An Overview of Work on the Oxford Sinkhole, 2018-2019

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Introduction

In late July, 2018, a small area of subsidence was observed by members of the Oxford Area Lions Club near the western end of the parking lot in the privately owned Lions Parkland in Oxford, Cumberland County (Fig. 1). The circular depression was described as approximately 60 cm deep by 100 cm wide. On August 9, 2018, approximately 12 tonnes of shale were used to fill the depression back to surface grade. On August 10, the area again subsided, resulting in a square-shaped depression approximately 1.5 m^2 and 30 cm deep. The area was cordoned off and monitored until August 20, when a witness described the sound of rushing water, a loud “whump” noise and felt the ground shake as a result of sudden collapse, leading to the development of the sinkhole. At that time, emergency responders were called to the scene and the park was closed to the public. From August 20 to early September, 2018, the sinkhole grew rapidly from a few metres to approximately 40 m in diameter (Fig. 2). The underground extent of the collapsed cavern is presently unknown.

The location of the sinkhole relative to surrounding infrastructure is of concern to the public and stake-holders in the area. Highway 321 is the primary access route to the Town of Oxford from the TransCanada Highway (104), providing efficient regional accessibility for the community and emergency first-responders. In addition to the local Community Centre at the Lions Parkland, several businesses operate adjacent to the property, including a fuel service station with underground storage tanks. In collaboration with the Oxford Area Lions Club, Regional Emergency Management Organization, and Town of Oxford, the sinkhole was closely monitored by the Department of Energy and Mines to help evaluate when surrounding infrastructure should be evacuated if the sinkhole continued to propagate at the rapid rate first observed.

Regional Geology

The area of the Lions Parkland is underlain by undivided Mississippian rocks of the Windsor Group, consisting of interstratified redbeds, evaporites, and carbonates. Evaporite and carbonate rocks include gypsum, salt, anhydrite, and limestone, all of which are variably soluble in water. Evaporitic rocks and sinkholes in the Oxford area were recorded in early geological maps by Barlow and Giroux (1886) and Norman and Bell (1938). Bell (1944) attributed the formation of Black, Slade, Vickery, and Park (Salt) lakes to the dissolution of water-soluble bedrock, resulting in groupings of interconnected sinkholes. Subsequent mapping by Ryan et al. (1990) further defined the area as an “area of extensive karst with sinkholes and gypsum outcrop.” Bedrock in the Oxford area is overlain by 3 to 30 m of sand, glacial till, and fluvial deposits, obscuring the surface expression of the karst topography (Stea and Finck, 1988). A thick deposit of gravelly sand conceals bedrock at the sinkhole, but gypsum crops out approximately 400 m to the southwest in an area of extensive karst topography.

In 1924 and 1926, three drillholes were completed in eastern Oxford by the Province of Nova Scotia (Nova Scotia Department of Mines, 1925, 1927). The drillholes intersected 4 to 15 m of overburden above interbedded gypsum, sandstone, and shale. A drillhole completed by the Malagash Salt Company (1953) 4 km east of Oxford intersected salt from 80 m depth to end-of-hole. Numerous salt springs in the Oxford area further support the presence of salt in the underlying stratigraphy (Cole, 1930).

The geology of the Oxford area is structurally complex, and there are few outcrops and few historical well and exploratory drill records to supply subsurface information. The northern and western limits of the Windsor Group in the Oxford area are interpreted to be in fault contact with the Upper Carboniferous Cumberland Group. The nature of the southern and eastern contacts is unknown. Based on the presence of interbedded evaporites, slates, and mudstones, the Windsor Group strata are interpreted to be folded in diapiric structures, regionally expressed in the east-northeast-trending Claremont-Malagash anticline, with localized zones of increased deformation (Boehner, 1986). Regional geophysical surveys help define the extent of the Windsor Group and

Tizzard, A., Demont, G. J. and Brushett, D. M. 2019: *in* Geoscience and Mines Branch, Report of Activities 2018-2019; Nova Scotia Department of Energy and Mines, Report ME 2019-002, p. 63-68.

Figure 1. Location of the Oxford sinkhole.

Figure 2. Photograph of the sinkhole in September 2018.

diapiric structures in the area, but the information is too limited in scale to model individual voids in the subsurface (see Nova Scotia Department of Energy, 2017, and references therein).

Monitoring Program

Formal identification and measurement of propagation cracks encompassing the Oxford sinkhole began on August 25, 2018. The boundary of the sinkhole was regularly surveyed by the Department of Lands and Forestry using real-time-kinematic GPS (Leica GNSS RTK GS 15). Propagation cracks and survey ground control points were collected using total-station GPS (Leica TS 11 5”). The sinkhole boundary was surveyed with a 7 m offset to operate at a safe distance away from the actively eroding margin. The offset readings were post-processed and corrected to obtain the actual outline of the sinkhole. Cracks located at a safe distance away from the sinkhole margin in the parking lot and surrounding ground surface were identified, numbered, photographed, surveyed, measured, and marked using spray paint. Cracks were then closely monitored for changes in width and depth, in addition to scanning the area for new signs of sinkhole growth. Water levels of both the sinkhole and the surrounding Salt Lake were also surveyed by the Department of Lands and Forestry.

During the course of initial rapid sinkhole development in late August and September, the sinkhole progressed at variable rates predominantly to the northeast toward playground infrastructure and surrounding Salt Lake (Fig. 3). Many cracks grew in width from hairline fractures to tens of millimetres wide to being unsafe to measure or being completely consumed by the sinkhole. The rate of growth of the sinkhole boundary was likely influenced by dense root masses of large trees in an otherwise homogenous sand deposit. The thick sand deposit in the area of the Lions Parkland likely contributed to the rapid growth of the sinkhole, due to the ability of surface and ground water to flow more easily through a permeable medium. Additionally, the steep walls of the sinkhole combined with the low cohesiveness of the sand are conditions favourable to a sudden bank collapse.

Water level in the sinkhole was approximately 10 m below surface at the onset of the collapse and was subsequently surveyed in comparison to the surrounding lake water levels (Table 1; Fig. 4). No

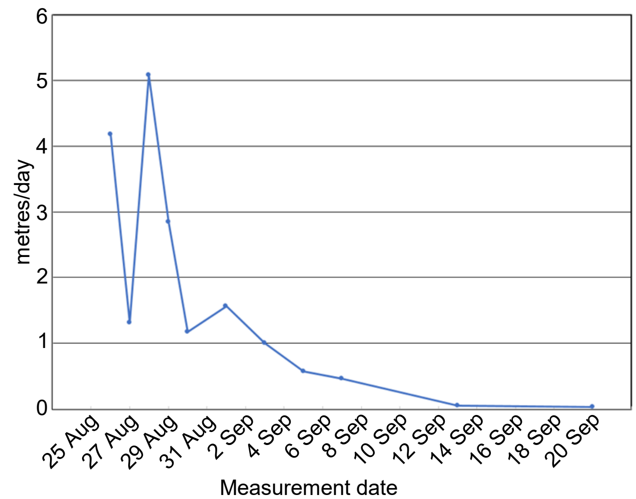

Figure 3. Rate of growth of the Oxford sinkhole, 25 August to 20 September 2018.

Table 1. Water level measurements of the sinkhole and Salt Lake. Note that no survey data were available prior to August 25.

Date (2018)	Salt Lake Water Level (masl)	Sinkhole Water Level (masl)
Aug 25	6.936	No measurement
Aug 26	6.98	5.497
Aug 27	6.967	5.516
Aug 28	6.983	5.875
Aug 29	6.98	5.933
Aug 30	6.94	5.985
Sept 1	6.952	6.041
Sept 3	6.989	6.151
Sept 5	6.963	6.272
Sept 7	6.895	6.318
Sept 10	6.978	6.409
Sept 13	6.987	6.523
Oct 2	6.984	6.874

bedrock was visible in the sinkhole at that time, therefore the overburden was estimated to be greater than 10 m in thickness in the area of the park. The initial difference in the water levels between the sinkhole and the surrounding lake indicates a limited hydraulic connection between the water bodies. At the time of this report, however, the water bodies appear to have equalized. No surveys were completed in the winter of 2019 due to freezing conditions.

Basic parameters of the water in the sinkhole, surrounding Salt Lake and River Philip were measured for a report commissioned by the Town of Oxford (Table 2; FracFlow Consultants Inc., 2018). The high specific conductance of the sinkhole and lake waters is comparable to the chemistry of brine springs in the area reported by Cole (1930).

Water in the sinkhole was extremely turbid at the time of its development. Aerial surveillance of the region was undertaken to examine surrounding water bodies for signs of change (Fig. 5). No unexpected turbidity was noted in surrounding water bodies, indicating no apparent immediate connectivity between the Oxford sinkhole and surrounding sinks or River Philip. The underground extent of fractures, fissures or voids beneath the Oxford sinkhole is unknown.

Examination of regional lidar and satellite imagery clearly demonstrates the karstic terrain in the Oxford area (Fig. 6). Numerous ponded and dry sinkholes are evident in a well-defined karst belt extending from the southern part of the Town of Oxford southwest toward Springhill for a distance of 5 km. Scalloped-shaped lake shorelines within the karstic belt, including Salt Lake, are indicative of coalescing sinkholes.

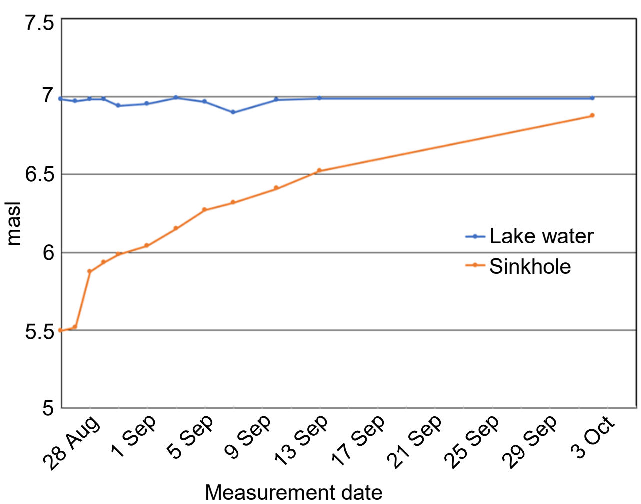

Figure 4. Water level differentials between the sinkhole and Salt Lake.

The sinkhole continues to slowly erode along its margins, but the rate of growth has significantly slowed. Due to the unpredictable nature of natural sinkhole development, and lack of background information, assessment of the stability of the site cannot be confidently ascertained without additional subsurface information. The thick overburden, high water table, and high conductivity of water pose challenges to geophysical investigation of the site, which will require specialized equipment and expertise.

Future Plans

The formation of contemporary, naturally occurring sinkholes like the one recently developed in the Lions Parkland in Oxford is often related to anthropogenic activities that alter the natural state of water, such as diversion of drainage ditches, downspouts, and runoff from surface grade. No apparent linkages can yet be made at the Oxford sinkhole. The Department of Energy and Mines plans to continue to monitor the development of the Oxford sinkhole and surrounding areas for active subsidence. No historical data regarding the depth, extent, or modal size of sinkholes has been found, therefore characterization of regional sinkhole features will help determine the associated risk in the area. Continued site surveying and the compilation and analysis of propagation cracks will be used to further examine the characteristics of an actively developing sinkhole.

A lidar survey was initially collected by the Cumberland Regional Emergency Management Organization (circa 2010) and another by the Province of Nova Scotia in September 2018. The two datasets will be used to examine change and characterize the surficial extent of stabilized

Table 2. Results of water testing, August 28, 2018 (FracFlow Consultants Inc., 2018; reproduced with permission from the Town of Oxford).

Sampling Point	Temperature	pH	Specific Conductance
Sinkhole	21.3°C	7.94	3580 µS/cm
Salt Lake	25.7°C	8.49	3970 µS/cm
River Philip upstream of karstic terrain	20.6°C	8.60	51 µS/cm
River Philip downstream of karstic terrain	23.5°C	8.79	490 µS/cm

Figure 5. Aerial view of the Oxford sinkhole and regional extent of karstic terrain. View is to the southwest. Photo taken August 29, 2018.

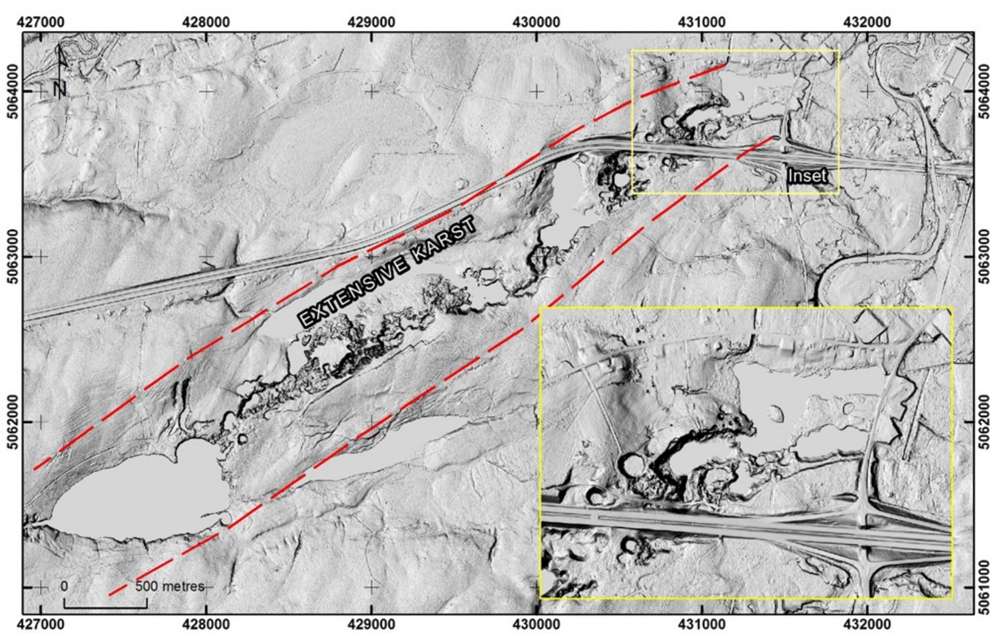

Figure 6. Lidar coverage of the Oxford area, flown September 2018.

sinkholes in the karstic terrain. The Department of Energy and Mines also plans to monitor and model the site using newly acquired drone technology.

Due to the rapid development and unpredictable nature of the sinkhole and karstic terrain, the Lions Parkland has remained closed to the public pending an investigation to better understand the subsurface conditions surrounding the sinkhole. A request for proposals was issued by the Town of Oxford in October 2018 to determine the underground extent of the active sinkhole area, and associated risk, using an integrated geophysical and geotechnical approach. Once the investigation is complete options for site remediation, if any, will be considered.

More information on sinkholes and other geohazards can be found on the Department of Energy and Mines website at https://novascotia.ca/natr/meb/environmental/geohazards.asp. The department also released an interactive Karst Risk Map in February 2019 that illustrates the high-risk karst belt transecting the Oxford area. The map can be viewed at https://fletcher.novascotia.ca/DNRViewer/?viewer=Karst.

Acknowledgments

Ensuring public safety throughout the development of the Oxford sinkhole was a great collaboration between numerous individuals and organizations. Prior to being present at the active sinkhole, the author relied upon observations and remarks from Oxford Area Lions Club members Bob Oickle and Bruce Selkirk, and Parkland summer student Ty Ingram. Thanks to Mark Rushton for providing images and testimony of the early sinkhole development. Tracy Lenfesty at the Department of Lands and Forestry library was tremendously helpful in tracking down historical documents. Jerry Borden and staff at the Department of Lands and Forestry Oxford office provided ground support at the sinkhole. Thank you to John Drage for insightful conversations about geohazards in Nova Scotia. Finally, the biggest thank-you goes out to Rachel Jones and the Town of Oxford, and Mike Johnson and Cumberland Regional Emergency Management Organization for their exceptional teamwork.

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