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Investigating the potential and mechanism of soil piping causing water-level drops in Mountain Lake, Giles County, Virginia

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ABSTRACT

Mountain Lake, located in Giles County, southwestern Virginia, is one of only two natural lakes in the state of Virginia. The lake exhibits rare self-draining behavior, with recent episodes in 2008, 2011, and 2012 that drained the lake almost completely and revealed the presence of four sinkhole-like depressions, with piping holes at their bottoms and sides, near the northeastern and northwestern margins of the lake. This phenomenon has raised concern over declining tourism to the Mountain Lake Lodge. The purpose of this study was to investigate the piping potential of lake-bottom sediment and its role in seepage and lake-level fluctuations.

Sixteen grab samples of lake-bottom sediment were collected from the vicinity of the depressions. Additionally, five Shelby tube samples were obtained to determine the in-situ density of the sediment. Grain size distribution, Atterberg limits, and compaction-mold permeameter tests were used to evaluate lake sediment's susceptibility to piping. Grain size distribution and Atterberg limits test results reveal that the lake-bottom sediment consists predominantly of fine sand and silt, which are well known for their susceptibility to piping. Results of the compaction-mold permeameter test show that the critical hydraulic gradient (i_c), the hydraulic gradient at which the sediment starts to pipe, ranges between 1 and 10, depending on the density, grain size distribution, and plasticity characteristics of the sediment. These results suggest that piping of lake sediment is the primary mechanism responsible for the formation of lake-bed depressions and lake level fluctuations.

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1. Introduction

Mountain Lake (Fig. 1) is located near the summit of Salt Pond Mountain, Giles County, Virginia (Fig. 2), at an approximate elevation of 1180 m AMSL, within the crest and northwestern limb of a gently-plunging breached anticline (Fig. 3). The anticline is associated with the Narrows thrust fault and the larger Valley and Ridge physiographic province of the United States. The axial plane of the anticline trends N60°E (Mills, 1989) and its axis plunges towards the northeast at 7.5° (Parker et al., 1975). Three major geologic units underlie the lake: the Silurian Tuscarora Sandstone (Stu) at the northern end, the Ordovician Juniata Sandstone (Oj) in the middle portion, and the Ordovician Reedsville-Trenton Formation (Ort) at the southern end, in a top to bottom sequence (Fig. 3).

Mountain Lake is an elongated, club-shaped body of water (Figs. 1 and 3), oriented from southeast to northwest, where it outlets into Pond Drain, a major stream in the area. When full, the lake has a total surface area of about 0.21 km^2 and a maximum water depth of 33 m at the northern end, which shallows towards the south (Williams, 1930; Cawley et al., 2001b; Roningen, 2011). Mountain Lake occupies a small watershed (1.3 km^2) within the Ohio Hydrologic Unit and is fed by precipitation, surface runoff, and a line of lake-bottom springs found at the contact between the Reedsville-Trenton Formation and the Juniata Formation (Cawley et al., 2001b). The headwaters of three major streams lie close to the lake: Sartain Branch to the east, Doe Creek to the southwest, and Pond Drain to the northwest. Aside from water loss through evapotranspiration and surface runoff through Pond Drain (only when the lake is full), water seeps out of the lake basin through subterranean pathways at the northern end of the lake (Marland, 1967; Parker et al., 1975; Cawley, 1999; Cawley et al., 2001b; Jansons et al., 2004; Roningen, 2011; Joyce, 2012). Water budget studies have estimated a net groundwater outflow of about 44–49 l/s (Jansons et al., 2004; Roningen, 2011), channeled through piping holes within the four lake-bottom depressions (Figs. 4 and 5). It should be noted that the term "piping", in this study, is used to refer to migration (erosion) of fine-grained lake-bottom sediment through the vertical holes in the centers of the sink-hole like depressions and through the coarser colluvial material near the northern end of the lake (the landslide dam), as the water seeps out of it.

The phenomenon of lake level fluctuations is not all that unusual for Mountain Lake but notably sharp drops in recent years have stirred concern over declining tourism to Mountain Lake Lodge. In 2008, 2011, and 2012 the lake was left nearly empty, revealing the presence of four distinctly large depressions, near the northeastern and

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Fig. 1. A 2005 image of Mountain Lake when it was full. Google Earth (2013).

northwestern margins of the lake (Figs. 5 and 6), containing piping holes at their bottoms and sides. In addition to these significant recent water-level drops, early accounts of lower lake levels can be traced to 1751 when Christopher Gist described "a lake or pond about ¾ of a Mile Long NE & SW & ¼ of a mile wide" (Gist, 1751). Based on 24 historical records, Parker (2003) provided a list of approximate percentages of a full Mountain Lake from 1751 to 2003. The periods when the lake was 60% or less full are as follows: 1768–1804, 1820, and 1865–1869, 1898–1904, and the spring of 1959 (Parker, 2003). Studies on radiocarbon dating of sediment cores and tree trunks (Marland, 1967; Parker et al., 1975; and Cawley et al., 2001a) have identified additional prolonged historical lows, the oldest being 4100 YBP (Cawley et al., 2001a).

Because lakes are so rare in the non-glaciated portion of the Appalachian Mountains, the origin of Mountain Lake has been of interest, but has remained enigmatic: suggestions include i) subjacent karst collapse and ii) damming of the valley of Pond Drain by a landslide, in either case possibly aided by a northwest–southeast trending fracture feature. The geological and hydrological controls responsible for lake-level fluctuations have often been debated among geologists as part of the controversy over the lake's origin. By far the most popular explanation has been that seepage at the northern end of the lake occurs through the mass of colluvial deposits from the Tuscarora Sandstone, which forms the presumed natural landslide dam (Sharp, 1933; Marland, 1967; Parker et al., 1975). Cawley et al. (2001b) suggested that the seepage occurs along a SE–NW lineation feature, identified by Cawley (1999), which was interpreted as a "fracture feature and probable fault". These authors support this hypothesis by explaining that a steep walled crevice-like feature at the northeastern margin of the lake and the two deeper depressions align parallel to the lineation feature. However, they also stated the possibility of additional seepage through the dam material. More recent seismic refraction studies (unpublished), performed by Watts and others from Radford University, Virginia,

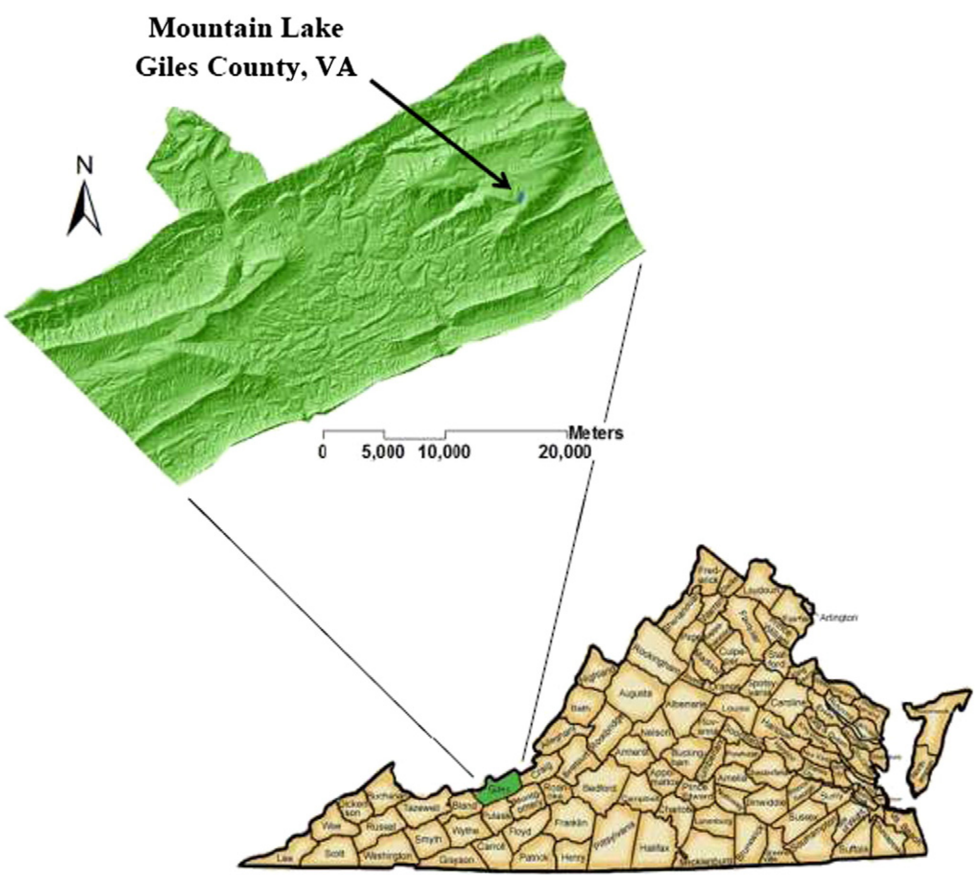

Fig. 2. Location of the study area.
From Joyce (2012): Map sources: USGS 1/3 arc sec DEM and www.gilescounty.net.