

Subterranean Loss and Gain of Water in Mountain Lake, Virginia: A Hydrologic Model

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ABSTRACT

Mountain Lake, Virginia is a small, unique, oligotrophic, subalpine ecosystem in the southern Appalachians. Previous studies have disclosed that this lake has manifested periodic prolonged low water levels during the several thousand years of its existence. The most recent low water level occurred during the drought years of 1999-2002. Measurements of lake level, precipitation, and other meteorological data including calculated evapotranspiration in the lake basin from 2/19/02 to 8/31/03 have enabled estimation of net subterranean water losses presumably through cracks between Clinch sandstone boulders and/or the recently discovered deep hole at the northwest end of Mountain Lake. These net losses reflect the balance between total losses and any gains from springs and boulder cracks not quantified in this study. Scuba divers have documented the existence of these cracks and the deep hole. Subterranean net water losses of about $0.04\text{-}0.05\text{ m}^3/\text{s}$ (634-792 gpm) apparently occur year-round.

INTRODUCTION

Mountain Lake, Giles County, Virginia ($37^{\circ}27'56''\text{N}$, $80^{\circ}31'39''\text{W}$) is the only natural lake in the unglaciated highlands of the southern Appalachians. This oligotrophic montane lake located at 1181 m (3875 ft) elevation occupies a watershed only 7.4 times the surface area of the full lake ($188,000\text{ m}^2$). In a review of the literature, Parker (2003) showed that this lake has manifested numerous fluctuations in water level from 100-20% full since its discovery and first description by Gist in 1751 (Johnston, 1898). Past intervals of lower lake levels also have been inferred by the occurrence of numerous in place stumps of trees that colonized and grew in the temporary meadow surrounding the less than full lake—e.g., a white pine (*Pinus strobus*) (ca. 1885-1904) and a southern yellow pine (*Pinus* sp., possibly *P. pungens*) (ca. 1645-65) at 7m and 10m below full pond respectively (Parker, 2003). Marland (1967) and Cawley et al.

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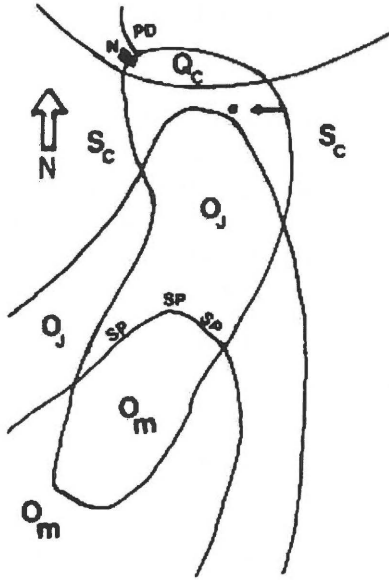


FIGURE 1. Sketch of Mountain Lake showing locations of Ordovician Martinsburg Shale [Om], Ordovician Juniata Sandstone [Oj], Silurian Clinch Sandstone [Sc], Quaternary Colluvium [Qc] which forms the natural dam, Springs [SP], Pond Drain [PD], Newport House [N], and the deep crevice and hole [←].

(2001b) used biological indicators from sediment cores showing that prolonged reductions of Mountain Lake water levels also occurred before 1751 going back several thousand years. These prolonged low water intervals in the lake have been attributed to large volumes of water lost through cracks in the incompletely sealed natural dam of Clinch sandstone colluvium at the northwestern end of the lake (Figure 1)(Parker et al., 1975; Parker, 2003). Mountain Lake's origin by formation of a natural dam across a mountain stream has been addressed by numerous investigators (Hutchinson and Pickford, 1932; Sharp, 1933; Eckroade, 1962; Marland, 1967; Parker et al., 1975; and Parker, 2003). Cawley et al. (2001a) further proposed that in addition to cracks between colluvial boulders at shallower water depths, sediment escape or entry may occur through a southeast-to-northwest fracture trace or fault located by sonar at the lake's maximum depth (Figure 1). This crevice-like feature has not been observed to fill with sediment since its first discovery by Williams (1930). Parker (2003) elaborated upon this aspect of the lake's hydrology, suggesting that the subterranean water loss should occur during drought and cause a lowering of the water table, whereas net gain should occur during wet (non-drought) conditions and cause a rising of the water table.

A prolonged drought during 1999-2002 accompanied the total cessation of surface outflow in Pond Drain (Figure 1) and a gradual drop in lake level, providing an opportunity to collect more information on Mountain Lake's hydrology. The purpose of this study was to measure lake water level in conjunction with precipitation and estimates of evapotranspiration, enabling a more complete hydrologic model for the

lake. We also conducted several SCUBA reconnaissances at the north end of the lake to obtain more information on possible holes between Clinch sandstone boulders and to examine the deep crevice feature.

METHODS

Documented monitoring of the lake level began in February 2002 with resort employee water line observations on the large (4m) Clinch boulders at the north end. Survey leveling undertaken by Jansons in May 2002 established local benchmarks and tied previous data. During June-August 2002 employees working at the floating boat dock recorded many daily readings at a partially submerged level rod. Beginning in September 2002 and continuing through August 2003 when the lake level reached the 0.46 m notch below the top of the dam (1180.64 m, 3873.5 ft), periodic lake level readings were recorded by Jansons and Parker near the Newport House by combination string-level and rod method.

A digital model of the lake bottom was developed using the Autodesk AutoCAD 2002 software package and the sonar-generated morphometric map of the lake in Cawley et al.(2002), from which lake volumes for each level reading were derived. Daily precipitation data was obtained for the period January 2002 through August 2003 from the National Weather Service Automated Flood Warning System (AFWS) rain gauge at Mountain Lake Biological Station (MLBS). Additional weather data was obtained from the MLBS web site and used to predict evaporation and transpiration (ET). Mean monthly temperature, wind speed, relative humidity, and photosynthetically available radiation (PAR) for the study period was utilized with the Penman-Mon-teith method for calculating ET

(<http://www.ierm.ed.ac.uk/cw2h/lec8/pm10.htm>, $W/m^2 = 0.22 \times \mu\text{mol/s/m}^2$).

The hydrologic model used was: $L = (P_b \times A_b) - \Delta V_L - ET$

= where L =average net subterranean water loss for the period

= P_b =precipitation for the period

= A_b =basin area =1,398,748 m^2 (346 acres)

= ΔV_L =lake volume change for the period

= ET =calculated basin evapotranspiration for the period

RESULTS AND DISCUSSION

Figure 2 summarizes the precipitation and lake level data from February 2002 to September 2003. The lake reached its lowest level of about 6.6 m below full in November 2002, at which time the drought began to subside with the onset of increased precipitation. From November 2002 to September 2003, Mountain Lake levels continuously rose to reach a nearly full capacity. Table 1 shows the monthly hydrologic model output for the period February 2002 to August 2003, during which no surface outflow occurred in Pond Drain. Time lag introduces a wide variability in outflow when the model is configured monthly (0.003-0.106 m^3/s). Over the 18-month study period the model indicates an average subterranean net water loss of 0.043 m^3/s (676 gpm).

While data from the model shows that water continuously leaves Mountain Lake via subterranean channels, equal or greater amounts of water must be entering during times when lake levels are steady or rising. Much of this entering water not indicated

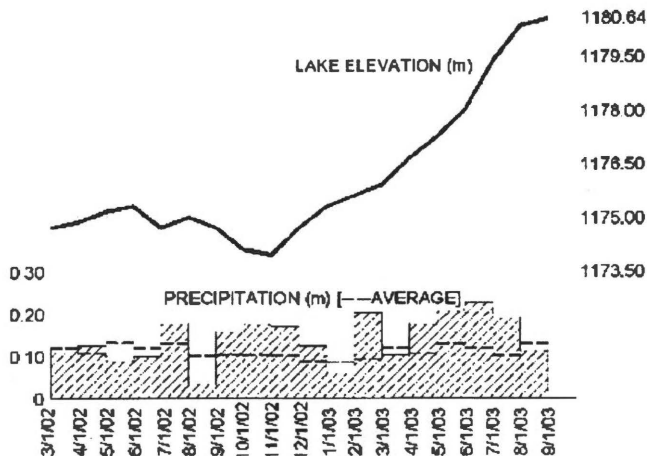


FIGURE 2. Mountain Lake precipitation and lake water level from February 2002 to September 2003.

TABLE 1. Mountain Lake hydrologic model data

MONTH	Calculated Net		Volume Change $\Delta V_L(m^3)$	Basin ET(m^3)
	Subterranean Outflow $L(m^3)$	Basin Precipitation $P_b(m^3)$		
MAR 02	141,864	163,074	-20,000	41,210
APR 02	68,031	170,535	40,000	62,504
MAY 02	9,372	121,862	50,000	62,490
JUN 02	149,456	135,718	-60,000	46,262
JUL 02	243,948	240,881	-20,000	16,934
AUG 02	31,122	46,897	-10,000	25,775
SEP 02	259,456	217,433	-50,000	7,976
OCT 02	283,013	243,013	-40,000	0
NOV 02	179,131	234,131	55,000	0
DEC 02	94,114	169,114	75,000	0
JAN 03	8,756	81,004	70,000	2,248
FEB 03	237,120	277,120	40,000	0
MAR 03	24,580	142,113	100,000	17,533
APR 03	84,266	243,013	80,000	78,747
MAY 03	70,789	282,449	170,000	41,660
JUN 03	84,995	313,003	170,000	58,009
JUL 03	46,802	265,396	160,000	58,594
AUG 03	6,919	154,192	120,000	27,274
TOTAL	2,023,735	3,500,949	930,000	547,215

PERIOD NET OUTFLOW = $3,686 \text{ m}^3/\text{d}$
 = $0.043 \text{ m}^3/\text{s}$
 = 676 gpm

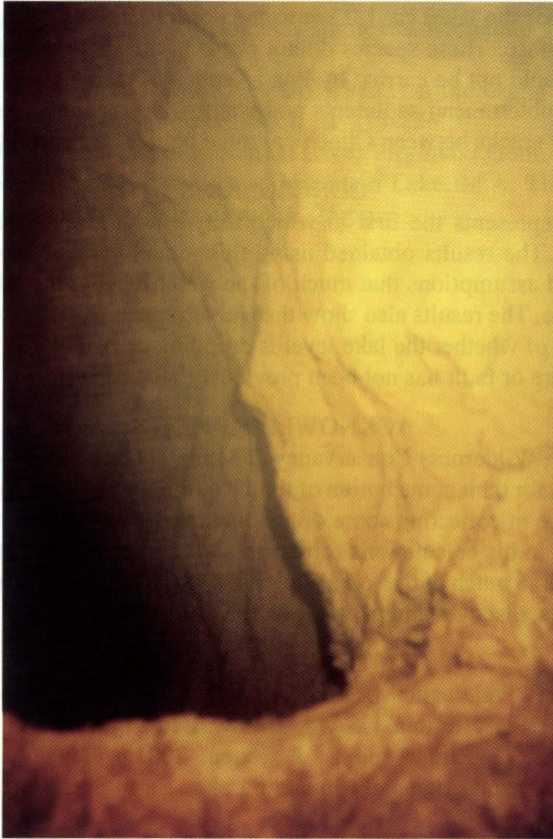


FIGURE 3. Hole (0.76m high, 0.46m wide) located at 32m depth at the northwestern end of the deep crevice in Mountain Lake (Photograph by J.E. Waller)

in the model probably comes from springs. Gist in 1751 (Johnston, 1898) reported five springs at the south end of the not full lake, and Cawley et al (1999) used SCUBA divers to locate these springs in the full lake at the Martinsburg shale-Juniata sandstone interface (Figure 1). Also, during a SCUBA reconnaissance of the north end of the lake, turbidity was noted at ca. 22 m below full pond moving from southeast to northwest approximately in line with the I-4 subterranean input stream that never dried up during the summer droughts of 1997 and 1998 (Cawley et al., 1999, 2001a).

SCUBA reconnaissance at the north end of the lake visually confirmed the probable existence of numerous potential cracks between Clinch sandstone boulders through which water might escape or enter. A dive into the deep crevice or fault, located earlier by Cawley et al. (2001a) using sonar, revealed both the sediment-free nature of this crevice and at the deepest (32 m or 108 ft) point to the northwest end a 0.76 m (2.5 ft) high and 0.46 m (1.5 ft) wide hole (Figure 1,3). During that brief visit, no detectable currents or movement of suspended sediments toward or away from the hole were noted. However, Cawley (pers. comm.,2003) documented the occurrence of abundant

deep-water Mountain Lake diatom species in sediments from Pond Drain (the only outflow stream for the lake) ca. 1.0 km to the northwest at 40-45 m lower elevation than the lake surface. These species do not occur in the shallower depths of the lake and therefore would not be carried by Pond Drain surface outflow. This observation suggested that subterranean sediments and water were reaching Pond Drain via the deep hole and/or cracks between Clinch colluvial boulders (Parker 2003).

CONCLUSIONS

This paper represents the first in which a hydrologic model has been used for Mountain Lake. The results obtained using this model support previous qualitative observations and assumptions that much of the water leaving the lake does so below the lake's surface. The results also show that subterranean water losses occur continuously regardless of whether the lake level is dropping or rising. The deep hole within the crevice feature or fault has not been previously viewed.

ACKNOWLEDGMENTS

We thank the Wilderness Conservancy at Mountain Lake and the Mountain Lake Hotel and Resort for their contribution of funds to support publication of the color plate and for assistance in collecting some of the data. Jansons collected or obtained much of the data used in his calculations for the model; Parker helped interpret the model output and prepared much of the text; Waller used SCUBA to confirm probable cracks between boulders, discover and photograph the deep hole.

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