White Lake Management Plan Attachment C:

This background information on geology, hydrology, the watershed and water budget includes information that has been presented at public workshops held at White Lake Town Hall in 2019.

White Lake: One of the Bay Lakes

Carolina Bays are distinctive landforms—shallow, elliptical depressions in the landscape outlined by a sand ridge, with a characteristic northwest-southeast orientation. They are particularly abundant in the sandy Coastal Plain soils of North and South Carolina, and most Carolina Bays are temporary ponds or wetlands where the namesake bay trees (loblolly bay, red bay and sweet bay) are found. Bladen County contains a number of Bay Lakes, including Jones, Salters, Singletary, White and Bay Tree (originally called Black Lake).

In describing the geological features of the area around Elizabethtown, Weems et al. (2011) noted that the Carolina Bays are associated with "windblown sand deposits on which are grown abundant crops of blueberries". The deposits around White Lake are associated with the late Pleistocene (Pinehurst Formation, age mostly 80 to 10 ka; Markewitch and Markewich 1994) with deposits from the middle Pleistocene nearby (Chuckatuck Formation, age about 450 to 400 ka; Weems and Lemon 1993). With respect to the formation of the Bays, Weems et al. (2011) describe the process from a geological perspective: "Where sand sheets are widespread, the winds that formed them also created many of the most obvious landforms—the Carolina bays. Where bays sit directly on older terrace surfaces that have thick, clay-rich weathering profiles, the underlying clayey soils block downward water percolation and thus allow the bays to become swamps or natural lakes." Figure 1 shows a clay layer in White Lake bottom sediments and Figure 2 shows a close-up of a surficial geological map of the region.

Figure 1. Clay layer found at around 15 cm depth in a sediment core taken at White Lake, February 12, 2019.

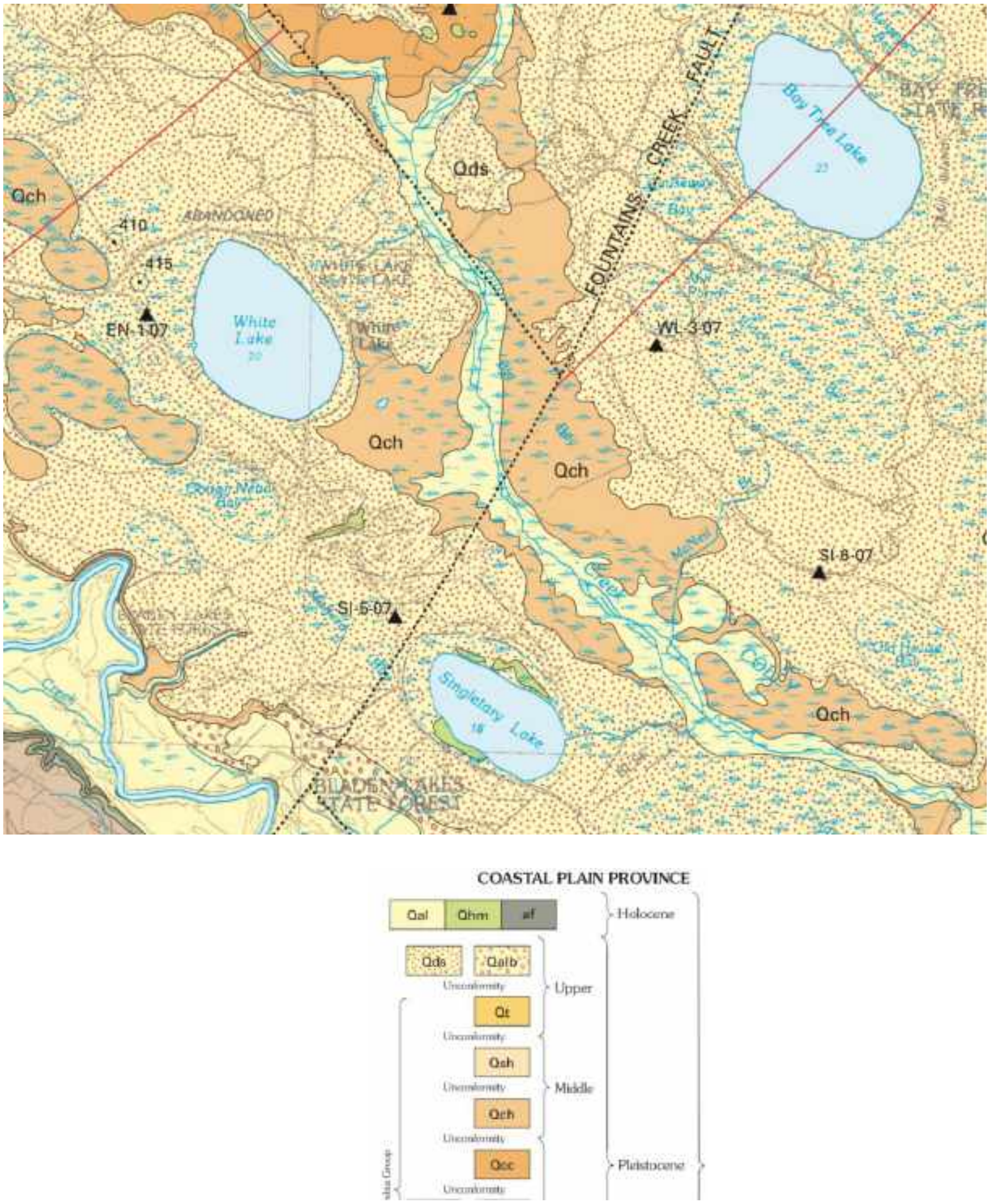


Figure 2. Close-up of a section of the surficial geologic map of the Elizabethtown 30’ x 60’ quadrangle, North Carolina. Pinehurst Formation (Qds) surrounds White Lake, with Chuckatuck Formation (Qch) also in the area. Weems and Lewis (2011), US Geological Survey Report 2011-1121.

While there have been a number of theories developed as to the origin of Carolina Bays (e.g., Savage, 1982), it is generally accepted that oriented lakes can be formed as a consequence of prevailing winds that act to generate currents in water-filled depressions; these currents can sculpt the sandy basins into the characteristic oriented, elliptical bay shapes (Kaczorowski, 1977, Beyer, 1991, Moore et al., 2016).

The amount of filling in of the bays varies, with the smaller Bay Lakes comprising a lower percentage of the total bay area (Jones Lake occupies just a third of the total area of its bay, for example) compared to White Lake, in which 71% of the original total bay area is occupied by the 1,068-acre lake (Frey 1949).

One of the oldest maps of the White Lake area is a 1914 Bladen County Soils map, which indicates the Turtle Cove outlet beginning as a relatively wide region along the western shoreline (Fig. 3). There is no defined inlet to the lake.

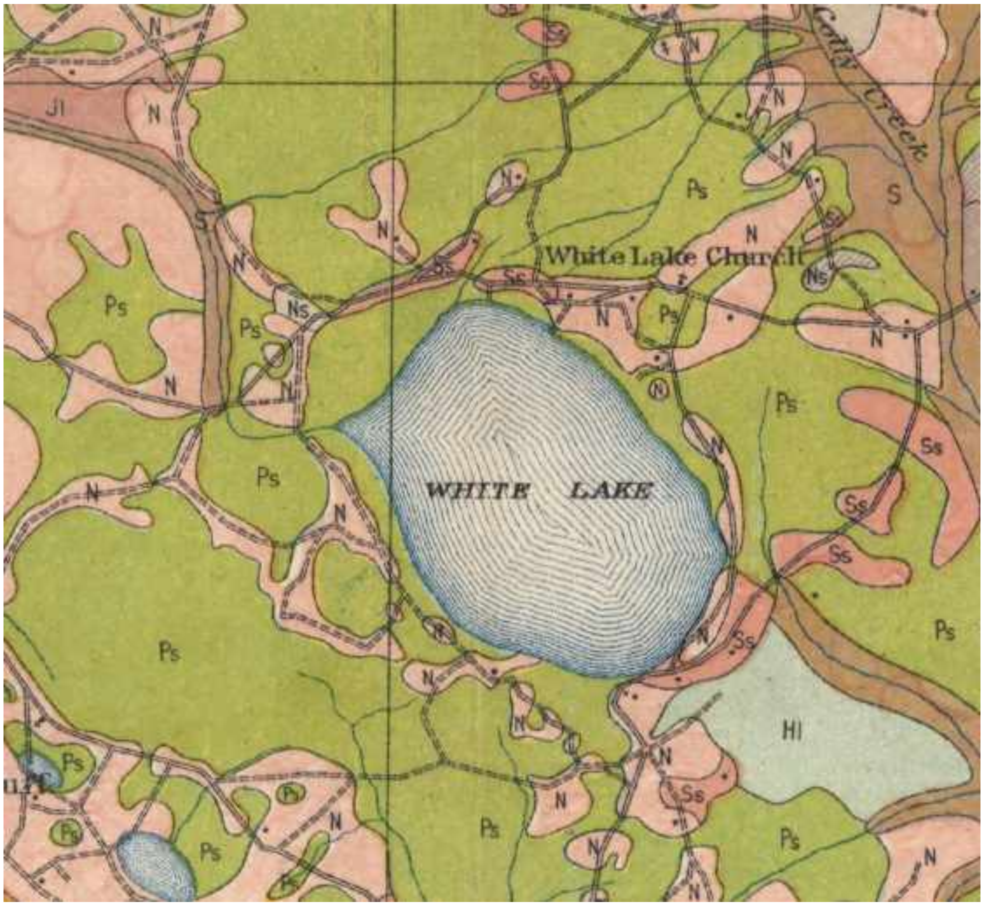


Figure 3. Detail from original 1914 “Soil map, North Carolina, Bladen County sheet” in the North Carolina State Archives, accessed from https://web.lib.unc.edu/nc-maps.

Early aerial photography provided a means for understanding how abundant and distinctive Carolina Bays were. A 1938 photograph also provides the best vantage point for appreciating the clarity of White Lake’s water, as some of the bottom features can be seen—particularly notable in the digitized photo (Fig. 4) are straight lines radiating out from the southern shoreline. These are apparently the remnants of the NC Wildlife Resources Commission’s barriers to create fishing-free zones in the lake, as mentioned in the NC State Parks 1996 General Management Plan for White Lake: “In 1928, large sections of the lake were staked off and fishing prohibited in these areas during breeding season; restocking efforts also took place.” (NCDPR 1996).

Figure 4. White Lake in 1938, a digitized assembly of multiple original aerial photographs taken by the US Department of Agriculture (Friends of Mountain to Sea Trail provided the digital update). The 1938 USDA originals were used in the morphometric studies by Frey (1949).

Also notable in this photograph are the natural features around the lake, particularly the wetlands that are part of the original bay in the northwest, and smaller bays in the southwest. The lake outlet, Turtle Cove, appears as a relatively wide area that is distinguished by vegetation differences (Fig. 4). It is unknown how deep the outlet channel was, but given the width at the lakeshore, it was presumably shallowest there.

Bay Lakes Are Shallow Basins

Much work was done on the Bay Lakes in the 1940's and 50's and the descriptor "Bay Lake" was coined by one of the researchers, Dr. David G. Frey, after studies comparing and contrasting six lakes: Jones, Salters, Singletary, White, and Black (now called Bay Tree) in Bladen County, and Lake Waccamaw in Columbus County (Frey, 1949).

Table 1 provides a summary of Frey's original data for White Lake, as well as comparative data from a more recent survey conducted by NC State University Aquatic Weed Extension personnel. The lake surface area calculations were very close between the two surveys, with a difference of a tenth of a percent, while there was a 15% difference in lake volume between the two surveys, as a result of the difference in depth determinations between years, with 2017 depths being 0.3 m (1 ft.) less than what was measured 70 years ago. No lake elevation data was collected in 1949, while the lake elevation measured on 12/17/19 by a registered land surveyor (Lloyd Walker) was 64.50' (NAVD 88), very near the time of the NCSU survey (11/29/17).

Table 1. <u>White Lake Morphometric Data:</u> Comparisons between historical survey data (from Frey, D.G. 1949. Morphometry and hydrography of some natural lakes of the North Carolina Coastal Plain: The Bay Lake as a morphometric type. J. Elisha Mitchell Scientific Society v. 65(1): 1-37), and a recent NC State University 2017 survey using Lowrance and Biobase software. Metric unit conversions are included.

	Frey 1949	NCSU 2017
Lake area	1,068 acres 4,322,043 m^2	1,067 acres 4,317,966 m^2
Volume	12,844,100 yd^3 9,820,019 m^3	6,796 acre-feet 8,382,730 m^3
Mean depth	7.5 ft 2.3 m	6.4 ft 1.9 m
Maximum depth	10.6 ft. 3.2 m	9.6 ft. 2.9 m
Shoreline length	4.77 miles 7,724.9 meters	

Frey noted that White Lake had "the most nearly regular basin of any of the lakes examined" with broader terraces on the eastern and western shorelines gradually sloping towards the deeper region of the lake (Fig. 5; Frey 1949).

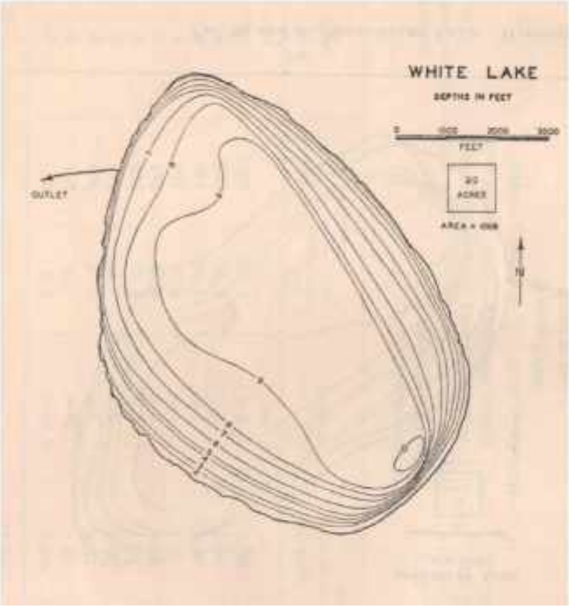


Figure 5. Bathymetric map of White Lake by Frey (1949); depth contours are marked in feet. The maximum length of the lake was measured as 1.81 miles. The outlet on the west side is Turtle Cove, in its original location. Scan of original reprint.

A more recent bathymetric map was created from 202 survey points, based on a 5.75 -acre grid pattern (NCSU 2017). It reflects conditions during summer low lake levels (Fig. 6).

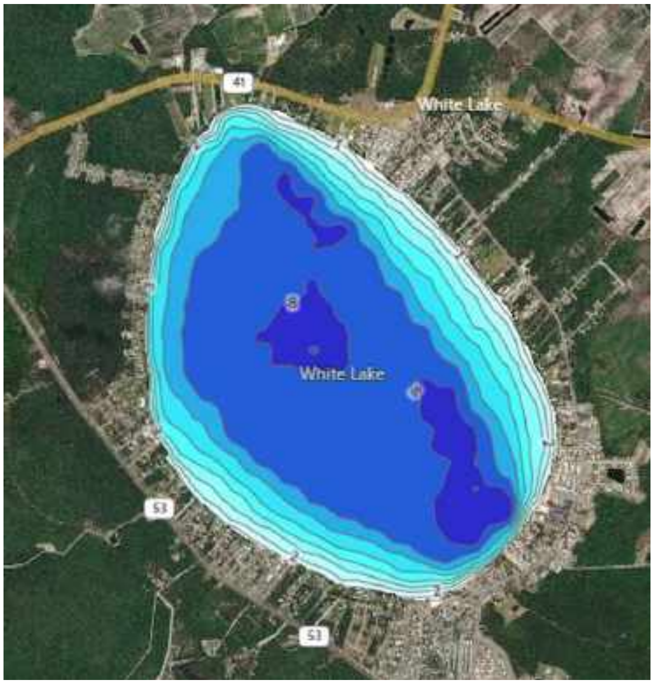


Figure 6. A bathymetric map of White Lake created from BioBase software, using depth measurements obtained with a Lowrance sonar receiver. The depth contours reflect conditions in 2019, when lake levels were approximately 1 foot lower than in 2017.

White Lake Watersheds

White Lake is located in the Lower Turnbull Creek Sub-watershed, the eastern boundary of which is delineated by the blue line to the right of the lake in the map below (and the Middle Colly Creek sub-watershed is to the east of the blue line). This sub-watershed includes 21,187 acres and is part of the Cape Fear River Basin. The White Lake outlet, Turtle Cove, located on the western lake shore, drains into Turnbull Creek, which flows west towards the Cape Fear River (Fig. 7).

Land uses within the sub-basin include urban (Town of White Lake) and agricultural.

12-Digit HUC (Subwatershed)

12-Digit Name:	Lower Turnbull Creek
12-Digit Code:	030300050205
10-Digit Name:	Turnbull Creek-Cape Fear River
10-Digit Code:	0303000502
8-Digit Code:	03030005
River Basin:	Cape Fear
12-Digit Area (ac):	21,187.00

Figure 7. White Lake sub-watersheds, from the North Carolina Department of Environmental Quality web site, https://deq.nc.gov/cape-fear-river-basin

Watershed boundaries are determined by topography; topographic mapping can also be done with LIDAR (Light Detection and Ranging) using a near-infrared laser as well as position and orientation data from GIS to map land surfaces. A 3-D terrain model developed from 2013 LIDAR data shows the ridges (in red) that define the sub-watersheds (Fig. 8; from Shank and Zamora 2019).

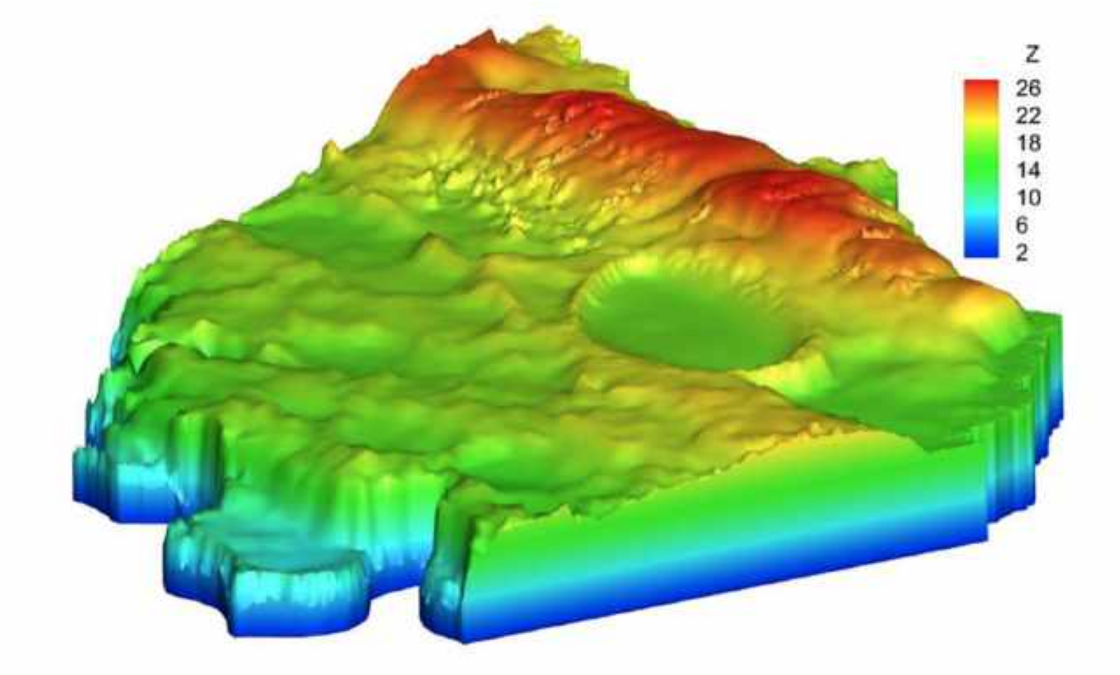


Figure 8. A 3-D terrain model developed by Dr. Peter Zamora, using 2013 LIDAR data and lake bathymetry data from Frey (1949). The vertical exaggeration is 70X.

Surface water flow in the Lower Turnbull sub-basin moves in a westerly direction from the higher ridge on the east, towards the Cape Fear River (the river channel is indicated in light blue on the left side of the above figure). There is no defined inlet to the lake, although surface water inflow is noticeable after rainfall of several inches or more, as the water is tea-colored. Two NC Department of Transportation culverts now channelize flow from wetlands at two points along White Lake Drive.

Shank and Zamora (2019) found groundwater flow moved in the same direction as surface water flow and delineated the lake's groundwatershed based on topography and modeling as an area smaller than the surface area of the lake.

Soil Types Around White Lake

The first soil survey of Bladen County was published more than a century ago; this survey was updated upon completion of fieldwork in 1983 and was published by the USDA Soil Conservation Service. It identifies the major soil series that surrounds much of the lake as the Centenary-Lakeland-Wakulla series. Permeability ranges from moderate to very rapid depending on soil type (all are sandy soils), while available water capacity is low. For Lakeland and Wakulla soils (found on ridges, terraces and the rims of Carolina Bays) the seasonal high-water table is over 6 feet in depth, while Centenary soils (found on broad flats) have a seasonal high-water table at a depth of 3.5 to 5 feet from winter to early spring (USDA NRCS 1985).

The minor soil series include the Lynn Haven-Pamlico-Leon series; these soils are found on the broad flats and within Carolina Bays and are poorly drained to very poorly drained. Permeability ranges from moderate to rapid, while available water capacity is low. The seasonal high-water table is at or near the surface for long periods from winter to early spring (or in the case of the sandy and organic Pamlico soils, for most of the year). A second minor soil series is the Roanoke-Wahee; Roanoke soils tend to be poorly drained with a seasonal (winter to spring) high water table depth of 0 to 1 foot, while the Wahee soils are somewhat poorly drained with a seasonal water table depth of 0.5 to 1.5 feet (USDA NRCS 1985). The updated soils map (Fig.9) shows a finer scale in comparison to Fig. 3)

Figure 9. Soils map overlay for the region around White Lake, from the Bladen County 1983 Soil Survey, USDA Soil Conservation Service.

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, considered as a "deep" well (E3D) showed an increase which mirrored the rise in a shallower well situated above the clay layer at this location (E3; Fig. 10).

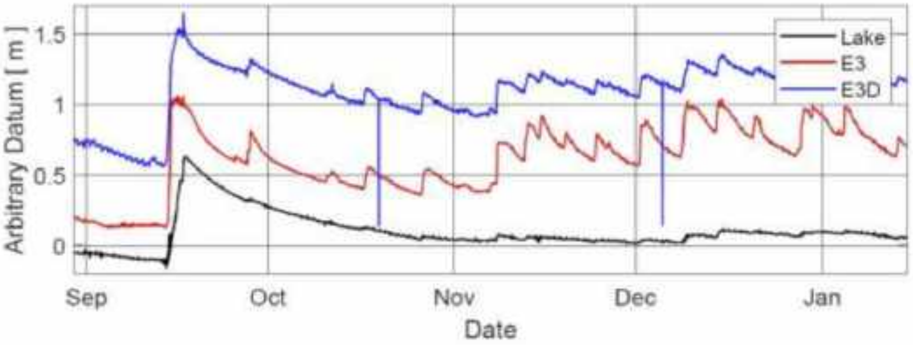


Figure 10. Groundwater levels at eastern shore well sites from August 2018 to January 2019; blue indicates levels in a deeper well (below clay hardpan) while red is groundwater levels in a well situated above the clay layer. The black line is the lake level. Data from Shank and Zamora (2019).

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):

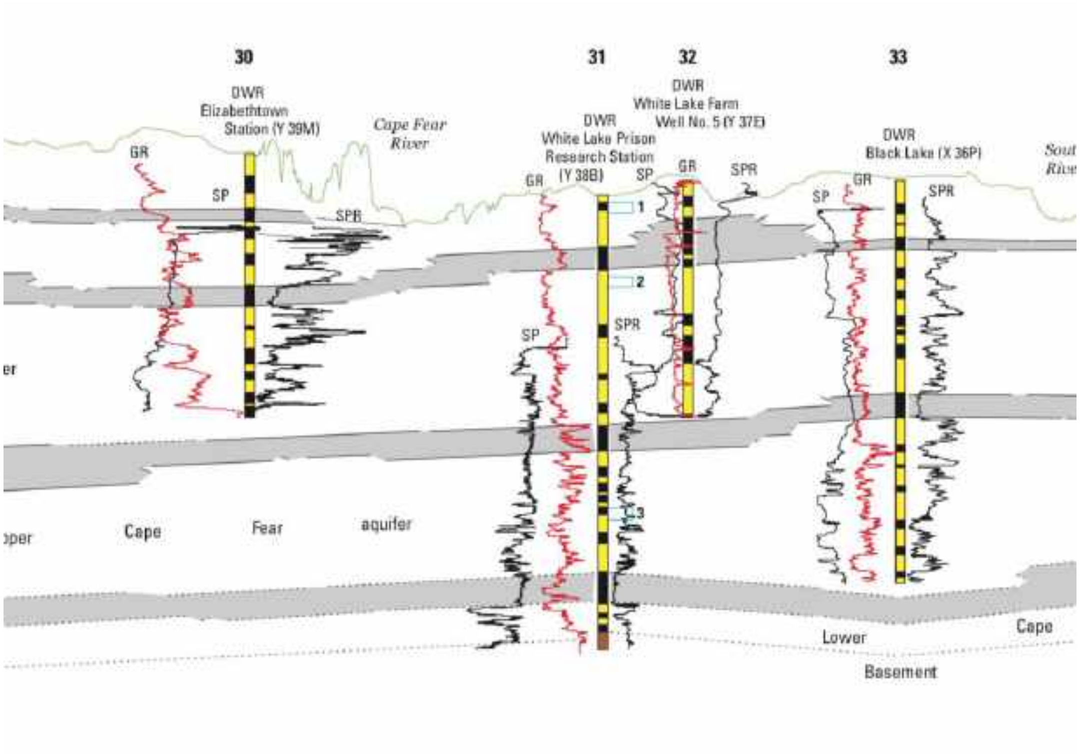


Figure 11. Close-up of a hydrogeological map of the area around White Lake, taken from Plate 5, Section G-G' in Campbell and Coes (2010). A pdf of this map is included in Appendix 1.

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.

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).

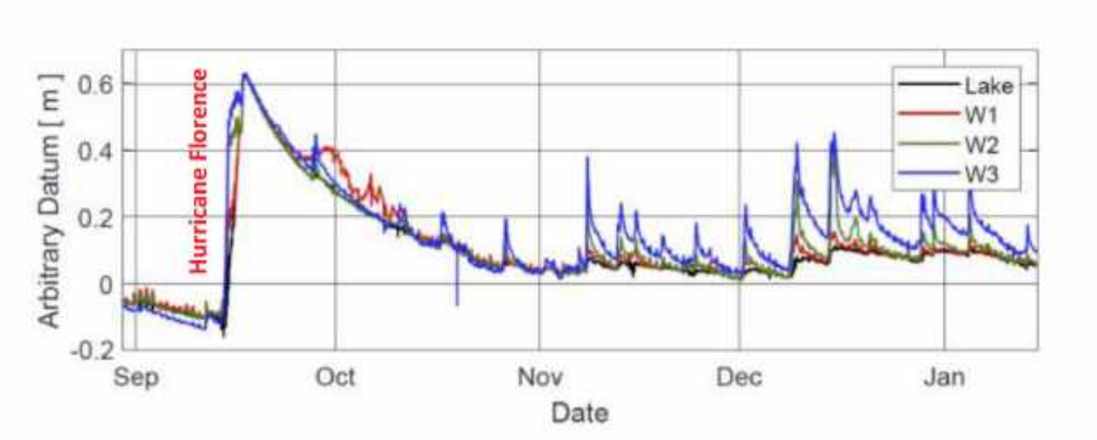
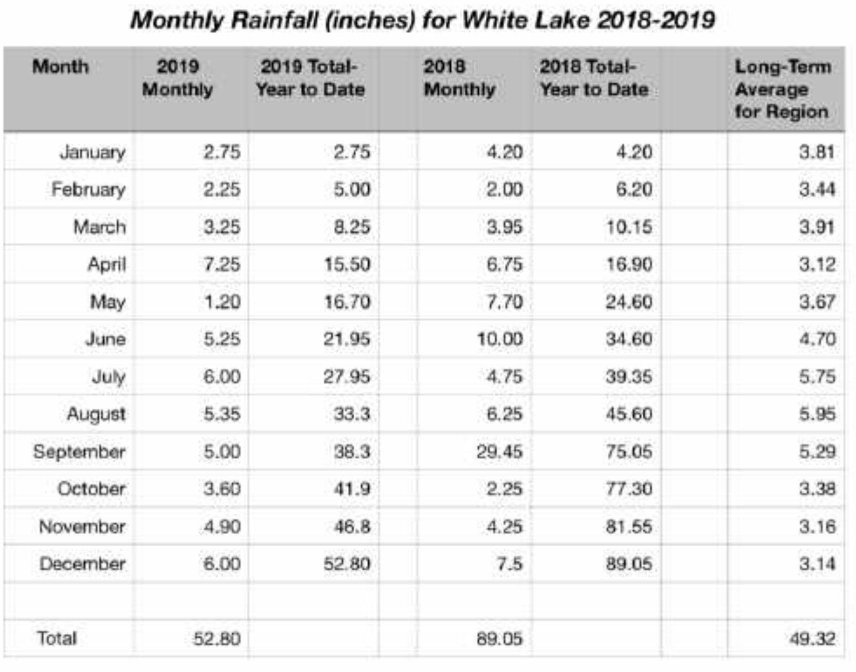


Figure 12. Groundwater levels at western shore well sites from August 2018 to January 2019; red (W1) is the shallow well closest to the lake and blue (W3) is a shallow well furthest from the lakeshore, while green (W2) is a shallow well midway between W1 and W3 (each of these wells were situated above 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 as something 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 Acidity 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 3.9-5.5) 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).

In the absence of having a water budget, it seems that attention has focused solely on groundwater and particularly on "springs" as the source water for the lake, rather than what has always been the dominant source: rainfall to the lake surface, as one inch of rain is roughly equivalent to 29 million gallons added to the lake.

Rainfall also 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, they are difficult to measure accurately, but in relative terms the importance of inputs can be viewed as:

Rainfall > (surface runoff +groundwater)

While the relative importance of outputs, or loss can be expressed as:

Evaporation >groundwater>Turtle Cove

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Appendix 1.

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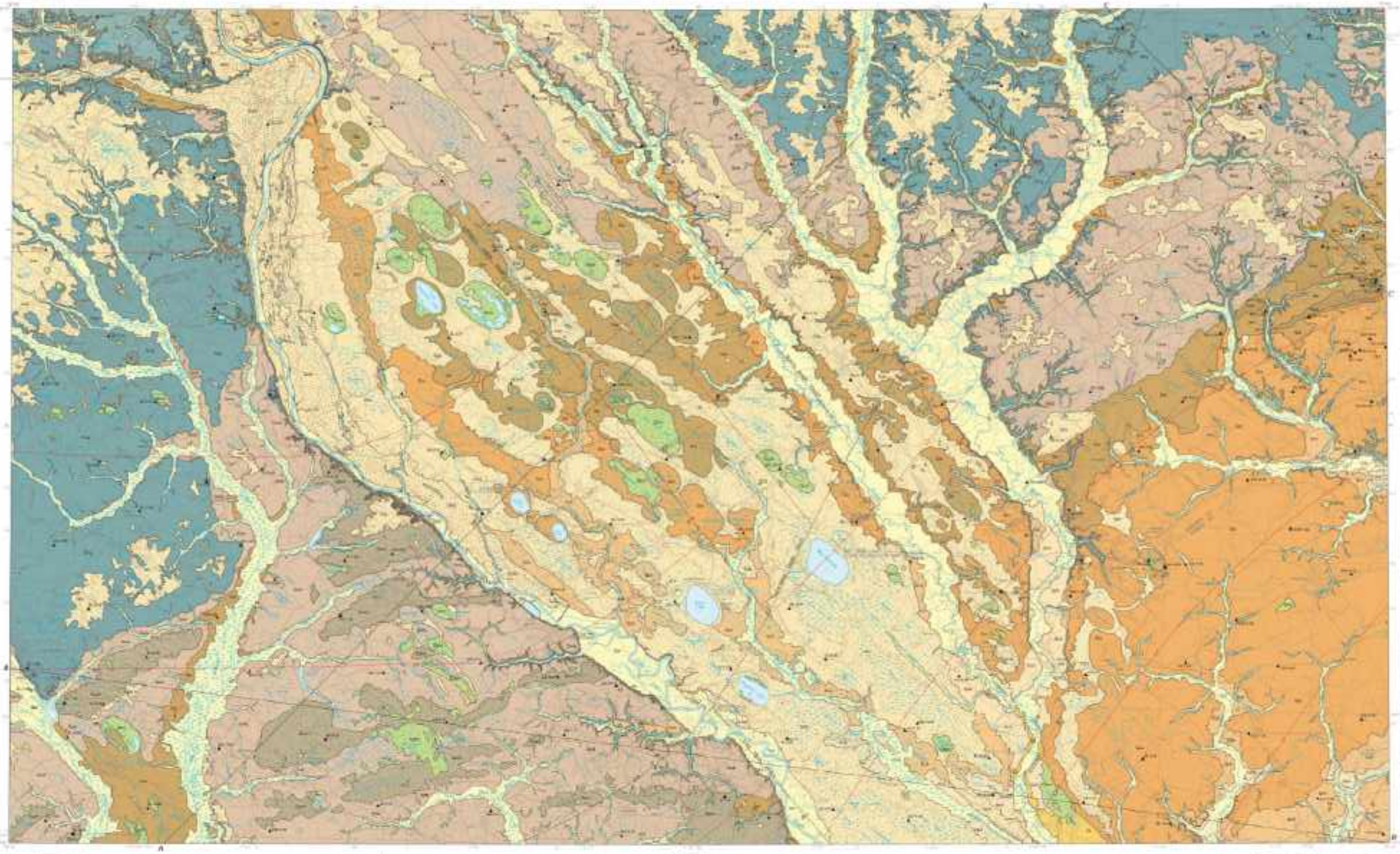
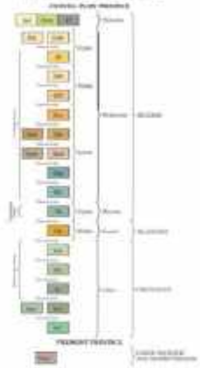
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY



CORRELATION OF MAP UNITS



COASTAL PLAIN PROVINCE

PIEDMONT PROVINCE

EXPLANATION OF MAP SYMBOLS

[illegible]

FAULTS

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OTHER FEATURES

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DISCUSSION

GEOLOGIC UNITS

The Elizabethtown 30' x 60' quadrangle is located in southeastern North Carolina between Fayetteville and Wilmington. [illegible]

Appendix 2.

Plate 5, G-G' from: Campbell, B.G., and A.L. Coes (eds.). 2010. Groundwater availability in the Atlantic Coastal Plain of North and South Carolina. U.S. Geological Survey Professional Paper 1773 241 p., 7 pls. (the report's plates are on a cd, included with the hard copy).