White Lake Hydrology and Water Budget

White Lake has often been referred to as a spring-fed lake, as its clear waters have provided a view of lake bottom features, including areas along the sandy eastern shoreline which have suggested groundwater input. Some of these features have been consistent in shape and size over time, while others have varied from year to year.

Frey examined similar areas in 1947, and found the centers to be about 8" lower than the edges, but the bottoms were hard sand and there was no detectible chemical evidence of any volume of water entering the lake through these depressions, although he noted that "at a time of higher lake level and more favorable ground water conditions there might be visible evidence of inflowing water" (Frey 1949).

While there is no historical data on groundwater flow rates into White Lake, a number of other reports associate inflow (whether or not it is occurring) with the height of the water table, which varies according to rainfall (e.g. NC DNRCD, 1982; NC DPR, 1996), and this has been noted for the other Bay Lakes as well (e.g., Jones Lake State Park Visitor's Center exhibits). Groundwater monitoring wells near the lake had been established by NC DNRCD in the past, but funding for sustained long-term monitoring has been lacking.

Groundwater observation wells installed in March 1981 "provided evidence of a semi-confined groundwater aquifer which is probably the source for the springs that have been reported near the northeastern shore in the lake"; this report goes on to state: "the exact relationship between rainfall, groundwater levels, and the lake level should become more clear as hydrological monitoring at White Lake continues (NC DNRCD, 1982). According to the definition provided by the US Geological Survey, "a water table, or unconfined aquifer is an aquifer whose upper water surface (water table) is at atmospheric pressure, and thus is able to rise and fall. Water-table aquifers are usually closer to the Earth's surface than confined aquifers are, and as such are impacted by drought conditions sooner than confined aquifers" (https://www.usgs.gov).

The relationship between water table (groundwater) levels and rainfall was documented in 2018-9 by Dr. Chris Shank and Dr. Peter Zamora as part of a groundwater study of White Lake. After the heavy rainfall from Hurricane Florence in September 2018 groundwater levels responded quickly, as did the lake level (Shank and Zamora, 2019). A relatively thin layer of clay, often referred to as hardpan lies below the land surface in places, at depths ranging from 5-20 feet (Campbell and Coes 2010). A groundwater well situated below this clay layer on the eastern side of the lake (E3D; Fig. 8) showed an increase which mirrored the rise in a shallower well situated above the clay layer at this location (E3; Fig. 10).

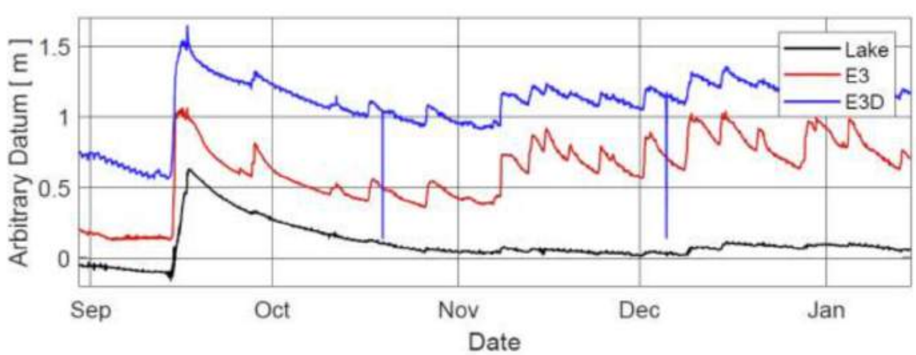

Figure 10. Groundwater levels at eastern shore well sites from August 2018 to January 2019; blue indicates levels in a deeper well (below clay hardpan) while red is groundwater levels in a well situated above the clay layer. The black line is the lake level. Data from Shank and Zamora (2019).

This indicates that the hardpan is not a true confining unit, and both the "shallower" and "deeper" aquifers are part of the surficial aquifer in this area. This is illustrated in the US Geological Survey hydrogeological map shown below, where clay layers are black bands, and sand layers are in yellow in the wells in Fig. 11, which is a close-up of Plate 5, Section G-G' in Campbell and Coes (2010); note the very shallow black bands at the top of the two wells near White Lake (31 and 32):

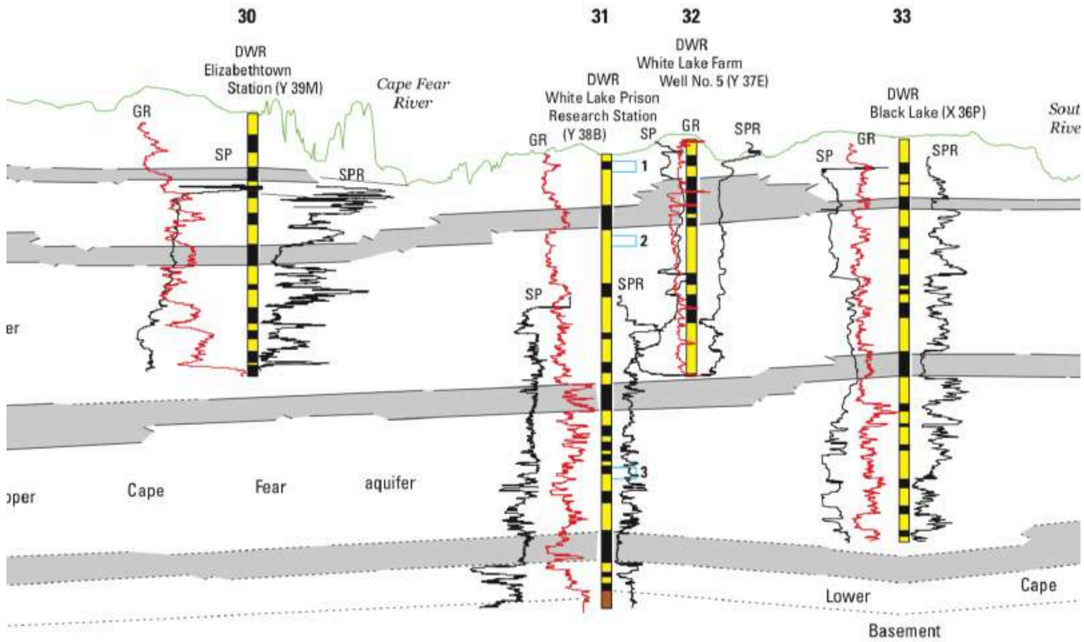

Figure 11. Close-up of a hydrogeological map of the area around White Lake, taken from Plate 5, Section G-G' in Campbell and Coes (2010). A pdf of this map is included in Appendix 1.

Heath (1980) estimated that the annual recharge to thick, sandy soils in the surficial aquifer could be as much as twenty inches of equivalent rainfall (these are the soils that are predominant along the eastern side of the lakeshore). As described in Winner and Cobble (1996), infiltration from rainfall provides the bulk of the recharge to the Coastal Plain aquifer system, which "transmits water laterally to streams and serves as a source bed holding the water that moves downgradient to deeper aquifers". In essence, the surficial aquifer functions as a short-term water storage "bank", as does the lake itself.

The water table is generally closer to the surface on the western side of the lake, as a result of topographical differences and soil types, although there have likely been some hydrological changes over time due to development and associated clearing and filling activities (e.g., Fig. 7).

The change in water depths in shallow wells on the western shore also relate to rainfall, but the increases are moderate by comparison to the eastern shore (Fig. 12, from Shank and Zamora, 2019; W1 is the closest to the lake and most closely mirrors lake level).

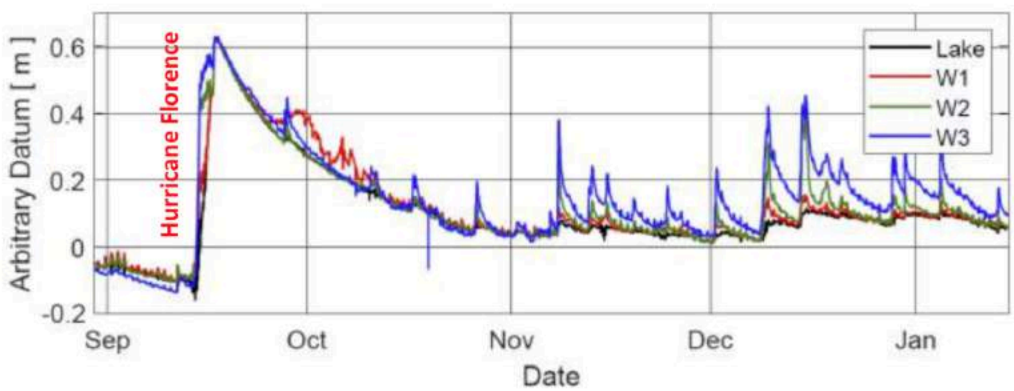

Figure 12. Groundwater levels at western shore well sites from August 2018 to January 2019; red (W1) is the shallow well closest to the lake and blue (W3) is a shallow well furthest from the lakeshore, while green (W2) is a shallow well midway between W1 and W3 (each of these wells were situated above the clay layer). The black line is the lake level. Data from Shank and Zamora (2019).

Monthly rainfall levels in 2018 that correspond to the time period September-December were 29.45", 2.25", 4.25", 7.5" (Table 2).

Table 2. Monthly rainfall at the White Lake Wastewater Treatment Plant (off Lakeshore Drive) in 2018 and 2019. The long-term average for the region is taken from data collected at Elizabethtown, which is posted at https://www.usclimatedata.com/climate/elizabethtown/north-carolina/united-states/usnc0205

Monthly Rainfall (inches) for White Lake 2018-2019

Month	2019 Monthly	2019 Total-Year to Date	2018 Monthly	2018 Total-Year to Date	Long-Term Average for Region
January	2.75	2.75	4.20	4.20	3.81
February	2.25	5.00	2.00	6.20	3.44
March	3.25	8.25	3.95	10.15	3.91
April	7.25	15.50	6.75	16.90	3.12
May	1.20	16.70	7.70	24.60	3.67
June	5.25	21.95	10.00	34.60	4.70
July	6.00	27.95	4.75	39.35	5.75
August	5.35	33.3	6.25	45.60	5.95
September	5.00	38.3	29.45	75.05	5.29
October	3.60	41.9	2.25	77.30	3.38
November	4.90	46.8	4.25	81.55	3.16
December	6.00	52.80	7.5	89.05	3.14
Total	52.80		89.05		49.32

The groundwater modeling and isotope studies conducted by Shank and Zamora concluded that the majority of source water to White Lake is rainfall onto the lake surface (over 90% of the total), and that groundwater flow rates vary based on precipitation, which impacts groundwater levels (water table), but are relatively low. Results based on their modeling work (which takes into account all of the conditions specific to the lake and its surroundings) indicate that a maximum of 6% of the total lake volume could come from groundwater. As there is no historical data on groundwater flow, it is not possible to determine whether it was higher in the past than it is now. Surficial aquifer levels and flows would be expected to be similar to what has been documented in larger-scale Coastal Plain groundwater studies (J. Perry, Lumber River Council of Governments, personal communication).

Results from sampling an isotope of the element strontium in the lake and in the groundwater found no evidence of deep, confined aquifer contributions to the lake (what they referred to as "old" groundwater, as the deep confined aquifer water has been in the ground for centuries and has a different isotopic signature compared to "new" groundwater, in which the isotopic signature is very similar to rainwater), so the conclusion is that groundwater flows into the lake consists of surficial aquifer water (Shank and Zamora 2019; J. Perry, LRCOG, personal communication).

A shoreline observation of groundwater movement made in 1952 led two NCSU researchers to the following conclusion: "White Lake is thus to be regarded as a huge artesian spring. The clarity of its water could not possibly be maintained on the basis of the slow movement of the ground water into the lake as Frey suggests" (Wells and Boyce, 1953). These researchers were not hydrologists, but botanists, and the main body of their paper focused on taking exception to David Frey's ideas about the origin of the Bay Lakes and their age. And yet their paper introduced the idea that artesian spring flow into White Lake existed (although it has never been measured) and that this was somehow wholly separate from surficial groundwater flow. Shank and Zamora's work confirms the close connection between the lake and groundwater, as is the case with other Bay Lakes, and the source of the lake's clarity: crystal-clear rainwater. And the rainfall, as it turns out, was once quite acidic (see the next section, Changes in the Chemistry of Rainwater).

Surface water inflow to the lake after rainfall events has been noticeable as it is tea-colored water from wetland areas around the lakeshore (noted also in Frey 1949). Much of the present-day runoff (which has a pH of 3.9-4.5) occurs on the eastern side of the lake and has been directed to the lake via two drainage ditches with culverts under White Lake Drive that drain approximately 50 acres on the east side of the road (Fig. 13).

Figure 13. Left photo shows the NC DOT drainage ditch at 580 White Lake Drive after a rainfall event; right photo taken at the lakeshore at the same location, on the same date (June 27, 2018). Total rainfall for the month of June 2018 was 10 inches (Table 2).

Surface water outflow from the lake at Turtle Cove is variable, and is highest when lake levels are highest, but it is a very small outlet relative to the volume of water in the lake. For example, a flow rate of 250 gallons/minute (360,000 gallons/day) was measured in February and March 2017 (NCDEQ 2018), which is equivalent to a discharge of 0.0163 % of the lake volume per day, but flow from the lake ceased in June of that year. This pattern has also been seen in 2018 and 2019 (even after Hurricane Florence added substantial amounts of water to the lake in September 2018). The outlet was relocated and reconfigured from its original location during the development of the Turtle Cove neighborhood (Fig. 14).

Figure 14. Turtle Cove outlet on February 8, 2020 when lake elevation was 64.8 feet above sea level (NAVD 88). During periods of low lake levels there is no flow out of the lake.

Outflow from the lake into the groundwater, particularly on the western side of the lake, was considered to be much more substantial than surface water outflow, although it is difficult to quantify (Shank and Zamora 2019).

Evaporation rates vary somewhat from year to year but are typically highest in the months of June through August (estimated annual evaporation is equivalent to 42 % of the total lake volume, on average; quoted in Shank and Zamora 2019).

A Relative Water Budget for White Lake

Rainfall influences the volume of flow of both surface runoff and groundwater inflow, and all of these are generally highest in the winter months. As surface runoff and groundwater inflow are relatively diffuse and variable over time, they are difficult to measure accurately, but in relative terms:

The Importance of Inputs

Rainfall on lake surface

(surface runoff + groundwater)

The Importance of Outputs/Loss

Evaporation

groundwater

Turtle Cove outlet