FIGURES

TABLES

4.0 ASSESSING VULNERABILITY OF DRINKING WATER SOURCES

In the Credit Valley Source Protection Area (CVSPA) municipal drinking water supplies are drawn from groundwater and Lake Ontario sources. As documented in **Chapter 2**, approximately 89% of residents within the CVSPA receive their drinking water from Lake Ontario after treatment in municipal plants. The remaining 11% of residents rely on municipally operated groundwater-based drinking water systems (estimated 83,000 residents) or private wells using groundwater as their drinking water source (estimated 33,000 residents).

Under the *Clean Water Act, 2006* (CWA), all sources of drinking water must be assessed for vulnerability. Surface water and groundwater that is used for drinking may be naturally vulnerable to depletion (a reduction in quantity), and/or contamination (a reduction in quality). The Director's Technical Rules outline the legislated content for assessment reports across Ontario. The *Technical Rules* were initially posted on the MOECC's website in December 2008 and further amended in November 2009 and 2017. Amendments to the Credit Valley Assessment Report resulting in versions 3.0 and 4.0 were made using the 2017 Director's Technical Rules and Tables of Drinking Water Threats. Sections of the Assessment Report that were not updated as part of those amendments refer to the 2009 edition of the Director's Technical Rules and Tables of Drinking Water Threats. The *Technical Rules* require that the source protection committees (SPC) identify four types of vulnerable areas within each source protection area (SPA). These vulnerable areas include:

- Wellhead Protection Areas (WHPAs);
- Highly Vulnerable Aquifers (HVAs);
- Significant Groundwater Recharge Areas (SGRAs); and
- Intake Protection Zones (IPZs).

Once vulnerable sources are identified, they are assessed and assigned a vulnerability score of high, medium, or low. The faster a contaminant can travel to a well or intake without being diluted or rendered less harmful, the more vulnerable the source water. The vulnerability scores are determined by factors such as:

- How deep/thick the aquifer is;
- What types of soil are present;
- How quickly water can travel through the ground (time of travel); and
- How fast a contaminant can travel to an intake given run-off patterns and surface water conditions.

Typically, shallow aquifers at or near the ground surface are considered vulnerable. Deeper aquifers, which are often the source of municipal drinking water supplies, tend to be less vulnerable. Under the *CWA*, vulnerability assessment of municipal wells, where they exist, entails more detailed well-specific analyses. Surface water intakes in rivers and small lakes are more vulnerable than those in the Great Lakes which are located further from shore and in deeper water.

Man-made transport pathways are also considered, such as pits, quarries, mines, road cuts, ditches, storm water, pipelines, sewers, and poorly constructed wells. These pathways can bypass the natural system, resulting in faster pathways to intakes. If any of these constructed pathways exist in a water source, the vulnerability score increases by one or two steps (i.e., from low to medium, from medium to high, or from low to high). The decision to increase the vulnerability score should be supported by data and is subject to professional judgment.

An uncertainty assessment is also required as part of the analysis. This assessment shows whether information gaps exist and identifies ways that the science behind the vulnerability assessment could be improved. Continuous improvement is expected in the areas with the greatest risk and/or uncertainty.

In source protection areas, vulnerability scores are used to evaluate and determine risk in the next step, i.e., drinking water threats related to water quantity or/and quality would be rated significant, moderate, or low (see **Chapter 5**). In **Chapter 5**, the natural vulnerability of an area is considered along with specific contaminants to determine risk, as contaminant behaviour varies based on surrounding environmental factors. The threat score (risk) takes these factors into account.

Under the Source Water Protection initiative, the following groundwater-based source water protection areas must be delineated, where they exist, and where appropriate, scored for vulnerability in terms of water quality:

- All areas within the jurisdiction that are naturally vulnerable to contamination (as opposed to supply depletion) are designated as HVAs;
- Areas with heightened importance to groundwater recharge are designated as SGRAs; and
- The specific capture zones for the municipal drinking water wells are designated WHPAs.

In the CVSPA, areas of high and medium vulnerability generally correspond to shallow unconfined aquifers associated with:

- Surficial stratified sediments;
- Upper aquifers largely comprised of ice-contact drift, Oak Ridges Moraine/Mackinaw Interstadial equivalent;
- Lower sediments (Thorncliffe equivalent, Sunnybrook equivalent, Scarborough Sands equivalent);
- The Amabel Formation (bedrock aquifer); and
- Weathered bedrock (upper 3 - 5 m of weathered bedrock outside valleys).

The areas that are low vulnerability are:

- Upper Till (Halton Till); and
- Intermediate Till (Port Stanley, Tavistock & Northern Tills).

The vulnerability of drinking water to water quantity depletion is assessed under the water budget component of this report. The results of the Aquifer Vulnerability Index (AVI) are used in the delineation and vulnerability scoring of HVAs.

4.1 GROUNDWATER VULNERABILITY ANALYSIS – HIGHLY VULNERABLE AQUIFER (HVA) AND SIGNIFICANT GROUNDWATER RECHARGE AREA (SGRA)

4.1.1 Groundwater Vulnerability Assessment

Most groundwater vulnerability assessments focus on estimating how hydrologic features let water particles move down through the ground to an aquifer. There are several ways to estimate the flow attributes of hydrologic features. The groundwater vulnerability as delineated in accordance with *Technical Rules (37 or 38) (Part IV)* take into account the best available understanding of the natural geological layers in relation to delineated aquifers.

The following approaches are outlined in the *Technical Rules* (2009):

- Aquifer Vulnerability Index (AVI)—This index value is based on mapping products (e.g., depth to aquifer, soil type and thickness, etc.). It measures the relative amount of protection provided by the type of materials above the aquifer.
- Intrinsic Susceptibility Index (ISI)—An index value is given to each well (e.g., MOECC Water Well Information System (WWIS). This information is used to produce a vulnerability map. Unlike AVI, this method takes into account water table or water level information that is captured in the WWIS records.
- Surface to Aquifer Advection Time (SAAT)—This is the travel time from the ground surface to the top of aquifer or water table.
- Surface to Well Advection Time (SWAT)—This is the travel time from the ground surface to the well intake.

MOECC Water Well Information System (WWIS): A database of geology, water levels, and pumping capacity from water wells installed across Ontario, maintained by the MECP.

The Province endorses all of the above approaches for assessing the vulnerability of water sources. Many factors determine the best approach to use, including data/model availability, level of understanding, and system complexity. These approaches are described in more detail in **Appendix D**.

The vulnerability of drinking water to water quantity depletion is assessed under the water budget component (**Chapter 3**) of this Assessment Report. The results of the AVI are used in the delineation and vulnerability scoring of HVAs.

The CVSPA has selected an advanced AVI approach to delineate HVAs and SGRAs. This approach uses the interpreted products of geological and numerical models (three dimensional geologic layers) produced for the study area, rather than the raw data available in the provincial *WWIS*. Estimates of vertical and horizontal flow directions and flux are also considered. This advanced AVI approach is approved by the Province. A more detailed description of the methodology used to delineate the HVAs is presented in **Appendix D**.

The AVI method produces a numerical index representing the relative vulnerability of an aquifer, based on the type and thickness of the soil above. The index quantifies the natural vulnerability of aquifers to sources of contamination at or near the surface, and through a translation process, categorizes groundwater vulnerability as high, medium, or low, as shown in **Table 4.1**, and **Figure 4.1**. Within HVAs, the groundwater vulnerability is then converted (per *Technical Rules 82-85*) into a vulnerability score, and this score provides the ultimate expression of the groundwater vulnerability. Each aquifer is scored separately. The vulnerability scores of deeper aquifers take into account the protection afforded by overlying materials (aquifers and aquitards).

Table 4.1: Translation of Groundwater Vulnerability to Vulnerability Score

Groundwater Vulnerability	Vulnerability Score
High	6
Medium	4
Low	2

This chapter considers factors affecting the vulnerability of a source protection area, as well as man-made transport pathways (where the data are available) using a consistent and systematic approach. *Technical Rules 39-41 (Part IV)* provide an opportunity to consider situations where man-made or anthropogenic influences can increase the natural vulnerability by decreasing the time required for contaminants to move down to the water supply aquifer. The vulnerability can be increased from medium to high, low to medium, or from low to high in accordance with the potential for artificial transport pathways to increase the observed vulnerability. Under the *Technical Rules*, the vulnerability cannot be increased beyond high.

4.1.2 Highly Vulnerable Aquifer (HVA) and Vulnerability Scoring

This analysis assumes that the vulnerability of the aquifer increases as the relative amount of protection provided by the overlying geological materials decreases. The type and thickness of the overlying material is crucial to the scoring.

According to the AVI methodology and *Technical Rule* (38) and *(43)*, an area with vulnerability score of 6 has a 'high' groundwater vulnerability and is therefore an HVA, as shown on **Table 4.1**. This analysis assumes that the vulnerability of the aquifer increases as the relative amount of protection provided by the overlying geological materials decreases. The type and thickness of the overlying material is crucial to the scoring. The vulnerability scores of deeper aquifers take into account the protection afforded by overlying materials (aquifers and aquitards).

Figure 4.1 shows the groundwater vulnerability utilizing the AVI methodology and including the transport pathways assessment. The CVSPA HVA map, **Figure 4.2** shows the vulnerability of all aquifers (shallow and deep) that have a vulnerability score of 6 (high). These areas represent about 65% of the land area within the CVSPA.

Based on the analyses undertaken, HVAs are primarily found in the following areas of the CVSPA:

- In the northwest (Erin and environs), where coarse grained stratified drift is extensive;
- Northwards into Orangeville, and eastwards where the Amabel Formation is at or near the ground surface;
- Along the base of the Niagara Escarpment, where the Halton Till is highly weathered, thin or absent and affords little protection to the underlying sediments of the upper aquifer; and
- Along the Credit River near and along the eastern boundary of the CVSPA, where the Halton Till is likewise weathered, thin or absent.

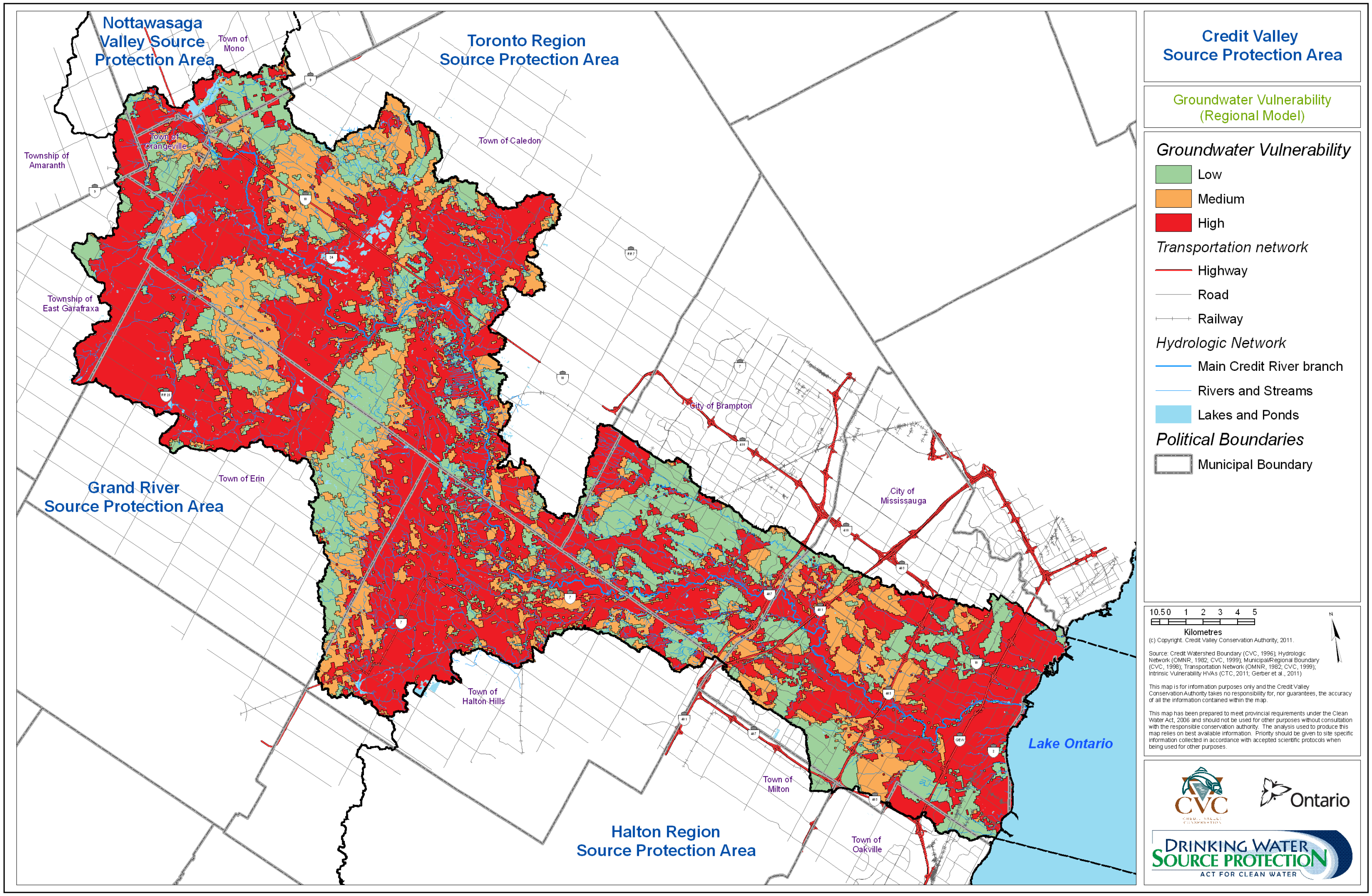

Figure 4.1: Groundwater Vulnerability (Regional Model)

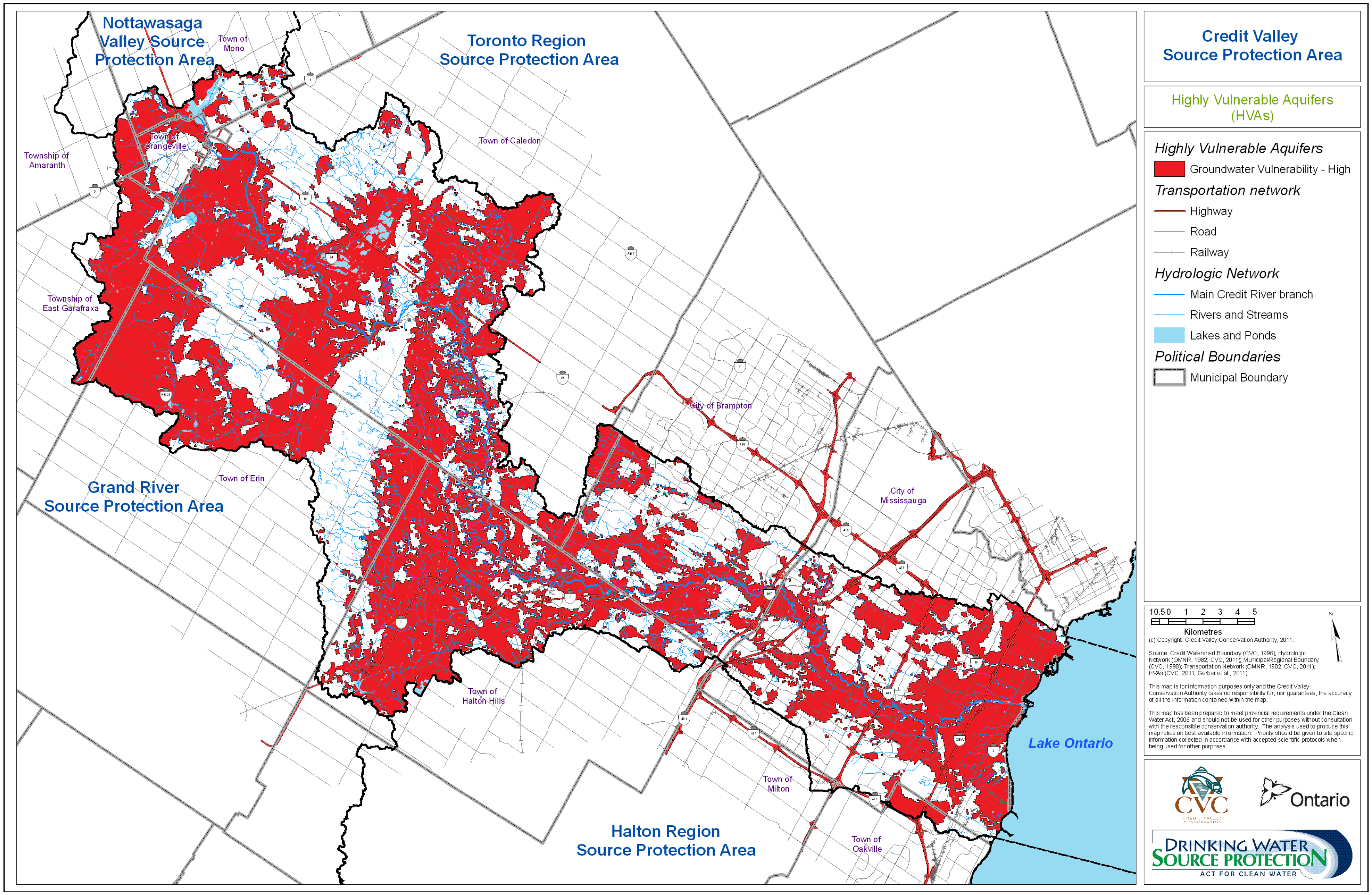

Figure 4.2: Highly Vulnerable Aquifers (HVAs)

4.1.3 Significant Groundwater Recharge Areas (SGRAs) Delineation

The land area where the rain or snow seeps down into the ground and flows to an aquifer is called a recharge area. Recharge areas often have loose or permeable soil, such as sand or gravel, which allows the water to seep easily into the ground. Areas of bedrock without much covering soil, and where a lot of fractures or cracks exist, are also often recharge areas. Areas of hummocky topography also tend to have increased recharge rates. These areas are delineated using the recharge results from the water budget process described in **Chapter 3** of this Assessment Report. The areas with the highest volumes of groundwater recharge linked to drinking water systems, including private wells, are SGRAs. The SGRAs must be delineated and protected under the *CWA.*

SGRAs are identified by measuring and comparing the volumes of water that infiltrate the ground across a watershed. In CVSPA, SGRAs were located using the Finite Element Flow (FeFLOW) model results, based on the annual average recharge over a 25 m^2 grid covering the area.

There are two ways to identify SGRAs, as outlined in the *Technical Rule (44)*:

- *44 (1): If the area annually recharges water to the underlying aquifer at a rate that is greater than rate of recharge across the whole of the related groundwater recharge area by a factor of 1.15 or more*; or
- *44 (2): If 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 (ET) for the whole groundwater recharge area from the annual precipitation for the whole groundwater recharge area*.

In CVSPA the approach outlined in Technical *Rule 44 (1)*, was selected. This approach and the rationale for selection are described in more detail in **Appendix D2**.

Three options were evaluated to derive the average annual recharge to calculate the SGRA threshold:

- Three-zone (upper, middle, and lower watershed zones of the CVSPA) recharge rates;
- Subwatershed-level recharge rates for each of the twenty-two subwatersheds in the CVSPA; and
- Recharge rates for entire watershed (full CVSPA physiographic boundary).

The jurisdictional average recharge of 200 millimeters per year (mm/yr.) was chosen as the most consistent and representative threshold, based on a review of the surface geology, stream temperature and groundwater discharge attributes. Backward particle tracking from areas of high discharge areas was also used to confirm the areas of significant recharge. The calculated SGRA threshold was therefore 230 mm/yr. Additional information on the options and analysis is provided in **Appendix D2**.

In total, SGRAs in CVSPA cover about 55% of the land area. The majority are delineated in areas at or above the Niagara Escarpment. SGRAs also exist in areas south of the escarpment, mainly in narrow corridors of the Credit River. Given the surficial geology and topography existing within these areas, the SGRAs appear to be logical and defensible.

The SGRA in Subwatershed 19 was further refined through local-scale analyses done as part of the Tier 3 Water Budget Study for the municipalities of Orangeville, Mono and Amaranth (see **Chapter 3.8**). The same recharge threshold of 230 mm/yr. was applied, using the refined calibration applied from the HSP-F model in this subwatershed. Further detail on the Tier 3 refinements to the SGRAs in Subwatershed 19, is given in **Appendix D2**.

The SGRA in Subwatersheds 10 and 11 were also further refined through local-scale analyses done as part of the Tier 3 Water Budget Study for the Region of Halton's wells serving the Town of Halton Hills (see **Chapter 3.8**). The same recharge threshold of 230 mm/yr. was applied, using the refined calibration applied from the MIKE SHE model in these subwatersheds. Further detail on the Tier 3 refinements to the SGRAs in Subwatersheds 10 and 11 is given in **Appendix D2**.

Clipping SGRAs

The jurisdictional identification of SGRAs was approved by the SPC. However, *Technical Rule* (*45)* requires that "an area shall NOT be delineated as a SGRA 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". This includes private systems (O. Reg.170/03). This *Technical Rule* introduces the idea of clipping out SGRAs that are of no significance from a drinking water point of view. These areas may be important in other contexts, but they are not considered significant under the *CWA.* In the CVSPA study area, the SGRAs located within the Lake Ontario municipal water service area have been clipped out if no drinking water systems (as defined in the *Safe Drinking Water Act, 2002*) are hydrologically connected to those SGRAs.

Property fabric data for the serviced area was also assessed. SGRAs were clipped out if private wells used as a drinking water supply were not present in the area. Where drinking water systems are located downgradient of a municipal service area, such as in the City of Brampton, the SGRAs within the service area are kept in the SGRA analysis.

The final SGRAs including the updates to Subwatershed 19, 10 and 11 and with the Lake Ontario serviced areas eliminated as per *Rule (45)* are shown as shaded areas on **Figure 4.3**. As expected, the majority of the SGRAs occur in areas at or above the Niagara Escarpment.

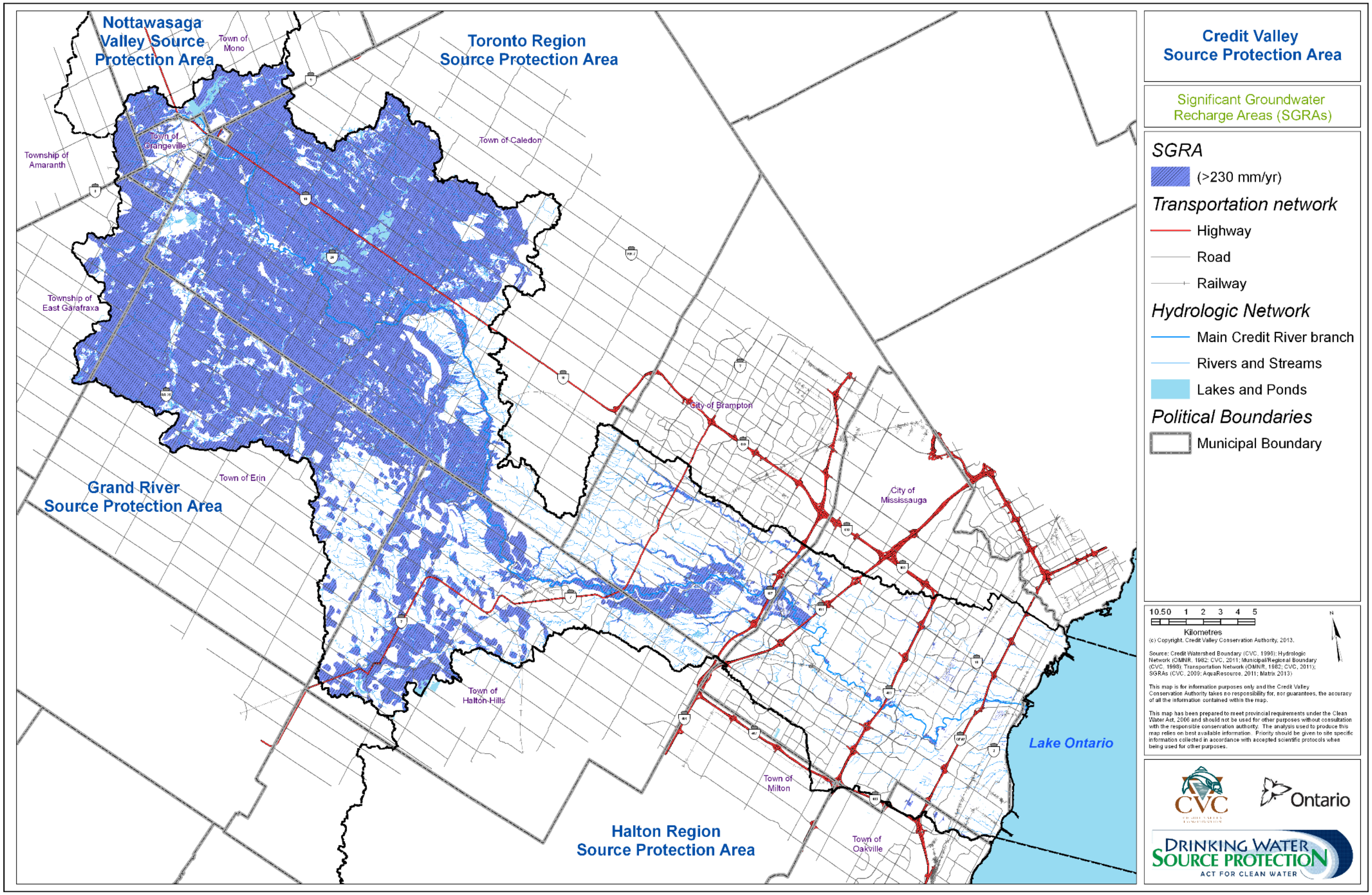

Figure 4.3: Significant Groundwater Recharge Areas (SGRAs)

4.1.4 Transport Pathways

Under the *CWA,* man-made structures such as improperly maintained or abandoned wells, aggregate pits, quarries, and storm water ponds may affect the natural vulnerability in a system and are termed "transport pathways." There are several such structures and features within the CVSPA that could increase the vulnerability of the various aquifers where they circumvent the natural protection that the overlying materials provide. There are private water wells that may be improperly maintained or left abandoned, quarries that may remove protective material, and horizontal structures, such as trunk sewers, that may provide a shorter pathway for potential contaminants to travel to drinking water sources.

The methodology followed to determine whether a vulnerability score increase is warranted due to transport pathways is described in more detail in **Appendix D4** of this Assessment Report. The *Technical Rules* indicate that a SPC may conclude that the data available may be insufficient or of too poor quality to justify an increase in vulnerability. Several datasets for pathway features were reviewed in an attempt to assess transport pathways within the CTC Source Protection Region, including the CVSPA jurisdiction. Only the data for pits and quarries were sufficient to adjust the vulnerability within the HVAs. This adjustment for pits and quarries was done consistently with the previous WHPAs vulnerability assessment.

The CTC SPC recommends that additional data be collected on pathways to re-visit the vulnerability assessment in a future iteration of this Assessment Report. The conservatism built into the current assessment provides assurance that vulnerability of the aquifers is sufficient at this time. Pits and quarries as transport pathways resulted in a 0.34% change (increase) in the area identified as HVAs.

4.1.5 Uncertainty Assessment

Confidence with the AVI depends on the density of data, the accuracy and currency of the surface geology mapping, and interpretations and assumptions made in the development of three-dimensional models. Over the last decade, the Oak Ridges Groundwater Moraine Program (ORGMP) has made significant advances in its understanding of the hydrogeologic system, adding new high integrity data sources, refining existing data, and developing cutting edge tools and products. As well, there is a relatively high density of data for the area of the CTC watershed region compared to other source protection regions.

The delineation of the SGRA mapping was based on a complex surface water model linked to a complex, three-dimensional groundwater flow model, and both models were calibrated to the satisfaction of external peer reviewers.

Together, these factors result in a high level of confidence in the results of the groundwater vulnerability analyses for the CTC Region. Therefore, the level of uncertainty is considered to be low. The reader is cautioned, however, that there is always a certain level of uncertainty, particularly in studies involving the subsurface, which cannot be observed directly. These studies are also regional in nature; site-specific information should always be used where available to determine local vulnerability. Data (quality and quantity) and knowledge gaps are complex.

Additional details on uncertainty factors surrounding HVA and SGRA analyses are provided in **Appendix D2**. Specific drinking water threats associated with all HVAs must be identified. Activities that pose a threat to the source water in these zones are listed in the Provincial Tables of Circumstances (*Technical Rules, Tables 10, 11, 17 and 18*) and discussed in **Chapter 5** of this document.

4.2 GROUNDWATER VULNERABILTY - WELLHEAD PROTECTION AREA (WHPA)

The groundwater-based municipal supplies in the CVSPA are currently delivered through nine active water systems which have a total of 46 wells, 43 of which are in active use.

A wellhead is the physical structure of the well above the ground. A wellhead protection area is the area that surrounds the well through which contaminants are reasonably likely to move toward or reach the well. The size of the area is determined by using a computer model that estimates the time it takes groundwater to travel within the aquifer to the well based on the rate the water is pumped out of the well, the type of geological materials around the well and the speed that groundwater travels. Pollutants from a variety of activities can seep into the ground and move toward a well. The following four WHPAs have been determined for each groundwater well listed in the *CVSPA Terms of Reference*:

- WHPA-A: the area within 100 m radius of the well - The area where the risk to the well is highest and the greatest care should be taken in handling any potential contaminant.
- WHPA-B: the area where groundwater is estimated to take up to 2 years to reach the well from within the aquifer. This second ring is important to protect from bacteria and viruses from human and animal waste as well as hazardous chemicals.
- WHPA-C: the area where groundwater is estimated to take up to 5 years to reach the well from within the aquifer. Although biological contaminants are less of a concern in the third ring, chemical pollutants remain a concern.
- WHPA-D: the area where groundwater is estimated to take up to 25 years to reach the well from within the aquifer. In this outer ring, the most persistent and hazardous pollutants remain a concern.

Two other WHPA (WHPA-E and WHPA-F) are delineated to include the area in and around the surface water body that is influencing a *GUDI well*. WHPA-E is delineated the same way as the IPZ-2 for a surface water intake (see **Section 4.9)** from the point of interaction between the aquifer and the surface water body. If the point of interaction is not known, the WHPA-E is delineated from the point of interaction between the aquifer and the surface water body that is nearest to the well. WHPA-F zones are only delineated where an issue has been confirmed for a GUDI well.

GUDI Well: Groundwater Under the Direct Influence of Surface Water. The Drinking Water Systems Regulations (Ont. Reg. 170/03) under the *Safe Drinking Water Act, 2002* defines specific circumstances under which a groundwater supply is considered to be GUDI. These wells are more susceptible to contamination than non-GUDI wells because they can be affected by short-term water quality issues associated with surface water sources.

Porosity: The percent of open spaces or voids occurring between mineral grains or in fractures of bedrock. It is a measure of the potential volume of water that can be stored in the geologic material.

Permeability: The ability of a material to transmit a fluid, a measure of how quickly fluid will flow through the rock or sediment. This is determined by the size of open spaces and degree to which they are connected.

Mapping of WHPAs has been completed by consultants working for the respective municipalities and then peer reviewed by consultants under the direction of the CTC SPC. The WHPAs have been mapped for all of the following 46 municipal wells in the CVSPA watersheds:

WHPAs A to D were delineated per *Technical Rule 47 (1*) to *(4)* and *Technical Rule 48 (3)*, using three-dimensional flow modelling. This involved the creation of numerical models, as done for the Tier 2 water budget study (see **Chapter 3**). The modelling packages used for the analysis varied amongst the municipalities. Most groundwater consultants used three-dimensional MODular FLOW (MODFLOW) modelling system, while others used the Finite Element FLOW (FeFLOW) model.

WHPAs A-D for all wells in the CVSPA were delineated through a time of travel assessment, using *backward particle tracking* analysis. Forward particle tracking analysis was used to cross-check the WHPA delineation.

The WHPAs were delineated by pumping each well to *steady state* at rates determined to be the maximum future average annual groundwater demand that can be sustained by the wells. The rates were chosen through consultation with individual municipalities.

Backward particle tracking analysis: A modelling technique where water particles are released at the wellhead and tracked back to their point of origin. The times-of-travel for particles are assigned based on the location of the originating cell.

Steady state: To determine steady-state capture, every particle is traced back to the location it entered the groundwater system. This represents the complete capture of the well.

4.2.1 WHPA Vulnerability Assessment

In the municipal-sourced aquifers of CVSPA, vulnerability analyses were conducted by consultants, who applied the AVI, SWAT or ISI methodology listed in **Chapter 4.1**. Each method produces a numerical index representing the relative vulnerability of an aquifer to sources of contamination at or near the surface, and through a translation process, categorizes vulnerability as high, medium, or low, as shown on **Table 4.2.** Since many municipal wells are located in deeper aquifers, they are less vulnerable because of the protection provided by overlying materials (aquifers and aquitards).

Vulnerability scoring of the WHPAs B – D is obtained by overlaying each delineated WHPA on the groundwater vulnerability developed for the area around the related wellhead. The groundwater vulnerability is then translated into a vulnerability score (per *Technical Rules 82-85*), and this score provides the ultimate expression of the groundwater vulnerability in the WHPAs. All WHPA-A areas are given a vulnerability score of 10, without considering the geological setting.

The scoring within the WHPAs B–D, based upon the vulnerability using the AVI, ISI and SWAT methodologies, respectively, are presented in **Table 4.2**.

Table 4.2: Range of Vulnerability Scores in WHPAs A–D

WHPA Zone	Vulnerability Score by SWAT Methodology			Vulnerability Score by ISI & AVI Methodology		
	Low (>25 yrs)	Medium (5-25 yrs)	High (< 5 yrs)	Low (>80)	Medium (30-80)	High (<30)
Zone A	10	10	10	10	10	10
Zone B	6	8	10	6	8	10
Zone C	2	6	8	4	6	8
Zone D	2	4	6	2	4	6

Vulnerability within WHPA-Es is also assessed using the *Technical Rules* relevant to the IPZ-2. The range of applicable vulnerability scores within the WHPA-E is shown in **Table 4.3.**

Table 4.3: Summary of Vulnerability Scores within WHPA-E

WHPA-E	Range of Vulnerability Scores
Inland Lakes	5.6, 6.3, 6.4, 7.0, 7.2, 8.0, 8.1, 9.0
Inland Rivers & Streams	6.3, 7.0, 7.2, 8.0, 8.1, 9.0

4.2.2 Transport Pathways

The *Technical Rules* allow for adjustments to the vulnerability scoring to account for the presence of transport pathways. Examples of potential pathways include subsurface utilities, aggregate operations, and clusters of private water wells. Adjustments to the vulnerability to account for the presence of transport pathways were considered.

Subsurface Utilities

Information on the location of sewers and other subsurface utilities was reviewed. Where a utility was thought to represent a possibility of becoming a transport pathway the vulnerability rating of the underlying aquifer was increased to the next category.

Aggregate Operations

Information on the locations, and status of aggregate operations was reviewed. Aggregate operations may create or enhance a transport pathway to groundwater increasing the vulnerability of the aquifer.

Water Wells

Domestic water wells are the most common transport pathway in rural areas. Improper construction can potentially introduce a cumulative impact to drinking water sources especially when the casing deteriorates. If the well is no longer in use, improper abandonment also provides a pathway for a contaminant to impact a drinking water source.

A review of the MOECC WWIS was undertaken to identify older, unused domestic wells. However, as many are decades old, it is not known if their status has been updated in the WWIS since being drilled, if they still exist, or if they have been decommissioned. Also, the *Technical Rules* do not provide guidance on how they should be considered. As a result, different consultants have applied a wide range of assumptions and standards in their assessments.

An analysis was applied to assess the effect of clusters of water wells as transport pathways. The methodology that was applied is described in **Appendix D4**. Based on this analysis, the CTC SPC opted against the inclusion of such pathways since the unreliability of the database used and the high uncertainty associated with the analyses were too high to defend in a reasonable manner.

Specific drinking water threats associated with large quantities of contaminants within all WHPAs must be identified. These analyses are done where the vulnerability score is 6 or higher for groundwater (WHPAs A to D) and 4.4 or higher for surface water (and WHPAs E). Activities that may pose a potential threat to the source water in these zones are listed in the Provincial Tables of Circumstances (*Technical Rules, Nov. 2009, Tables 10, 11, 17 and 18*) and discussed in **Chapter 5** of this document.

WHPAs for municipal wells in the CVSPA are shown in **Figure 4.4.**

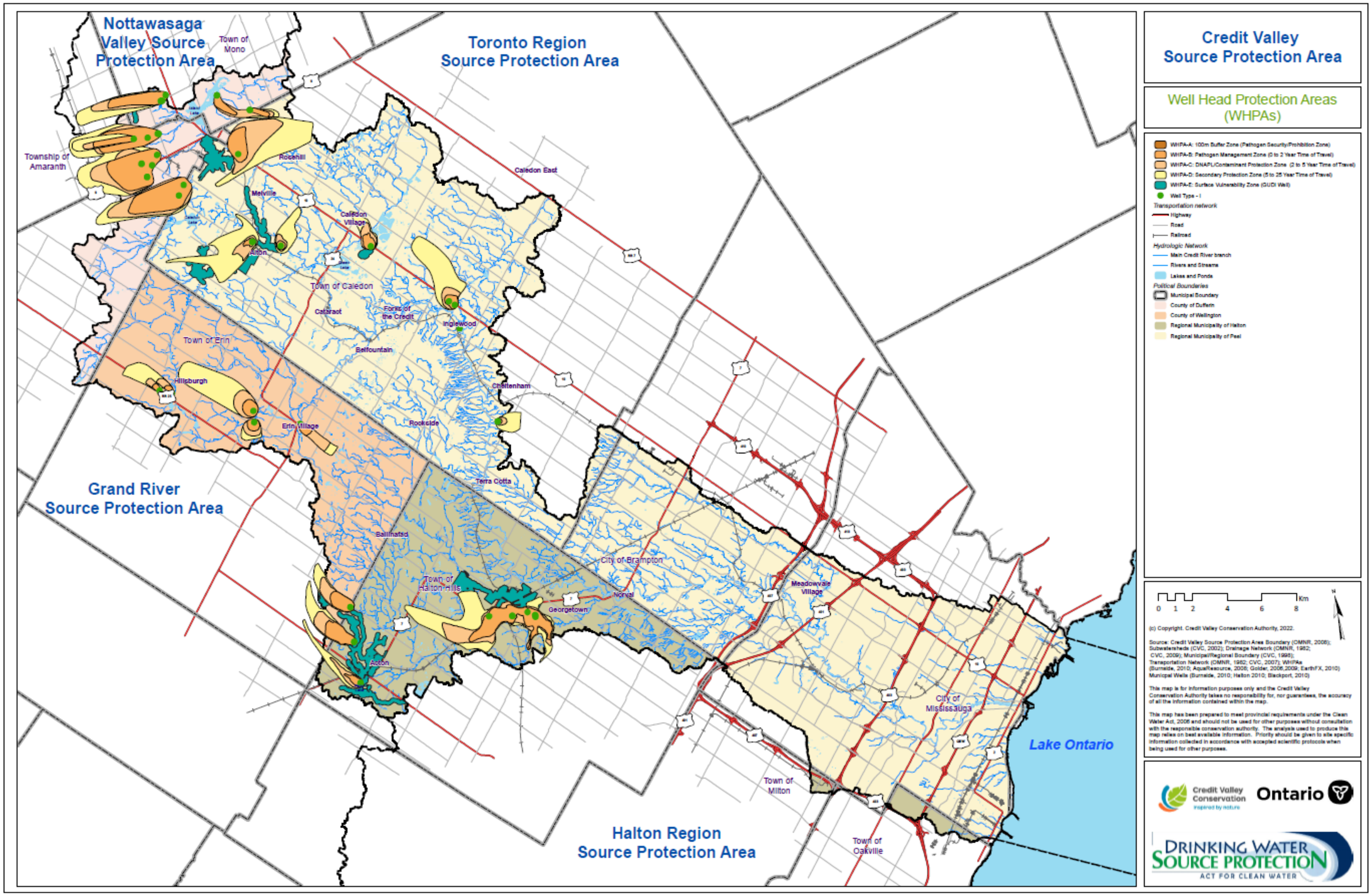

Figure 4.4: Wellhead Protection Areas (WHPAs)

4.3 COUNTY OF DUFFERIN - TOWN OF ORANGEVILLE

The Town of Orangeville is located at the headwaters of the Credit River in the CVSPA and provides municipal supply through 12 wells in nine wellfields. The town's municipal well and monitoring networks are shown in **Figure 4.5.**

WHPA delineations for Orangeville and Mono wellheads are documented in the report "Towns of Orangeville and Mono Wellhead Protection Area Delineation Report" (AquaResource Inc., March 2010). Details of the vulnerability assessment are given in the report "Groundwater Vulnerability Assessment - Town of Orangeville, Final (R.J. Burnside and Associates, Ltd., March 2010). These documents have been subject to extensive peer review by a panel of municipal representatives, private consultants, and the CVC prior to acceptance by the CTC SPC, and inclusion in this Assessment Report. The following is a summary of these reports.

4.3.1 Geological Setting

The majority of the municipal wells are in semi-confined dolostone bedrock aquifers of the Amabel and the Guelph Formations. The remaining three wells are in unconfined overburden aquifers. Details of well depth, geological setting and aquifer type is given in **Appendix D2**.

4.3.2 Data Sources and Study Methodology

An initial understanding of the hydrogeology of the Orangeville/Mono area was developed through work done for the "Orangeville and Surrounding Areas Groundwater Study", which was completed in 2001 (WHI, 2001). This study also delineated municipal capture zones and assessed aquifer vulnerability. The groundwater flow model was further refined through the "Town of Orangeville Groundwater Resources and Contamination Assessment/ Prevention Study" (Burnside and WHI, 2001), and the capture zones were again updated in 2006 in another modelling study "Aquifer Performance Response and Sustainability Groundwater Modeling for the Town of Orangeville" (WHI, 2006). Technical data and analyses informing the Tier 3 Water Budget Study for Orangeville, Mono and Amaranth (see **Chapter 3.7**) were used to develop the capture zones and to delineate the WHPAs for the municipal wells of the three municipalities. As such, the uncertainty associated with these WHPAs is relatively low.

Technical information on model construction and calibration are summarized in **Appendix D2** and detailed in the foundation report referenced above.

4.3.3 WHPA A-D Delineation and Vulnerability Scoring

WHPA-A was delineated as a fixed circle with a radius of 100 metres centred on the wellhead. WHPAs B-D were delineated through particle tracking analysis (**Chapter 4.2**), pumping each well to steady state at rates determined with the town, to be the maximum future average annual groundwater demand that can be sustained by the wells. **Appendix D2** (**Table D-12**) shows a comparison amongst the rates used for the delineation, the permitted rate, and 2008 average day demand.

The WHPAs for the municipal wells are shown in **Figure 4.5**. WHPAs B, C and D for all wells, except Well 10, extend in a westerly direction from the wellhead, crossing the CVSPA/Grand River Source Protection Area (GRSPA) boundary. The WHPAs for Well 10, trend in a north-easterly direction from the wellhead, with the extreme tip of the WHPA-D entering the TRSPA.

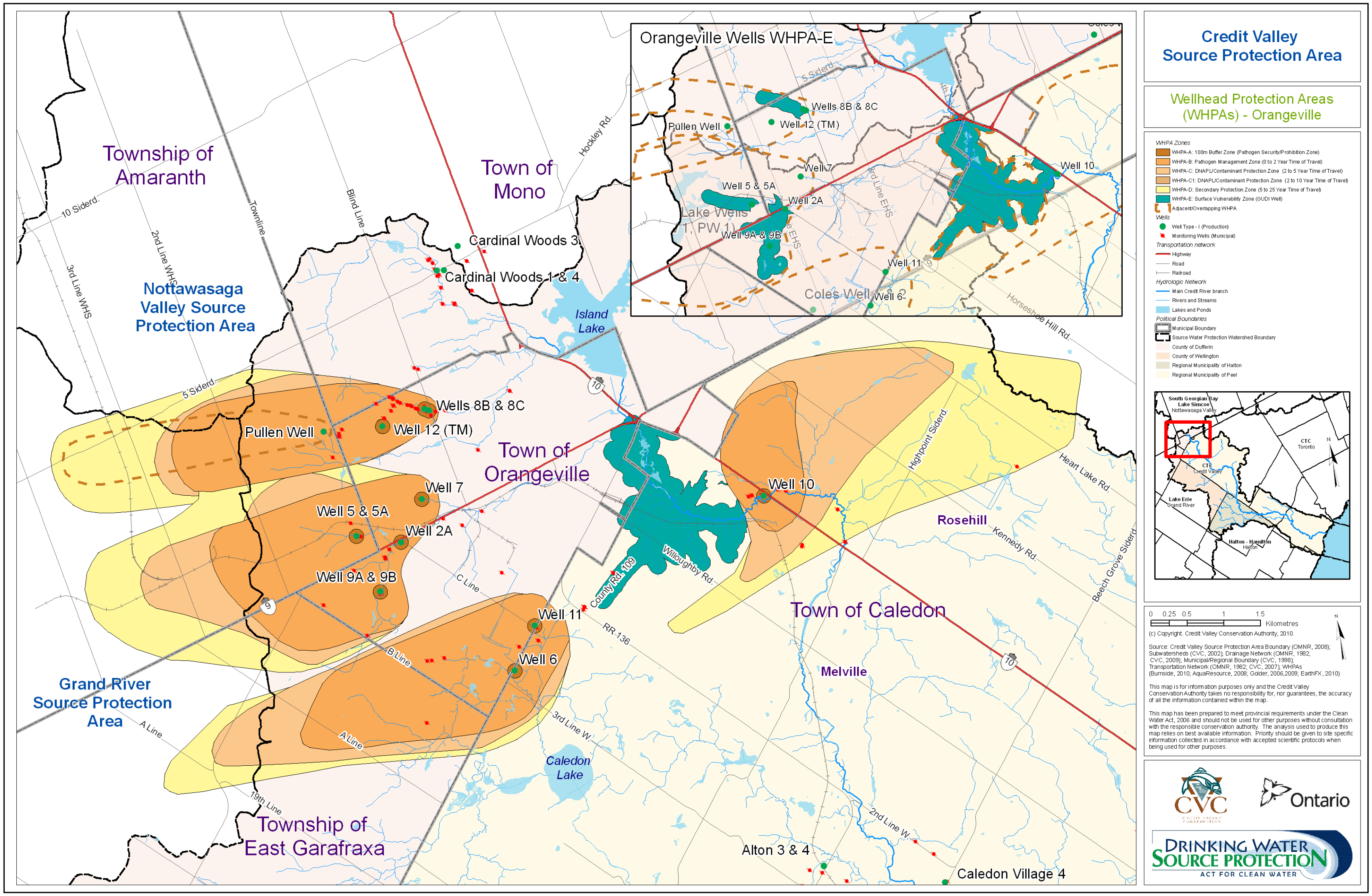

Figure 4.5: Wellhead Protection Areas (WHPAs) – Town of Orangeville

The vulnerability assessment was conducted concurrently for the towns of Orangeville and Mono, and the Township of Amaranth, based on proximity and the similarity in the background data requirements for the analysis.

The AVI methodology was selected for this area, based on the following:

- The approach provides a conservative assessment of vulnerability and can be derived based on information in the MOECC water well database;
- More advanced methods require additional data input that is not as readily available for the study area; and
- An AVI assessment had been previously completed in 2007 for the Town of Mono. This previous assessment could be easily updated to include the Town of Orangeville.

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

This methodology resulted in AVI data that agreed with the other related datasets, an important aspect of spatial datasets since ultimately these data are usually employed together for mapping and analysis purposes.

Calculations for aquifer vulnerability are based upon the geologic material present and the thickness of the material overlying an aquifer. Additional detail on the methodology is provided in **Appendix D2**.

The groundwater vulnerability is shown in Figure 4.6. The town is dominated by aquifers classed as low to medium vulnerability with some patches of high vulnerability located on the east side of town and within the capture zone of Well 10. There are very few areas of high vulnerability on the west side of the town, which is also the location of the capture zones and wells for the majority of the municipal water supply.

WHPA vulnerability was scored by overlaying the groundwater vulnerability on the delineated WHPAs B to D, and applying a score, as shown on **Table 4.2.**

The vulnerability scoring in Orangeville's WHPAs are shown in **Figure 4.7**.

4.3.4 WHPA-E Delineation and Vulnerability Scoring

Municipal wells 2A, 5, 5A, 8B/8C, 9A, 9B and 10 are designated as GUDI sources (per subsection 2 (2) of O. Reg. 170/03). Specifics are shown in **Appendix D2 (Table D2-6)**.

The key tasks in delineating the WHPA-Es are identified in **Chapter 4.2**. Since the exact point of interaction was not defined for any of Orangeville's wells, the closest surface water body to the wells were used as the starting point for the delineation.

Details on the calculation procedures and assumptions used in the derivation of WHPA-Es is summarized in **Appendix D2** and presented in the foundation reports referenced. WHPA-Fs were not derived as the WHPA-Es extended to the full length of the streams contributing to intake points. The WHPA-Es are shown in Figure 4.5**.**

Vulnerability scores for WHPA-Es were assigned per the *Technical Rules*, as the product of the area vulnerability factor and the source vulnerability factor.

The derivation of the value of each factor is described in **Appendix D2**. The WHPA-E vulnerability scores are shown in **Figure 4.7.**

4.3.5 Transport Pathways

The features studied within the context of the transport pathway analysis have been outlined in **Chapter 4.2**. Based on the analyses undertaken, no transport pathways were identified, so the vulnerability categorization (low, medium) was not bumped up.

4.3.6 Uncertainty Assessment

WHPAs B-D were delineated through the analysis done for the Tier 3 study for Orangeville and its environs. They benefit from the most recent enhancement of the conceptual, hydrostratigraphic and numerical models of the area, and represent the most recent refinements in the numerical modelling for headwaters area of the CVSPA.

The dimensions of WHPA-A and the vulnerability scoring are set within the *Technical Rules*. With the other WHPAs though, there is an intrinsic level of uncertainty in the analysis, given the complexity of the study area and data gaps in certain instances. The vulnerability assessment also has a certain level of uncertainty associated with it.

Uncertainty associated with Orangeville's wellfield assessments is found in **Table 4.4**, and further discussed in **Appendix D2.** Uncertainty is summarized as follows:

- The WHPAs were delineated with a sub-regional scale model and had good calibration. A sensitivity analysis was completed to account for variation in model parameters. The uncertainty in the WHPAs is low.
- Considering the variability in the density of the data used to create the AVI mapping and that the well database has inherent uncertainty, the vulnerability mapping of the area is considered to have high uncertainty.

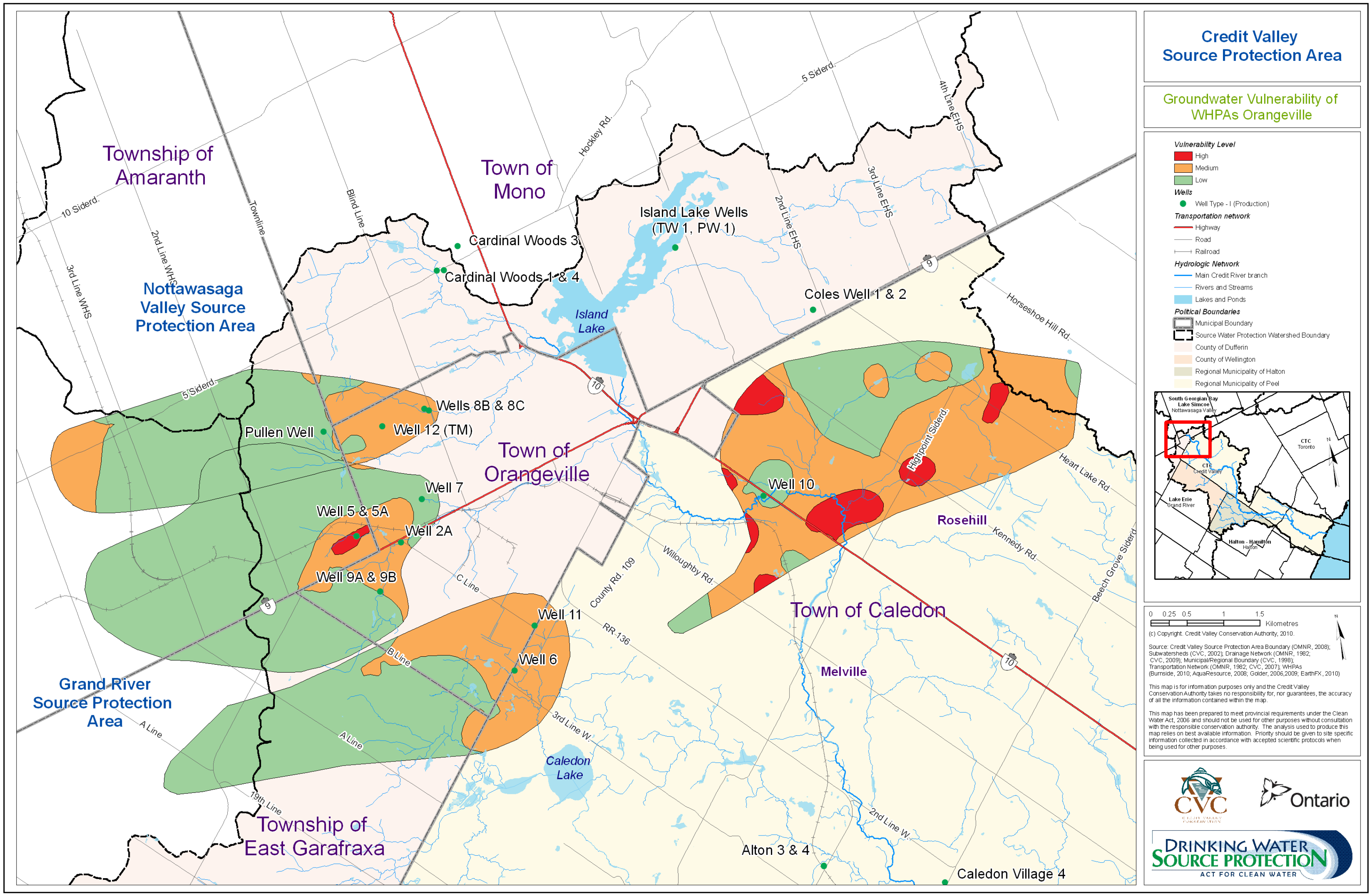

Figure 4.6: Groundwater Vulnerability of WHPAs – Orangeville

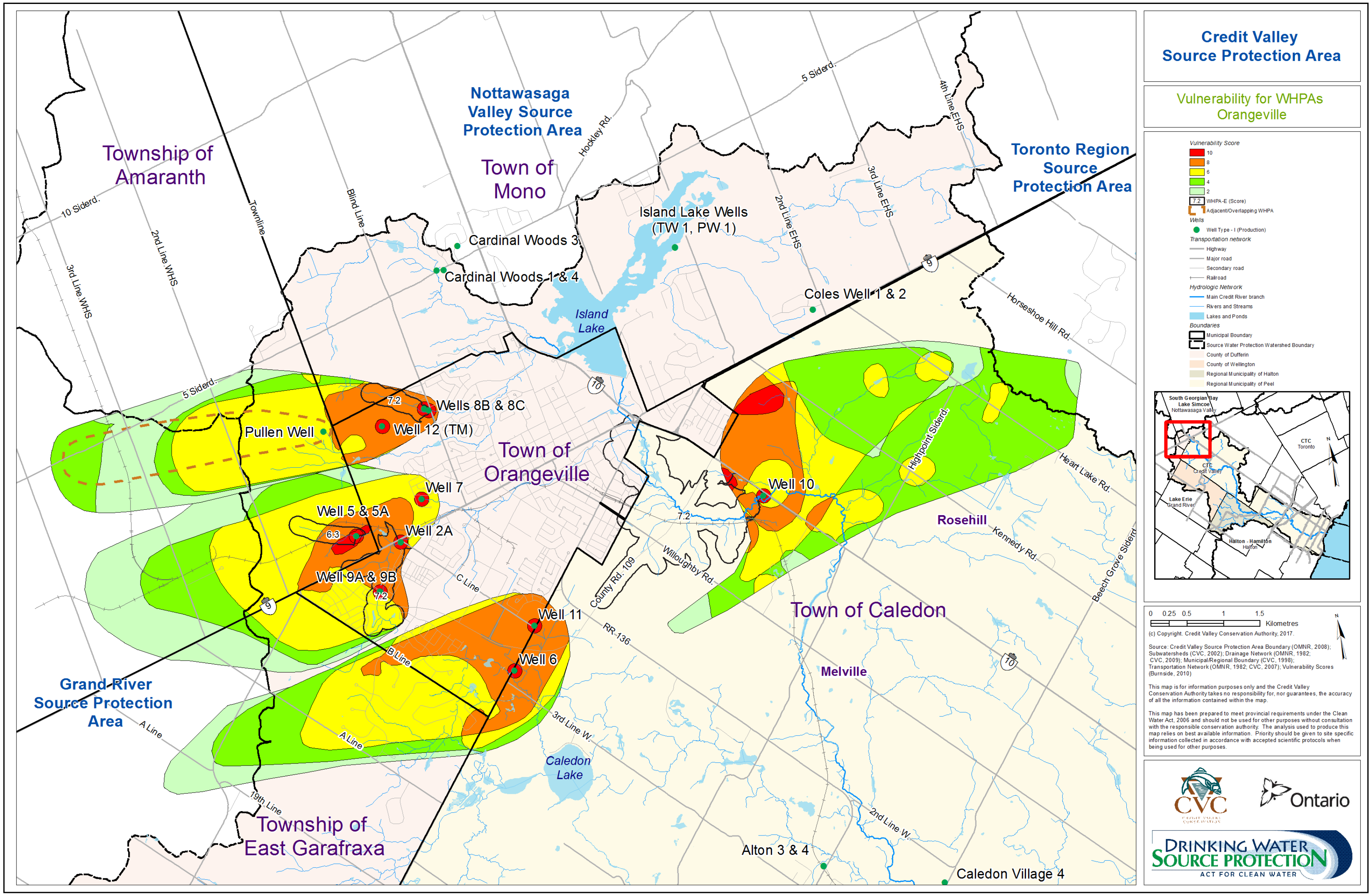

Figure 4.7: Vulnerability for WHPAs – Orangeville

Table 4.4: Uncertainty Assessments—Town of Orangeville

	Uncertainty Type	WHPA-A	WHPA-B	WHPA-C	WHPA-D	WHPA-E
Well 2A, 5/5A, 7, 9A/9B	Delineation of WHPA	Low	Low	Low	Low	Low
	AVI computation	Low	Low	High	High	
	Overall – Vulnerability Scores	Low	High	High	High	Low
Well 6, 11	Delineation of WHPA	Low	Low	Low	Low	-
	AVI computation	Low	Low	High	High	
	Overall – Vulnerability Scores	Low	Low	High	High	-
Well 8B, 8C, 12	Delineation of WHPA	Low	Low	Low	Low	Low
	AVI computation	Low	High	High	High	
	Overall – Vulnerability Scores	Low	High	High	High	
Well 10	Delineation of WHPA	Low	Low	High	High	Low
	AVI computation	Low	High	High	High	
	Overall – Vulnerability Scores	Low	High	High	High	

4.4 COUNTY OF DUFFERIN - TOWN OF MONO

The Town of Mono is located in the headwaters area of the CVSPA, and provides municipal supply though a water system comprised of the following wellfields:

- Cardinal Woods – Wells MW-1, MW-3 and MW-4;
- Coles – Wells 1 and 2; and
- Island Lake – Wells PW 1, PW 2-06, and TW 1.

Mono's municipal wells are operated by the Town of Orangeville, on behalf of the Town of Mono. Three wells (MW-3, Coles PW-1, and Island Lake PW-1) service the town on an ongoing basis, while the remainder serve as standby supplies. Island Lake PW-2-06 is currently inactive. Cardinal Woods MW-3 is located outside of the CVSPA, in the Nottwasaga Valley Source Protection Area (NVSPA). The Mono water system is shown in Figure 4.8**.**

4.4.1 Geological Setting

The Coles and Island Lake wells are in overburden aquifers which are confined by overlying clay, while the Cardinal Woods wells are within the Amabel Formation. A summary of well depth associated geological setting and aquifer type is presented in **Appendix D2**.

4.4.2 Data Sources and Study Methodology

WHPA delineations for the town's wellheads are documented in the report "Towns of Orangeville and Mono Wellhead Protection Area Delineation Report" (AquaResource Inc., March 2010). The vulnerability assessment is given in the report "Groundwater Vulnerability Assessment, Town of Mono, Final" (R.J. Burnside and Associates, Ltd., April 2010). These documents have been subject to extensive peer review by a panel of municipal representatives, private consultants, and the CVC prior to acceptance by the CTC SPC, and inclusion in this Assessment Report. Data acquisition and hydrogeologic analyses are the same as the wells in Orangeville.

4.4.3 WHPA B-D Delineation and Vulnerability Scoring

Delineation of WHPAs B-D was undertaken through technical work done for the Orangeville, Mono and Amaranth Tier 3 Water Budget Study, using particle tracking analysis (**Chapter 4.2**). Each well was pumped to steady state at rates determined to be the maximum future average annual groundwater demand that can be sustained by the wells (consultation with the Town).

The WHPAs for the Cardinal Woods were delineated using two different pumping scenarios to reflect conditions of the town's PTTW which prohibits Wells 1, 3, and 4 from being pumped at the same time. The first scenario simulated only Well 3 as active, and the second scenario simulated Wells 1 and 4 as active and Well 3 inactive. The model scenarios were configured this way to delineate the maximum capture area that would result from the two operating schemes. **Appendix D2** presents the pump rates used for the delineation.

The WHPAs are shown in Figure 4.8. The WHPAs for Island Lake and Coles Wells extend in a south-easterly direction from the wellheads, while those of Cardinal Woods extend westerly from the wellhead. Cardinal Woods WHPA-B, C and D cross the CVSPA boundary into the GRSPA. The WHPA-A for Cardinal Woods Well MW-3 is located entirely within the NVSPA.

Groundwater vulnerability was assessed using the AVI, as described for Orangeville. The intrinsic vulnerability at Mono's wellfields is shown in Figure 4.9.

Mono 's aquifers are primarily low to medium vulnerability with areas of high vulnerability located north of Island Lake, just east of the Cardinal Woods sub-division and at the Coles Industrial Subdivision on Highway 9. WHPA vulnerability was scored by overlaying the groundwater vulnerability on the delineated WHPAs A to D, and applying a score, as shown on **Table 4.2**. The vulnerability scores in Mono's WHPAs are shown in Figure 4.10**.**

4.4.4 WHPA E Delineation and Vulnerability Scoring

The Cardinal Woods Wells MW1 and MW4 have been identified as the only GUDI wells (per subsection 2 (2) of O. Reg. 170/03) in Mono. Specifics are shown in **Appendix D2 (Table D2-16)**. WHPA-E delineation, vulnerability assessment and scoring for Wells MW1 and MW4 were conducted using the same methodology described for Orangeville. The WHPA-E for MW1 and MW4 extend in a northwest direction approximately 600 metres ending at the surface water ponds. The WHPA-Es extend to the full length of the streams contributing to intake points and are shown on Figure 4.8.

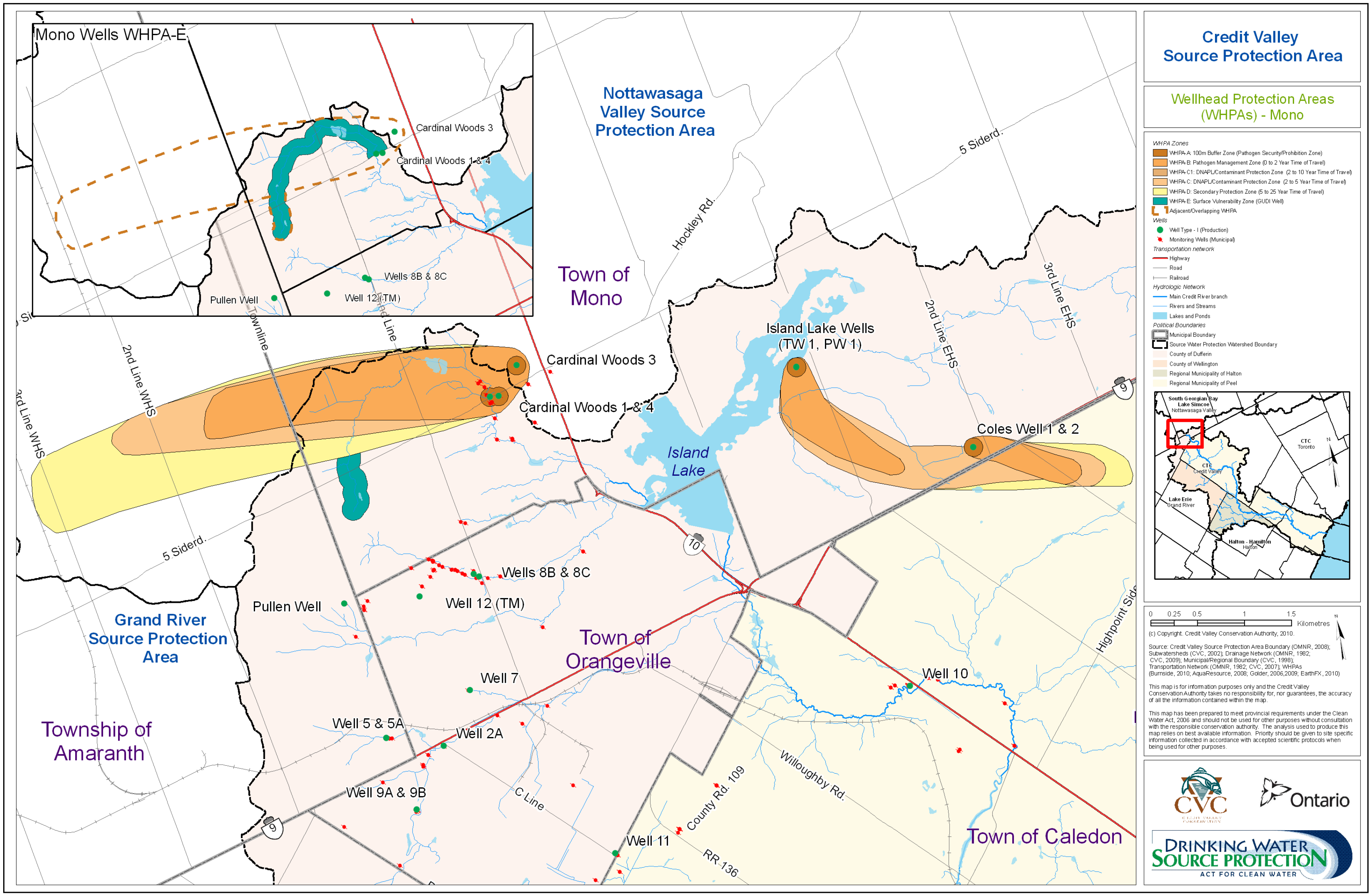

Figure 4.8: Wellhead Protection Areas (WHPAs)—Mono

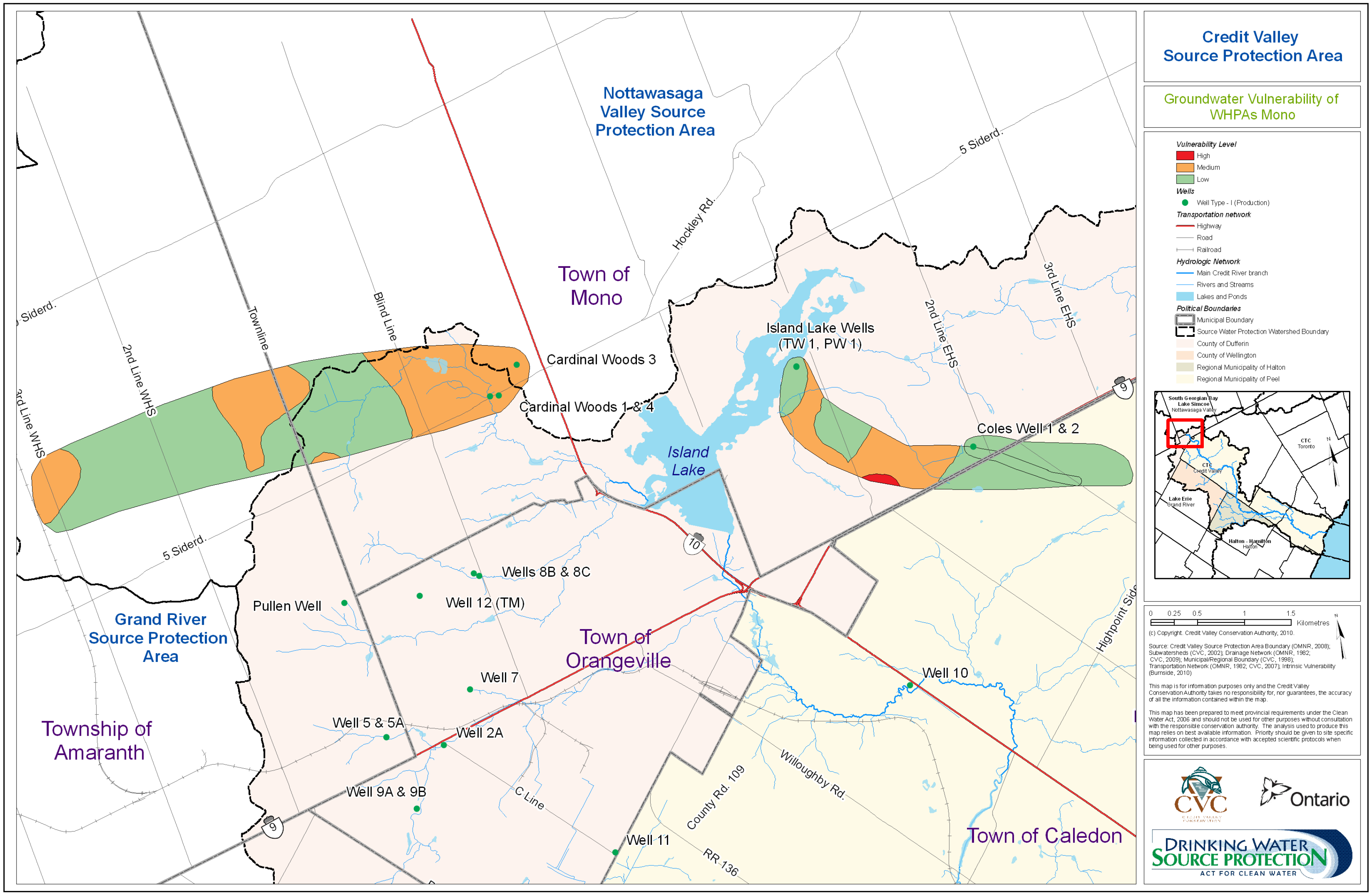

Figure 4.9: Groundwater Vulnerability of WHPAs – Mono

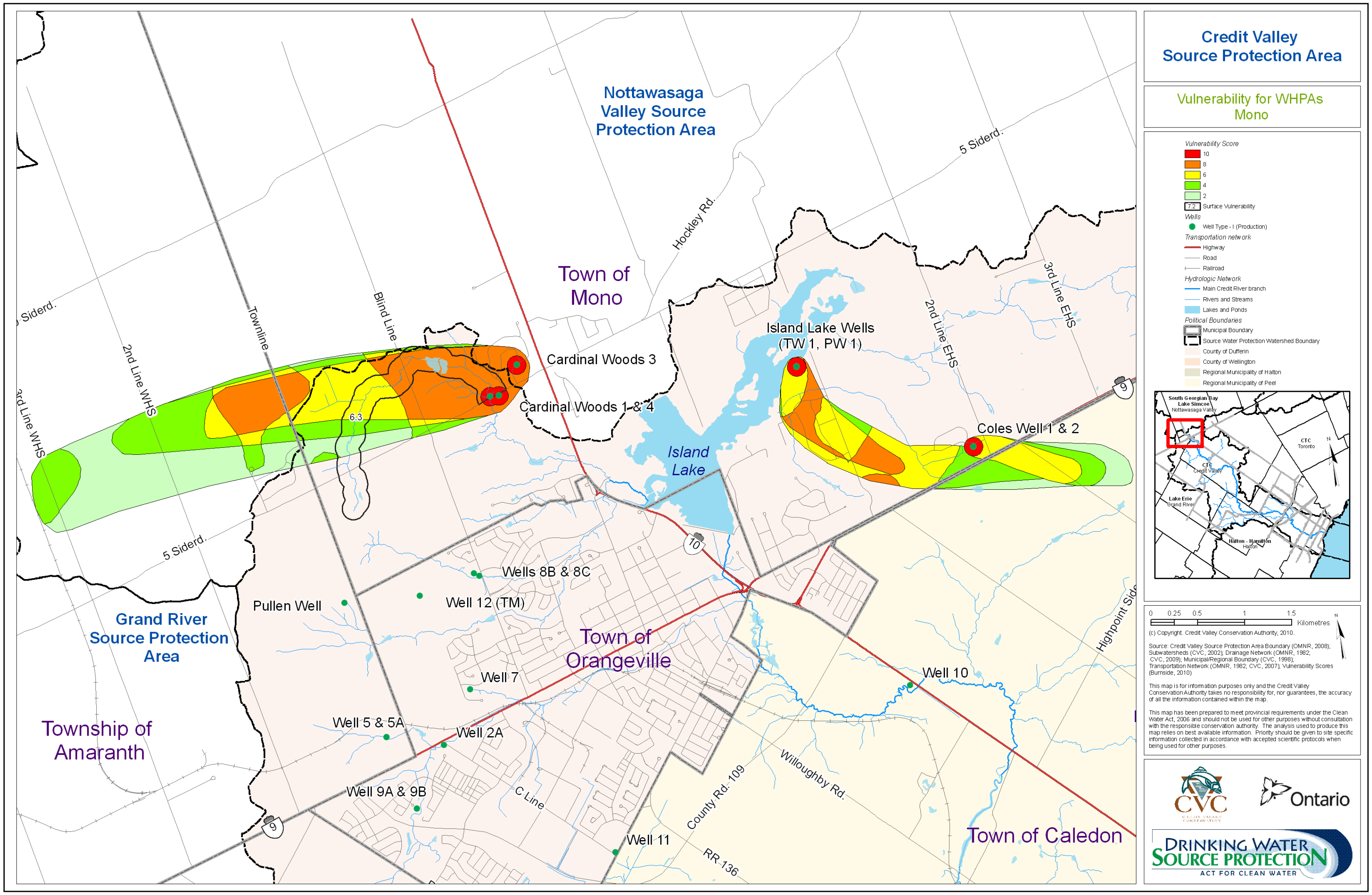

Figure 4.10: Vulnerability for WHPAs - Mono

Vulnerability scores were determined using the methodology referenced earlier. The derivation of the scores is summarized in **Appendix D2**, and fully presented in the foundation report cited above. The vulnerability scores are shown in Figure 4.10.

4.4.5 Transport Pathways

The features studied within the context of this analysis are outlined in **Chapter 4.2**. No transport pathways were identified so the vulnerability rating was not bumped up.

4.4.6 Uncertainty Assessment

Uncertainty associated with Mono's wellfield assessments is found in **Table 4.5** below and further discussed in **Appendix D2**. Uncertainty for the Town of Mono WHPAs is summarized as follows:

- The WHPAs were delineated with a sub-regional scale model and had good calibration. A sensitivity analysis was completed to account for variation in model parameters. The uncertainty in the WHPAs is low; and
- Considering the density of the data used to create the AVI mapping was variable, and the well database has inherent uncertainty, the vulnerability mapping of the area is considered to have high uncertainty.

Table 4.5: Uncertainty Assessment—Town of Mono

Wellfield	Uncertainty Type	WHPA-A	WHPA-B	WHPA-C	WHPA-D	WHPA-E
Cardinal Woods Wells	Delineation of WHPA	Low	Low	Low	Low	Low
	AVI computation	Low	High	High	High	
	Vulnerability Scores	**Low**	**High**	**High**	**High**	**Low**
Island Lake Wells	Delineation of WHPA	Low	Low	Low	Low	-
	AVI computation	Low	High	High	High	
	Vulnerability Scores	**Low**	**High**	**High**	**High**	-
Coles Wells	Delineation of WHPA	**Low**	**Low**	**Low**	**Low**	-
	AVI computation	Low	High	High	High	
	Vulnerability Scores	**Low**	**High**	**High**	**High**	-

4.5 COUNTY OF DUFFERIN - TOWNSHIP OF AMARANTH

The Township of Amaranth is located in the north-west corner of the CVSPA, straddling the GRSPA and the NVSPA. The township has one municipal supply within the GRSPA and in 2008 designated the Pullen Well in the CVSPA as part of its planned municipal supply.

4.5.1 Geological Setting

The Pullen Well is in the limestone bedrock. The Pullen Well lies in very close proximity to Orangeville wells 8B, 8C, 12, and all four wells extract water from the Amabel Formation aquifer.

4.5.2 Data Sources and Study Methodology

WHPA delineation for the Pullen Well is described in "Township of Amaranth Wellhead Protection Area Delineation Report" (AquaResource Inc., March 2010). Details of the vulnerability assessment are contained in the report "Groundwater Vulnerability Assessment - Township of Amaranth, Final: (R.J. Burnside and Associates, Ltd., March 2010). These documents have been subject to extensive peer review by a panel of municipal representatives, private consultants, and the CVC prior to acceptance by the CTC SPC, and inclusion in this Assessment Report.

4.5.3 WHPA A-D Delineation and Vulnerability Scoring

Delineation of WHPAs B-D was undertaken through technical work done for the Orangeville, Mono and Amaranth Tier 3 Water Budget Study, using particle tracking analysis (**Chapter 4.2**). The WHPAs were delineated using an average daily pump rate of 220 cubic metres per day, based upon consultation with the Township of Amaranth, and the Town of Orangeville. The WHPAs extend in a westerly direction from the wellhead, and like those of Orangeville, cross the CVSPA boundary into the GRSPA, and are shown in **Figure 4.11**.

Groundwater vulnerability was assessed using the AVI methodology, in the same manner described for Orangeville. The intrinsic vulnerability in the area of the Pullen Well is shown in **Figure 4.12**. The township is dominated by aquifers classified as low to medium vulnerability.

WHPA vulnerability was scored by overlaying the groundwater vulnerability classification (high, medium, low) of the wider area, on the delineated WHPAs A to D, and applying a score, as shown on **Table 4.2**. The vulnerability scores in the Pullen's WHPAs are shown in **Figure 4.13**.

4.5.4 Transport Pathways

The features considered for this analysis are outlined in **Chapter 4.2**. No transport pathways were identified so the vulnerability rating was not bumped up.

4.5.5 Uncertainty Assessment

The uncertainty associated with the Pullen Well analyses is found in **Table 4.6,** and further discussed in **Appendix D2**.

Table 4.6: Uncertainty Assessment – Pullen Well

Uncertainty Type	WHPA-A	WHPA-B	WHPA-C	WHPA-D
Delineation of WHPA	Low	Low	Low	Low
AVI computation	Low	High	High	High
Overall – Vulnerability Scores	**Low**	**High**	**High**	**High**

Uncertainty for the Pullen WHPAs is summarized as follows:

- The WHPAs were delineated with a sub-regional scale model and had good calibration. A sensitivity analysis was completed to account for variation in model parameters. The uncertainty in the WHPAs is low; and
- Considering the density of the data used to create the AVI mapping was variable and the well database has inherent uncertainty, the vulnerability mapping of the area is considered to have high uncertainty.

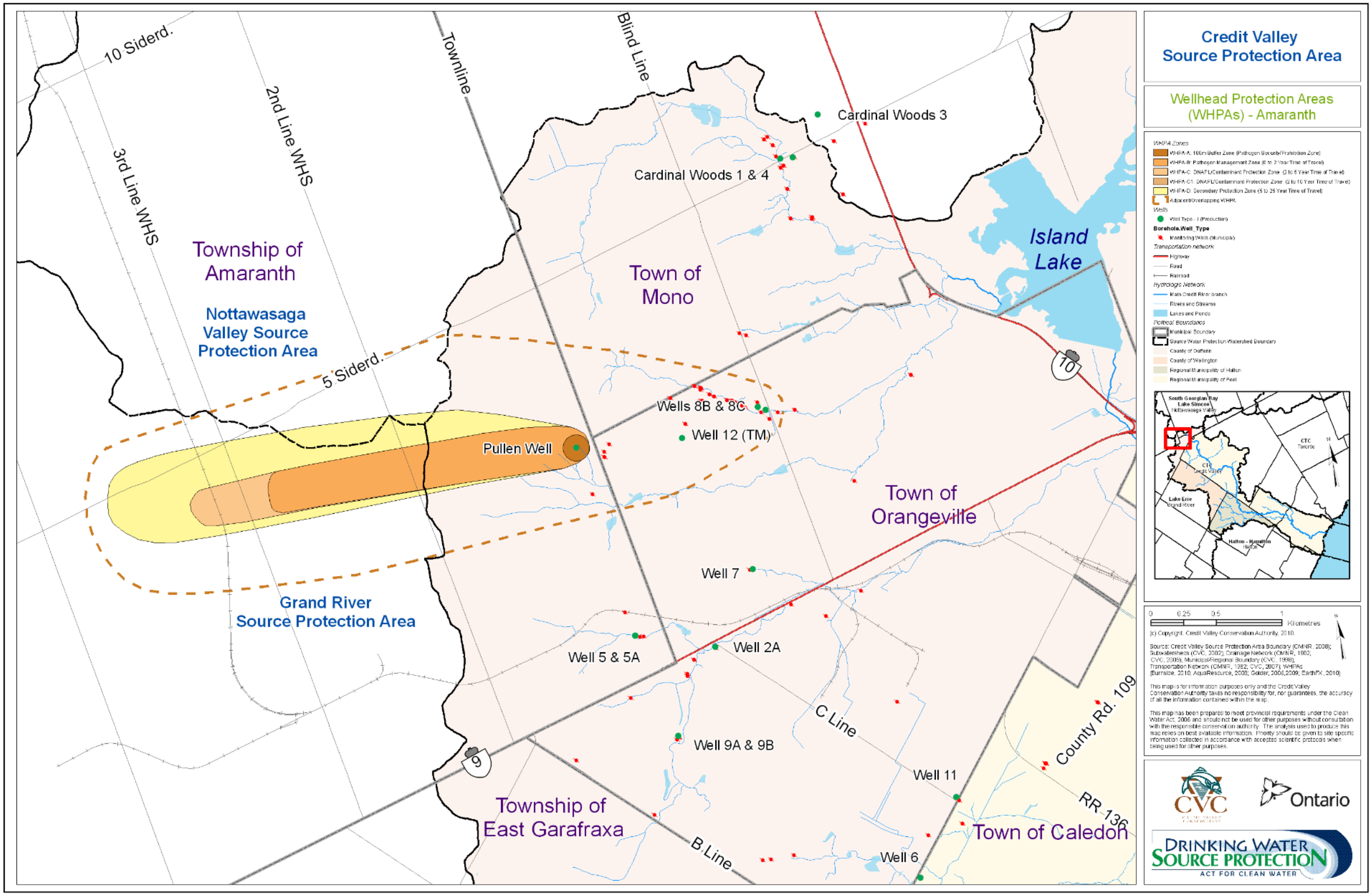

Figure 4.11: Wellhead Protection Areas (WHPAs)—Amaranth

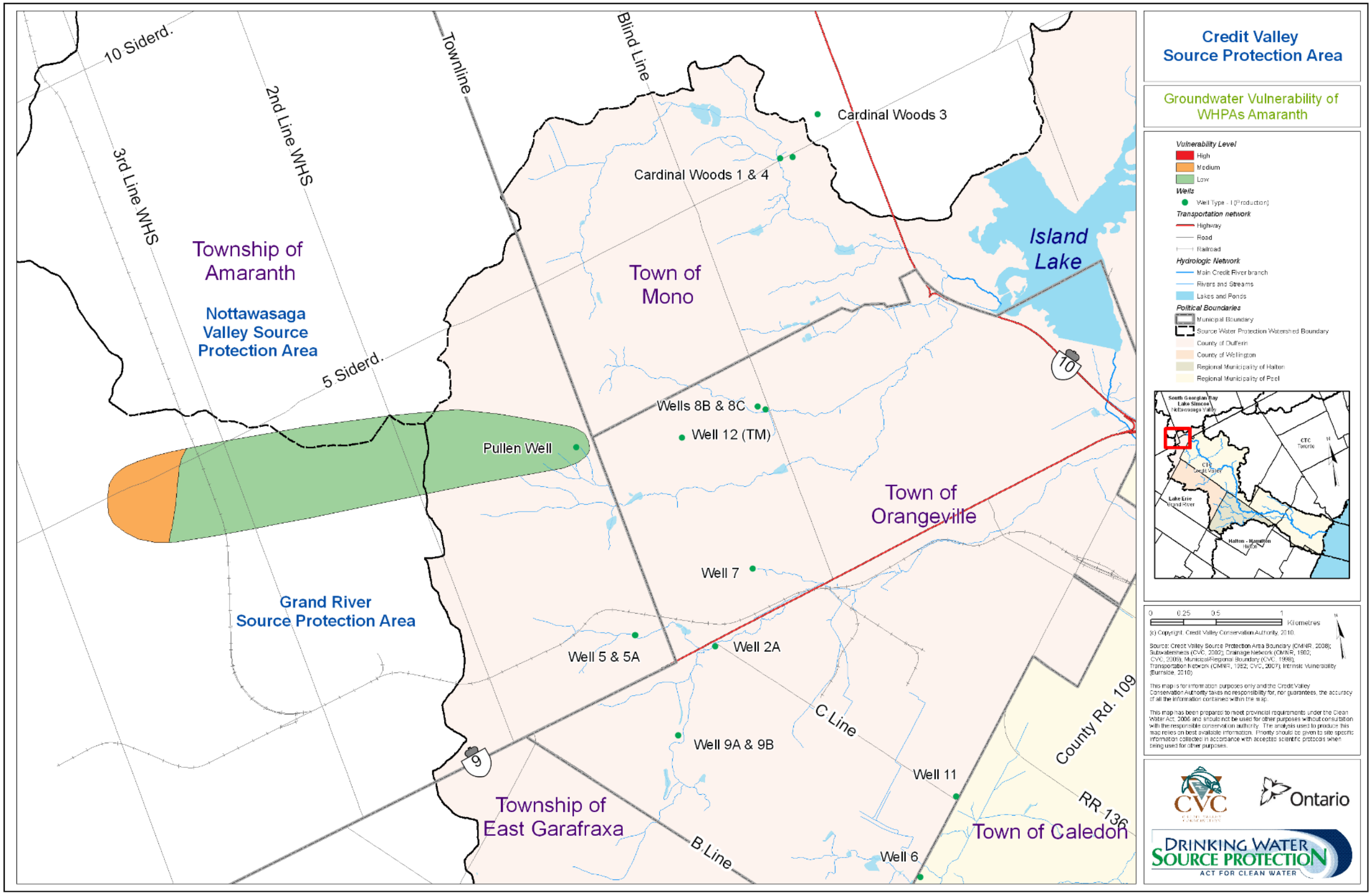

Figure 4.12: Groundwater Vulnerability of WHPAs – Amaranth

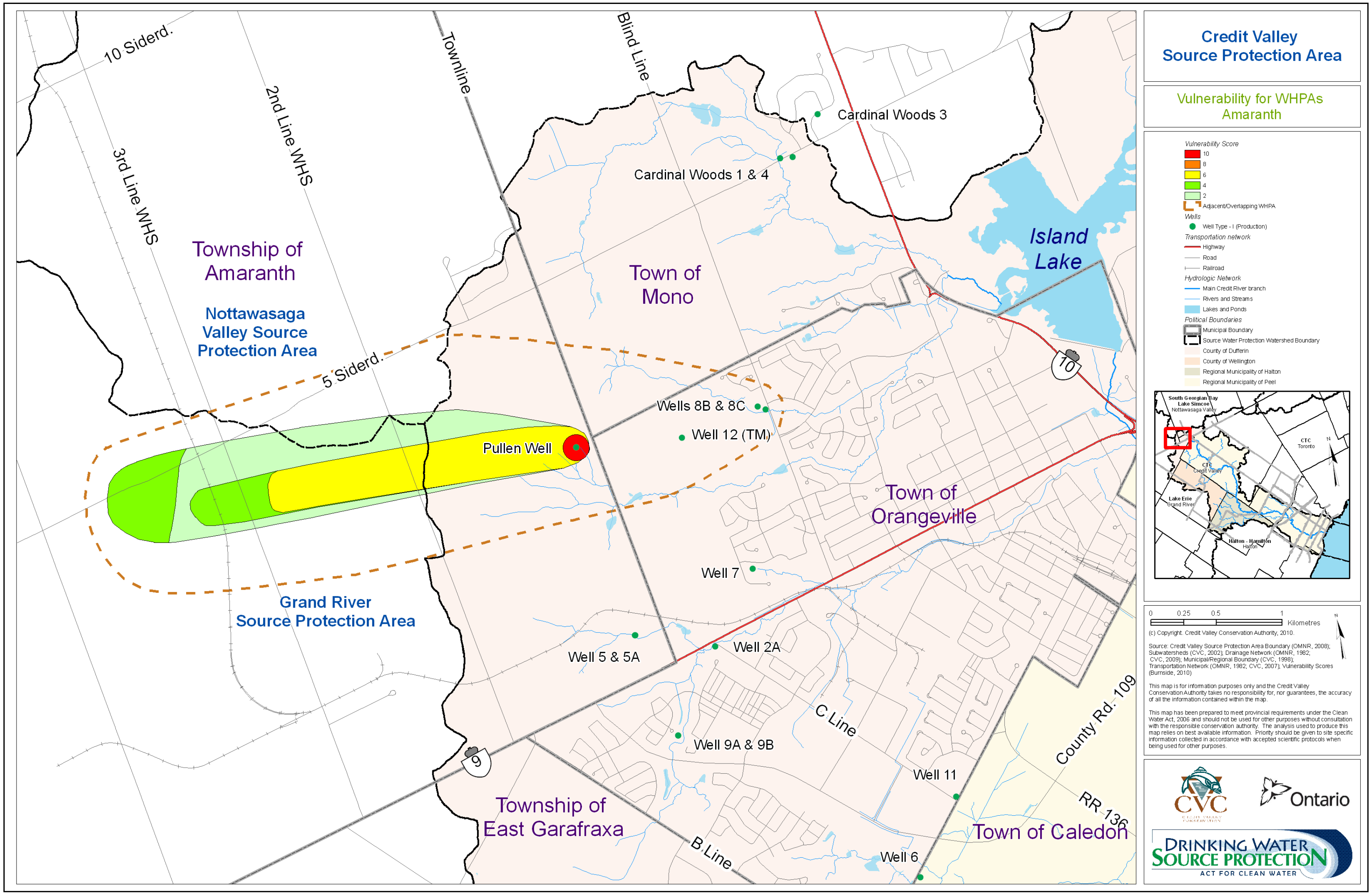

Figure 4.13: Vulnerability Scores for WHPAs – Amaranth

4.6 COUNTY OF WELLINGTON - TOWN OF ERIN AND VILLAGE OF HILLSBURGH

The Town of Erin is comprised of the former Villages of Erin and Hillsburgh and is located in the upper zone of the CVSPA. The Town of Erin operates and provides municipal water supply through the following water systems:

- Erin Village – Wells E7, and E8;
- Hillsburgh Village – Wells H2 and H3; and
- Bel-Erin –2 wells (currently not in service).

The Bel Erin wells were operated in the 1990's, but pumping was stopped in 2002. The Town is evaluating bringing them in service again and therefore they are considered in this analysis.

4.6.1 Geological Setting

The Erin wells are in the Limestone Guelph-Amabel Bedrock Formation, at depths ranging from 43 to 46 metres below ground level. The Hillsburgh wells are also in the Guelph-Amabel Formation, at depths ranging from 50 – 60 metres below ground level. The Bel-Erin wells are in unconfined overburden, consisting of a sand and gravel outwash deposit. The shallowest well is at depths ranging from 11.3 to 16.2 metres below ground level.

4.6.2 Data Sources and Study Methodology

A groundwater study for the Town of Erin was completed in late 2003, which resulted in the creation of a conceptual hydrostratigraphic model, and the development and calibration of a three-dimensional groundwater flow model using MODFLOW. The Erin Groundwater flow model was then used to develop capture zones for the Erin and Hillsburgh water supply wells. Wellhead protection areas were delineated from these capture zones as part of this study.

In 2006, the County of Wellington updated the Erin and Hillsburgh flow model as part of a county-wide study. The findings are documented in the report "The County of Wellington Groundwater Study" (Golder Associates, 2006). The County of Wellington study was undertaken in accordance with the MOECC Technical Terms of Reference for Groundwater Studies 2001/2002, and following the specific terms of reference prepared by the MOECC in March 2003. The data sources used in this study are presented in **Appendix D2**.

Erin and Hillsburgh

In 2009, the pumping rates used in the 2006 County of Wellington study were re-examined by the County of Wellington as part of a proposed update to the County Official Plan Growth Strategy "Memorandum – Updated Capture Zones for Wellington County" (Golder Associates, March 2010). The analysis was undertaken to determine whether updated future projections (and demands) could potentially change the shape and/or orientation of the WHPAs generated in 2006, and if so, whether the WHPAs therefore should be updated. No changes to the Erin and Hillsurgh WHPAs were required. The WHPAs established for Erin and Hillsburgh from the 2006 updates have been used in this Assessment Report.

Aquifer vulnerability of the Erin and Hillsburgh wells was also assessed as part of the previous studies. The 2003 study used the AVI, while the 2006 study used the Intrinsic Susceptibility Index (ISI). Both are accepted by the province as reliable methodologies for assessing intrinsic aquifer vulnerability. The vulnerability analysis undertaken for the Erin and Hillsburgh systems in the 2006 study was updated for this assessment based on the report “WHPA Delineation and Vulnerability Assessment, Town of Erin Municipal Wells” (Blackport Hydrogeologic Inc., in Association with Golder Associates Ltd., April 2010).

Bel –Erin

WHPA delineation and vulnerability analyses were not undertaken for the Bel-Erin wells through previous work. A new study was undertaken for this Assessment Report, which is found in the report “WHPA Delineation and Vulnerability Assessment, Town of Erin Municipal Wells” (Blackport Hydrogeologic Inc., in Association with Golder Associates Ltd., April 2010).

Each document referenced above, has been peer reviewed prior to finalization and submission. The last report in particular, was subject to extensive peer review by municipal representatives, the CVC, and by private consultants prior to acceptance by the CTC SPC, and inclusion in the Assessment Report.

The studies referenced above, contain the foundation technical data and information upon which the summary below has been based.

4.6.3 WHPA A-D Delineation and Vulnerability Scoring

Erin and Hillsburgh

The WHPAs B-D were delineated using a steady-state three-dimensional MODFLOW model. The MODPATH CODE was then used to predict the wellhead capture areas.

The steady-state flow model was calibrated to both water level data and stream flow data. Analyses of the model calculated head contours showed that the model represented the overall gradient and flow directions within the aquifer very well. Once calibrated, the model was used to predict capture zones of the well fields. Detail on the construction and calibration of the groundwater flow model are provided in both the County of Wellington study (2006) and in the Town of Erin (2010) report.

A schematic of the modelling process is shown in **Figure 3.18** of **Chapter 3**, and technical details on numerical model construction and calibration are summarized in **Appendix D2** and fully presented in the foundation reports cited above. WHPAs A-D were delineated using backward and forward particle tracking analysis (**Chapter 4.2**), by pumping each well to steady state at rates determined to be the maximum future average annual groundwater demand that can be sustained by the wells.

The Erin and Hillsburgh pump rates were agreed to through consultation with the municipality, based on forecast rates that considered future growth (40% projection in current population).

Bel-Erin

To delineate WHPAs B-D for the Bel-Erin wells, the larger groundwater model was used with refinements made to the conceptual geologic model to focus on the local setting. Since the Bel-Erin wells are shallow overburden wells and the other municipal wells are bedrock wells, the model was refined to look at more local overburden conditions. Technical details on numerical model construction and calibration are summarized in **Appendix D2** and fully presented in the foundation reports.

Since the Bel-Erin wells are not currently in operation and future plans for their use are unknown, the WHPAs were delineated using the permitted rates. These rates are reported in **Appendix D2 (Table D.17)** and are considered to be conservative.

The WHPAs for Erin, Hillsburgh and Bel-Erin are shown in Figure 4.14to Figure 4.16**.** The modelling results indicate that the 25-year capture zone for Erin Well No. 7 extends approximately 5 km to the northwest, while the 25-year capture zone for Erin Well No. 8 extends approximately 1.5 km to the south. The land use overlying virtually all of the 25-year capture zones for both wells is rural agricultural.

The results indicate that the 25-year capture zones for the Hillsburgh wells merge together and extend approximately 3 km to the northwest in the direction (upgradient) of regional groundwater flow in the bedrock. The land use overlying the 25-year capture zones is mainly rural agricultural, although the urban area of Hillsburgh is within the capture zone for Well H3.

The results indicate that Bel-Erin's 25-year capture zone extends in a southerly direction approximately 2.6 km from the wells to locally higher topographic recharge areas.

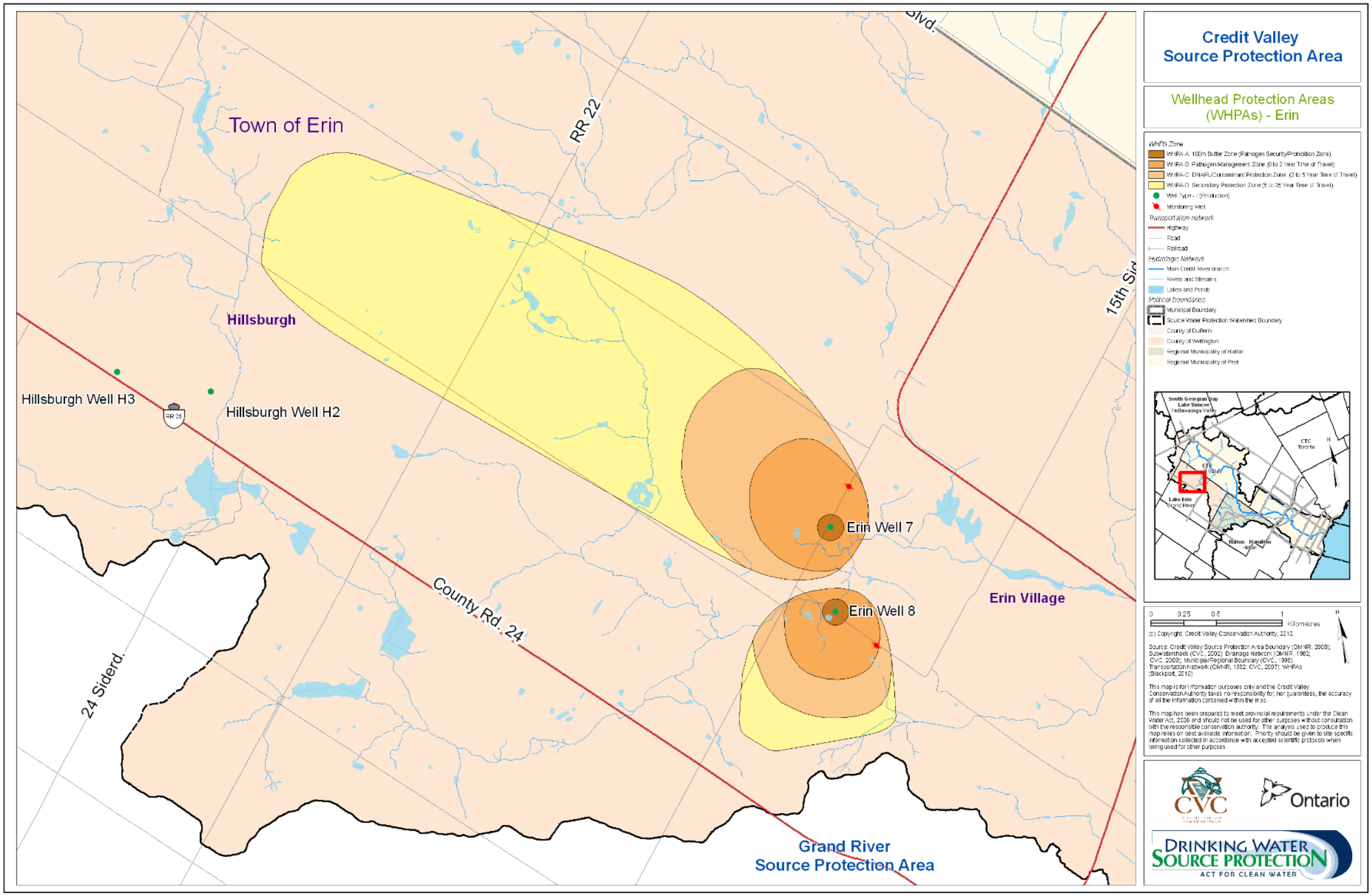

Figure 4.14: Wellhead Protection Areas (WHPAs)—Erin

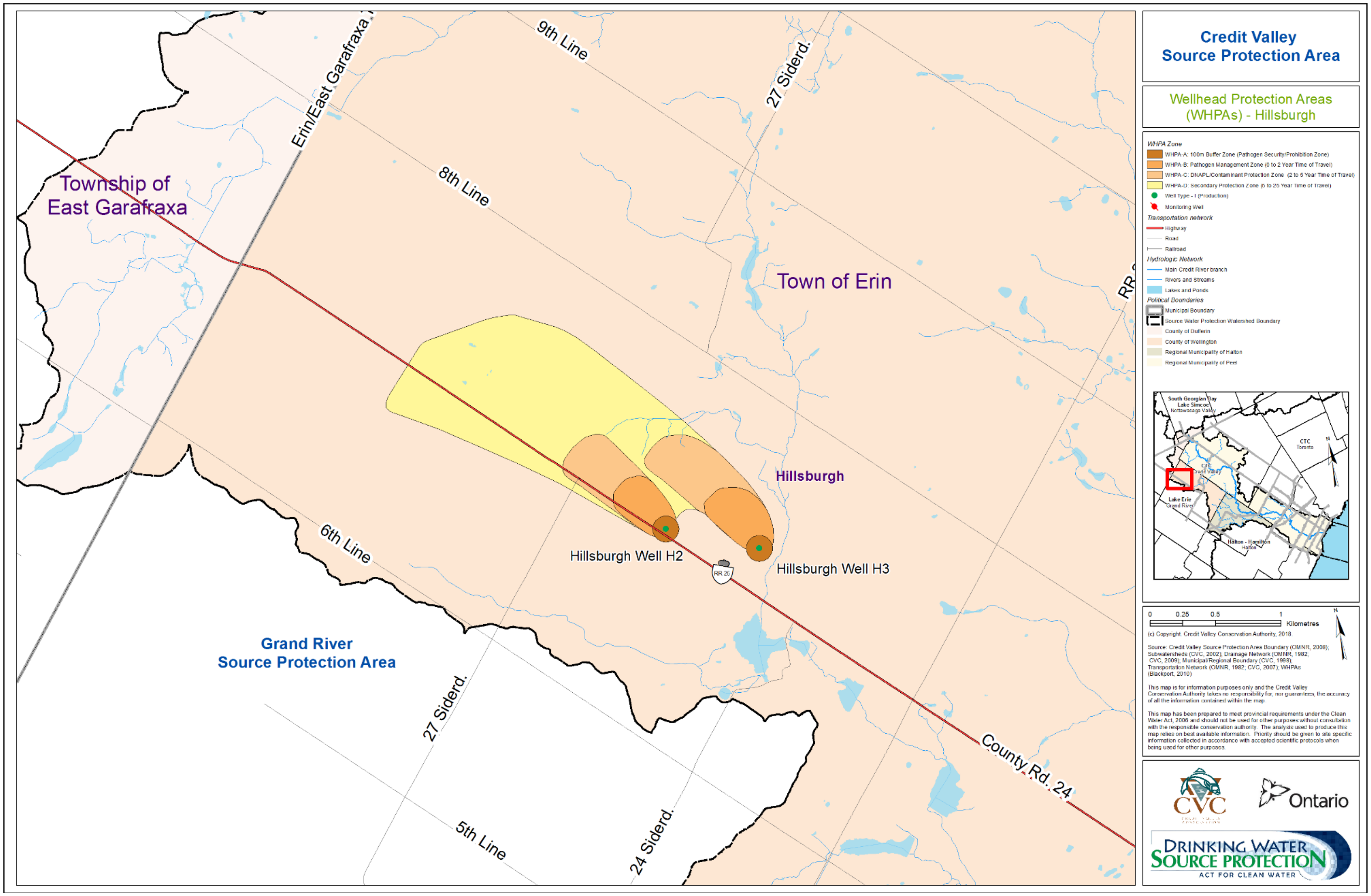

Figure 4.15: Wellhead Protection Areas (WHPAs)—Hillsburgh

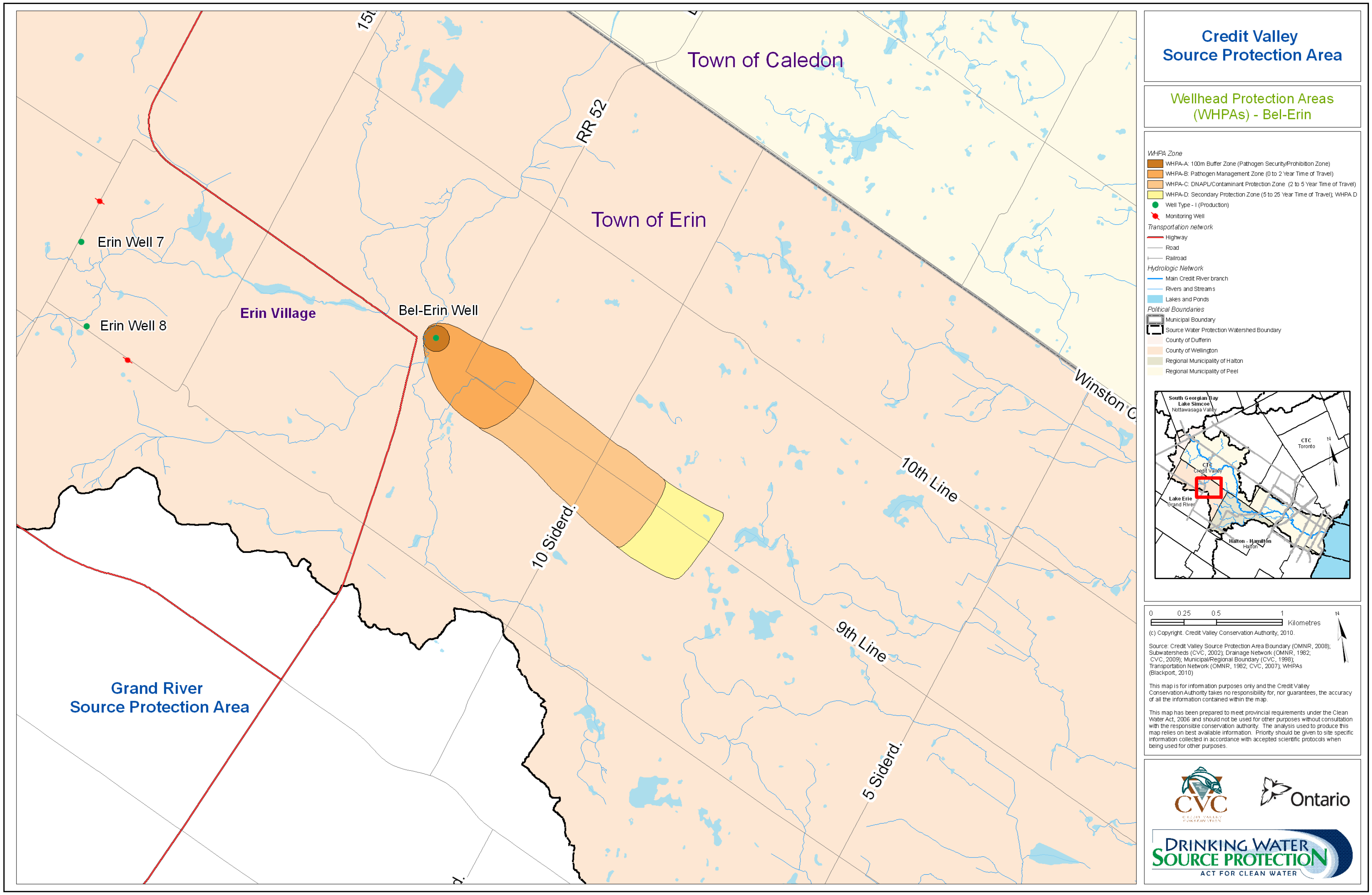

Figure 4.16: Wellhead Protection Areas (WHPAs)—Bel-Erin

Vulnerability was assessed using the Intrinsic Susceptibility Index (ISI) approach. This approach was selected for this area, based on the flowing:

- The approach provides a conservative assessment of vulnerability and can be derived based on information in the MOECC water well database;
- More advanced methods require additional data input that is not as readily available for the study area; and
- An ISI assessment had been previously completed in 2006 for the Town of Erin.

Additional information of the ISI methodology is given in **Appendix D2**.

The groundwater vulnerability for Erin, Hillsburgh and Bel-Erin are shown in **Figure 4.17**, **Figure 4.18**, and **Figure 4.19**. The vulnerability of the bedrock aquifer that supplies the municipal wells in Erin is generally medium to low, with overburden thicknesses within the capture zone ranging from about 10 metres in the vicinity of the pumping wells, to over 40 metres in the 2 to 25 year time of travel zone. A local area of high vulnerability is mapped in the vicinity of Erin Well 8, based on the thin overburden and limited fine-grained soils in the local MOECC well logs.

The vulnerability of the bedrock aquifer that supplies the municipal wells in Hillsburgh follows a similar pattern to that observed for Erin that is generally medium to low. The overburden thickness above the bedrock aquifer is generally in the order of 40 metres thick, although the overburden thins in an easterly to south-easterly direction, towards the West Credit River.

The vulnerability of the overburden aquifer in the vicinity of the Bel-Erin wells is high throughout the entire area. Much of the area is an outwash sand and gravel, and although there are local areas showing the presence of "pockets" of silt till, it is not continuous throughout the area. As a result, the entire area is considered to be highly vulnerable to contamination from a surface source.

WHPA vulnerability was scored by overlaying the groundwater vulnerability classification (high, medium, low) of the wider area, on the delineated WHPAs A to D, and applying a score, as shown on **Table 4.2**. The WHPA-A is always scored as 10, while the other WHPAs are assigned according to the relevant vulnerability classification. The highest vulnerability tend to exist in WHPAs A and B at Erin and Hillsburgh, but also cover the WHPA-C at Bel-Erin. This is logical when considering that the Bel-Erin wells are screened in relatively shallow overburden (vis-à-vis bedrock at Erin and Hillsburgh) with little protective cover.

Vulnerability scoring in Erin, Hillsburgh and Bel Erin WHPAs is shown in **Figure 4.20**, **Figure 4.21**, and **Figure 4.22.**

4.6.4 Transport Pathways

The features studied within the context of this analysis are outlined in **Chapter 4.2**. No transport pathways were identified so the vulnerability rating was not bumped up.

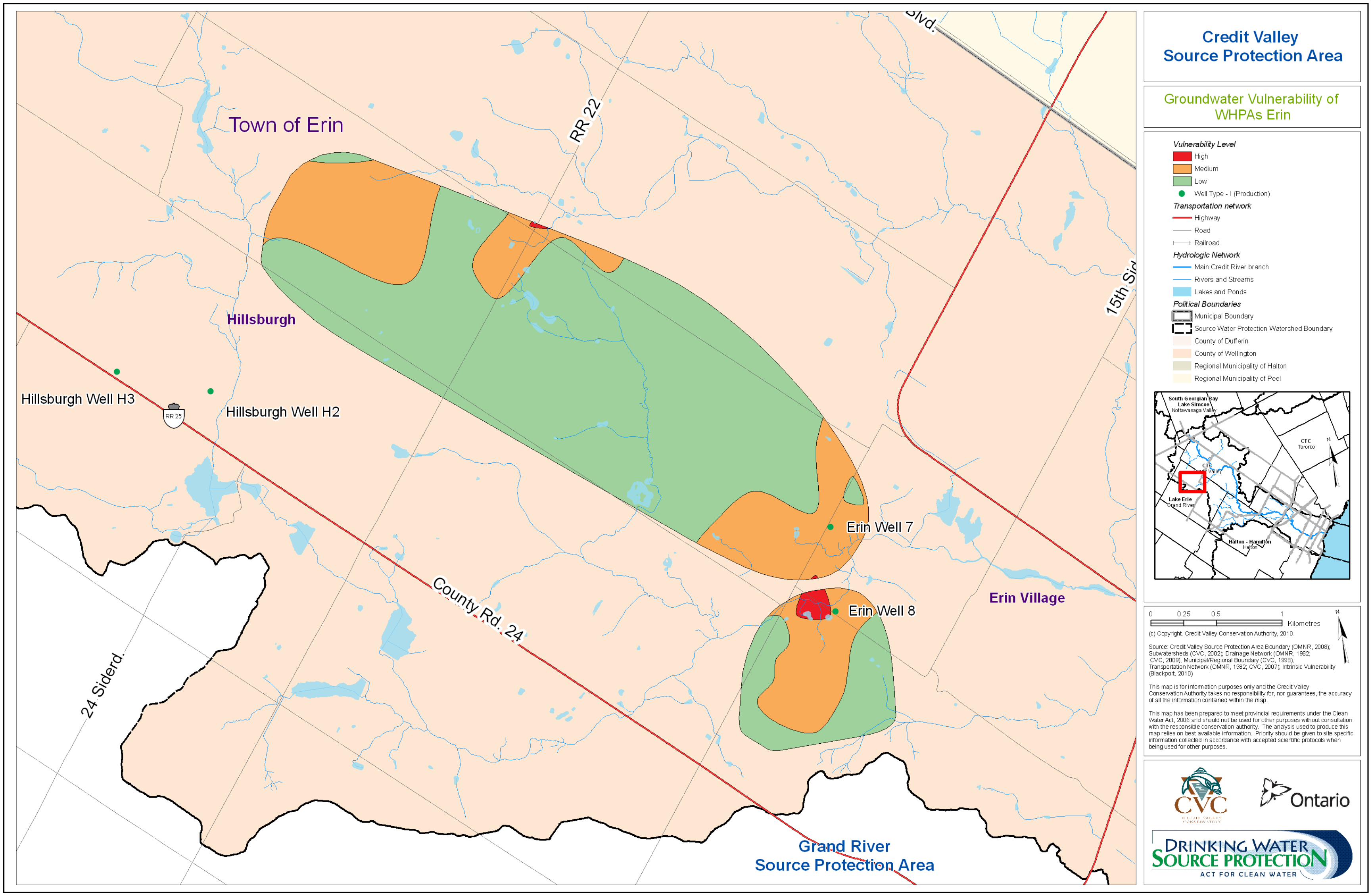

Figure 4.17: Groundwater Vulnerability of WHPAs—Erin

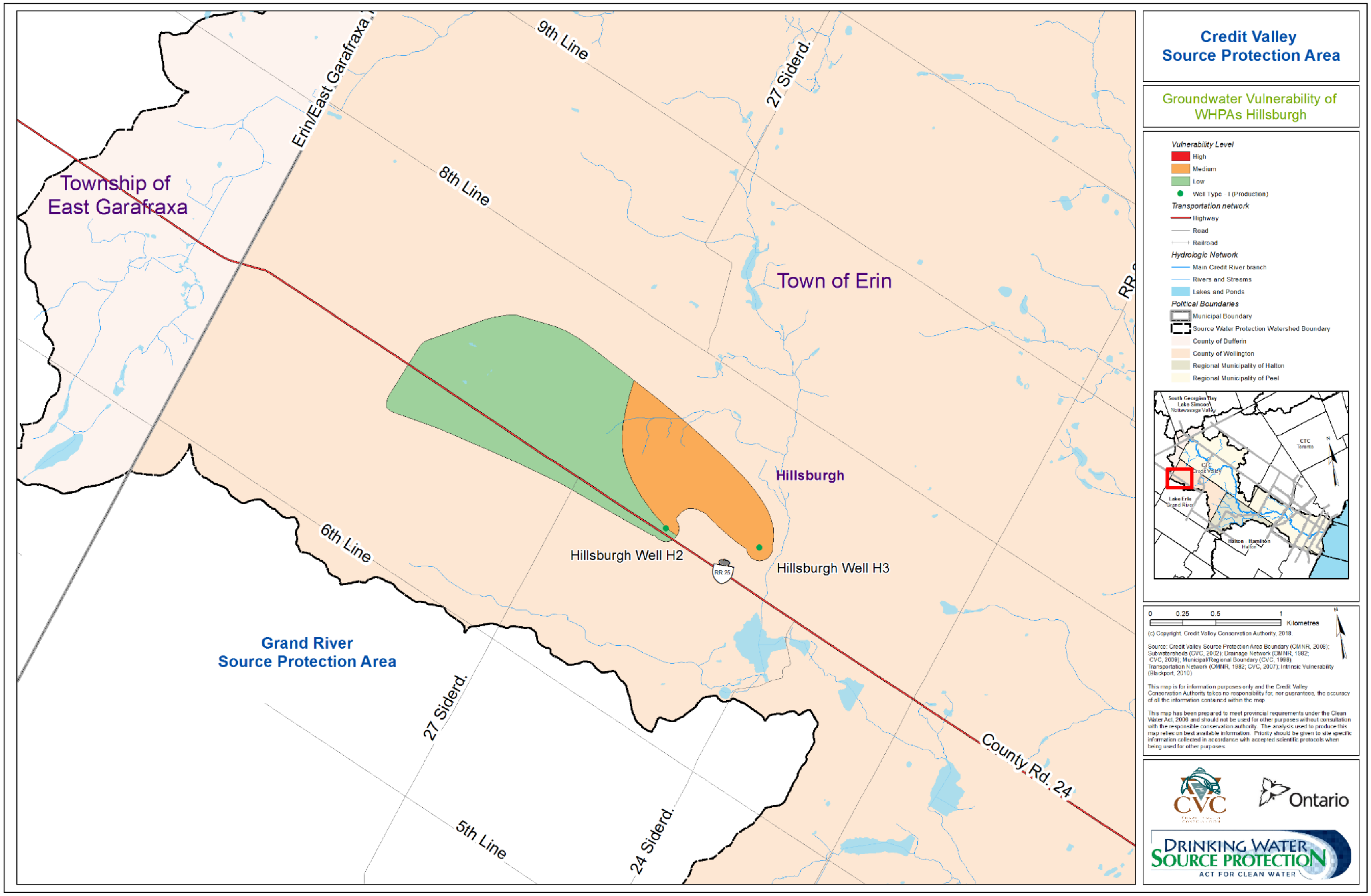

Figure 4.18: Groundwater Vulnerability of WHPAs—Hillsburgh

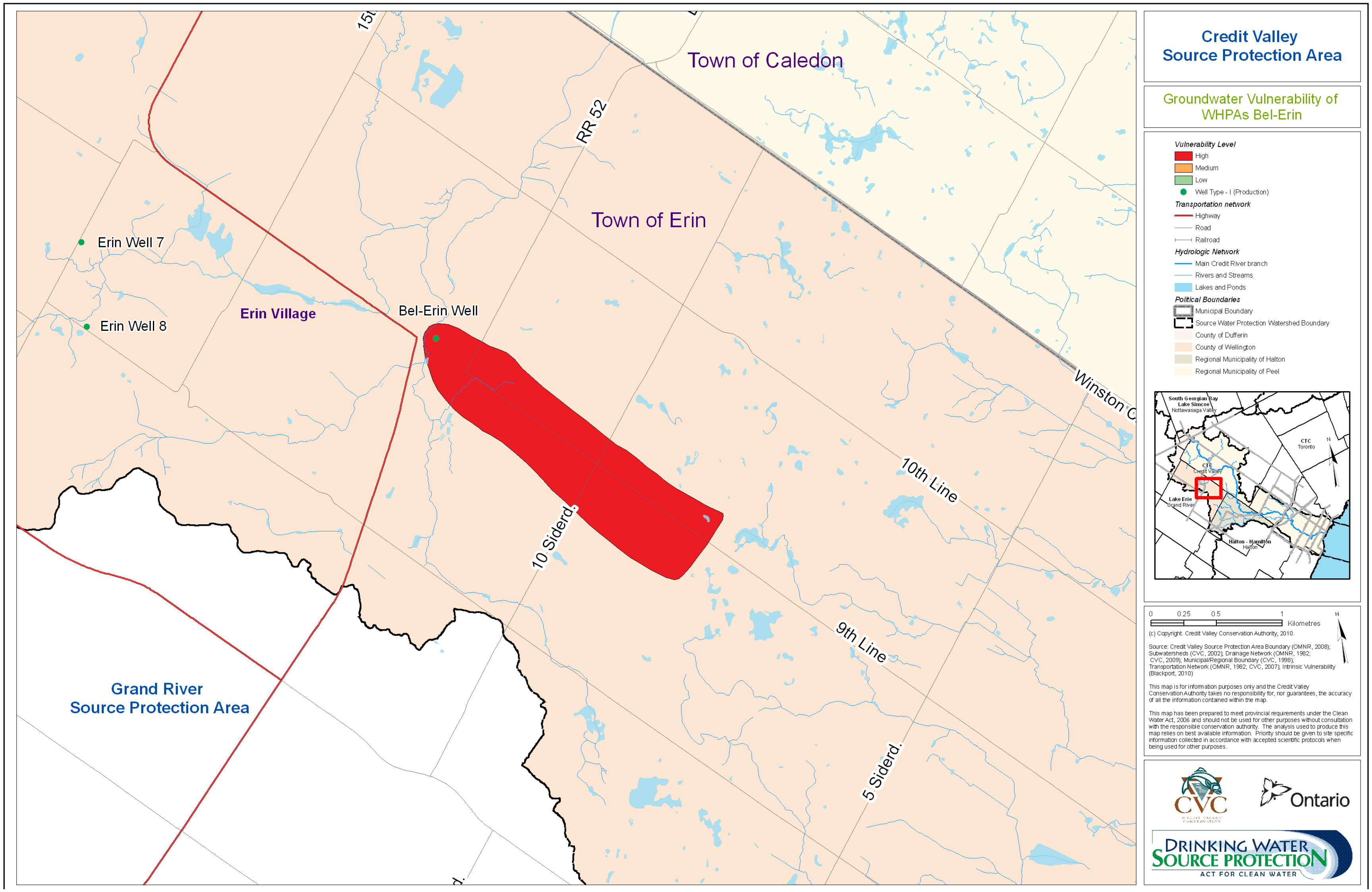

Figure 4.19: Groundwater Vulnerability of WHPAs—Bel-Erin

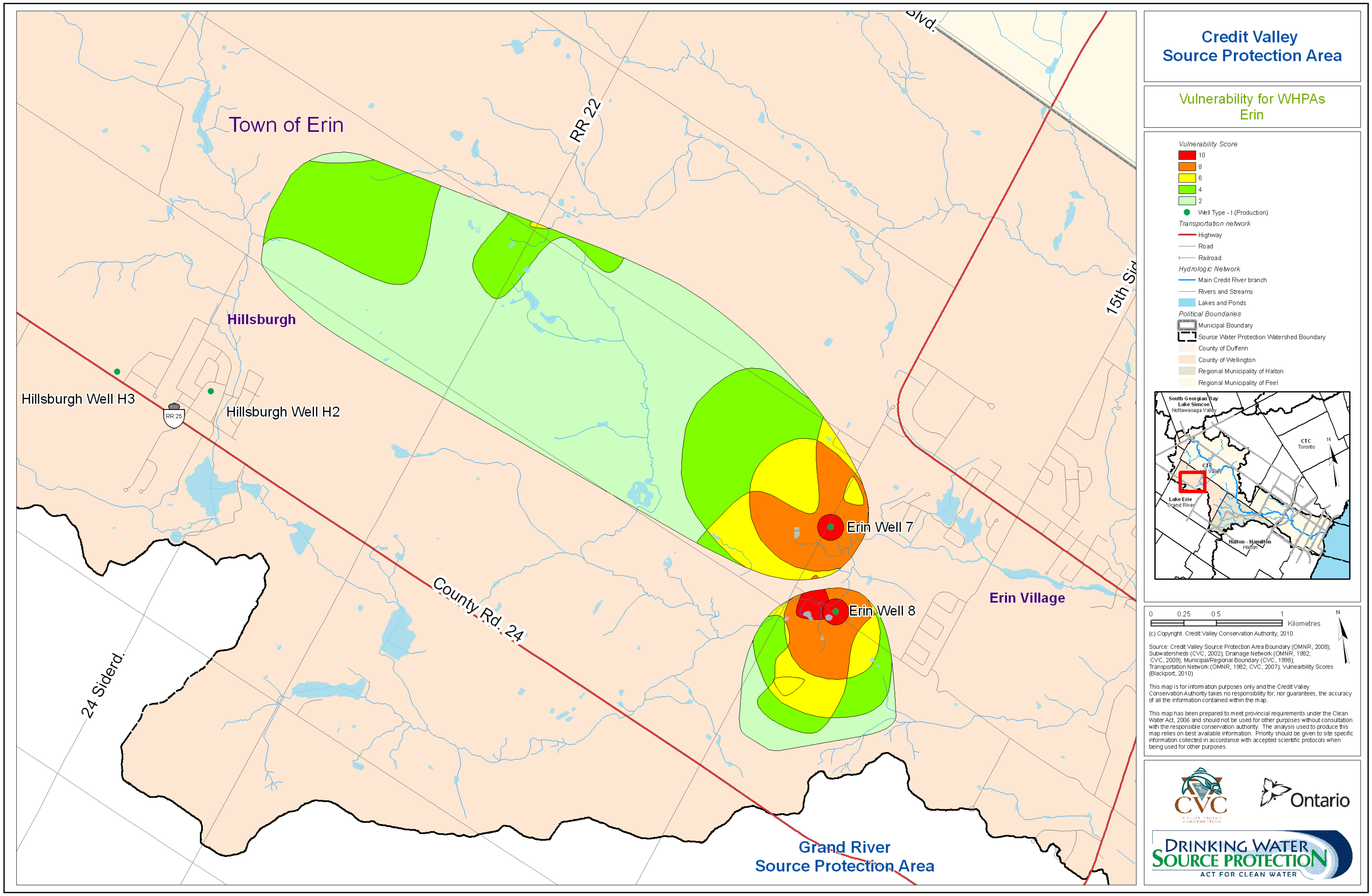

Figure 4.20: Vulnerability Scores for WHPAs – Erin

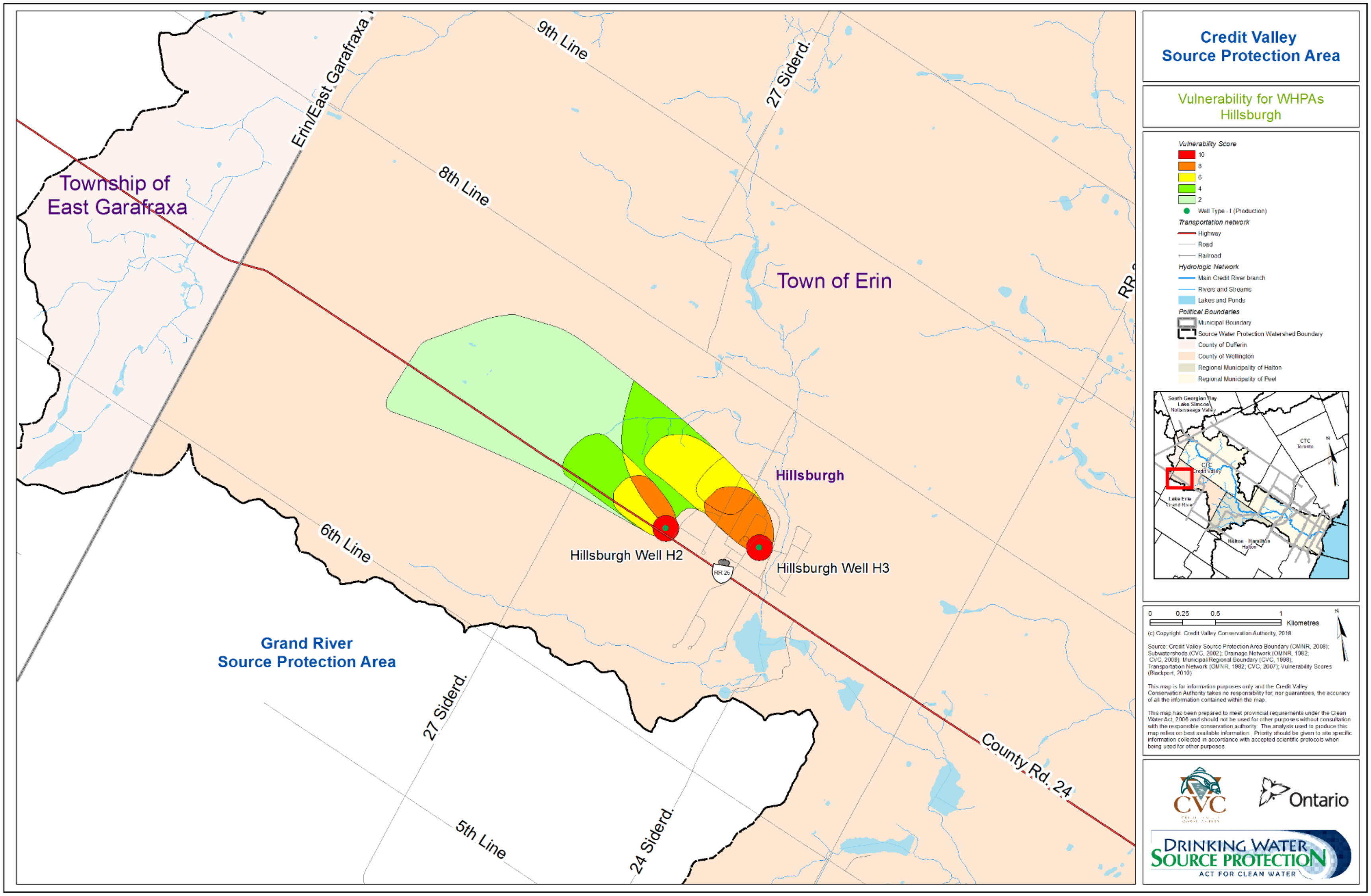

Figure 4.21: Vulnerability Scores for WHPAs – Hillsburgh

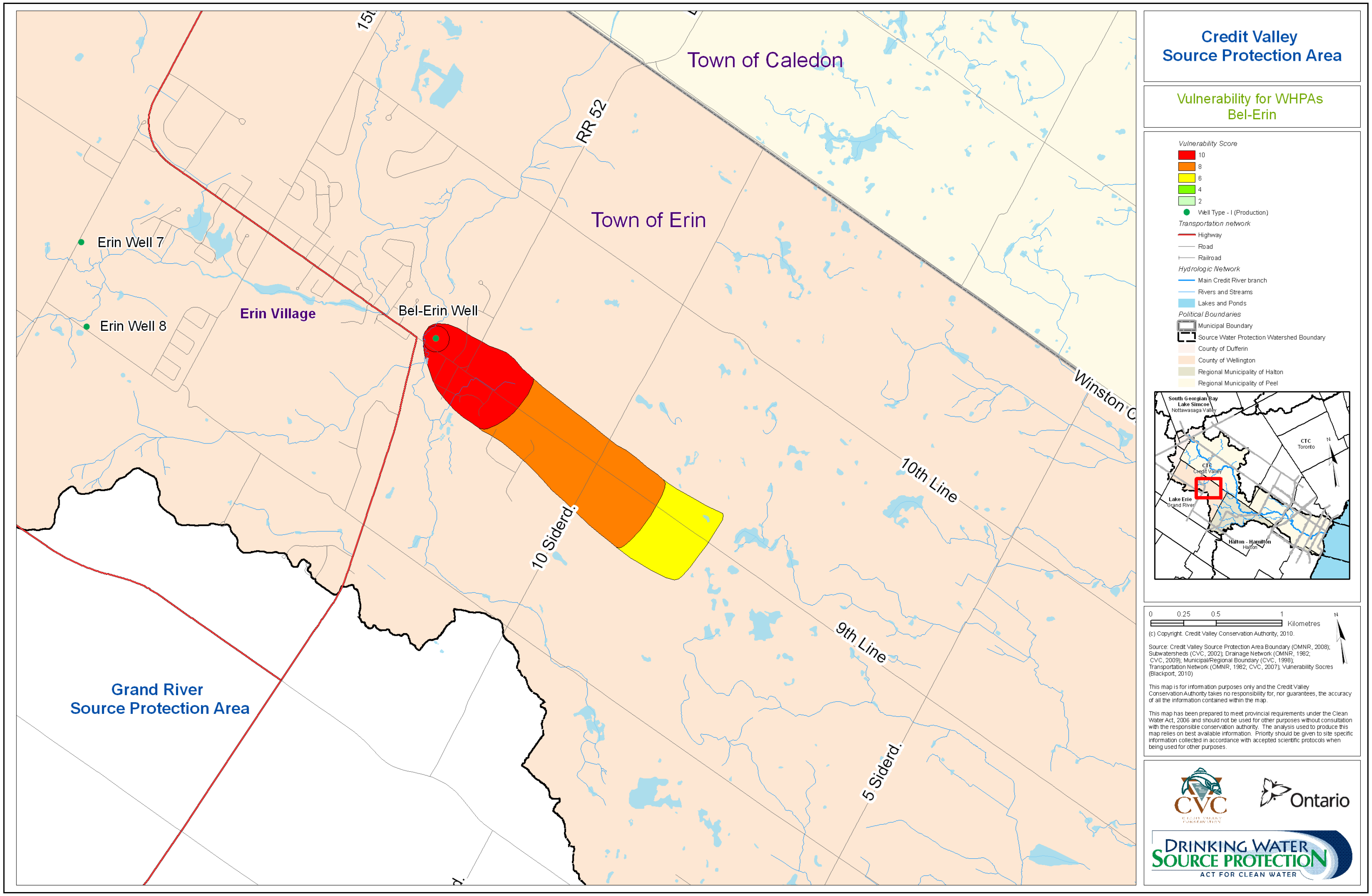

Figure 4.22: Vulnerability Scores for WHPAs – Bel-Erin

4.6.5 Uncertainty Assessment

Overall uncertainty associated with the analyses on the three systems is summarized in **Table 4.7** and further discussed in **Appendix D2**.

- A regional scale groundwater flow model has been developed and calibrated to water levels and stream flows were made using an extensive data base. There will be inherent uncertainties at this scale of assessment, but the studies provide a good understanding of the conceptual hydrogeologic model.
- Local testing has been conducted for each well field, including both pumping tests to assess the sustainable yield of the well and pumping tests to determine any potential connections to adjacent surface water features.
- All WHPAs B-D were delineated with a numerical groundwater flow model, using local scale data and the results calibrated reasonably well with the field data.
- The uncertainty in capture zone delineation was addressed by the use of two correction factors an expansion of the capture zone by 5 degrees from the centerline, and an increase of 20% from the centerline of the capture zone.
- There is uncertainty associated with the ISI mapping, given the interpolation between data points and the variation in the geologic descriptions for private water wells. This data was examined, based on interpreted hydrogeologic conditions and a determination was made as to whether any data was unreliable and should be excluded.
- There are potential uncertainties with transport pathways for private wells, however there are few private wells within the capture zones for Erin, Hillsburgh and Bel-Erin, and their locations are generally known.

Table 4.7: Uncertainty Assessment—Town of Erin

Wellfield	Uncertainty Type	WHPA-A	WHPA-B	WHPA-C	WHPA-D
Erin	Delineation of WHPA	Low	Low	Low	Low
	ISI computation	Low	Low	Low	Low
	Vulnerability Scores	**Low**	**Low**	**Low**	**Low**
Hillsburgh	Delineation of WHPA	Low	Low	Low	Low
	ISI computation	Low	Low	Low	Low
	Vulnerability Scores	**Low**	**Low**	**Low**	**Low**
Bel-Erin	Delineation of WHPA	Low	Low	Low	Low
	ISI computation	Low	High	Low	Low
	Vulnerability Scores	**Low**	**High**	**Low**	**Low**

4.7 REGIONAL MUNICIPALITY OF HALTON - TOWN OF HALTON HILLS

Halton Region provides municipal supply to the Town of Halton Hills in the CVSPA, through the Georgetown and Acton groundwater systems.

The Georgetown water system is comprised of seven wells in three wellfields:

- Lindsay Court – well 9;
- Princess Anne – wells 5 and 6; and
- Cedarvale Park – wells 1a, 3a, 4, and 4a.

Cedarvale wells 1A and 3A are replacement wells (for older wells, Well 1 and 3, which have been decommissioned), while Well 4 and Well 4A operate as supply/back-up.

The Acton water system is comprised of five wells in three wellfields:

- 4th Line;
- Davidson – wells 1 and 2; and
- Prospect Park – wells 1 and 2.

The previous WHPA B-D delineation and vulnerability assessments (CVC, 2012) for these systems were premised on technical work completed in 2009. With the advent of the Tier 3 Water Budget Study for Halton Hills in 2010, advancements in geological knowledge base have occurred through pointed field investigations and the acquisition of higher quality borehole data. The availability of new datasets has prompted several key revisions to the conceptual and numerical groundwater models that form the basis for WHPA B-D delineation.

Model runs utilizing the revised numerical model have shown vast changes in predicted source areas from which the municipal wells draw water, prompting the Region of Halton to undertake a revision of the previous WHPA delineations.

The updated WHPA B-D delineation and vulnerability assessment are described in the report "Updated Vulnerability Analysis Acton and Georgetown Well fields, Wellhead Protection Delineation Report" (AquaResource Inc. and Aecom Canada Limited, November 2012). This document was extensively peer reviewed by municipal staff, the CVC, and by private consultants prior to acceptance by the CTC SPC. It contains the foundation technical data and information upon which the summary below has been based.

4.7.1 Geological Setting

The Georgetown wells are located in aquifers in a bedrock valley. This bedrock valley originates west of Acton and trends southwesterly over the Niagara Escarpment, through Limehouse into Georgetown. Georgetown's wells are at depths varying between 25 and 35 metres below ground level.

The knowledge of the geology and hydrogeology of the Acton Buried Bedrock Valley System has been enhanced through the collection of high quality field data and by refinements in the modelling studies recently undertaken as part of the Tier 3 Water Budget Study for The Town of Halton Hills.

The Acton wells draw water from both the overburden and bedrock aquifers. Prospect Park Wells are within the overburden of the Acton Bedrock Valley Aquifer System, while the Fourth Line and Davidson wells draw water from the bedrock in the Amabel formation. Acton's wells are screened at depths varying between 14 metres and 24 metres below ground level.

4.7.2 Data Sources and Study Methodology

An initial description of the hydrogeology of the area was presented in the Halton Aquifer Management Plan (Holysh, 1997). In 2001, that model was updated, and locally applied in the vicinity of the Georgetown area for the purpose of evaluating a proposed well on 6th Line, southwest of Georgetown (Earthfx, 2002). Further model updates were initiated in 2005 by the Conservation Authority Moraine Coalition (CAMC) and the Region of Halton. These updates focused on improving the numerical representation of regional till and bedrock surface topography. The 2005 model updates were incorporated into a Water Budget Model of the CVC area, prepared by AquaResource (2006).

Updated capture zone delineations were subsequently undertaken by Earthfx, which built upon the 2006 CVC model. This work occurred concurrently with updates on well rating for the Cedarvale wellfield. The collective data informed refinements in the conceptual model, which was utilized to support the Cedarvale wellfield Class EA project. The numerical groundwater model was subsequently revised and applied to delineate the WHPAs B-D for Source Water Protection in 2009 (CVC, 2012).

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

Model runs utilizing the revised numerical model have shown vast changes in predicted source areas from which the municipal wells draw water, necessitating a revision of the previous WHPA delineations.

4.7.3 WHPA A-D Delineation and Vulnerability Scoring

A key task in the WHPA B – D delineation was the development of a detailed three-dimensional groundwater flow model of the Acton and Georgetown wellfields and surrounding area using the most current conceptual model and field data. The model was developed using the finite-element FEFLOW software code and was calibrated to steady-state groundwater levels and stream-flow observations. The simulated steady-state conditions represented average water levels and pumping rates in 2005 through 2009.

Groundwater recharge specified across the top surface of the groundwater flow model was estimated via a calibrated integrated groundwater-surface water model developed for the Tier 3 assessment using the MIKESHE software program.

In developing the model, the following tasks were undertaken:

- Review of the physical setting (topography, physiography, surface water hydrology and stratigraphy) of the study area;
- Development of a conceptual hydrogeologic model to define hydrostratigraphy and general groundwater flow conditions; and
- Development, and calibration of a numerical model to represent groundwater flow under annual average conditions.

The model was calibrated to steady state using observation wells within the modelled area. A schematic of the flow modelling process is shown in **Figure 3.18**, and technical details on model construction and calibration are summarized in **Appendix D2**, and detailed in the foundation report.

WHPAs B-D were delineated through using backward and forward particle tracking analysis (**Chapter 4.2**). The WHPAs were delineated by independently pumping each well field to steady state, at the maximum permitted rates (**Appendix D2**). Rate selection considered future demand and growth projections for the Town of Halton Hills. WHPAs delineated for Acton and Georgetown wells are shown in Figure 4.23through Figure 4.25**,** and Figure 4.26**,** respectively.

WHPAs B-D for the Prospect Park wells extend up-gradient of the wellfield in a northwest direction. WHPAs-B, C and D exhibit a tear-drop shape, with an elongated tail that extends up-gradient of the wells in a northwesterly direction. WHPA-D extends approximately 5 km up-gradient of the wells, crossing the watershed divide into the GRSPA. WHPA-C extends about 2 km upgradient of the wells, and WHPA-B extends around 1 km up-gradient of the wells. The previous WHPAs show similar length, but less width despite being simulated under the same pumping rate. Differences relate to a smaller recharge rate in the updated model, but are not significant.

WHPAs B-D for the Davidson wells extend up-gradient of the wellfield initially in a northwest direction then more northerly in WHPA-D, which extends about 5 km up-gradient, and crosses the watershed divide into the GRSPA. Previous WHPA delineations were 200 to 300 m wider, and did not extend as far upgradient over the 2-year and 5-year time of travel. The differences are likely attributable to lower recharge rates and updated interpretation in the revised bedrock conceptualization, but are not significant.

WHPAs B-D for the Fourth Line Well are similar in shape to those delineated for Davidson, which is expected given the commonalities in their hydrogeologic settings. WHPA-D extends about 3.5 km up-gradient of the wellfield, and crosses the watershed divide into the GRSPA. WHPA-B, C and D have similar maximum widths. The previous capture zones appear to be thinner and longer, extending about 800 m further up-gradient than the current delineation. This change may be due to variations in the extent, topography and permeability of local bedrock units, and to differences in recharge rates.

The WHPAs B-D for the Georgetown wells overlap since they are all screened in the sediment infill of the buried bedrock valley. The WHPAs extend to the west to Limehouse; to the south past the Cedarvale wells; and to the northwest about 3 km from Limehouse.

The current WHPAs for Georgetown differ significantly from the previous ones (CVC, 2012) in that they:

- No longer extend west continuously through the Limehouse area into Acton;
- Spread to the northwest through bedrock aquifers to areas above the escarpment;
- Now expand to the south along the Inglewood-Milton buried bedrock valley into the Sixteen-Mile Creek Subwatershed of the Halton Conservation Area; and
- No longer extend south into the area of the Acton Quarry.

The differences result from refinements made to the conceptual geological model, and are based on newer datasets generated for the Tier 3 study. The revisions have allowed for an improved understanding of the shape and morphology of the buried bedrock valley system, and of the thickness and extent of its sand and gravel infill, which serve as the major aquifer for the Georgetown wells.

The previous delineations were based upon a conceptual model that assumed relative continuity in the aquifer between Acton and Georgetown. This resulted in a westward extension of the WHPA–C and D between Georgetown and Acton.

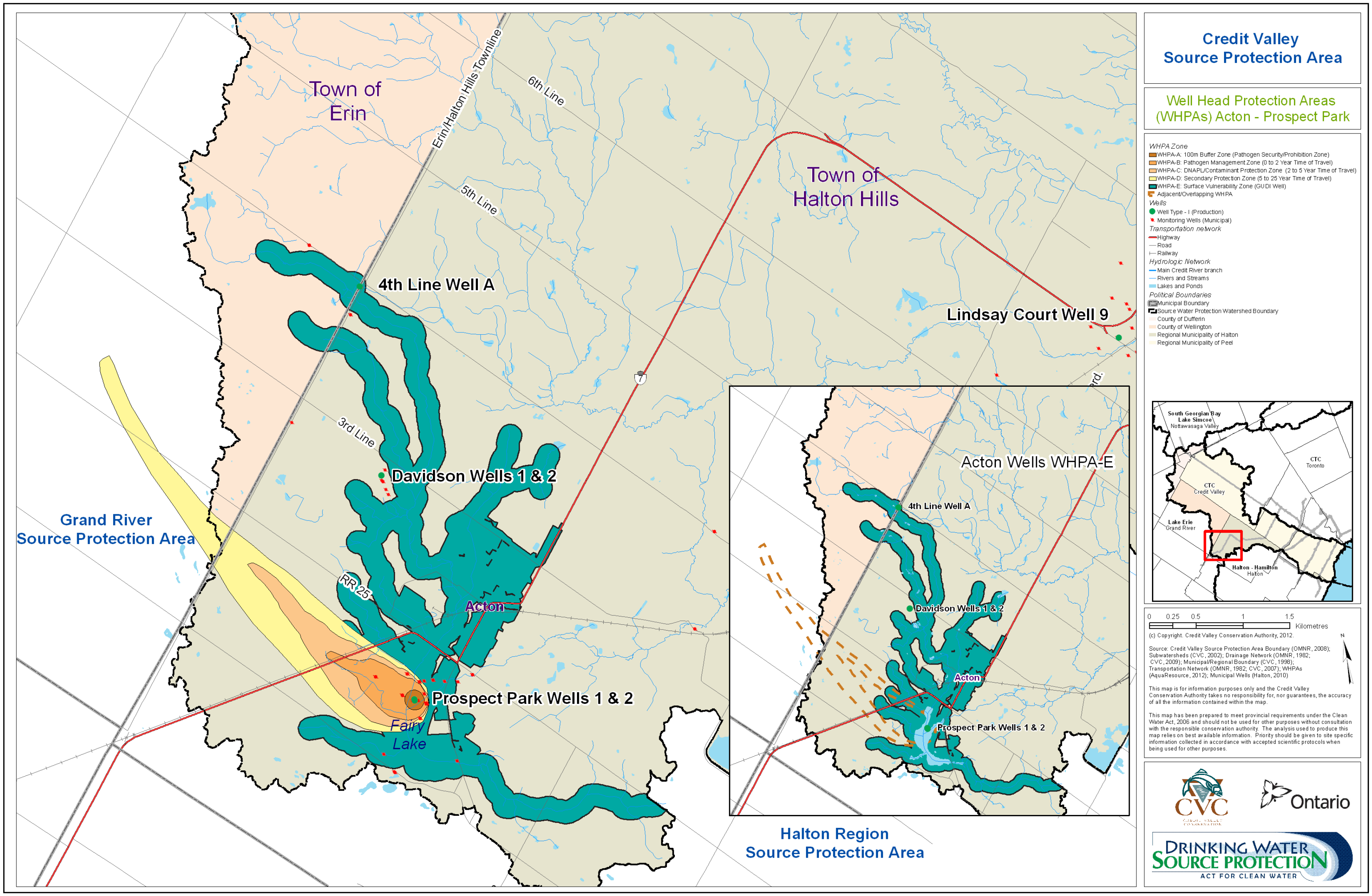

Figure 4.23: Wellhead Protection Areas (WHPAs)—Acton (a) Prospect Park

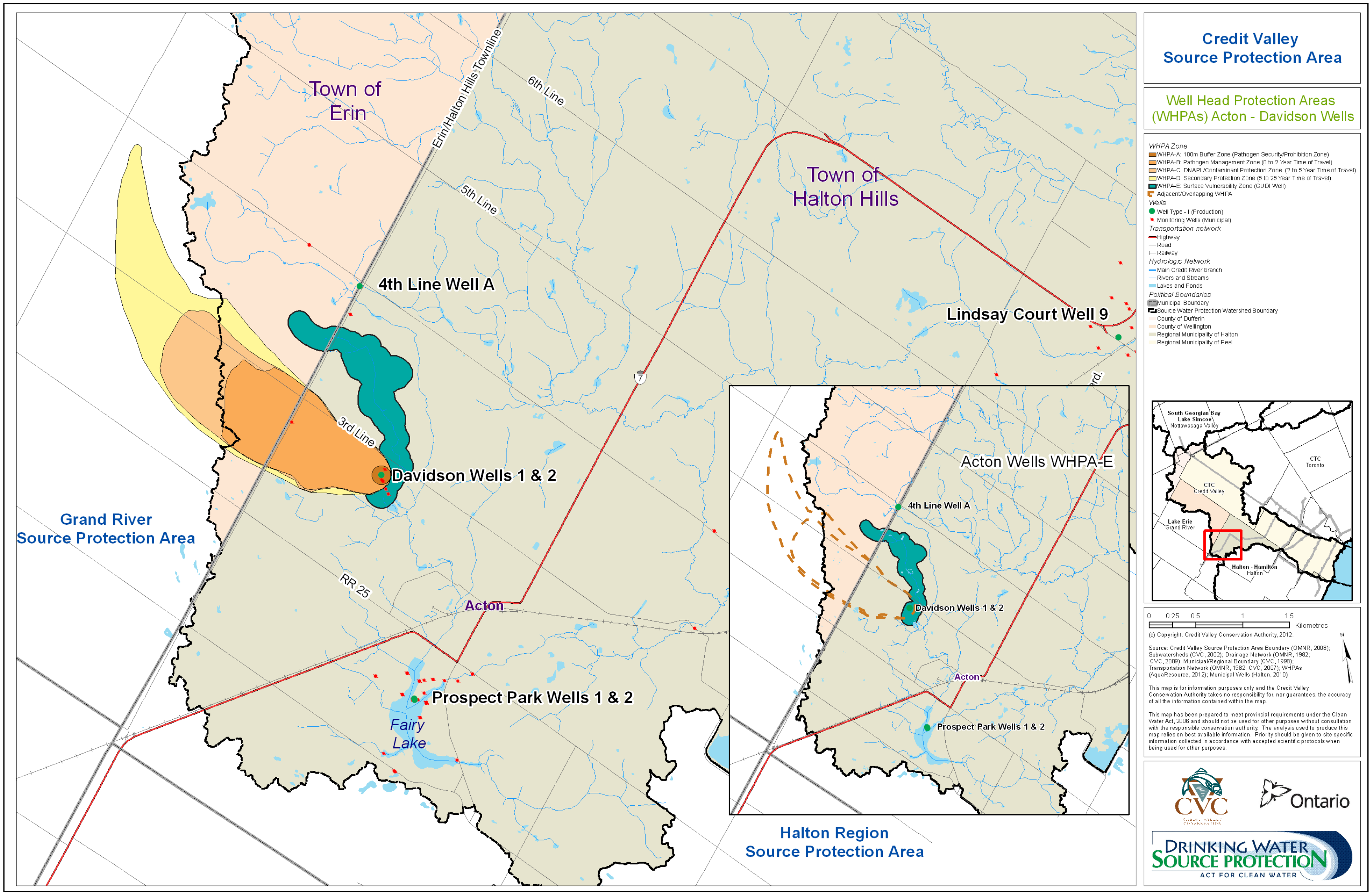

Figure 4.24: Wellhead Protection Areas (WHPAs) – Acton (b) Davidson Wells

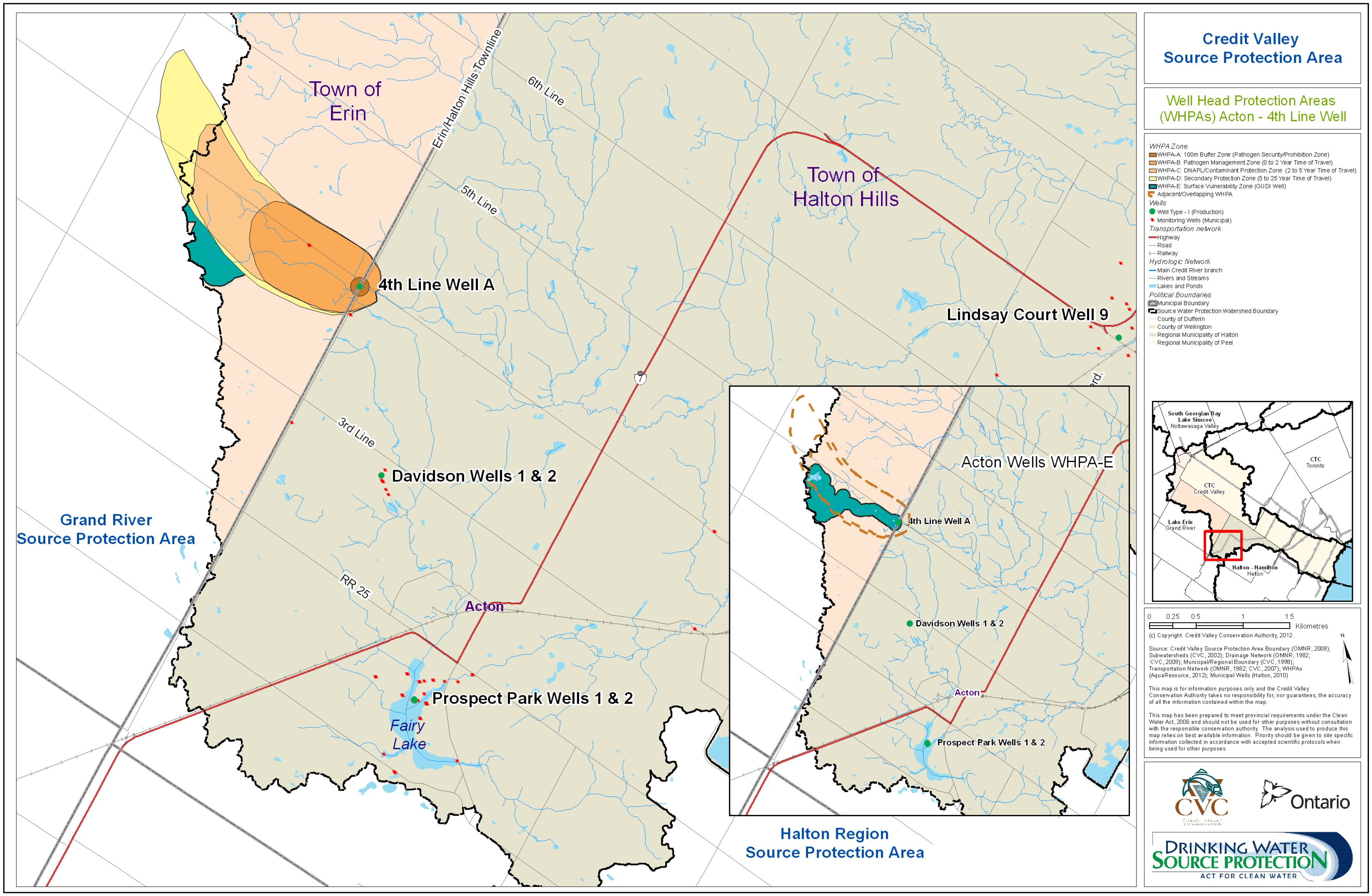

Figure 4.25: Wellhead Protection Areas (WHPAs) – Acton(c) Fourth Line

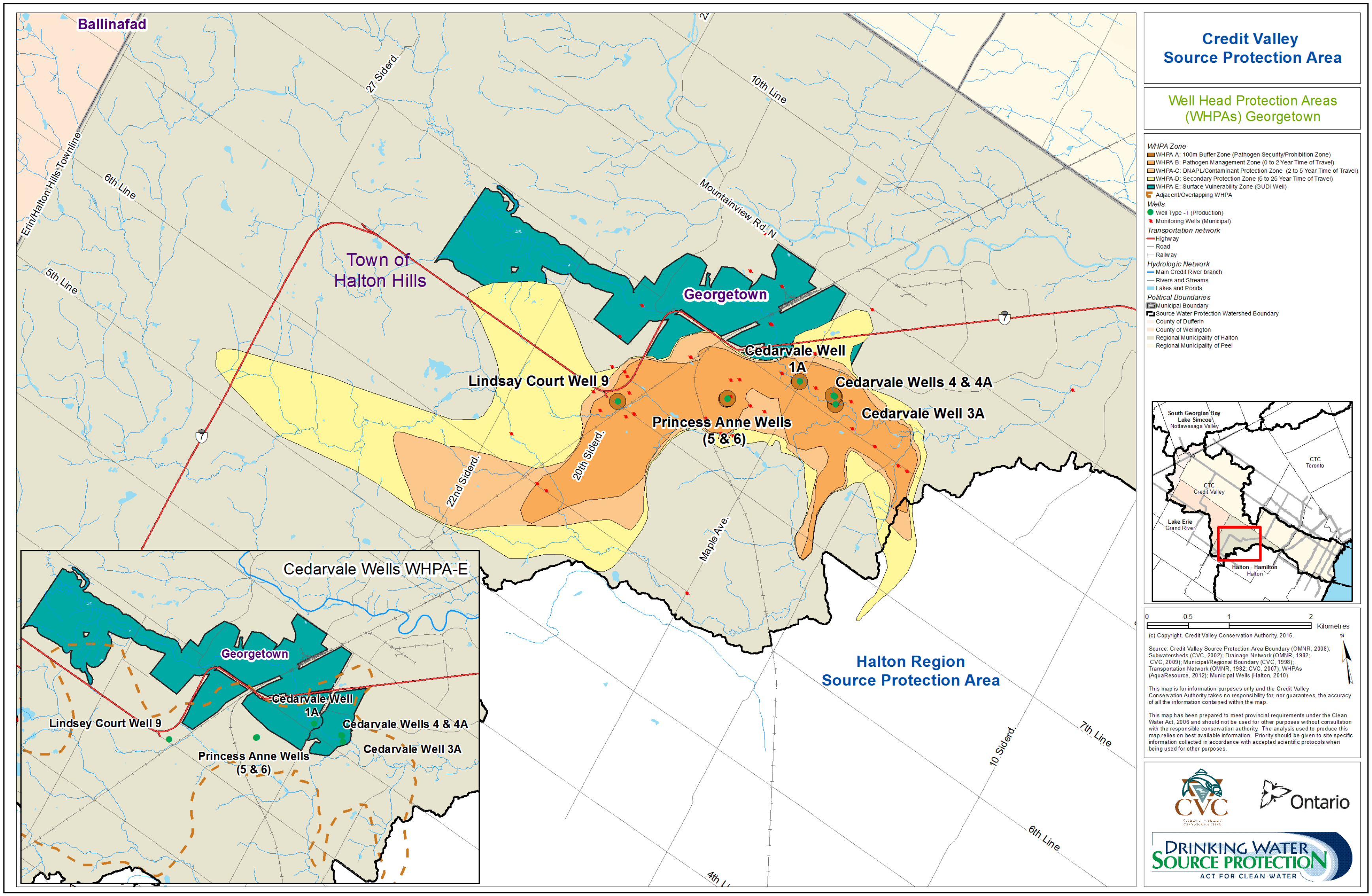

Figure 4.26: Wellhead Protection Areas (WHPAs)—Georgetown

The recent analyses show compelling evidence of a rising bedrock surface at Limehouse, which acts to reduce the continuity of the sediment infill west and east of Limehouse. This effectively creates two discontinuous hydrostratigraphic units, which works to limit the westward extension of the WHPA-C and WHPA–D as noted above.

From Limehouse, the WHPA spreads to the northwest through bedrock aquifers to areas above the escarpment. There is also expansion of the Cedarvale WHPA south along the Inglewood-Milton buried bedrock valley. Updates to the lateral extent and permeability of buried valley infill sediments to the south and north of Lindsay Court have led to wider WHPAs in this area as well including the extension of permeable units outside of the discrete channel infill represented in the previous delineations.

Groundwater vulnerability was assessed using a Surface to Well Advection Time (SWAT) method, which calculates the travel time separately through the unsaturated zone (ground surface to the water table - UZAT), and the saturated zone (water table to the well screen - WWAT), then sums them. The SWAT methodology was selected since it is numerically consistent with the model used to delineate the WHPAs i.e., it used MODFLOW model for calculating travel times in the saturated zone.

Forward particle tracking was used to determine the saturated zone travel time (WWAT), while the unsaturated zone travel times (UZAT) were calculated independently within a GIS using modelled recharge rates, estimates of mobile water content and the thickness of the unsaturated zone.

The travel time through the unsaturated zone in the immediate vicinity of the wells are very low and assumed as zero. As such, the WWAT component of the SWAT was chosen to form the basis of the analysis. A letter from the Director, MOECC granting permission for this approach is presented as **Appendix D3**. The WWAT approach considers only the movement of water particles within the aquifer and assumes that the contaminant is introduced within this zone bypassing quickly through the unsaturated zone. It is therefore regarded as a conservative indicator of vulnerability.

Technical detail on the computation of UZAT and WWAT are presented in **Appendix D2** and in the foundation report.

The groundwater vulnerability for Acton and Georgetown are shown in **Figure 4.27**and **Figure 4.28**. Georgetown is dominated by aquifers that are classed as medium vulnerability with patches of low and medium vulnerability located mainly in WHPA-C and WHPA-D. The distribution of the vulnerability scores at Georgetown appears complex, but in general areas with higher vulnerability zones are centered on the wells and extend westward along the axis of the buried bedrock valley and southward along the axis of the Inglewood-Milton buried bedrock valley.

At Acton, since the wells are well separated, the shapes of the vulnerability zones are more regular and extend up gradient from the wells to the northwest. The highest vulnerability exists within the WHPA-As and in portions of the WHPA-Bs, extending in a north-westerly direction from wellheads. The Prospect Park aquifers are classed as medium to low vulnerability with patches of high vulnerability extending from the immediate vicinity of the municipal wells out to the WHPA-C. At the Davidson and to a less extent Fourth Line wells the aquifers have a high vulnerability both near the wells and further away within WHPA-B. The Davidson wells are the most vulnerable in the water system.

WHPA vulnerability was scored by overlaying the groundwater vulnerability classification (high, medium, low) of the wider area, on the delineated WHPAs (A through D). The vulnerability scoring system for the SWAT methodology is shown in **Table 4.2**, while the vulnerability scores derived for Acton and Georgetown's WHPAs are shown in **Figure 4.29**and **Figure 4.30**.

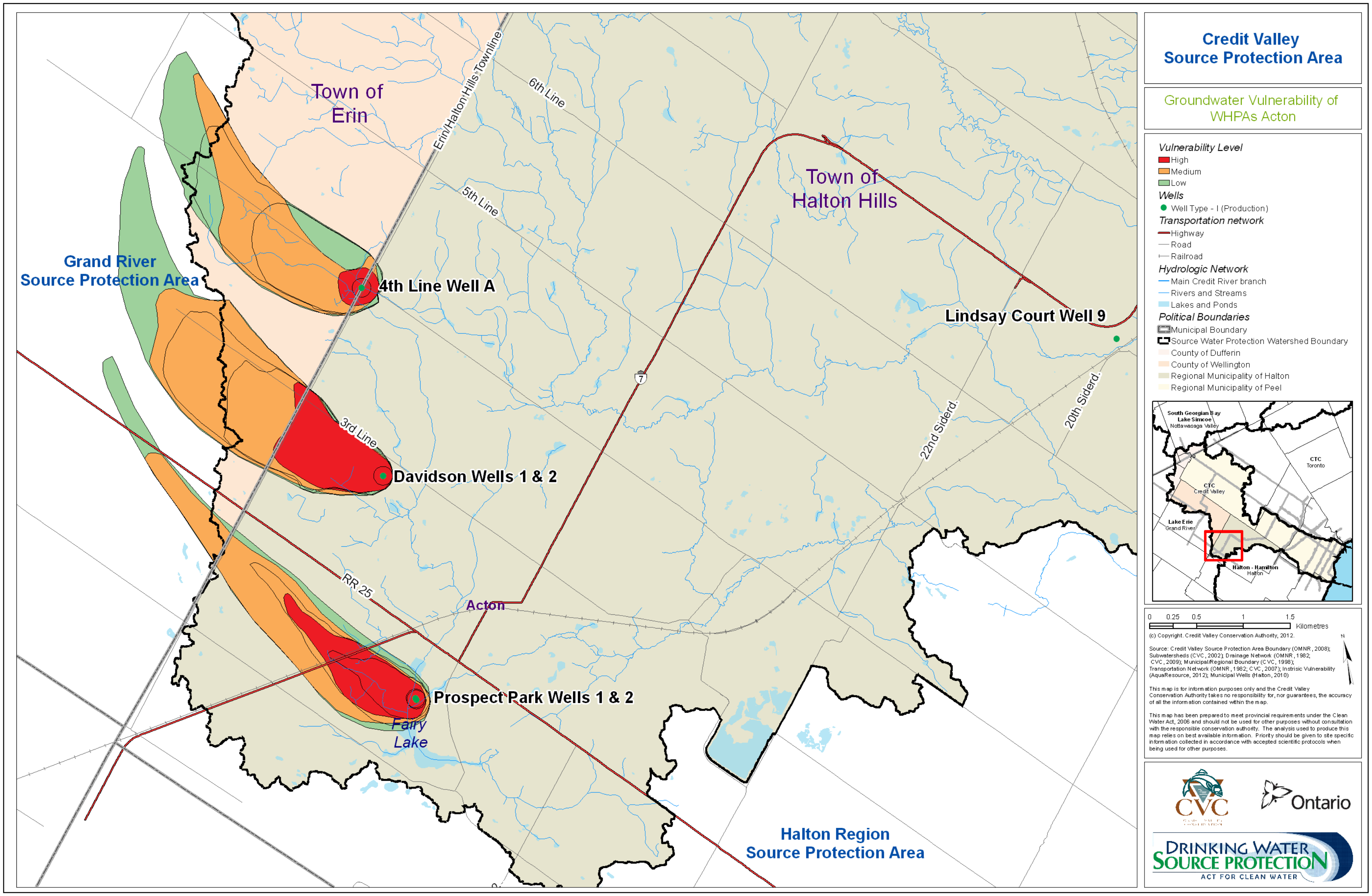

Figure 4.27: Groundwater Vulnerability of WHPAs - Acton

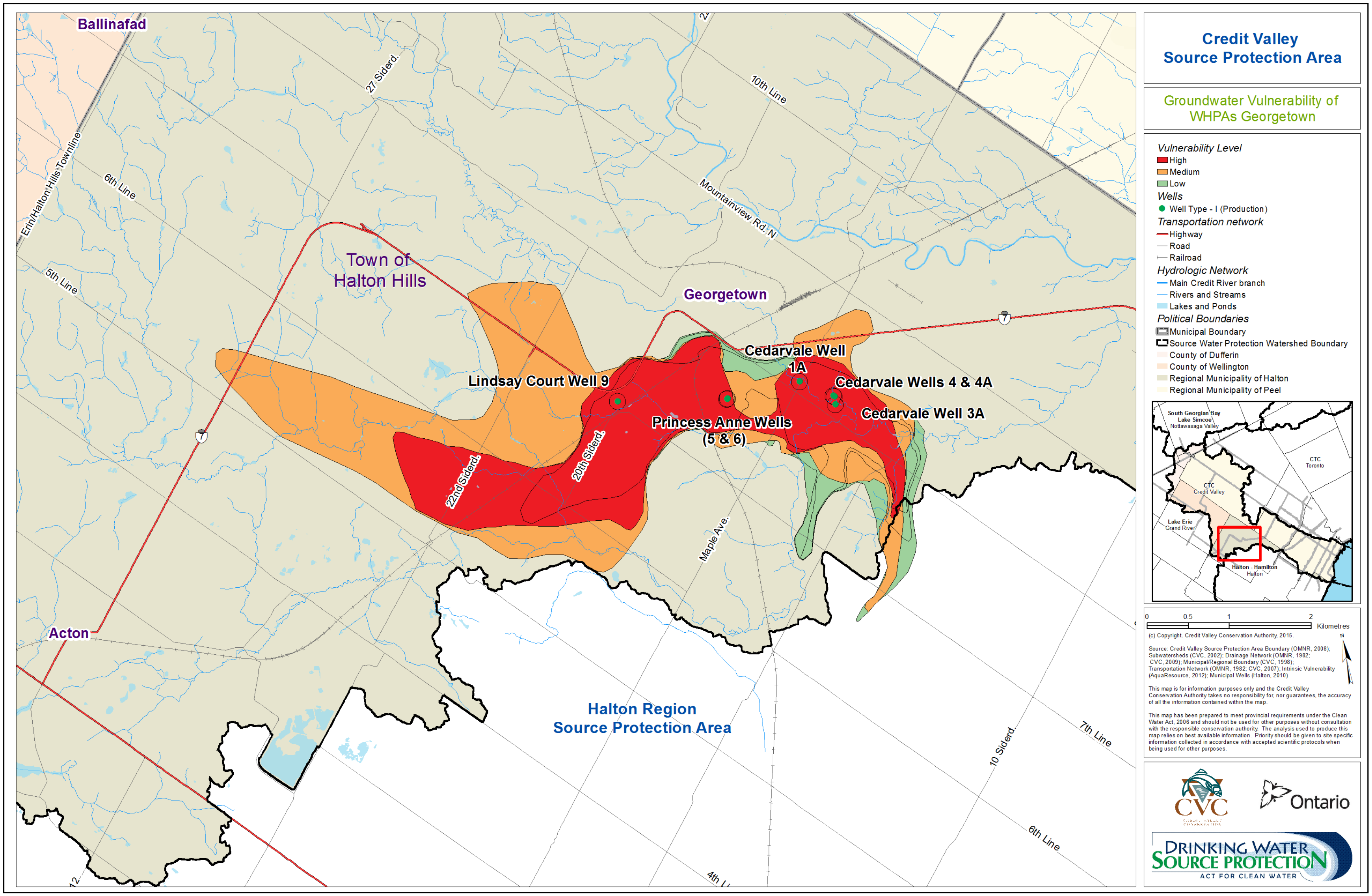

Figure 4.28: Groundwater Vulnerability of WHPAs - Georgetown

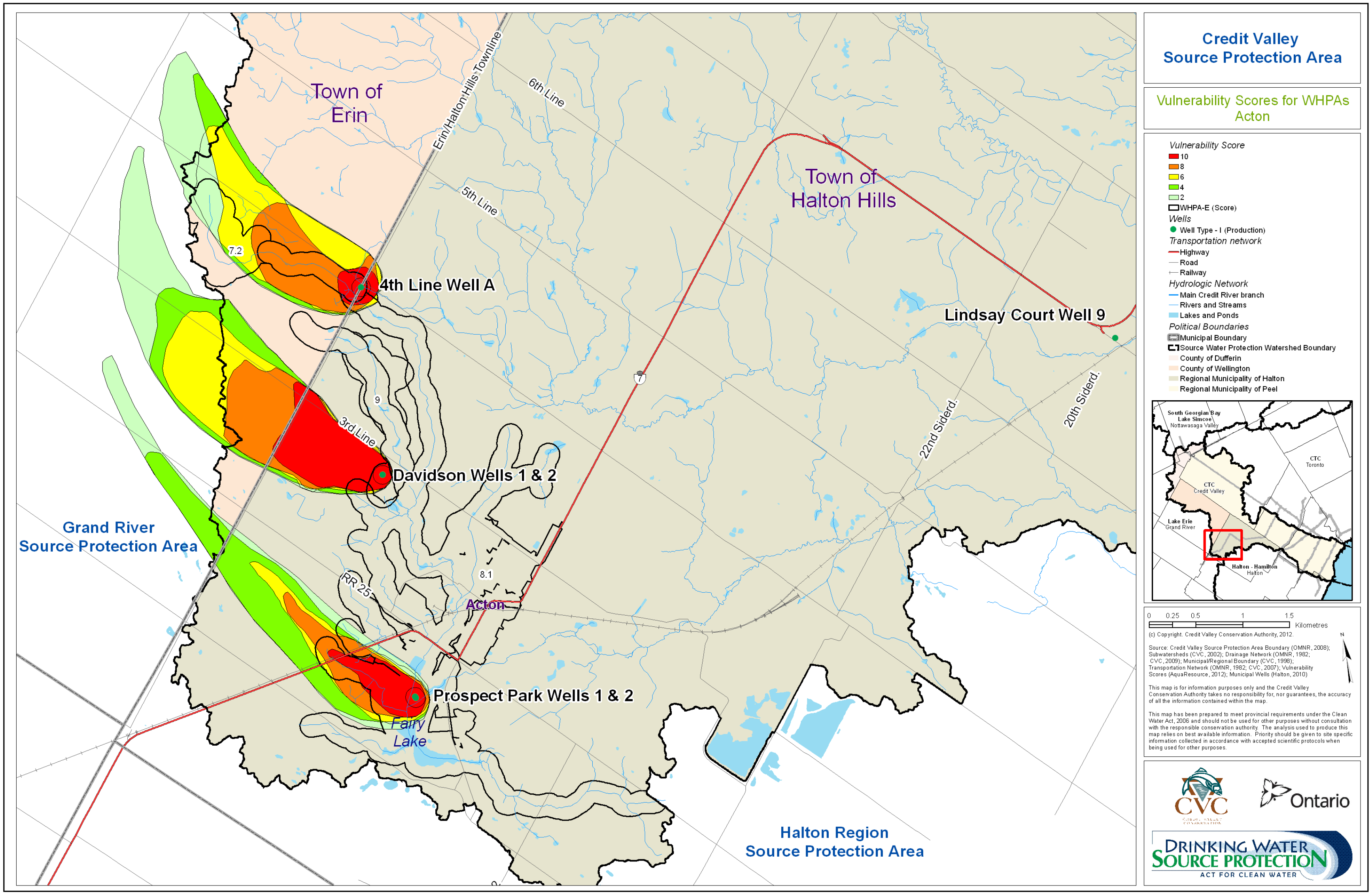

Figure 4.29: Vulnerability Scores for WHPAs - Acton

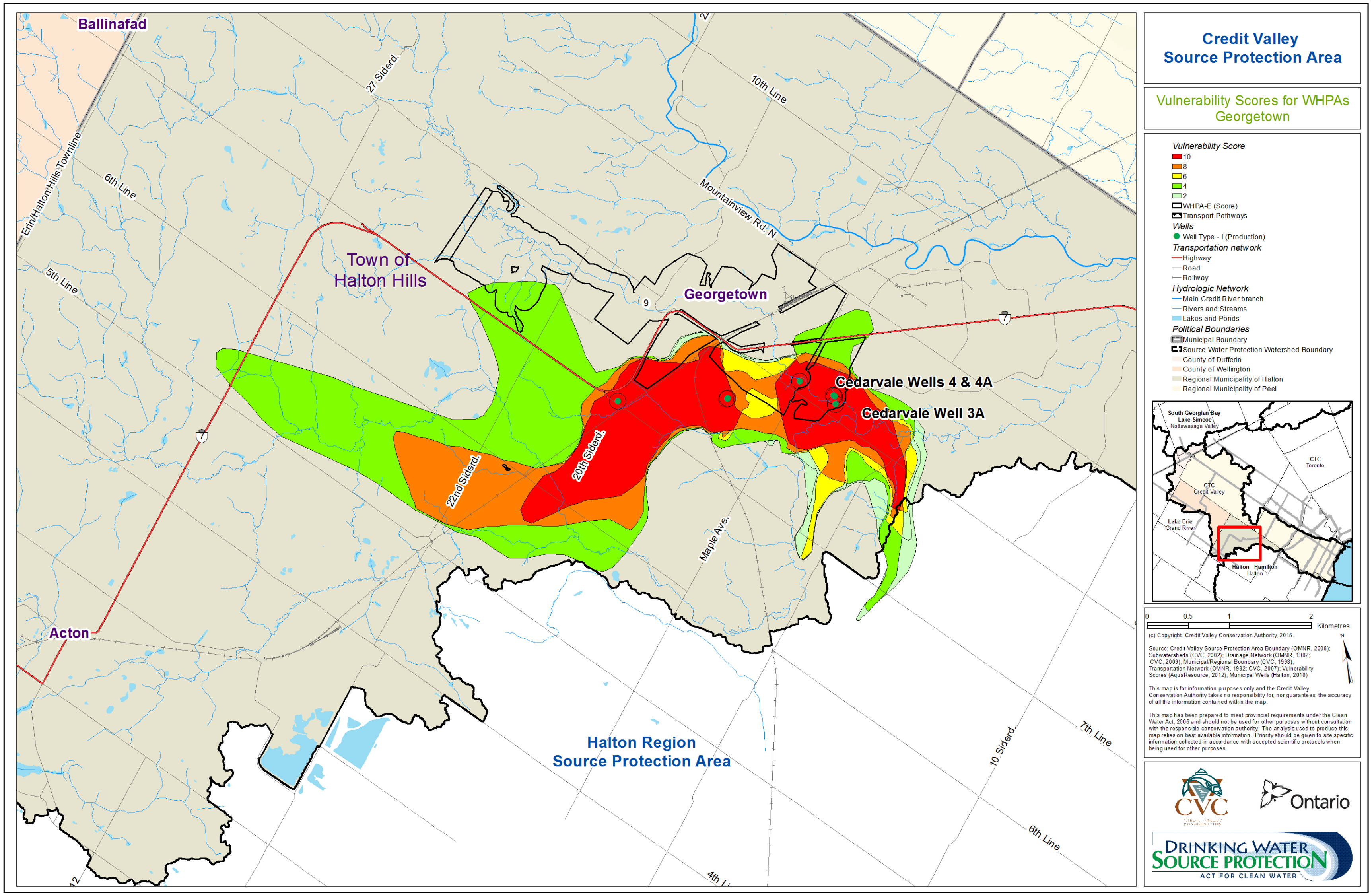

Figure 4.30: Vulnerability Scores for WHPAs - Georgetown

4.7.4 WHPA-E Delineation and Vulnerability Scoring

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

Details of the WHPA-E delineations are presented in the report "Delineation and Vulnerability Analysis of WHPA-E Analysis for the Georgetown and Acton Wellfields" (Earth *fx* Inc., November 2009). This document was subject to extensive peer review by municipal staff, the CVC, and by private consultants prior to acceptance by the CTC SPC, and inclusion in this Assessment Report. This report contains the foundation technical data and information upon which the summary below has been based.

The key tasks in their delineation are identified in **Chapter 4.2**. Since the exact point of interaction was not defined for either the Cedarvale or Acton wells, the closest surface water body to the wells were used as the starting point for the WHPA-E.

Details on the calculation procedures, design assumptions and vulnerability scoring of WHPA-Es is summarized below and in **Appendix D2**, and described in the foundation report. The WHPA-Es for Acton and Georgetown are shown in **Figure 4.23**and **Figure 4.26**, respectively**.**

Vulnerability scores for WHPA-Es were assigned per the *Technical Rule*s as the product of the area vulnerability factor and the source vulnerability factor.

The vulnerability scores for WHPA-Es are shown in **Figure 4.29**and **Figure 4.30**.

4.7.5 Transport Pathways

In the WWAT analysis, unsaturated zone travel times are considered negligible. As such, many pathways that might reduce travel times are accounted for through this conservative approach.

The features studied within the context of the pathways analysis are outlined in **Chapter 4.2**, and the findings are as follows:

Gravel Pits/Aggregate Operations

Digital mapping provided by MNRF was used to locate active and inactive pits and quarries in the WHPAs that extend below the water table. Since the vulnerability ranking was based only on the saturated travel times, the impact of features that reduce unsaturated travel times (i.e., those above the water table) were not included in the assessment.

The analyses resulted in the identification of a small (2,370 m^2) pathway south of Sixth Line and 22nd Side Road. Because the initial vulnerability for this area was assessed as being high, no further adjustments to the vulnerability were required.

4.7.6 Uncertainty Assessment

WHPAs B-D were delineated using updated datasets collected for the Tier 3 Water Budget Study for Halton Hills. They benefit from the most recent enhancements of the conceptual, and hydrostratigraphic models developed for this area, and represent the most accurate refinements in the numerical model used to delineate them.

The dimensions of WHPA-A and the vulnerability scoring, are set within the *Technical Rules*. With the other WHPAs though, there is an intrinsic level of uncertainty in the analysis, given the complexity of the study area and the paucity of data in certain instances. The vulnerability assessment also has a certain level of uncertainty associated with it.

Uncertainty associated with the assessment of the Region of Halton's wellfields in Halton Hills is summarized in **Table 4.8**, **Table 4.9**, and **Table 4.10,** and further discussed in **Appendix D2**. Uncertainty is summarized as follows:

- The WHPAs were delineated with a sub-regional scale model and had good calibration. A sensitivity analysis was completed to account for variation in model parameters. The uncertainty in the WHPAs is low for the Georgetown wells and for the Prospect Park, but high for the other wells in Acton. This is related to uncertainty in the characterization of fracture zones supplying the Davidson and Fourth Line wells.
- Considering the relative variability in the density of the data used to create the SWAT mapping and that the well database has inherent uncertainty, the vulnerability mapping of the area is considered to have low uncertainty for the Georgetown wells and for Prospect Park, but high for the other wells in Acton.

Table 4.8: Uncertainty Wellhead Protection Area B- D—Georgetown

Uncertainty Element	Cedarvale	Princess Anne	Lindsay Court
Distribution, variability, quality and relevance of data	Low	Low	Low
Ability of the methods and models used to accurately reflect the flow processes in the hydrological system	Low	Low	Low
Quality assurance and quality control procedures applied	Low	Low	Low
Extent and level of calibration and validation achieved for models used or calculations or general assessments completed	Low	Low	Low
Accuracy to which to which the groundwater vulnerability categories effectively assess the relative vulnerability of the underlying hydrogeological features	Low	Low	Low
WHPA delineation	Low	Low	Low
Vulnerability Scores	Low	Low	Low

Table 4.9: Uncertainty Wellhead Protection Area B- D—Acton

Uncertainty Element	Prospect Park	Davidson	4th Line
Distribution, variability, quality and relevance of data	Low	High	High
Ability of the methods and models used to accurately reflect the flow processes in the hydrological system	Low	High	High
Quality assurance and quality control procedures applied	Low	Low	Low
Extent and level of calibration and validation achieved for models used or calculations or general assessments completed	Low	High	High
Accuracy to which to which the groundwater vulnerability categories effectively assess the relative vulnerability of the underlying hydrogeological features	Low	Low	Low
WHPA delineation	Low	High	High
Vulnerability Scores	Low	High	High

Table 4.10: Uncertainty—Wellhead Protection Area E's

Uncertainty Element	Cedarvale	Prospect Park	Davidson	4th Line
Distribution, variability, quality and relevance of data	High	Low	Low	Low
Ability of the methods and models used to accurately reflect the flow processes in the hydrological system	Low	Low	Low	Low
Quality assurance and quality control procedures applied	Low	Low	Low	Low
Extent and level of calibration and validation achieved for models used or calculations or general assessments completed	High	High	High	High
Accuracy to which the area vulnerability factor and the source vulnerability factor effectively assesses the relative vulnerability of the hydrological features	High	High	High	High
WHPA delineation	High	High	High	High
Vulnerability Scores	High	High	High	High

4.8 REGIONAL MUNICIPALITY OF PEEL - TOWN OF CALEDON

The Town of Caledon is situated in the north eastern portion of the Credit River Watershed. Municipal water is supplied to the town by the Region of Peel through the following drinking water systems:

- Caledon Village – Alton (Alton Wells 3 and 4A; Caledon Village Wells 3 and 4);
- Inglewood – Wells 3 and 4; and
- Cheltenham – Wells 1 and 2.

4.8.1 Geological Setting

Alton Wells 3 and 4A are in an unconfined sand and gravel aquifer, 15-25 metres below ground.

Caledon Village Well 4 (61-75 metres below ground) is in a confined gravel aquifer (bedrock valley infill) that forms part of a melt water channel running between Orangeville and Halton Hills, while Caledon Village Well 3 (29-35 metres below ground) is in an unconfined sand, and gravel aquifer.

The Village of Inglewood obtains its water from two municipal wells; Inglewood Wells 3 and 4. These wells are completed to depths of approximately 50-55 metres below ground in a buried valley aquifer.

Cheltenham Wells 1 and 2 are located in the Peel Plain, 45 to 55 metres below ground within a bedrock valley underlying the meltwater channel and the Halton Till deposits.

A summary of well depths and associated geological setting of Caledon's municipal wellfields is presented in **Appendix D2 (Table D-28)**.

4.8.2 Data Sources and Study Methodology

The WHPA delineations and vulnerability assessment are detailed in the following reports:

- Region of Peel WHPA Study for Municipal Residential Groundwater Systems located within the Credit River Watershed, AquaResource Inc., 2007;
- Wellhead Protection Area Delineations and Vulnerability Assessments for Alton 1-2 Standy by Wells, Cheltenham PW1/PW2 Amended PTTW, and Caledon Village Proposed Well 5 (TW2-05), AquaResources Inc., April 2008;
- Surface to Aquifer and Surface to Well Advection Time Wellhead Protection Areas in Credit Valley Watershed Caledon Village Wells 3 and 4, Inglewood Wells 1/2 and 3, Cheltenham PW1/ PW2, & Alton Wells 3 and 4, AquaResources Inc., April 2008;
- Transport Pathways Update to Vulnerability, Region of Peel, R.J. Burnside and Associates Ltd., May 2010;
- Inglewood Wellhead Protection Area Delineation Wells ING3 and ING4, Peel Region, Matrix Solutions Inc., February 2017;
- Vulnerability Assessment and Vulnerability Scoring for Inglewood Well 4, Region of Peel, Matrix Solutions Inc., August 2018; and
- Phase 1: Alton Wellhead Protection Area Delineation, Peel Water Resources Management Model, Region of Peel, Earthfx and GeoKamp Ltd., June 2019.

Documents published prior to 2015 were subjected to extensive peer review by municipal staff, the CVC, and private consultants, prior to acceptance by the CTC SPC, and inclusion in this Assessment Report. Additionally, the base models upon which the studies are premised, were also subject to independent peer review during previous (to source protection) studies for which they were initially developed. These reports contain the foundation technical data and information upon which this Assessment Report has been based. Reports prepared after 2015 to amend the Assessment Report to reflect wells being brought on-line were, at a minimum, prepared and/or reviewed by a qualified professional.

WHPA delineation was undertaken through computer-based three-dimensional groundwater flow modelling, using the FEFLOW (Finite Element Flow - WASY, 2006) code. The model was built upon data from previous initiatives (regional water budget studies; WHI 2002; WHI 2004), and the Tier 2 Water Budget, Aqua Resource Inc. (2009) (**Chapter 3**).

In 2019, a regional-scale numerical model of groundwater and surface water flow systems in Peel Region was initiated. Given the breadth of a study of this magnitude, there are multiple phases. Phase 1 includes the development of a steady-state groundwater flow model for Peel Region. The first application of the model is to delineate wellhead protection areas (WHPA) for the Alton Wellfield, using the USGS MODFLOW-NWT code. Eventually, this model will allow the vulnerable areas around all municipal wellfields to be refined.

To ensure that the model represents conditions at the local scale required that the regional model grid used for the Tier 2 water budget study be refined within the vicinity of the wellheads. A finer grid cell size provides for a more accurate representation of aquifer and stream properties, as well as the drawdown simulation near pumping wells.

The model was calibrated to steady state using water level and baseflow measurements within the modelled area. Calibration was done by systematically adjusting the model parameters and boundary conditions to match field observations within an acceptable range.

A schematic of the flow modelling process is shown in **Figure 3.18**, and technical details on the model construction and calibration are summarized in **Appendix D2**, and described in detail in the foundation reports cited above.

4.8.3 WHPA A-D Delineation and Vulnerability Scoring

WHPAs B-D were delineated using backward and forward particle tracking analysis (**Chapter 4.3**), by pumping each well field to steady state, at its maximum permitted rate (**Appendix D2, Table D-30**). Rate selection considered future demand and growth projections for the Town of Caledon. The WHPAs for the Caledon Village-Alton, Inglewood and Cheltenham Drinking Water Systems are shown in **Figure 4.31, Figure 4.32,** and **Figure 4.33,** respectively. It should be noted that the WHPA-D for the Cheltenham wells 1 and 2 extends eastward across the CVSPA boundary into the TRSPA.

Groundwater vulnerability was assessed using the Surface to Well Advection Time (SWAT) method, which calculates travel time separately through the unsaturated zone (ground surface to the water table - UZAT), and the saturated zone (water table to the well screen - WWAT), then sums them. The SWAT methodology was selected since it is numerically consistent with the model used to delineate the WHPAs (i.e., it used the FEFLOW model for calculating travel times in the saturated zone).

Forward particle tracking was used to determine the saturated zone travel time (WWAT), while the unsaturated zone travel times (UZAT) were calculated independently within a GIS using modelled recharge rates, estimates of mobile water content and the thickness of the unsaturated zone.

The travel time through the unsaturated zone in the immediate vicinity of the wells are very low and assumed as zero. As such, the WWAT component of the SWAT was chosen to form the basis of the analysis. A letter from the Director, MOECC granting permission for this approach can be found in **Appendix D3**. The WWAT approach considers only the movement of water particles within the aquifer and assumes that the contaminant is introduced within this zone bypassing the unsaturated zone. It is therefore regarded as a conservative indicator of vulnerability.

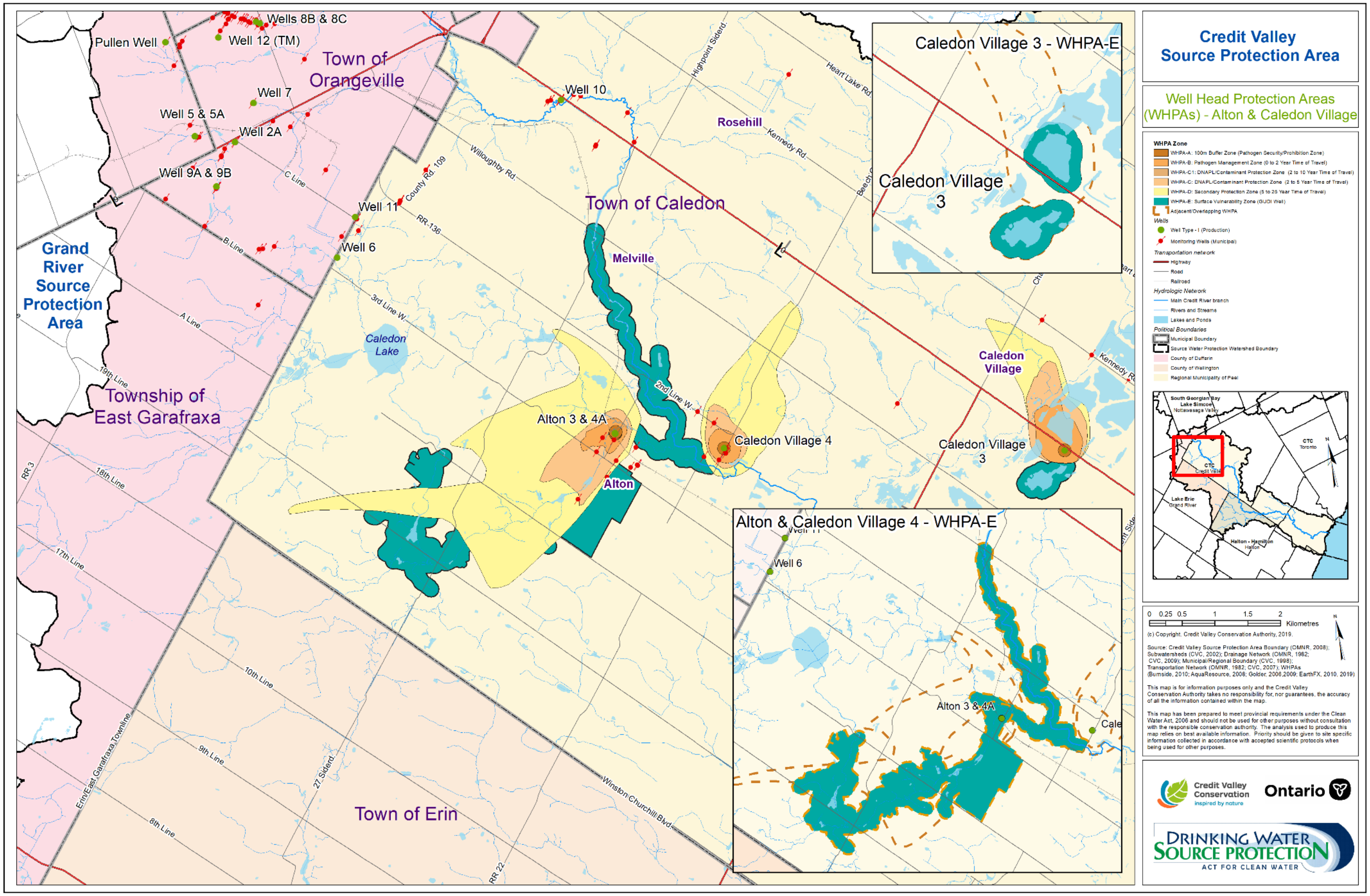

Figure 4.31: Wellhead Protection Areas (WHPAs) – Caledon Village – Alton

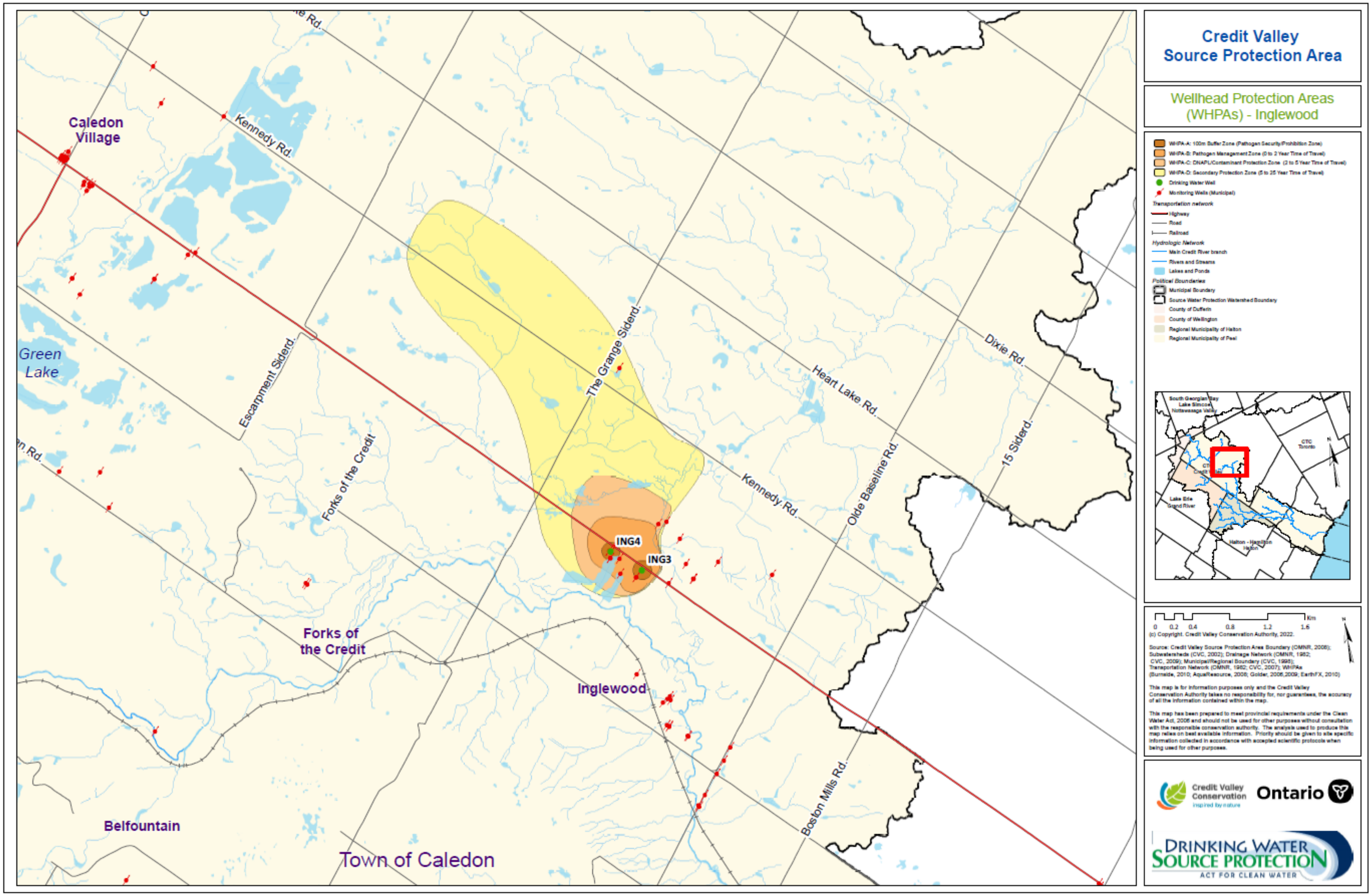

Figure 4.32: Wellhead Protection Areas (WHPAs) – Inglewood

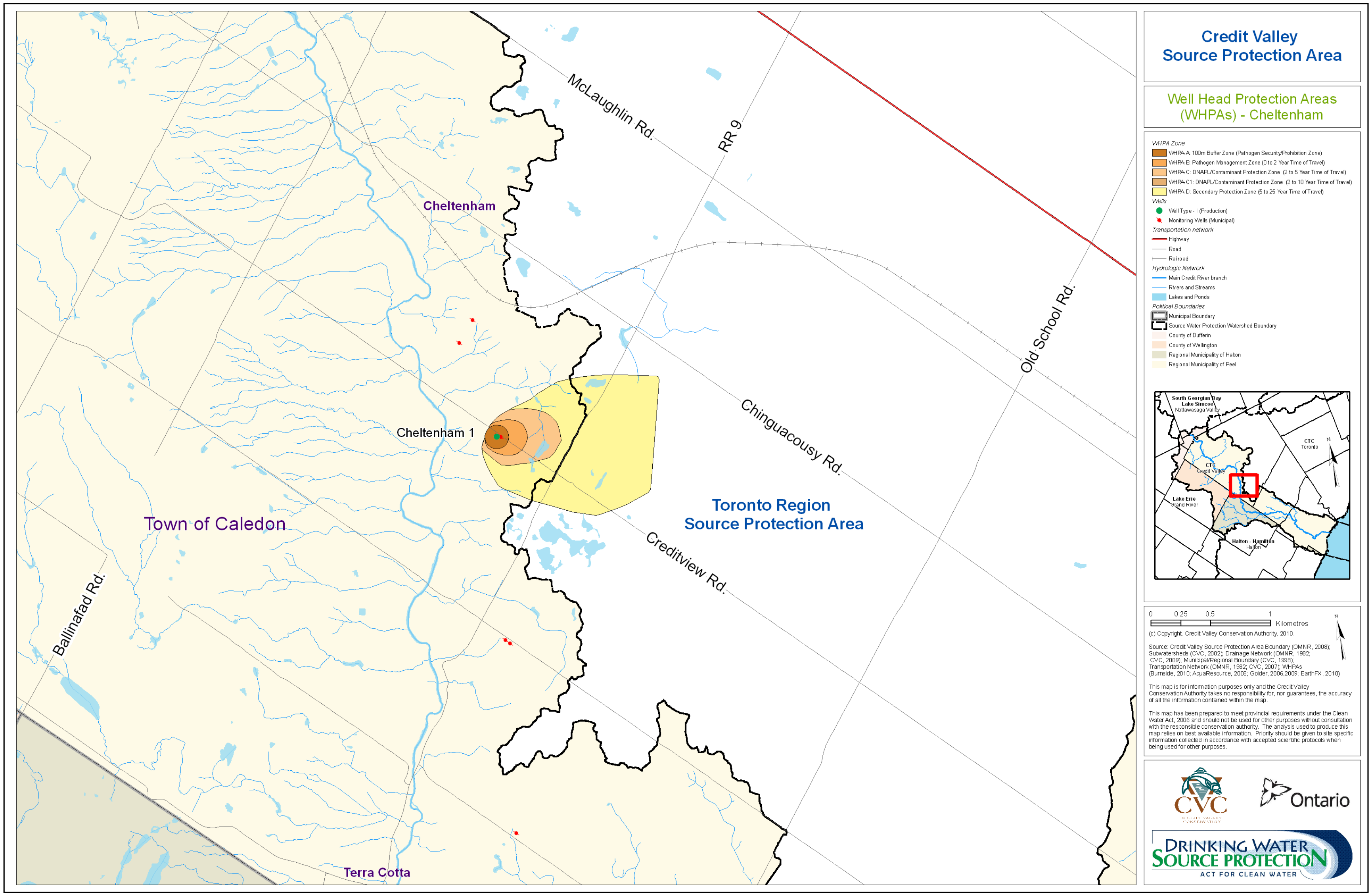

Figure 4.33: Wellhead Protection Areas (WHPAs) - Cheltenham

Groundwater vulnerability was assessed as being high, medium or low, in keeping with *Technical Rule* 38 (2). The groundwater vulnerability in the vicinity of the Caledon Village - Alton, Inglewood and Cheltenham WHPAs is shown on **Figure 4.34, Figure 4.35,** and **Figure 4.36**respectively**.**

WHPA vulnerability was scored by overlaying the groundwater vulnerability classification of the area (high, medium, low), on the delineated WHPAs (A to D), and applying a score, as shown in **Table 4.2**.

The vulnerability scores developed for the WHPAs are shown in **Figure 4.37**, **Figure 4.38**, and **Figure 4.39**, respectively.

4.8.4 WHPA-E Delineation and Vulnerability Scoring

The majority of WHPA-E delineations are described in the document "Transport Pathways Update to Vulnerability, Region of Peel" (R.J. Burnside and Associates Ltd., May 2010). For Alton Wells 3 and 4A, the WHPA-E delineation is outlined in Earthfx and GeoCamp (2019), with additional details provided in Appendix D. The methodology used to delineate the WHPA-E is consistent with the approach used for an IPZ-2 (surface water intake) delineation.

A brief overview of the methodology used in delineating a WHPA-E is provided in **Chapter 4.2**. Since the exact point of interaction was not defined for any of the wells, the closest surface water body to the wells were used as the starting point for the delineation.

Details on the calculation procedures, design assumptions and vulnerability scoring used in the derivation of the WHPA-Es are summarized in **Appendix D2**. The WHPA-Es found at the Caledon Village-Alton Drinking Water System is shown in **Figure 4.31**. Vulnerability scores were assigned per the *Technical Rule*s as the product of the area vulnerability factor and the source vulnerability factor. WHPA-E vulnerability scores are provided in **Figure 4.37.**

4.8.5 Transport Pathways

The features studied within the context of this analysis are outlined in **Chapter 4.2**.

Gravel Pits/Aggregate Operations

An aggregate operation was identified in the WHPAs associated with Caledon Village Well 3. This aggregate operation consists of several pits that extend below the water table, covering an area of approximately 20 hectares. Within the footprint of the sand and gravel pits, the entire overburden layer has been removed, resulting in the loss of the protective layers overlying the aquifer. Therefore, the vulnerability score in the area where the gravel pits are located was increased from medium to high for Caledon Village Well 3.

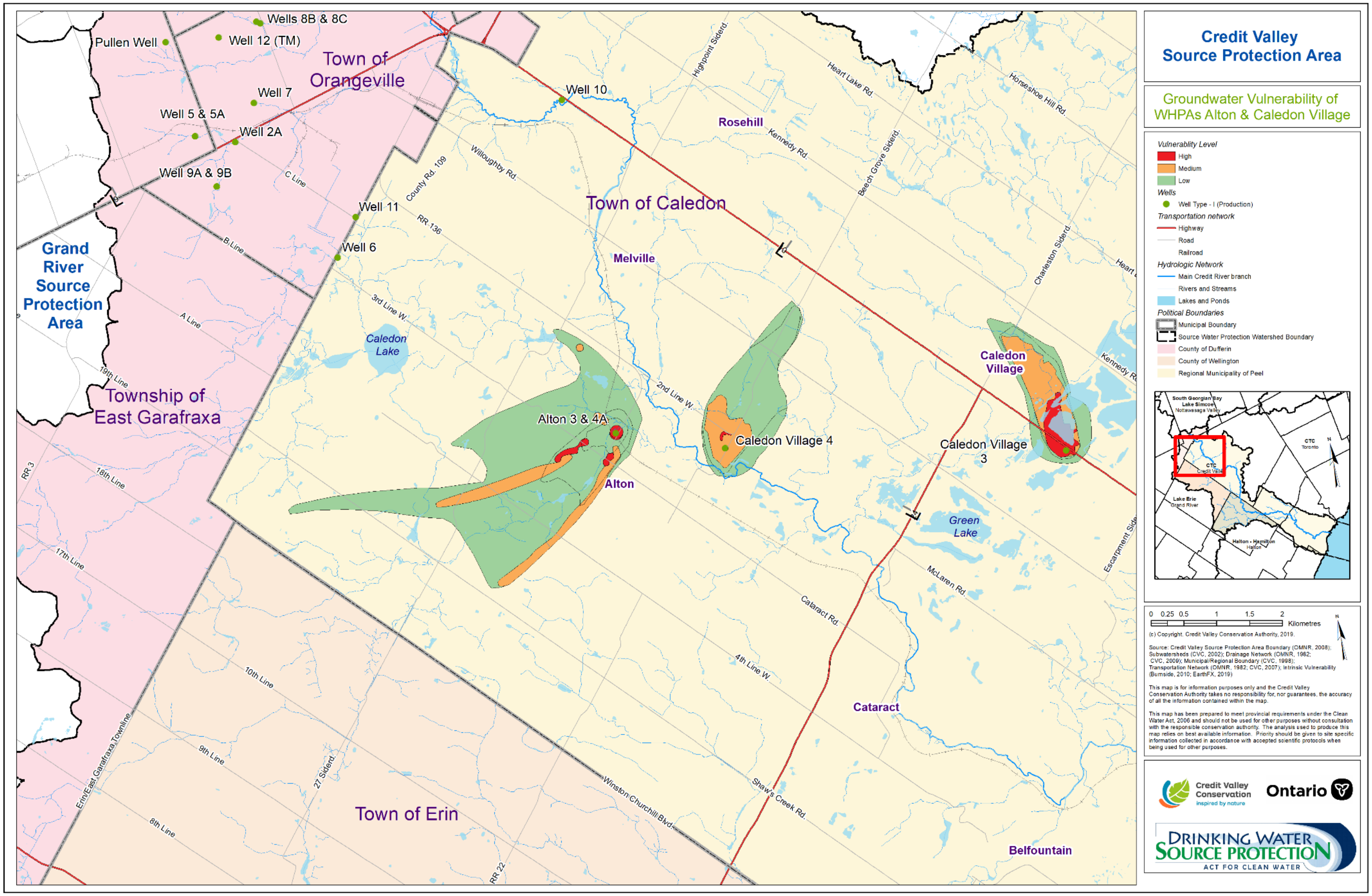

Figure 4.34: Groundwater Vulnerability of WHPAs— Caledon Village – Alton

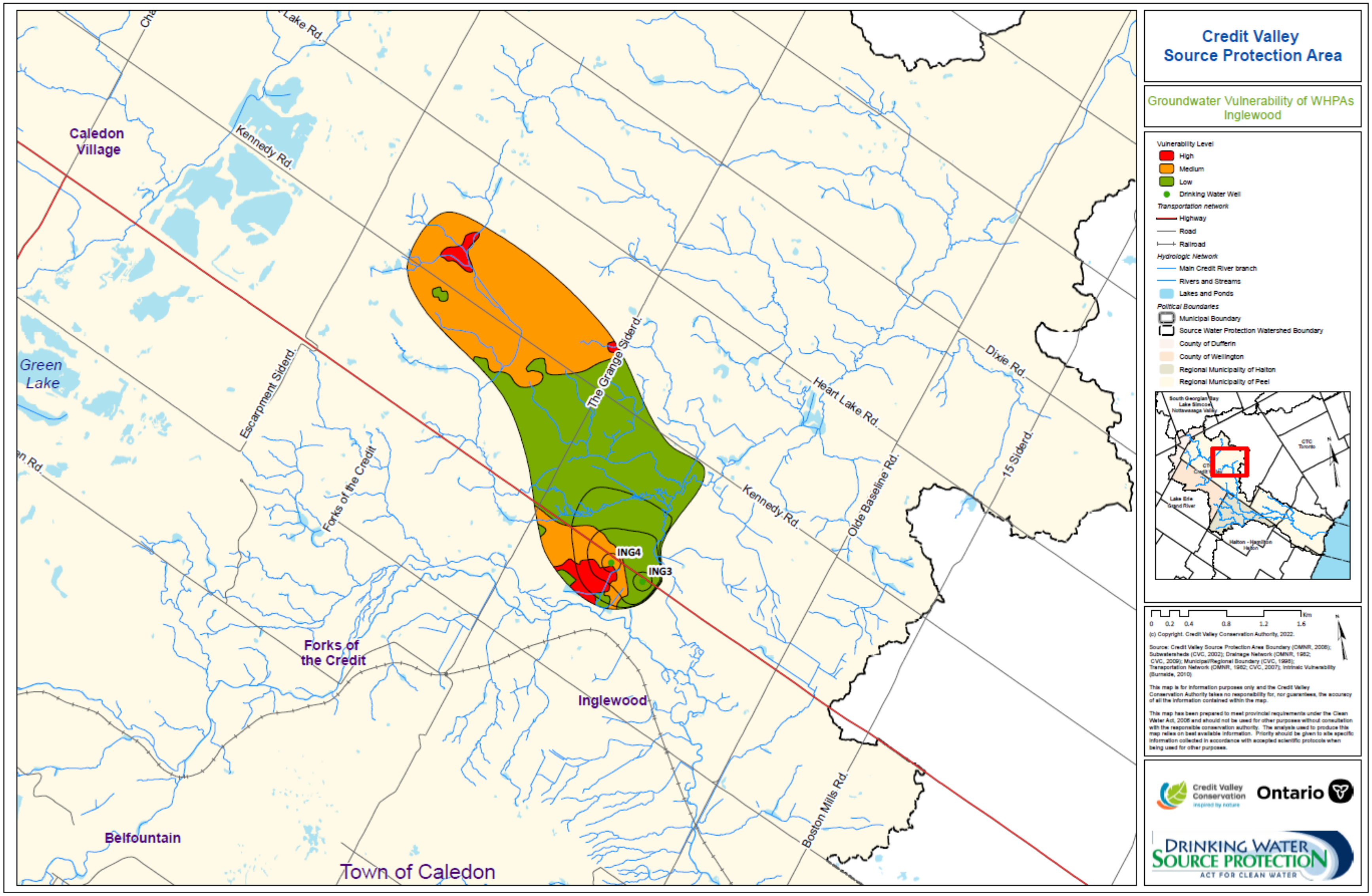

Figure 4.35: Groundwater Vulnerability of WHPAs—Inglewood

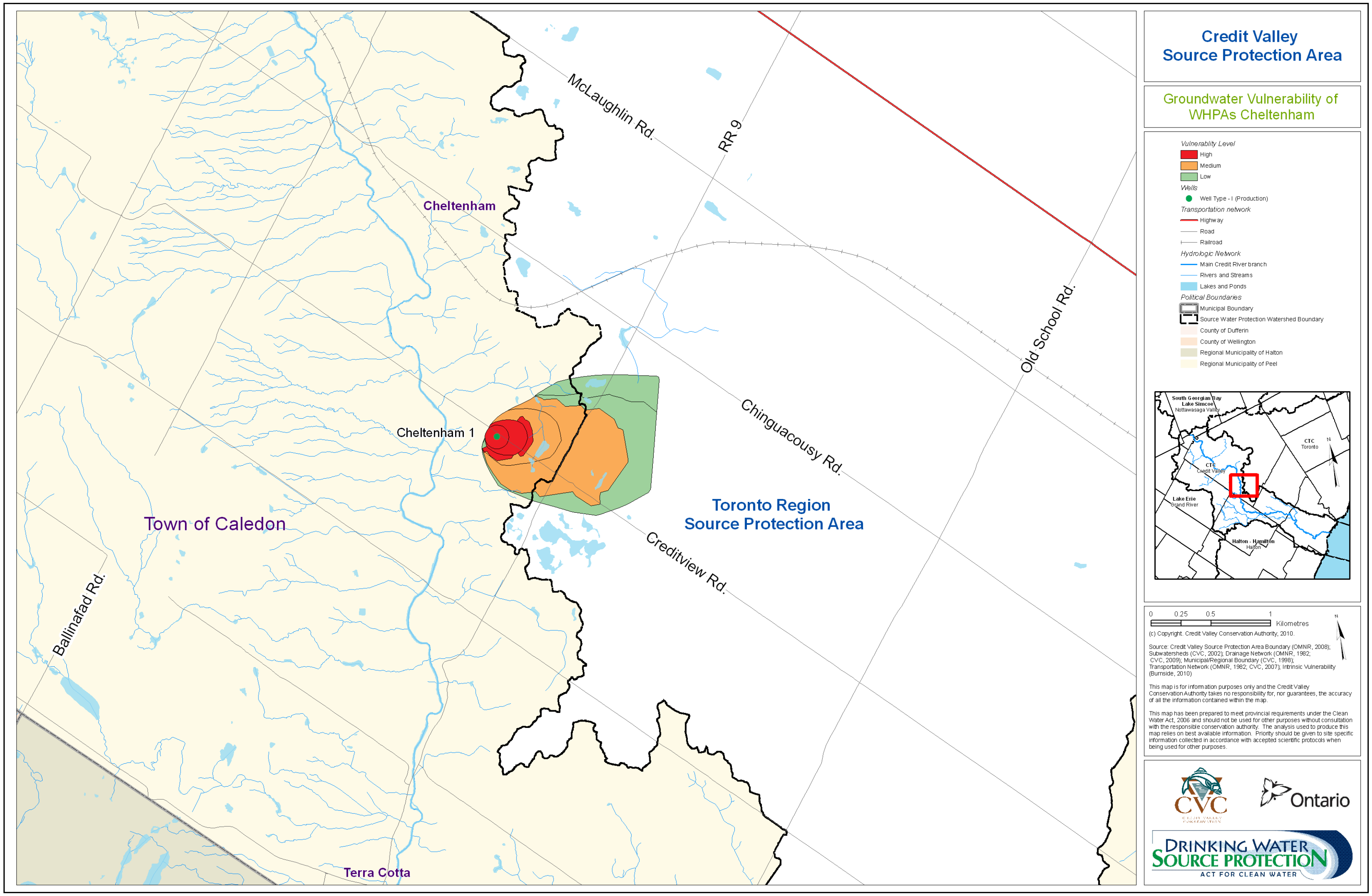

Figure 4.36: Groundwater Vulnerability of WHPAs—Cheltenham

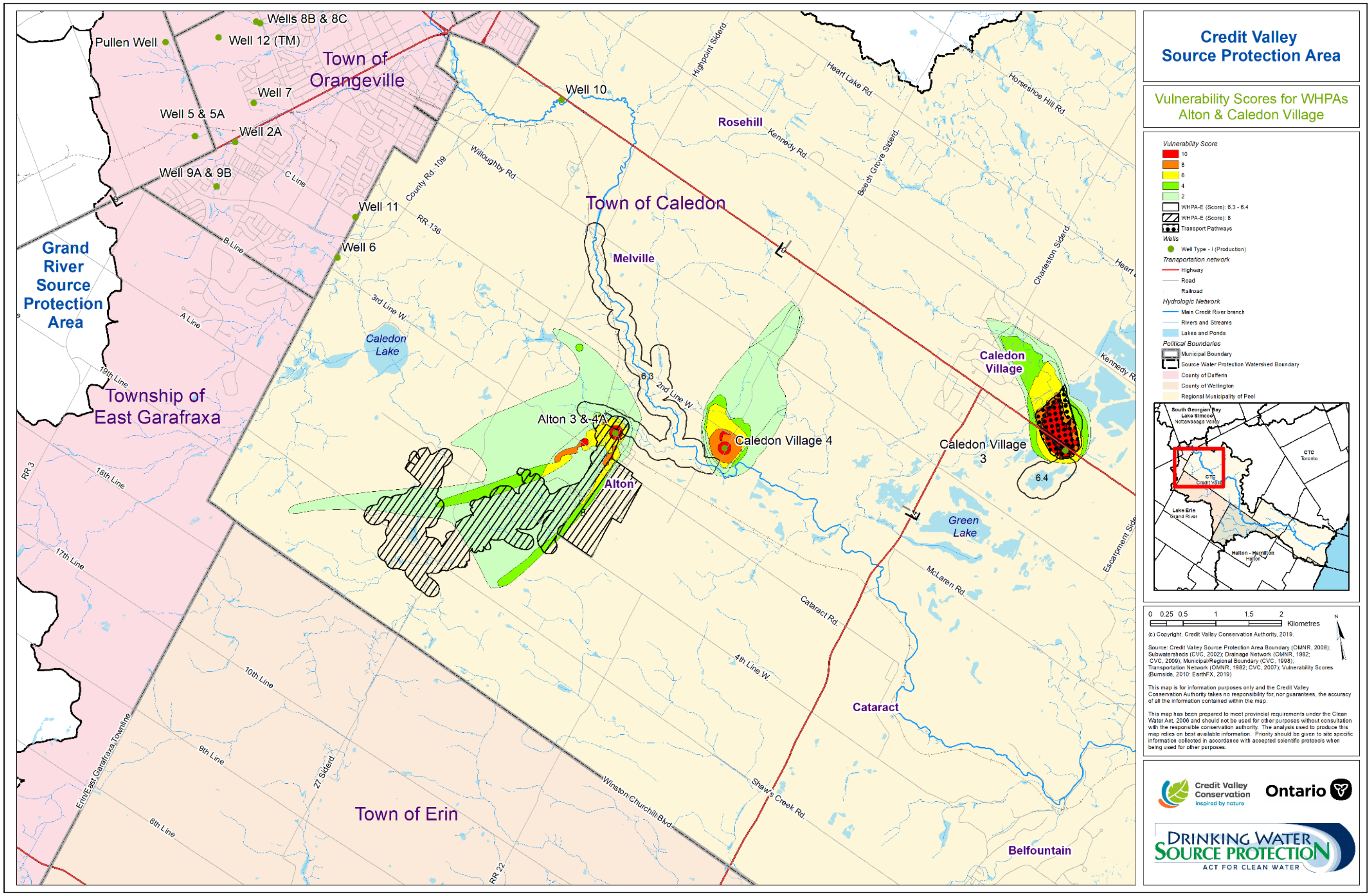

Figure 4.37: Vulnerability Scores for WHPAs - Caledon Village - Alton

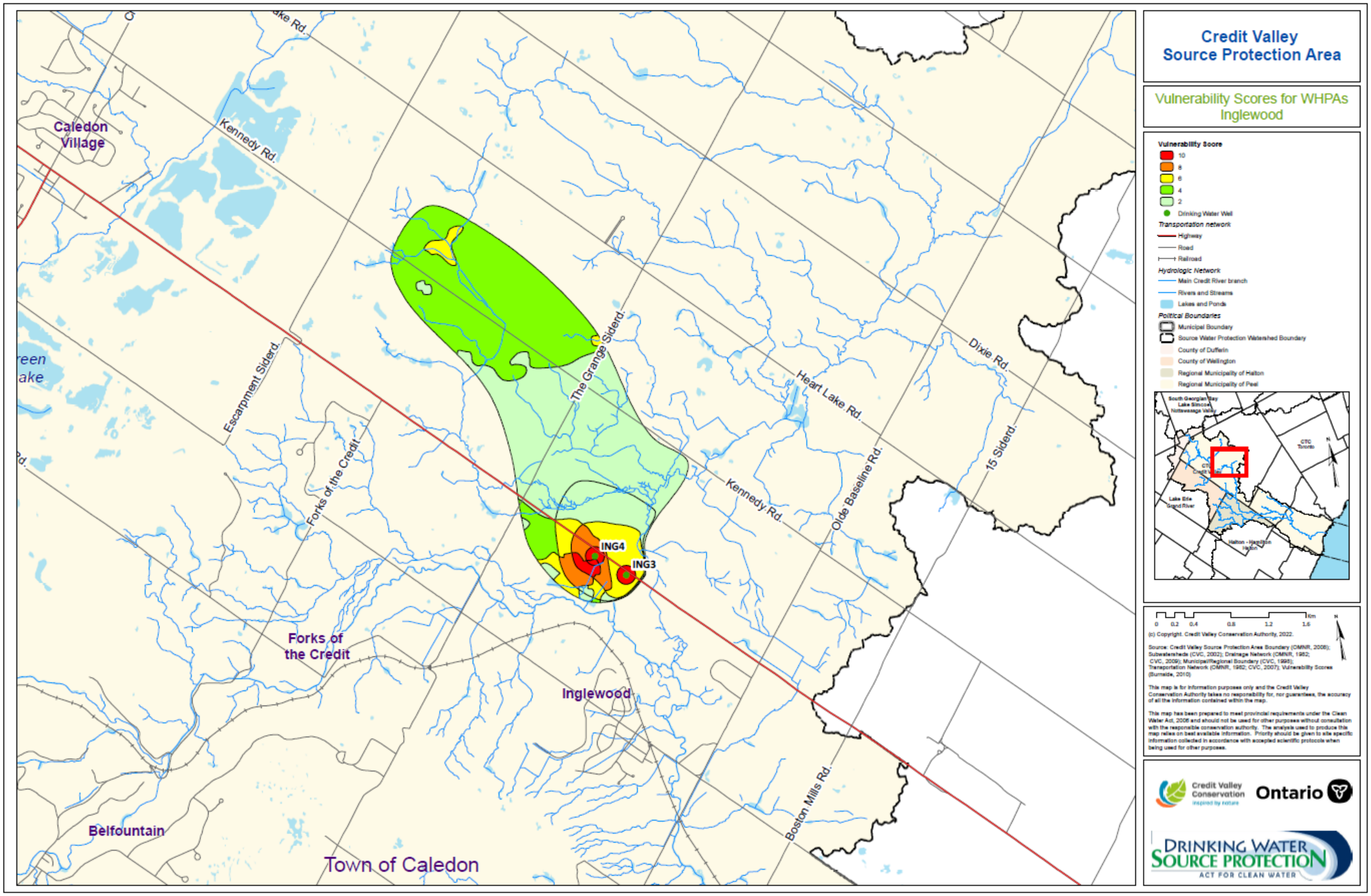

Figure 4.38: Vulnerability Scores for WHPAs - Inglewood

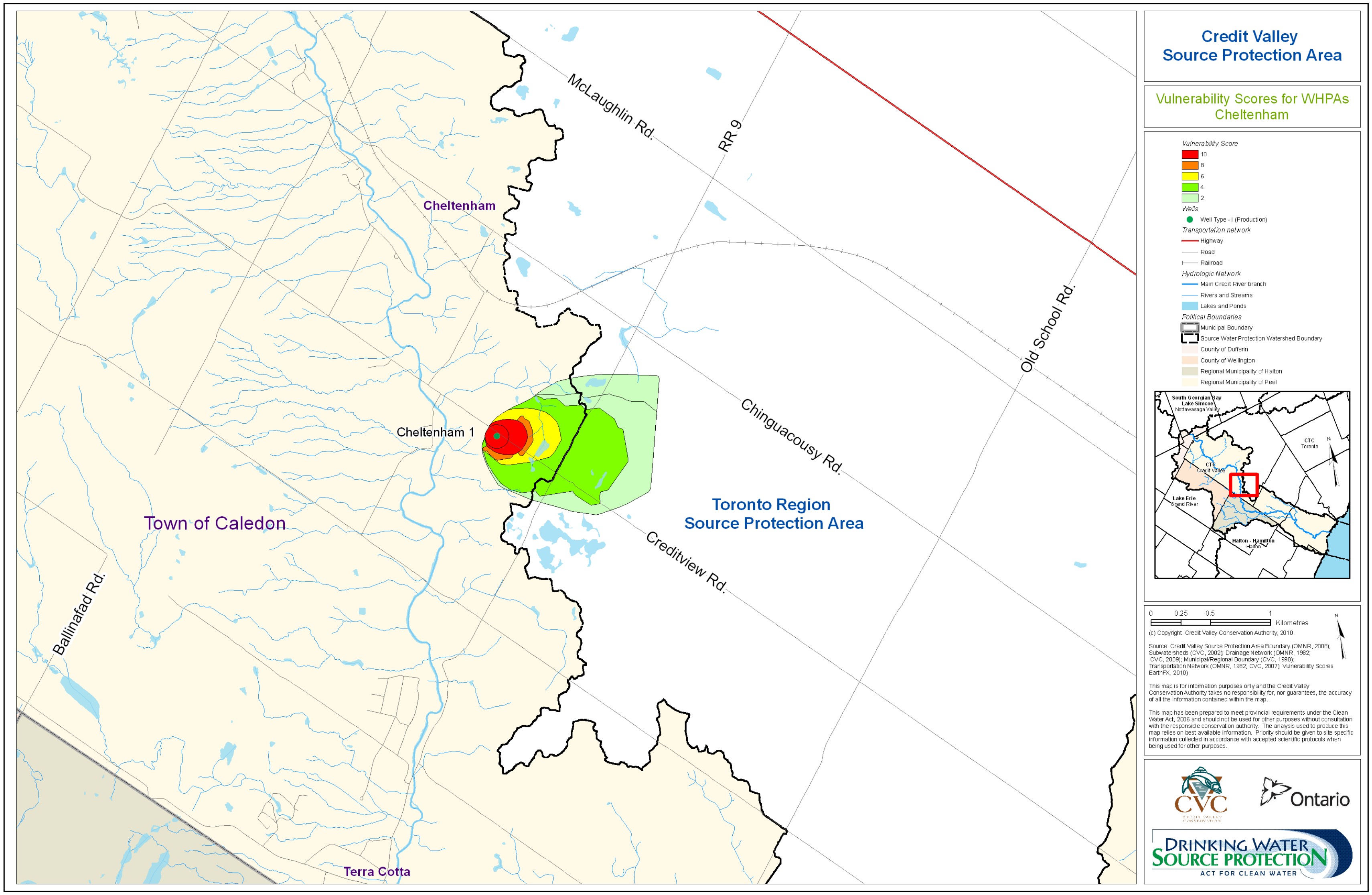

Figure 4.39: Vulnerability Scores for WHPAs - Cheltenham

4.8.6 Uncertainty Assessment

Alton and Cheltenham Wells

When the initial WHPA delineations (circa 2007) were completed for incorporation into this Assessment Report, some peer reviewers highlighted concerns regarding the WHPA delineations and vulnerability assessment prepared for the Cheltenham wells. These concerns were associated with the variations in the shapes and size of the WHPAs compared to previous delineations (circa 2000), as well as the orientation of the Cheltenham WHPAs. Based upon comments obtained through the peer review of the foundation reports and of the base models, Peel Region accepted the initial WHPA delineations, and in 2009 recommended that they be included in the Official Plan for the Town of Caledon. The Region was mindful of the concerns brought forward by these reviewers and recommended that the WHPAs be accepted for the time being pending further refinement of the groundwater flow model through the inclusion of additional data.

To assist with the collection of additional data, the Region initiated independent water quality monitoring programs with extensive data collection. These programs are described below:

- Re-evaluation of Early Warning Wells (EWW) Monitoring Program – installation of additional early warning wells to improve the resolution of the EWW network, including some in the vicinity of the Cheltenham and Alton municipal wells. This program commenced in early 2011; and
- Development of a Nitrate Management Plan for Alton which included the installation of boreholes and monitoring wells. This Program was initiated in Fall 2010.

The data generated from these programs will be used when refining the geologic/hydrogeologic interpretations near the municipal wells and updating the groundwater flow model used to delineate the WHPAs. With the inclusion of improved data sets, there is the potential for alterations in the shape and size of the WHPAs.

General WHPA Delineation and Vulnerability Assessment

The dimensions of WHPA-A and the vulnerability scoring assigned, are outlined in the *Technical Rules* (MOE, 2009, 2017). With WHPAs B through E there is an intrinsic level of uncertainty in the analysis, given the complexity of the study area and the paucity of data in certain instances. The vulnerability assessment also has a certain level of uncertainty associated with it.

The vulnerability assessment is a combination of several components each with their own uncertainty associated to them. These components include:

- The time of travel zones are based on the calibration match and the response of the capture zones within the sensitivity scenarios;
- The quality of the data used to calculate the vulnerability; and
- The vulnerability rating, which is often due to uncertainty associated with the understanding and conceptualization of the hydrostratigraphic groundwater system.

In some areas, the hydrostratigraphy is well understood, and therefore the resulting vulnerability mapping may be clear, leading to low uncertainty. In contrast, hydrogeologically complex areas may result in higher uncertainty. **Table 4.11** outlines the uncertainty estimated for each factor, at each municipal wellhead.

Uncertainty for the Peel Region WHPAs is summarized as follows:

- The WHPAs were delineated using a multiple scenario sensitivity analysis to account for variation in multiple parameters. The resulting WHPAs are conservative in nature with good calibration results therefore, the uncertainty can be considered low with the exception of Alton Wells 3 and 4A, and Cheltenham Wells.
- WWAT uncertainty was determined based on the groundwater model used to delineate the WHPAs and that these zones cannot be field verified.
- Although the delineation of the WHPA-E for Alton Well 4A includes a significant amount of stream flow data (8 years), parameter values used to complete Mannings equation (flow volume, channel slope and section geometry) introduced some uncertainty. Given that each segment of the WHPA-E was not field verified, a high uncertainty rating was assigned to both the WHPA delineation and the vulnerability assessment.

Table 4.11: Uncertainty Assessment—Town of Caledon

	Uncertainty Type	WHPA-A	WHPA-B	WHPA-C	WHPA-D	WHPA-E
Alton Well 3	Delineation of WHPA	Low	High	High	High	Low
	Vulnerability assessment	Low	High	High	Low	Low
	Overall – Vulnerability Scores	**Low**	**High**	**High**	**Low**	**Low**
Alton Well 4A	Delineation of WHPA	Low	High	High	High	High
	Vulnerability assessment	Low	High	High	High	High
	Overall – Vulnerability Scores	**Low**	**High**	**High**	**High**	**High**
Caledon Village Well 3	Delineation of WHPA	Low	Low	Low	Low	—
	Vulnerability assessment	Low	High	High	Low	—
	Overall – Vulnerability Scores	**Low**	**High**	**High**	**Low**	—
Caledon Village Well 4	Delineation of WHPA	Low	Low	Low	Low	—
	Vulnerability assessment	Low	High	Low	Low	—
	Overall – Vulnerability Scores	**Low**	**High**	**Low**	**Low**	**—**
Inglewood Well 3	Delineation of WHPA	Low	Low	Low	Low	—
	Vulnerability assessment	Low	High	Low	Low	—
	Overall – Vulnerability Scores	**Low**	**High**	**Low**	**Low**	—
Inglewood Well 4	Delineation of WHPA	Low	Low	Low	Low	—
	Vulnerability assessment	Low	High	Low	Low	—
	Overall – Vulnerability Scores	**Low**	**High**	**Low**	**Low**	—
Cheltenham	Delineation of WHPA	Low	High	High	High	—
	Vulnerability assessment	Low	High	High	Low	—
	Overall – Vulnerability Scores	**Low**	**High**	**High**	**Low**	

4.9 SURFACE WATER VULNERABILITY ANALYSIS

The focus of the *CWA* is on municipal drinking water supplies. The source of drinking water for the majority of the population in the CVSPA jurisdiction is from Lake Ontario. The Region of Peel owns two water treatment plants (WTPs) Arthur P. Kennedy (formerly Lakeview) and Lorne Park, which provide water to Mississauga and Brampton as well as supplying water to York Region (see **Table 2.5** for details).

Under the *CWA*, vulnerable areas for surface water are referred to as Intake Protection Zones (IPZs). For municipalities to protect the area around their intakes, they must protect the surrounding water and, in most cases, the land area nearest the intakes.

The surface water vulnerability analysis for the Lake Ontario municipal intakes was undertaken by Stantec Consulting Ltd. (*Lake Ontario Collaborative—Surface Water Vulnerability Assessment, Phase 1 and 2, 2008, 2010 & 2011*) under the leadership of the Region of Peel. This included the analysis of the vulnerability of these two intakes and nine others, supplying municipalities along Lake Ontario - from Niagara in the west, to Prince Edward County in the east.

The vulnerability analysis included a characterization of the intakes and near shore areas, delineation of IPZ-1 and IPZ-2 zones for each intake, and scoring of vulnerability of each intake to contamination. The IPZ-1 is based on a circular area that extends 1 kilometre away from the intake. The IPZ-2 for each intake was delineated using complex *hydrodynamic* models. These computer-based models were constructed using data inputs such as water current direction and speed, wind direction and speed, water temperature profiles, etc. The surface water vulnerability analysis assesses the likelihood that surface water can become contaminated, particularly in the areas surrounding the intakes of water treatment plants. Vulnerability analysis considered:

- Characterization of the intakes and near areas;
- Delineation of vulnerable areas around intakes—Intake Protection Zones (IPZs); and
- Assessment of raw water vulnerability around intakes, and the assignment of vulnerability scores.

> **Hydrodynamic Model**: A tool able to describe or represent the motion of water.
>
> **Bathymetry**: The shape of the bottom of a lake.

The study also assesses storm-sewer systems (per *Technical Rule 65 (2)*) and transport pathways (per *Technical Rule 72*) within the IPZ s, that could potentially allow contaminants to reach an intake at a quicker rate.

4.9.1 Intake Protection Zones Delineation

Protecting the area around a surface water intake means protecting the surrounding water and in most cases, the land adjacent to the body of water. Under the *CWA,* these areas of water and land are known as water quality IPZs. Intake protection zones in a large lake where the intake pipe is located far from shore, such as in one of the Great Lakes, often never touch shore. IPZs in smaller lakes or on rivers may also include the land surrounding it, as well as several smaller feeder rivers or tributaries.

Under the *CWA*, the Province of Ontario has required that three IPZ areas be identified. The size of each area varies depending on where the intake is located, *bathymetry*, currents, contributing area, loadings, etc. CVSPA's intakes are all located in Lake Ontario and are municipally owned and operated. Great Lake intakes are designated as "Type A" under the *Technical Rules*. The following short descriptions clarify the zones around intakes. Great Lake IPZs associated with the Great Lakes intakes include:

- **IPZ-1 -** This zone represents the area immediately adjacent to the drinking water intake. According to the *Technical Rules,* it is a circle with a radius of 1 km measured from the entry point where raw water enters the system. It is generally considered the most vulnerable zone because it is adjacent to the intake and because contaminants discharged within this area are presumably undiluted.

  Per Technical Rule (62), "If the area delineated in accordance with *Rule (61)* (delineation of IPZ-1 as described) includes any land, the IPZ-1 shall only include a setback on the land that is the greater of:

  - (1) The area of land that drains into the surface water body measured from the high water mark and the area must not exceed 120 metres. The term 'high water mark' under the Director's Technical Rules is consistent with the definition of 'ordinary high water mark' as defined by DFO-Fact Sheet T-6, Fisheries and Ocean Canada, as the usual or average level to which a body of water rises at its highest point and remains for sufficient time so as to change the characteristics of the land; and
  - (2) If a Conservation Authority Regulation Limit is in effect in the IPZ-1, the area of land that is within the Conservation Authority Regulation Limit.

- ***IPZ-2 -*** This zone represents the area, both on land and in water, where a spill of a contaminant might reach the intake before the plant operator can respond. In CVSPA, the minimum response time, as specified in the *Technical Rules*, is 2 hours, which has been used for all intakes. The IPZ-2 is comprised of two components, in-lake and upland, which are described below. The two elements for each intake are summarized in **Table 4.12** and **Figure 4.40**.

  - In-Lake - This component of the IPZ-2 was calculated using hydrodynamic models to calculate the distance that a particle released at the surface would travel in 2-hours. Inputs to the models include but are not limited to: wind and wave data*;* bathymetry data; as well as water quality parameters at the intake. In CVSPA, the IPZ-2 is based on estimating the distance a contaminant might move in two hours along the water surface, calculated from the water intake crib outwards under wind conditions that reflect a one year return period to the east, and a three year return period to the west. In locations where the in-lake IPZ-2 does not reach the shore, it has been extended from the outer limits to the shore at an angle perpendicular to the model. This extension was recommended by the modelling team to ensure a more conservative approach, recognizing that there is a level of uncertainty within the model.

  - Upland – This component has two sub-components – setbacks and transport pathways. The setbacks are determined as the greater of 120 m or the Conservation Authority Regulated limit, measured from the high mark. The measured high water mark is based on the CGVD28 (Canadian Geographic Vertical Datum) converted from the IGLD (International Great Lakes Datum 1985). The high water mark was delineated and setback extended from this datum. The transport pathways component includes areas that are drained by storm sewers and watercourses. The upper limit of this latter component is determined based on the 2-hour time of travel 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 2-hour time of travel analysis. A full description of this analysis is found in **Appendix D2**. Local tributaries were defined in the model and a 2-year return period flow was used in all runs. 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.

- **IPZ-3** - A number of spill scenarios were modelled as part of the Lake Ontario Collaborative to determine if certain land-based activities could pose a potential drinking water threat to these intakes. Any scenario that identifies conditions under which a contaminant could exceed a threshold in the raw water is identified as a significant drinking water threat. An IPZ-3 was delineated using the required setbacks from the point of its release in the tributary to a point representing the maximum landward extent of the IPZ-2. A dashed line is also drawn from the point of entry at the lake to the affected intake. This line is termed the “spill collector” and represents the shortest transport path between the shoreline and the affected intakes. An IPZ-3 that falls in the lake such as a spill at a WWTP is represented by a spill collector dashed line only. This work is reported in **Chapter 5** of this Assessment Report.

The IPZ-1 for Arthur P. Kennedy and Lorne Park intakes do not extend to the shore. The discussion of the models and approach used to delineate the IPZ-1 and 2, are found in the following foundation reports in **Appendix D2**:

- “Intake Protection Zone Delineation and Vulnerability Assessment Studies for the Arthur P. Kennedy and Lorne Park Water Treatment Plants, Final Report”;
- “Addendum to the Intake Protection Zone Delineation and Vulnerability Assessment Study for the Region of Peel”;
- “Collaborative Study to Protect Lake Ontario Drinking Water Addendum to Final Phase 1 Report for the Regional Municipality of Halton”; and
- “Lake Ontario Collaborative Source Protection Planning R.L. Clark WTP Vulnerability Scoring”.

The model results show that near-shore current patterns are strongly correlated to wind direction which is primarily westerly and easterly. Particularly at the western end of Lake Ontario the current patterns within the lake are three-dimensional. While surface water is moving in one direction, the currents near the bottom move in the reverse direction, which can also cause upwelling of bottom water to the surface, and down welling of surface water to lower depths. Down welling can bring surface contaminants down to the depth where the intakes are located. These intakes are located a sufficient distance offshore so they are not influenced by shoreline structures. Adjacent tributaries did not influence current patterns around the intakes under the analyzed two-year flow events.

A summary of the IPZ-2 delineation is provided in **Table 4.12** and the vulnerability scoring is summarized in **Table 4.13** with details by water system provided. Mapping of the Intake Protection Zones and vulnerability scores for the CVSPA are shown in **Figure 4.41** through **Figure 4.44**.

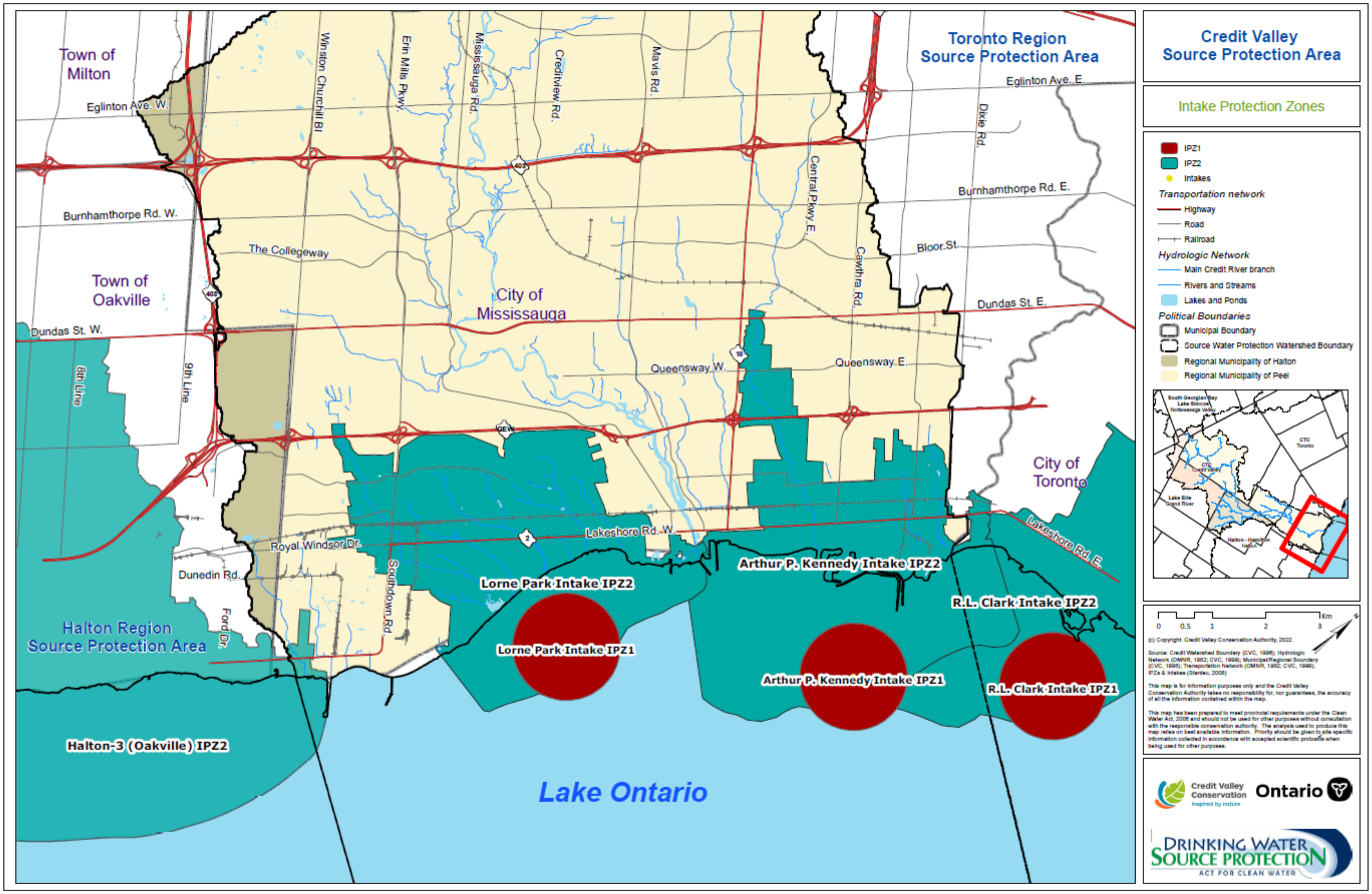

Figure 4.40: Intake Protection Zones

Summary – IPZ-2 Delineation

Table 4.12 summarizes the information on the IPZ-2s for intakes in the CVSPA. A description of IPZs for the WTPs of neighbouring SPAs has also been included, where they extend into the CVSPA.

- R. L. Clark WTP: located in the TRSPA, east of CVSPA, but its IPZ-2 extends into the CVSPA abutting the IPZs of Arthur P. Kennedy intake;
- Oakville WTP: located in the Halton Source Protection Area (HSPA), west of CVSPA, but its IPZ-2 enters the western edge of the CVSPA. It does not touch the IPZs of Lorne Park's intake.

For a full discussion of the water treatment plants located in the TRSPA and HSPA, please consult the assessment reports of each of the respective SPAs concerned.

Table 4.12: Extent of IPZ-2 in the Credit Valley Source Protection Area and Environs

SPA/SPR	WTP	In-Lake Extent	Upland Extent
CVSPA / CTC	**Lorne Park**	Extends approximately 2.5 km north and 2 km south of the intake, respectively. Particle tracking indicates that the IPZ-2 does not touch the shoreline, but it has been extended to the mouth of the Credit River to provide a measure of conservativeness.	The IPZ-2 was extended to the shoreline and upland to encompass stormshed boundaries, and the following watercourses that contribute to the source water intake area - Credit River, Sheridan Creek, Birchwood Creek, Lornewood Creek, Moore Creek, Tecumseh Creek, and Turtle Creek.
	Arthur P. Kennedy	Extends approximately 3.2 km northeast and 2.9 km southwest of the intake, respectively. Particle tracking indicates that the IPZ does not touch the shoreline, but its western extent is the Credit River.	The IPZ-2 was extended to the shoreline and upland to encompass stormshed boundaries, and the following watercourses that contribute to the source water intake area - Credit River, Etobicoke Creek, Cooksville Creek, Applewood Creek; and Serson Creek.
TRSPA/ CTC	**R.L. Clark**	Extends approximately 3.6 km northeast and 3 km southwest of the intake, respectively. Particle tracking indicates that the IPZ-2 extends close to the shore and it has been extended to include 800 m of shoreline.	Extended to the west and east of the decommissioned Lakeview Generating Station. It travels along Lake Promenade, to the CN rail tracks, and follows the northeast line until it approaches the Etobicoke River along, a setback of 120 m.
Halton/ Halton-Hamilton	**Oakville**	Occupies an area of 97.1 km^2, with dimensions extending approximately 2 km south, 5 km west and 6 km east of the intake, respectively.	The upland extent ends at Burnamthorpe Rd. in the north, and shoreline extent of 13.8 km. The major expressway, QEW, and a rail corridor is included.

4.9.2 Vulnerability Scoring for IPZs

Once water quality IPZs are delineated, scientific calculations, along with professional experience, are used to determine how vulnerable each IPZ is to contamination. This vulnerability score (V) is essentially qualitative and derived from the formula provided in *Technical Rules*:

$$V = Vf_z \times Vf_s$$

The zone vulnerability factors (Vf_z) are assigned to each IPZ according to its susceptibility to becoming contaminated. Zone vulnerability factors depend on varying circumstances, such as the surrounding environmental conditions, the percentage of the area that is land, and how water flows through the area. As indicated earlier, transport pathways (conduits by which potential contaminants might enter the IPZ) are also considered. Natural pathways such as small channels, gullies, or fractured rock that create an opening for contaminants may also increase vulnerability.

Each intake is assigned a source vulnerability factor (Vf_s) between 0.5 and 0.7. This score depends on factors such as the type of intake, the depth and length of the intake, and the number of past incidents of exceeding the water quality guidance/standards. Water quality and trends are summarized in **Chapter 2.** Also, information about intake depth and intake distance from shoreline is shown in **Table 2.5**.

The formula does not consider specific contaminants, their respective properties, or their behaviours. The vulnerability score (V) and assigned Vf_z and Vf_s scores, do not have units. Additional discussion on the vulnerability scoring for the lake-based intakes is provided in **Appendix D2.**

The vulnerability score for each intake is assigned a score based on the following criteria:

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

IPZ-3s related to the Type A intakes (Great Lakes) in the study area have been delineated and are reported in **Chapter 5** of this Assessment Report. Once the IPZs have been delineated, the assignment of a vulnerability score is derived from the equation given in Part VIII of the *Technical Rules*, which provides for a possible range of scores.

Final Vulnerability Scores

The Lorne Park and Arthur P. Kennedy Water Treatment Plants (WTP) are located in a highly urbanized area close to the shore of Lake Ontario. As shown in **Chapter 2.3**, the Lorne Park WTP extends 1.5 km offshore, at a depth of about 10 m, while the Arthur P. Kennedy WTP extends 2 km offshore, at a depth of about 18 m.

The vulnerability score for lake-based intakes is based upon an area vulnerability score factor (Vfz), and source vulnerability factor (Vfs).

The area vulnerability score factor (Vfz) does not consider the nature of a contaminant but rather the ability of a contaminant to reach the source water body – in this case Lake Ontario. The IPZ-1 for both Lorne Park and Arthur P. Kennedy WTPs are assigned a Vfz of 10 in accordance with *Rule 88*, which states that all IPZ-1s shall be assigned an area vulnerability factor of 10.

The *Technical Rules* require that IPZ-2s shall be assigned an area vulnerability factor that is not less than 7 and not more than 9 (*Rule 89*) based on both natural and anthropogenic influences. The natural characteristics that were considered by the Lake Ontario Collaborative in determining the Vfz within the

IPZ-2 for both WTP's include the slope of the upland environment and the discharges from the watercourses listed in **Table 4.12**. Surface water runoff may transport sediment, salt, oil and other contaminants into these creeks, or directly into Lake Ontario.

The area surrounding both WTPs is highly urbanized, which has resulted in large quantities of storm and surface water runoff. Anthropogenic pathways in the IPZ-2 include large surface runoff volumes from urban areas and transportation routes, and discharges from storm sewers and CSOs.

Given these conditions, the natural and anthropogenic characteristics of the area around the intake around the area, provide for the discharge of contaminants into the lake. The Vfz for the IPZ-2 for both WTPs is assigned a high ranking of 9 based on these considerations.

The source vulnerability factor (Vfs) varies between 0.5 and 0.7. This score depends on factors such as the type of intake, the depth and length of the intake, and the number of past incidents of exceeding the water quality guidance/standards. Based on these factors, both the Lorne Park and Arthur P. Kennedy WTPs are assigned a Vfs score of 0.5.

Additional detail on the considerations applied to the vulnerability scoring for the Lorne Park and Arthur P. Kennedy WTPs is provided in **Appendix D2.**

Table 4.13 summarizes the vulnerability assessment for the Arthur P. Kennedy and Lorne Park WTPs, as well as the neighbouring Oakville (HSPA) and R.L. Clarke (TRSPA) WTPs.

Table 4.13: Vulnerability Scores—Credit Valley Source Protection Area and Neighbouring Intakes

Intake Location (WTP)	Area Vulnerability Factor (V_{fz})		Source VulnerabilityFactor (V_{fs})	Vulnerability Score[1] (V)	
	IPZ-1	IPZ-2		IPZ-1	IPZ-2
Arthur P. Kennedy	10	9	0.5	5	4.5
Lorne Park	10	9	0.5	5	4.5
R. L. Clark	10	9	0.5	5	4.5
Oakville	10	8	0.6	6	4.8

The resulting vulnerability score for IPZ-1 for Peel Region and Toronto intakes is considered low (5), while being moderate (6) for the Halton Region intake. The vulnerability score for the IPZ-2s of Oakville (4.8), Peel Region (4.5), and Toronto (4.5) intakes, is also considered low.

The vulnerability scores within the IPZ-2s of the Oakville WTP, and the IPZ-1s and 2s of Arthur P. Kennedy, Lorne Park WTPs and R.L. Clark WTPs are shown in **Figure 4.41** through **Figure 4.44**.

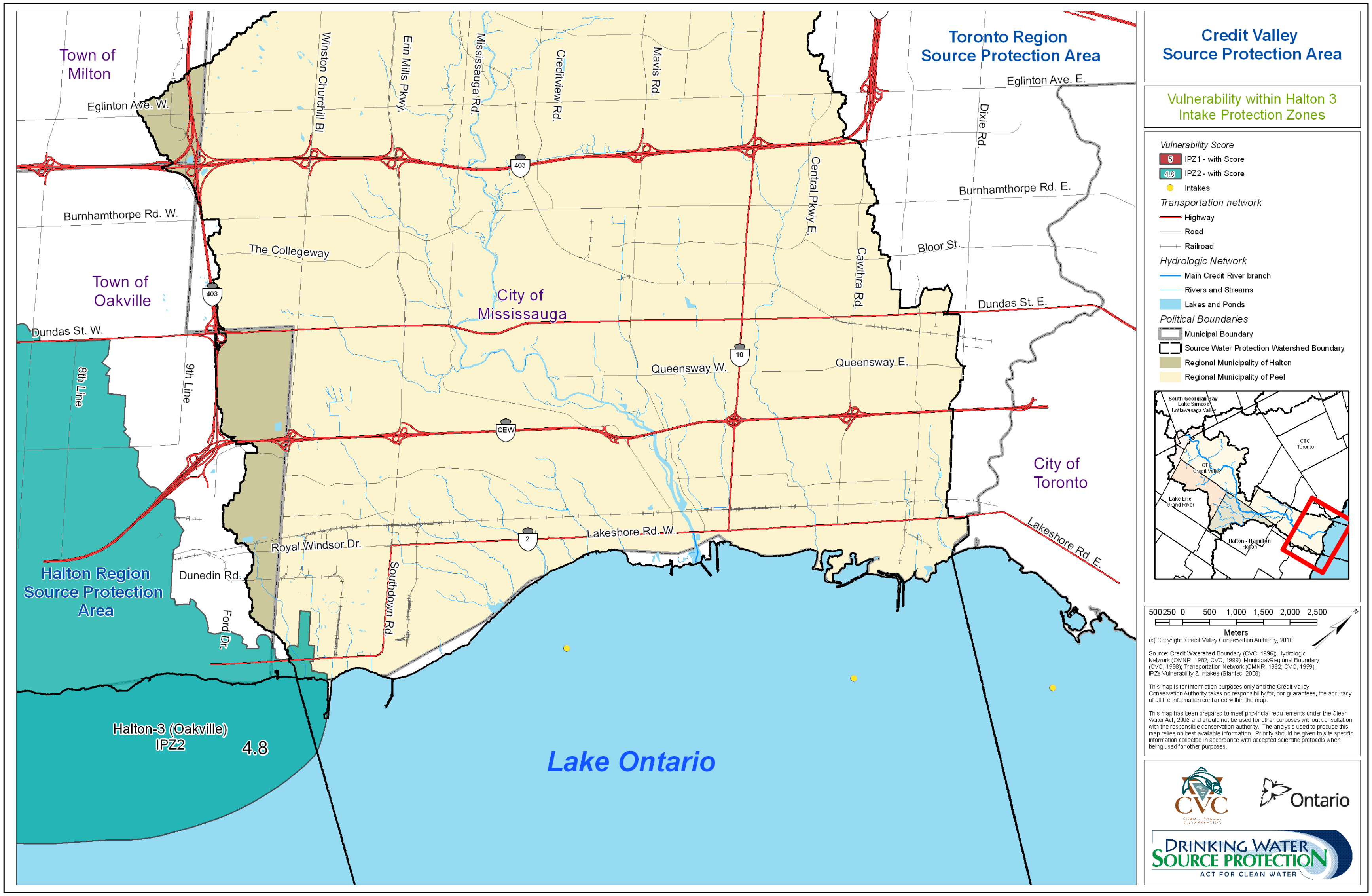

Figure 4.41: Vulnerability within Halton-3 Intake Protection Zone

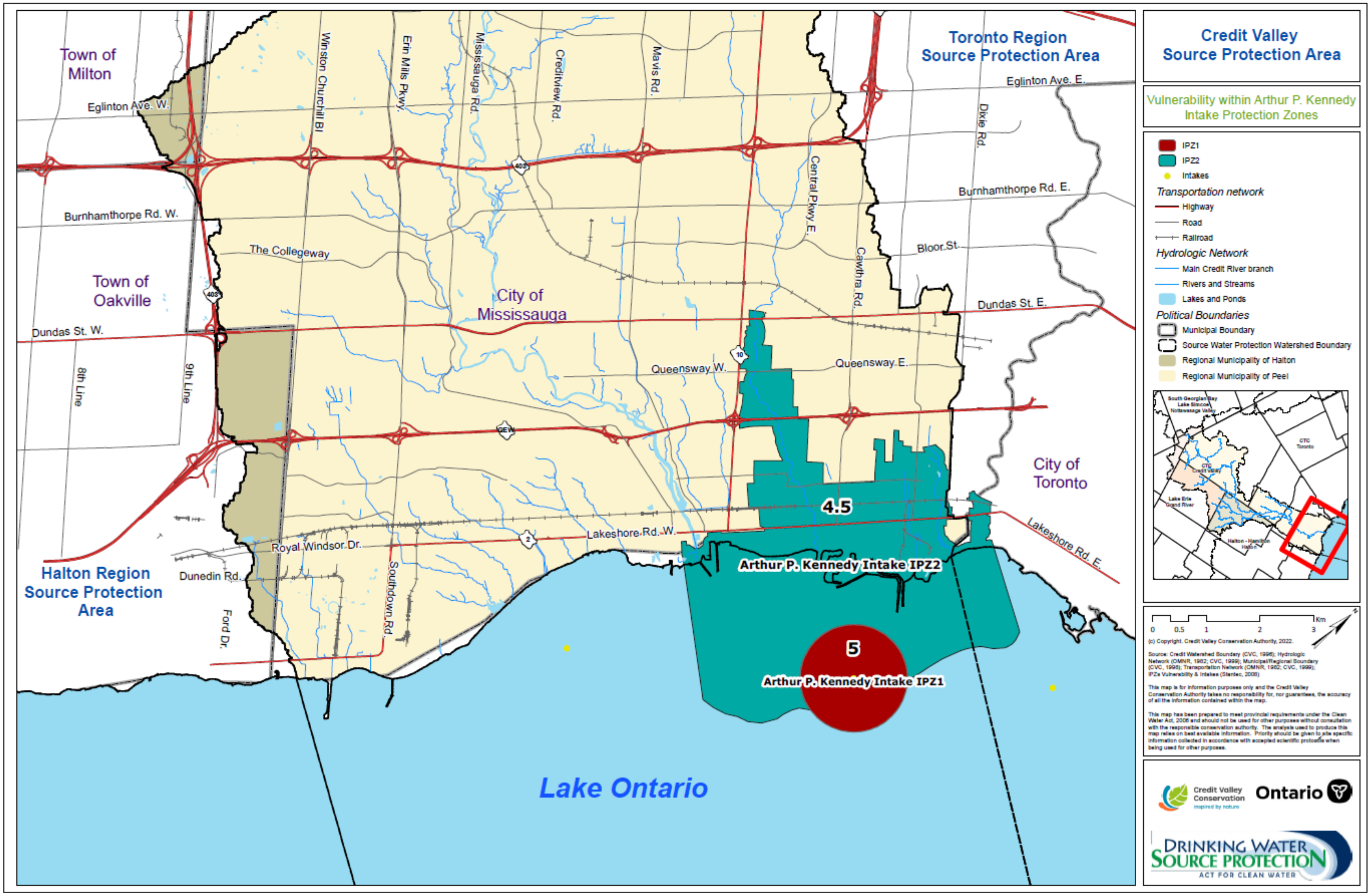

Figure 4.42: Vulnerability within Arthur P. Kennedy Intake Protection Zones (CVSPA)

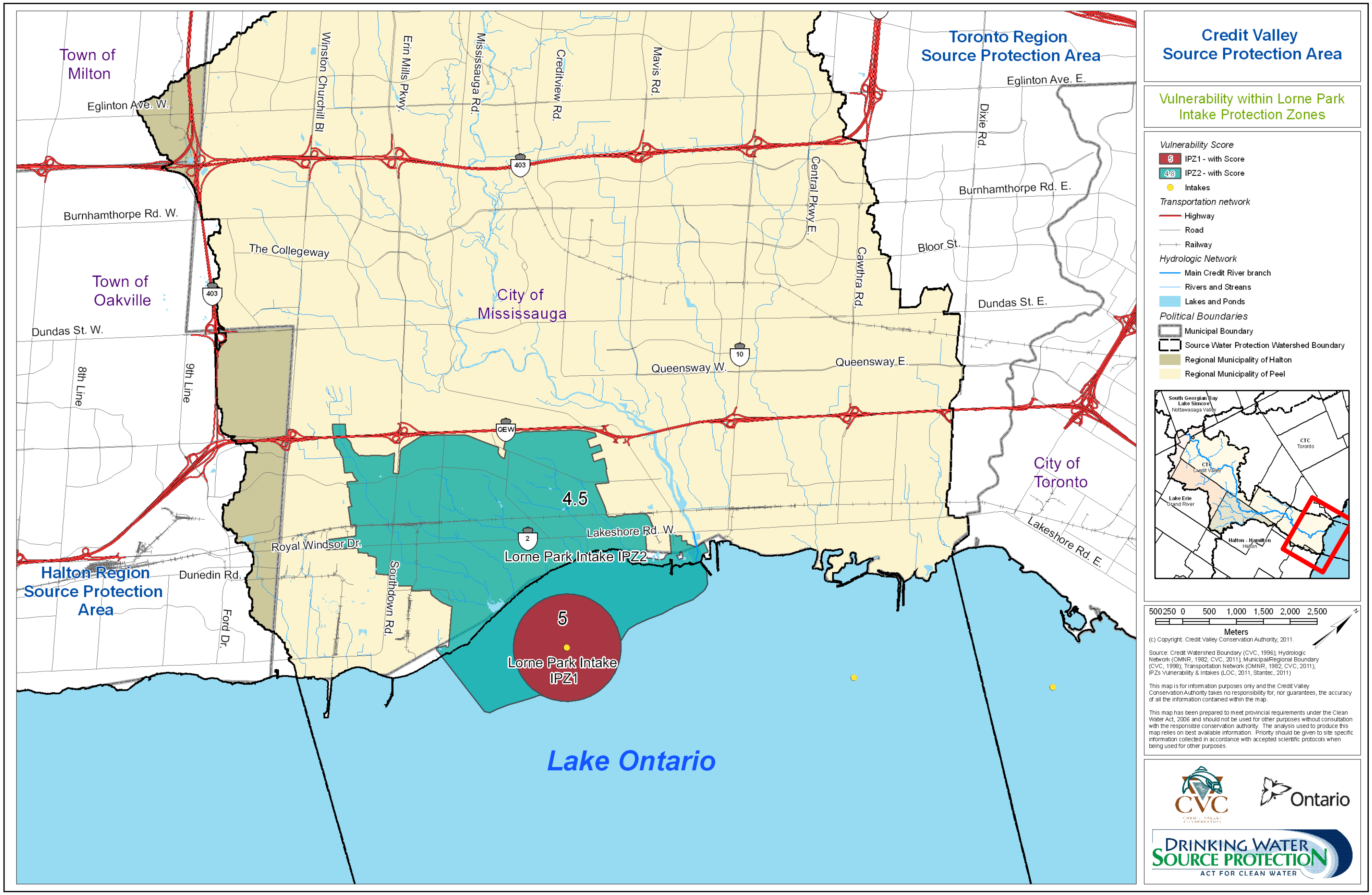

Figure 4.43: Vulnerability within Lorne Park Intake Protection Zones (CVSPA)

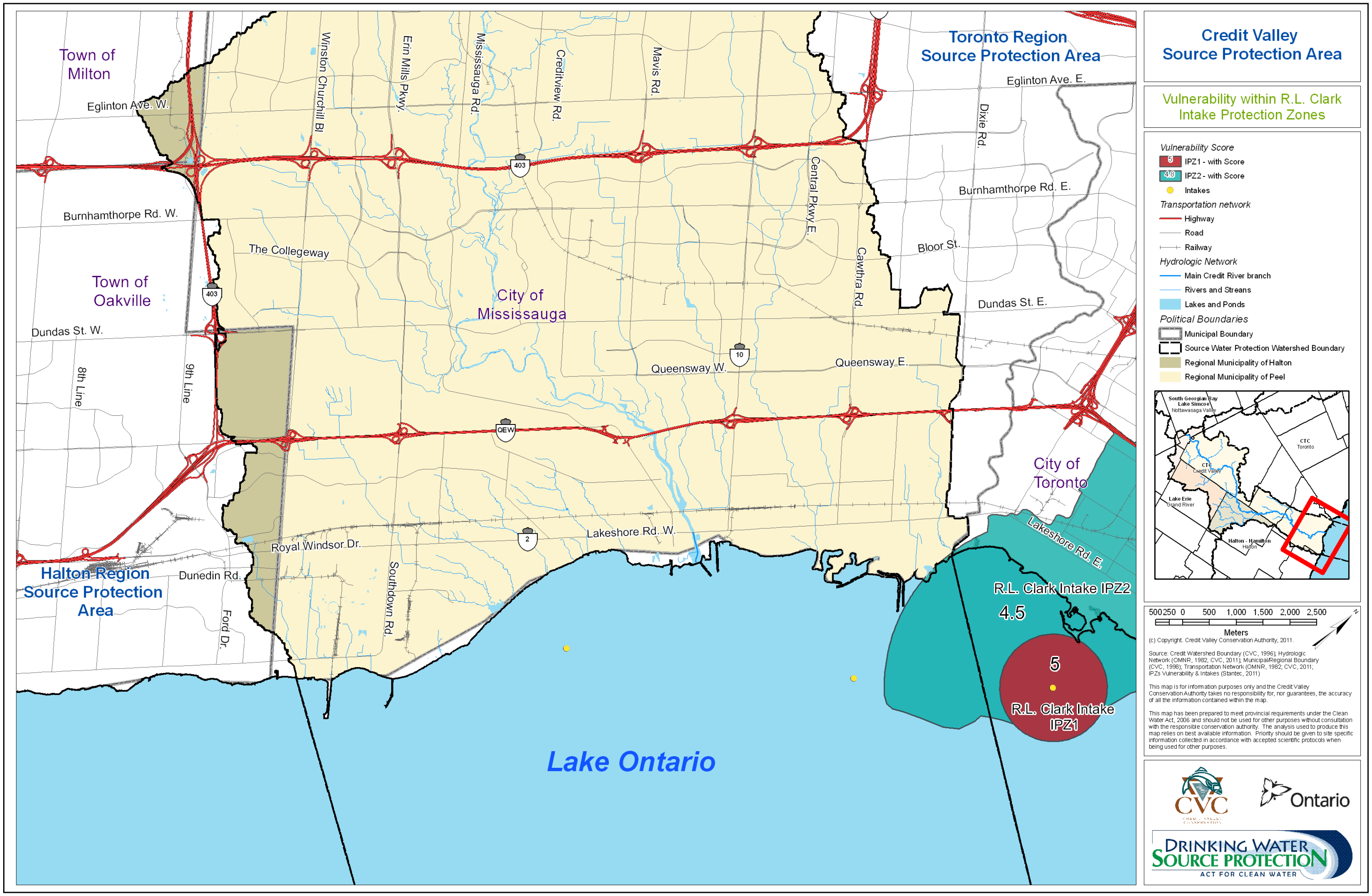

Figure 4.44: Vulnerability within R. L. Clark Intake Protection Zones (TRSPA)

4.9.3 Uncertainty Assessment

The uncertainty level for IPZ-1 in all WTPs is low (meaning a high level of confidence). The IPZ-2 for the in lake component for each WTP was calculated using a hydrodynamic model, which included data inputs from water movement, winds, currents and temperatures. The uncertainty level for all the IPZ-2 in lake zones for the Peel Region intakes located in CVSPA is high (meaning a low level of confidence) due to the general lack of data to calibrate the model suites, as well as the limited data used to drive the model and reach steady state conditions.

More detailed hydraulic data is required to run a variety of scenarios and effectively model water movement in the study area. In addition, there is high uncertainty associated with the extension of the IPZ-2 to the shore as the in-water modeling did not originally include a connection to the shore. The uncertainty level for the IPZ-2 for the upland component for each WTP is also high. The 2-hour time of travel within the creek systems was based on modeled velocities, where models were available, and conservative estimates, where models were not available.

As mentioned above, the hydrologic (flow) models are conservative and were selected due to the absence of streamflow monitoring stations that are located in close proximity to the lake. The 2-hour time of travel within the storm sewers was based on an estimated and somewhat high velocity to ensure that IPZ was delineated in a conservative manner. As a result of the above, the combined uncertainty is high for all Peel Region intakes located in CVSPA, even though the critical data needed to delineate the vulnerability zones and score the intake vulnerability was sufficient.

Overall, the information available at the time of writing was of sufficient density, quality, and quantity to adequately complete a surface water vulnerability analysis at a scoping level. The uncertainty associated with the IPZ delineations and vulnerability scores, for Arthur P. Kennedy, Lorne Park, R.L. Clark, and Oakville WTPs are shown in **Table 4.14**.

Table 4.14: Uncertainty Assessments of Vulnerability Scores.

SPA/SPR	Intake Location		Vulnerability Score	Uncertainty IPZ Delineation	Uncertainty Vulnerability Score	Combined Uncertainty Level
TRSPA/CTC	**R.L. Clarke**	IPZ-1	5.0	Low	Low	Low
		IPZ-2	4.5	High	Low	High
CVSPA/CTC	**Arthur P. Kennedy**	IPZ-1	5.0	Low	Low	Low
		IPZ-2	4.5	High	Low	High
	Lorne Park	IPZ-1	5.0	Low	Low	Low
		IPZ-2	4.5	High	Low	High
Halton/ Halton-Hamilton	**Oakville**	IPZ-1	6.0	Low	Low	Low
		IPZ-2	4.8	High	Low	High

Vulnerability scores below 6 are considered low (Lake Ontario Collaborative—Surface Water Vulnerability Assessment, Phase 1 and 2, 2008, 2009 & 2011). A discussion of the factors influencing the uncertainty in the delineation and vulnerability scoring are presented in **Appendix D2**.

The IPZ-2 upland was delineated based on a conservative methodology in order to provide a scoping level delineation. In determining the landward and up-tributary extent of the IPZ-2 the following uncertainties have been note:

- Due to the conservative nature of the HEC-RAS data, the up-tributary delineations have a moderate level of uncertainty; and
- Catchment areas for storm sewer networks were not available, so were therefore estimated. Velocity data for the storm sewers were also not available. There is low uncertainty as to which storm networks ought to be included, but high uncertainty as to the extent of the network that should be included.

Also, the potential for high volumes of runoff to be produced within the study area and the channelling of runoff into nearby watercourses, the absence of flow data, stream flow velocities and other watercourse characteristics leads to a high uncertainty in the upland extent component for the IPZ-2. The IPZs upland was delineated based on a conservative methodology in order to provide a scoping level delineation.

The uncertainties associated with the in-lake and alongshore IPZ-2 delineation, and the data gaps identified with respect to the information used for the determination of the landward and up-tributary IPZ-2 component necessitates a high level of uncertainty.

Site-specific data contributing to the vulnerability factor are from ongoing provincial monitoring programs, federal monitoring programs, as well as input from the WTP operators and conservation authorities. They are not of sufficient quality and frequency to impart high confidence in the vulnerability scoring.

4.10 SUMMARY

The *CWA* requires the mapping and assessment of the natural vulnerability in vulnerable source water areas located within the CVSPA's jurisdiction – HVAs, SGRAs, WHPAs and IPZs. These areas can be vulnerable based on water quantity or water quality considerations, or both. The natural vulnerability of HVAs, WHPAs, and IPZs are assessed and scored high, medium, or low, using approved provincial methodologies. The vulnerability scoring is required in the determination of risk to the sources when assessing the different land-uses and activities that exist on the landscape. To calculate the hazard rating for each land use activity, the Province made a series of assumptions that have an uncertainty associated with them. In their analysis, it was assumed that any possible threats associated with an activity were present and that all potential chemicals were present. The circumstances and quantity for each threat were assigned based on available knowledge, such as typical storage practices, typical chemical quantities, and typical waste disposal practices for that particular land use activity. Risk is determined using the vulnerability score and hazard scores assigned to the different activities and their associated chemicals and pathogens, as outlined in **Chapter 5.**

In the CVSPA, over 95% of the population receives its drinking water from municipal systems, sourced either from Lake Ontario (surface water – 90%) or from municipal wells (groundwater – 5%).

HVAs are areas susceptible to contamination moving from the surface into the groundwater. In the CVSPA jurisdiction, there are large areas underlain by shallow bedrock deposits that support many shallow wells. These aquifers are considered vulnerable to contamination that may cause deterioration of the water quality in water wells that use this source. Although minimum water well construction standards are set out in O. Reg. 903, under the *Ontario Water Resources Act, 1990*, extra caution should be taken when constructing wells in vulnerable aquifers. Incidentally, these wells are also vulnerable to water quantity impacts during periods of drought. Deeper aquifers that are thicker, and/or have a dense protective layer such as a till overlying them, are generally less vulnerable. Where these aquifers are closer to the surface or are exposed, they are more vulnerable.

The vulnerability of the HVAs was assessed using the AVI method. Highly vulnerable aquifers are assigned a vulnerability score of 6 per the *Technical Rules*. The features associated with the transport pathways were determined, based on the existence of pits and quarries. The vulnerability in the affected areas was increased by one level. Where this resulted in a change of vulnerability score of 4 to 6, the zone was defined as an HVA.

SGRAs are areas where the highest volume of recharge to the aquifers occurs, and are delineated as part of the water budget process (see **Chapter 3**). SGRAs are important water quantity areas — replenishing the aquifers that serve as a source of drinking water (including both municipal and other drinking water uses, such as private wells).

WHPAs are zones drawn around the wellheads of municipal wells. They can be susceptible to contamination moving from the surface into the groundwater. They are delineated in order to estimate the horizontal time of travel of water particles as they travel from a given point in an aquifer, towards an associated municipal well. Water in the furthest zone (WHPA-D) takes the longest period of time (up to 25 yrs.) to arrive at the wellhead. The vulnerability of the WHPAs were assessed using a variety of methodologies such as the Aquifer Vulnerability Index, to the Intrinsic Susceptibility Index, and the Surface to Well Advection Time (SWAT). In addition, WHPA-E is delineated where the well is under the direct influence of surface water (GUDI). The WHPA-E is the area where contamination can move within the water course to the point closest to the well within two hours.

IPZs are vulnerable areas around the Lake Ontario drinking water intakes. The IPZ-1 is delineated based on a one kilometre radius measured from the entry point where raw water enters the system. IPZ-2s in lake component was delineated using hydrodynamic models to estimate the distance that a contaminant could travel in two hours. The models include estimating such factors as wind direction and speed, stream loadings, and lake currents.

The IPZ-2 upland component was determined by a combination of administratively selected setbacks and areas that are drained by transport pathways (storm sewers and water courses). The upper limits of the area drained by transport pathways were determined by the distance a contaminant could travel in two hours. According to the Director's Rules, the setbacks are the greater of 120 metres or the CA Regulation limit measured from the high water mark. The measured high water mark is based on the CGVD28 (Canadian Geographic Vertical Datum) converted from the IGLD (International Great Lakes Datum 1985). The high water mark was delineated and setback extended from this datum.

The vulnerability for IPZ-1 and IPZ-2 areas is scored based on factors set out in the *Technical Rules*. The IPZ-1s located in the CVSPA jurisdiction (associated with the Arthur P. Kennedy, and Lorne Park WTPs) both scored 5 (low vulnerability). The vulnerability scores for IPZ-2s ranged from 4.5 to 5.0 (low vulnerability).

Additional work has been completed to model the potential impacts of a number of scenarios to determine if there are land-based sources of contaminants that could pose a potential drinking water threat to these intakes. The delineated IPZ-3 is shown by a straight dashed line to marks the connection from the shoreline to the affected intakes. The dashed line is labelled a “spill collector” to show the connection between the threat and the intake. As per the *CWA 2006, Rule (75),* the delineated IPZ-3 cannot contain any part of the IPZ-1 or 2 and so the IPZ-3 are clipped to the furthest extent of the IPZ-2. The dashed line remains as a component of the IPZ-3. This work is reported in Chapter 5 of this Assessment Report.

Analyses of uncertainty have been carried out for all vulnerable areas. The vulnerable area delineation and vulnerability assessments for groundwater were based on a combination of a complex surface water model linked to a complex, three-dimensional groundwater flow model, and in each case, the models were deemed to be calibrated to the satisfaction of external peer reviewers. Together, these factors result in a high level of confidence in the results of this vulnerability analyses for the CTC Region.

The uncertainties associated with the in-lake and along-shore IPZ-2 delineation, and the data gaps identified with respect to the information used for the determination of the landward and up-tributary IPZ-2 component necessitates a high level of uncertainty. Uncertainty information for the event based modelling and IPZ-3 is also provided in **Chapter 5**.

Finally, the reader is cautioned that there is always a certain level of uncertainty in regional assessment, and where available, site-specific information should always be used to determine local vulnerability.