GEOSCIENCE AND MINES BRANCH

A Karst Risk Map of Nova Scotia

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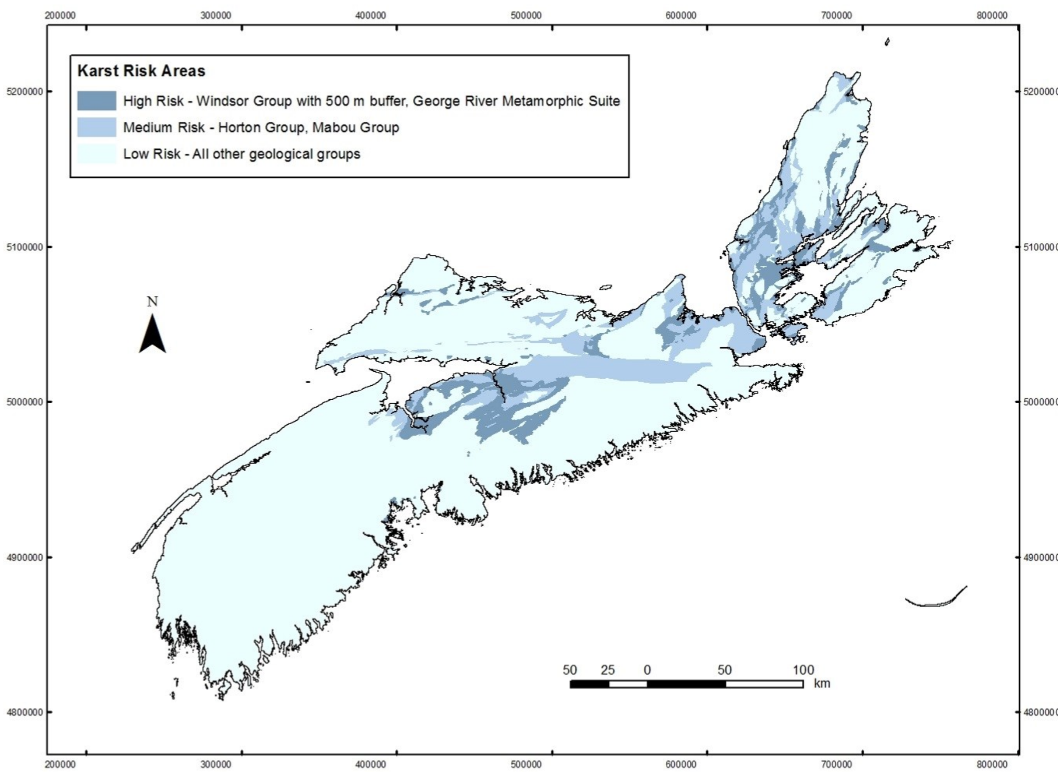
Open File Report ME 2019-001



NOVA SCOTIA

Energy and Mines

Halifax, Nova Scotia

February 2019

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Introduction

Karst refers to the distinctive terrain that develops over soluble bedrock and includes features such as sinkholes, caves, and springs. Sinkhole development in karst terrain can cause extensive damage to buildings, roads, and other infrastructure. The primary geohazard in karst areas is the sudden catastrophic subsidence of the ground. This may occur due to the collapse of cavities in bedrock that have been created by the dissolution of soluble evaporite rocks (e.g. gypsum, anhydrite, salt) or carbonate rocks (e.g. limestone, dolostone). It may also occur when soil is washed into openings in underlying soluble bedrock, which creates a void in the soil that migrates upwards by progressive collapse (Waltham et al., 2005). Sinkholes can be a serious geohazard in some areas of the province and, therefore, caution should be exercised in potential karst areas when constructing buildings, roads, or other infrastructure.

Most natural sinkholes in Nova Scotia are formed in areas where gypsum occurs at or near the ground surface. Figure 1 shows a generalized conceptual model for karst and sinkhole development in Nova Scotia, and examples from the field are shown in Figures 2 and 3. The geological contact between the gypsum- and salt-bearing Windsor Group and the underlying sandstones and shales of the Horton Group or older basement rocks is particularly prone to sinkhole development. Sinkholes are also known to occur

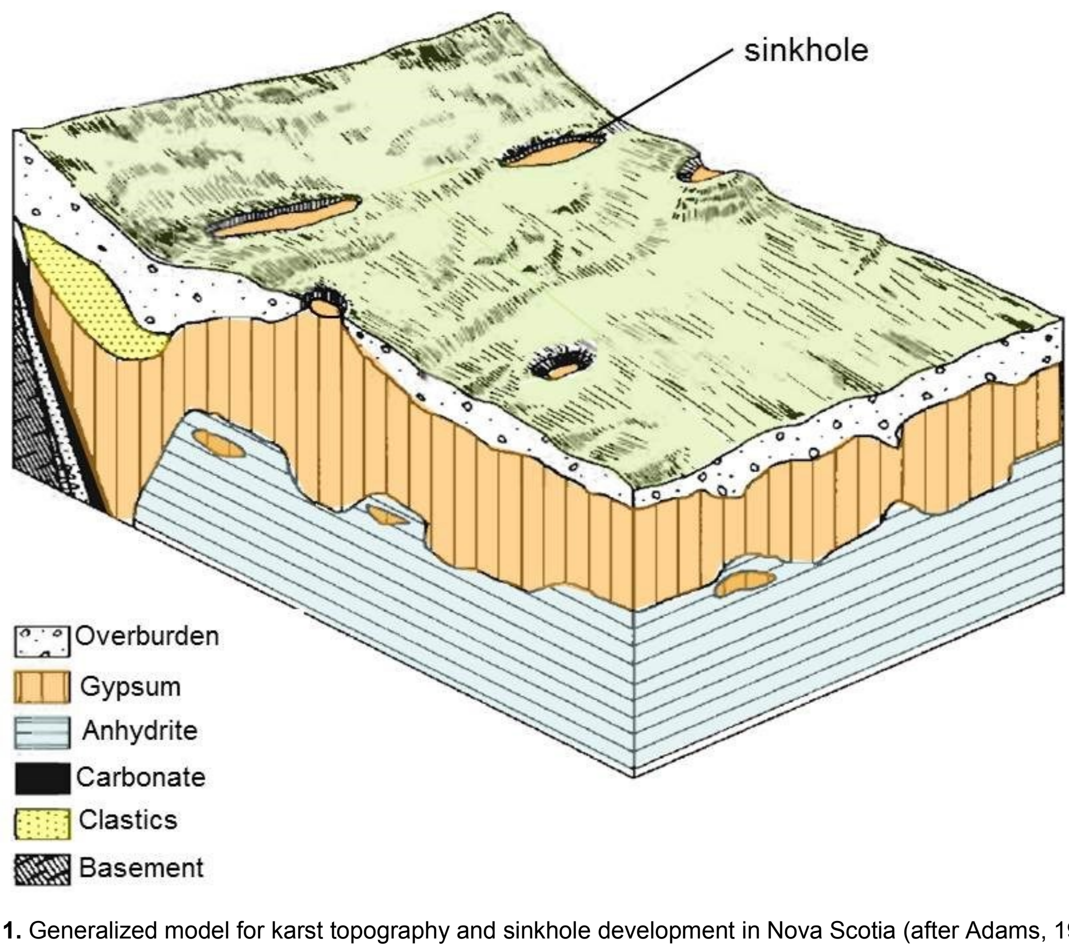

Figure 1. Generalized model for karst topography and sinkhole development in Nova Scotia (after Adams, 1991).

Figure 2. Gypsum outcrop showing karst topography, Cheverie area, Nova Scotia.

Figure 3. Two-metre-wide sinkhole in gypsum, Cheverie area, Nova Scotia.

outside the Windsor Group, for example in the carbonate rocks of the George River Metamorphic Suite in Cape Breton.

This report describes a new karst risk map for Nova Scotia. The report and map are restricted to naturally occurring karst that is associated with soluble bedrock, rather than sinkholes associated with various human activities such as historical underground coal mining or abandoned mine openings. Preparation of the map involved the compilation of digital geology maps, compilation of karst and sinkhole occurrence data, review of lidar data, and field verification of selected sinkhole occurrences. The new map is available online as an interactive map (Nova Scotia Department of Energy and Mines, 2019).

Methods

Data Sources

The database prepared during this project contains 1,057 records of known locations with sinkholes, karst topography, caves, and karst springs. The majority of records are sinkholes or areas of karst topography that contain sinkholes. Therefore, for ease of discussion, all records in the database will be referred to as sinkhole locations hereafter in this report and the database is referred to as the Nova Scotia Sinkhole Database.

The sinkhole occurrence data were obtained from several sources (Table 1). The primary data sources were existing geology maps and reports. The majority of these data was obtained by reviewing digital geology maps of the province and compiling sinkhole data from these maps into the database. Sinkhole data were also digitized from selected older hardcopy maps that were known to contain karst information. The main source of data from older maps were those associated with the report entitled *Gypsum and Anhydrite Resources of Nova Scotia* (Adams, 1991). Sinkhole data were also obtained for the central Antigonish area from a project that used lidar to visually identify karst topography (Demont and Utting, 2011). The database also benefitted from sinkhole data provided by municipal agencies and geological consultants.

The boundaries for geological groups and formations were taken from geological maps of the province, which were selected in consultation with senior mapping geologists of the former Nova Scotia Department of Natural Resources (now with the Department of Energy and Mines). In addition

Table 1. List of data sources for the Nova Scotia Sinkhole Database.

No.	Source	Year	Description	Number of Sinkholes
1	Provincial geology maps	Various years	Best available geology maps of the province	475
2	Adams (1991)	1991	Report on gypsum and anhydrite resources of Nova Scotia	457
3	Demont and Utting (2011)	2011	Karst locations in Antigonish County identified by lidar analysis	76
4	Municipality of the District of West Hants	2015	Sinkhole locations identified by the Municipality of the District of West Hants	17
5	Geological consultants	2016	Karst and sinkhole locations identified by geological consultants	32
			TOTAL	1,057

to geological maps, hydrogeological databases were reviewed to identify evidence of subsurface occurrences of soluble rocks that were not shown on existing geological maps. This may occur near the Windsor Group boundaries where the contact has been inferred due to lack of outcrop. It may also occur in areas where the Windsor Group occurs as small, unmapped outliers that may or may not be exposed at the ground surface.

The hydrogeological databases that were reviewed included the Nova Scotia Well Logs Database, Nova Scotia Pumping Test Database, Nova Scotia Test Hole Database, and the Nova Scotia Groundwater Chemistry Database, all of which can be accessed online through the Nova Scotia Groundwater Atlas (Nova Scotia Department of Natural Resources, undated). These databases were searched for wells and test holes with stratigraphic information indicative of evaporite and carbonate rocks, evidence of subsurface voids (e.g. karst solution channels), and groundwater chemistry indicative of soluble rocks (i.e. high concentrations of sulphate, hardness, or total dissolved solids). Areas were assigned the same relative risk as the Windsor Group if they had clusters of wells or test holes with evidence of soluble rocks. At least three wells and/or test holes within 1000 m were required to classify an area this way. Further details about the method used to process the hydrogeological spatial data can be found in the report entitled *Identification and Preliminary Mapping of Surficial Aquifers in Nova Scotia* (Kennedy, 2014), which uses the same spatial analysis method to identify surficial aquifer locations based on hydrogeological data.

Data Analysis

The geological maps and sinkhole data were plotted in ArcGIS™10 (Esri Inc.) and the number of sinkhole occurrences were counted for each geological group and formation. The density of sinkholes (i.e. number of sinkholes per 100 km^2) were calculated for geological groups that contain at least five sinkholes. It should be noted that each karst terrain area that was identified using lidar was counted as single a sinkhole occurrence using the centroid of the area as its co-ordinates, even though the area may contain multiple sinkholes.

Geological groups with sinkholes were further analysed at the formation level by calculating sinkhole densities for formations with at least five sinkhole occurrences. Geological groups were ranked according to their sinkhole densities and divided into three relative-risk categories: high, medium, and low. The assignment of risk categories to geological groups was based on sinkhole densities and professional geoscience judgement. It should be noted that sinkhole densities presented in this report are calculated based on records in the Nova Scotia Sinkhole Database, which does not necessarily include all existing sinkhole occurrences. Therefore, actual sinkhole densities may be higher than reported here.

Results and Discussion

Sinkholes were identified in eight geological groups, five of which (Windsor, Horton, Mabou, Cumberland, and George River Metamorphic Suite) contain more than five sinkholes occurrences (Table 2). The majority of sinkholes (83%) are located in the Windsor Group. Table 3 shows sinkhole occurrences and densities broken down at the formation level for groups with at least five sinkholes. The results in Table 3 show that three formations of the Windsor Group (White Quarry, Miller Creek, and Bridgeville) have higher sinkhole densities (>12 sinkholes per 10 km^2) than other formations. The White Quarry Formation has the highest density (35 sinkholes per 10 km^2) and contains 26% of the sinkhole occurrences in the database.

As discussed above, the majority of sinkholes in the Nova Scotia Sinkhole Database (83%) are located in the Windsor Group. For the remaining sinkholes that lie outside of the Windsor Group, a high

Table 2. Sinkholes and densities by geological group.

No.	Geological Group	No. of Sinkholes	Percent of Sinkholes in the Nova Scotia Sinkhole Database	Sinkhole Density (per 100 km^2)
1	Windsor	878	83.1%	22
2	Horton	102	9.6%	1.6
3	Mabou	47	4.4%	2.5
4	Cumberland	18	1.7%	0.5
5	George River Metamorphic Suite	7	0.7%	1.7
6	Total of all other groups with less than 5 sinkholes	5	0.5%	-
	TOTAL	1,057	100%	-

percentage are located near the Windsor Group. Figure 4 shows the relationship between non-Windsor Group sinkholes and distance to the Windsor Group. Approximately 50% of all non-Windsor Group sinkholes lie within 200 m of the Windsor Group and approximately 70% lie within 500 m. This indicates that there is a relatively high risk of encountering sinkholes in areas near the Windsor Group. This also suggests that Windsor Group rocks may be present outside areas currently mapped as Windsor Group, possibly due to inaccuracies in the assumed Windsor Group contact in areas that lack outcrop.

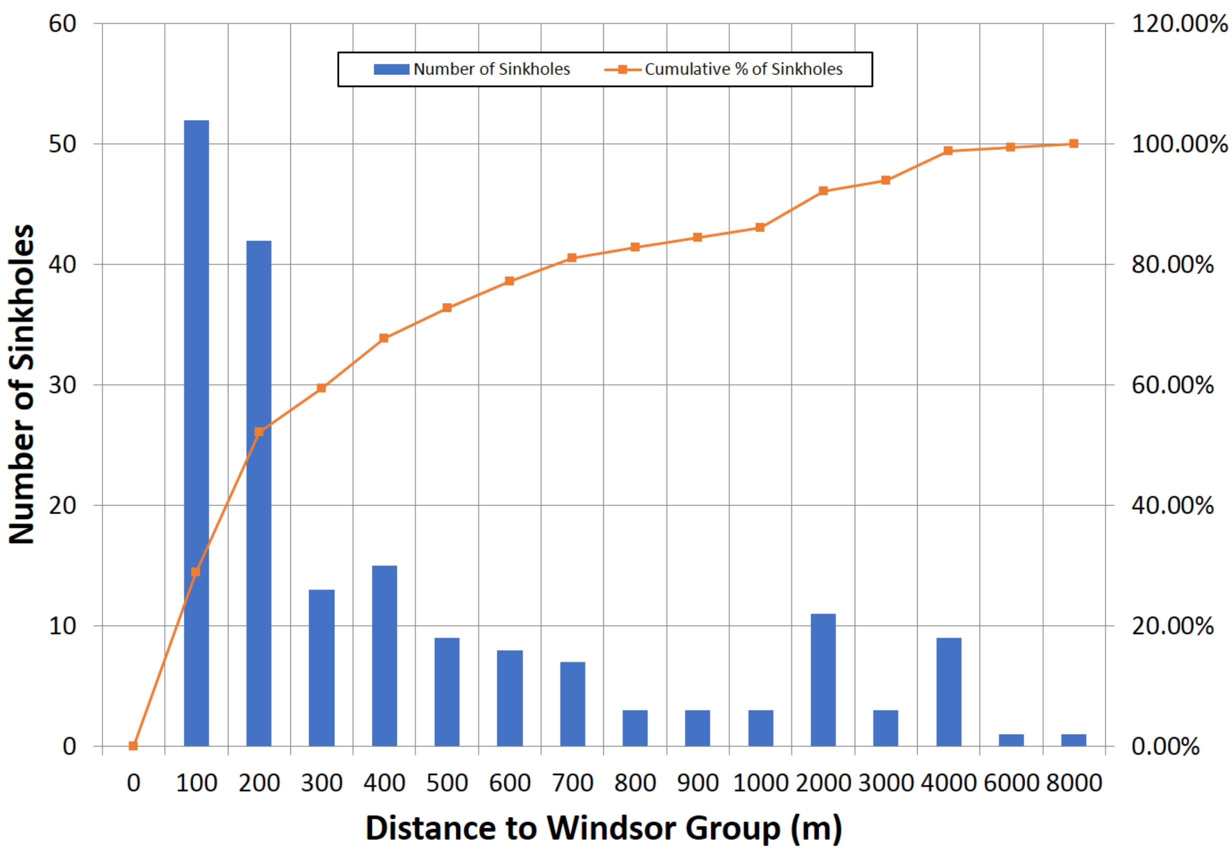

Figure 4. Number and cumulative per cent of sinkholes in non-Windsor Group bedrock relative to distance from the Windsor Group.

Table 3. Sinkholes and densities by geological formation.

No.	Geological Formation	No. of Sinkholes	Percent of Sinkholes in the Nova Scotia Sinkhole Database	Sinkhole Density (per 10 km^2)
	Windsor Group			
1.1	White Quarry Formation	279	26.4	35
1.2	Undivided Windsor Group	213	20.2	-
1.3	Bridgeville Formation	74	7.0	12
1.4	Hood Island Formation	50	4.7	5.0
1.5	Miller Creek Formation	50	4.7	18
1.6	MacDonald Road Formation	46	4.4	2.9
1.7	Carrolls Corner Formation	43	4.1	1.4
1.8	Murphy Road Formation	29	2.7	3.7
1.9	Green Oaks Formation	24	2.3	0.7
1.10	Macumber Formation	14	1.3	2.4
1.11	Wentworth Station Formation	14	1.3	7.4
1.12	Meadows Road Formation	13	1.2	0.46
1.13	Pugwash Mine Formation	11	1.0	4.4
1.14	Sydney River Formation	6	0.6	1.0
1.15	Total of all other formations with less than 5 sinkholes	12	1.1	-
	Horton Group			
2.1	Undivided Horton Group	43	4.1	-
2.2	Creignish Formation	17	1.6	0.22
2.3	Ainslie Formation	16	1.5	0.53
2.4	Cheverie Formation	10	0.9	0.18
2.5	Strathlorne Formation	8	0.8	0.36
2.6	Total of all other formations with less than 5 sinkholes	8	0.8	-
	Mabou Group			
3.1	Hastings Formation	20	1.9	0.41
3.2	Watering Brook Formation	17	1.6	0.64
3.3	Pomquet Formation	5	0.5	0.14
3.4	Total of all other formations with less than 5 sinkholes	5	0.5	-

(Table 3 continues on next page.)

Due to the high number of sinkholes located near the Windsor Group, a 500 m buffer zone was added to the Windsor Group for the purposes of preparing the risk map. Table 4 shows recalculated sinkhole densities using a 500 m buffer, and indicates that 95% of sinkholes in the database are contained within

Table 3 *(concluded).*

No.	Geological Formation	No. of Sinkholes	Percent of Sinkholes in the Nova Scotia Sinkhole Database	Sinkhole Density (per 10 km^2)
	Cumberland Group			
4.1	Port Hood Formation	7	0.7	0.38
4.2	Total of all other formations with less than 5 sinkholes	11	0.11	-
	George River Metamorphic Suite			
5.1	Total of all other formations with less than 5 sinkholes	7	0.7	-
	Other Groups			
6.1	Total of all other formations with less than 5 sinkholes	5	0.5	-
	TOTAL	1,057	100%	-

the combined Windsor Group and 500 m buffer. The buffer itself contains 12% of the sinkholes in the database. It should be noted that even with a 500 m buffer around the Windsor Group, there is still a number of sinkholes (about 4% of the database) that are located in geological groups that are not known to contain evaporate or carbonate rocks, mainly in the Horton and Mabou Groups. This may be due to the presence of small areas of unmapped Windsor Group, especially along faults that may have mobilized or helped preserved these rocks from erosion.

An alternative approach to identifying potential karst risk was tested in which all non-Windsor Group formations containing soluble rocks (carbonates or evaporites) in their lithological descriptions were flagged and the number of sinkholes in these formations was counted. This approach captured 6% of sinkholes in the database, compared to 12% using the 500 m buffer around the Windsor Group. Therefore, for areas outside of the Windsor Group, proximity to the Windsor Group was a stronger predictor of karst risk than the presence of carbonate or evaporate in lithological descriptions.

The new karst risk map is presented in Figure 5. It contains three karst risk zones: high, medium, and low. The risk zones are based on several factors, including geology, sinkhole locations, and professional judgement. The high-risk zone contains 96% of the sinkholes in the Nova Scotia Sinkhole Database and has densities of greater than 1 sinkhole per 100 km^2. This zone includes the Windsor Group, a 500 m buffer zone around the Windsor Group, and the George River Metamorphic Suite. The medium-risk zone contains 3.9% of the sinkholes in the Nova Scotia Sinkhole Database and has densities between 0.1 and 1 sinkhole per 100 km^2. This zone includes the Horton Group and Mabou Group. The low-risk zone contains less than 0.1% of the sinkholes in the Nova Scotia Sinkhole Database. This zone typically does not contain sinkholes; however, sinkholes may still occur in this area due to unmapped soluble rocks (i.e. evaporites or carbonates) or where soluble rocks are close to the ground surface but overlain by other rock types or unconsolidated material.

Summary

The new karst risk map for Nova Scotia was constructed using geological maps of the province and a new sinkhole database that includes 1,057 sinkhole records. The map includes three karst risk areas: high, medium, and low. The high-risk area contains 96% of the sinkholes in the Nova Scotia Sinkhole Database and includes the Windsor Group, a 500 m buffer around the Windsor Group and the George

Table 4. Sinkholes by geological group with 500 m buffer around Windsor Group.

No.	Geological Group	No. of Sinkholes	Percent of Sinkholes in the Nova Scotia Sinkhole Database	Sinkhole Density (per 100 km^2)
1	Windsor plus 500 m buffer	1008	95.4%	11
	Windsor only	(878)	(83.1%)	22
	500 m buffer zone only	(130)	(12.3%)	2.6
2	Horton	29	2.7%	0.51
3	Mabou	12	1.1%	0.84
4	George River Metamorphic Suite	7	0.7%	1.7
5	Total of all other groups with less than 5 sinkholes	1	0.1%	-
	TOTAL (not including values in parentheses)	1,057	100%	-

Note: The values in parentheses show how sinkholes are apportioned between the Windsor Group and the buffer around it. The sum of these values is included in row one of the table and, therefore, the values in parentheses are not double counted in the total at the bottom of the table.

River Metamorphic Suite. The group with the highest number of sinkholes is the Windsor Group, which contains 83% of the sinkholes in the Nova Scotia Sinkhole Database. Within the Windsor Group, the formation with highest number of sinkholes is the White Quarry Formation. This formation contains 26% of the sinkholes in the Nova Scotia Sinkhole Database and a has a density of 35 sinkholes per 10 km^2.

Caution should be exercised in potential karst areas, especially high-risk areas, when constructing buildings, roads or other infrastructure. It should be noted that sinkholes may still occur in low-risk areas due to unmapped soluble rocks or where soluble rocks are close to the ground surface but are overlain by other rock types or unconsolidated material.

The karst risk map should be re-evaluated as new sinkhole data and geological mapping becomes available. Because the Windsor Group has the highest karst risk in the province, it is particularly important to update the karst risk map when new Windsor Group mapping becomes available. In addition, lidar has proven extremely useful for identifying karst topography and, therefore, the karst risk map should be updated when new provincial lidar coverage becomes available. There is currently an initiative underway to obtain lidar for the entire province (Provincial Lidar Acquisition Project), which is expected to be completed by 2020.

Acknowledgments

The author gratefully acknowledges contributions to this report from many individuals, including Jeff McKinnon for GIS support; Haley LeBlanc for digitizing sinkhole locations; Gavin Kennedy for hydrogeological database analysis and interpretation; and Gordon Adams, Sean Basquill, Brian Fisher, and Bob Ryan for their technical advice. The project greatly benefited from sinkhole location data provided by Fred Baechler and the Municipality of the District of West Hants. Review comments provided by Ian Campbell and Garth Demont on an earlier version of this report led to substantial improvements.

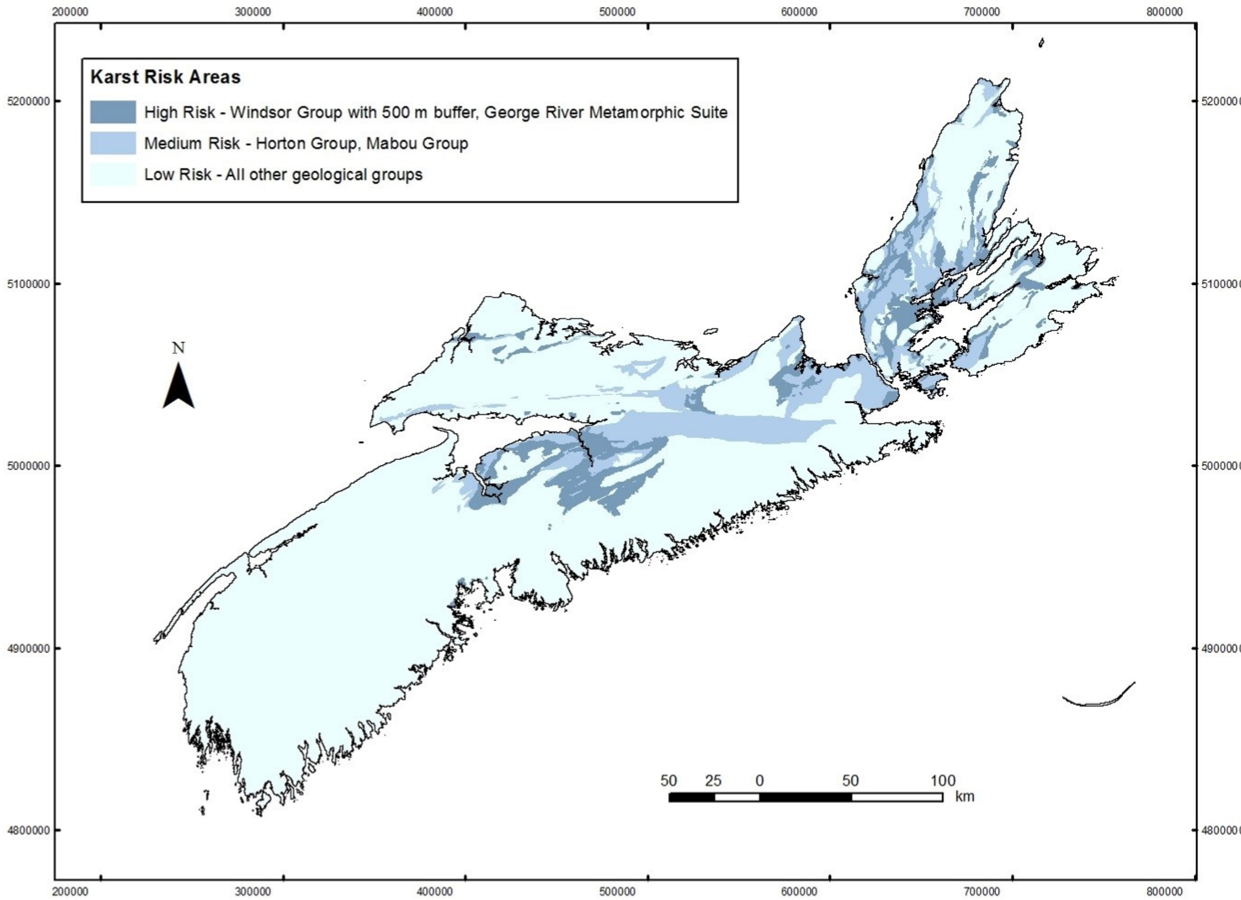

Figure 5. Karst risk map of Nova Scotia.

References

Adams, G.C., 1991. Gypsum and anhydrite resources of Nova Scotia; Nova Scotia Department of Natural Resources, Economic Geology Series 91-1, 243 p. <https://novascotia.ca/natr/meb/pdf/91egs01.asp>

DeMont, G.J. and Utting, D.J., 2011. 2010 report on the central Antigonish County land-use planning and climate change adaptation project; *in* Mineral Resources Branch, Report of Activities 2010; Nova Scotia Department of Natural Resources, Report ME 2011-1, p. 5-13. <https://novascotia.ca/natr/meb/data/pubs/11re01/11re01_04DeMontandUtting.pdf>

Kennedy, G.W. 2014. Identification and preliminary mapping of surficial aquifers in Nova Scotia; *in* Mineral Resources Branch Report of Activities 2013; Nova Scotia Department of Natural Resources, Report ME 2014-001, p. 33-43. <https://novascotia.ca/natr/meb/data/pubs/14re01/14re01_Kennedy.pdf>

Nova Scotia Department of Energy and Mines, 2019. Karst risk map. Nova Scotia Department of Energy and Mines. <https://fletcher.novascotia.ca/DNRViewer/?viewer=Karst>

Nova Scotia Department of Natural Resources, undated. Nova Scotia Groundwater Atlas. Nova Scotia Department of Natural Resources. <https://fletcher.novascotia.ca/DNRViewer/?viewer=Groundwater> [Accessed March 28, 2018]

Waltham, T., Bell, F.G. and Culshaw, M.G., 2005. Sinkholes and subsidence: karst and cavernous rocks in engineering and construction; Praxis Publishing Ltd., Chichester, UK, 382 p.