Cataraqui Source Protection Area Groundwater Vulnerability Guideline

Revision: 0 (Final)

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Cataraqui Region Conservation Authority staff coordinated the development of this report. However, neither of the Cataraqui Region Conservation Authority or the Cataraqui Source Protection Authority Boards have reviewed or approved the report.

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I INTRODUCTION

I.1 Objectives

This guideline has been prepared to help support the protection of clean and plentiful drinking water sources in the Cataraqui Source Protection Area (CSPA) of southeastern Ontario. The objective of the guideline is to identify the requirements for proponents of developments, consultants and planning approval authorities to:

- Assess the inherent vulnerability of the groundwater in a local area (i.e. property parcel or small group of contiguous parcels), based on typically available desktop and field data such as nearby well records, soil maps, and bedrock information, soil test pits and field surveys.
- Identify the presence, extent and impact on groundwater vulnerability of karst features on a property.

This is important because of the shallow soils, fractured bedrock and high water table in much of the CSPA, and because karst is present in some areas.

The goal of the Guideline is to prevent future problems in communities by identifying potential pathways of water into the subsurface before development begins, and tailor the development to meet the needs of the proponent while curtailing environmental impacts.

I.2 Approach and Applicability

The guideline is intended to assist land use planning authorities, development proponents and consultants within the CSPA in the assessment of groundwater vulnerability during the development application process. This guidance applies to:

- multi-lot severances and developments;
- commercial developments;
- industrial developments; and
- any new land use that will store or handle hazardous materials such as those identified by Policy 5.5.1-HR in the Cataraqui Source Protection Plan (CRCA, 2014).

It is not intended to:

- address unstable bedrock associated with karst;
- apply to single lot residential severances or developments; or
- identify management measures.

There are a wide range of developments that will occur within the Cataraqui Source Protection Area and the data required to support developments may range in quality across the area. The guideline enables flexibility with the methods and data required to characterize aquifer vulnerability and karstic features at each site. Where there are questions regarding the vulnerability assessment or karst assessment, the proponent is encouraged to consult with the subject municipality, or the peer reviewer for the municipality, to identify the expectations.

The guideline is separated into two components, an aquifer vulnerability assessment and a karst assessment. The aquifer vulnerability assessment is conducted first, and is required for all applicable developments. The results of the aquifer vulnerability assessment are used to determine whether or not a karst assessment is required. If a karst assessment is required, the first step is to conduct a preliminary assessment, which will determine if a more in-depth field-based investigation is required. The field-based investigation is required to delineate the extent of karst at the site, determine the depth to which the karst penetrates the bedrock and assess the connectivity, travel times and groundwater movement at the site.

The guideline is supported by a flow chart found in Appendix A, which is numbered as per the sections of this document. Checklists are included in Appendix B to ensure proponents obtain the required information to carry out the assessments. A Supporting Document (Geofirma, 2016a) was prepared under separate cover to provide supplementary information about guideline submissions, as well as a glossary and photographs of karstic features. The guideline should be read together with the Appendices and the Supporting Document.

I.3 Sources of Data

Users of this guideline are encouraged to obtain the most up-to-date data. Digital maps are available for free at the Ontario Geological Survey website: http://www.geologyontario.mndm.gov.on.ca/. Information that may be required for a vulnerability and karst assessment include:

- Bedrock Geology (Ontario Geological Survey, 2011).
- Bedrock Topography and Overburden Thickness (Gao et al., 2006).
- Karst (Brunton and Dodge, 2008).
- Paleozoic Geology (Armstrong and Dodge, 2007).
- Surficial Geology (Ontario Geological Survey, 2010).
- Ambient groundwater geochemistry data (Hamilton, 2015).
- Physiography of Southern Ontario (Chapman and Putnam, 2007).
- Assessment Report: Cataraqui Source Protection Area (CRCA, 2011).
- Groundwater Vulnerability Analysis Report (Dillon Consulting Limited and Malroz Engineering Inc., 2008).

1 AQUIFER VULNERABILITY ASSESSMENT

The overall objective of the vulnerability assessment is to determine whether or not a site is underlain by a highly vulnerable aquifer (HVA). The approach is to determine the intrinsic susceptibility index (ISI) for the site and determine if the regional identification of an HVA is still valid at the site scale. In this document the term "site" refers to a proposed development site. A checklist is presented in Appendix B as an aid to ensure the necessary data have been reviewed while conducting the assessment.

1.1 Mapped Highly Vulnerable Aquifers

The first step for the vulnerability assessment guideline is to determine if the proposed site, or part of the site, has been mapped as a HVA by comparing the proposed site location to the map presented on the Cataraqui drinking water source protection webpage (http://www.cleanwatercataraqui.ca/maps/HVAs-and-SGRAs.pdf).

The Groundwater Vulnerability Analysis Report (Dillon Consulting Limited and Malroz Engineering Inc., 2008), as appended to the Assessment Report: Cataraqui Source Protection Area (CRCA, 2011), mapped HVAs in the CSPA (http://www.cleanwatercataraqui.ca/maps/HVAs-and-SGRAs.pdf). More than 90 percent of the CSPA was classified as having HVAs due to the thin soil present throughout most of the area. There are small, isolated areas within the CSPA that have thicker overburden deposits and which may have lower vulnerability. The Groundwater Vulnerability Analysis Report (Dillon Consulting Limited and Malroz Engineering Inc., 2008) was carried out at a regional scale, and property-scale variability in geologic materials was not captured by the analysis. As acknowledged by the authors of that report, a site-specific assessment may show low groundwater vulnerability despite the regional classification as an HVA.

1.1.1 No Further Assessment Required

If the site is not mapped as an HVA, then no further assessment is required.

If the site is mapped as an HVA, and the proponents agree with the regional-scale HVA designation, proceed to the karst assessment section (Section 2).

1.1.2 Aquifer Vulnerability Assessment Required

If the site, or part of the site, is mapped as a highly vulnerable aquifer then the vulnerability of the site must be determined.

1.2 Determining the Vulnerability of a Site

Aquifer vulnerability was assessed using the Intrinsic Susceptibility Index (ISI) method in the Groundwater Vulnerability Analysis Report (Dillon Consulting Limited and Malroz Engineering Inc., 2008), which is included in the Assessment Report: Cataraqui Source Protection Area (CRCA, 2011). This same method should also be used to perform the assessment at the property level.

1.2.1 Data

Ideally, information for the ISI calculation is from a borehole (water well, test hole or other) located at the site. If data from the site are not available, then off-site data can be used provided that the off-site data are representative of the proposed development site. Representative data can be obtained by examining the surficial geology and bedrock geology of the site and comparing the geology to water well information from neighbouring properties. If water level and geological data from a neighbouring property are determined to be representative of the conditions at the site, then those data may be used. For example, it would not be acceptable to use geologic data from a site with clay overlying Precambrian Shield bedrock for a site with sand overlying the bedrock.

The selection of off-site data should consider the surficial and bedrock geology to identify the most representative data set to use in the ISI calculation. This will require plotting water wells or boreholes from surrounding properties on maps of surficial and bedrock geology to identify wells or boreholes that are within the same surficial and bedrock geology units as the site. Water well data may be obtained from the Province of Ontario's Water Well Information System, which contains data regarding the well location, depth to water, and depths to geological units encountered.

1.2.2 Unconfined or Confined Aquifer

The next step is to determine if the aquifer is unconfined or confined. Data should be used from the site and neighbouring properties to determine if the aquifer is an unconfined aquifer or a confined aquifer. If the aquifer is unconfined, then the ISI calculation will be carried out using geological data from the surface to the water table. Water table data are available from the well records in the Water Well Information System. If the aquifer is confined, then the ISI calculation will be carried out from the surface down to the top of the shallowest aquifer. The shallowest aquifer should be determined by examining the depths of the water wells in the area that could become contaminated by activities proposed at the site.

1.2.3 Thickness

Once the geological data is obtained, the thickness of each geological unit must be calculated. For unconfined aquifers, determine the thickness of each unit from the surface down to the water table. For confined aquifers, determine the thickness of each unit from the surface down to the top of the shallowest aquifer.

1.2.4 K-Factors

K-factors for each of the geological units must be assigned. Table 1 below identifies the K-factors for geological materials that may be encountered within the Cataraqui Source Protection Area and that were used to calculate the ISI values for the Groundwater Vulnerability Analysis Report (Dillon Consulting Limited and Malroz Engineering Inc., 2008). Appendix C to that report contains the same table, as well as descriptors for how to select the appropriate geological material.

Table 1. Geological materials and their associated K-Factors for calculating ISI values (MOECC, 2002).

Geological Material	Representative K-Factor (Dimensionless)	Hydraulic Conductivity (m/s)
Gravel Weathered Dolomite/Limestone Karst Permeable Basalt	1	1×10^{-1} 1×10^{-6} 1×10^{-3} 1×10^{-3}
Sand	2	1×10^{-2}
Peat (Organics) Silty Sand Weathered Clay (<5 m Below Surface) Shrinking/Fractured & Aggregated Clay Fractured Igneous Metamorphic Rock Weathered Shale	3	1×10^{-3} 1×10^{-4} 1×10^{-4} 1×10^{-4} 1×10^{-5} 1×10^{-5}
Silt Loess Limestone/Dolomite	4	1×10^{-6} 1×10^{-6} 1×10^{-6}
Weathered/Fractured Till Diamicton (Sandy, Silty) Diamicton (Silty, Clayey) Sandstone	5	1×10^{-7} 1×10^{-7} 1×10^{-8} 1×10^{-7}
Clay Till Clay (Unweathered Marine)	8	1×10^{-9} 1×10^{-10}
Unfractured Igneous and Metamorphic Rock	9	1×10^{-13}

1.2.5 ISI Calculation

The ISI is calculated through a two-step process. First, the product of the thickness (in metres) of each geological unit and the K-Factor is determined. For unconfined wells, this is carried out from the surface down to the water table. For confined aquifers this is carried out from the surface down to the top of the aquifer. Second, the product of the thickness and K-Factor for each unit is added together. The sum is the ISI value.

1.2.6 ISI is Representative of the Site

The calculated ISI should be representative of the specific part of the site where activities are proposed to occur (i.e. the proposed building envelope / area of site alteration). An ISI calculated for a part of the site with thick overburden would not appropriately represent the aquifer vulnerability if a potential threat to groundwater was developed for another part of a site with thin overburden.

For larger scale developments where multiple boreholes are required to characterize the site (e.g. subdivisions or commercial sites), ISI data should be calculated for each borehole to develop an understanding of the distribution of aquifer vulnerability at the site. For this and similar scenarios, the distribution of ISI values at the site should be mapped to identify the spatial distribution of aquifer vulnerability.

1.3 No Further Assessment Required

If the ISI value for the site is greater than or equal to 80, and the ISI value is considered to be representative of the proposed building envelope / area of site alteration, the site is not considered to be overlying a highly vulnerable aquifer.

If the ISI value for the site is greater than or equal to 80, and the ISI value is considered to be representative of the proposed building envelope / area of site alteration, then a karst assessment is not required because ISI values greater than or equal to 80 are associated with significant protection overlying the drinking water aquifer.

1.4 Karst Assessment Required

The site is considered to be overlying an HVA if one of the following conditions is met:

1. The calculated ISI for the site is less than 80; or
2. The calculated ISI is greater than 80, but there is reason to believe the ISI at the site is less than 80 for part of the site where development will occur (e.g. exposed bedrock or thin overburden).

If one of the conditions above is met, then a karst assessment is required. The karst assessment is described in the next section.

2 KARST ASSESSMENT

Karst is carbonate or gypsiferous rock eroded by water dissolving the rock producing ridges, towers, fissures, conduits, sinkholes, and other types of landforms, including caves. These examples of karstic features allow water to rapidly infiltrate and move through the subsurface, inhibiting the natural protection geologic material provides for buffering groundwater from contaminants. A list of karstic features and example photographs are shown in Appendices A and B, respectively to the Supporting Document (Geofirma Engineering, 2016a). The Ontario Geological Survey (OGS) has identified karst in the CSPA; it is present due to the dissolution of carbonate bedrock (Brunton and Dodge, 2008).

The karst assessment guideline is based on a method currently being developed by the OGS (Brunton, 2013) with considerations for guidelines from other agencies that were identified in the literature review (Geofirma Engineering, 2016b).

The OGS is in the early stages of formulating a province-wide strategy to assess karstic features and landforms in Ontario. The work to date has focused on recommending geoscience field work and data sets that could be used to assess karst terrains (Brunton, 2013). The same strategy used to assess karstic features and landforms can be used to determine groundwater intrinsic susceptibility to contamination in karst areas.

Karst in Ontario has been mapped by the OGS (Brunton and Dodge, 2008) in three categories:

1. Known Karst – observed, measured field data or data from published reports. Key features include karren, cave types and associated precipitates, sinkholes and disappearing streams.
2. Inferred Karst – regions of carbonate bedrock units highlighted as most vulnerable or susceptible to karstification, where direct field observations have not yet been made by OGS staff or other sources. This is a natural extrapolation of the known karst areas for given rock units.
3. Potential Karst – areas of carbonate rock units identified as most susceptible to karst processes.

The boundaries between these three categories are subject to change due to on-going data gathering and studies. Brunton (2013) recommends a “best practices” approach that should be carried out in a staged manner to improve the understanding of karst in an area or at a site-scale. A checklist is presented in Appendix B as an aid to ensure that the necessary data have been reviewed while conducting the assessment.

The goal of the karst assessment is to first identify if karstic features are present at the site. If karst is present, the distribution of karst at the site must be delineated, as well as an assessment of how groundwater moves through the karst.

2.1 Carbonate Bedrock at the Site

The first step in the karst assessment should be to determine the bedrock units at the site. Both Paleozoic carbonate bedrock formations and Precambrian marble rocks have been noted in the CSPA; these types are susceptible to karstic weathering. If carbonate bedrock (Paleozoic carbonate or Precambrian marble) is not present at the site, then karstic features will not be present.

Investigators should compare the site location to bedrock and Paleozoic geological maps (Armstrong and Dodge, 2007; OGS, 2011) and conduct a site visit (including photographs) to confirm that the bedrock at or near the site is not carbonate bedrock.

2.1.1 No Further Assessment Required

If carbonate bedrock is not present at the site, further karst assessment is not required.

2.1.2 Preliminary Karst Assessment Required

If carbonate rocks are present at the site, proceed with the preliminary karst assessment.

2.2 Preliminary Karst Assessment

The preliminary assessment will determine if there are available data that can be used to show whether the site has karstic features. The preliminary assessment should mark the extent of the site on appropriate maps and include historical and present-day information regarding karst (Brunton and Dodge, 2008), ground and bedrock topography (Gao et al., 2006), physiography (Chapman and Putnam, 2007), surficial geology (OGS, 2010) and bedrock geology (Armstrong and Dodge, 2007; OGS, 2011). These maps are available for free from the OGS website.

If aerial photographs are available, then they should be reviewed for indicators of karstic features (e.g. sinkholes, closed surface depressions, bedrock pinnacles, lineaments, changes in vegetation). If possible, a comparison of a time-series of air photos to determine if changes in the landscape may be due to karstic processes/features.

Existing reports on engineering, geological, geotechnical, hydrogeological, hydrological conditions, agricultural studies; land-use publications; and other archival records should also be examined to determine if there is any evidence that karstic features are not present. The local knowledge of surficial geology, soil types, overburden thickness and underlying bedrock type is necessary to provide an idea of relative susceptibility to karstification and address the relative karst hazards and risks for a site.

A preliminary site reconnaissance should be performed and photos should be taken to compare present-day ground and drainage conditions to information shown on older air photos and/or satellite imagery, as well as to confirm the bedrock type(s) at the site. Photographs of exposed bedrock, sinkholes, topographically closed depressions and other features should be obtained at this stage of the investigation. The site reconnaissance cannot be carried out when the ground is snow covered. It may be easier to identify karst in the spring and fall to avoid vegetation that may hide karstic features. The Supporting Document contains information that may be helpful for identifying sinkholes.

Brunton (2013) suggests the data should be compiled and interpreted to create a geological model for the site.

2.2.1 No Further Karst Assessment Required

If the preliminary investigation shows there are no signs of karst, and the proposed site use does not include handling or storage of the hazardous materials listed in the Source Protection Plan Policy 5.5.1-HR, then no further work is required.

2.2.2 Field-Based Karst Assessment Required

If the preliminary assessment identifies karst features at the site then a field-based karst investigation is required. Karst features include: caves, closed depressions, disappearing streams, dolines/sinkholes, dissolution features in exposed bedrock, and karren. The Supporting Document (Geofirma, 2016a) has more information on these features.

If the preliminary investigation shows there are no signs of karst, but the proposed site use will include handling or storage of the hazardous materials listed in the Source Protection Plan Policy 5.5.1-HR, then the subject municipality may require a field-based karst assessment to improve the understanding of karst at the site and the potential for off-site contaminant migration to neighbouring properties.

2.3 Field-Based Karst Assessment

It is important to note that field-based karst assessments require the expertise of a karst specialist (defined below). The field investigation will impose additional costs for property development and these costs may not be recovered. The level of investigation will vary based on the proposed development (including the potential risks to surrounding properties), the site, and the local knowledge of karstic features at the site or in the area of the site. The proponent and karst specialist are encouraged to work with the approval authority to ensure the level of effort is commensurate with the potential contamination from the development.

The field-based karst assessment will delineate the extent of karst at the site, determine the depth to which the karst penetrates the bedrock and assess the connectivity, travel times, and groundwater movement at the site.

There is no single approach or method to delineate and assess karst in bedrock or at a proposed development site. The approach and method for a karst assessment will depend on numerous factors including the location of the site, the surrounding drainage pattern, the type of bedrock, the depth of bedrock and the current knowledge of karst in the area. Because of these complications the field-based karst investigations should be designed and carried out by Qualified Persons including professionals who possess either a P.Geo. or P.Eng. designation and who have pertinent experience and knowledge, for example

- Paleozoic bedrock geologist (P.Geo.);
- hydrogeologists and/or hydrologists (P.Eng. optional; karst experience preferred);
- geotechnical or geological engineer.

This guideline does not detail a single approach for delineating the karst or assessing the groundwater flow at the site. Methods are presented which could be used as part of a field-based karst assessment. Investigators are encouraged to use the most appropriate and up-to-date methods to carry out the karst assessment. The submission detailing the karst assessment should include the rationale for the karst assessment approach and the methods used to evaluate karstic features at the site.

There are direct and indirect field methods that can be used to investigate karst at a site. Direct methods allow overburden or rock samples to be obtained, inspected and tested. Indirect methods include geophysical methods and tracer studies that do not disturb the soil at the site. Direct methods include:

1. Test pits are backhoe excavations generally to the depth of bedrock, water table or limitation of the backhoe. Test pits are a simple, inexpensive way to view the overburden materials and the condition and variability of the carbonate rock surface.
2. Test probes include the standard penetration test (SPT) and the cone penetrometer test (CPT).
3. Coring through karstic carbonates and chemical sedimentary strata (gypsum and salt-bearing chemical sedimentary rocks) can provide important information regarding the karstic nature of bedrock groundwaters within a site area.

Direct methods are the most common methods for examining karst. The test pits, test probes or rotary drilling should be carried out to delineate overburden and rock units that overlay the most shallow drinking water aquifer. This work should be coupled with the needs of Guidelines D-5-4 and/or D-5-5 (MOE, 1996a,b), as applicable, to determine that satisfactory drinking water quantity and drinking water quality are available on site and that there is sufficient soil on site to properly design and install a sewage system.

The goal of the field-based investigations is to delineate the extent of karst at the site to improve the understanding of aquifer vulnerability and potential contaminant transport. Karst delineation may include test pitting to view karstic features on the bedrock surface. Drilling may also be used to delineate surficial geological units and their thicknesses and the depth of karst in the bedrock.

If the calculated ISI values for the site are less than 80, then the top 3 m of bedrock should be cored to determine if karstic features are present in the shallow bedrock (NJRCD, 1993). If karstic features are identified in the shallow bedrock, coring should continue to determine the depth of the karstic features. The number of test pits and boreholes required to delineate the karst at the site is dependent on the size of the property, the proposed distribution of drinking water threats on the property, and the geological heterogeneity at the site. The site should be well-characterized for areas where a proposed development involves activities that could contaminate the groundwater.

The karst assessment is considered complete once the spatial distribution of karst on the property is determined, the depth of karst in the bedrock is determined and the movement of groundwater is assessed (including an estimate of the groundwater travel time through the karstic features).

2.3.1 Tracer Studies

Tracer studies are a type of indirect assessment method which involves the use of dyes, salts (chloride or bromide) or deuterated waters to trace the speed and direction of water movement within bedrock. Field work is usually carried out where streams disappear and where springs occur. Tracer studies represent the most in-depth, direct method to determine transport pathways and aquifer vulnerability due to rapid infiltration of water. It is anticipated that tracer studies will only be employed for relatively large scale developments where hazardous materials will be handled or stored.

Tracer studies designed to reliably characterize groundwater flow through karstic features are difficult to carry out. There are unique problems designing and conducting tracer studies in karstic systems because the hydrology of karst terrains is significantly different than other groundwater systems where Darcian groundwater flow occurs. Tracer studies are complicated and should only be conducted by professionals who have significant experience designing, conducting and interpreting tracer studies in karstic terrain.

2.3.2 Geophysical Methods

Geophysical methods for investigating karst are considered to be indirect methods because the soil is not disturbed and the bedrock is not visually observed. Geophysical methods indirectly observe the bedrock to identify fissures or voids in the rock as a means of delineating karstic features.

The field methods and numerical analysis of the results for these geophysical techniques have significantly improved in the last decade. There are guidelines available for selecting the most appropriate geophysical method for delineating karstic features (e.g. American Society for Testing and Materials (ASTM) 1999; Hoover, 2003). Typical methods used for assessing sinkholes or voids are seismic refraction, electrical resistivity, ground penetrating radar, gravity and frequency domain (electromagnetic).

The ASTM standard provides an index table to simplify the selection of the geophysical method for a particular application, including investigating sinkholes and voids. Each method has benefits and limitations based on the field conditions, costs and detail of information that can be provided. Geophysical methods should be employed and interpreted by professionals. It is anticipated that geophysical methods will only be employed for relatively large scale developments where hazardous materials will be handled or stored and when potentially significant subsurface features need to be delineated. Geophysical investigations should only be conducted by professionals who have significant experience designing, conducting and interpreting studies in karstic terrain.

3 SUBMISSION INFORMATION

Information provided in submissions prepared, as per this guideline, will vary depending on the level of investigation required for aquifer vulnerability and karst assessment, but should generally follow the information provided below when applicable.

The submission should include a description of the proposed development and proposed site activities including the handling or storage of hazardous materials and their quantities. The submission should indicate if there will be hazardous materials on site in excess of the amounts listed in Policy 5.1.1-HR of the Cataraqui Source Protection Plan (CRCA, 2014). This section outlines some of the more basic components of the assessment that may be included in the submission.

The site should be identified and mapped at a logical scale preferably using GIS software. Maps with a 1:10,000 scale are a recommended starting point to enable the site to be displayed on an 8.5” × 11” sheet of paper and have elements of the site displayed in a clear manner. The scale should be adjusted as needed in order to present the site data in the clearest manner possible and consideration should be given for showing important offsite features such as private wells, bedrock formations or surficial geology on surrounding properties.

The desktop study and preliminary work should identify the property and proposed site plan on the following maps (note some maps may be combined if the data can be clearly presented):

1. Cultural features with topography.
2. Surficial geology and thickness.
3. Bedrock geology.
4. CRCA HVA map.
5. OGS karst map.
6. Aerial photographs.
7. Location of neighbouring wells, surface water features, as well as known bedrock outcrops, springs, sinkholes, disappearing streams and faults.
8. Other geologic information that may be relevant to the proposed development.
9. Site plan showing the proposed site development

If a field investigation was carried out, then the submission should include a site map with the location of test pits, test probes or test boreholes and logs of the geology encountered at each location with depth and a description of the geologic material encountered in text and in test pit, test boring (e.g. CPT logs) or wellbore logs.

The submission must provide the ISI calculation, including a rationalization for the selection of the uppermost aquifer, the geological data (depth and geologic material) used for the calculation, and which part of the site the calculated ISI value is representative of. The submission should clearly state whether there is or is not a HVA at the site.

The submission should state whether or not a karst assessment was required. If a karst assessment was not required, then the rationale should be provided based on the criteria listed in Section 2.2. If a karst assessment was required, then the submission should also include:

1. Name, address and qualifications of the individual who carried out the assessment.
2. Name and address of licensed well driller.
3. A description of any zones of lost circulation or drilling rod dropped.
4. A detailed description of any direct and / or indirect methods used, the rationale for the selection of the assessment methods and the results of these methods or studies.

The karst assessment component of the submission must include a geologic interpretation of the observed subsurface conditions including soil and rock type, jointing (size and spacing) faulting, voids, fracturing, grain size and sinkhole formation. The submission must also discuss the results of the karst assessment in the context of the proposed development. The presence or absence of karstic features should be noted for each test pit and/or borehole.

The submission should state whether or not the bedrock at the site has karstic features, and identify the lateral and vertical extent of karst on the property. An assessment of groundwater flow at the site should at least estimate the velocity and direction of groundwater flow. If a tracer study is carried out, then a more detailed assessment of the groundwater flow should be reported.

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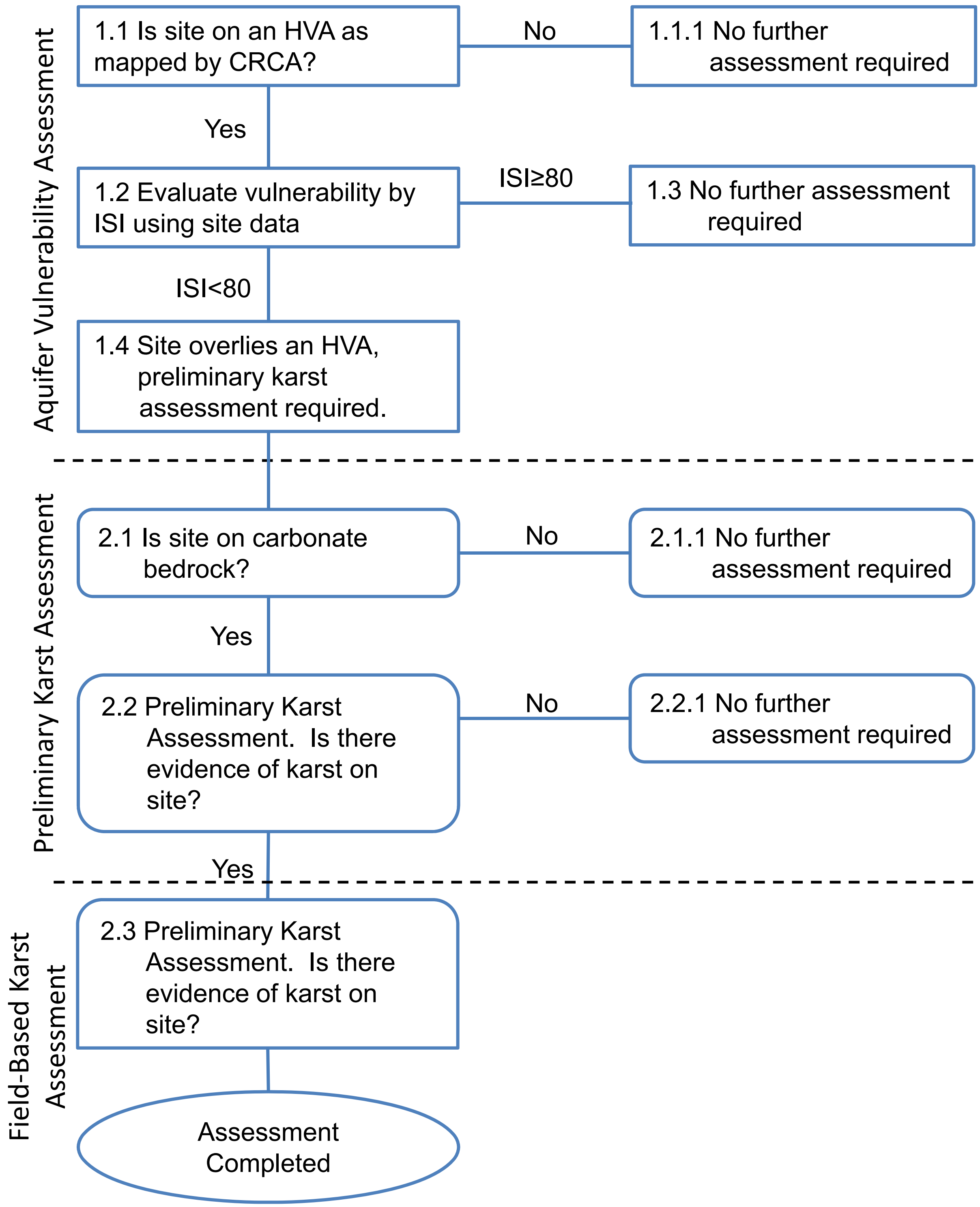
APPENDIX A

Assessment Process Flow Chart

Assessment Process Flow Chart



APPENDIX B

Checklists for Aquifer Vulnerability Assessments and Karst Assessments

Vulnerability Assessment Checklist

__________ Description of the proposed site activity.
__________ Does the proposed development include the handling or storage of any of the hazardous substances listed in the Source Water Protection Plan Policy HR-5.1.1?
__________ Cultural features with topography.
__________ Map of surficial geology and thickness.
__________ Map of bedrock geology.
__________ CRCA HVA map.
__________ OGS karst map.
__________ Map of location of neighbouring wells, surface water features, as well as known outcrops, springs, sinkholes, disappearing streams and faults.
__________ Aerial photographs.
__________ Other geologic information that may be relevant to the proposed development.
__________ Site plan showing the proposed site development.
__________ Do maps show test pits, test probes or test boreholes?
__________ Does report include rationale for selection of ISI data.
__________ Does report include calculated ISI value for the site?
__________ Map of ISI values across the site.
__________ Does the site have a highly vulnerable aquifer?
__________ Is a karst assessment required?

Karst Assessment Checklist
Preliminary Karst Assessment

__________ Is there carbonate bedrock at the site?
__________ Is the site mapped as having known, inferred or potential karst?
__________ Were aerial photographs reviewed?
__________ Were existing engineering, geological, geotechnical, hydrogeological or other studies reviewed?
__________ Was a preliminary site reconnaissance performed?
__________ Were site photographs of exposed bedrock, topographically-closed depressions, other karstic features included?
__________ Does the proposed development include the handling or storage of any of the hazardous substances listed in the Source Water Protection Plan Policy HR-5.1.1?
__________ Were karstic features observed on site or are karstic features potentially present on site?
__________ Is a field-based karst investigation required?

Field-Based Karst Investigation

__________ Detailed description and rationale for the field investigation program including the site-specific investigation techniques, equipment, and observations.
__________ Name of Qualified Person.
__________ Name of licensed well driller.
__________ List of zones of lost circulation or rod drops.
__________ Map of test pits and test boreholes.
__________ Depth of karstic features.
__________ List of the types of features observed/likely at site.
__________ Are there areas at the site that are unsuitable for development.
__________ Borehole logs with geologic descriptions.
__________ Test pit logs with geologic descriptions.
__________ Descriptions of monitoring well completions.
__________ Descriptive geologic model of the karst at site.