White Lake Background Information

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 to400 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 portion 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.

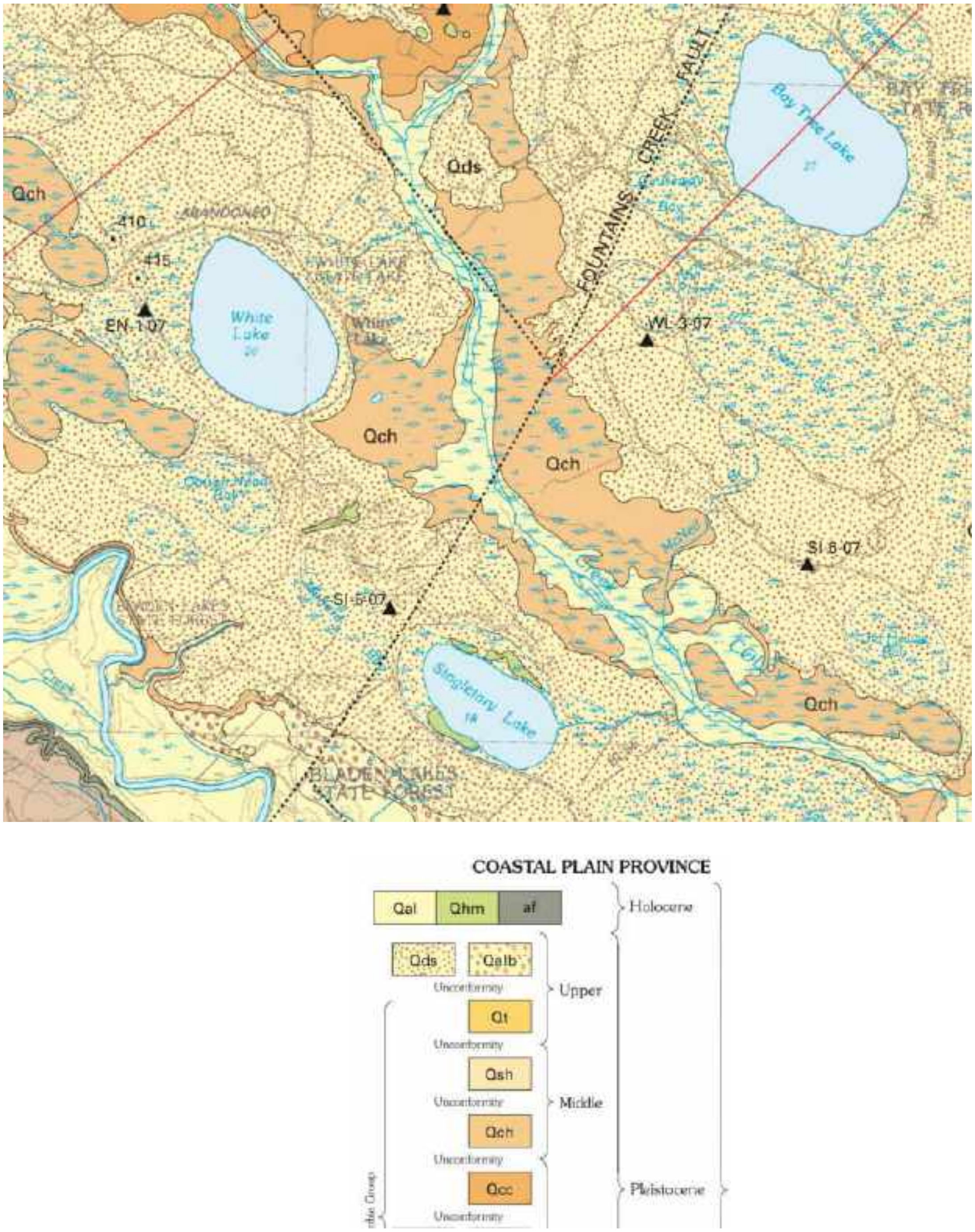

Figure 2. Close-up of a section of the surficial geologic map of the Elizabethtown 30' x 60' quadrangle, North Carolina. Pinehurst Formation (Qds) surrounds White Lake, with Chuckatuck Formation (Qch) also in the area. Weems and Lewis (2011), US Geological Survey Report 2011-1121.

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).

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. 3) 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).

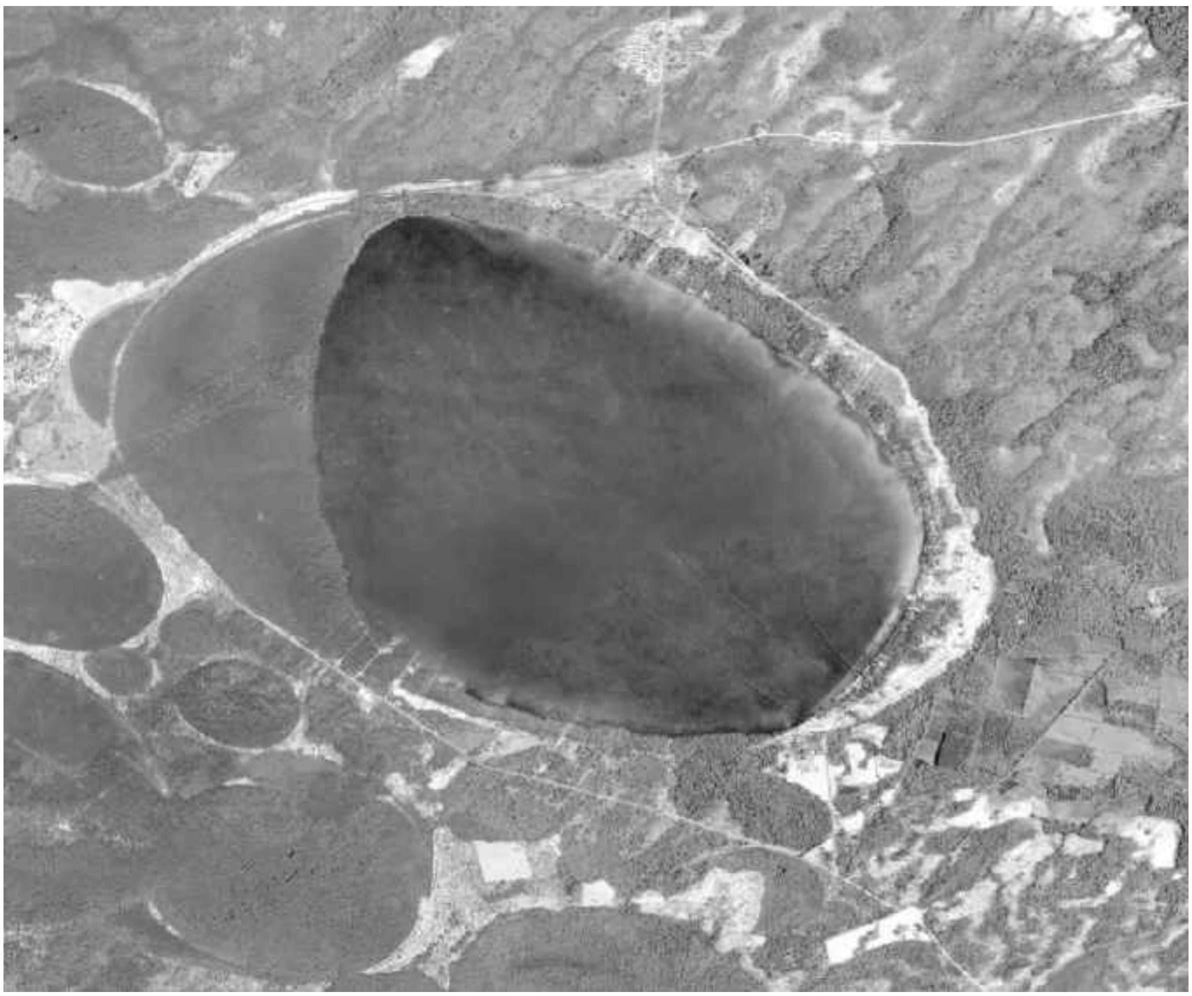

Figure 3. White Lake in 1938, a digitized assembly of multiple original aerial photographs taken by the US Department of Agriculture (Friends of Mountain to Sea Trail provided the digital update). The 1938 USDA originals were used in the morphometric studies by Frey (1949).

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. 3).

Soil Types Around White Lake

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. 4). There is no defined inlet to the lake.

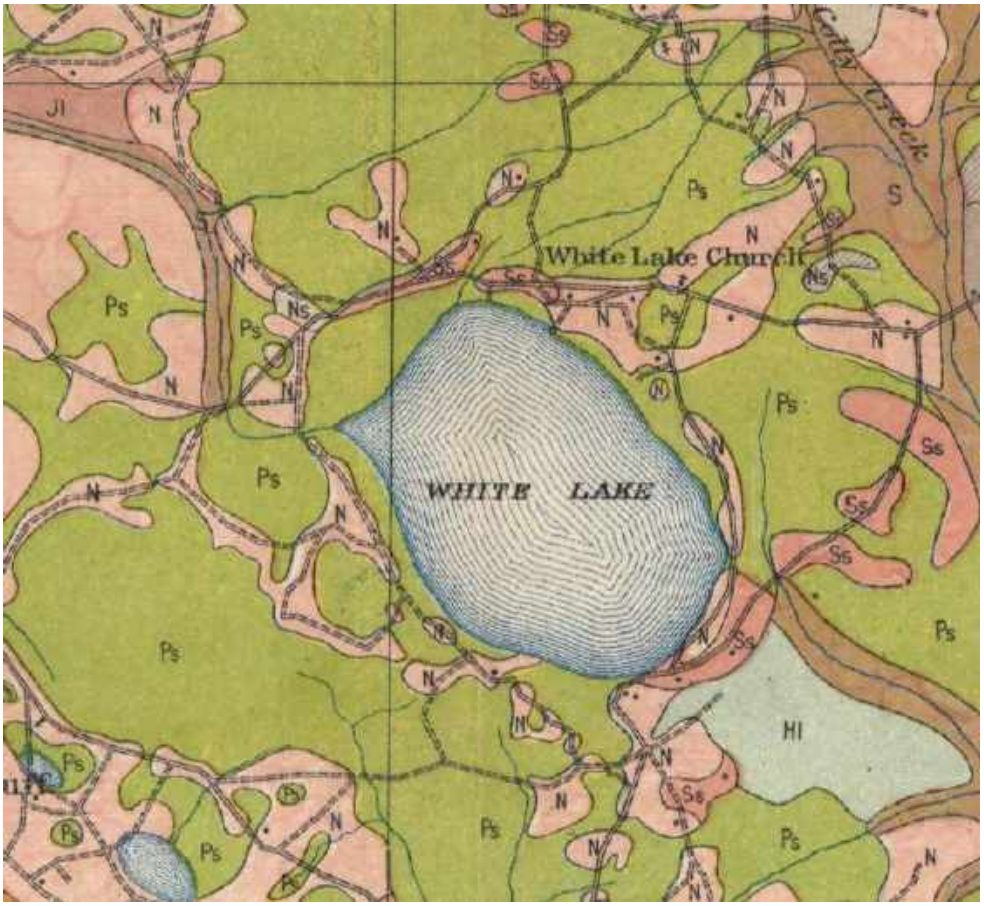

Figure 4. Detail from original 1914 "Soil map, North Carolina, Bladen County sheet" in the North Carolina State Archives, accessed from https://web.lib.unc.edu/nc-maps.

The first Bladen County soil 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.5) shows a finer scale in comparison to Figure 4.

Figure 5. Soils map overlay for the region around White Lake, from the Bladen County 1983 Soil Survey, USDA Soil Conservation Service.

Bay Lakes Are Shallow Basins

Much work was done on these shallow Coastal Plain 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 six of the lakes: Jones, Salters, Singletary, White, and Black (now called Bay Tree) in Bladen County, and Lake Waccamaw in Columbus County (Frey, 1949). He found that the amount of filling in of the bays varied, with the smaller Bay Lakes comprising a lower percentage of the total bay area (Jones Lake occupied 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 was occupied by the 1,068-acre lake (Frey 1949). The USDA aerial photos taken in 1938 were used to develop the hand drawn maps of the lakes included in his 1949 manuscript (Fig. 6).

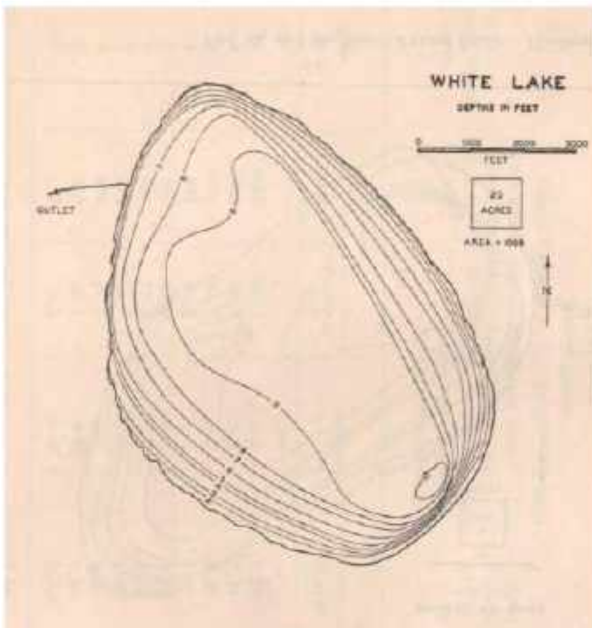

Figure 6. Bathymetric map of White Lake by Frey (1949); depth contours are marked in feet. The maximum length of the lake was measured as 1.81 miles. The outlet on the west side is Turtle Cove, in its original location. Scan of original reprint.

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. 6; 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, because 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 (the relatively small deep "hole" was not detected for example). 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. White Lake Morphometric Data: 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	

A more recent bathymetric map was created from 202 survey points (used in vegetation surveys of the lake), based on a 5.75 -acre grid pattern (NCSU 2017). It reflects conditions during summer low lake levels (Fig. 7).

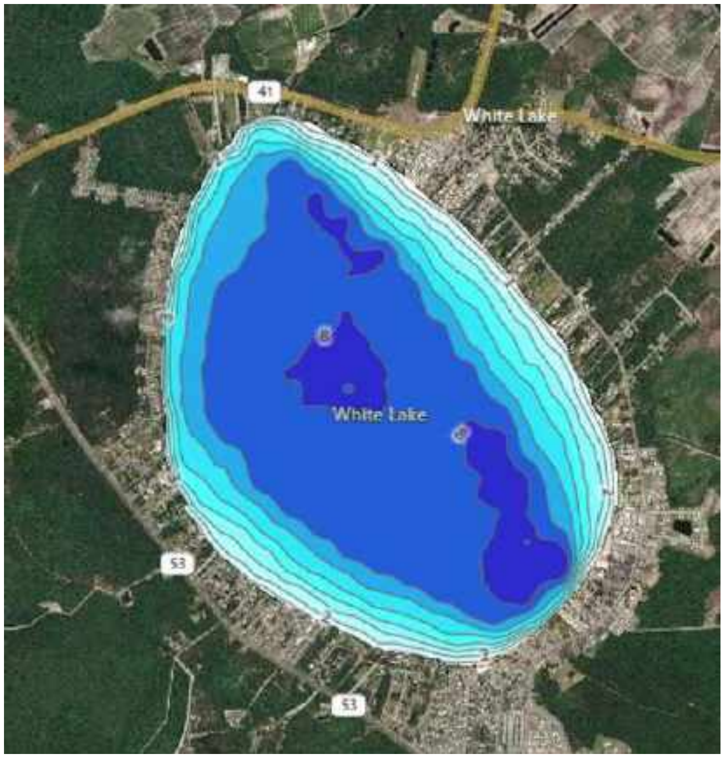

Figure 7. A bathymetric map of White Lake created from BioBase software, using depth measurements obtained with a Lowrance sonar receiver. The depth contours reflect conditions in 2019, when lake levels were approximately 1 foot lower than in 2017.

White Lake Rainfall and Lake Levels

At White Lake, lake levels vary primarily due to rainfall--both the total amount, and how it is distributed over the course of a year—so keeping records of both is important. Because of the relationship between rainfall and temperatures (and evaporation rates), lake levels are generally higher in winter and lower in summer (although large rainfall events can occur in summer, as was the case in June-July 2013). The variability that we see in weather is due to the ENSO—El Niño Southern Oscillation—and increasingly, by the influences of climate change. Rainfall patterns are changing, with more big rains and more severe droughts.

In 2013, rainfall was below average for the first five months of the year, followed by a six-week period over June-July in which 26.75 inches fell, (including two rain events of 4 inches), which was equivalent to 54% of the total average annual rainfall. From September through November there was little rain, so that the total annual rainfall in 2013 was only 10% above average (Table 2). Heavy rain from Hurricane Matthew in early October 2016 caused widespread flooding in the region, as did the multi-day heavy rains from Hurricane Florence in September of 2018. Tropical Storm Idalia dropped 7 inches of rain in August 2023, which resulted in a 6-inch rise in lake level.

Table 2. Monthly rainfall amounts measured at the Town's wastewater treatment lagoon (off Lakeshore Drive) (2014 data was not included because of missing data over a three-month period). 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 2012-2023

Month	2023	2022	2021	2020	2019	2018	2017	2016	2015	2013	2012	Monthly Average for Region
January	4.3	5.75	8.25	4.5	2.75	4.20	7.0	3.0	2.5	1.75	2.75	3.81
February	3.6	1.0	9.2	6.7	2.25	2.00	1.5	10.7	5.5	2.5	4.0	3.44
March	2.5	2.45	2.7	3.7	3.25	3.95	3.7	1.55	4.15	1.0	7.0	3.91
April	6.5	3.75	1.75	5.1	7.25	6.75	6.75	6.75	4.55	1.75	2.25	3.12
May	1.5	2.2	3.0	12.25	1.20	7.70	2.7	4.5	4.20	2.25	9.25	3.67
June	6.3	6.2	7.9	7.15	5.25	10.00	4.5	3.65	8.70	17.0	2.0	4.70
July	3.8	10.5	7.5	6.85	6.00	4.75	6.75	3.75	3.0	11.25	8.6	5.75
August	7.5	5.5	6.5	7.55	5.35	6.25	5.6	4.12	9.4	8.25	9.75	5.95
September		6.5	3.2	5.95	5.00	29.45	5.2	15.0	4.7	1.0	5.0	5.29
October		0.8	0.6	3.35	3.80	2.25	2.95	14.25	9.75	1.75	2.25	3.38
November		1.55	0.4	7.5	4.90	4.25	1.0	0.50	7.25	0	2.25	3.16
December		1.2	3.4	4.25	6.00	7.5	5.45	5.1	6.5	5.75	4.25	3.14
Total		**47.2**	**54.4**	**74.85**	**52.80**	**89.05**	**53.1**	**72.87**	**70.20**	**54.25**	**59.35**	**49.32**
% of Lake Volume		**61.8**	**71**	**97**	**69**	**116**	**69**	**95**	**91**	**70**	**77**	**64**

(Volume of Total Rainfall on Lake Surface/Total Lake Volume) x 100 Gives an Estimate of Volume of Rainfall as % of Lake Volume)

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).

Low lake levels and potential threats to lake levels, such as drainage ditches and agricultural activity, have raised concerns many times in the past and several studies and reports have been generated to respond to those concerns. A hydrological study was conducted by the State Hydrographic Engineer C.R. Edgerton in 1968 because of concerns about ditching and clearing activities along the western side of White Lake. A large, deep ditch was being proposed to facilitate development, and Edgerton concluded that seepage into this ditch could reduce lake level by 1 foot over the course of a year. In addition, he concluded that no openings should be allowed under U.S. 701 below the elevation of 66.0 feet, mean sea level (NGVD 29). He sent a copy of his report to the U.S. Geological Survey for review, and the district chief in the Raleigh office responded in July 1969: "our present knowledge suggests that White Lake is supplied by precipitation on the lake and by ground water flow from the adjoining area…drainage of any area adjacent to the lake will first stop ground-water inflow to the lake from that area and second permit water to drain from the lake into the drainage channels", so in his opinion any project designed to drain areas should be carefully considered.

The North Carolina Legislature ratified H.B. 406, titled "AN ACT TO PREVENT THE DIGGING OF DITCHES BELOW A CERTAIN LEVEL IN BLADEN COUNTY", in 1971. Section 1 of that bill states: "It shall be unlawful for any person, firm or corporation to dig any ditch under any portions of U.S. Highway No. 701, N.C. Highway No. 53 and S.R. 1515 which surround that body of water in Bladen County known as White Lake below 66 feet above sea level". A second House Bill (994) was ratified in 1973, titled "AN ACT TO AMEND CHAPTER 570 OF THE SESSION LAWS OF 1971 SO AS TO ALLOW THE TOWN OF WHITE LAKE TO DIG DITCHES BELOW A CERTAIN LEVEL IN BLADEN COUNTY". This bill goes on to state that the Town of White Lake can obtain a written permit from the State Highway Commission for digging associated with the "installation, repair and maintenance of its water and sewer mains and lines".

Nothing in the language of either bill establishes or mandates a lake level of 66 feet (NGVD 29) above sea level—the intention was to prohibit ditching actions that could have a detrimental effect on lake levels.

The Town of White Lake asked Walker Surveying Company to survey the elevation of the Turtle Cove spillway in December of 2017; at this time the lake elevation was 64.5 feet above mean sea level, NAVD 88 (a newer datum that is one foot lower than the old NGVD 29 datum [the elevation would have been 65.5 using the NGVD 29 datum] and at that time, sandbags were in place along the base of the invert to block water flow below a level that was roughly equivalent to 65 feet (NAVD 88). Personnel from NC DWR recommended removal of the sandbags, and that was done in April of 2018. A second survey of lake elevation was done by Walker Surveying in January of 2020 and the reading was again 64.5 feet (NAVD 88); these two surveys represent the only documented measurements of lake elevation that have been found in a search of records kept by the Town.

An easily visible lake level gauge was installed in late 2018 on the Goldston's Motel Pier (eastern side of the lake, not far from Town Hall, by UNC-Chapel Hill personnel with the Lake Observations by Citizen Scientists program (www.locss.org), so it was possible to collect regular lake level measurements from this gauge in 2019. A second gauge, which reads lake elevations, was installed at Turtle Cove in January 2020 (Fig. 8). A comparison table was developed so that lake elevations can be determined from both gauges (Table 3).

Figure 8. (Left) Lake level gauge installed by the Lake Observations by Citizen Scientists and Satellites program at the University of North Carolina-Chapel Hill, located at Goldston's Motel Pier (1608 White Lake Drive), and (right) lake elevation gauge installed by Walker Surveying Company at Turtle Cove. Elevations are given in the NAVD 88 Vertical Datum. Photos taken January 16, 2020.

Table 3. Lake elevation gauge readings at Turtle Cove compared to lake level gauge readings at Goldston's Motel Pier. Table developed by Steve Bunn, Lake Stewardship Officer.

Elevation Above Sea Level in Feet (NAVD 88)	Goldston's Motel Pier Gauge
66.00	3.40
65.90	3.30
65.80	3.20
65.70	3.10
65.60	3.00
65.50	2.90
65.40	2.80
65.30	2.70
65.20	2.60
65.10	2.50
65.00	2.40
64.90	2.30
64.80	2.20
64.70	2.10
64.60	2.00
64.50	1.90
64.40	1.80
64.30	1.70
64.20	1.60
64.10	1.50
64.00	1.40
63.90	1.30
63.80	1.20
63.70	1.10
63.60	1.00
63.50	0.90
63.40	0.80
63.30	0.70
63.20	0.60
63.10	0.50
63.00	0.40
62.90	0.30
62.80	0.20
62.70	0.10
62.60	
62.50	

Using survey data from 2017 and 2018 and lake elevation readings collected since 2019, it is possible to compare end of year lake levels and annual rainfall over a six-year period. In only two years was rainfall substantially above the long-term average, with the greatest variation in lake levels (>9 inches) between 2020 and 2021 (Table 4).

Table 4. End of year lake elevations (feet above sea level NAVD 88) at White Lake for the past six years (2017-2022) and total annual rainfall amounts.

12/17/17	64.5 ft	53.1" rainfall for 2017 Elevation measurement by surveyor
12/31/18	64.7 ft	89.1" rainfall for 2018 (Hurricane Florence in September)
12/31/19	64.3 ft	52.8" rainfall for 2019
12/31/20	64.9 ft	74.9" rainfall for 2020
12/31/21	64.1 ft	54.4" rainfall for 2021
12/31/22	63.7 ft	47.2" rainfall for 2022

The mean high-water level for the four-year period 2019-2022 is 64.85 feet above sea level NAVD 88 datum (Table 5). In September 2018, lake levels spiked after Hurricane Florence (although no elevation measurements were taken), while 2020 and 2021 levels exceeded 65 feet for brief periods (Fig 9).

Table 5. White Lake annual lake elevation variations (elevation reported as NAVD 88 datum) and mean high-water level for 2019-2022.

2019 High (January 25): 64.6 Ft	**2019 Low** (July 9): 63.5 Ft
2020 High (June 16): 65.2 Ft	**2020 Low** (January 1): 64.3 Ft
2021 High (February 19): 65.3 Ft	**2021 Low** (November 29): 63.9 Ft
2022 High (January 17): 64.3 Ft	**2022 Low** (May, Oct-Dec.): 63.7 Ft

2019 Lake Level Variation (High to Low): 12.7 Inches
2020 Lake Level Variation (High to Low): 10.3 Inches
2021 Lake Level Variation (High to Low): 16.8 Inches
2022 Lake Level Variation (High to Low): 7.2 Inches

Variation (Highest-Lowest) Over the Four-Year Period 2019-2022: 21.1 Inches
Four-Year Mean High-Water Level: 64.85 Feet NAVD 88

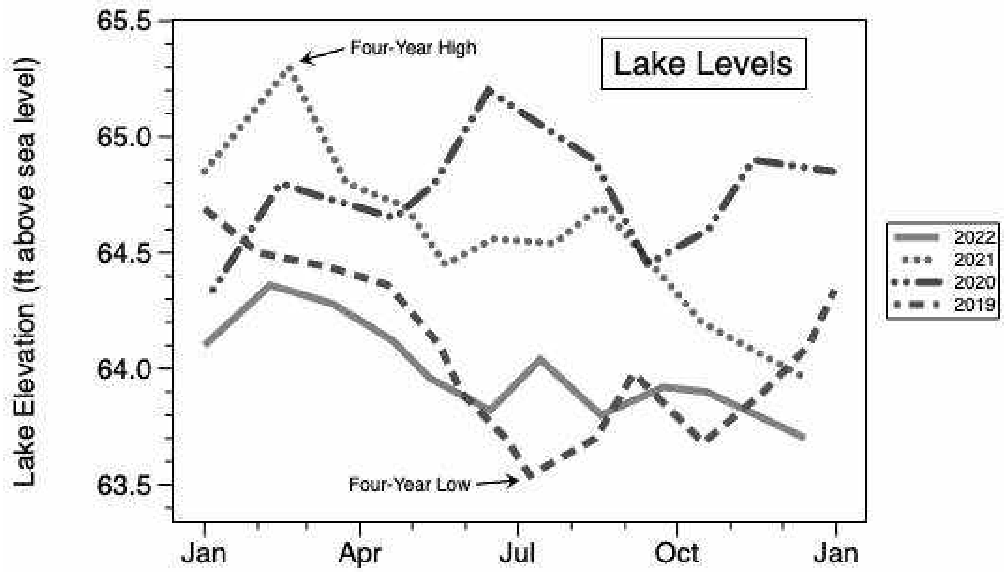

Figure 9. Lake elevation comparisons for the four-years 2019-2022, reported as feet above sea level using the NAVD 88 datum (which is one foot lower than the older NGVD 29 datum), for White Lake from 2019 through 2022.

Historical Data on Lake Levels

Lake level variation (high to low) in 1965 was 14.5”, in 1966 was 10”, and in 1967 was 10”, while Frey [1949] noted a variation of 14” over the time he was working at the lake. A comparison graph of lake levels in White Lake and nearby Bay Tree Lake from 1984 to 1988 showed similar trends in each lake, although lake elevations (and therefore a mean high-water level) are different in each lake. Over the period in which levels were recorded, the total variation high to low in White Lake was about 25 inches, with highest lake levels in 1984 and low lake levels in much of 1986 (Fig. 10).

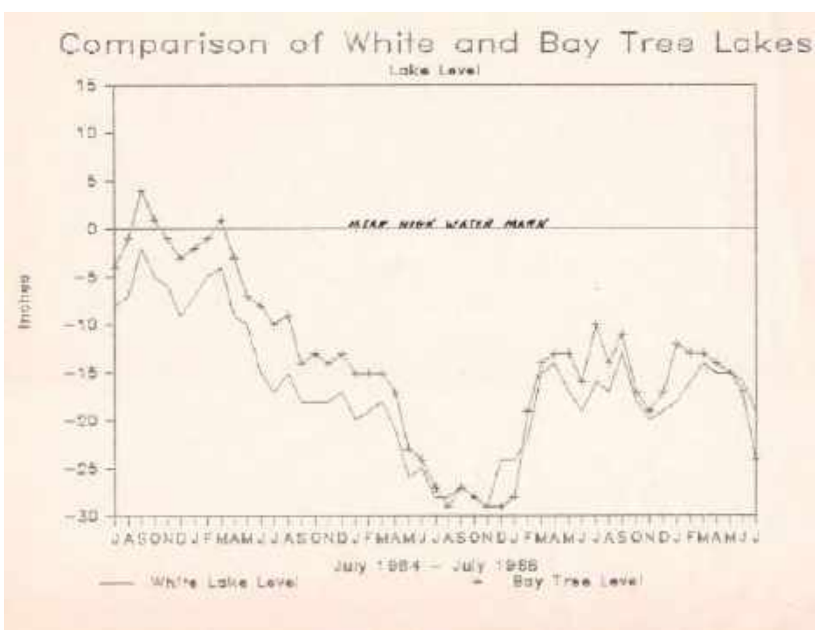

Figure 10. Lake level changes in White Lake and Bay Tree Lake from July 1984 to July 1988 (data recorded by State Parks personnel).

Turtle Cove Outlet

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 was also 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 natural location during the development of the Turtle Cove neighborhood.

In December 2017, Walker Surveying Company provided the elevations of the six corrugated metal pipes at Turtle Cove: the inverts ranged from 63.39 to 63.55 feet (NAVD 88). Elevations were also made in the outlet channel; the mid-channel elevation at a point close to the lake shore was 64.44 feet (NAVD 88), which was very near the lake elevation of 64.5 feet at the time. Outlet channel elevations gradually decline as the distance from the lakeshore increases, which would be of benefit in high water conditions. Placing sandbags at the inverts would impede flow under high water conditions and have no impact on lake levels at other times.

State Parks personnel worked with the Town in late 2019 to establish a plan for adding sandbags at the Turtle Cove shoreline as the lake levels started to increase with increased rainfall; the large amount of rain in 2020 raised the lake level to over 65 feet (NAVD 88), so that the sandbag dam required maintenance and repair at times (Fig. 11). Blocking outlet flow in the belief that it prevents “draining the lake” has long been an issue in this shallow lake, although the primary losses of water are to groundwater seepage and evaporation.

Figure 11. 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. Sandbags have been placed at the lakeshore to prevent flow, and the ditch has become overgrown with weeds and trees since this photo was taken.

Attachment 1. White Lake Hydrology Study, September 1968, by C.R. Edgerton
Attachment 2. Comment Letter on White Lake hydrology from U.S. Geological Survey, July 1969
Attachment 3. Memo from State Highway Commission, with copies of NC House Bill 406, Chapter 570, 1971, and NC House Bill 994, Chapter 252, 1973.
Attachment 4. Memo from Walker Surveying Company with lake elevations, January 2020.
Attachment 5. Walker Surveying Company Survey of Turtle Cove outlet, December 2017. Of note is the slope of the outlet—it is 64.4 ft elevation at the lake shore, which is where the sandbags are presently placed.

White Lake Watersheds

White Lake is 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. 12).

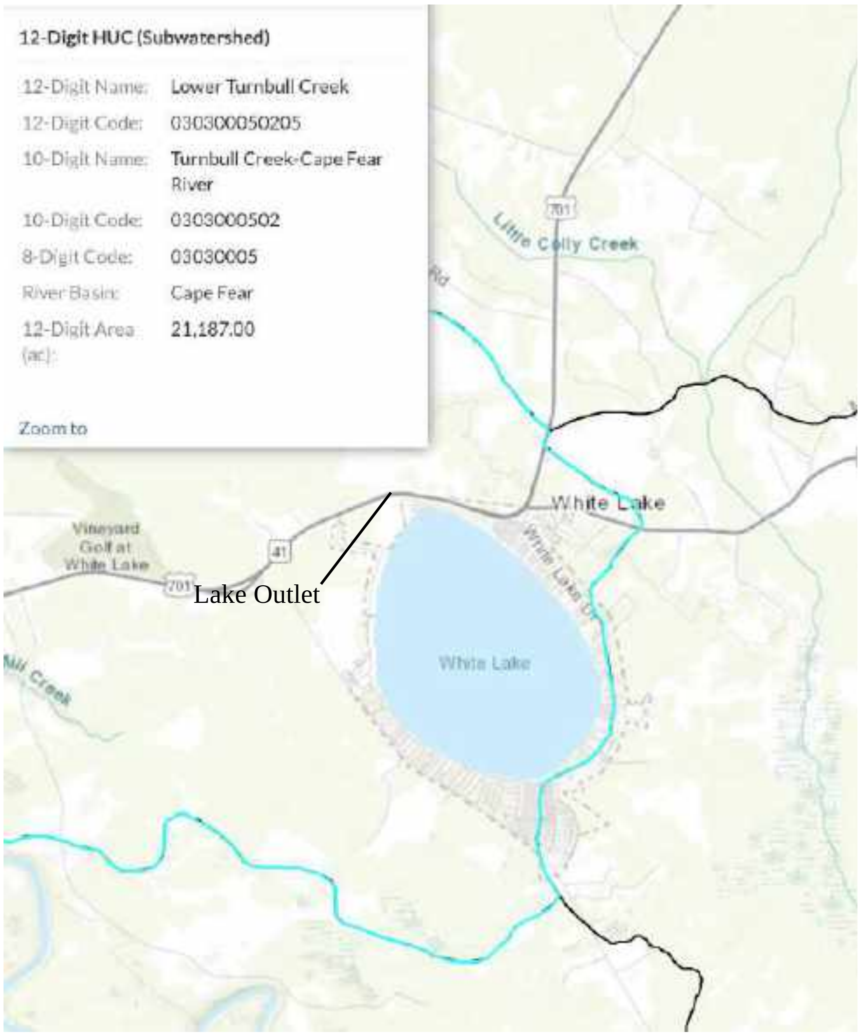

Figure 12. White Lake sub-watersheds, from the North Carolina Department of Environmental Quality web site, https://deq.nc.gov/cape-fear-river-basin

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. 13) (Shank and Zamora 2019).

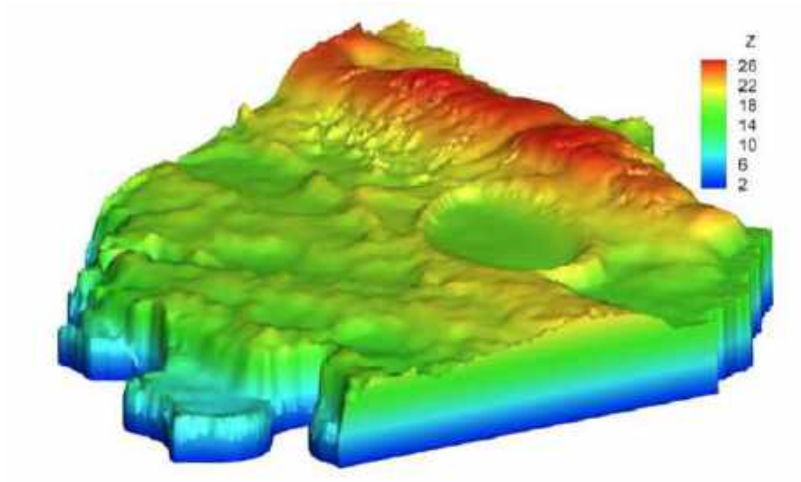

Figure 13. A 3-D terrain model developed by Dr. Peter Zamora, using 2013 LIDAR data and lake bathymetry data from Frey (1949). The vertical exaggeration is 70X.

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 in Fig. 13).

Land uses within the sub-basin include urban (Town of White Lake; the amount of impervious surface is indicated in Fig. 14) and agricultural (primarily blueberry farming, with numerous confined animal feed operations in the region).

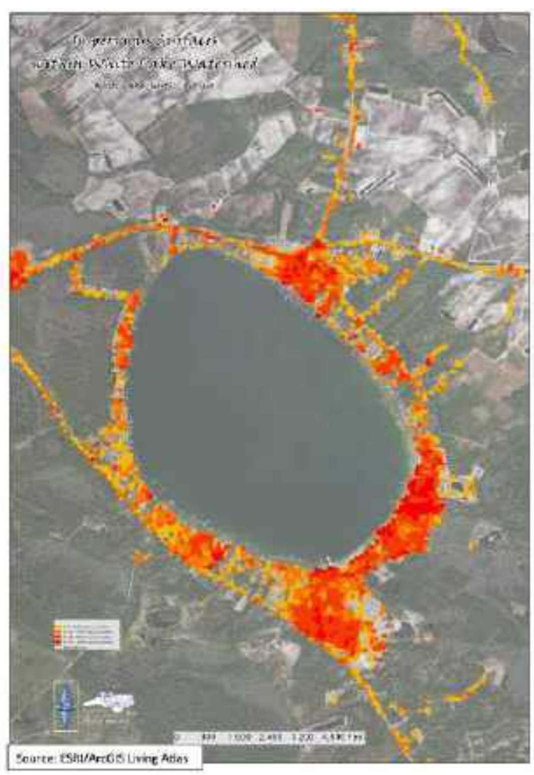

Figure 14. Impervious surfaces within the White Lake watershed in 2022, from the Lumber River Council of Governments.

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 NC Department of Transportation drainage ditches with culverts under White Lake Drive that drain approximately 50 acres on the east side of the road (Fig. 14).

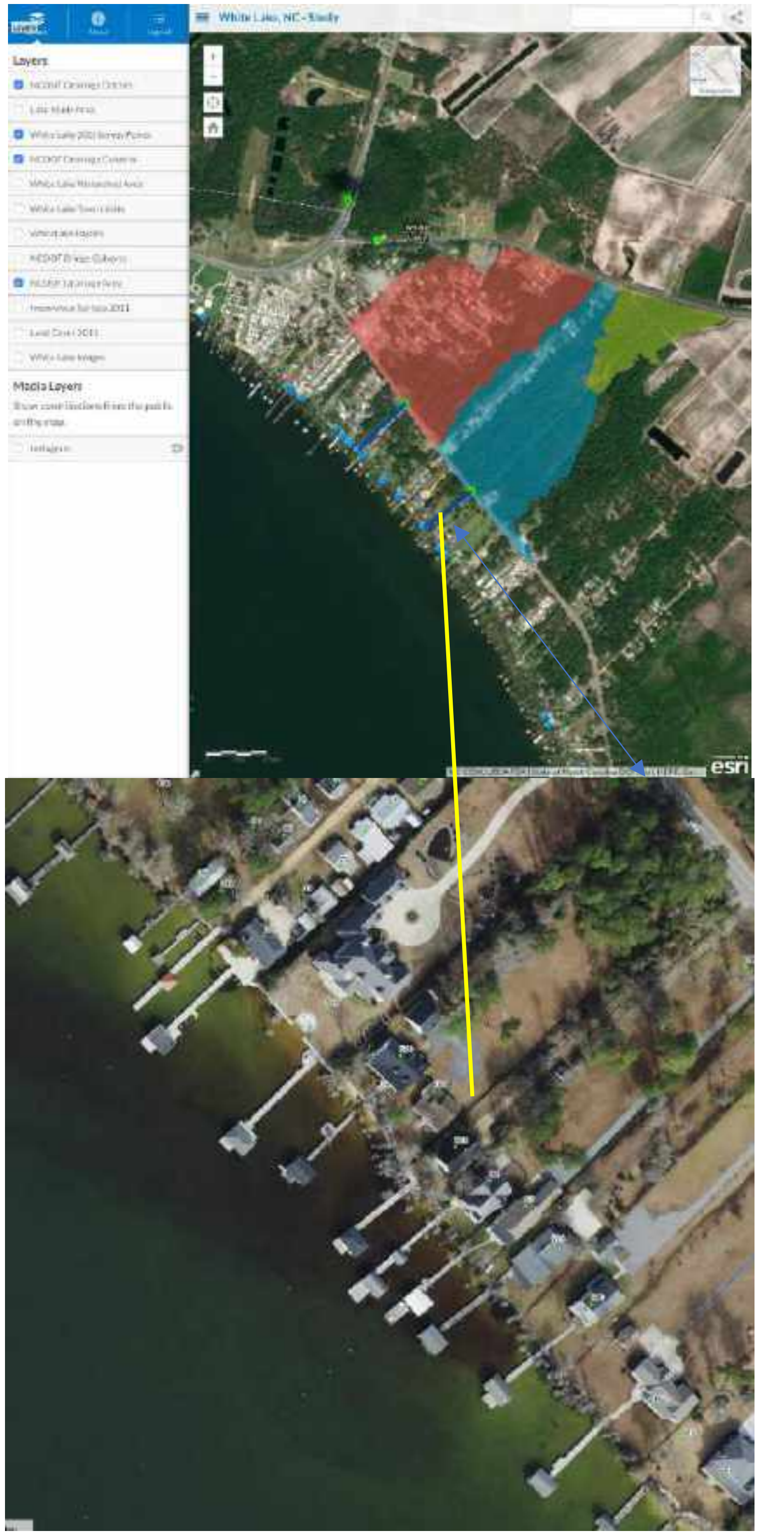

Figure 14. Top screen shot shows drainage area and location of two NC DOT drainage ditches on the eastern side of the lake (Lumber River Council of Governments 2019); bottom screenshot shows lower ditch at 580 White Lake Drive and the small plume of brown water along the lakeshore (https://gis.bladenco.org).

White Lake Groundwater Hydrology

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 (Fig. 15), while others have varied from year to year.

Figure 15. Screenshot of 2013 aerial photo of White Lake (https://gis.bladenco.org), showing the springs, which cluster around the 7-foot contour on the eastern shoreline. Rainfall in June and July of 2013 was very high.

David 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). He also noted that similar features were visible in the other Bay Lakes that he studied.

An observation of dye movement in a series of shallow wells adjacent to the lake led two 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). The authors were not hydrologists, 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, with their opinions about the springs in White Lake seemingly another nail in his coffin. Their paper introduced the idea that artesian spring flow into White Lake was somehow wholly separate from, and much greater than surficial aquifer flow, which fostered a long-standing misunderstanding about lake clarity, the source of the springs, and the relative importance of springs flow to the lake.

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). The US Geological Survey defines an unconfined aquifer as "an aquifer whose upper water surface (water table) is at atmospheric pressure, and thus can 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).

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.

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). This is illustrated in the US Geological Survey hydrogeological map (Fig. 16), where clay layers are black bands, and sand layers are in yellow in wells near White Lake (31 and 32 in Fig. 16) (Campbell and Coes 2010).

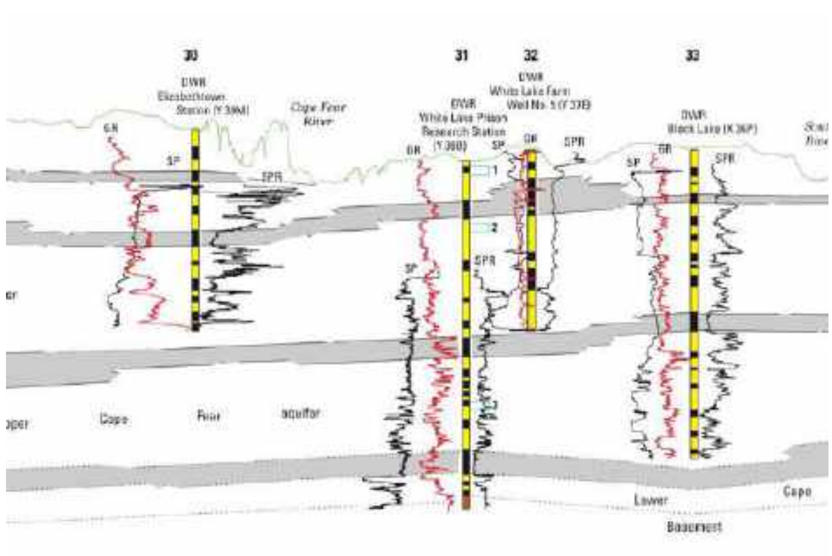

Figure 16. Close-up of a hydrogeological map of the area around White Lake, taken from Plate 5, Section G-G' in Campbell and Coes (2010). A pdf of this map is included in Appendix 1.

The relationship between 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. Their team placed nested piezometers around the lakeshore, including sites on the eastern and western sides of the lake. 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. 16) showed an increase in level which mirrored the rise in a shallower well situated above the clay layer at this location (E3; Fig. 17). After the heavy rainfall from Hurricane Florence in September 2018 groundwater levels responded quickly, as did the lake level, which increased >25 inches (Fig. 17 [Shank and Zamora 2019]).

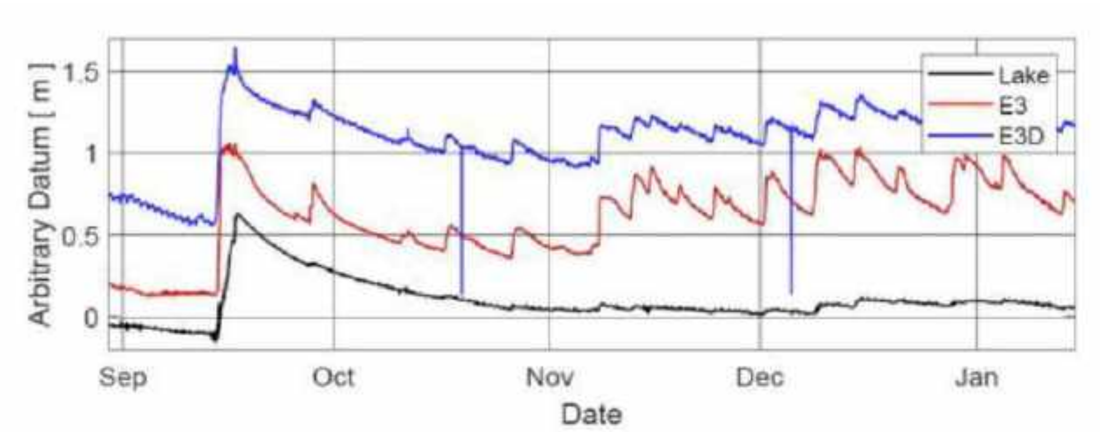

Figure 17. Groundwater levels at eastern shore well sites from August 2018 to January 2019; E3D indicates levels in a deeper well (below clay hardpan) while E3 indicates groundwater levels in a well situated above the clay layer. The black line indicates the lake level. Data from Shank and Zamora (2019).

The water table is generally closer to the surface on the western side of the lake, because of differences in topography and soil type, 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 related to rainfall, but the increases were moderate by comparison to the eastern shore (Fig. 18, from Shank and Zamora 2019; W1 is the closest to the lake and most closely mirrors lake level).

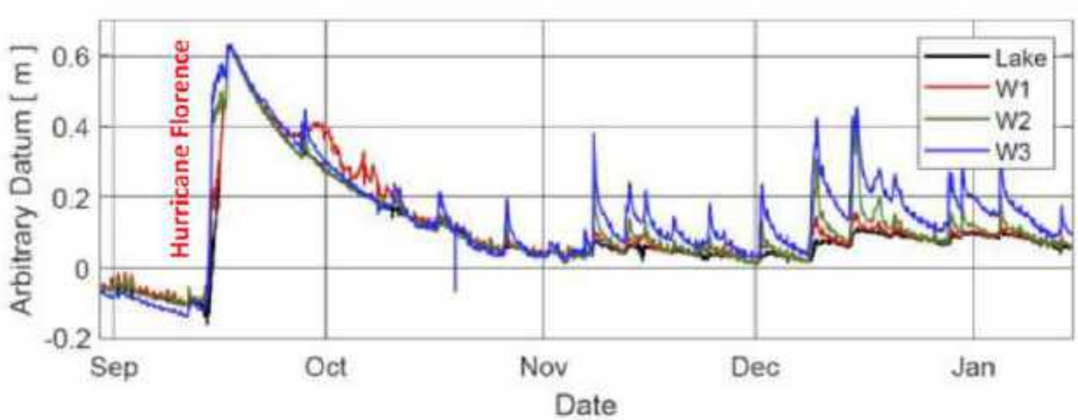

Figure 18. Groundwater levels at western shore well sites from August 2018 to January 2019; W1 is the shallow well closest to the lake and W3 is a shallow well furthest from the lakeshore, while W2is a shallow well midway between W1 and W3 (each of these wells were situated above the clay layer). The black line indicates the lake level. Data from Shank and Zamora (2019).

Based on groundwater modeling and isotope studies, Shank and Zamora (2019) concluded that most of the source water to White Lake is rainfall onto the lake surface (over 90% of the total), with variable (based on rainfall) but relatively low groundwater flow rates. Their modeling work accounted for all the conditions specific to the lake and its surroundings, with results indicating ta maximum of 6% of the total lake volume could come from groundwater.

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 their conclusion was that groundwater flows into the lake consist of surficial aquifer water (Shank and Zamora 2019). Surficial aquifer levels and flows around White Lake 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).

The higher the water table level is above the lake level, the greater the hydraulic gradient—the driving force to move groundwater into the lake. Water table elevations rise because of rainfall (and fall when there is a lack of it). Shank and Zamora (2019) found groundwater flow generally moved in the same direction as surface water flow (Fig. 19) and their model delineated the lake’s groundwatershed as an area smaller than the surface area of the lake (Fig. 20).

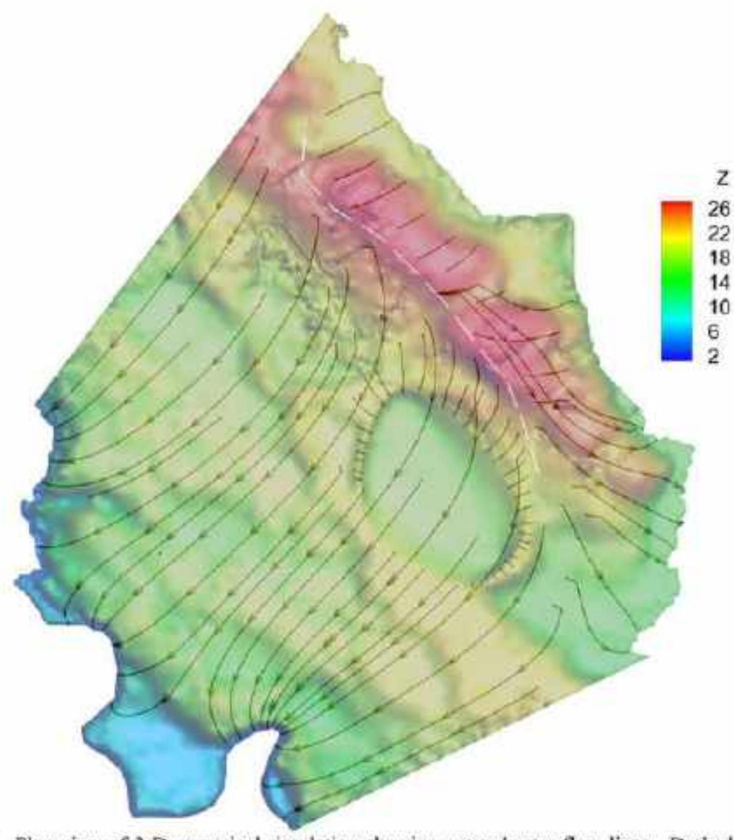

Figure 20. Plan view of 3-D numerical simulation showing groundwater flow lines. Dashed white line marks the flow divide: groundwater on the left side generally flows towards the Cape Fear River and groundwater on the right side generally flows towards Colly Creek. All flow lines begin at the terrain surface.

Figure 19. Simulation of groundwater flow lines, from Shank and Zamora (2019).

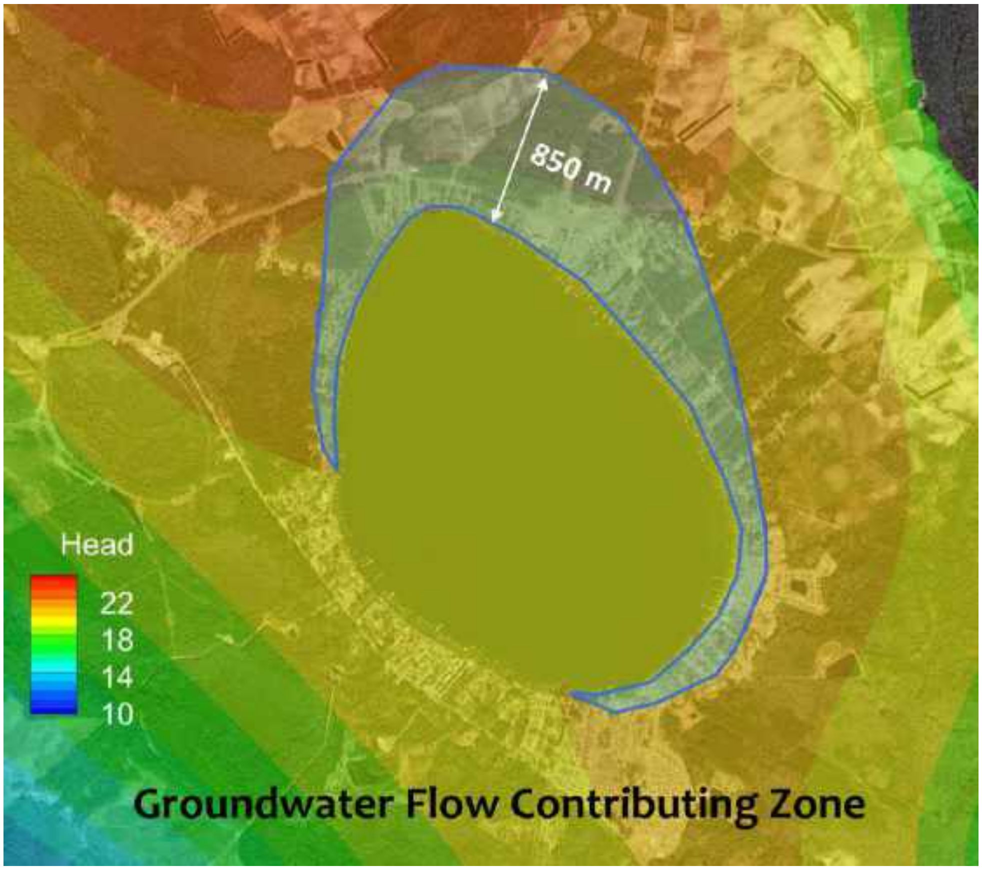

Figure 20. White Lake's groundwater contributing zone, from the Power Point presentation to the Town of White Lake, February 2019 by Chris Shank and Peter Zamora.

Groundwater flow interactions with White Lake are variable, depending on the dynamics between lake levels and water table levels. Shank and Zamora observed three types of conditions at different times during their 2018-19 study: flow-through, recharge, and discharge; these flow types have been described by various researchers, including Winter, Judson, Franke, and Alley in a 1998 publication (A-recharge, B-discharge, C-flow-through) at different times during their 2018-2019 study.

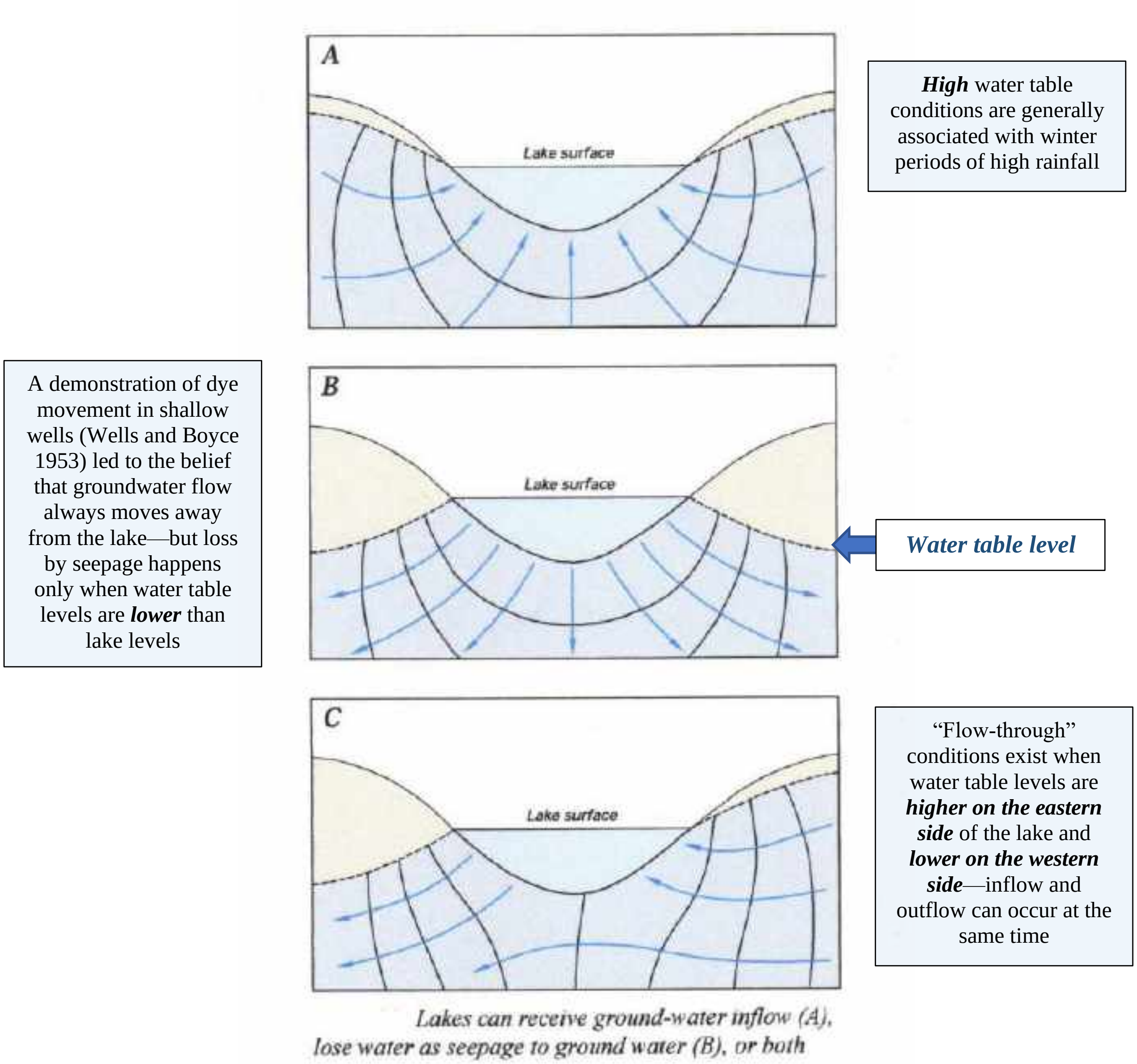

Figure 21. Reproduced from: Winter, T.C., W.H. Judson, O.L. Franke, and W.M. Alley. 1998. Ground water and surface water: a single resource. U.S. Geological Survey Circular 1139 https://doi.org/10.3133/cir1139 Annotations in adjoining text boxes not in the original figure.

A geohydrological synthesis was completed by Curtis Consolvo, under contract to the Lumber River Council of Governments, and his report, "Sources of Groundwater Supplying White Lake" is included in Attachment 6.

Changes in the Chemistry of Rainfall

A large number of studies were done in the U.S. in the 1970s and 1980s documenting the wide-spread occurrence of acid rain as well as its effects of on freshwater ecosystems (e.g., Schindler, 1988). In North Carolina, acid rain and fog greatly impacted terrestrial ecosystems in the mountains, where dead trees were commonly seen at higher elevations.

The National Atmospheric Deposition Program (NADP) developed a National Trends Network (NTN) for measurements of wet deposition with the nearest monitoring station to White Lake being found in Clinton, NC. A graph of pH over time (Fig. 15) shows that rainfall was quite acidic (meeting the definition of acid rain, at around 4.5 standard units) before the year 1990, which corresponds to the lake pH during that period (pH levels of 4.6-4.8 measured in 1974 [Weiss and Kuenzler, 1976]). There was a relatively rapid increase over the period 2008-2013, with values since 2013 hovering around 5.8 SU. During the 2013 NC DEQ monitoring of White Lake, the lowest pH measured was 5.6 SU, a 1-unit increase from what was seen in 2008 (NC DEQ 2014) (Fig. 16).

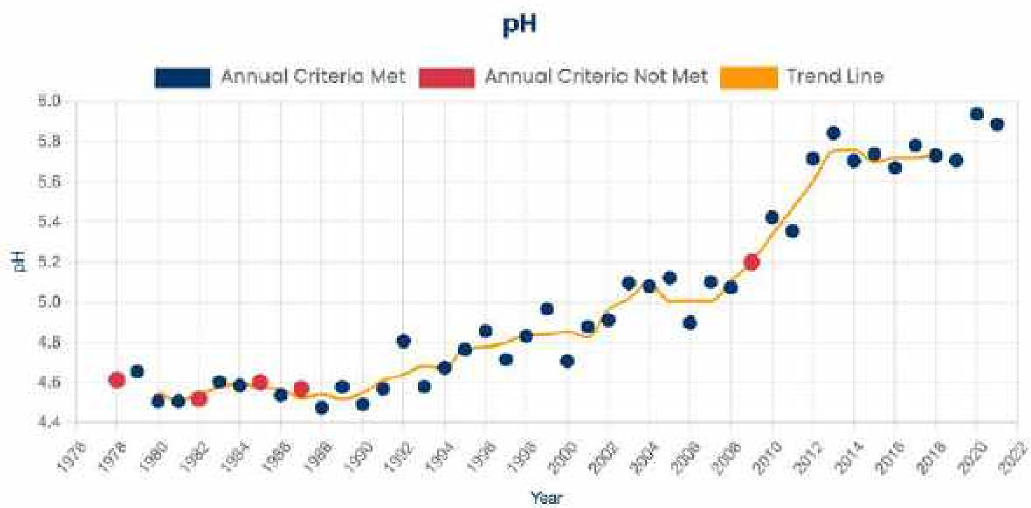

Figure 15. Annual rainfall pH at the National Atmospheric Deposition Program monitoring station NC35, Clinton, NC (http://nadp.slh.wisc.edu/NTN/maps.aspx).

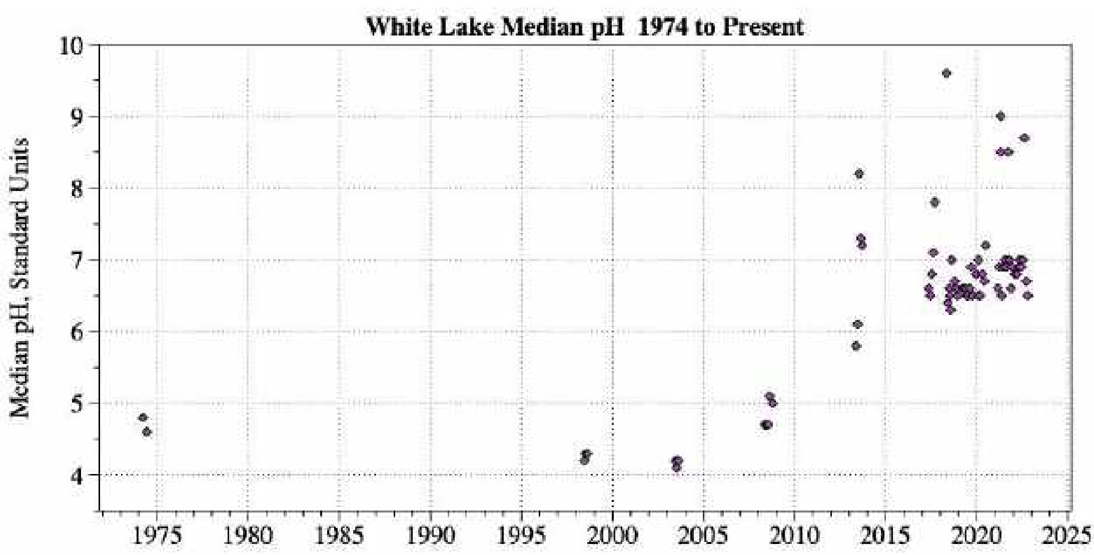

Figure 15. Median pH levels at White Lake. 1974 data from Weiss and Kuenzler (1976), 1998-2017 data from NCDEQ monitoring, 2018 to 2022 data from LIMNOSCIENCES monitoring.

North Carolina passed the Clean Smokestacks Act in 2002; this innovative and far-reaching legislation resulted in the two state electric utilities (the largest sources of acid rain pollution in the state) reducing their sulfur dioxide emissions by a combined 85% over a ten-year period (2002-2011), with an equivalent reduction projected by the largest "upwind" utility, the TVA, by 2015 (Andrews, 2013).

The reduction in sulfate deposition shows the inverse trend of pH, as this is an acidic substance and the primary contributor to acid rain; reductions measured at Clinton have been greater than 80% since 1990 (Fig. 16).

Figure 16. Annual SO_4 concentration (measured as mg/L) at NC35, from the National Atmospheric Deposition Program monitoring station at Clinton, NC. https://nadp.slh.wisc.edu/sites/ntn-NC35/

In the past, all of the water sources to White Lake—rainfall, surface runoff, groundwater--had similar and relatively low pH levels. Now that the acidity of the rainfall has changed, this is no longer the case, and the most acidic sources are surface runoff (from wetlands) and groundwater—both of which contribute a relatively low volume of water to the lake. The pH of the lake is therefore reflective of the primary water source—rainfall--and there is no indication that this has changed over time. The lake was acidic due to atmospheric deposition, not the influence of springs. Lakes in many parts of the US are seeing changes in pH as a result of the dramatic reductions in sulfate deposition over a relatively short period of time (e.g., Smol 2019).

Short duration increases in lake water pH are related to periods of increased primary productivity (e.g., Frey 1949, NCDEQ 2018, LIMNOSCIENCES 2021), as carbon dioxide (which acts as a weak acid in water) is used for algal and plant growth.

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Appendix 1.

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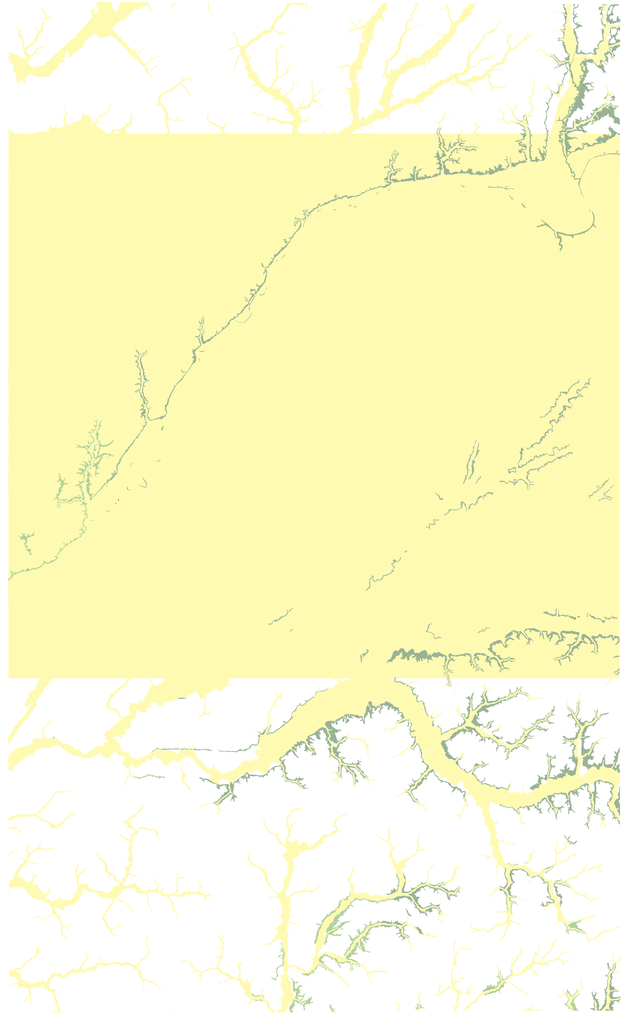

Appendix 2.

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).