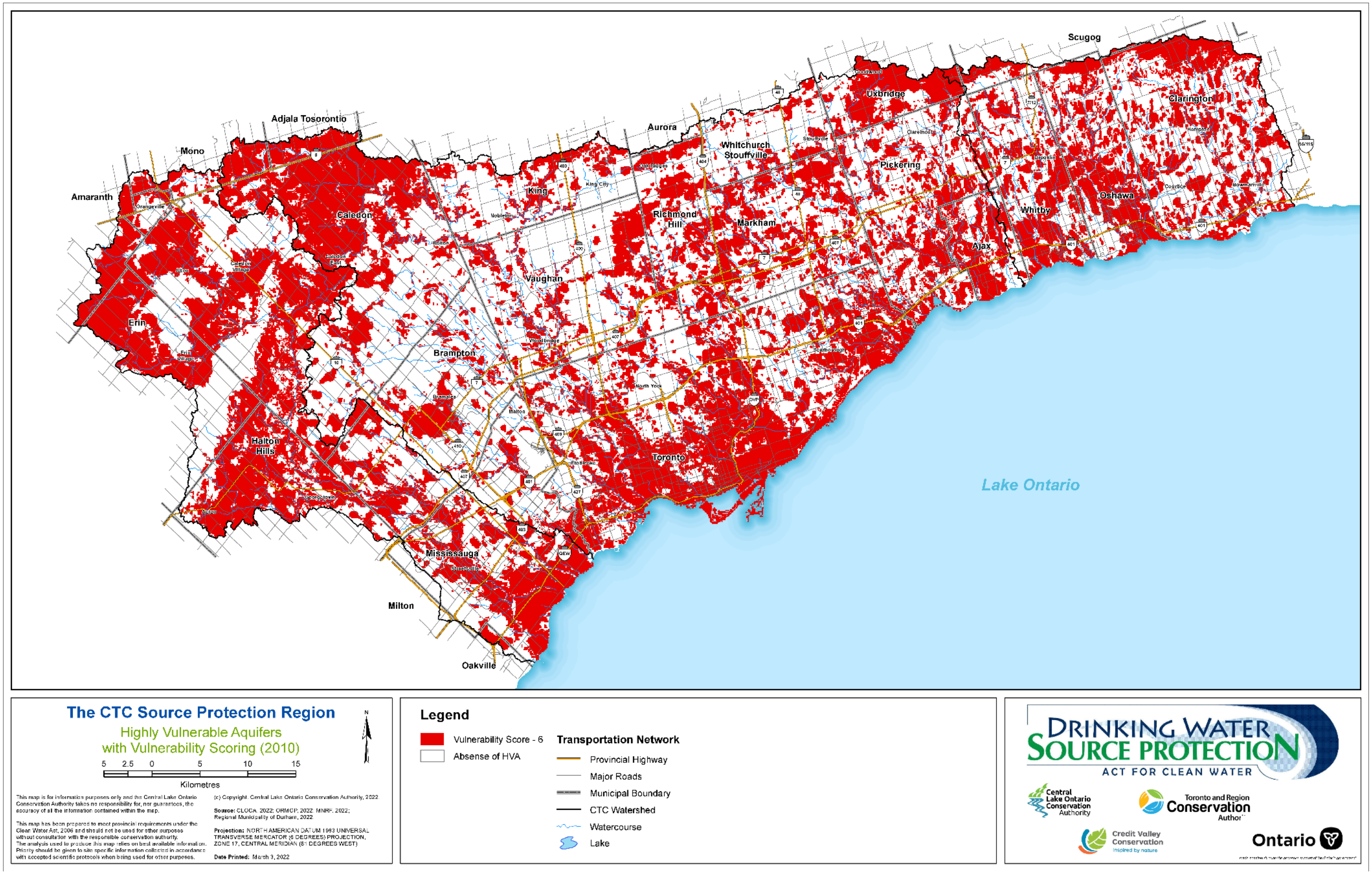


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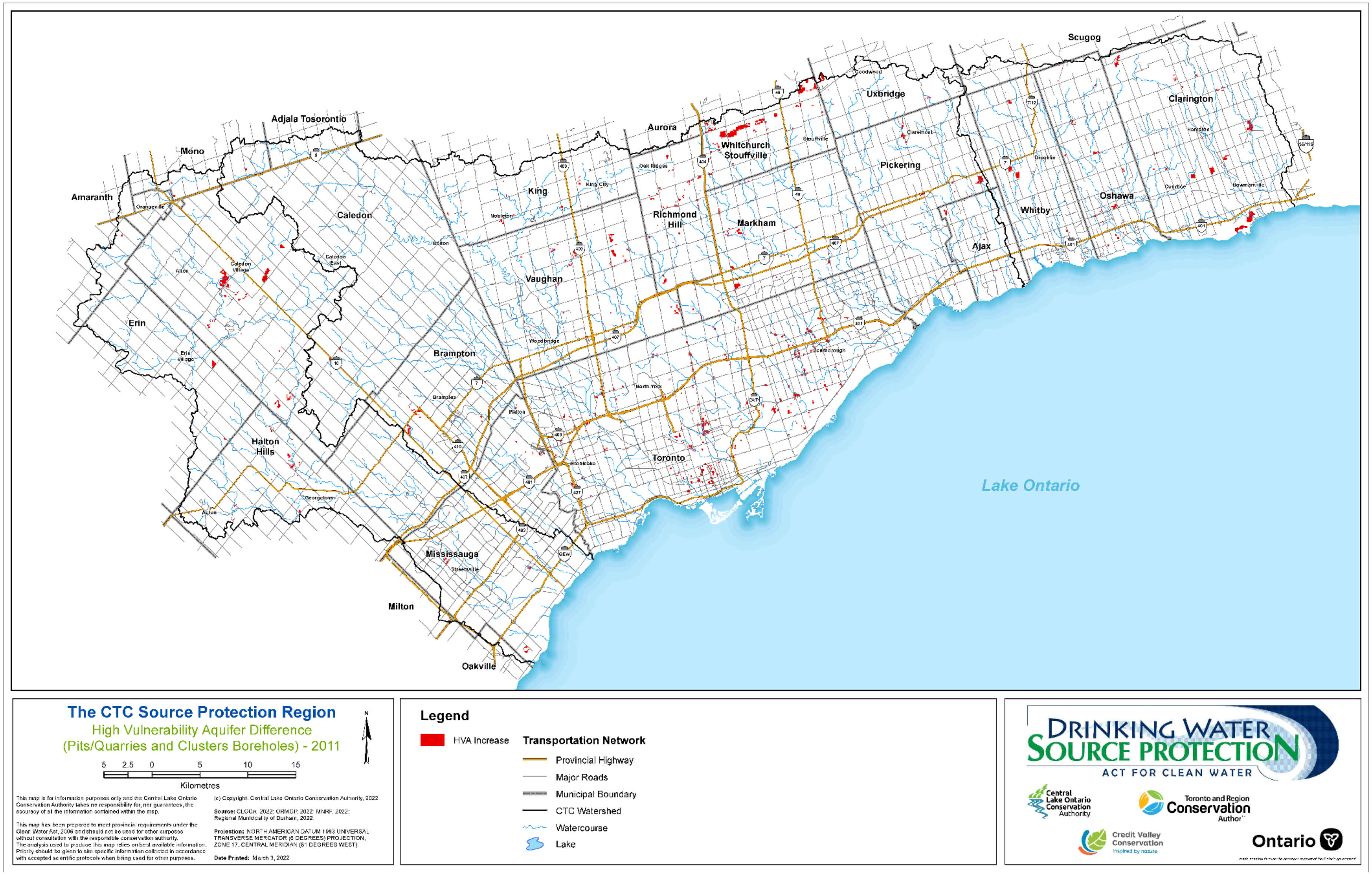
Figure D3-2: CTC - High Vulnerability Aquifer with Vulnerability Scoring (without Pathways Adjustment, 2010)



The CTC Source Protection Region
High Vulnerability Aquifer Difference
(Pits/Quarries and Clusters Boreholes) - 2011

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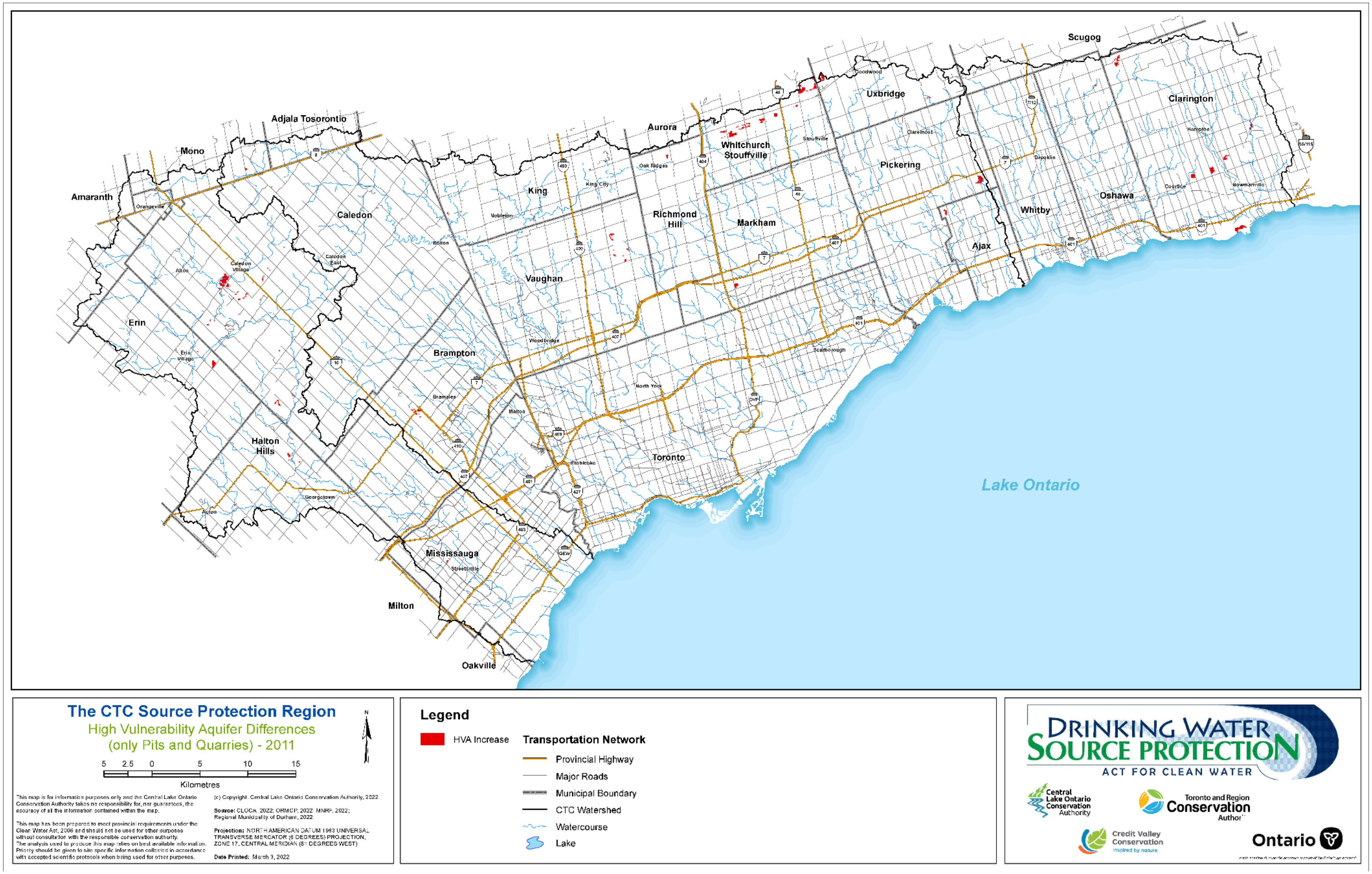
Figure D3-3: CTC Differences between Old and New HVAs with Aggregate and Well Bumps (Pits/quarries and Clusters Boreholes, 2011)



The CTC Source Protection Region
High Vulnerability Aquifer Differences
(only Pits and Quarries) - 2011

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Figure D3-4: CTC Differences between Old and New HVAs with Aggregate Bump (only Pit/quarries, 2011)

D3.4.2 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 D3-5** to **Figure D3-9**) 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. The increase in vulnerability within Whitchurch-Stouffville is minor (4.59 % or 291,607 m^2 – **Figure D3-9**).

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. The increase in vulnerability within Inglewood afforded by the borehole clusters was minor (2.34 % or 66,773 m^2 - see **Figure D3-10**)

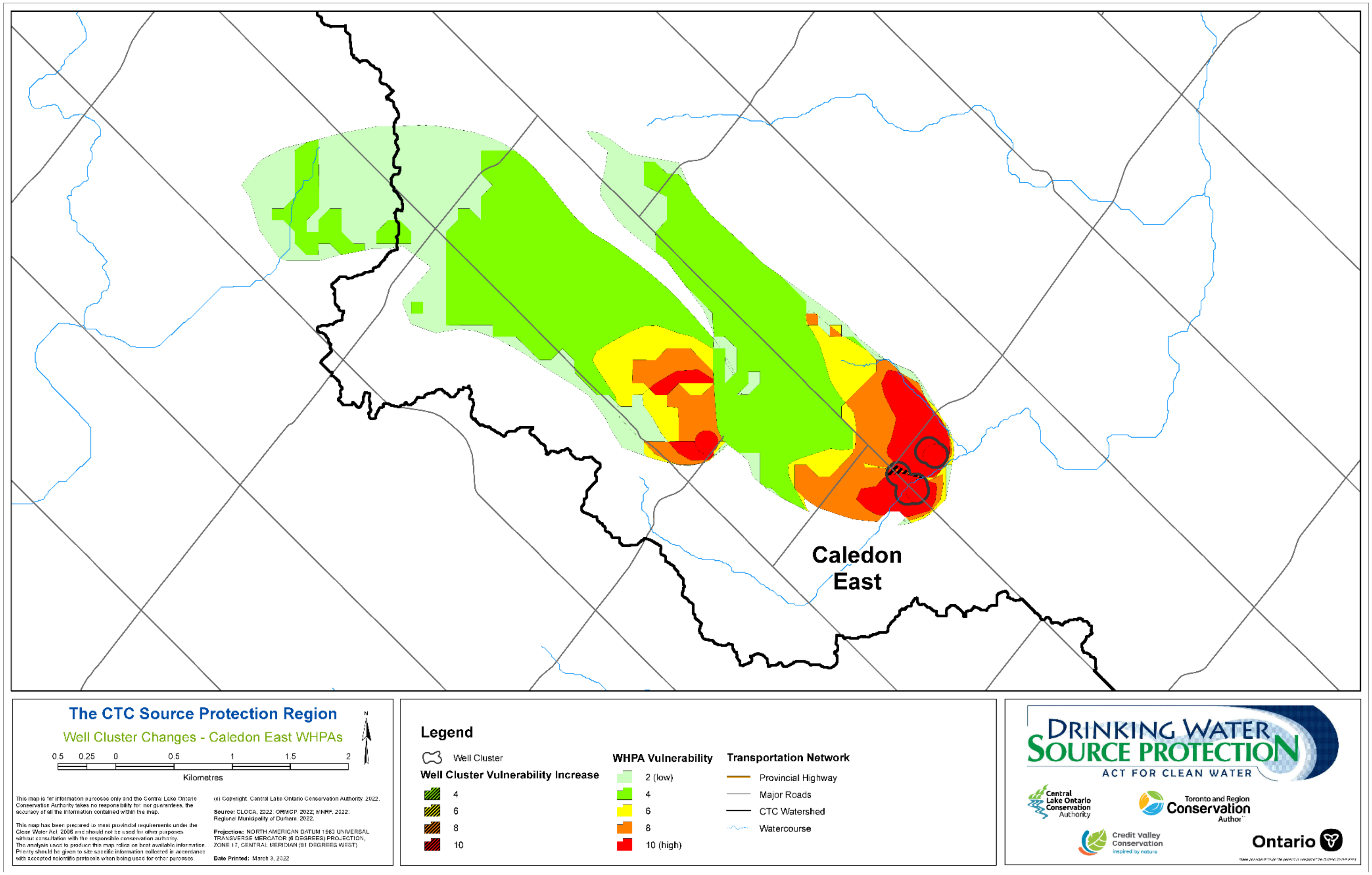

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Figure D3-5: CTC Well Cluster Changes - Caledon East (TRSPA-Peel)

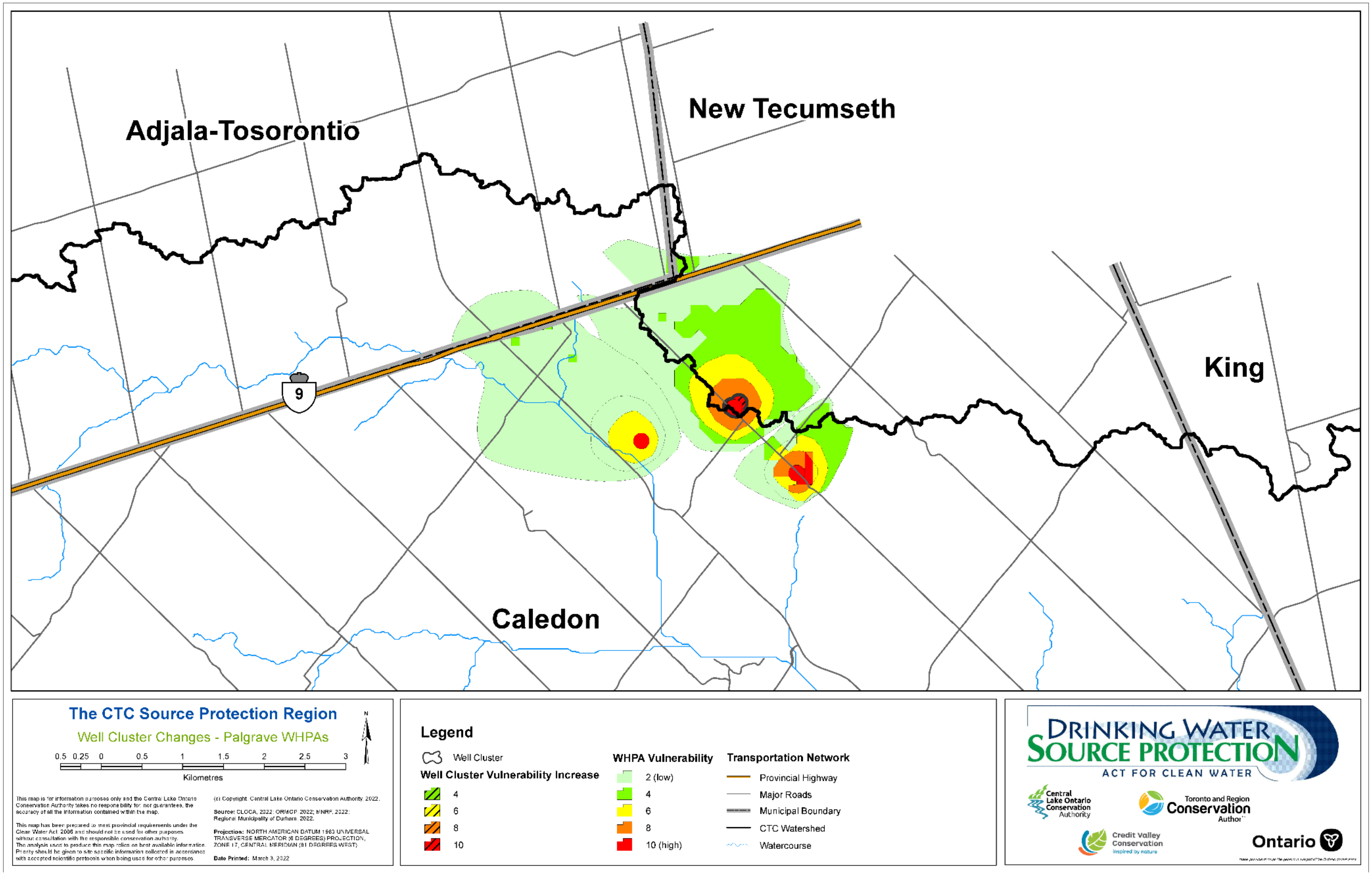

Figure D3-6: CTC Well Cluster Changes - Palgrave WHPAs (TRSPA-Peel)

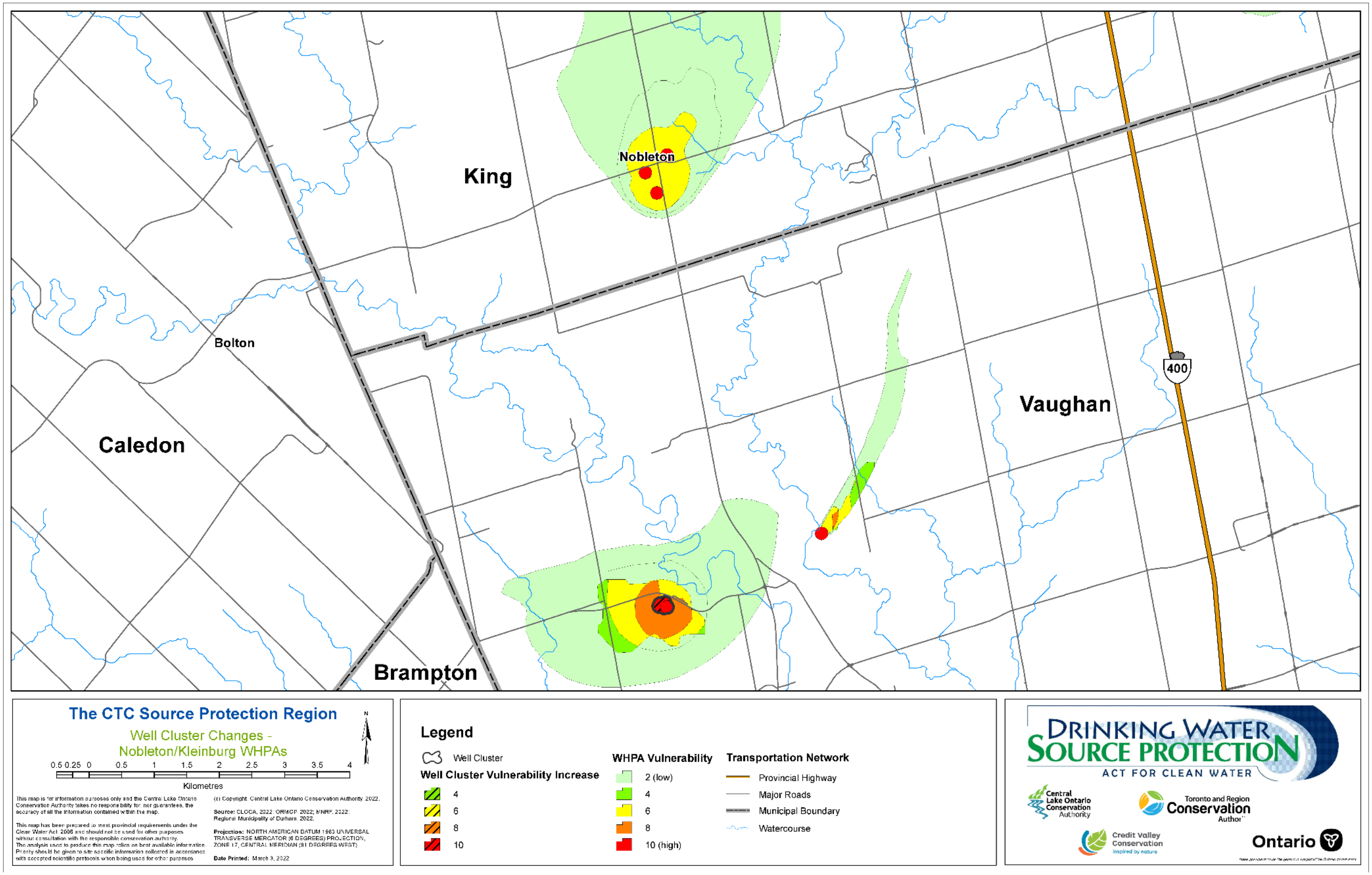

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Figure D3-7: CTC Well Cluster Changes Nobleton/ Kleinburg WHPAs (TRSPA-York)

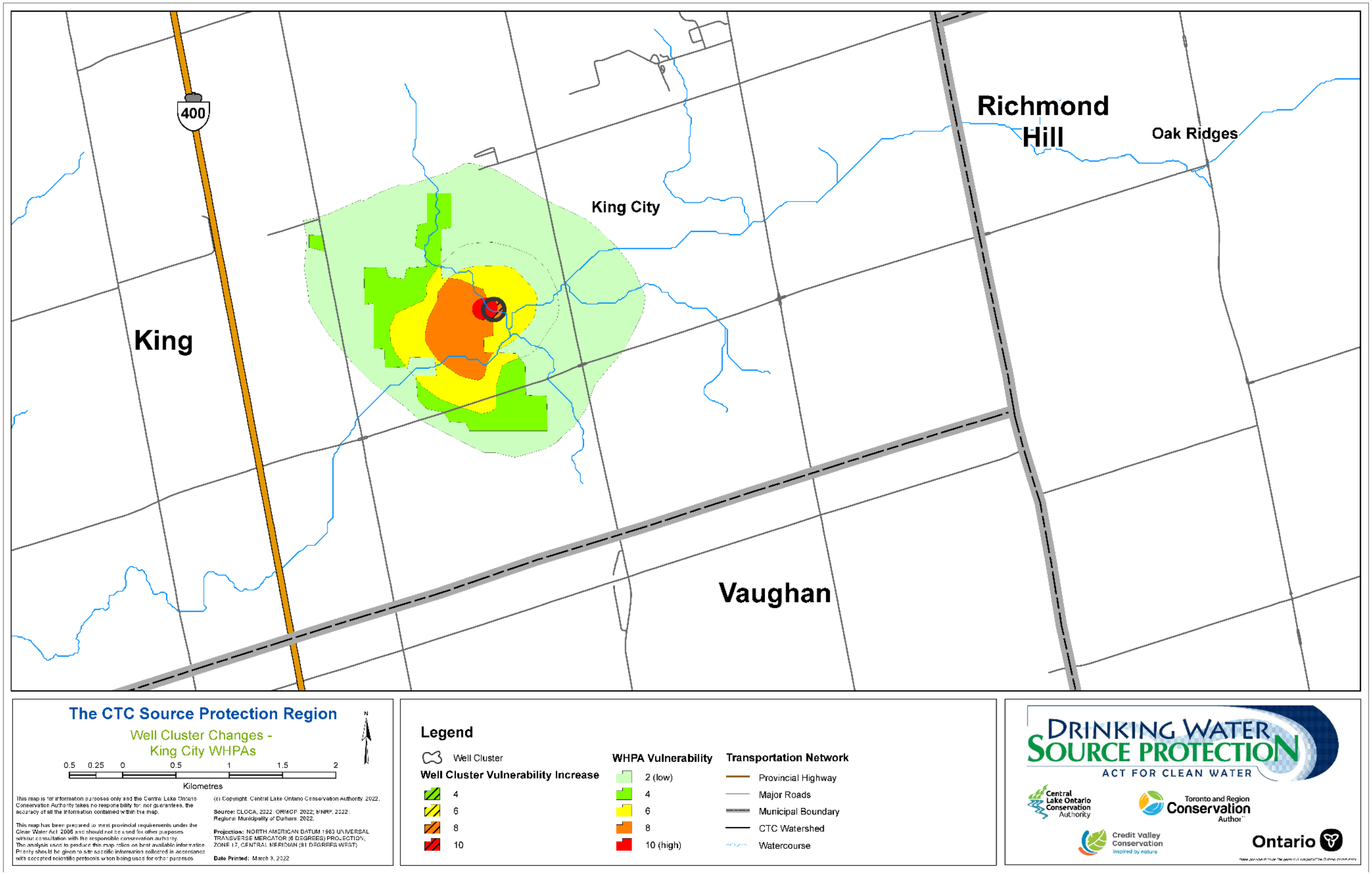

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Figure D3-8: CTC Well Cluster Changes - King City WHPAs (TRSPA-Yor

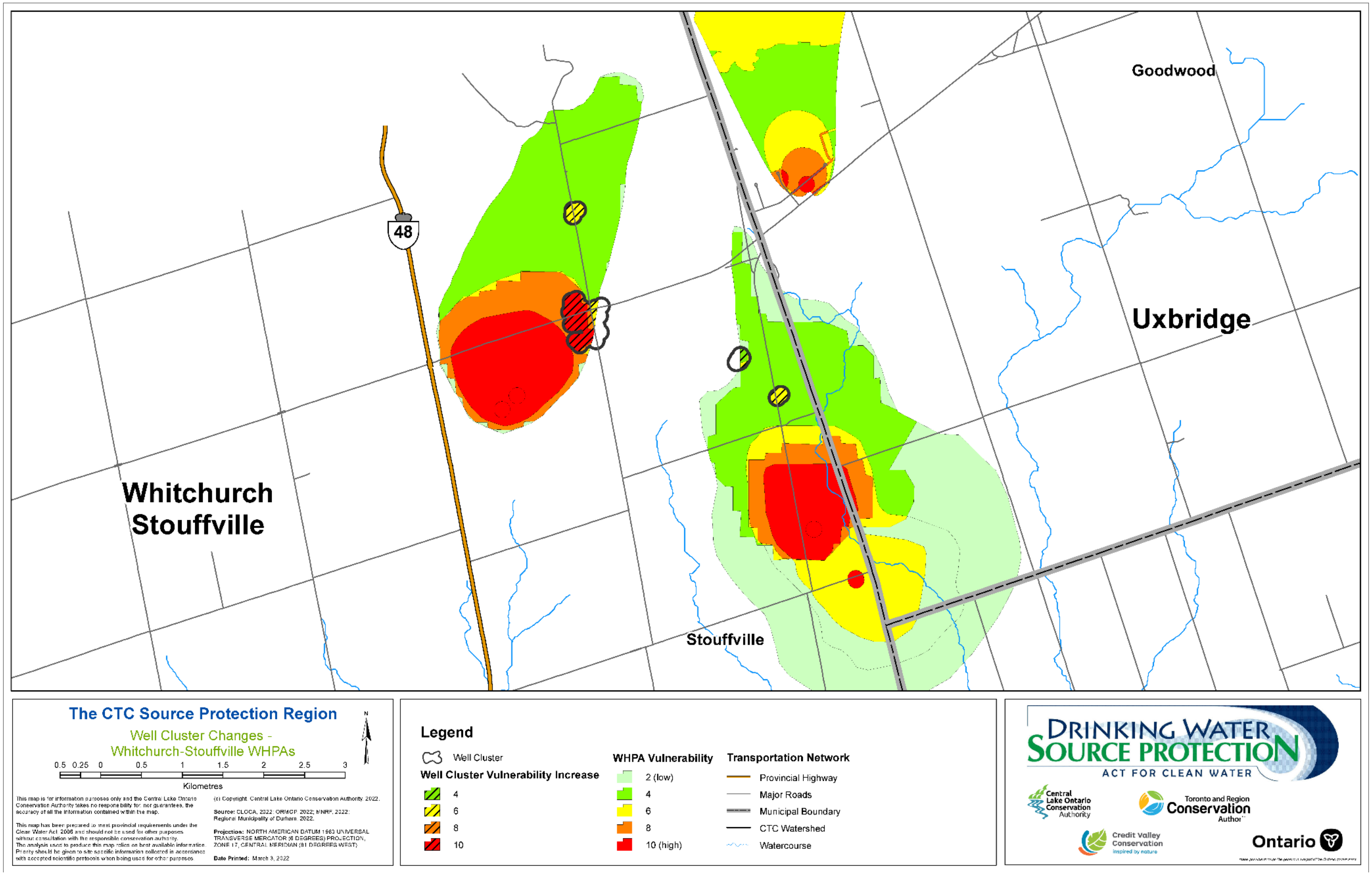

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Figure D3-9: CTC Well Cluster Changes - Whitchurch-Stouffville WHPAs (TRSPA-York)

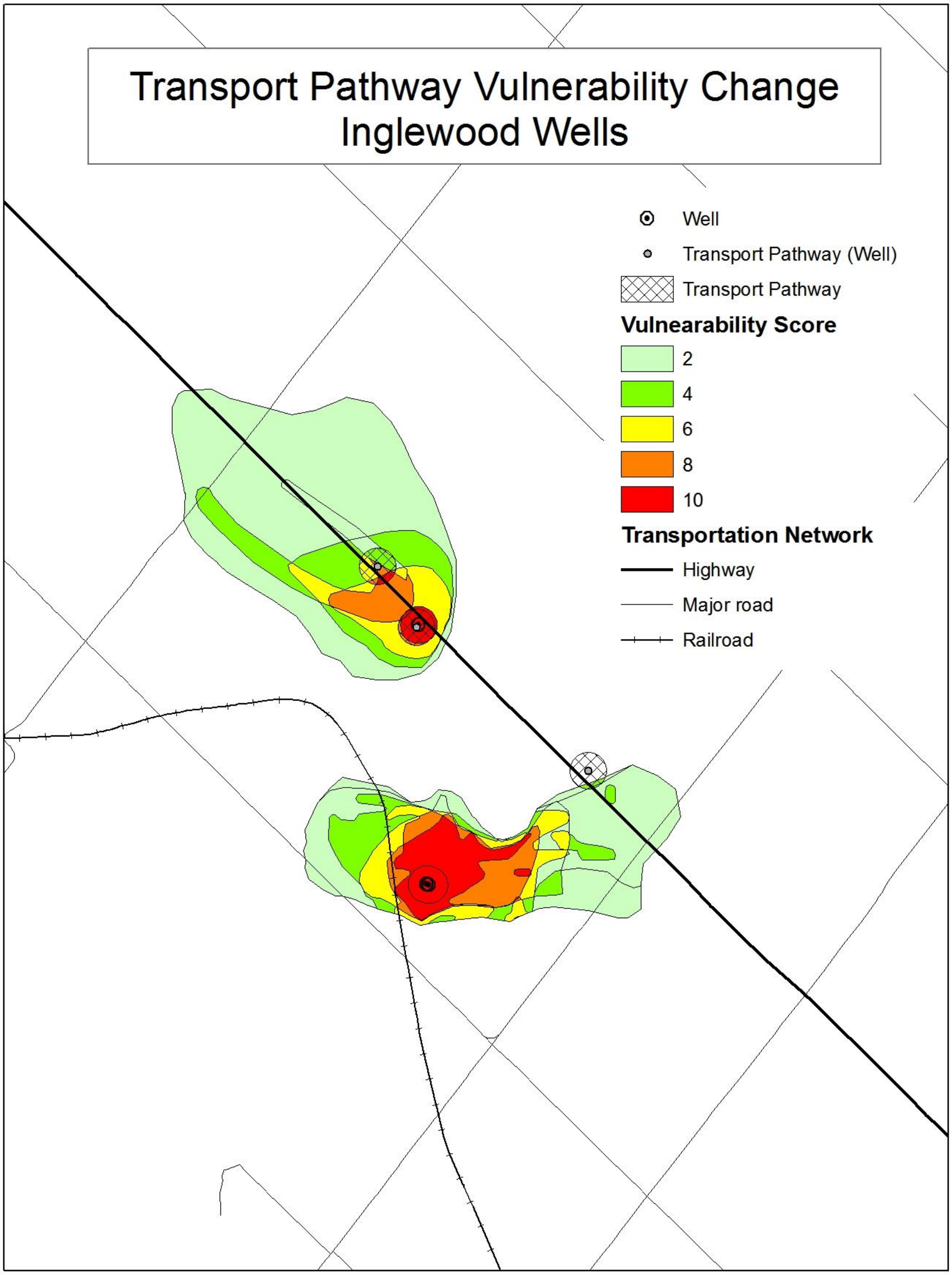

Figure D3-10: Borehole Cluster Changes Inglewood (CVSPA-Peel)

D.3.4.3 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 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.

D3.4.4 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;
- The inherent uncertainty in the geologic models to assign boreholes to the aquifer formation;
- Engineering solutions may not be considered;
- The 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; and
- Ground-truthing (out of scope for this study).

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 the most vulnerable areas. In doing so, many components are utilized that each individually has 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.

D3.5 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 D-20**). 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 D21**).

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 D3-11** to **Figure D3-13**.

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 believe 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.

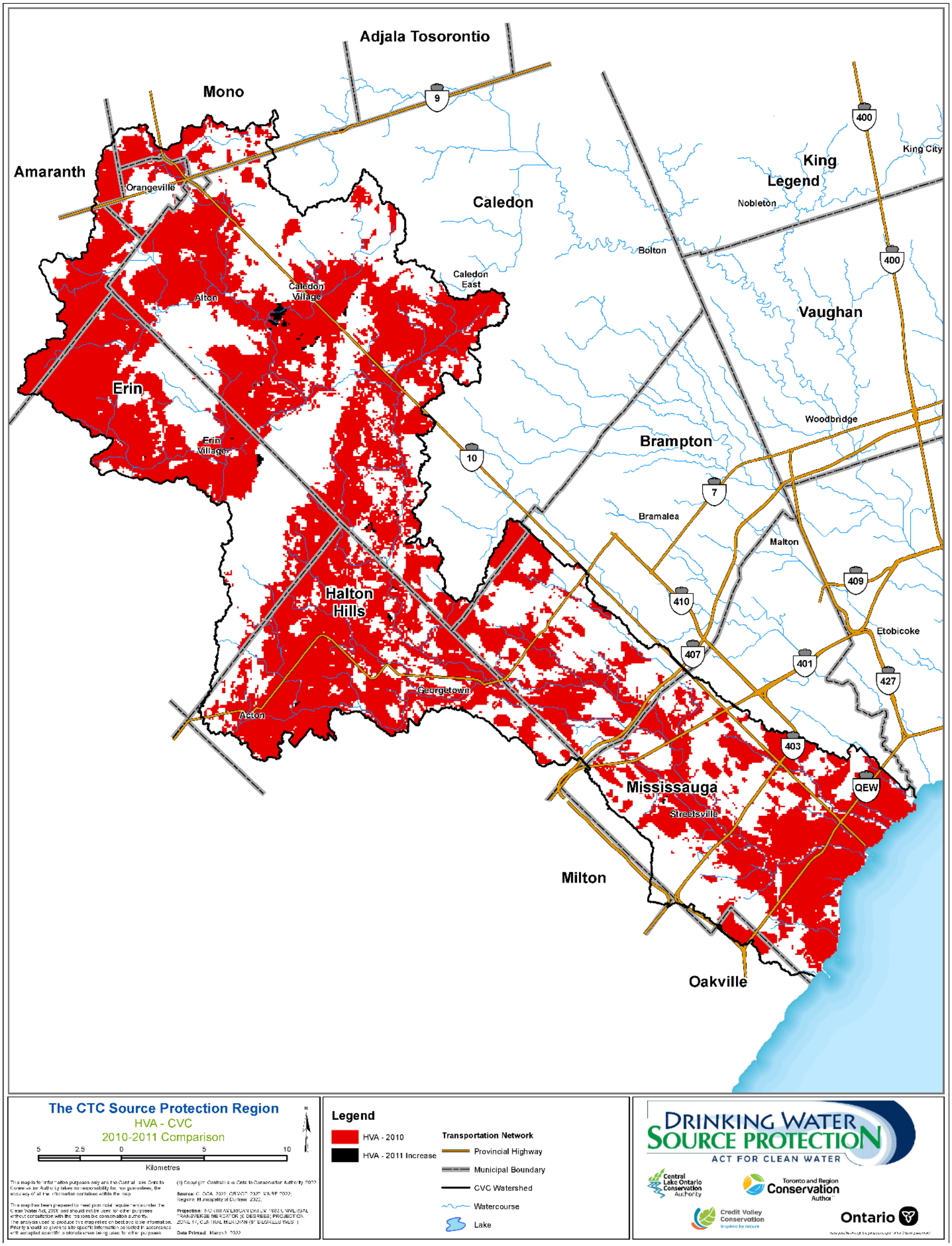

Figure D3-11: CVSPA - High Vulnerability Aquifer Comparison 2010-2011 (Pits/quarries)

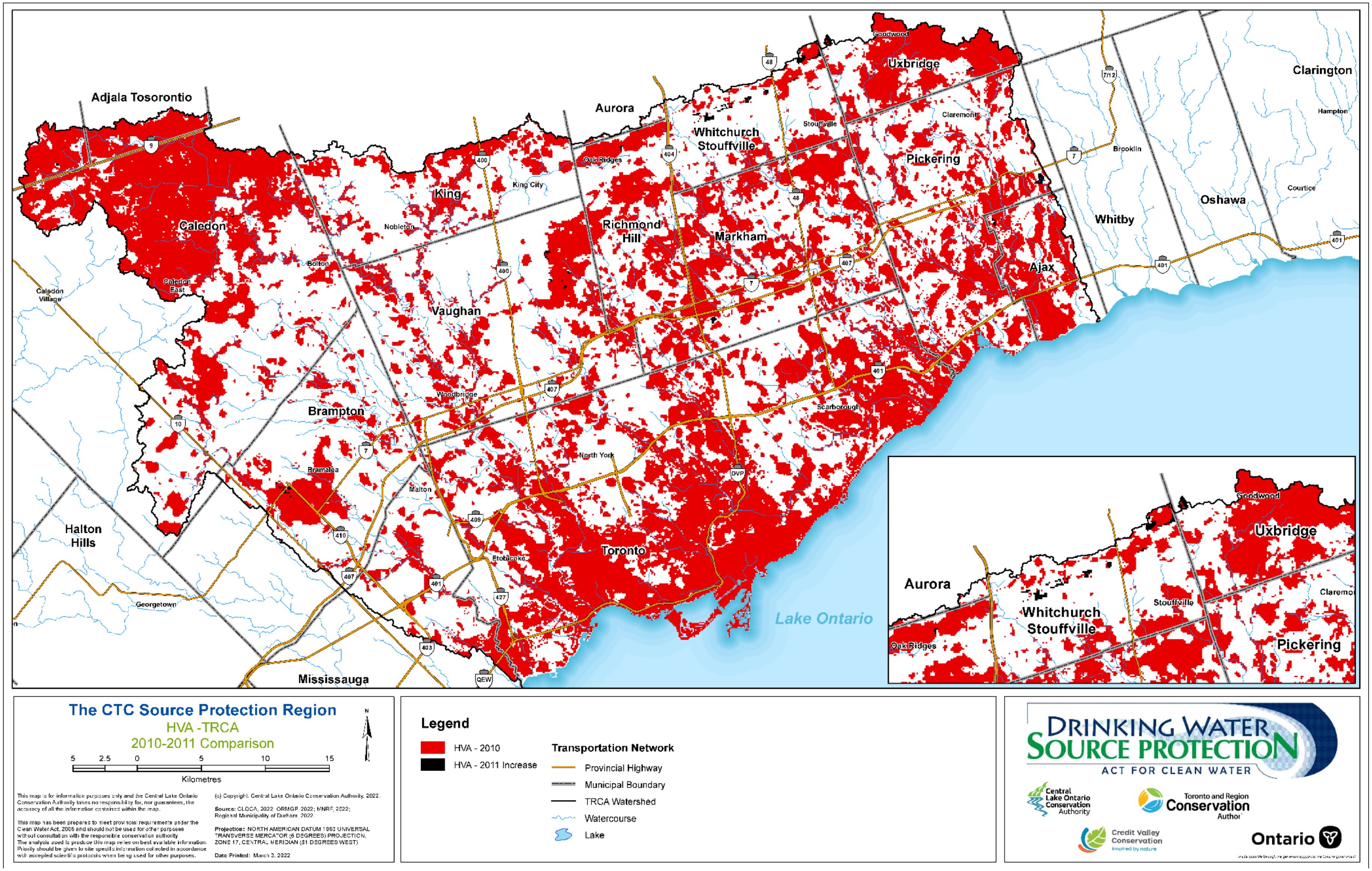

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Figure D3-12: TRSPA - High Vulnerability Aquifer Comparison 2010-2011 (Pits/quarries)

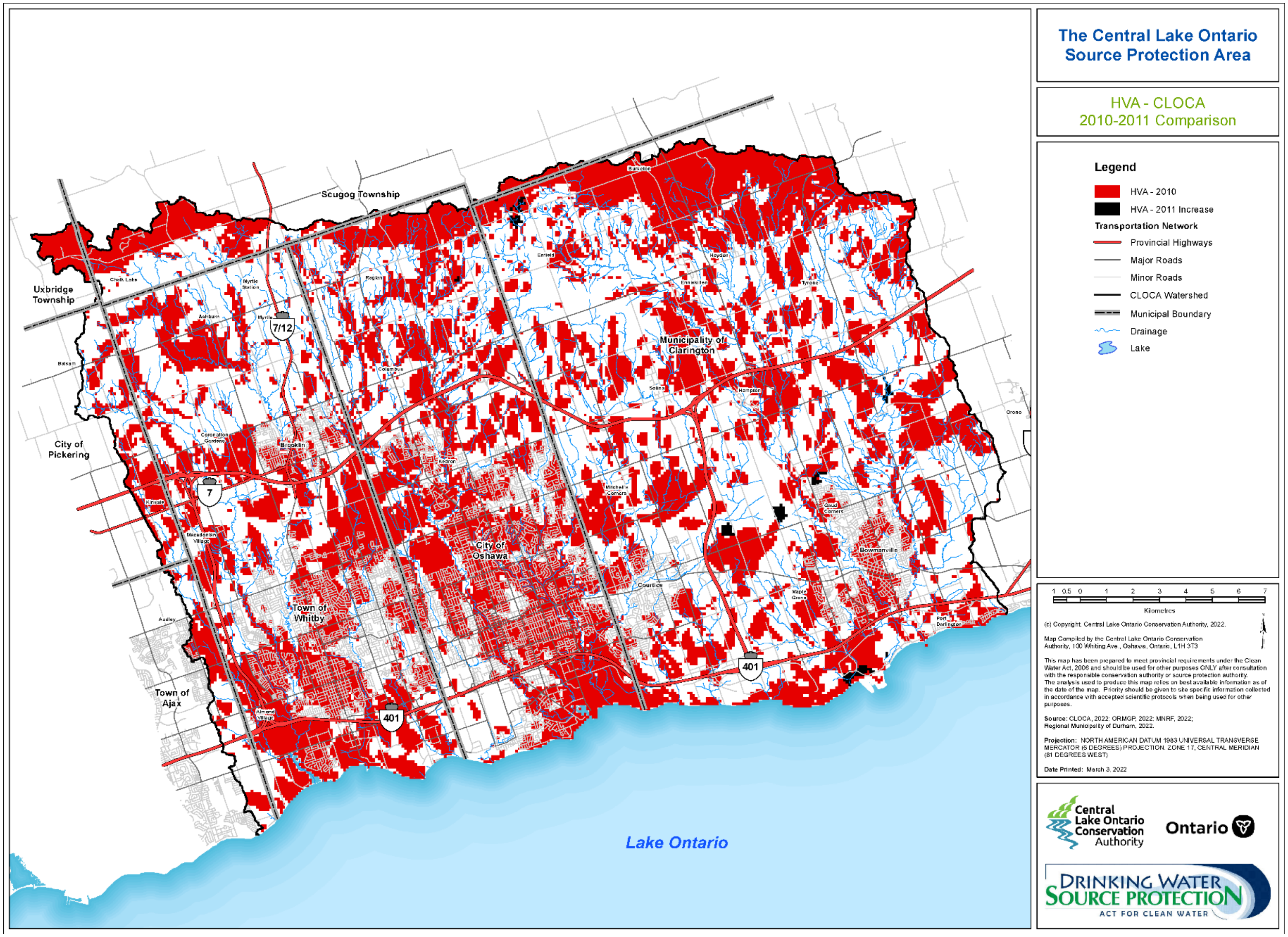

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Figure D3-13: CLOSPA - High Vulnerability Aquifer Comparison 2010-2011 (Pits/quarries)

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