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**Subject: Candidate Ecologically Significant Groundwater Recharge Areas Mapping  
for the Credit River Watershed**

Dear Kata:

Thank you for the opportunity to work with staff from Credit Valley Conservation (CVC) and the Oak Ridges Moraine Groundwater Program (ORMGP) to develop Ecologically Significant Groundwater Recharge Area (ESGRA) mapping in support of the development of a new watershed plan for the Credit River watershed. This report summarizes the input data, methodologies, and analyses applied in this study and provides an overview of findings and recommendations.

## 1 INTRODUCTION

CVC is in the process of developing a new watershed plan for the Credit River watershed. The Credit River watershed plan will characterize the form, function, and current condition of water resources and natural heritage systems. It will also assess potential impacts of future changes in climate and land cover and evaluate the implementation of management actions (e.g., stormwater management, natural heritage). The resulting plan will provide management strategies to protect, restore, or enhance the health of the watershed, including policies to protect ESGRAs.

The *Greenbelt Plan, 2017* defines ESGRAs as “areas of land that are responsible for replenishing groundwater systems that directly support sensitive areas like coldwater streams and wetlands” (MMA 2017). The connection between recharge areas and groundwater discharge locations represents a valuable hydrological function and, therefore, should be maintained or, where possible, enhanced.

Marchildon et al. (2015) developed a methodology to delineate ESGRAs using numerical groundwater models together with particle tracking techniques to identify linkages between recharge areas and groundwater dependent ecological target features (ETFs). The objective of the current study was to conduct the technical exercise outlined in Marchildon et al. (2015) for the Credit River watershed to inform the watershed plan update. At this time, the mapped areas are not designated as Special Policy Areas but rather identified to support the development of future land use policy. As such, the word *significant* is used in this document in a technical context indicating recharge areas that are linked to groundwater dependent ecological features and not in a policy context. The ESGRAs will have to go through an official approval process by municipalities before they can be formalized. Therefore, they will be referred to as “candidate” ESGRAs (c-ESGRAs) before the approval process is completed.

CVC and Matrix Solutions Inc. have developed, maintained, and applied groundwater flow models to support the management of groundwater in the Credit River watershed for over two decades. In 2006, AquaResource Inc. (now Matrix) updated both the conceptual and FEFLOW groundwater flow models previously developed by AquaResource between 1999 and 2006 (AquaResource 2006). Updates included watershed-wide hydrostratigraphic analysis (cross-sections), refinement of model mesh and layers, assignment of boundary conditions, collection and review of field observation data, and calibration of model parameters. The model was used in the 2008 Integrated Tier 2 Water Budget (AquaResource 2009) and has since been updated (AquaResource 2011) and used in several studies throughout the watershed.

For this study, Matrix reviewed existing groundwater recharge mapping and reviewed and updated the 2011 FEFLOW model to represent the most current land cover mapping and potential groundwater discharge features identified by CVC, including all perennial streams (including first order) and wetlands with an area greater than 1 ha. The updated model was used to generate c-ESGRA mapping in support of the CVC's development of a new watershed plan for the Credit River watershed.

## 2 MODEL UPDATES AND CALIBRATION

The following sections provide a description of the tasks performed to update the FEFLOW model and generate new c-ESGRA mapping based on updated data sets provided by CVC, in particular target features of ecological interest (ETFs).

### 2.1 Updated Data Sets

CVC provided several updated data sets for this study. These included the following latest mapping:

- CVC Hydrologic Network (2021-10-06; Map 1): stream segments of ecological interest (ETFs) were attributed as “Coldwater - Brook Trout Habitat,” “Coldwater - Brown/Rainbow Trout/Atlantic Salmon Habitat,” and “Redside Dace Habitat.”
- Spawning Redds (2021-01-14; Map 1): in many locations this point data set overlapped with stream segments that were already flagged as ETFs. Where this was not the case, segments were added to the set of ETFs as “Redd habitat” in appreciation that spawning redds, while mapped as isolated locations, can occur along the entire stream segment.
- Wetlands (based on 2021 Ecological Land Classification; Map 2): the polygons in this data file were simplified, and only wetlands with an area of more than 1 ha were included in the analysis. The 1 ha (100 m x 100 m) threshold was selected to ensure a sufficient number of model nodes were associated with each wetland features. This threshold was also informed by the original ESGRA methodology, where model features were required to have a resolution greater than the 100 m x 100 m resolution of the model. Insights into EGRAs associated with wetland features smaller than 1 ha would require a site-level analysis.
- Seep Indicators/Areas (2021-10-26; Map 2): the polygons in this data file were simplified, and only wetlands with an area of more than 1 ha were included in the analysis.

- Features of Hydrologic Interest/Sensitive Ecological Habitats (2022-02-10; Map 3): these represent areas with shallow groundwater (depth to groundwater less than 2 m). These were identified by the presence of groundwater-dependent species, as determined by CVC in the polygon shapefile “Final\_Ecohyd\_Habitats\_20220210” delivered to Matrix on February 10, 2022. The polygons in this data file were simplified, and only wetlands with an area of more than 1 ha were included in the analysis.
- Land Use (based on 2021 Ecological Land Classification; Map 4): the current land use mapping was compared to mapping used in the 2011 FEFLOW model and recharge values updated (Section 2.2.3) to account for land use changes (primarily from natural/agricultural to urban).

Additional information and details on the provided and used data sets are summarized in Appendix A.

## 2.2 Model Updates

In 2011, AquaResource Inc. updated the three-dimensional (3D) regional groundwater flow model (AquaResource 2012) developed to support the Tier 2 Water Budget for the Credit River watershed. In 2017, Matrix incorporated additional updates as part of the Inglewood Wellhead Protection Area Delineation (Matrix 2017). Matrix reviewed the CVC FEFLOW models and proposed model updates to CVC before generating c-ESGRA mapping. The proposed updates were discussed and agreed upon with CVC and ORMGP staff and are detailed in the following sections.

### 2.2.1 Mesh Refinements Around Steams, Wetlands, and Seepage Faces

The existing version of the FEFLOW model included streams of Strahler order two and higher. To determine which additional (mostly lower order) drainage features needed to be represented in the model, the updated hydrologic network mapping was compared against the existing FEFLOW mesh and orthophotographs. The latter helped identify actual streams from intermittent drainage features (e.g., swales). In areas where additional stream boundary conditions were applied, some local modifications (i.e., moving/aligning nodes, refining mesh locally) were usually required.

The 2011 model only included larger wetland complexes. The updated wetland and seepage area mapping was compared against the existing FEFLOW mesh to identify areas where additional boundary conditions were needed. The model was updated to include wetlands and seepage areas with a mapped surface area greater than 1 ha. While the mesh node density was generally high enough to represent wetlands and seepage faces, local modifications (i.e., moving/aligning nodes, refining mesh locally) were required in some areas. Local mesh refinement changes node structure by introducing new nodes within the selected region. The resultant higher density of model nodes allows for a better representation of hydrologic features. This helps to provide sufficient boundary conditions are applied to represent the feature in the model and improves the detail of the simulation results. Mesh refinement typically results in an increase in model run time, and thus it can be preferable to only move/align existing nodes with features of interest if the existing node density is already suitably high. Targeted refinements allow for better representation of the feature in the model without an increase in simulation run time.

## 2.2.2 Boundary Condition Updates

Matrix reviewed the representation of streams, wetlands, and lakes in the 2011 model. In FEFLOW, discharge-only features are represented by applying a head dependant flux boundary condition with an inflow boundary constraint. This allows for groundwater to discharge to a stream dependent on the groundwater level and stream stage, while preventing boundaries from adding unlimited amounts of water to the model when the groundwater level falls below the stream stage. The inflow constraint can vary throughout the model; no inflow can be specified for intermittent headwater drainage features that collect but do not recharge water, while some inflow can be allowed along stream reaches and wetlands that are known to be leaking water into the groundwater system.

The 2011 model used head-dependent boundary conditions (Type 3) to represent streams and wetland; however, only discharging boundary nodes were included. In consultation with CVC and ORMGP staff, for the updated model, all existing and additional boundary conditions were set as constant head (Type 1) boundary conditions and allowed to both discharge (to the represented surface feature) and recharge (into the groundwater flow system). Boundary condition constraints were used to only allow discharging conditions for seepage faces and lower order (i.e., ephemeral) streams.

Since the geology represented in the model was not updated (see Section 2.2.4), it was not necessary to change boundary conditions along the lateral border of the model domain at this point.

## 2.2.3 Land Cover and Recharge Updates

Recharge in the 2011 FEFLOW model was based on estimates from an HSP-F precipitation runoff model (AquaResource 2009). Land use polygons had been assigned to a corresponding HSP-F hydrologic response unit to develop spatially distributed recharge mapping and model inputs. The updated land cover polygons were reviewed and compared against the previous mapping. Where changes in land cover were identified, recharge mapping in the model was updated by applying recharge values from comparable areas of the model with the same land cover and similar slope and surficial geology. A more elaborate recharge update (e.g., by updating and rerunning the HSP-F model) is not part of this scope.

## 2.2.4 Hydrostratigraphic and Numerical Layer Updates

New geological information within the CVC watershed had become available that was not represented in the 2011 model. These included insights from recently drilled boreholes as well as an updated understanding of the location of bedrock valleys not currently represented in the model. Matrix reviewed the available new geological information and potential impacts on the groundwater flow system. It was determined that updates to the geological representation in the model would likely not significantly change the shallow groundwater system where most of the recharge/discharge flow connections exist. This was discussed with CVC and ORMGP staff, and it was agreed to leave updates of the geology for a future update.

However, lower permeability hydrostratigraphic units were refined (i.e., split vertically) to achieve more representative particle tracking. Specifically, additional numerical layers were inserted into shallow overburden aquitards. This does not change the representation of the hydrostratigraphy but adds additional calculation points to better resolve the simulated velocity field across these key units used for particle tracking.

## 2.2.5 Confirmation of Model Calibration

After completing the model input updates described in the previous section, Matrix completed flow simulations and compared the results from the refined 2022 model with the outputs from the 2011 model to confirm the model is still calibrated and appropriate for generating c-ESGRA mapping. The calibration was evaluated based on the following observation criteria:

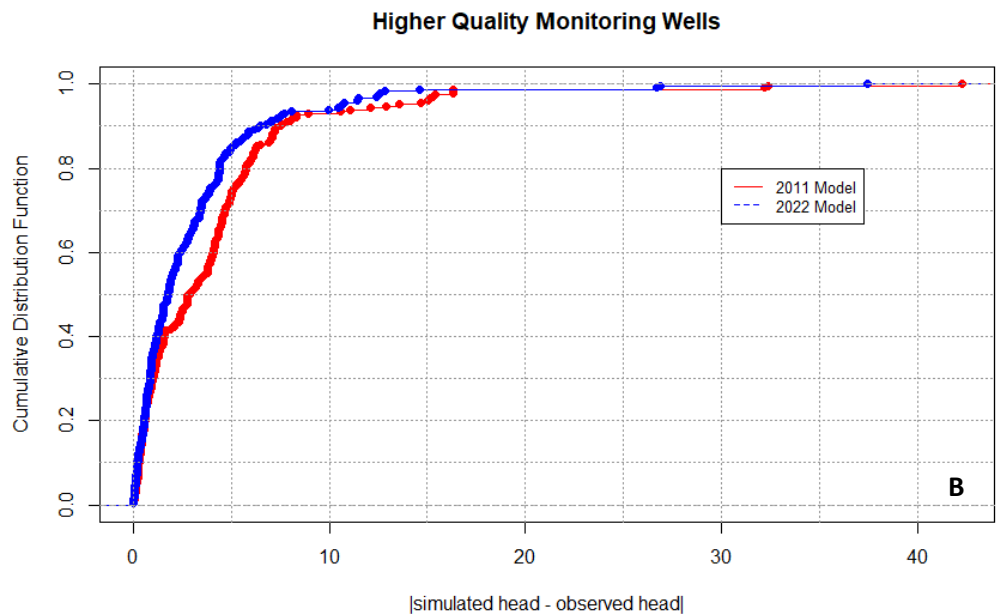
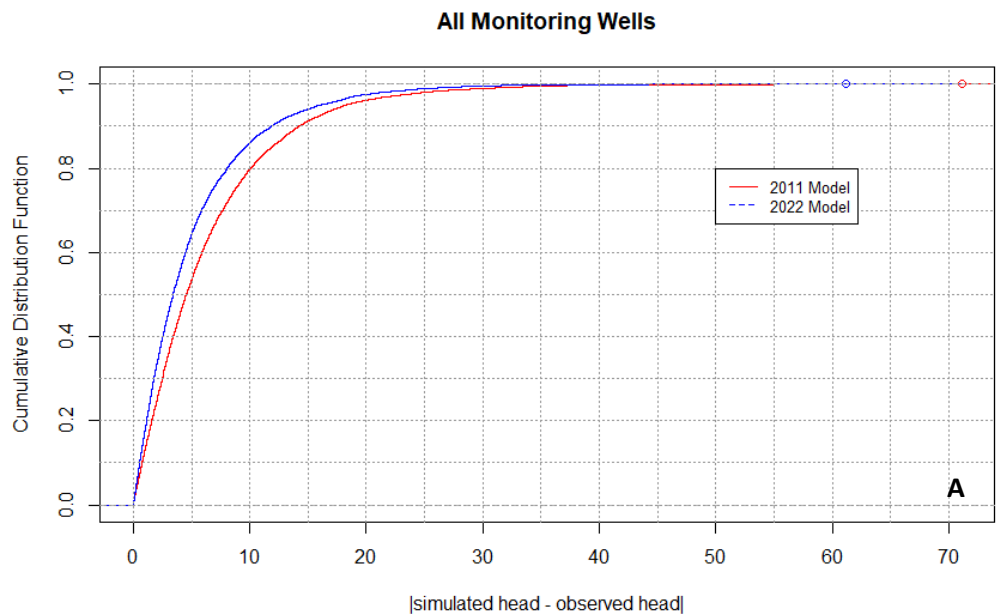
- improved fit between simulated groundwater head and observed groundwater head values compared to the 2011 model (Chart 1)
- baseflow discharge values within the range of observed values at Water Survey Canada (WSC) gauges within the CVC watershed (Table 1)
  - ✦ As WSC gauge measurements include discharge from upstream wastewater treatment plants, previous estimates of wastewater treatment plant inputs from AquaResource (2012) were added to simulated baseflow estimates (where applicable) to allow an appropriate comparison. Pumping wells are simulated in the model, and any potential withdrawals associated with pumping are included in simulated estimates of baseflow. Simulated baseflows in the updated model are similar to 2011 model results and generally fall within the range of observed values.

**TABLE 1 Comparison of Simulated Baseflows Between the Previous (2011) Model and the Updated (2022) Model for Water Survey of Canada Gauges in the Credit Valley Conservation Watershed**

Water Survey of Canada Gauge	Flow Estimated (m <sup>3</sup> /s)				
	Simulated with 2011 Model	Simulated with 2022 Model	Minimum Observed Baseflow	Average Observed Baseflow	Maximum Observed Baseflow
Black Creek	0.2	0.17	0.14	0.16	0.18
West Credit Above Erin	0.34	0.39	0.3	0.33	0.36
Melville	0.47	0.42	0.33	0.37	0.41
Shaw's Creek	0.58	0.47	0.49	0.55	0.61
Silver Creek/Norval	0.96	0.94	0.69	0.8	0.91
Cataract	1.61	1.14	1.24	1.36	1.48
Boston Mills	3.64	2.80	2.97	3.26	3.56
Credit River/Norval	5.09	4.15	4.16	4.66	5.16
Erindale	5.25	4.98	5.08	5.9	6.71

Note:

Simulated baseflows in the updated model are similar to 2011 model results and generally fall within the range of observed values.



Note: The location of the blue line (updated 2022 model) to the left of the red line (2011 model) indicates reduced head residuals (i.e., better fits) at more monitoring locations in the update than the 2011 model.

**CHART 1 Cumulative Distribution Function of Simulated Head Residuals (abs[simulated head - observed head]) for (A) All and (B) Higher Quality Monitoring Wells**

### 3 ECOLOGICALLY SIGNIFICANT GROUNDWATER RECHARGE AREA MAPPING

Marchildon et al. (2015) published a methodology for identifying ESGRAs. Toronto and Region Conservation Authority (TRCA) summarized this methodology in a technical memorandum (TRCA 2019). Matrix applied and adapted this approach after consultation with CVC and ORMGP staff on the parameters and thresholds used in this methodology. The output of the GIS analysis (density estimate, cluster analysis) of simulated particle tracks from the numerical model was used to generate updated c-ESGRA mapping. The following sections describe the steps involved in the applied methodology in detail.

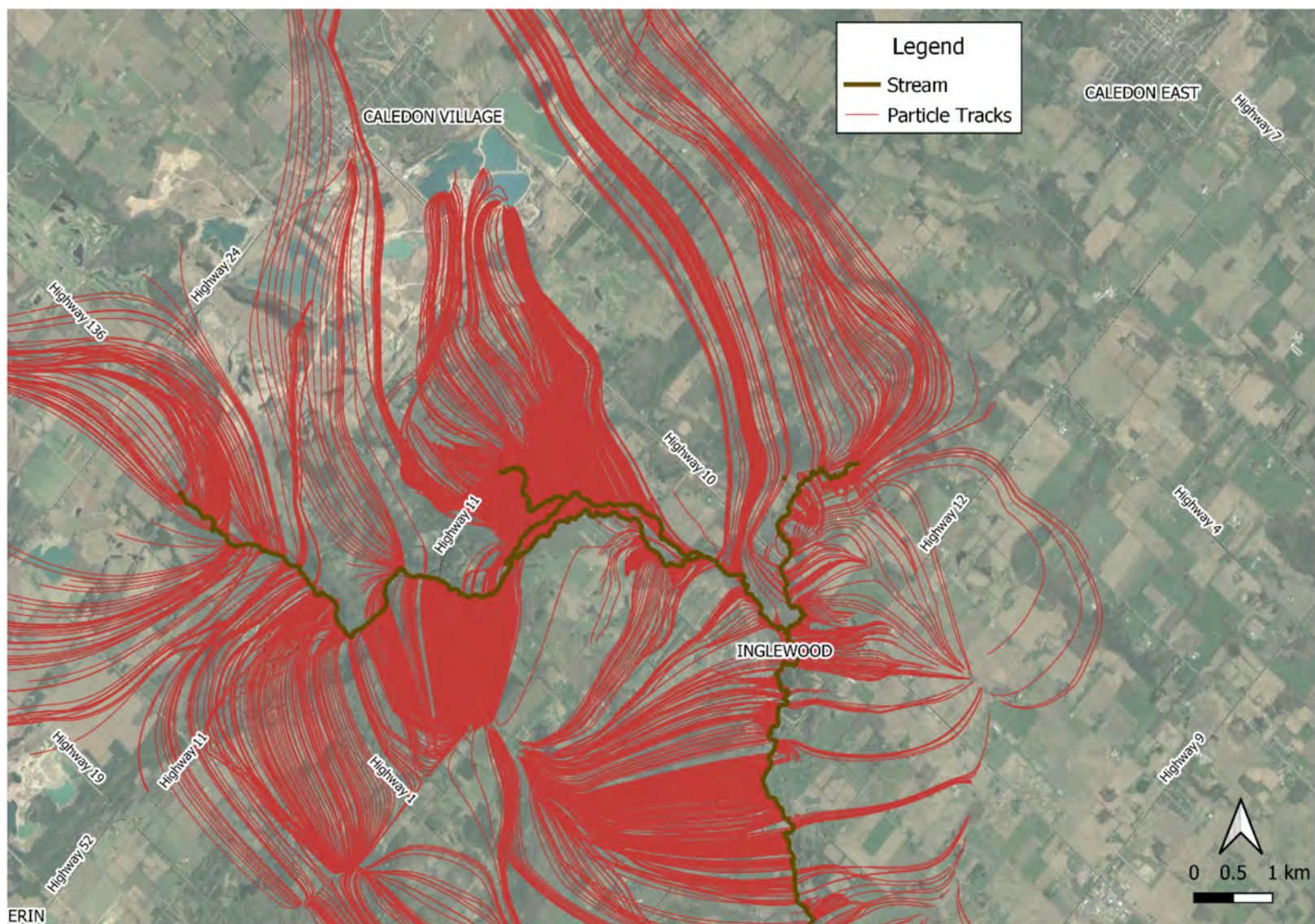
#### 3.1 Backward Particle Tracking

Matrix reviewed the ETFs provided by CVC with CVC and ORMGP staff and used backward particle tracking to link these target features to their corresponding recharge areas. For backward particle tracking, imaginary particles are released in selected locations within the model domain and tracked backwards through the groundwater flow system to a recharge location, indicating they have reached their end point. Three classes of discharge features were identified for this study: coldwater streams and spawning redd locations, wetlands and seeps, and features of hydrologic interest. These features have been mapped in the field and are considered in this study, as they are supported by shallow groundwater levels and/or groundwater discharge and, therefore, are potentially sensitive to changes in shallow groundwater flow conditions.

Coldwater streams were provided as linear features and are classified by the observed occurrence of coldwater fish species including Brook/Brown/Rainbow Trout, Atlantic Salmon, and Redside Dace. Spawning redd locations were provided as points; these points were converted into linear features by assigning the nearest stream segment if it was not already classified as a coldwater fish habitat. Some Redside Dace stream segments in urban areas east of Highway 1 were modified to match model boundary conditions due to minor spatial discrepancies between the stream segment features and the associated model boundary condition nodes. At linear stream features, particles were released every 10 m at a depth of 5 m. The appropriate particle release depth is controlled by the scale of the model. For the current model, a 5 m release depth was tested against a 1 m release depth and was determined appropriate for capturing more distance sources of recharge to features. At the scale of the current model, 1 m release depths resulted in generally short flow pathways capturing very local recharge-discharge gradients.

Wetlands, seeps, and features of hydrologic interest are represented by polygonal features, and particles were released from these features along a uniform 10 m grid at a depth of 5 m.

In total, 996,509 particles were released in the watershed, and the resultant 996,509 tracks and end points informed the development of c-ESGRA scenarios. Figure 1 illustrates particle tracks from below stream segments classified as “Coldwater - Brown/Rainbow Trout/Atlantic Salmon Habitat” in a section of the model domain near Inglewood.



Note: red lines indicate particle tracks from stream segments classified as “Coldwater - Brown/Rainbow Trout/Atlantic Salmon Habitat” (brown lines).

**FIGURE 1** Example of Backward Particle Tracks

### 3.2 Ecologically Significant Groundwater Recharge Area Mapping

The ESGRA methodology converts dense clusters of backward particle track end points into recharge areas. The methodology applies two general steps: (1) generating backward particle tracks and (2) delineating recharge areas. Backward particle tracks are created by releasing particles from target ecological discharge features in a groundwater flow model. The model produces a start point and a pathway for the particle by analyzing the groundwater flow gradients and velocity field that led the particle to their end point. The bulk of the ESGRA methodology refers to specific logic that is applied to convert particle end points into recharge areas; this logic is controlled by three threshold parameters: density threshold, aggregation distance, and minimum area. The ESGRA methodology is summarized in Figure 2 (TRCA 2019). This methodology is specific to ESRI Arc products and was modified to be applied in the QGIS environment. As a result, the polygon *aggregation distance threshold* in the Arc-based methodology is re-interpreted as a *search radius*, which is equal to half the equivalent *aggregation distance threshold* value.

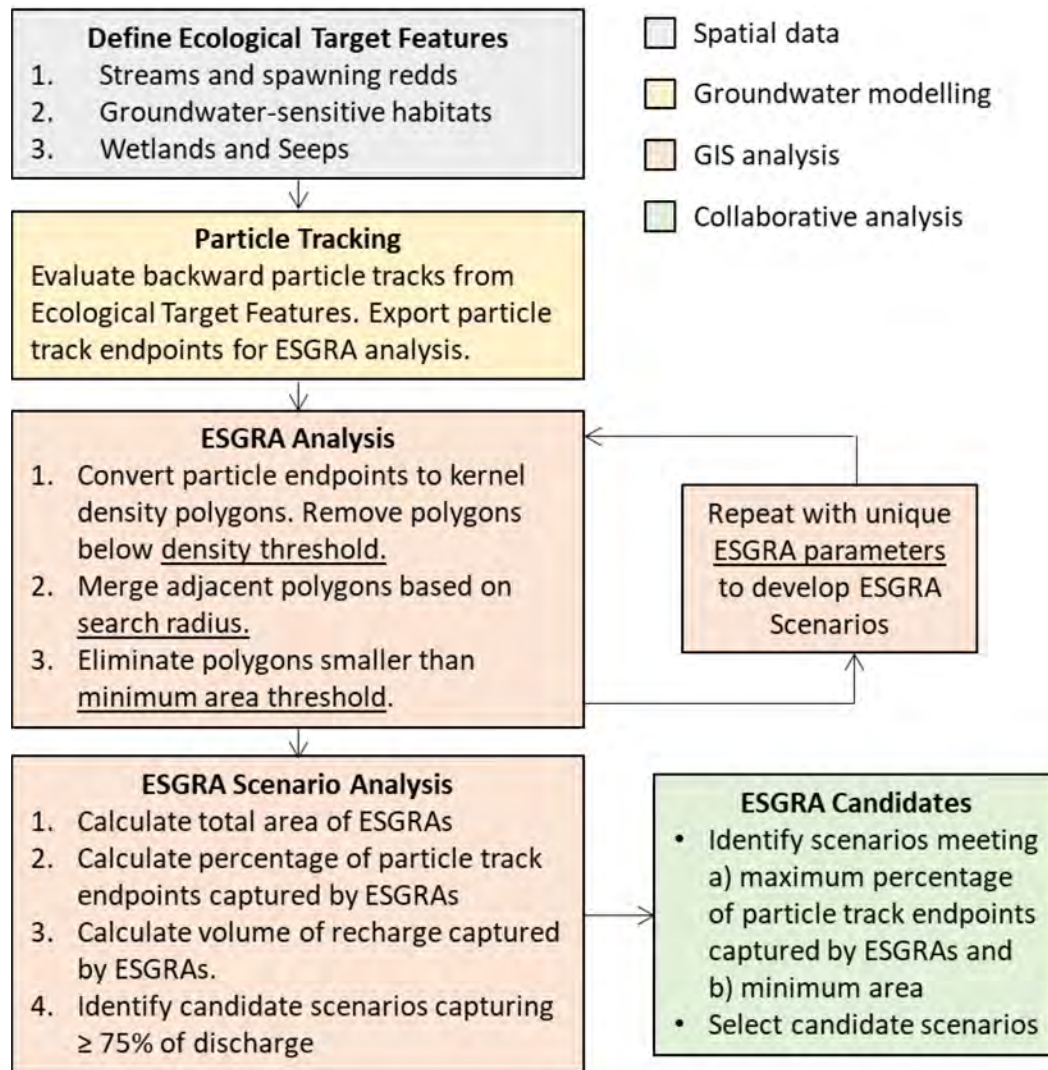
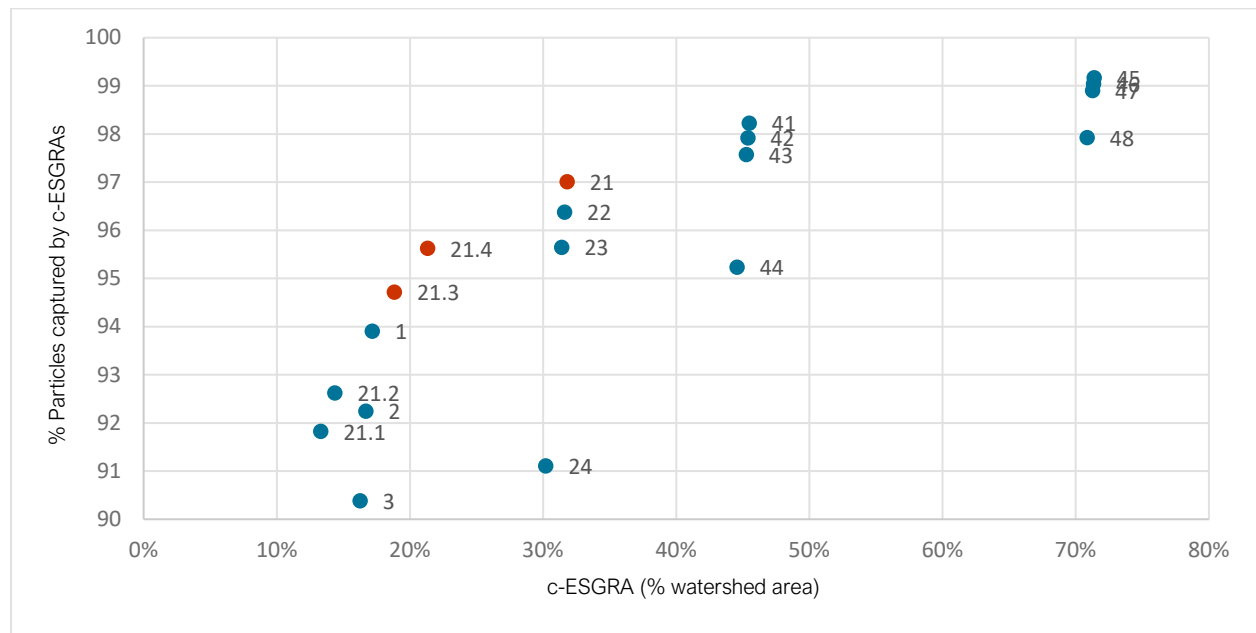


FIGURE 2 Flow Chart (modified from TRCA 2019)

In the example presented in (TRCA 2019), one of the thresholds was varied while two (aggregation distance and minimum area) of the three parameters were held constant. This produced a unique set of ESGRA polygons for each unique value of the varied threshold. The preferred scenario was then selected as the set of polygons that capture the smallest area of the watershed while capturing the largest number of particle track end points.

In the analysis presented here, all three ESGRA parameter thresholds were varied to eliminate any bias in the assignment of a constant value. As an additional requirement, Matrix implemented that the preferred scenario capture a recharge volume of at least 75% of the total discharge at target ecological features. This added condition resulted c-ESGRA polygons that capture the majority of the recharge supporting the discharging ecological features.

Thirty-eight initial c-ESGRA scenarios were generated. For each scenario, the percentage of total number of particles captured was plotted against total area of c-ESGRAs as a percentage of watershed area. Figure 3 illustrates 19 scenarios with more than 90% of particle end points captured by c-ESGRA polygons that capture recharge volumes greater than 75% of total discharge. The applied methodology implements a pareto-optimum approach that tries to optimize the percentage of the total number of particles captured against the total area of c-ESGRAs. Candidates for optimal balanced scenarios lie in the upper left part of the plot. The 19 scenarios not displayed on Figure 3 have recharge volumes less than 75% of total discharge or capture less than 90% of particle end points, and thus are not viable pareto-optimal scenarios.



Notes: The three red points indicate pareto-optimal candidate scenarios evaluated with CVC and ORMGP staff.

**FIGURE 3** Nineteen of the Thirty-eight Environmentally Significant Groundwater Recharge Area Scenarios Generated by Varying Density Threshold, Aggregation Distance, and Minimum Area

### 3.2.1 Selected Approach

In consultation with CVC and ORMGP staff, Scenario 21.3 was selected as the preferred c-ESGRA scenario, with the following threshold parameter values.

- search radius equal to 30 m (equivalent to a 60 m aggregation distance threshold)
- kernel density contour threshold equal to 0.001
- area threshold equal to 0.1 ha

The resulting c-ESGRAs are shown in Map 5. Scenario 21.3 was selected based on its “pareto-optimal” setting providing an acceptable compromise between the proportion of the watershed classified as EGRAs and the number of particle tracks captured by EGRAs. Note that a strict 90% threshold was determined appropriate such that a significant number of recharge-discharge pathways were captured by the resultant set of EGRAs. Any scenario not meeting this threshold was excluded from the selected options. Further, a strict threshold that the set of EGRAs capture recharge greater than or equal to 75% of total discharge in the watershed. Any scenario not meeting this threshold was also excluded from the selected options. Of the 19 candidate scenarios meeting these thresholds, Scenarios 21, 21.3, 21.4 are equally pareto-optimal, located on the outer top-left region of Figure 3. Scenarios 21.3 and 21.4 capture 2% and 1% fewer particles than Scenario 21, while requiring 13% and 11% less area, respectively. This trade-off focused attention on 21.3 and 21.4 as the selected scenario. Of the two remaining scenarios, 21.3 captures 1% fewer particles with 2% less area, and this trade-off, along with qualitative and visual assessments made by CVC and ORMGP staff, lead to selection of 21.3 as the ideal candidate. However, as these three Scenarios are equally pareto-optimal, there is not a single quantitative metric that distinguished the “best” scenario. As such, all three candidate scenarios were delivered as shapefiles to CVC.

### 3.2.2 Comparison of Credit Valley Conservation to Toronto and Region Conservation Authority Approach

In the previously mentioned example (TRCA 2019), the ideal scenario used thresholds equal to 50 m, 0.004, and 5 ha, respectively (TRCA 2019). Applying these “TRCA thresholds” to the current analysis in the CVC watershed resulted in an c-ESGRA scenario that only captures 5% of watershed area, 53% of particle track end points, and 31% of total feature discharge. Differences in these applications can partially be attributed to the use of a finer-scale finite element mesh in the current study versus a coarser finite difference grid in the TRCA analysis. The current model utilizes mesh elements as small as 5 m in length, whereas the finite different approach utilized a grid with 100 m spacing. The resultant groundwater flow solutions in each model are representative of different scales, and the use of a 5 ha threshold in the TRCA application is evidence that a coarser grid inherently results in larger ESGRA areas. The differences in applications can further be attributed to the unique hydrology of each watershed; parameters appropriate to the TRCA watershed are not inherently applicable to the Credit River watershed.

## 3.3 Ecologically Significant Groundwater Recharge Area Analyses

To complement Map 5, the following sections document analyses that provide statistics and insights for the selected c-ESGRA scenario.

### 3.3.1 Proportions of Ecologically Significant Groundwater Recharge Areas per Subwatershed

Using the c-ESGRA mapping scenario 21-3 and the most current delineation of the 23 subwatersheds provided by CVC, the proportion of c-ESGRAs in each subwatershed was calculated. The results of these analyses are summarized in Table 2, ranking the subwatersheds by their proportion of c-ESGRA to subwatershed area. The largest proportion is 44.5 % in the Silver Creek subwatershed, while the smallest proportion is 1.8 % in the Lake Ontario Shoreline East Tributaries subwatershed. The 10 subwatersheds with less than 5% of c-ESGRA by area coincide with urbanized subwatersheds in the southern portions of the watershed where there are limited ETFs.

**TABLE 2 Proportions of Candidate Environmentally Significant Groundwater Recharges Subwatershed**

Subwatershed	ID	Percentage of Area Within c-ESGRAs	Percentage of Area not Within c-ESGRAs	Rank (by Percentage Area within c-ESGRAs)
Silver Creek	11	44.5%	55.5%	1
Caledon Creek	16	42.8%	57.2%	2
Credit River - Cheltenham to Glen Williams	12	42.2%	57.8%	3
Shaw's Creek	17	38.7%	61.3%	4
Orangeville	19	37.3%	62.7%	5
West Credit River	15	33.9%	66.1%	6
Black Creek	10	32.5%	67.5%	7
Credit River - Forks of the Credit to Cheltenham	20	28.1%	71.9%	8
East Credit River	13	25.3%	74.7%	9
Credit River - Melville to Forks of the Credit	18	17.9%	82.1%	10
Huttonville Creek	7	7.7%	92.3%	11
Credit River - Glen Williams to Norval	14	7.5%	92.5%	12
Norval to Port Credit	9	6.7%	93.3%	13
Churchville Tributary	8b	4.4%	95.6%	14
Springbrook Tributary	8a	4.3%	95.7%	15
Carolyn Creek	2	4.2%	95.8%	16
Lake Ontario Shoreline West Tributaries	21	3.9%	96.1%	17
Loyalist Creek	1	3.7%	96.3%	18
Levi Creek	6	3.5%	96.5%	19
Sawmill Creek	3	3.0%	97.0%	20
Fletcher's Creek	5	2.6%	97.4%	21
Mullett Creek	4	1.9%	98.1%	22
Lake Ontario Shoreline East Tributaries	22	1.8%	98.2%	23

Note:  
c-ESGRA - candidate Environmentally Significant Groundwater Recharge Area

### 3.3.2 Percentage Discharge Reaching Target Features

The volumetric rate of discharge reaching ETFs is estimated by aggregating the discharge at model nodes in each subwatershed that coincide with ETF locations. In this analysis, ETFs are subdivided into three general categories: streams and spawning redds, wetlands and seeps, and groundwater-sensitive habitats. Streams and spawning redd polyline features are buffered at a 10 m distance to produce polygons for the spatial overlay analysis. Wetlands, seeps, and groundwater-sensitive habitats are described by polygons and, thus, no modification was required. Table 3 summarizes the groundwater discharge in each subwatershed and the percentage of discharge reaching the ETFs. Table 3 is organized using the ranking from Table 2; this sorting indicates that the subwatersheds with smaller proportions of c-ESGRAs by area generally receive less groundwater discharge. In the 10 subwatersheds with the largest proportions of c-ESGRAs by area, wetlands and seeps receive the largest proportion of groundwater discharge. Several of the subwatersheds at the bottom of the table (subwatersheds with smaller proportions of c-ESGRA by area) receive a higher proportion of discharge to stream features that are not ETFs and, therefore, have a large percentage of discharge that is not associated with ETFs.

**TABLE 3 Percentage Discharge per Subwatershed Reaching Streams and Spawning Redds, Wetlands and Seeps, and Groundwater-sensitive Habitat Ecological Target Features**

Subwatershed	ID	GW Discharge (m <sup>3</sup> /s)	To Streams + Spawning Redds	To Wetlands + Seeps	To GW-sensitive Habitats	Not to ETF
Silver Creek	11	0.45	15%	60%	20%	30%
Caledon Creek	16	1.05	5%	20%	10%	75%
Credit River - Cheltenham to Glen Williams	12	0.76	30%	45%	40%	25%
Shaw's Creek	17	1.42	10%	70%	30%	25%
Orangeville	19	2.26	30%	65%	25%	15%
West Credit River	15	4.44	35%	85%	5%	10%
Black Creek	10	0.93	25%	55%	5%	25%
Credit River - Forks of the Credit to Cheltenham	20	1.26	30%	45%	30%	30%
East Credit River	13	1.17	30%	70%	10%	20%
Credit River - Melville to Forks of the Credit	18	2.18	35%	70%	50%	10%
Huttonville Creek	7	0.03	75%	10%	0%	15%
Credit River - Glen Williams to Norval	14	0.09	40%	10%	30%	45%
Norval to Port Credit	9	0.76	0%	10%	75%	20%
Churchville Tributary	8b	0.02	80%	10%	0%	20%
Springbrook Tributary	8a	0.02	95%	5%	0%	5%
Carolyn Creek	2	0.03	0%	0%	0%	100%
Lake Ontario Shoreline West Tributaries	21	0.26	0%	35%	10%	60%
Loyalist Creek	1	0.04	0%	20%	0%	80%
Levi Creek	6	0.19	0%	10%	0%	90%
Sawmill Creek	3	0.02	0%	0%	15%	85%
Fletcher's Creek	5	0.15	85%	0%	20%	15%
Mullett Creek	4	0.08	0%	0%	0%	100%
Lake Ontario Shoreline East Tributaries	22	0.10	0%	5%	20%	80%

Note:

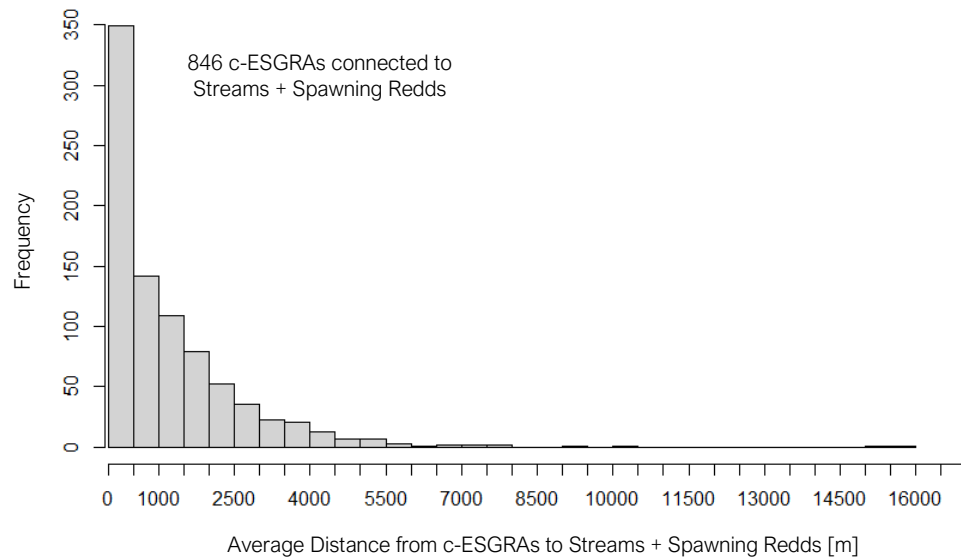
ETF - ecological target features

GW - groundwater

A few caveats must be associated with this analysis. First, the polygons characterizing wetlands, seeps, and groundwater-sensitive habitats overlap in parts of the watershed; therefore, the sum of percent discharge reaching the ETFs can sum to greater than 100% of the subwatershed discharge. Second, although many new model nodes were added in the mesh refinement exercise to capture new features, there are many more ETFs than model nodes, including smaller ETF features where a discharge value cannot be estimated. Therefore, these discharge values should be interpreted as a general and relative summary of discharge as opposed to absolute.

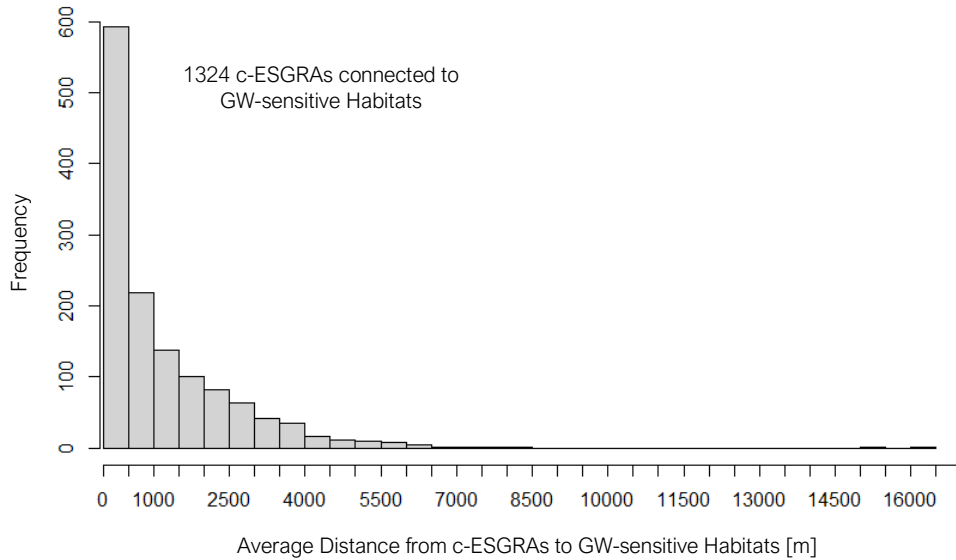
### 3.3.3 Patterns Related to the Distance Between Recharge and Discharge Areas

The distance between ETFs and c-ESGRAs can be estimated by the distance between particle track start points at ETFs and particle track end points in c-ESGRAs. Because c-ESGRAs can be connected to a single ETF by more than one particle track, the distance between an c-ESGRA and ETF is expressed as an average, representing the mean distance of the bundle of tracks that connects the two features. These mean distances can be visualized using histograms, as in Charts 2a to 2c, and summarized by mean, average, maximum, and minimum average distances in Table 4. These results indicate that wetlands and seeps are generally closer to recharge areas than any other feature, with a lower median, average, and maximum value than the other two categories of ETF. Streams and spawning redds receive discharge from the furthest distance, although groundwater-sensitive habitats have the largest distance between an c-ESGRA and ETF. All three categories have instances where ETFs are within 1 m of the c-ESGRA.



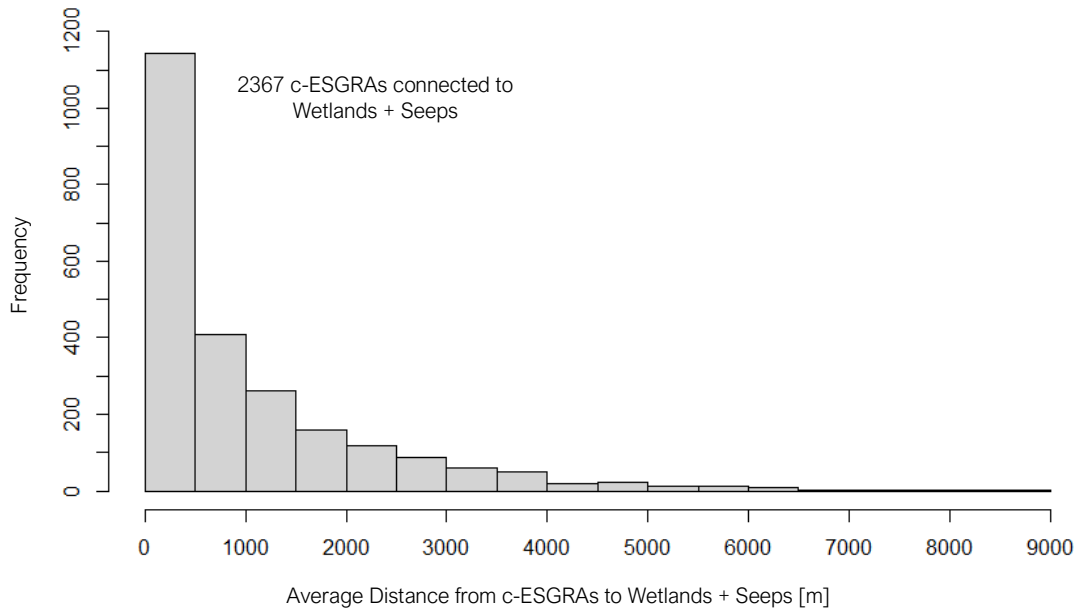
Note: 846 c-ESGRAs are connected to streams and spawning redds ETFs.

**CHART 2a Distribution of Average Distances Between Environmentally Significant Groundwater Recharge Areas and Streams and Spawning Redds Ecological Target Features**



Note: 1324 c-ESGRAs are connected to GW-Sensitive Habitats.

**CHART 2b Distribution of Distances between Environmentally Significant Groundwater Recharge Areas and Groundwater-sensitive Habitats Ecological Target Features**



Note: 2367 c-ESGRAs are connects to wetlands and seeps ETFs.

**CHART 2c Distribution of Distances Between Environmentally Significant Groundwater Recharge Areas and Wetlands and Seeps Ecological Target Features**

**TABLE 4 Summary Statistics for Average Distance from Environmentally Significant Groundwater Recharge Areas to Ecological Target Features**

ETF	Average Distance from c-ESGRA (m)				
	Minimum	Maximum	Average	Median	Range
Streams + Spawning Redds	0	15,845	1,210	740	15,845
Wetlands + Seeps	0	8,580	1,020	540	8,580
Groundwater-sensitive Habitats	0	16,410	1,160	620	16,410

Note:

c-ESGRA - candidate Environmentally Significant Groundwater Recharge Area

ETF - ecological target feature

The connection between ETFs and c-ESGRAs can also be analyzed on a subwatershed-by-subwatershed basis to identify the proportion of particle tracks that connect an ETF within a subwatershed to an c-ESGRA within the same subwatershed. The results of this analysis are presented in Table 5 and Maps 1 to 5. These results indicate that ETFs are primarily connected to c-ESGRAs within a subwatershed, although some ETFs have almost a third of particle tracks reaching c-ESGRAs outside the subwatershed boundary. The distance between ETFs and c-ESGRAs can be analyzed on a subwatershed-by-subwatershed basis by evaluating mean distances of particle bundles between ETFs within a subwatershed to c-ESGRAs within a subwatershed. The results of this analysis are presented in the histograms in Maps 1 to 5 as well as Table 5. These results indicate that c-ESGRAs are generally within 500 m of an ETF, although there is a wide spread of results, and maximum values can be over 7 km in some cases.

**TABLE 5 Proportion of ETFs in a Subwatershed Connected to c-ESGRAs Outside and Inside the Subwatershed and Representative Distances Between c-ESGRAs and ETFs Within the Same Subwatershed**

Subwatershed	ID	Proportion of ETFs Connected to EGRAs Outside Subwatershed	Proportion of ETFs Connected to EGRAs Inside Subwatershed	Distance from c-ESGRA Inside Subwatershed to ETF Inside Subwatershed (m)			
				Minimum	Maximum	Average	Median
Silver Creek	11	21%	79%	0.00	7,405	635	250
Caledon Creek	16	10%	90%	0.00	4,915	340	200
Credit River - Cheltenham to Glen Williams	12	8%	92%	0.00	8,245	595	315
Shaw's Creek	17	9%	91%	0.00	7,885	830	495
Orangeville	19	15%	85%	0.00	5,550	360	125
West Credit River	15	9%	91%	0.00	7,295	590	335
Black Creek	10	13%	87%	0.00	7,655	495	255
Credit River - Forks of the Credit to Cheltenham	20	21%	79%	0.00	5,560	635	305
East Credit River	13	17%	83%	0.00	6,035	995	485
Credit River - Melville to Forks of the Credit	18	30%	70%	0.00	4,205	570	380
Huttonville Creek	7	9%	91%	0.00	6,045	385	50
Credit River - Glen Williams to Norval	14	43%	57%	0.00	6,755	1325	265
Norval to Port Credit	9	22%	78%	0.00	3,460	530	440

Subwatershed	ID	Proportion of ETFs	Proportion of ETFs	Distance from c-ESGRA Inside Subwatershed to ETF Inside Subwatershed (m)			
Churchville Tributary	8b	7%	93%	0.09	1,930	225	145
Springbrook Tributary	8a	13%	87%	0.24	1,960	220	150
Carolyn Creek	2	0%	100%	0.16	265	100	120
Lake Ontario Shoreline West Tributaries	21	1%	99%	0.00	3,980	1,040	1,075
Loyalist Creek	1	26%	74%	0.18	1770	410	410
Levi Creek	6	1%	99%	0.00	1600	170	75
Sawmill Creek	3	38%	62%	0.19	4835	1135	900
Fletcher's Creek	5	30%	70%	0.00	4000	480	160
Mullett Creek	4	0%	100%	0.30	1740	465	260
Lake Ontario Shoreline East Tributaries	22	1%	99%	0.05	4170	1200	1225

Note:

c-ESGRA - candidate Environmentally Significant Groundwater Recharge Area

ETF - ecological target feature

The lack of one-to-one correlation between model nodes and ETFs described in Section 3.2 is underscored here by an analysis of the Carolyn Creek subwatershed (Map 1, Subwatershed #2). Maps 1 to 5 and Table 5 indicate that the Carolyn Creek subwatershed has two c-ESGRAs that are connected to ETFs within the subwatershed, which spatial analysis reveals is a groundwater-sensitive habitat ETF at the southwest end of the subwatershed, where the Carolyn Creek tributary connects to the larger drainage network and a wetland ETF in the eastern portion of the subwatershed. However, Table 3 indicates that 100% of discharge does not reach any ETF, that is, discharging model nodes are not coincident with ETFs in the subwatershed. Importantly, this does not mean that ETFs are not receiving discharge in the field; it means that the model cannot tell us that discharge is happening here because the model is not refined finely enough to answer this question at the scale of the watershed. Rather, the model is constructed to answer questions related to the c-ESGRA analysis by particle tracking analyses that utilize the continuous flow field generated by the model to answer the question “where does a particle released in the subwatershed start from when we analyze the flow field?” This analysis of converging flow fields is completely tenable with the refined model, but discharge can only be captured generally at this model scale.

### 3.3.4 Patterns Related to the Travel Time Between Recharge and Discharge Areas

The travel time between ETFs and c-ESGRAs can be estimated by the simulated travel time between particle track start points at ETFs and particle track end points in c-ESGRAs. Because c-ESGRAs can be connected to a single ETF by more than one particle track, the travel time between an c-ESGRA and ETF is expressed as an average, representing the mean travel time of the bundle of tracks that connects the two features. These mean travel times can be visualized using histograms, as in Charts 3a to 3c, and summarized by mean, average, maximum, and minimum average travel times in Table 5. Note that the results in Charts 3a to 3c are displayed as the logarithm of travel time due to the large variation in magnitudes between particle travel times. With a logarithmic scale, a value of “3” indicates that travel time is  $10^3 = 1,000$  years. A value of “0.5” indicates that travel time is  $100.5 = 3.2$  years. These results indicate that wetlands and seeps have generally shorter pathways to recharge areas than any other feature, with a lower median, average, and maximum value than the other two categories of ETF. All three categories have instances where ETFs are within 1 day of travel time of the c-ESGRA.

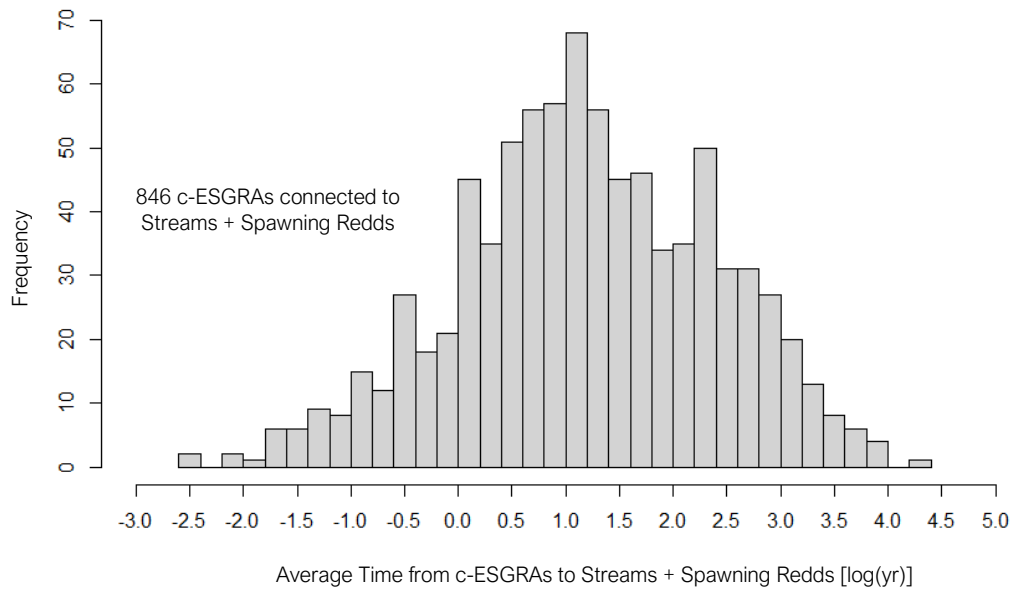
**TABLE 6 Summary Statistics for Average Travel Time for Candidate Environmentally Significant Groundwater Recharge Area to Ecological Target Feature**

EFT	Average Travel Time from c-ESGRA				
	Minimum (day)	Maximum (year)	Average (year)	Median (year)	Range (year)
Streams + Spawning Redds	1 day	16,197	275	14	16,197
Wetlands + Seeps	<1 day	9,531	86	7	9,531
Groundwater-Sensitive Habitats	<1 day	15,807	198	16	15,807

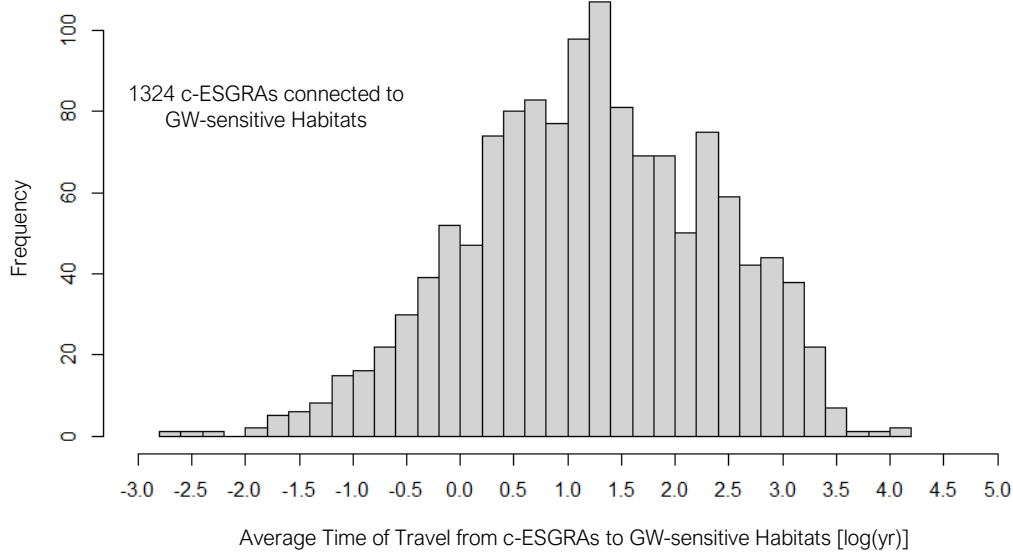
Notes:

c-ESGRA - candidate Environmentally Significant Groundwater Recharge Area

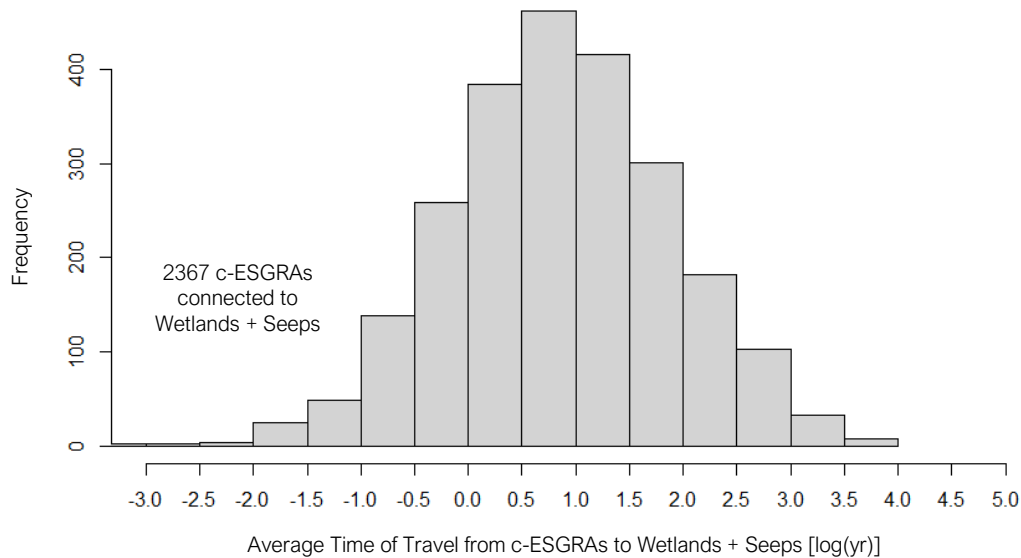
EFT - ecological target feature



**CHART 3a Distribution of Average Travel Time Between Candidate Environmentally Significant Groundwater Recharge Areas and Streams and Spawning Redds Ecological Target Features**



**CHART 3b** Distribution of Average Travel Time Between Candidate Environmentally Significant Groundwater Recharge Areas and Groundwater-sensitive Habitats Ecological Target Features



**CHART 3c** Distribution of Average Travel Time Between Candidate Environmentally Significant Groundwater Recharge Areas and Wetlands and Seeps Ecological Target Features

## 4 SUMMARY

To support the development of a new watershed plan for the Credit River watershed, Matrix, in consultation with CVC and ORMGP staff, updated and applied the CVC FEFLOW model to delineate c-ESGRAs. The method uses backward particle tracking from selected groundwater dependent ETFs (e.g., coldwater streams) to identify recharge areas supporting these features using the methodology described by Marchildon et al. (2015). The c-ESGRA mapping (Map 5) and supplementary analyses (Section 3.3) are provided to support the watershed plan update being undertaken by CVC. At this time, the mapped areas are not being designated as Special Policy Areas but rather to identified to support the development of future land use policy to protect these features.

The c-ESGRAs mapped throughout the CVC subwatershed identify recharge areas that support groundwater discharge for sustaining selected aquatic habitat. The ETFs (Section 2.1) identified for this study include:

- coldwater streams
- spawning redds
- wetlands
- seeps
- other features of hydrologic interest

The connection between recharge areas and groundwater discharge locations represents a valuable hydrological function and, therefore, should be maintained or, where possible, enhanced. The mapped c-ESGRAs should be given consideration in future policy updates and/or development assessment, as they represent potential low to moderate or some cases high constraints on future development. Since this study was completed on a watershed scale, it can serve as a screening tool for future policy or development reviews. However, local smaller-scale assessments (e.g., on a subwatershed scale or for specific development applications) more of a refined, detailed evaluation should be considered of these linkages and dependencies and functions of the ecological features, including seasonal considerations.

When using the provided c-ESGRA mapping, the following limitations and recommendations should be recognized:

- ESGRAs are based on a steady-state groundwater flow model. As such, they represent long-term average annual condition based on historic climate conditions, while actual recharge areas in the field may change to some degree seasonally and with climate (change).
- ESGRAs may be incomplete as there may be additional ETFs that have not yet been mapped or observed. For example, there may be streams reaches that receive groundwater discharge but have not yet been evaluated or captured by the CVC's ETF mapping.
- The process of particle tracking is sensitive to model resolution and the location and density of particle start point. Initial testing of different start locations and particle densities relative to the ETFs was included in this study to arrive at a suitable set of particle tracks for the subsequent the c-ESGRA delineation process. However, model resolution and release location and density should be revisited for studies on a smaller scale.

- The clustering approach used to delineate c-ESGRAs from particle track end points relies on three input parameters (density threshold, aggregation distance, and minimum area). Each combination of these parameters generates c-ESGRA scenarios of different shapes and sizes. While the selected scenario tries to objectively balance the size of c-ESGRAs relative to the watershed size (pareto optimum), there might be other considerations to justify the use of a one of the other scenarios with c-ESGRAs of different shapes and sizes, especially if the model is refined for use in smaller scale studies.
- This study used a regional scale to identify key recharge areas in the CVC watershed. There may be other areas contributing to support aquatic habitat. To include more localized recharge areas additional assessments should be considered at an appropriate scale (e.g., subwatershed scale).
- The c-ESGRAs have not been field validated but are informed by a large number of field observations used to calibrate the model. Additional water level, stream/wetland stage and flow data should be collected as part of smaller scale studies to further identify and evaluate the function of groundwater dependent features in the study areas.

## 5 CLOSURE

We trust that this letter report suits your present requirements. If you have any questions or comments, please call either of the undersigned at 519.772.3777.

Yours truly,

**MATRIX SOLUTIONS INC:**

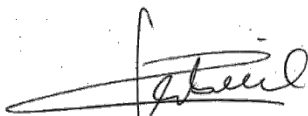


Mark Ranjram, Ph.D., E.I.T.  
Hydrogeological EIT

**Reviewed by**



Daron Abbey, M.Sc., P.Geo.  
Principal Hydrogeologist



Chris Gabriel, Dipl.-Ing., M.Sc.  
Senior Environmental Consultant

MR/CG/vc  
Attachments

### DISCLAIMER

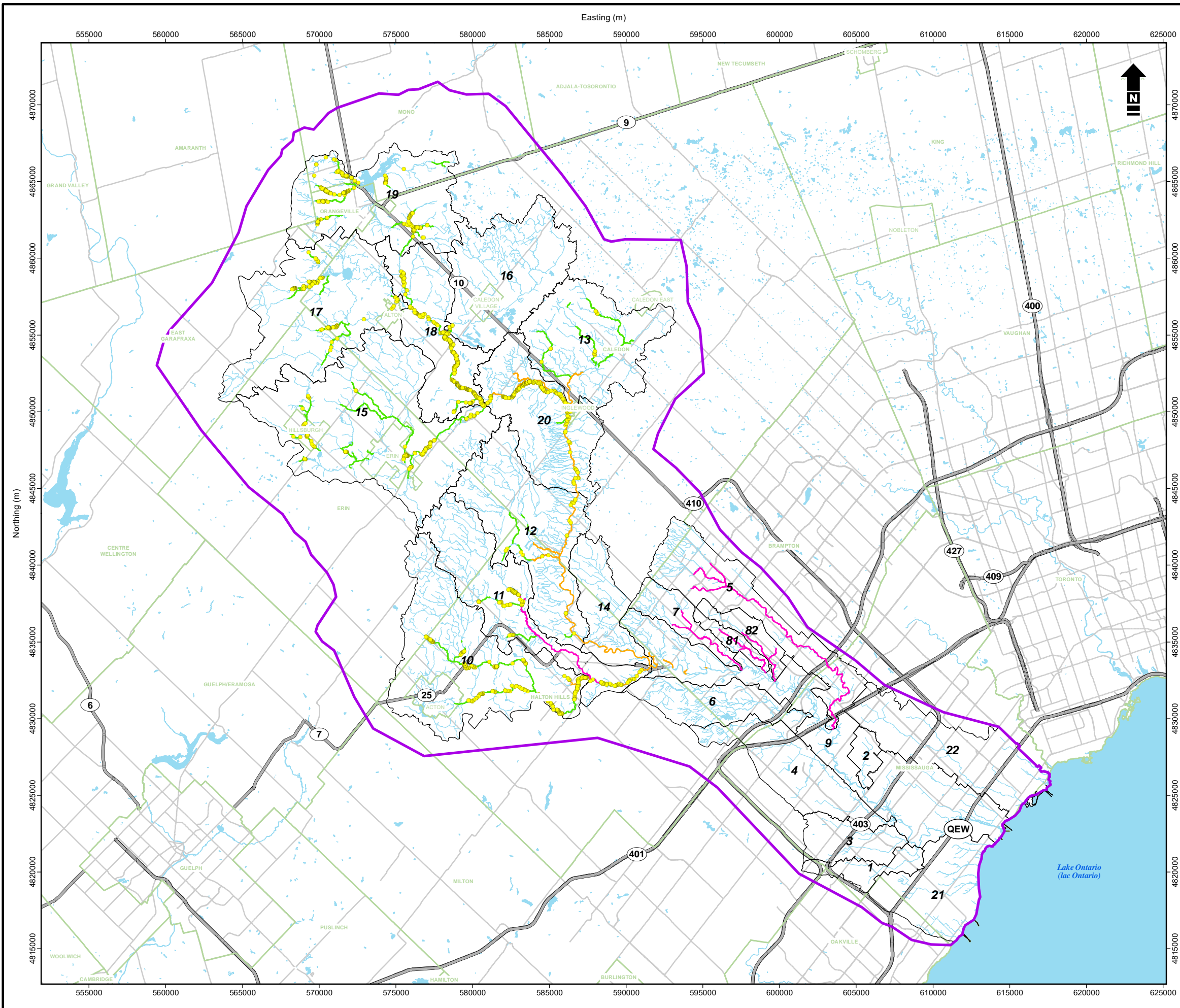
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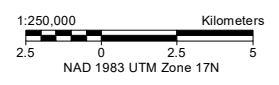
Version	Date	Issue Type	Filename	Description
V0.1	09-Sept-2022	Draft	33711-303 CVC ESGRA Mapping Update LR 2022-09-09 draft V0.1.docx	Issued to client for review
V1.0	19-July-2023	Final	33711-303 CVC ESGRA Mapping Update LR 2022-07-19 final V1.0.docx	Issued to client

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- Model Domain
- Municipality
- Subwatershed Boundary
- Water Body
- Highway
- Watercourse
- Coldwater Brook Trout
- Coldwater Brown / Rainbow Trout / Atlantic Salmon
- Reside Dace
- Spawning Redds



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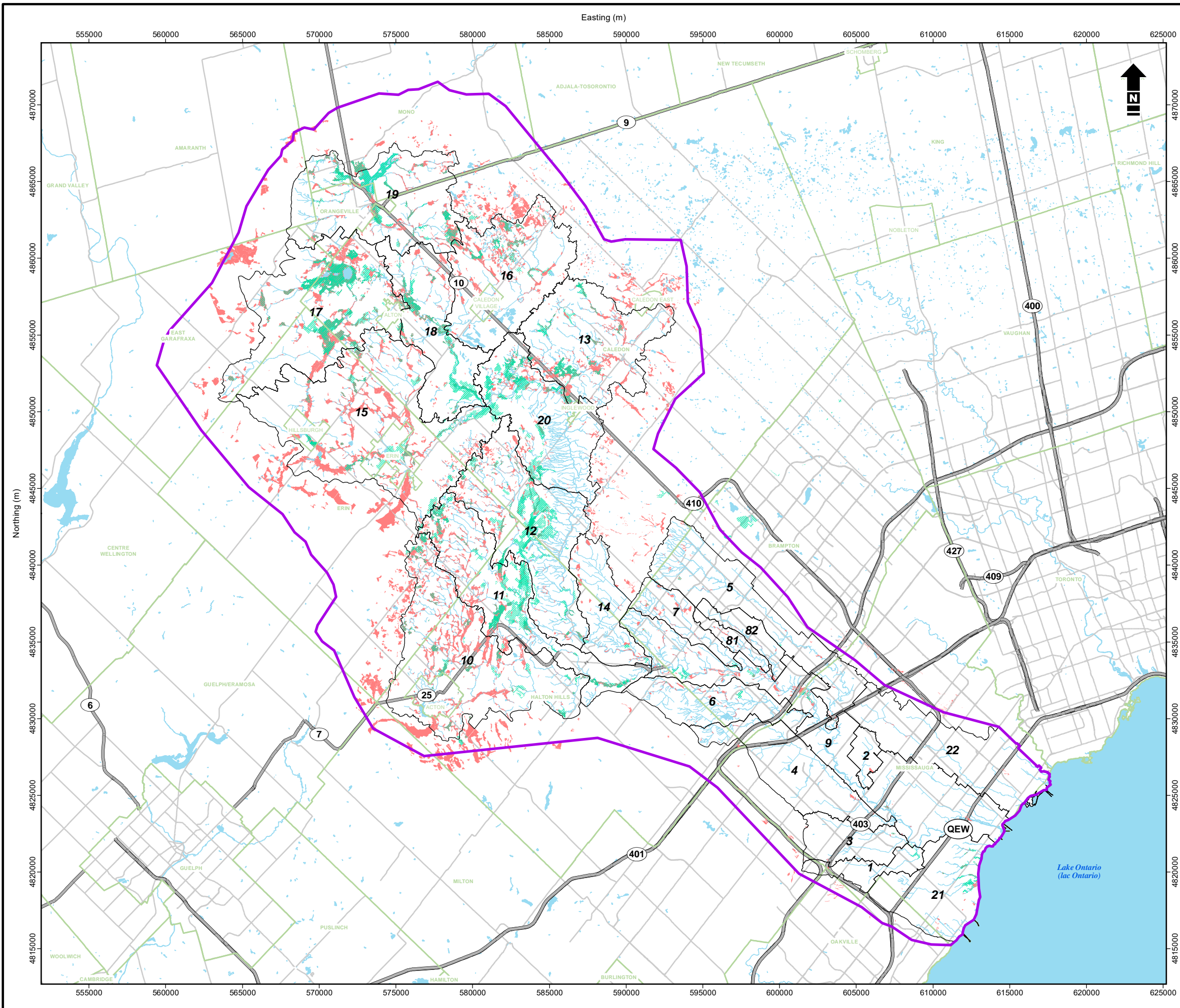
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CVC Watershed

### Ecological Target Features Streams and Spawning Redds

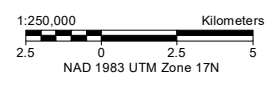
Date: August 2022 | Project: 33711 | Submitter: C. Gabriel | Reviewer: D. Abbey

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- Model Domain
- Municipality
- Seeps
- Wetlands
- Subwatershed Boundary
- Water Body
- Highway
- Watercourse



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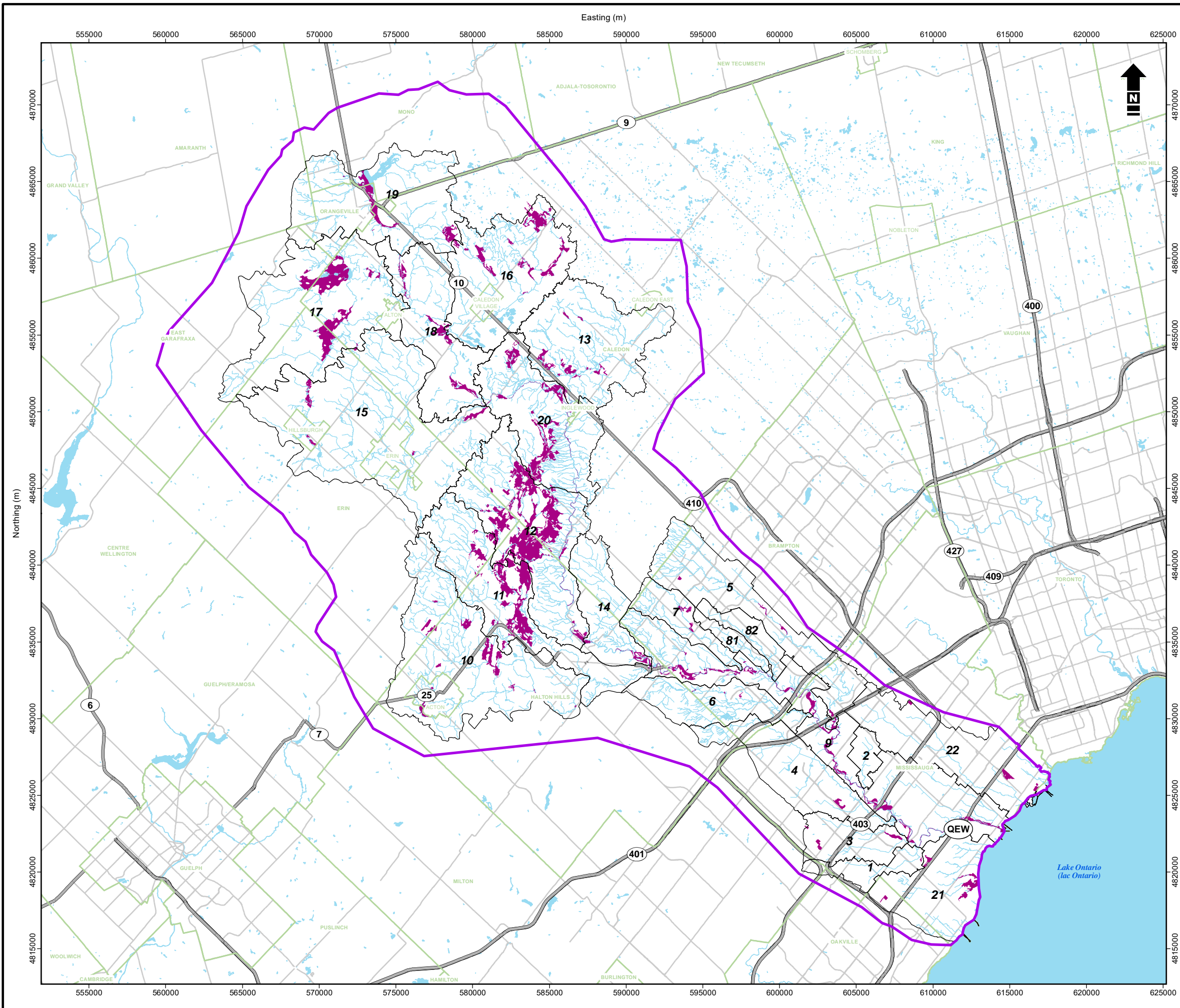
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### Ecological Target Features Wetlands and Seeps

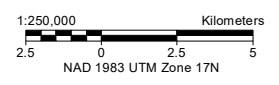
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- Model Domain
- Sensitive Ecological Habitats
- Municipality
- Subwatershed Boundary
- Water Body
- Highway
- Watercourse



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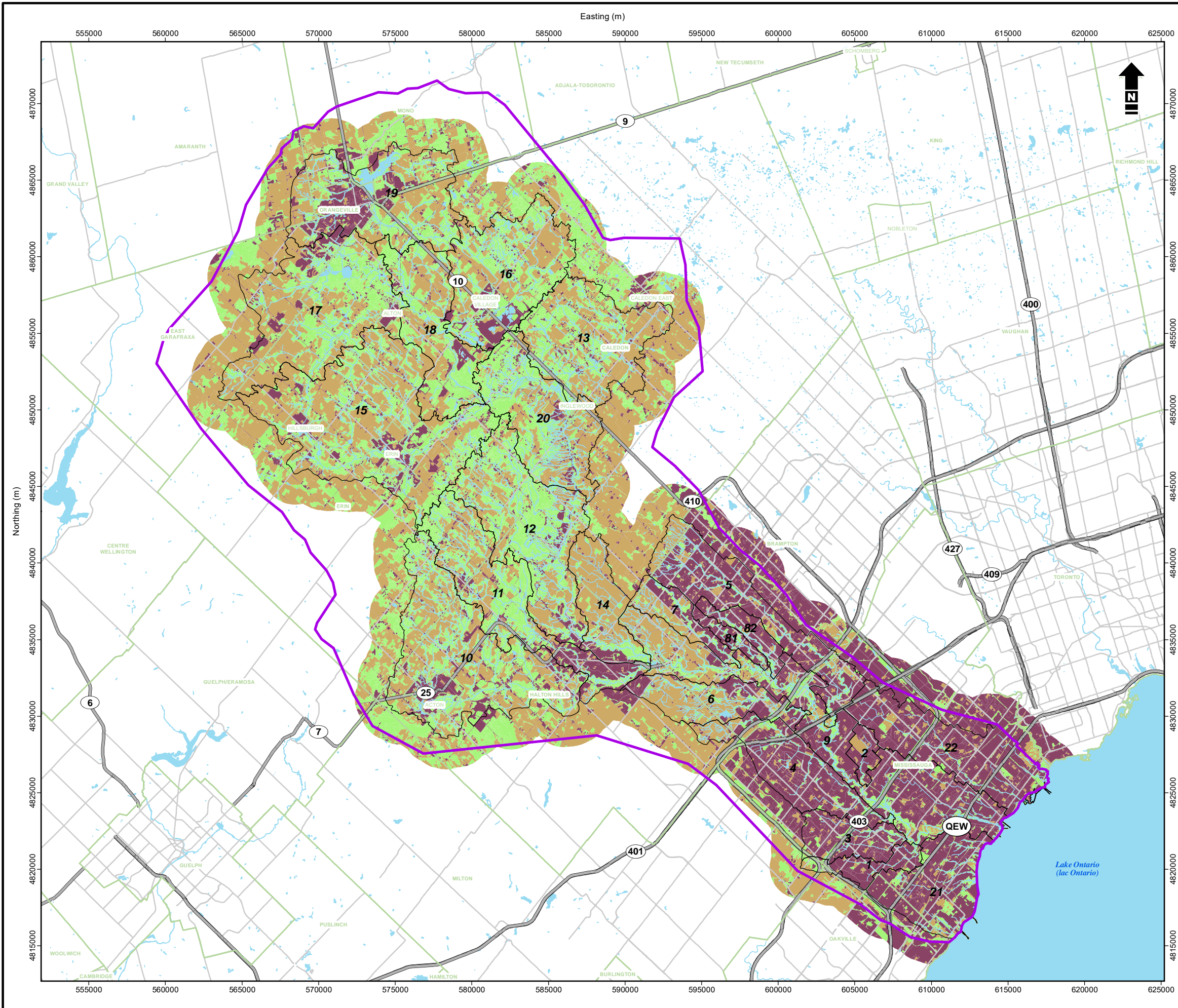


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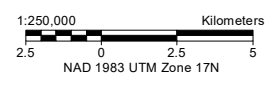
### Ecological Target Features Features of Hydrological Interest

Date: August 2022 Project: 33711 Submitter: C. Gabriel Reviewer: D. Abbey

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- Model Domain
  - Municipality
  - Subwatershed Boundary
  - Water Body
  - Highway
  - Watercourse
- Land Use**
- Agriculture and Open Space
  - Natural
  - Urban



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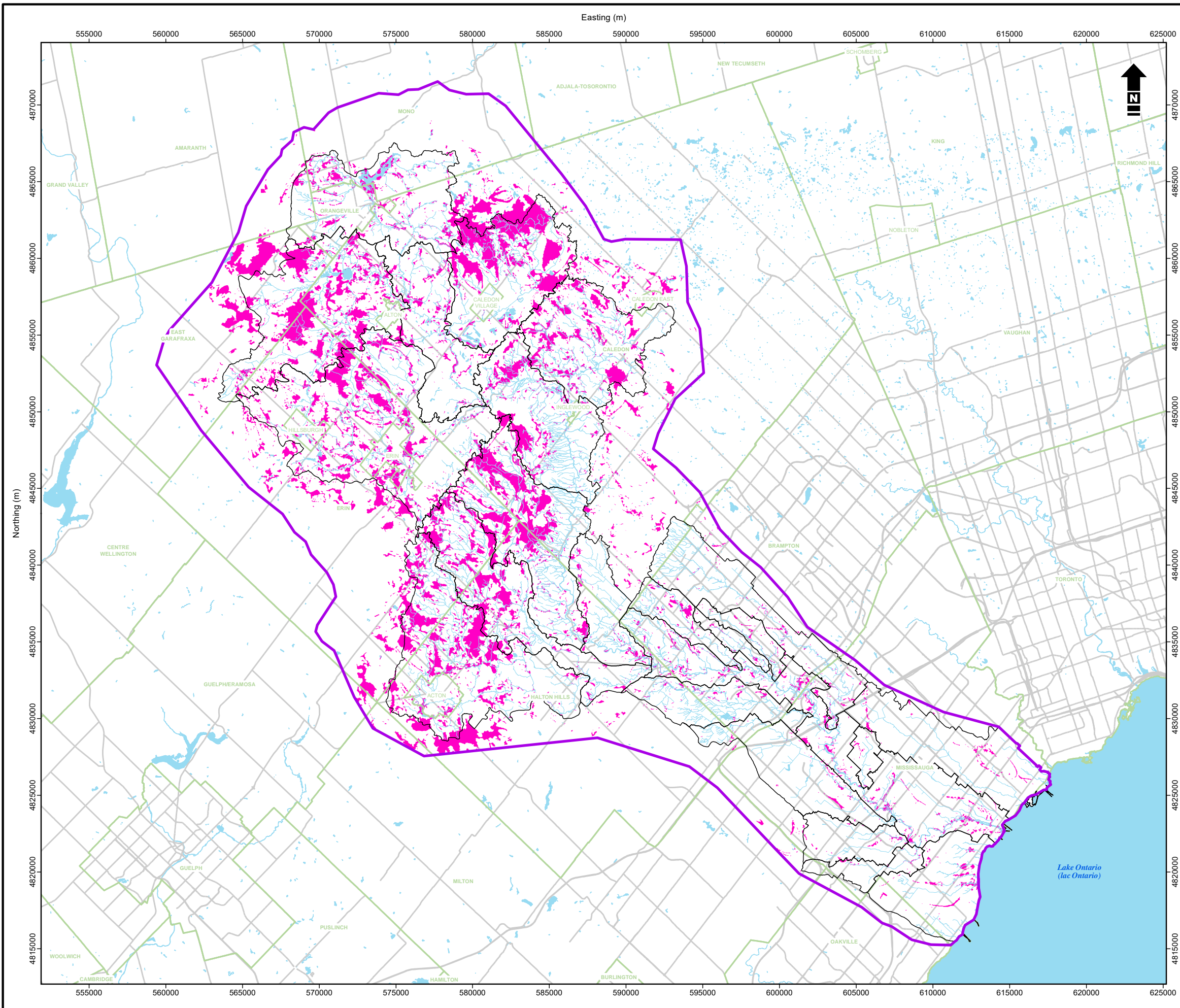
Credit Valley Conservation  
CVC Watershed








### Land Use

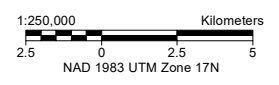
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-  Model Domain
-  Ecologically Significant Groundwater Recharge Areas
-  Municipality
-  Subwatershed Boundary
-  Water Body
-  Highway
-  Watercourse



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## Ecologically Significant Groundwater Recharge Areas

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APPENDIX A  
Supplementary Information

## APPENDIX A SUPPLEMENTARY INFORMATION

### 1 SUMMARY OF SCENARIO GENERATION AND ENVIRONMENTALLY SIGNIFICANT GROUNDWATER RECHARGE AREA PARAMETERS

A summary of all generated scenarios, including the three Environmentally Significant Groundwater Recharge Area (ESGRA) parameters (search radius, density threshold, minimum area) and the three metrics of scenario quality (ESGRA area, percentage of particles captured, and percentage of discharge captured), is provided in Table A1. Initially, scenario search radii varied between 25 to 50 m. This was then extended up to 100 m and down to 15 m. Density threshold was varied between 0.001, 0.005, and 0.01. Minimum area was varied between 0.1 and 5 ha.

The Scenario ID was assigned based on an initial assessment of potential scenarios to evaluate. The gaps in Scenario IDs between 1 and 40 reflect scenarios that would be assessed with 0.0025 and 0.0075 density threshold, respectively. These scenarios were not simulated in the interest of time and budget as the surrounding density values (0.001, 0.005, 0.01) were already included in the analysis. Scenarios 41 to 48 were refinements based on the pareto-optimality of the 0.001 density threshold. These scenarios investigated the benefit of wider search radii. After these initial 32 runs were complete, the ESGRA settings associated with Scenario 21 were further investigated due to its pareto-optimality (largest percentage of particle captured without the largest ESGRA area). Scenarios 21.1, 21.2, 21.3, 21.4 use the same density and area thresholds as Scenario 21 but utilized smaller search radii. Finally, a Toronto and Region Conservation Authority (TRCA)-type scenario was using the ESGRA parameters in the TRCA ESGRA analysis was generated for context. A second TRCA-type scenario with smaller minimum area threshold was also investigated.

**TABLE A1 ESGRA Parameters and Scenario Metrics**

Scenario ID	ESGRA Area (Percentage of Watershed Area) (%)	Percentage of Particles Captured by ESGRAs (%)	Search Radius (m)	Density Threshold	Minimum Area (ha)	Total Recharge (m <sup>3</sup> /d)	Percentage of Discharge Captured by Recharge (%)
1	17.2	93.9	25	0.001	0.1	1,022,464	71.6
2	16.7	92.2	25	0.001	0.5	985,899	69.0
3	16.3	90.4	25	0.001	1	935,188	65.5
4	14.2	78.3	25	0.001	5	720,147	50.4
9	3.8	63.8	25	0.005	0.1	543,113	38.0
10	3.4	58.6	25	0.005	0.5	467,272	32.7
11	3.1	53.2	25	0.005	1	412,321	28.9
12	1.9	31.7	25	0.005	5	173,994	12.2
17	1.2	38.9	25	0.01	0.1	243,509	17.0
18	1.0	31.9	25	0.01	0.5	196,556	13.8

Scenario ID	ESGRA Area (Percentage of Watershed Area) (%)	Percentage of Particles Captured by ESGRAs (%)	Search Radius (m)	Density Threshold	Minimum Area (ha)	Total Recharge (m <sup>3</sup> /d)	Percentage of Discharge Captured by Recharge (%)
19	0.8	26.0	25	0.01	1	147,816	10.3
20	0.2	5.7	25	0.01	5	16,755	1.2
21	31.8	97.0	50	0.001	0.1	1,209,790	84.7
22	31.6	96.4	50	0.001	0.5	1,195,781	83.7
23	31.4	95.6	50	0.001	1	1,169,442	81.9
24	30.2	91.1	50	0.001	5	1,064,397	74.5
29	5.3	68.2	50	0.005	0.1	634,438	44.4
30	5.1	65.3	50	0.005	0.5	592,519	41.5
31	4.9	61.7	50	0.005	1	547,456	38.3
32	3.7	45.2	50	0.005	5	357,293	25.0
37	1.7	42.7	50	0.01	0.1	311,164	21.8
38	1.5	38.3	50	0.01	0.5	267,258	18.7
39	1.4	34.1	50	0.01	1	236,767	16.6
40	0.7	16.3	50	0.01	5	94,049	6.6
41	45.5	98.2	75	0.001	0.1	1,375,448	96.3
42	45.4	97.9	75	0.001	0.5	1,368,452	95.8
43	45.3	97.6	75	0.001	1	1,354,447	94.8
44	44.6	95.2	75	0.001	5	1,287,432	90.1
45	71.4	99.2	100	0.001	0.1	1,663,642	116.5
46	71.3	99.0	100	0.001	0.5	1,662,316	116.4
47	71.3	98.9	100	0.001	1	1,658,405	116.1
48	70.9	97.9	100	0.001	5	1,638,291	114.7
21.1	13.3	91.8	10	0.001	0.1	949,758	66.5
21.2	14.4	92.6	15	0.001	0.1	964,820	67.5
21.3	18.9	94.7	30	0.001	0.1	1,066,147	74.6
21.4	21.3	95.6	35	0.001	0.1	1,093,591	76.5
TRCA	5.2	53.2	50	0.004	5	445,150	31.2
TRCA-2	6.9	74.8	50	0.004	0.1	717,022	50.2

Notes:

ESGRA - Environmentally Significant Groundwater Recharge Area

TRCA - Toronto and Region Conservation Authority

## 2 GLOSSARY

Table A2 contains definitions for specific modelling terms used in the main report. More detailed definitions and discussion of modelling concepts are available in Anderson et al. (2015). Additional context for ESGRA parameters can be found in TRCA (2019).

TABLE A2 Glossary

Term	Definition
Model node	A point in space where the groundwater model solves for groundwater head.
Boundary condition	A model node that is configured to behave a certain way based on the conceptual understanding of the system and hydrologic features. For example, a wetland feature known to exist in a certain region can be represented by boundary condition nodes, and this ensures that the model accounts for that information in the solution. Boundaries may be Type 1 (specified head), Type 2 (specified flow), or Type 3 (head-dependent flux).
Boundary condition constraint	Boundary conditions may be constrained based on our understanding of the represented feature. For example, if a feature is classified in the field as a “discharge feature,” we can ensure that the model produces a head solution that results in discharge to that feature.
Type 1 (constant head) boundary condition	A model node that is configured to have a certain head. For example, a stream at surface can be assigned as a constant head boundary condition based on the elevation of the stream.
Type 3 (head-dependant) boundary condition	A model node that is configured to have a certain flow as a function of its head and a conductance parameter. For example, a stream at surface can be assigned as a head-dependent flow boundary condition where the stream recharges/discharges as a function of the conductance parameter, the elevation in the stream, and the surrounding head values at model nodes.
Inflow boundary constraint (head dependant flux)	A type of boundary condition constraint (see above) applied at Type 1 nodes to include the specified head only if the resultant flux from that node is discharging. This is informed by our conceptual understanding of features represented at boundary condition nodes. For example, if we know that stream reach receives groundwater discharge, an inflow boundary constraint can ensure that the model produces a head solution that respects this insight.
ESGRA parameter: density threshold	In the ESGRA methodology, particle track end points are converted to a “kernel density,” which is a statistical estimate of the relative density of the points. That is, locations with more points will have a higher kernel density value. The ESGRA methodology requires a density threshold value to determine what density of particle track endpoints should be accounted for as ESGRAs. A threshold of 0.001 would eliminate all regions where the relative density is less than 0.001, for example.
ESGRA parameter: minimum area	In the ESGRA methodology, generated ESGRAs below an identified threshold area are removed from the associated scenario. The “minimum area” threshold parameter controls this cut-off.

Term	Definition
ESGRA parameter: Search radius	In the ESGRA methodology, regions that satisfy the density threshold are converted into individual polygons, and these polygons are merged based on the distance between them. The “search radius” parameter controls the radius at which nearby density polygons are merged. These merged areas become candidate ESGRAs that are then filtered through the “minimum area” parameter. The “search radius” parameter is a reinterpretation of the ESGRA “aggregation distance” parameter described below.
aggregation distance	In the original ESGRA methodology (TRCA 2019), the “aggregate polygon distance threshold,” here referred to as the “aggregation distance,” represents the distance at which polygons are merged using the ESRI ArcGIS “Aggregate Polygons” tool.

Notes:

ESGRA - Environmentally Significant Groundwater Recharge Area

### 3 DATA SOURCES

Tables A3 to AX indicate the data sets used in the ESGRA study and their relation to Features and shapefiles classified by CVC on October 20, 2021. Table A1 summarizes the relationship between data sets in the study and the CVC feature. Table A2 links CVC features to specific data sources. Additional context on data sources is summarized in Table A3, representing insights from CVC dated October 13, 2021.

**TABLE A3 Credit Valley Conservation Data Sets Informing Environmentally Significant Groundwater Recharge Area Study**

Data Set	Feature (October 20, 2021; Table A4)	Additional Information
CVC Hydrologic Network	<ul style="list-style-type: none"> <li>Brook trout habitat</li> <li>other coldwater stream ecosystems</li> <li>Redside dace habitat</li> </ul>	
Spawning Redds	<ul style="list-style-type: none"> <li>Brook trout spawning habitat</li> </ul>	
Wetland	<ul style="list-style-type: none"> <li>wetlands</li> <li>fen wetland communities</li> </ul>	<ul style="list-style-type: none"> <li>Wetlands and fens were not distinguished.</li> </ul>
Seep Indicators/Areas	<ul style="list-style-type: none"> <li>ELC vegetation communities with associated groundwater features</li> </ul>	
Spawning_Redds	<ul style="list-style-type: none"> <li>Brook trout spawning habitat</li> </ul>	<ul style="list-style-type: none"> <li>Spawning redd points were converted into stream segments and particles were released along these segments. Stream segments near spawning Redd points, that were not already classified as another coldwater fish habitat, became a spawning Redd stream segment.</li> </ul>

Data Set	Feature (October 20, 2021; Table A4)	Additional Information
Features of Hydrologic Interest	<ul style="list-style-type: none"> <li>features of hydrologic interest</li> </ul>	<ul style="list-style-type: none"> <li>The “features of hydrologic interest” points shapefile was replaced with the “Final_Ecohyd_Habitats_20220210” polygon shapefile delivered to Matrix on February 10, 2022.</li> </ul>

Notes:

CVC - Credit Valley Conservation

ELC - Ecological Land Classification

**TABLE A4 Preliminary Target Features for Environmentally Significant Groundwater Recharge Area Mapping (Provided by Credit Valley Conservation on October 20, 2021)**

Feature	Data Source	Directions
Brook Trout Habitat	<ul style="list-style-type: none"> <li>Dta_HydrologicNetwork_20211006</li> </ul>	<ul style="list-style-type: none"> <li>Brook trout reaches are a subset of CVC stream network mapping where the “FishComm” attribute is “coldwater brook trout”</li> </ul>
Brook Trout Spawning Habitat	<ul style="list-style-type: none"> <li>Dta_spawn_redds_upto_2020_20210114</li> </ul>	
Other Coldwater Stream Ecosystems	<ul style="list-style-type: none"> <li>Dta_HydrologicNetwork_20211006</li> </ul>	<ul style="list-style-type: none"> <li>Coldwater streams are a subset of CVC stream network mapping where the “FishComm” attribute is “Coldwater Brown/Rainbow Trout/Atlantic Salmon”</li> </ul>
Redside Dace Habitat	<ul style="list-style-type: none"> <li>Dta_HydrologicNetwork_20211006</li> </ul>	<ul style="list-style-type: none"> <li>Redside dace habitat is a subset of CVC stream network reaches where the “FishComm” attribute is “Redside Dace”</li> <li>CVC notes that this mapping may differ from MECP/DFO regulated habitat mapping.</li> </ul>
Wetlands	<ul style="list-style-type: none"> <li>ELC_Land_Use_2021</li> </ul>	<ul style="list-style-type: none"> <li>Wetlands are a subset of ELC mapping where the “Comm_Type” attribute is “wetland.”</li> </ul>
Fen Wetland Communities	<ul style="list-style-type: none"> <li>ELC_Land_Use_2021</li> </ul>	<ul style="list-style-type: none"> <li>Fen wetland communities are a subset of ELC mapping where the “Type” attribute is any of: <ul style="list-style-type: none"> <li>✦ Open fen</li> <li>✦ Shrub fen</li> <li>✦ Treed fen</li> </ul> </li> </ul>
ELC Vegetation Communities with Associated Groundwater Indicator	<ul style="list-style-type: none"> <li>Dta_seep_indicator_polygons_20211026</li> </ul>	<ul style="list-style-type: none"> <li>Feature layer derived by CVC containing ELC polygons with records of groundwater obligate and facultative species (derived from CVC natural heritage database and ELC mapping)</li> </ul>

Feature	Data Source	Directions
Features of Hydrologic Interest	<ul style="list-style-type: none"> <li>dta_Features_Hydrologic_Interest</li> </ul>	<ul style="list-style-type: none"> <li>Point features</li> </ul>

Notes:

CVC - Credit Valley Conservation

ELC - Ecological Land Classification

DFO - Fisheries and Oceans Canada

MECP - Ontario Ministry of the Environment, Conservation and Parks

**TABLE A5 Credit Valley Conservation Data Sources for Features (Dated October 13, 2021)**

Feature	Status	Directions
Stream Network	<ul style="list-style-type: none"> <li>CVC provided a shapefile for the Stream Network to help get the work started.</li> </ul>	
Coldwater Stream Ecosystems	<ul style="list-style-type: none"> <li>Jon Clayton has completed his classification of fish habitat. Information has been sent to IM to produce an update to the Stream Network. IM to finalize layer and send to the consultant.</li> <li>IMPORTANT: Locations of watercourses have not been changed.</li> </ul>	<ul style="list-style-type: none"> <li>Information is contained in the new Stream Network shapefile under the "FishComm" field. Stream reaches labelled as "Coldwater Brown/Rainbow Trout/Atlantic Salmon" are considered coldwater stream ecosystems.</li> <li>Use particle tracking in the model to trace the origins of the groundwater associated with these reaches back to their associated recharge areas.</li> </ul>
Redside Dace Habitat	<ul style="list-style-type: none"> <li>Jon Clayton has completed his classification of fish habitat. Information has been sent to IM to produce an update to the Stream Network. IM to finalize layer and send to the consultant.</li> <li>IMPORTANT: Locations of watercourses have not been changed.</li> </ul>	<ul style="list-style-type: none"> <li>Information is contained in the new Stream Network shapefile under the "FishComm" field. Stream reaches labelled as "Redside dace" are considered Redside dace habitat. Does not exactly match regulated habitat mapping for Redside dace habitat. Need to consult MECP and DFO.</li> <li>Use particle tracking in the model to trace the origins of the groundwater associated with these reaches back to their associated recharge areas.</li> </ul>
Brook Trout Habitat	<ul style="list-style-type: none"> <li>Jon Clayton has completed his classification of fish habitat. Information has been sent to IM to produce an update to the Stream Network. IM to finalize layer and send to the consultant.</li> <li>IMPORTANT: Locations of watercourses have not been changed.</li> </ul>	<ul style="list-style-type: none"> <li>Information is contained in the new Stream Network shapefile under the "FishComm" field. Stream reaches labelled as "Coldwater Brook Trout" are considered Brook trout habitat.</li> <li>Use particle tracking in the model to trace the origins of the groundwater associated with these reaches back to their associated recharge areas.</li> </ul>

Feature	Status	Directions
ELC and Land Use	<ul style="list-style-type: none"> <li>Mapping of all natural areas and land uses. Layer was developed through a combination of remote sensing and field work.</li> <li>CVC provided ELC_Land_Use_2021 shapefile</li> </ul>	<ul style="list-style-type: none"> <li>ELC_Land_Use_2021.shp</li> </ul>
Fen Wetland Communities	<ul style="list-style-type: none"> <li>CVC provided ELC_Land_Use_2021 shapefile</li> </ul>	<ul style="list-style-type: none"> <li>ELC_Land_Use_2021.shp</li> <li>"TYPE" = 'Open fen' OR "TYPE" = 'Shrub fen' OR "TYPE" = 'Treed fen'</li> </ul>
Wetlands	<ul style="list-style-type: none"> <li>CVC provided ELC_Land_Use_2021</li> </ul>	<ul style="list-style-type: none"> <li>ELC_Land_Use_2021.shp</li> <li>"Comm_Type" = 'Wetland'</li> </ul>
ELC vegetation communities with associated groundwater indicator	<ul style="list-style-type: none"> <li>CVC Natural Heritage Inventory has extracted the data from the Natural Heritage Database and produced a shapefile. Need to clean up the table.</li> </ul>	<ul style="list-style-type: none"> <li>Indicator_point_polygons_final_20211015</li> <li>There are two lists in the table of the shapefile. One is based on TRCA's list of groundwater obligate species. The other list is CVC's list of groundwater obligate species.</li> <li>CVC strongly disagrees with TRCA's list of groundwater obligate species. CVC staff are of the opinion that many of the species on the list are not groundwater obligate species. Instead, these species are groundwater facultative species, or in other words, species that are frequently associated with groundwater discharge area but not restricted to groundwater discharge areas. Bulblet fern is a good example. This fern can be found in groundwater discharge areas but can also be found in other habitats not associated with groundwater discharge (e.g., on top of boulders).</li> </ul>
SAR Habitat	<ul style="list-style-type: none"> <li>To be completed after the development of the model.</li> </ul>	<ul style="list-style-type: none"> <li>CVC to overlay species at risk occurrences with the groundwater elevation model to identify habitats for SAR that likely have an association with groundwater. Then use the ELC to identify vegetation communities supporting SAR. This approach strives to protect and maintain the hydrology that supports the habitat of the species and ensures that the species' habitat requirements are met. This approach does not just consider whether a SAR is groundwater dependent but focuses on maintaining the characteristics and quality of the habitat that supports species at risk (may not be applicable to fish species at risk).</li> <li>Particle track in the model will then be used to trace the origins of the groundwater back to its recharge area.</li> <li>Recommended management approach- any development in the surface catchment of the associated recharge area should conduct a water balance study to maintain groundwater recharge. Proponent and agencies should consult with MECP.</li> </ul>

Feature	Status	Directions
Brook Trout Spawning Habitat	<ul style="list-style-type: none"> <li>Jon Clayton to contact Phil Bird for data. This maybe a Microsoft® Excel spreadsheet. CVC IM to convert to a point shapefile and send to consultant.</li> </ul>	<ul style="list-style-type: none"> <li>Overlay Brook trout spawning habitat points with the groundwater elevation model to identify habitats for Brook trout spawning habitats that likely have an association with groundwater.</li> <li>Particle tracking in the model will be used to trace the origins of the groundwater back to its recharge area.</li> </ul>

Notes:

CVC - Credit Valley Conservation

ELC - Ecological Land Classification

DFO - Fisheries and Oceans Canada

MECP - Ontario Ministry of the Environment, Conservation and Parks

SAR - species at risk

TRCA - Toronto and Region Conservation Authority

## 4 REFERENCES

Anderson M.P. et al. 2015. *Applied Groundwater Modeling*. Elsevier Inc. Second Edition. London, UK. August 2015.

Toronto and Region Conservation Authority (TRCA). 2019. *Methodology for Delineation of Ecologically Significant Groundwater Recharge Areas*. September 2019.