

A Preliminary Volumetric Analysis of Water Draw-Down in Active Karst Terrain, Slade Lake, Cumberland County, 2020

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Introduction

Karst topography is characterized by the presence of sinkholes, springs, disappearing streams, sculpted rock faces, and other unique landforms that result from the interaction of ground and surface water with soluble bedrock and sediment. In Nova Scotia, rocks of the Mississippian Windsor Group, such as gypsum, halite, anhydrite, and limestone, are the most susceptible to physical and chemical weathering that leads to the development of karst features. Dissolution of soluble materials at depth can lead to the formation of sinkholes, such as the one that destroyed part of a community park

in the Town of Oxford in 2018 (Tizzard et al. 2019). The Oxford sinkhole formed after 41.6 m of overlying overburden, sandstone, and conglomerate collapsed into a void of unknown size (GHD 2019). The sinkhole quickly filled with water and grew to over 40 m in diameter, closely resembling one of the many ponded sinkhole features in a well-defined belt of karst topography in the Oxford area.

Slade Lake is located approximately 2.5 km southwest of the Town of Oxford, within the same belt of karst topography as the Oxford sinkhole (Fig. 1). In early May 2020, a member of the public reported that the water level of Slade Lake

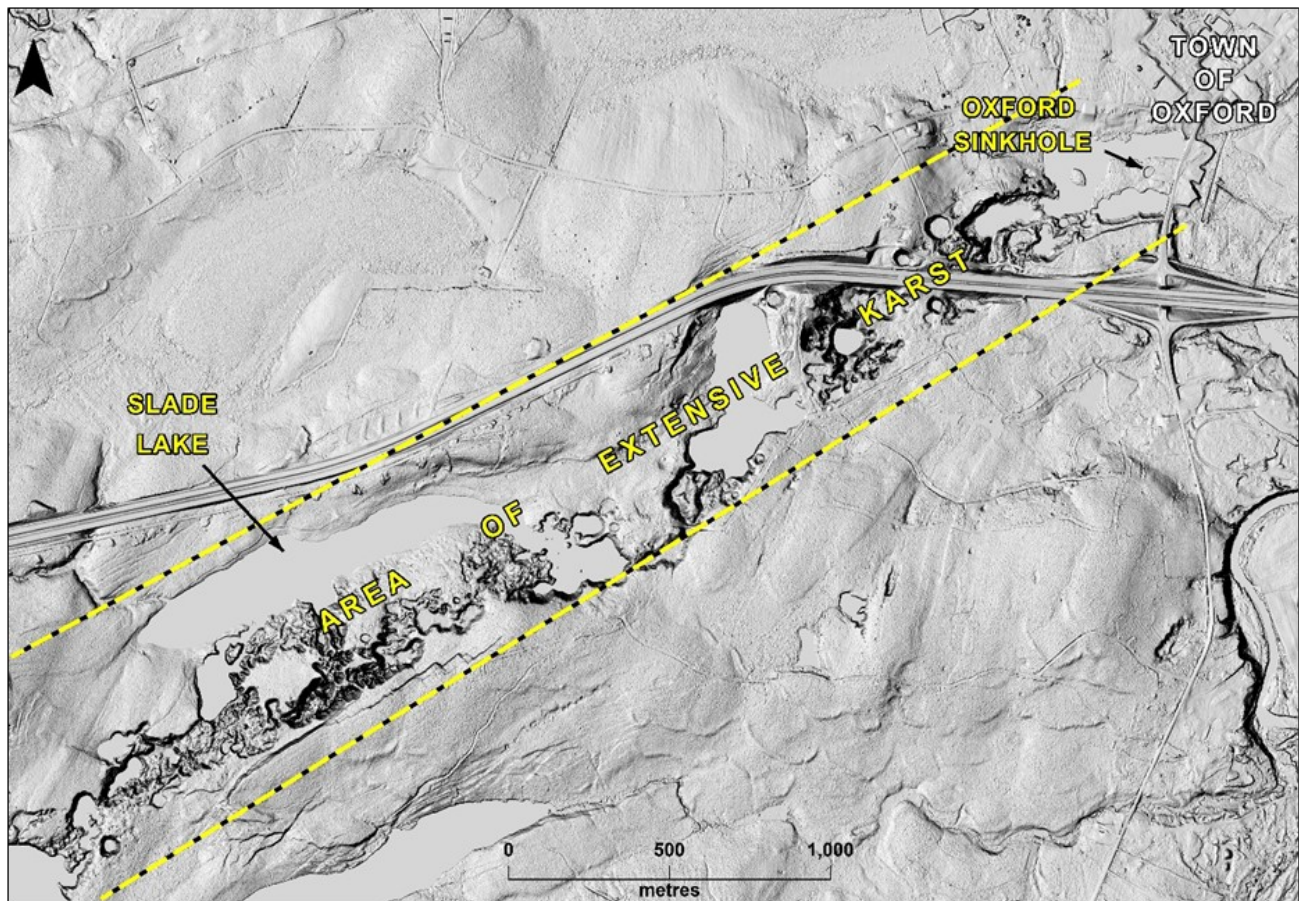


Figure 1. Lidar-derived hillshade showing location of Slade Lake within area of extensive karst, Cumberland County.

appeared to be considerably lower than usual. Subsequent site assessments by the Nova Scotia Geological Survey confirmed that the water level had decreased significantly since 2019. Water levels continued to decrease throughout the spring and summer of 2020, revealing a number of karst features in the recently exposed lakebed.

Geological Setting

The Slade Lake region is underlain by undivided rocks of the Windsor Group, including interstratified redbeds, evaporites, and carbonates (Ryan et al. 1990). Evaporite rocks such as gypsum, halite, and anhydrite have all been noted in the Oxford area in outcrop or inferred from the presence of saline springs in a number of localities (Boehner, 1986). Gypsum cliffs are visible in the southwest end of Slade Lake and several additional exposures were observed in the recently exposed lakebed (Fig. 2). The area of extensive karst that extends for several kilometers southwest from the Town of Oxford attests to the presence of the Windsor Group and the solubility of evaporite rocks in that area. Sinkholes and karst topography are abundant in the form of ponds, lakes, and circular depressions that are distinctive in lidar imagery (Fig. 1). As the water levels in Slade Lake receded, several vertical solution pipes and potential cave openings were noted (Fig. 2c). Reddish-brown gravelly sand till overlies the Windsor Group in the Oxford area, ranging as a veneer to several metres thick (Stea and Finck, 1988). The varying thickness of till deposits has potential to conceal additional areas of karst topography.

RPAS Survey

On May 27, 2020, the area of Slade Lake was surveyed using a DJI Phantom 4 RTK Remotely Piloted Aerial System (RPAS), more commonly known as a drone, and a survey-grade RTK Leica GPS. The RPAS survey was flown in a grid pattern to collect a series of images at 70 m above ground level, with an 80% frontal and 70% side overlap. The photos were processed within Pix4D mapping software to generate a high-resolution, 3 cm orthomosaic image of Slade Lake, along with a 10 cm Digital Surface Model (DSM) depicting the ground and vegetation elevations accurate to within 3 to 5 cm XYZ.

Volumetric Analysis

The RPAS survey data were used to produce 0.25 m topographic contours and a digital elevation model (DEM) of the exposed lakebed (Fig. 3). This surface model was compared to a provincial lidar-derived digital elevation model that correlated to a time when high water levels were observed in October 2019. A volumetric analysis was then completed using the site-specific DEM and 2019 water level. The resultant total draw-down was 783 280 m³ of water between October 10, 2019, and May 27, 2020. Water levels continued to decrease for the remainder of 2020, therefore the calculated volume reflects a minimum amount of water removed from the lake based on the May 2020 survey date.

Ground Penetrating Radar

A team from the Basin and Reservoir Lab, Department of Earth Sciences, Dalhousie University, undertook an exploratory survey of the exposed lakebed using ground penetrating radar (GPR) on July 9, 2020. Results of the GPR survey will be available in a forthcoming open file report and will not be discussed in further detail here.

Timing and Frequency

The water level of Slade Lake has been known to historically fluctuate and, accordingly, is locally referred to as “Dry Lake.” A review of historical aerial photography and satellite imagery demonstrates the fluctuating nature of the water levels. Table 1 summarizes a review of available imagery where water levels have been categorized into three classes: high (lake levels close to the tree line); moderate (some emerged beach and/or islands); or low (extensive beach and/or islands visible). Examples of high, moderate, and low lake water levels are shown in Figure 4.

Aerial photos of Slade Lake were collected in September 2019 showing high water levels (Fig. 4). The timing of the main draw-down event is therefore constrained to within an 8-month period between September 2019 and April 2020. Additional photographs of Slade Lake from early March 2020 show a broken ice shelf around the margin of the lake (Fig. 5). The subsidence of the



Figure 2. (A) Gypsum outcropping along the steep walls of the northeastern end of Slade Lake. (B) Deformed gypsum with selenite nodules exposed in the recently revealed lakebed. (C) Drone image looking down into recently exposed vertical solution pipe or cave opening in gypsum rocks. Photo: Mike Johnson.

ice surface suggests that the draw-down began after the lake surface froze, therefore further constraining the timing to within a four-month period from January to April 2020.

Discussion

Slade Lake is located within an area of karst terrain with a very high density of sinkholes. As the lake water level decreased, many additional karst features, such as sinkholes, solution pipes, and caves, were exposed. These karst features likely served as natural drainage conduits for the lake water. When water levels are very low, a 50 m wide sinkhole is clearly visible in aerial imagery as a circular feature near the center of the lake (Figs. 3B, 5A). It is likely that a shift or collapse in the underground prompted the draw-down event, and when these cavities are

sealed off by debris the lake water will begin to rise. Alternatively, the newly opened cavities and/or fractures and solution channels in the bedrock may have changed the storage and permeability of the underlying aquifer and, therefore, water levels will eventually stabilize when a new steady-state condition is reached.

Several factors can influence the rate of discharge and recharge of the lake water. There are no major water courses entering or leaving Slade Lake, therefore recharge of the lake water is most likely influenced by evaporation, overland flow, precipitation, and groundwater inflow/outflow. The historical annual precipitation rate calculated from 1981 to 2010 for the nearest Environment Canada weather station (Nappan) is 1154.8 mm/year. In 2019, there was an above average amount of precipitation (1559.79 mm) followed by a less than average amount of precipitation in 2020 (800.4 mm). It is interesting to note, however, that water levels in the surrounding lakes (Salt, Vickery, and Black lakes) within the karst belt were unaffected by the less than average amount of precipitation.

Future Plans

Continued monitoring and mapping of the karst belt in the region will be used to examine the frequency of change, physical characteristics, and associated risk of karst activity to the surrounding

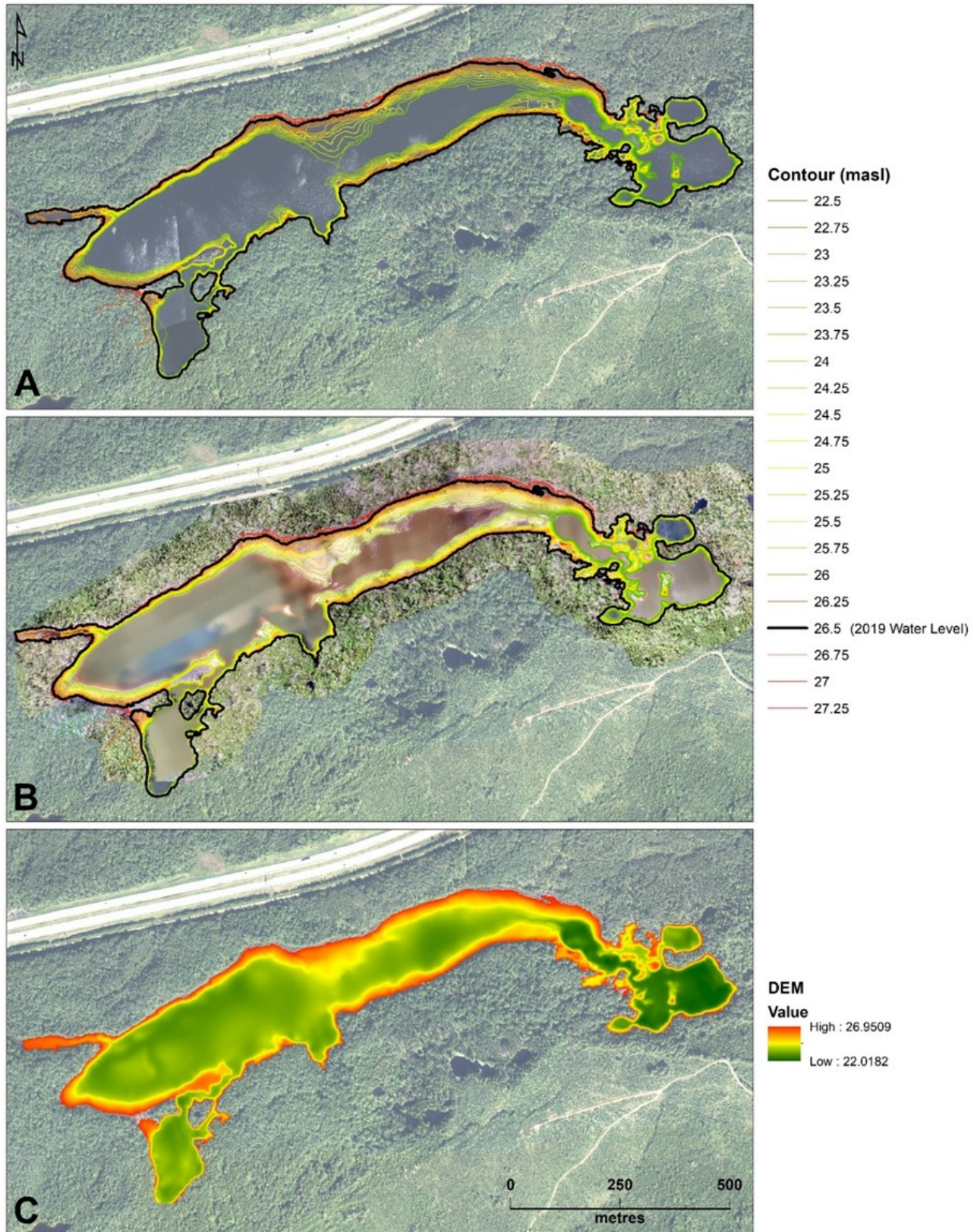


Figure 3. (A) Satellite imagery (2013) showing high lake water levels with superimposed 0.25 metre topographic contours of dry lakebed. (B) May 2020 RPAS image of dry lakebed and topographic contours. (C) DEM derived from 0.25 m contours.

Table 1. Summary of lake water levels in available satellite and aerial imagery.

Image Year	Image Type	Water Level
1939	Air Photo	Low
1954	Air Photo	Moderate
1964	Air Photo	Low
1972	Air Photo	High
1975	Air Photo	High
1984	Satellite	High
1985	Air Photo	Moderate
1986	Satellite	Moderate
1987	Satellite	Low
1988	Satellite	Moderate
1989	Satellite	Low
1990	Satellite	Low
1992	Satellite	Moderate
1993	Satellite	Low
1994	Satellite	Low
1995	Air Photo	Low
1995	Satellite	Low
1996	Satellite	Low
1998	Satellite	Low
1999	Satellite	Moderate
2000	Satellite	High
2002	Satellite	Moderate
2003	Satellite	Moderate
2005	Air Photo	Moderate
2005	Satellite	Moderate
2006	Satellite	Moderate
2007	Air Photo	Low
2007	Satellite	Low
2008	Satellite	Low
2009	Satellite	Moderate
2011	Satellite	High
2012	Satellite	High
2013	Satellite	High
2013	Air Photo	High
2014	Air Photo	High
2014	Satellite	High
2015	Satellite	High
2016	Satellite	High
2017	Satellite	High
2018	Satellite	High
2019	Satellite	High
2019	Satellite	High
2020	Satellite	Low

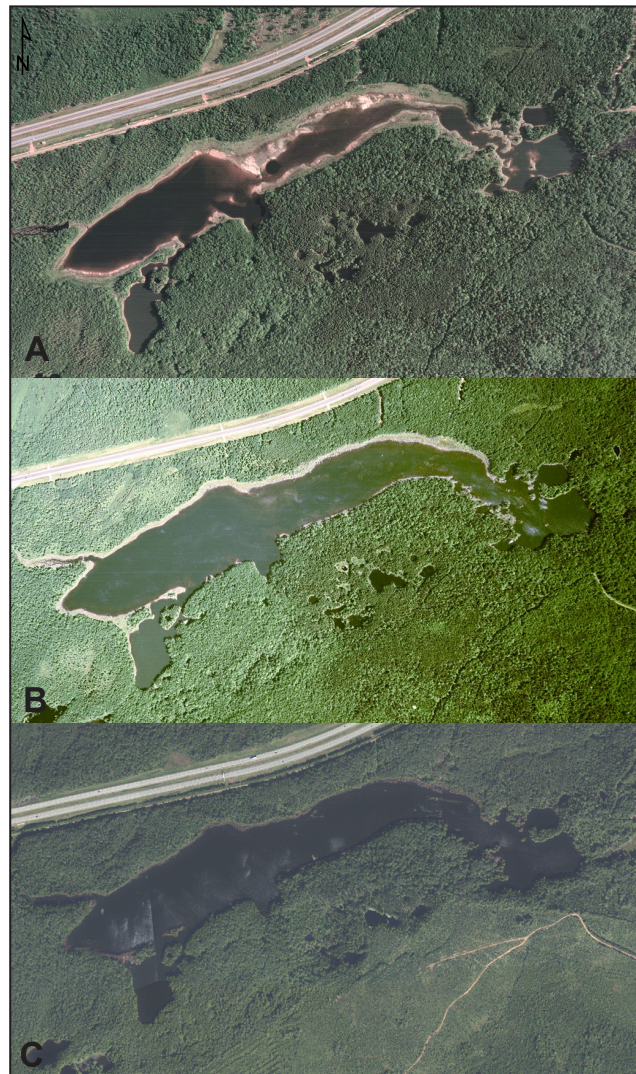


Figure 4. Examples of (A) low (1995); (B) moderate (1985); and (C) high lake water levels (2013).

area. A more thorough review of climatic conditions and groundwater regime is recommended.

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Figure 5. Northeastern end of Slade Lake, September 2019 (left) and September 2020 (right).



Figure 6. Ice shelf in Slade Lake in early March, 2020. Photo: Dana Rector.

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