Karst (Unstable Bedrock) Investigation Guidelines

April, 2023

From the Minutes of the meeting of the Quinte Conservation Executive Board April 20, 2023, 3:30 pm.

Item 11. Karst (Unstable Bedrock) Investigation Guidelines

Questions were directed to Paul McCoy

Motion # QC-23-040

Moved by: Don Kuntze

Seconded by: Dave Ogden

THAT, the Unstable Bedrock Investigation Guidelines be approved.

1.0 INTRODUCTION

Karst topography is a unique landscape that is found throughout southern Ontario as well as in the Quinte Conservation watershed. In the context of human interaction, this landform can be considered as a natural hazard and is regulated by Quinte Conservation through Ontario Regulation 319/09. Karst topography is a landform that is not well understood and can present challenges when properties with this landscape are being considered for development. This document has been prepared in effort to improve the understanding of this hazard, how it is regulated, and what is required in terms of technical studies in support of land development applications. Karst topography also referred to as unstable bedrock can be described as follows:

"*landscapes that display distinctive features from the physical erosion, and dissolution of bedrock by surface or ground water. This landscape can be exhibited in various forms such as illustrated below in Figure 1*"

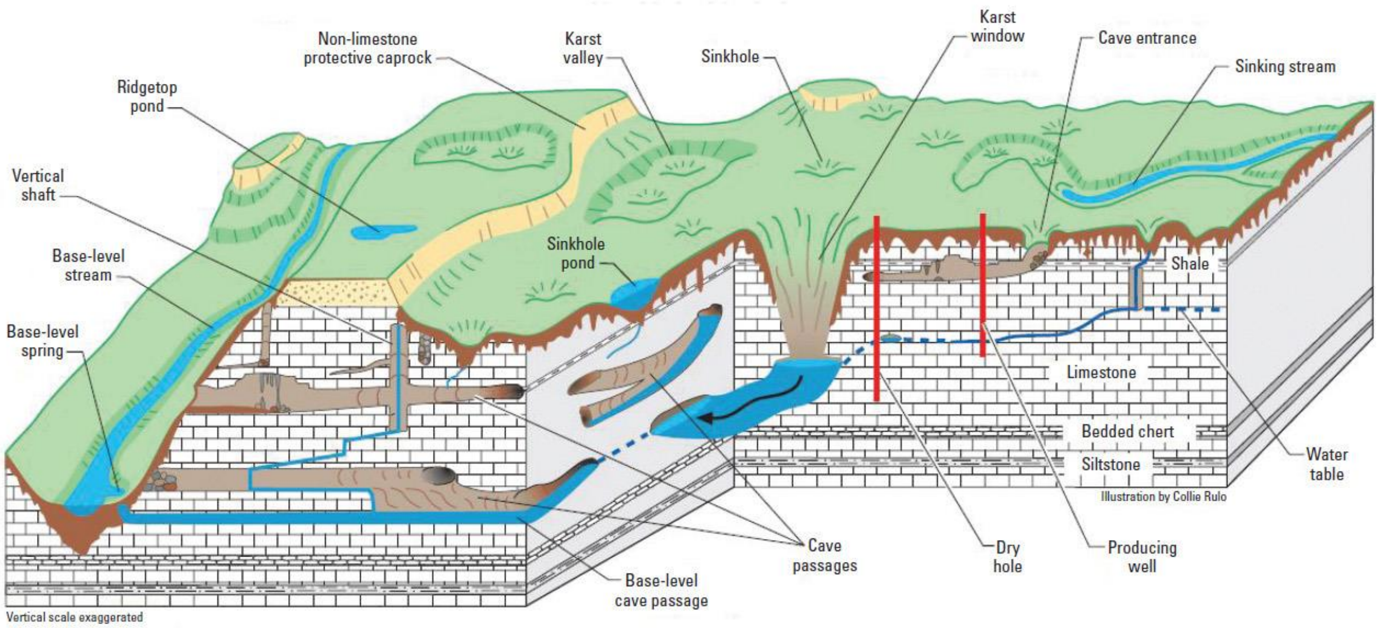


Figure 1: Illustration of Features of a Well-Developed Karst Terrain (Currens, 2001).

Hazards are associated with this type of bedrock because the dissolving and erosion can weaken the rock creating unstable conditions. Sink holes or collapse of the rock can occur potentially resulting in property damage as well as potential harm to human health. Groundwater in areas of karst topography is also at risk due to the potential rapid movement of contaminants near the ground surface into the underlying aquifers. The risk of contamination also increases when karst topography and land development are located near surface water features such as lakes, rivers, streams and springs.

The following report contains pertinent information regarding the following:

1.) The occurrence of karst in the Quinte watershed,
2.) Regulations and Policy regarding karst bedrock, &
3.) Technical study requirements for karst bedrock.

2.0 KARST TOPOGRAPHY IN THE QUINTE WATERSHED

Karst topography is a unique landscape that is shaped by the dissolution of soluble bedrock (i.e. limestone) by mildly acidic groundwater and precipitation. This landscape that is formed can be characterized as exhibiting natural voids, solution openings (i.e. fissures), sinkholes, subsurface caverns, caves and/or, disappearing streams. A term “karren” is sometimes used to describe karst bedrock which is in the early stages of karstification. The karst process occurs over a very long period of time in the order of thousands to millions of years.

Shallow limestone bedrock (minimal soil cover) is abundant throughout the Quinte watershed and some karst formations can be easily viewed at ground surface such as shown in Figure 2. Mapping of karst topography in southern Ontario has been completed by the Ontario Geological Survey – OGS (Brunton & Dodge, 2008) as shown by Figure 3. This Figure illustrates a significant portion of the Quinte watershed is mapped as karst topography according to the following three categories:

1. **Known Karst**, directly observed, measured, or noted in published reports,
2. **Potential Karst,** bedrock that is susceptible to karst processes.
3. **Inferred Karst**, carbonate bedrocks that are vulnerable or susceptible to karstification,

Although the mapping covers a large area, some of the more notable karst features found in the Quinte watershed include the Tyendinaga Cavern and Caves which is a local tourist attraction. Anecdotally this feature is a cave at approximately 12 metres deep containing fossils and a pool of groundwater. Another area referred to as the Hell Holes is located amongst a series of small caves in the valley of the Salmon River in the northern portion of Stone Mills Township. Perhaps the most significant karst feature in the Quinte watershed occurs along the Moira River in the northern portion of the City of Belleville. This area contains a series of caves and sinkholes, locally known as the scuttleholes, that are reported to extend approximately 3 kilometres in length along the River and is one of the longest cave systems known in Ontario. Much of the karst bedrock is found in the Bobcaygeon and Gull River Ordovician limestone.

Figure 2: Example of karst bedrock found in the Quinte Watershed-Quinte Conservation Lands

Figure 3: Southern Ontario Karst

Ontario

Ontario Geological Survey

Karst study for

SOUTHERN ONTARIO

This map is published with the permission of the Senior Manager, Sedimentary Geoscience Section, Ontario Geological Survey.

Location Map

SOURCES OF INFORMATION

Base map: Natural Resources and Values Information System (NRVIS)

Projection: NAD 83

Image overlay: Bedrock topography (bedrock surface with the glacial materials removed)

CREDITS

Author: The Ontario Geological Survey

Acknowledgements: Derek Armstrong, Mark Boone, Marcus Buck, Sandra Clarke, Daryl Cowell, Lona-Kate Dekeyser, Shannon Evers, Simon Gautrey, Joanna Gaweda, Harvey Goodfellow, Ken Goodfellow, Ron Hopper, Walter Jensen, Charlie Koch, Phil Kor, Arley Leader, Brian Luinstra, Ryan Mariotti, Gord Middleton, Scott Parker, John Petric, Paul Ritchie, Dan Russell, Mr. Spearing, Jeff Truscott, Cody Walter, John Warbick, Dave Webster, William White, David Williams and Steve Worthington.

Every possible effort has been made to ensure the accuracy of the information presented on this map; however, the Ontario Ministry of Northern Development and Mines does not assume any liabilities for errors that may occur. Users may wish to verify critical information.

Issued 2008.

Information from this publication may be quoted if credit is given. It is recommended that reference be made in the following form:

Brunton, F.R. and Dodge, J.E.P. Karst map of Southern Ontario, including Manitoulin Island; Ontario Geological Survey, Groundwater Resource Study 5.

LEGEND

Known Karst - observed, measured field data or data from Published reports. Key features include: karren, cave types and associated precipitates, sinkholes and disappearing streams.

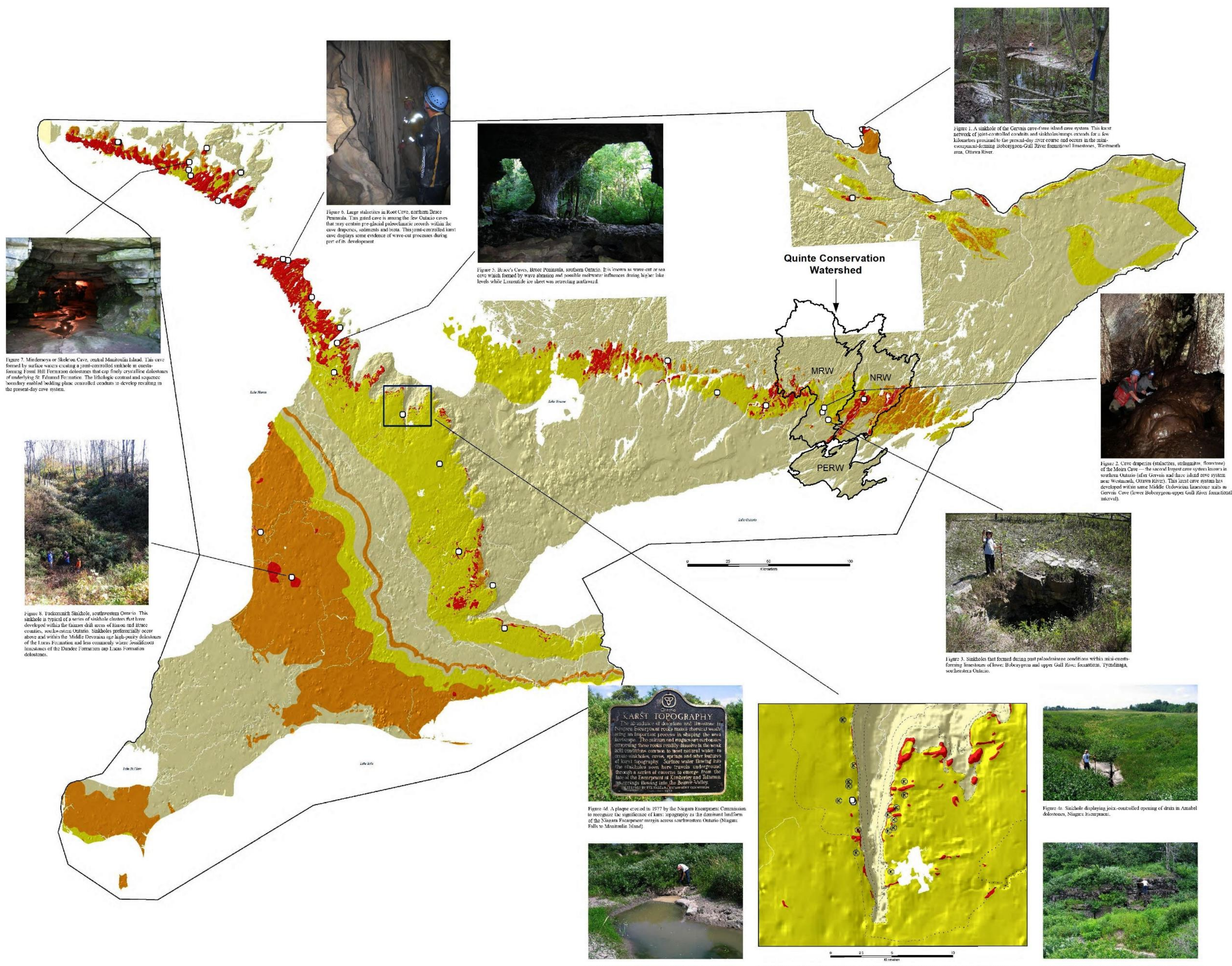
Inferred Karst - regions of carbonate bedrock units highlighted as most vulnerable or susceptible to karstification, where direct field observations have not been made by OGS staff or other sources. A natural extrapolation of the known karst areas for given rock units.

Potential Karst - areas of carbonate rock units identified as most susceptible to karst processes.

Unknown or no observed evidence of karstification due to the character of bedrock, lack of outcrop and/or relative thickness of overburden.

SYMBOLS

- Karst features - cave, crevice, sinkhole
- Joints, hyperlinked
- Borehole logs, hyperlinked
- Field photos, hyperlinked
- Contact, approximate
- Contact, interpreted
- Contact, observed
- Provincial boundary
- Fault-contact, ball on downthrown side
- Fault-contact, no dip, no downthrown side indicated
- Fault, ball on downthrown side
- Fault, no dip, no downthrown side indicated



2.1 Living with Karst

Karst in itself may not actually be considered a problem as this landscape is a naturally occurring physical and ecological process that has shaped and re-shaped the landscape. The formations typically become a problem or a 'hazard" when human activities and structures are located within the area(s) that are directly impacted by these natural processes.

Such problems can be attributed to structural integrity of the bedrock and ability to support foundations and structures. Migration of soil into underlying cavities can occur resulting in solution openings; collapse or shifting of rock beneath a foundation can also occur resulting in structural damage. Sometimes such occurrences can be attributed to impacts after a site is developed due to increased stress caused by loadings from foundations, and changes in drainage patterns that may enhance water movement into karst areas.

Karst formations can also influence groundwater recharge and the movement of groundwater with enhanced rates of flow. This can present problems of contamination for the underlying groundwater where servicing may be provided by onsite septic systems or where sources of contamination may be stored or generated (i.e. fuel storage or runoff from parking lots) near open bedrock features. The risk of groundwater contamination in the Quinte watershed is partially supported by the mapping of the entire region as being underlain by a highly vulnerable aquifer (Quinte Region Source Protection Plan, 2019). Examples of this vulnerability have been demonstrated by study of microbiological groundwater quality throughout southern Ontario (Krolik et al, 2013, Perkins et al 2009). These studies have identified that in the Quinte Region there is increased risk of encountering groundwater with E.coli contamination of both human and animal origin- see Figure 4. Such risk could in part be associated with development in areas of karst bedrock.

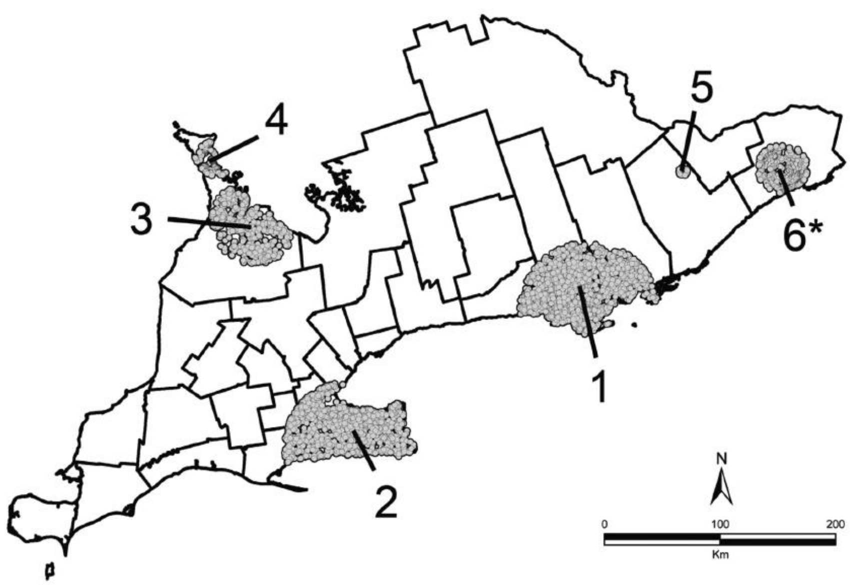


Figure 4: Areas of e.coli contamination in ground water in Southern Ontario - Krolik et al, 2013

3. REGULATION AND POLICIES REGARDING KARST BEDROCK

Responsibility for the management of development in the vicinity of karst bedrock falls under Provincial Policy through the *Provincial Policy Statement 2020* (PPS) and regulations under the *Conservation Authorities Act, R.S.O. 1990, c.C.27* as well as Municipal Planning through zoning and official plans. A brief overview of the various policies and regulation is provided below.

3.1 Provincial Policy Statement (PPS) 2020

Through the PPS (2020) section 3.1 (3.1.1) – Natural Hazards - the Province recommends that development be directed to areas outside of hazardous sites. In accordance with the PPS, hazardous sites are defined as follows:

Hazardous Sites: *means property of lands that could be unsafe for development and site alteration due to naturally occurring hazards. These may include unstable soils (sensitive marine clays (leda), organic soils) or unstable bedrock (karst topography).*

3.2 Conservation Authority Act

Natural hazards are regulated through the *Conservation Authorities Act, R.S.O. 1990, c.C.27* which indicates that development in areas of hazardous lands require a permit or permission for development from the Conservation Authority. Under the Conservation Authorities Act hazardous lands mean:

> *"land that could be unsafe for development because of naturally occurring processes associated with flooding, erosion, dynamic beaches or unstable soil or bedrock;"*

In the context of unstable bedrock this includes bedrock that has been subject to karst processes.

3.3 Quinte Conservation Regulation

Quinte Conservation is responsible for regulating natural hazards by virtue of Ontario Regulation 319/09: Quinte Conservation Authority: Regulation of Development, Interference, with Wetlands and Alterations to Shorelines and Watercourses under *Conservation Authorities Act, R.S.O. 1990, c.C.27* which states that development is regulated in areas of hazardous lands (unstable-karst bedrock). In areas of hazardous lands permission to develop is required from Quinte Conservation through an application for a permit.

Quinte Conservation reviews these applications in respect of its obligations under the *Act* and compliance with the *Quinte Conservation Watershed Regulations (O.Reg.319/09) Policy Manual, January 2023*. Policies relevant to karst bedrock are contained in section 6.3 through 6.7 and generally indicate the following:

- Development is not permitted in areas of unstable bedrock,
- Mitigative measures to stabilise the bedrock to allow for new development are not permitted,
- Repair or replacement of an existing building or structure may be permitted in hazardous lands under certain conditions (see section 6.6.1 of the Quinte Conservation Policy Manual).

- Fill placement, excavation and or grade modifications associated with existing access roads, driveways and septic systems within areas of hazardous lands may be permitted under certain conditions (see section 6.6.3). Such development will require a technical study by a qualified professional to map the extent of hazardous lands.
- Septic systems and dug wells associated with new development are not permitted in areas of hazardous lands. Technical studies by a qualified professional will be required to establish appropriate setbacks from hazardous lands and recommended well construction.
- In areas where development is permitted drainage improvements shall be completed in a manner that will not effect the existing karst features and will not promote drainage into areas of karst topography,

In the cases where development may be permitted in accordance with Quinte Conservation Policies the identification of the hazard limit will be required through completion of a site specific technical study by a qualified professional to the satisfaction of Quinte Conservation. **The details of the requirements for a technical study are provided in Section 4 of this Document.**

3.4 Municipal Zoning and Official Plans

Some local municipalities contain polices through their zoning and official plans that address or raise awareness about the hazards associated with unstable bedrock – karst topography. An overview of the content of some of these official plans is provided as follows:

The Township of Stone Mills Official Plan update (2022) contains mapping of areas referred to as High Risk Zones. These areas are reported to be associated with karst bedrock that is within 500 metres of the Napanee and Salmon Rivers. The hazards of these areas are associated with sink holes, fissure widening, bedrock collapse, and direct pathways into groundwater aquifers. If development is proposed in such areas the Municipality of Stone Mills is to consult with Quinte Conservation regarding technical studies such as hydrogeological studies, terrain analysis or geotechnical investigations. Recommendations regarding consideration for the content of such studies is also provided in the official plan.

The Hastings County Official Plan (2018) also contains policies and Ontario Geological Survey Mapping of karst topography in regards to new development proposals in these areas. **Such policies outline that development should be directed to areas outside of karst topography**, and that technical studies and site evaluation reports may be required to define the hazard as well as identify potential mitigative solutions.

The City of Belleville contains policies and mapping in its official plan update (October 20, 2021) that speak to unstable bedrock and the need for technical studies and where development is considered appropriate. Mapping of karst features is also included in this update.

Municipalities within the Quinte Conservation watershed circulate planning applications to the Authority in effort to identify potential hazards before the approval of new development. This process should help direct development outside areas of natural hazards, however should a potential development be approved by a municipality in such areas, this does not guarantee that the Conservation Authority will provide a permit for such development.

4.0 TECHNICAL STUDY - KARST

The OGS mapping of Karst in the Quinte watershed is regional in nature and provides a good screening tool for identifying areas where karst may exist. Quinte Conservation staff use this mapping as a tool for screening development applications. However, one of the inherent problems of karst bedrock is the difficulty in precisely identifying the location or characteristics of the formation. Because of this unpredictability it is often necessary for Quinte Conservation staff to visit the site in question to verify mapping and/or request that a technical study by completed by a qualified professional. Such mapping is intended to assist in identifying the extent of the hazard such that appropriate setbacks can be to minimize risk from the natural hazard.

In view of increasing development pressure in the region, Quinte Conservation has seen a rise in the number of Karst technical studies being completed as lands that may contain natural hazards are considered for development. The review of these studies has initiated the development of these guidelines to provide property owners, consultants and municipalities with a better understanding of the submission requirements. Accurate site investigations by a qualified professional must be conducted to establish the limit of the hazard on individual properties.

The following sections provide an outline of technical study requirements and an overview of how Quinte Conservation regulates karst (unstable bedrock). These recommendations have been provided in reference to existing Ontario Guidelines on karst which include:

- Project Unit 08-004. Karst and Hazards Lands Mitigation: Some Guidelines for Geological and Geotechnical Investigations in Ontario Karst Terrains, F.R. Brunton Ontario Geological Survey &,
- Hazardous Sites Technical Guide (V.1.0, December 1996) Ministry of Natural Resources.

4.1 Qualified Professionals for Technical Studies

Technical studies for karst must be undertaken by Qualified Persons (Brunton,2013) including those professionals who possess either a *P.Geo.* or *P.Eng.* designation and having pertinent experience and knowledge with karst, for example:

- Paleozoic bedrock geologist (P.Geo.);
- Hydrogeologists and/or Hydrologists (P.Eng. or P.Geo);
- Geotechnical or Geological engineer (P.Eng.).

It is important to note that the qualified person should have proven experience in dealing with this hazard.

4.2 Technical Study Requirements

Technical studies may require different levels of review depending on the extent of the hazard on the subject property. The following sections provide an overview of the two main phases of work required to assess a subject property which are:

- **Phase 1**: Desktop Study and Site Visit to provide evidence regarding the presence or absence of karst on the subject property.
- **Phase 2**: If the potential for karst is identified from Phase 1, a field based subsurface investigation is required to map the extent of the hazard and to prepare a suitable building envelope site plan.

Some of the recommended minimum requirements of the various phases have been summarised below. Please note that these are suggested as minimum, as the qualified professional may require further detail and study in order to properly assess the hazard at a given site.

4.2.1 Phase 1: Desktop Study and Site Visit

A desktop evaluation and site visit, undertaken by a qualified professional with knowledge and experience in identification of karst topography, shall be undertaken to determine the potential for the presence of karst topography. The desktop study shall include but not be limited to the gathering and review of the following information.

a) Mapping that shows historic and present day karst, ground and bedrock topography, physiography, hydrology, Quaternary and Paleozoic geology, and groundwater aquifers. This information could include maps, satellite imagery, air photos, and reports. The Ontario Geological Survey has a number of data sets to assist in this regard such as karst mapping, bedrock topography, physiography, quaternary and bedrock geology as well as hydrology and subsurface groundwater data;
b) Existing engineering, scientific, geological (including oil/gas and geotechnical well records), hydrogeologic, hydrologic, geographic, agricultural studies, regional groundwater studies, and land use publications;
c) Surface water and groundwater well record data to determine the position of the water table and seasonal fluctuations, rainfall records, river discharge data, water chemistry data;
d) Comparison of historic and recent air photos and/or satellite imagery to determine changes in the landscape that may have resulted from karstification and subsurface drainage and/or anthropogenic changes;
e) A visit to the property to provide comparison to historic air photo and/or satellite imagery to evaluate changes in the landscape. This visit would include a site inspection when the ground surface is visible (i.e. no snow) to record observations regarding the presence or absence of karst bedrock, sinkholes, fissures, solution openings, karren, caverns, depressions in the ground surface, drainage patterns, etc. A photo log of field observations is to be taken and reported (including GPS coordinates & locations on a map);
f) Interview property owners or local contacts (i.e. residents and municipal roads staff) regarding potential locations of known karst formations, sinkhole occurrences, disappearing streams, etc. this could also include known sinkholes that have been filled or altered.

If the Phase 1 evaluation determines that karst is not present, no further study of karst is required. A report is to be prepared summarising the results of the evaluation including a summary of the information review, site visit description, maps, photo log and summary of any interviews. Should the Phase 1 evaluation identify the presence of karst features and/or karst terrain characteristics, a Phase 2 evaluation will be required. Based on the results of the Phase 1 assessment a work plan can be prepared by the project consultants on how to assess the site. Following the completion of the Phase 2 work a report is to be prepared in summary of the assessment.

4.2.2 Phase 2 – Field Based Karst Investigation

In areas where a Phase 1 evaluation has identified the presence of karst features and/or karst formation characteristics, a Phase 2 field based karst evaluation shall be undertaken by a qualified professional.

The type of field work to be undertaken will be determined based on the areal extent and complexity of the proposed development relevant to the risk or potential for impacts related to karst. If desired, a terms of reference may be prepared and submitted to Quinte Conservation for consultation prior to undertaking field work. A review of relevant background information indicates that there is no single method which is universally used for detection and mapping of karst features. The accurate assessment of a given site may require the use of a combination of methods to characterize and locate subsurface karst, as well as the professional judgment of the qualified professional.

The type of field work that may be required includes but is not limited to the following:

a) Geophysical methods-for mapping of karst features
b) Test pitting and soil-probing to assess the condition of the bedrock surface and any soil subsidence,
c) Drilling to assess rock and groundwater conditions,
d) Dye tracer studies - to determine the sources, speed and direction of shallow potable water movement within bedrock.

Based on the various methods available for the assessment and mapping of karst a written rationale as to the sampling plan such as location and numbers of samples etc. must be provided along with the study results in the final report.

For information purposes a brief description of some of the various methods is summarised below. Please note that this list is not exhaustive as there may be other methods and techniques that may be employed subject to industry standards, techniques, and technology.

Geophysical Methods

Various types of geophysical instruments are available for conducting ground surveys without significant disturbance of the site. These include:

- Electromagnetic profiling (EM) assesses resistivity or conductivity of the subsurface to detect variations in the below grade conditions.

- Ground Penetrating Radar (GPR) a geophysical method that uses radar pulses to image what is below the ground surface. This method can aid in detecting voids and cracks in the rock. The depth of penetration of the signal can decrease with attenuation by deeper soil deposits.
- Gravity and microgravity- measures density contrasts to detect the presence of cavities,
- Seismic Refraction to send seismic waves through the ground for locating boundaries between various subsurface strata but not necessarily caves or voids which this method is not typically used for,
- Cross hole tomography- used to assess subsurface conditions at various depths using open onsite boreholes. This method can be expensive due to the requirement of onsite boreholes.

Test Pitting – Soil probing

Where bedrock is not directly visible at surface, test pits and soil probing are sometimes used to assess subsurface conditions. A plan should be prepared to determine the number and location of test pits or soil probes to provide sufficient representative information about the site. Soil probing is often used to detect buried voids or solution openings in the bedrock and potential clues of where to perform test pit excavation. Test holes may be used with other forms of testing to assess the site such as geophysics, sounding, or penetration testing. Information to be considered in the test pit program includes the anticipated depth of the test pits, minimum base area of test pits and cleaning process to permit inspection of the rock surface.

Drilling

Various drilling methods can also be used to assess subsurface conditions. Such methods include air percussion or air track probes, bedrock coring etc. The methods of detecting voids or cavities are to be evaluated and identified such as air loss, drilling speed, and rod drops. Boreholes can also permit the use of down hole cameras, geophysical borehole tools (optical and acoustic televiewer), 3-D tomography, packer and or pumping tests to examine drawdown responses between boreholes. Information to be provided from this work includes - the location and number of boreholes, anticipated depth, sampling interval, borehole techniques are to be provided including how such boreholes are to be sealed or decommissioned after testing is complete.

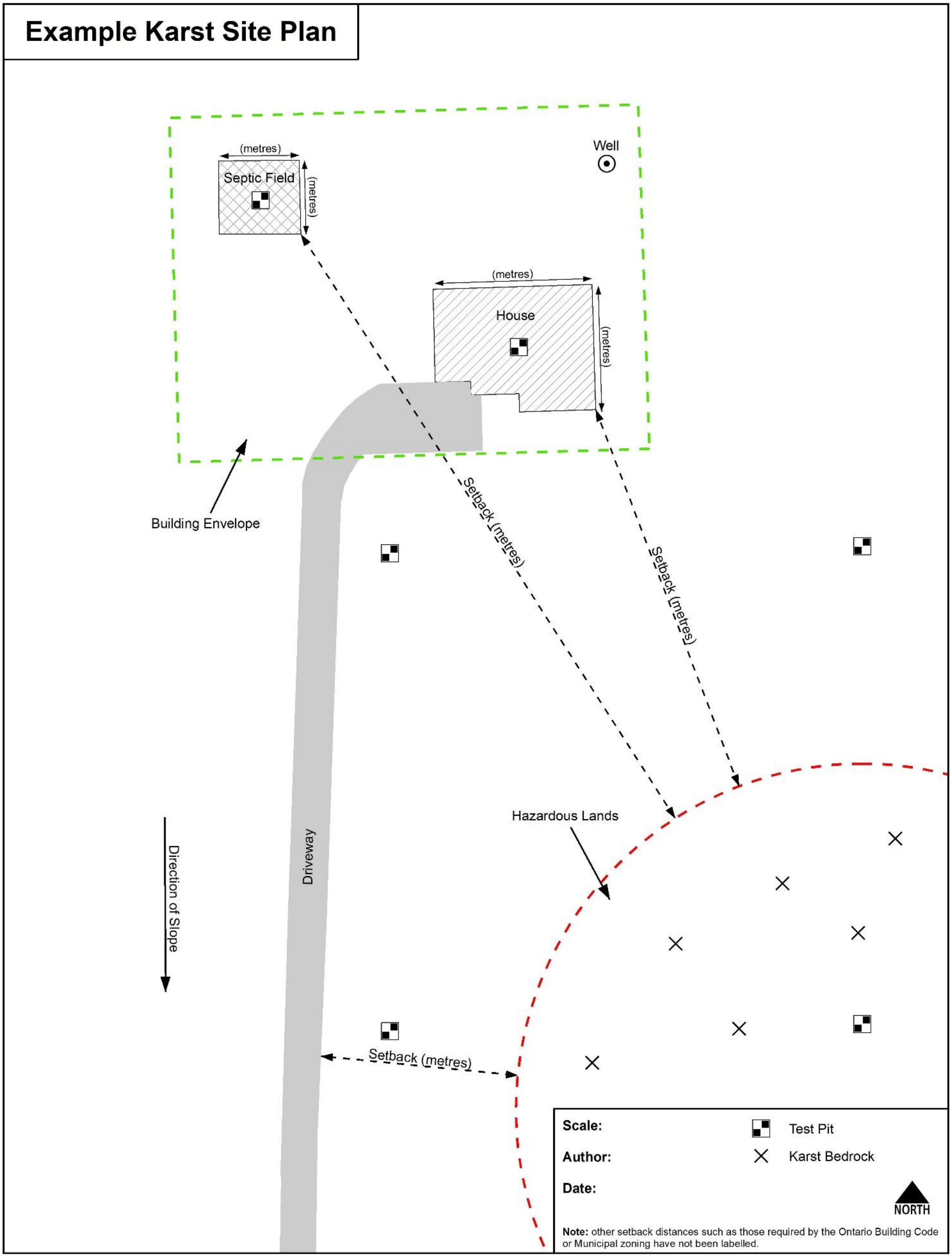
Tracer Studies

Tracer studies involves the use of dyes, salts (chloride or bromide) and low conductivity or deuterated waters to trace speed and direction of water movement within bedrock. Field work is usually carried out where streams sink and where springs occur. Such studies can also be carried out between bedrock wells (see Ontario references by J. Hurley, F.R. Brunton, M.J. Buck, D.W. Cowell, C.C. Smart and S.R.H. Worthington).

4.2.3 Report

Following the completion of the Phase 1 and/or 2 studies, a report is to be prepared by the qualified person summarising the work that was completed and a description of the outcome of the study. The content of the report should include the following as a minimum:

1. Description of the background information review including what information was reviewed and the outcome of the review,
2. The background summary should include a summary of the information that was used to confirm the presence or absence of karst on the subject property,
3. Description of the site visit and observations made in the field. This would include observations or evidence suggesting the presence of karst conditions. If the site inspection confirms the presence of karst, a map of the karst hazard must be prepared and provided with the report. If further assessment is needed than a summary of the plan for subsurface investigations is to be provided. This plan should include the rationale for the type of subsurface investigation chosen as well as the location, pattern and frequency of sample locations.
4. Provision of site description and terrain analysis,
5. A map showing the site including locations of karst (exposed or covered), surface drainage features and patterns, testing locations and building envelope (house, septic and well) with setbacks from any relevant karst features or other applicable setbacks,
6. A **clear** statement that karst is either present or absent on the property and if present a map **clearly** showing the limits of the karst features.
7. If karst is mapped on the property and a potential building envelope is identified. **A building envelope site plan must be prepared which includes recommended setbacks for buildings, septic systems, wells, driveways etc. outside the area of hazardous lands. Recommendations regarding well construction are also to be provided.** An example of a typical building envelope site plan is provided on page 14.
8. Signature and stamp of the qualified professional who completed the work and report.
9. Quinte Conservation may require an independent peer review of any technical report. The cost of the peer review will be at the applicant's expense.


Example Karst Site Plan
(metres)
Septic Field
(metres)
Well
(metres)
House
(metres)
Building Envelope
Setback (metres)
Setback (metres)
Hazardous Lands
Direction of Slope
Driveway
Setback (metres)
Scale:
Author:
Date:
Test Pit
Karst Bedrock
NORTH
Note: other setback distances such as those required by the Ontario Building Code or Municipal zoning have not been labelled.

Definitions – as taken from Karst and Hazards Lands Mitigation: Some Guidelines for Geological and Geotechnical Investigation in Ontario Karst Terrains. F.R. Brunton, 2013

Aggressive groundwater – unsaturated groundwater with respect to the local bedrock geochemistry, so the rock is susceptible to dissolution.

Carbonate rocks – sedimentary rocks (e.g., limestones, dolostones) composed mainly of calcium carbonate. Dolostones have magnesium and calcium within the carbonate rock.

Cave – a natural opening in rock large enough to be entered by man and extending to points where daylight does not penetrate.

Cave system – a cave or caves having a complex network of interconnected chambers and passages that constitute an underground drainage system.

Disappearing streams – areas of exposed bedrock or thin sedimentary cover where surface streams disappear into the ground; these locations are often referred to as sinkholes or sinks.

Dissolution or chemical solution – a chemical weathering process of bedrock in which the combination of water and carbonic acid slowly removes mineral compounds from bedrock and carries them away in solution; when waters become saturated or over saturated with dissolved elements then precipitation will happen.

Dolines or sinkholes – a closed surface depression draining underground in karst terrain. Dolines are usually "bowl-shaped" and can be a few to many hundreds of metres in diameter.

Groundwater – water below the level at which all voids in the rock are completely filled with water.

Karren – a complex group of small- to medium-scale karstic landforms, commonly found on limestone pavements, showing a variety of dissolution, sculpted features, such as sharp-ridged grooves, widely opened joints, horseshoe-shaped stepped structures.

Karst – a distinctive landform topography created by a combination of physical erosion and chemical dissolution of underlying soluble rocks (carbonates, gypsum, salts) by surface water or groundwater.

Permeability – a property of rock or unconsolidated soils and underlying sediments that permits water to pass through it via interconnected voids (spaces). Permeable bedrock makes a good aquifer, a rock layer that yields water to wells.

Porosity – a volume of void space in soils, unconsolidated surficial sediments or bedrock. When these voids are interconnected, water or air (or other fluids) can migrate through voids making the sediment or bedrock permeable.

Sinkholes or dolines – are closed surface depressions that allow rain and river waters to flow underground and help create subterranean karst features. Sinkholes are often "bowl-shaped" and can be a few to many hundreds of metres in diameter.

Springs or resurgence – the point where ground water reappears at the earth's surface and begins flowing downhill as a surface stream. It is the opposite of a sinking stream.

Water table – the surface between the zone of pure water saturation and zone of pure aeration under the ground surface. In some low-lying areas, the water table can be above ground surface resulting in springs and/or groundwater discharge, usually into rivers.

References

Brunton & Dodge, 2008. Karst of Southern Ontario and Manitoulin Island, Ontario Geological Survey, Groundwater Resources Study 5,

Brunton, F.R. 2013, Karst and Hazards Lands Mitigation: Some Guidelines for Geological and Geotechnical Investigation in Ontario Karst Terrains. Ontario Geological Survey open File Report 6290 pg 37-1 to 37-24.

Currens, 2001 Generalized Block Diagram of the Eastern Pennroyal Karst. Kentucky Geological Survey.

Conservation Authorities Act, R.S.O. 1990, c. C.27

City of Belleville Official Plan Draft – October, 2021

Grace & Associates Inc. and Oakridge Environmental Ltd. 2008. Final Report: Karst hazard mitigation next steps strategy for Ontario; internal report for Ontario Ministry of Natural Resources, 61p., including references and appendices.

Hastings County Official Plan, August 3, 2018.

Ministry of Natural Resources, Dec.1996. Hazardous Sites Technical Guide Version 1.0

Ontario Regulation 319/09: Quinte Conservation Authority: Regulation of Development, Interference with Wetlands, and Alterations to Shorelines and Watercourses. *Conservation Authorities Act, R.S.O. 1990, c. C.27*. November 28, 2022.

Krolik. J, Maier. A, Evans. G, Belanger.P, Hall.G, Joyce.A, Majury.A, (2013) A Spatial Analysis of Private Well Water Escherichia coli Contamination in Southern Ontario. Geospatial Health 8 (1), 2013, pp.65-75.

Perkins.N.R., Kelton.D.F., Hand.K.J., MacNaughton. G., Berke. O., Leslie. K.E. (2009) An Analysis of the Relationship between bulk tank milk quality and wash water quality on diary farms in Ontario, Canada J.Day Sci.92.3714-3722. American Dairy Science Association, 2009.

Provincial Policy Statement, 2020 Under the Planning Act, Ontario Government

Quinte Region Source Protection Committee, September 2019, Approved Quinte Region Assessment Report Version 6.0

Taylor, Charles J., and Earl A. Greene. Hydrogeologic Characterization and Methods used in the Investigation of Karst Hydrology. US Geological Survey (2008).

Township of Stone Mills Official Plan Review Adoption Draft (September, 2022).