

PART A: Examination of Groundwater Supplying White Lake

Summary of Key Findings

1. Sources of water supplying White Lake are precipitation and groundwater from the surficial aquifer. The extent to which the lake gains or loses water from/to groundwater varies with water table elevations/heads in the surficial aquifer surrounding and underlying the lake, and rainfall is the key factor affecting those.
2. Groundwater recharge at the higher land elevations to the northeast of White Lake provides a means for water table elevations to be substantially higher than lake levels. At times following recharge events, deeper flow lines can be expected for groundwater reaching the lake bottom from those elevations/distances versus recharge closer to the lake, such as from the sandy rim.
3. Water levels measurements, taken via a temporary well pipe, placed about 13 feet into the lake bottom at a known springs site, demonstrated that at times, there is a downward hydraulic gradient even in the vicinity of the known springs, with the lake level measured one foot higher than the stabilized water level in the pipe (which represented head levels in the surficial aquifer sands beneath the lake). With a downward hydraulic gradient at this location and depth, seepage losses are likely to occur at times across the entire lake bottom.
4. A clay hardpan layer is well-known to occur in most places around the lake perimeter, typically about 7-feet thick, from a depth near 5 to about 12 feet, extending some distance into the lake. The hardpan was not encountered at the springs site when the temporary well pipe was installed to a depth of 21 feet below lake level. It was also absent at the site of a deep well drilled east and uphill from White Lake, at an elevation of approximately 78 feet. If the hardpan is largely absent beneath the elevated land areas to the northeast and also absent beneath portions of the lake, the hardpan may act as a “caprock” for a distance in between, preventing underlying groundwater from discharging up to the lake bottom until it reaches the point where the hardpan pinches out or is otherwise breached. This may explain the unusual way in which groundwater discharges at times to the lake bottom in concentrated locations (versus in more typical lakes, where this occurs over broad areas of the bottom).
5. The lake (and hardpan) lies entirely within the surficial aquifer sediments. The clay confining unit that underlies the surficial aquifer is deeper in the surrounding region and was encountered at elevations of 10 to 32 feet at three local research sites (versus a typical lake level elevation of 64 feet, with bottom depths of about 8 feet in

deeper parts). That would equate to the confining unit being 24 to 46 feet below the lake bottom.

6. The effectiveness of the confining unit as a hydraulic barrier between the surficial aquifer and deeper Black Creek aquifer has been demonstrated by water level differences in monitoring wells at a nearby State research station, with surficial aquifer levels typically about 10 to 12 feet above Black Creek aquifer heads (potentiometric levels). The downward hydraulic gradient means a downward potential for flow. If the confining unit between the aquifers is absent or leaky beneath some area(s) of the lake, which is very unlikely, the surficial aquifer would drain downward into the Black Creek aquifer.
7. Leaks in the Town's sewer piping and manholes are capturing and transferring groundwater to the wastewater treatment plant. This groundwater entering the waste treatment system is called Inflow and Infiltration (I/I). A significant amount of this piping system underlies the sand rim surrounding the lake. This sand rim separates the lake from the elevated land areas to the northeast. A comparison of numbers for water being pumped from the Town's public water supply wells versus gallons discharged from the treatment plant from 1993 to 2008 shows that the differences averaged 227,644 gallons per month and exceeded 300,000 gallons for 54 months for the 109-month period. Greater differences tended to occur during/following months with higher precipitation and in seasons when the water table is typically higher (winter and spring) versus other times of the year.
8. Another concern is whether or not excavation depths for sewer replacements/repairs have removed or otherwise breached portions of the hardpan layer. If the hardpan functions as a caprock as described above, breaches could cause a reduction in groundwater pressure beneath the hardpan (at times when surficial aquifer heads are sufficiently high to impose pressure from higher elevations). This could potentially affect flow at the renowned springs and would mean a larger proportion of groundwater entering the lake/lake bottom from more shallow depths, nearer to the shoreline.
9. The Town of White Lake has been working to address this I/I problem in the sewer system. They are now in Phase 3 of a multi-phased approach to correct this I/I problem by replacing the decades-old pipe surrounding the Lake. This program to repair and replace leaky portions of the sewer system will have an overall effect of reducing the amount of groundwater captured in the sewer pipes and transported to the treatment plant, thereby allowing more groundwater to enter the lake. The extent of that impact will be difficult to gauge with future groundwater monitoring, with the repairs/replacements already underway and other variables, primarily rainfall.
10. The many ponds at the blueberry farms to the northeast and uphill from White Lake are likely to have an overall lowering impact on the water table because of land drainage and evaporative losses between precipitation events. These higher

elevation areas are where water table elevations can be substantially higher at times than lake levels, providing hydraulic gradients for groundwater discharge into the lake bottom. The extent to which hydraulic gradients are lessened by the ponds is difficult to assess without more information closer to the source and monitoring wells at deeper depths within the surficial aquifer.

11. For ponds that are pumped for irrigation or freeze protection, water table levels would be further lowered during pumping. However, if irrigation ponds are supplied by deep pumping wells screened in a confined aquifer such as the Black Creek, the impact to the surficial aquifer would depend upon levels maintained in the pond, with ponds contributing water to the surficial aquifer when pond levels are higher than the surrounding water table.
12. Impacts for most ditches at the blueberry farms would be similar to ponds, with many appearing (from aerial views) to function as long, narrow ponds, not connected to drainage areas other than nearby ponds. However, there is a long ditch to the north of White Lake that is an exception, draining to swamps that then flow to Turnbull Creek. The NC Division of Water Resources has considered whether or not it affects groundwater inflow to White Lake, noting that flow in the ditch has appeared to be constant, with the flow rate measured on one occasion at 750 gallons per minute. The topography suggests that the uplands being drained by this ditch may be too far north to affect White Lake, but possible impacts could be better assessed with monitoring wells north of White Lake and with ditch monitoring.
13. Well pumping from deep confined aquifers (the Black Creek and/or Upper Cape Fear aquifers) is not likely to have any impact upon groundwater inflow or outflow to/from White Lake. The lake is underlain by the surficial aquifer, which is separated from the deeper, Black Creek aquifer by a confining unit that is well-documented regionally and has an effectiveness that has been demonstrated locally. The Town of White Lake's public water supply wells utilize the Black Creek and Upper Cape Fear aquifers, and the wells at the blueberry farms likely do too. Drawdown impacts in the deeper aquifers, even at these close locations, should not affect White Lake at all.
14. There is an indirect way that deep, confined aquifer wells could affect groundwater inflow to White Lake. Deep wells could be a source of surficial aquifer drawdown if wells have not been properly sealed at depths of the confining unit. If no bentonite grout has been placed where the confining unit was encountered (and drilled through), the surficial aquifer could drain into the Black Creek aquifer via the well's gravel pack, lowering surficial aquifer heads and potentially impacting the lake. Unlike the short drawdown cycles that are typical for surficial aquifer wells, drainage from the surficial aquifer to the Black Creek aquifer via leaky wells would cause constant drawdown of surficial aquifer levels.
15. The impacts of pumping shallow wells (screened in the surficial aquifer) at properties surrounding the lake is likely to be minor, assuming the wells are for purposes such

as residential supply or irrigation and do not have substantial pumping rates/periods. Wells for higher yields will likely be screened in the deeper, confined aquifers, with the only risk being leaky seals, as previously mentioned. If any of the wells at the blueberry farms are screened in the surficial aquifer, there could be seasonal drawdown impacts to hydraulic gradients between the elevated areas and the lake, but it is more likely that these wells utilize the deeper, confined aquifers.

Background

GeoResources, PLLC was contracted by Lumber River Council of Governments (LRCOG) to review existing hydrogeological information and provide opinions regarding sources of groundwater supplying White Lake and factors affecting groundwater inflow. In addition, GeoResources was asked to outline plans for an additional study with “ballpark” costs that would be helpful in further characterizing sources of groundwater, the extent to which groundwater comprises overall water input to the lake, and the factors affecting that. Cost estimates provided herein are simply based on the author’s experience with other projects and do not represent a proposal or actual quotes. Opinions that follow are those of Curtis Consolvo, L.G., GeoResources, PLLC. No new data were collected for preparing this report.

Groundwater contributions to White Lake have been the subject of many studies. Some, such as the recent, extensive study by Shank and Zamora (2019), include evaluations of water quality in groundwater and lake water to learn more about flow between the two. This report focuses on groundwater flow in response to the hydraulic head differences/hydraulic gradients that drive flow and the strata through which flow occurs (or does not). Water quality characteristics, especially with respect to surface waters and biological factors are outside the expertise of this author and are left to be addressed in other parts of the larger LRCOG document in which this report is presented.

Shallow Groundwater Contributions

Flow interactions between the lake and groundwater

Sources of water supplying White Lake are precipitation and groundwater from the surficial aquifer. The lake is surrounded and underlain by the surficial aquifer, also known as the water table aquifer. The extent to which the lake gains or loses water from/to the lake bottom varies with the dynamics between lake levels versus water table levels/heads surrounding and underlying the lake. ***Rainfall is the key factor affecting both levels in the lake and in the surficial aquifer.***

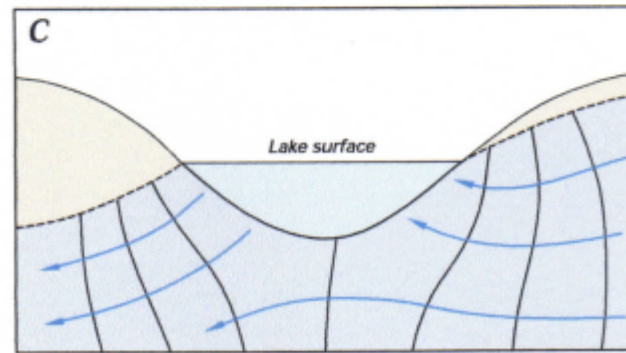
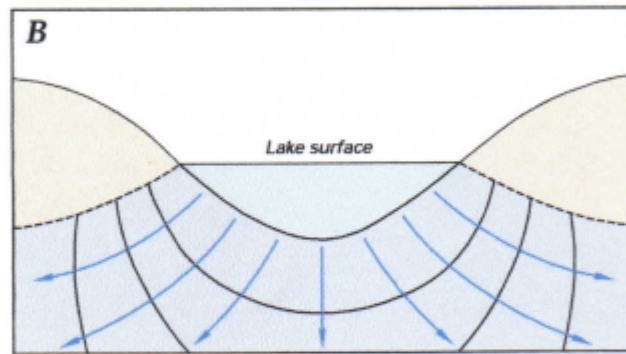
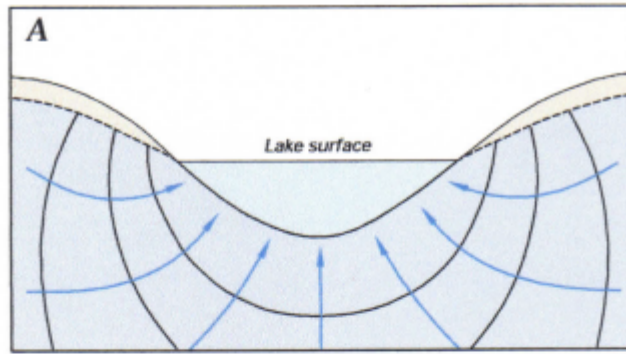
At times and in places where water table elevations surrounding the lake are higher than lake levels, hydraulic gradients provide the driving force for groundwater inflow to the lake bottom. The higher the water table, the greater the driving force, so that rainfall, and the effect of rainfall on table elevations, is the primary variable affecting how much groundwater enters the lake.

Differing types of flow interactions between groundwater and lakes are shown in a generalized diagram (**Figure 1**) by Winter and others (1999). Flow interactions at White Lake can vary between these, depending primarily upon rainfall. Results of an extensive study by Shank and Zamora (2019) indicate that groundwater inflow to the lake occurs from the north and east and water is lost from the lake to the southwest, most closely resembling diagram C (**Figure 1**). They also found that following heavy precipitation, the water table elevation, even at the southwestern edge of the lake, can briefly be elevated above the lake level, more closely resembling diagram A.

Flow variations at the springs

The variability of flow interactions between groundwater and White Lake has also been evident at the known/observed springs, with a long history of being active at times and inactive at other times. Frey (1949) described the springs as being “a number of round clean areas in a region where the sand is thinly covered with fine dark detritus”, with “centers about 8 inches lower than edges”. He describes the location as being offshore about the middle of the northeast side, which coincides with aerial photographs and anecdotal evidence of features that appear to be plumes of light-colored sand suspended in the water. He also describes that “the bottoms were hard, no bubbling as reported by other visitors could be observed through a water glass”. Wells and Boyce (1953) reported that Wells had observed sand “boiling over a number of orifices” many years earlier, but then later observed that “during times of extended drought the outlet stream came down to a mere trickle”.

Figure 1. Interaction of Groundwater and Lakes.



*Lakes can receive ground-water inflow (A),
lose water as seepage to ground water (B), or both*

Source: Winters and Others, 1999

In the summer of 2017, the NC Division of Water Resources (NC DWR) placed a temporary well into the lake bottom (from a boat) at a location about 1,175 feet from the northeastern shoreline approximately where springs have been observable at times. The springs were not visible from the boat at the time, and an aerial image showing what appears to be clouds of suspended sand (believed to represent spring sites) was used in combination with triangulating to shoreline features for siting the well (K. White, NC DWR, personal communication, August 1, 2022). The pipe was washed into place to a depth of approximately 21 feet below lake level, or about 13 feet below the bottom of the lake. The

water level in the well pipe stabilized at a level approximately one foot below the lake level, indicating a downward hydraulic gradient/seepage into the lake bottom.

The study by the NC DWR (2017) also found that water table elevations in nested monitoring wells at eastern and western edges of the lake exhibited downward hydraulic gradients throughout the summer/early fall monitoring period. Water levels were consistently higher in the shallower monitoring wells than in adjacent deeper wells (both depths were within the surficial aquifer). The data suggest that the downward hydraulic gradient evidenced at the springs site and resulting seepage losses to groundwater may occur at times across the entire lake bottom.

Contributing area for groundwater reaching White Lake

When and where water table levels in the land surrounding White Lake exceed lake levels, there is the potential for flow to the lake. As described by Heath (1983), “the water table is usually a subdued replica of the land surface”, and simply based on topography, the slightly elevated rim surrounding most of the lake and uphill areas extending to the northeast are the likely source areas for groundwater supplying the lake.

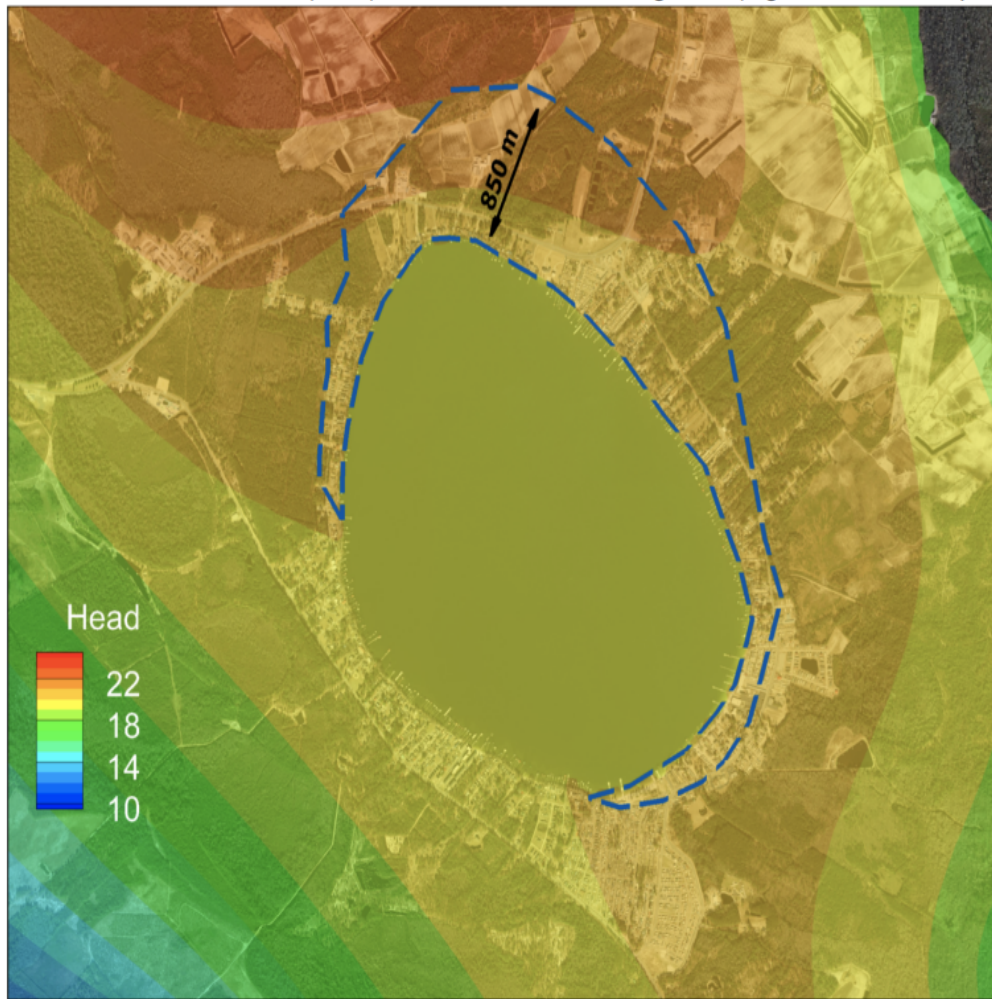
The hydraulic gradients surrounding and underlying the lake vary with lake levels and water table levels/heads, such that source areas for groundwater inflow will also vary, primarily with rainfall, but attempts can be made to determine the areas (and depths) that most often serve as sources of groundwater supply to White lake. Groundwater from deeper aquifers underlying the surficial aquifer is not a source of lake water, as discussed in the following section (Deeper Groundwater).

Shank and Zamora (2019) conducted an extensive, one-year study and delineated source areas for groundwater contribution to White Lake (**Figure 2**). These findings were supported by water level monitoring in the lake and in the surficial aquifer, water quality analyses, and hydrologic model simulations. Monitoring wells for water levels and quality were placed along transects extending away from the shoreline at multiple locations surrounding the lake. The contributing zone (**Figure 2**) generally conforms with topography, and Shank and Zamora (2019) incorporated LiDAR data for development of the surface terrain in their model. However, the topography, as it appears on a river basin boundary map, suggests that the contributing area may extend somewhat farther to the east (**Figure 3**).

Hardpan occurrences and possible explanation for unusual springs

A clay, “hardpan” layer is commonly encountered in the subsurface surrounding the lake and underlying portions of the lake bottom and extending a distance into the lake. Shank and Zamora (2019) found that it consistently occurred at depths of 5 to 12 feet around White Lake. The NC DWR encountered very hard clay at both east and west well nests

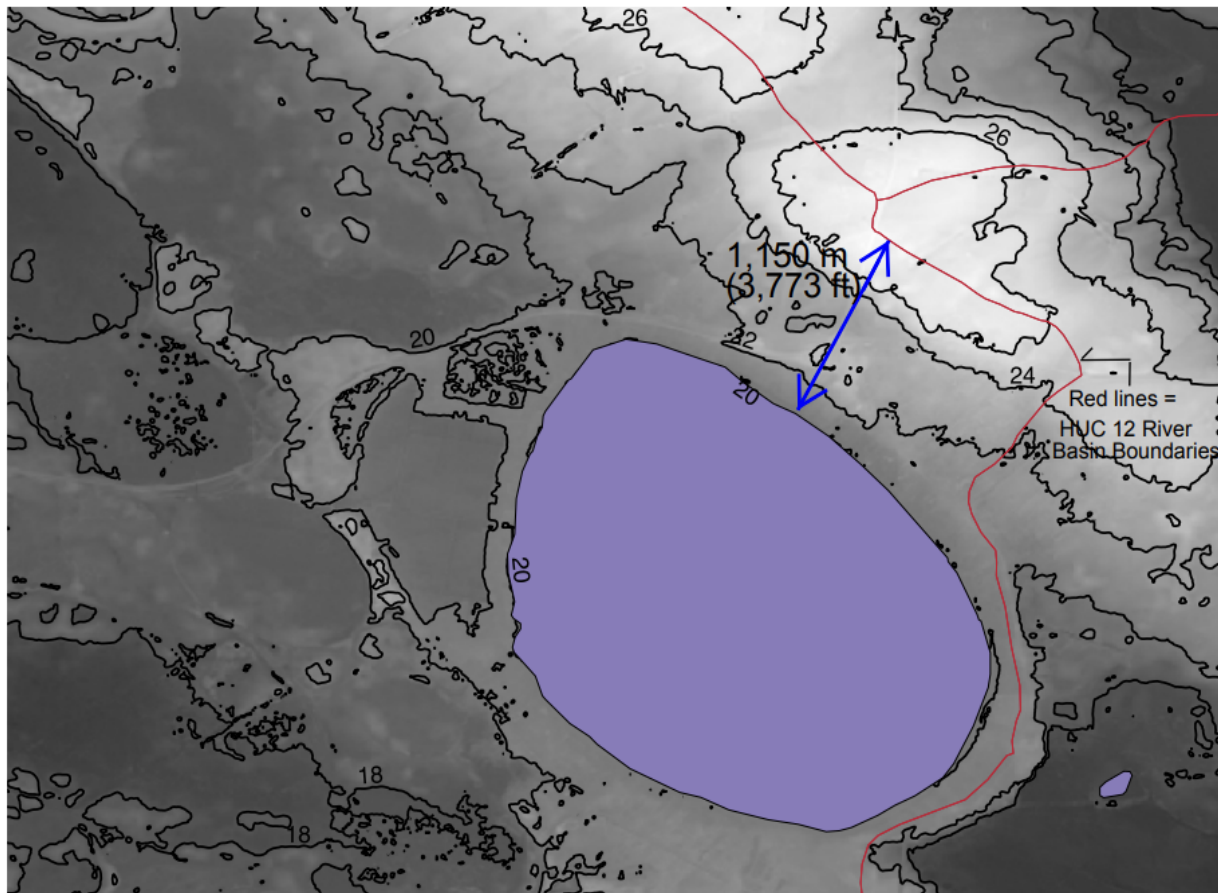
Figure 2. Groundwater Contributing Zone for White Lake (2019).



Source: Shank and Zamora

(each about 100 feet from the lake). Clay occurrences were similar at both sites, at a depth of 5 feet and continuing to a depth of approximately 13 feet, where it became mixed with sand that increased with depth to the bottom of the holes, at depths near 25 feet (K. White, NC DWR, personal communication, September 8, 2022). The hardpan is well known to pier/dock builders, with anecdotal accounts of encountering it all around the lake and using it as a base for piles (K. White, NC DWR, personal communication, September 8, 2022).

Figure 3. Additional Contributing Zone for White Lake (2019).



Source of base map is a figure prepared by the NC DWR (N. Wilson, personal correspondence, August 2, 2022). Contours are in meters, with a contour interval of 2 meters. HUC = Hydrologic Units Code (US Geological Survey)
20 meters = 65.6 feet 26 meters = 85.3 feet

The hardpan is evidently not continuous across the lake bottom, as it was not encountered at the approximate location of the known/observed springs when the NC DWR installed the temporary monitoring well, as previously described. The well pipe was easily advanced to a depth of 21 feet below lake level or about 13 feet below the bottom of the lake (K. White, NC DWR, personal communication, August 1, 2022). With a water depth of about 8 feet to the lake bottom in that location, the bottom elevation of the pipe was below the elevation of common hardpan occurrences at near the lake edges. That and the anecdotal accounts of a sandy bottom in other deep areas of the lake suggest that the hardpan is either absent or sharply dips/becomes deeper beneath central portions of the lake.

At a U.S. Geological Survey borehole site, approximately 2,100 feet west of White Lake and at an elevation of 71 feet along NC Highway 53, clay was encountered at a depth of 39 feet (elevation 32 feet), which was interpreted to be the base of the surficial aquifer (Weems and others, 2011). There apparently was no hardpan, as the only clay reported

in the drilling log above 39 feet is a 0.3-foot zone of clayey, silty sand, at a depth of 17 feet.

To the east and uphill of White Lake, at an elevation of approximately 78 feet, the hardpan was not encountered in a deep hole drilled for a Black Creek aquifer production well with the NC DWR on-site (K. White, NC DWR, personal communication, September 7, 2022).

With an apparent absence of the hardpan underlying the lake at the location of known/observed springs and with the hardpan not being encountered at a drill site uphill from the lake to the east, it is likely that groundwater flow from the east, and possibly northeast, contributes to White Lake via flow paths both above and below the hardpan. The flow above the hardpan has been documented by Shank and Zamora (2019) for discharging to the lake near the shoreline, but some portion of flow from the more distant, uphill recharge area to the northeast likely reaches the lake via deeper flow beneath the hardpan (along flow lines such as depicted in **Figure 1, C**).

The flow may be comparable to flow in a pipe, with higher head at the northeast end (via uphill water table elevations) and lower head (lake level) at the southwest end. Groundwater flow for a distance between those endpoints could be trapped between the hardpan and the confining unit at the base of the surficial aquifer, with upward discharge into the lake bottom prevented by the hardpan until flow reaches the point beneath the lake where the hardpan pinches out (or is otherwise breached). Discharge then may finally occur in concentrated areas of the lake bottom, making the “boils” boil at times when surficial aquifer heads are sufficiently higher than lake levels. More typical discharge (springs) at other lakes occurs over broader areas of lake bottoms, such that the discharge is not so distinctly observable.

Deeper Groundwater

The surficial aquifer in the vicinity of White Lake is underlain by a clayey confining unit that separates the aquifer from the deeper, Black Creek aquifer, as evidenced by studies of the regional hydrogeologic framework by Campbell and Coes (2010), GMA and Wooten (2003), and Winner and Coble (1996). A portion of a cross-sectional diagram by Campbell and Coes (2010), **Figure 4**, shows hydrogeologic framework interpretations at four NC DWR research sites. The two sites nearest to White Lake are those at the NCDOT Maintenance Facility research station and the White Lake Farm site (**Figure 5**). Water level data are available from the research station at the NCDOT Maintenance Facility for monitoring wells screened in the surficial, Black Creek, and Upper Cape Fear aquifers, and levels indicate a consistent, downward hydraulic gradient between aquifers (**Figure 4**).

The differing heads in each aquifer attest to the effectiveness of the confining units that separate them. Levels in the Black Creek and Upper Cape Fear wells rise above the tops of their confining units (representing the potentiometric surfaces/heads of these aquifers), but levels are still lower than surficial aquifer levels/heads. The downward hydraulic gradient means there is a downward potential for flow. Under these hydraulic conditions,

Figure 4. Regional Hydrogeologic Framework at White Lake (2010).

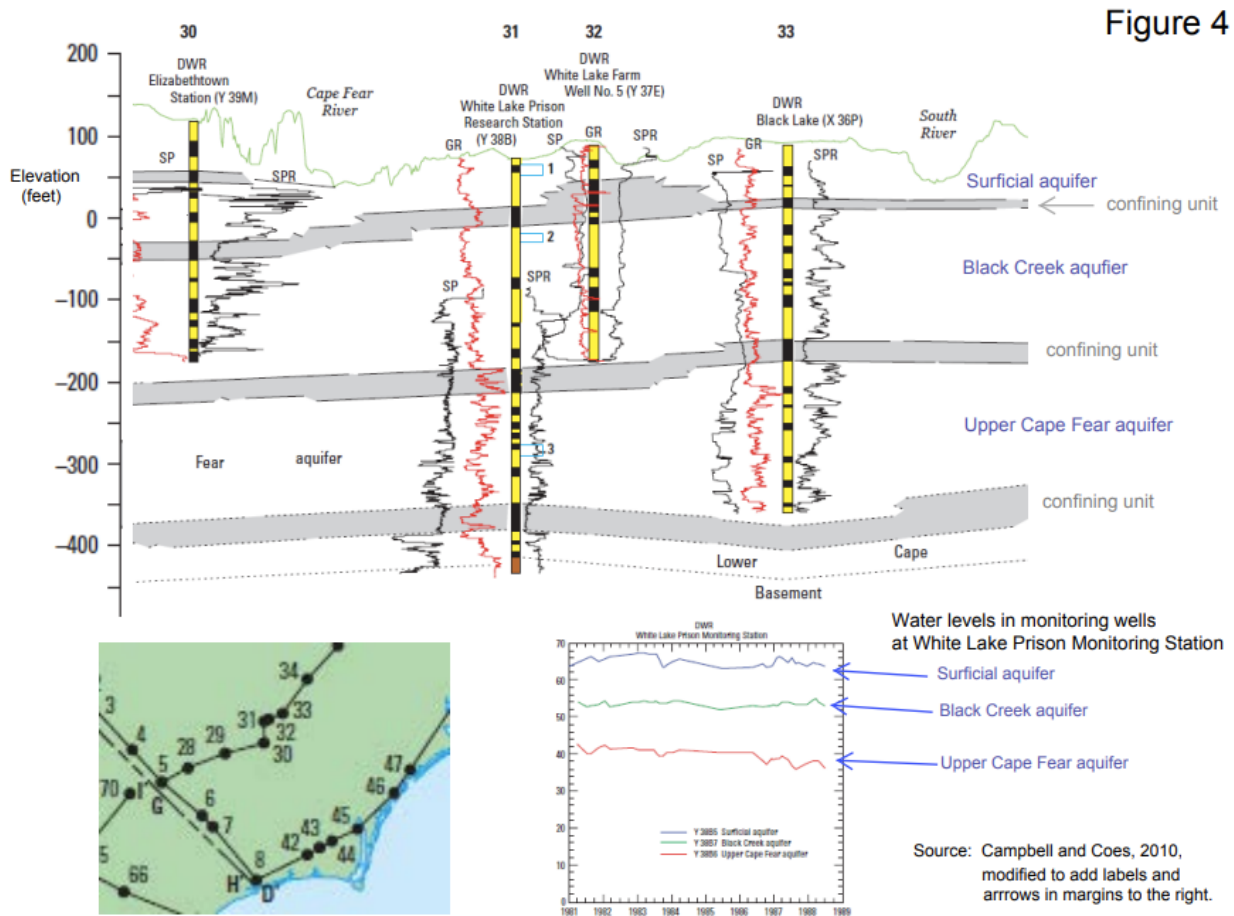


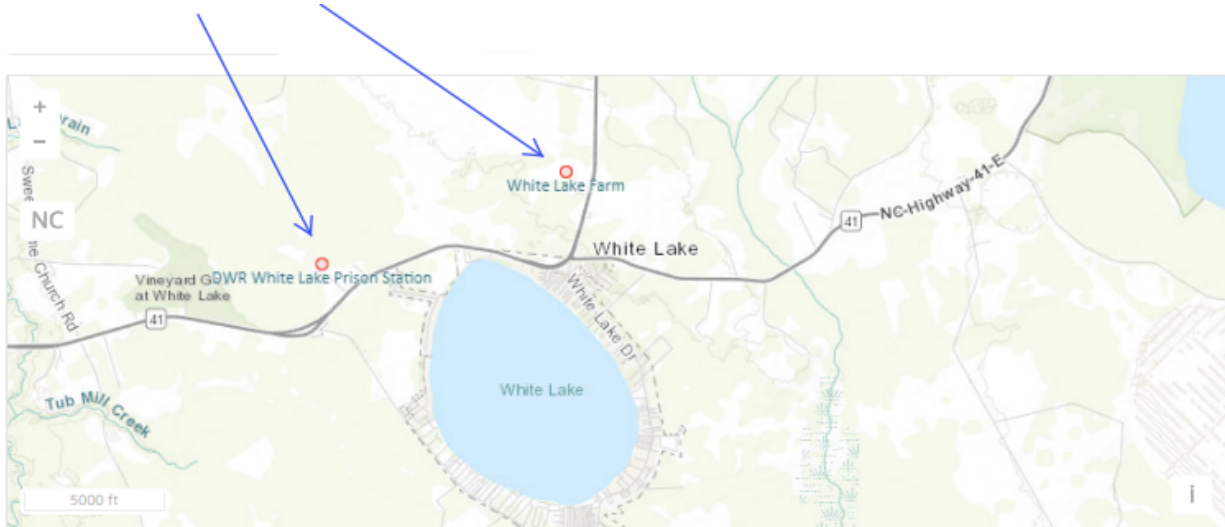
Figure 4

wherever (and to whatever extent) leakage may occur across the confining unit, flow will be downward.

Water levels from **Figure 4** for surficial and Black Creek aquifer wells are shown at expanded scales in **Figure 6**. Elevations for Black Creek aquifer levels remained between 52 to 55 feet from 1981 to 1989, typically about 10 to 12 feet lower than surficial aquifer levels. Recent data from these monitoring wells are not available, with the research station having been abandoned (N. Wilson, NC DWR, personal communication, September 12, 2022). A review of the NC DWR's Groundwater Level database (<https://www.ncwater.org/?page=343>) indicates that 2022 levels from more distant Black Creek aquifer monitoring wells are lower throughout the general region than levels from 1980s at the NC DWR's site at the NCDOT Maintenance Facility.

Geophysical logs for the NC DWR's sites at the NCDOT Maintenance Facility and White Lake Farm are shown with hydrogeologic framework interpretations by the NC DWR on **Figures 7 and 8**. Depths to the top of the confining unit at the base of the surficial aquifer are approximately 60 feet (NCDOT site) and 55 feet (White Lake Farm). Both depths equate to an elevation of 10 feet. The thickness of the confining unit is approximately 25 feet at both sites (note that **Figures 7 and 8** vertical scales differ, so it is not immediately apparent that thicknesses are nearly identical).

Figure 5. Locations of NCDWR Research Stations Nearest to White Lake.



Source: modified from the NC DWR on-line Hydrogeological Framework database: <https://www.ncwater.org/?page=348>

The previously mentioned borehole drilled by the U.S. Geological Survey (Weems and others, 2011) along NC Highway 53, west of White Lake, encountered a clay layer at a depth of 39 feet (elevation 32 feet). The clay was interpreted as being the base of the surficial aquifer, which is equivalent to the top of the Black Creek aquifer confining unit. The 32-foot elevation puts it 22 feet higher than it was encountered at the NC DWR sites. The clay continued to the hole's terminal depth at 56 feet, equating to a confining unit thickness of at least 24 feet, versus the 25-foot thickness at both NC DWR sites.

Elevations for the base of the surficial aquifer (10 feet at both NC DWR sites and 32 feet at the U.S. Geological Survey site) would put it about 32 to 54 feet below typical lake levels, if depths to the confining unit are consistent beneath the lake (and based on a lake level elevation of 64 feet). For an 8-foot depth to the lake bottom (in deeper portions of

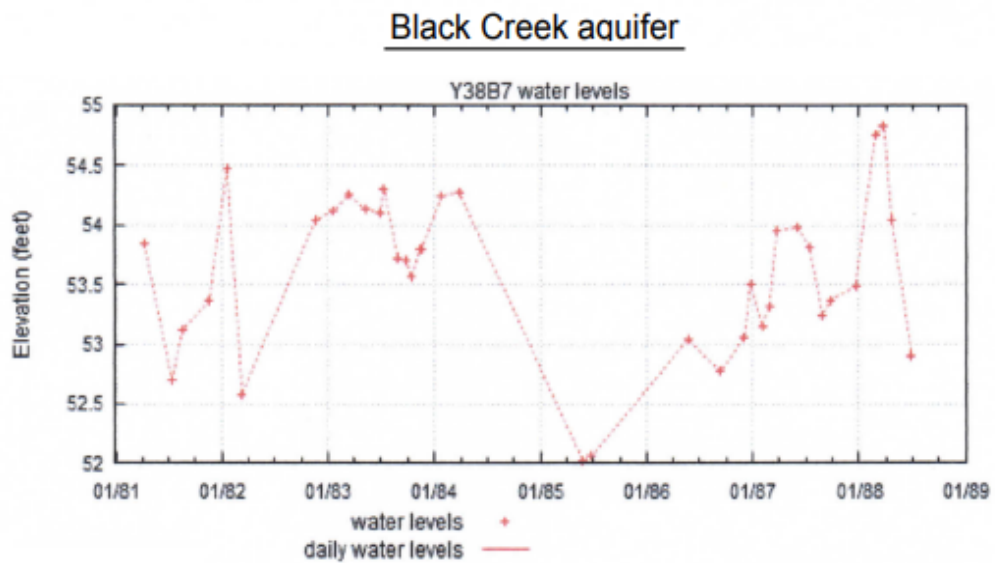
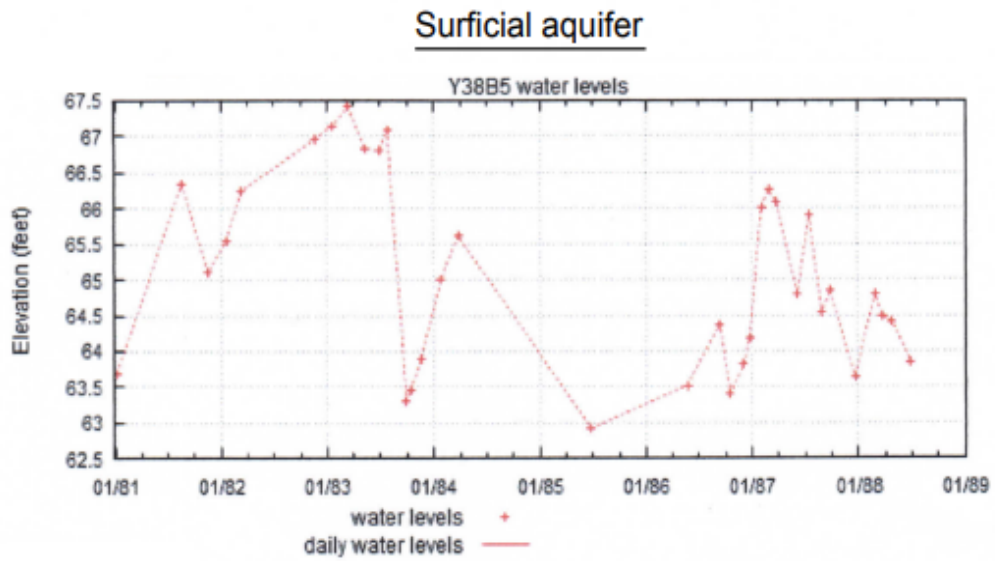
the lake), the thickness of the surficial aquifer beneath the lake bottom would be 24 to 46 feet.

The likelihood that the confining unit is present and continuous beneath White Lake and the surrounding area is supported by the unit's well-recognized presence on a regional basis and by confirmation of its presence at the local sites described above. Stronger evidence is the differences between water levels in surficial and Black Creek monitoring wells, demonstrating the effectiveness of the confining unit as a hydraulic barrier in the vicinity of White Lake.

In addition, Shank and Zamora's (2019) evaluations of radon concentrations and also strontium, oxygen and hydrogen isotopes also support that a deeper confined aquifer is not contributing groundwater to White Lake.

If there were an area beneath the lake where the confining unit is absent or especially thin or permeable/leaky, the downward hydraulic gradient would dictate that groundwater flow is from the surficial aquifer to the Black Creek aquifer. The opposite hydraulic gradient (an upward gradient) would be needed for the reverse to occur (Black Creek aquifer flows into the surficial aquifer or somehow directly into the lake bottom). At times when, and at places where, groundwater discharges into White Lake, the source of that groundwater is the surficial aquifer.

Figure 6. Water Levels in Monitoring Wells at NCDWR NCDOT Maintenance Site in White Lake.



Source: Both hydrographs copied from the NC DWR Groundwater Level Database: ncwater.org/page?343

Figure 7. Well Logs, NCDWR at NCDOT Maintenance Site in White Lake.

Field	Data
County	Bladen
Latitude	34.655278
Longitude	-78.522500
Location Accuracy	Map
Quad	Y 38B
Land Surface	70.00
Dates	02/06/1981
Source	DWAR

[click on each log chart to access complete log](#)

log legend

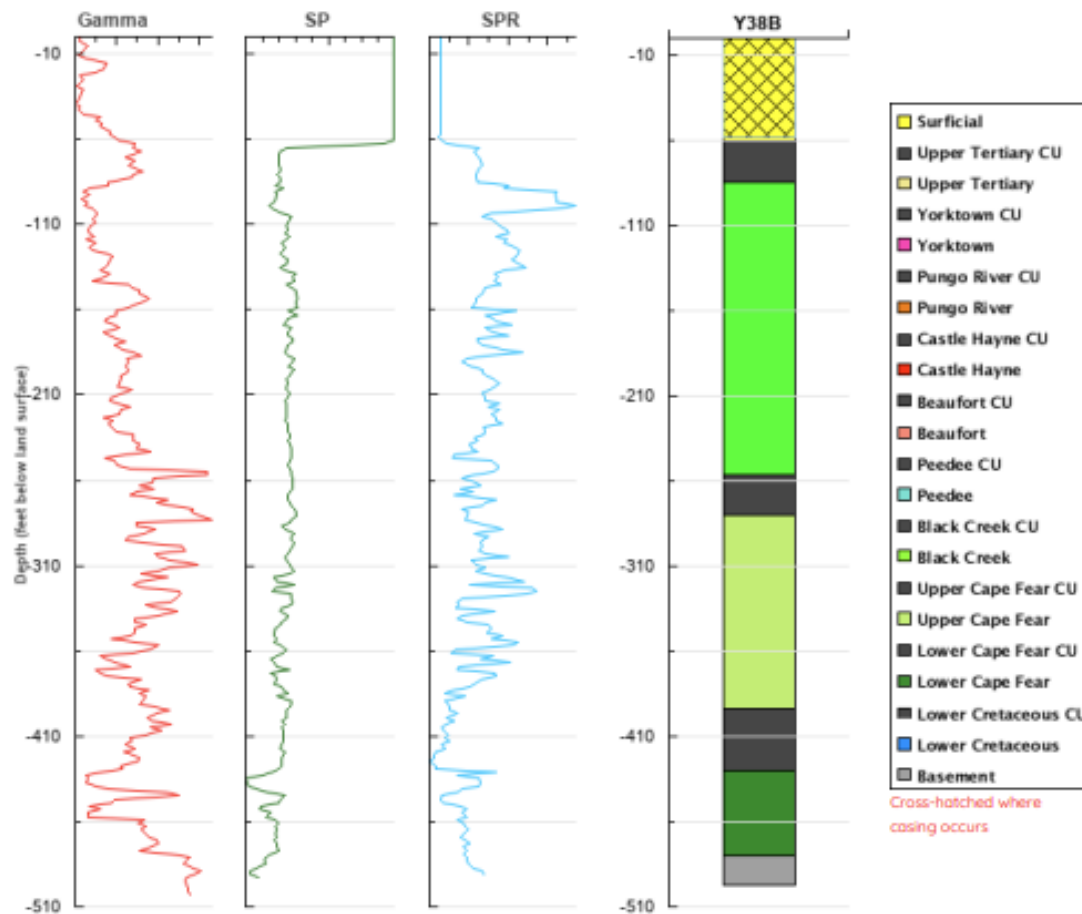


Figure 7

White Lake Prison

Yellow = Surficial aquifer

Black = Confining unit

Lime Green = Black Creek aquifer

Figure 8. Well Logs, NCDWR Farm Site near White Lake.

Field	Data
County	Bladen
Latitude	34.664444
Longitude	-78.493609
Location Accuracy	Map
Quad	Y 37E
Land Surface	85.00
Dates	01/06/1984
Source	DWAR

[click on each log chart to access complete log](#)

log legend

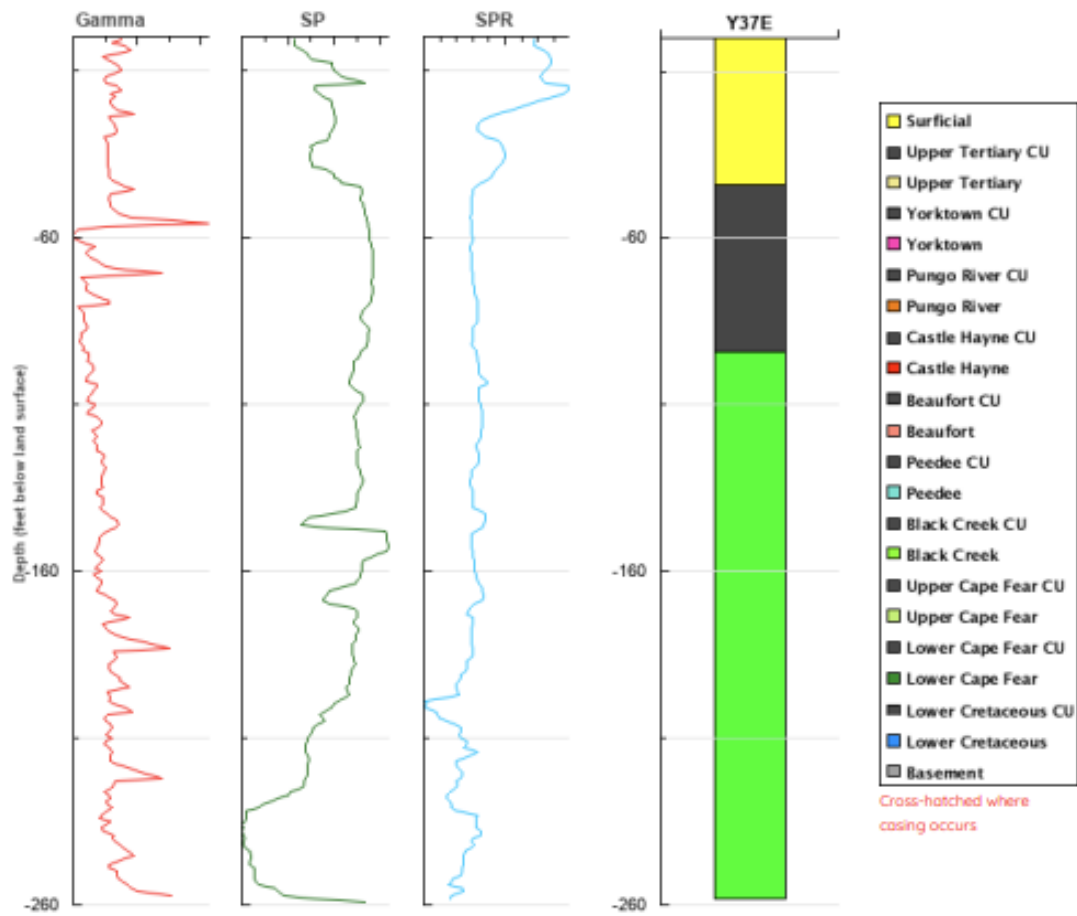


Figure 8

White Lake Farm

Yellow = Surficial aquifer

Black = Confining unit

Lime Green = Black Creek aquifer

Impacts of Drainage Features and Pumping Wells

Any lowering of the water table within those areas that contribute groundwater at times to White Lake, as characterized by Shank and Zamora (2019), reduces the hydraulic gradient that is the driving force for the surficial aquifer to discharge into the lake. In these areas, when the water table elevation exceeds lake-level elevation, there is potential for groundwater flow into the lake. **The lower the water table elevation, the lower the potential.**

Water table elevations vary primarily with rainfall, but also with the factors discussed below. The extent to which each of these affects water table elevations is unknown and will be difficult to determine or to characterize with much degree of certainty, even with extensive studies and monitoring. They are listed below in order of most-to-least impact based upon this author's opinion from reviewing and considering existing information for preparation of this document.

Sewer system leaks:

Leaks in the Town of White Lake sewer system act as a drain that captures and transfers groundwater to the wastewater treatment plant. This lowers the water table, lessening the hydraulic gradient needed for groundwater flow into the lake/lake bottom. A map of the system by ES Engineering Services (2022) shows that the sewer system encircles most of the lake and underlies the surrounding sand rim that comprises much of the groundwater contributing zone delineated by Shank and Zamora (2019). Much of the sewer system lies between the lake and the elevated land areas to the northeast, intercepting some portion of groundwater from this area.

Another concern is whether or not excavation depths for sewer installations or repairs have removed or otherwise breached the hardpan layer. The NC DWR found in their 2017 study that the hardpan clay started at a depth of 5 feet and became mixed with sand at 13 feet at both their east and west monitoring well sites, each about 100 feet from the lake shore (K. White, personal communication, September 8, 2022). If the layer has been breached by sewer excavations, a reduction in groundwater pressure from below the hardpan could affect the springs (see Shallow Groundwater section, Hardpan subsection).

The groundwater discharged/transferred through the gaps from below the hardpan to above the hardpan is still likely to discharge into the lake, joining other groundwater that started off above the hardpan from recharge areas closer to White Lake. This would mean a larger proportion of groundwater entering the lake/lake bottom from more shallow depths and nearer to the shoreline. Beyond the dampening inflow at the renowned springs sites, the mixing with more shallow groundwater and discharging closer to shore may have lake water quality and biological implications (not addressed herein).

A comparison was made by the NC Division of Water Resources of gallons pumped from Town of White Lake public water supply wells, gallons discharged from the Town's wastewater treatment plant, and precipitation for the period from January 1993 to March 2008 (N. Wilson, personal communication, August 30, 2022). The volume of wastewater exceeded the water supplied to the town nearly every month (185 months out of the 197 sampled), with the excess water averaging 227,644 gallons per month (based on monthly averages). The difference was more than 300,000 gallons for 54 months for the 109-month period.

It is apparent that the difference represents groundwater draining into sewer system leaks, with greater differences tending to occur during/following months with higher precipitation and in seasons when the water table is typically higher (winter and spring) than other times of the year. Sewer system gains tended to be less, and at times even reversed (with wastewater leaking out versus groundwater leaking in) during summer months. This coincides with times when public water use is greatest and the water table is typically relatively low, though reversals only occurred during 5 summers out of the 15 included in the data set. For most summers, groundwater losses to the sewer system appear to have been still occurring. The overall effect of the sewer system throughout the year and even during most summers is to drain groundwater, thus lowering the water table and reducing the hydraulic gradient for groundwater to discharge into the lake.

The current program to repair and replace leaky portions of the sewer system will have an overall effect of allowing more groundwater to enter the lake. The extent of that impact will be difficult to gauge with future groundwater monitoring, with the repairs/replacements already underway and other variables, primarily rainfall.

Ponds and ditches:

A large number of ponds and ditches have been excavated at the blueberry farms to the north and east of White Lake (**Figure 9**). These areas at higher land elevations (**Figure 3**) are where water table elevations are substantially higher at times than lake levels and provide hydraulic gradients for groundwater discharge into the lake bottom, such as shown in the (generalized) diagram, **Figure 1, C**. The ponds and ditches appear to be primarily for land drainage, with a fewer number appearing to be equipped with irrigation pumps (simply from overhead images). Between periods of precipitation, ponds typically cause a lowering of the water table because of evaporation, with inflow to the pond from the surficial aquifer.

For ponds that are pumped for irrigation or freeze protection, water table levels would be further lowered during pumping; however, if irrigation ponds are supplied by deep pumping wells screened in confined aquifer(s), the impact to the surficial aquifer would

depend upon levels maintained in the pond, with ponds losing water to the surficial aquifer when pond levels are higher than the surrounding water table.

The ponds likely have an overall impact of lowering the water table because of land drainage and water table discharge to ponds in response to evaporative losses between precipitation events. During rainy periods, ponds and ditches may temporarily fill to levels above the surrounding water table and contribute water to the surficial aquifer, but not likely any more so than the recharge that the surficial aquifer would have otherwise received.

Ditches in these areas north and east of White Lake (**Figure 9**) appear to either function as elongated ponds or to flow short distances to nearby ponds. These ditches, like ponds, can be expected to have an overall lowering effect on the water table because of land drainage and evaporative losses between precipitation events.

The long ditch (**Figure 9**) is outside of Shank and Zamora's (2019) contributing zone, but the NC Division of Water Resources has considered whether or not its drainage has affected groundwater inflow to White Lake. The ditch flows to the swamps to the west, which drain to Turnbull Creek, and flow in the ditch appears to be constant, based on observations by the NC DWR at varying times over a number of years (K. White, personal communication, August 1, 2022). Constant flow would indicate that the ditch receives groundwater discharge even when rainfall and water table elevations are minimal, with the ditch serving to drain shallow groundwater from the upslope areas east of the ditch and north of White Lake. The flow rate in the ditch was estimated to be 750 gallons per minute on one occasion when the NCDWR took measurements at a culvert (K. White, personal communication, August 1, 2022).

Based on topography, the land areas drained by the ditch may be too far north of White Lake for lowering of the water table there to impact groundwater flow to the lake. But monitoring wells between White Lake and the ditch and/or the area that topography suggests is drained by the ditch (east of the ditch) would be helpful toward determining whether or not the ditch affects groundwater inflow to White Lake.

Ditches just west of White Lake are topographically lower than the sand rim that separates the area from the lake and falls outside of the groundwater contributing zone determined by Shank and Zamora (2019), **Figure 2**. The effect of lowering the water table in this area would be to increase the hydraulic gradient between this area and the lake, potentially increasing the rate of water loss to seepage in western portions of the lake bottom (the left side of **diagram C, Figure 1** provides an example of the setting). The extent to which seepage is increased largely depends upon the effectiveness of the ditching in draining land and lowering water table elevations and may be difficult to determine.

Figure 9. Ponds and Ditches to the North of White Lake.



Source: Google maps

Well Pumping:

Well pumping from deep, confined aquifers (the Black Creek and/or Upper Cape Fear aquifers) is not likely to have any impact upon groundwater inflow to White Lake. The lake lies entirely within surficial aquifer sediments. The base of the aquifer (top of the confining unit) has been identified at nearby NC DWR sites and by Weems (2011) at elevations equating to depths of 24 to 46 feet below deeper parts of the lake bottom (see preceding *Deeper Groundwater section*).

If, contrary to this evidence, the confining unit between the aquifers is absent or leaky beneath some area of the lake, there would be a greater potential for loss from the lake, as the underlying surficial aquifer would drain downward into the Black Creek aquifer in response to the lower heads at the deeper depths. With no effective confining unit, Black

Creek aquifer pumping would increase the downward hydraulic gradient even more between aquifers.

More information about depths and thicknesses of the confining unit could be learned from records for the Town's three public water supply wells, if drilling and/or geophysical logs are available. Screen depths for the three wells are listed at depths ranging from 154 to 392 feet on the Town's 2021 Local Water Supply Plan (NC DWR, 2021), so each was drilled through depths where the confining unit occurs at the two NC DWR research sites (**Figures 5, 7, and 8**) and was encountered by Weems and others (2011) west of White Lake.

Town wells were determined by GMA and Wooten (2003) to utilize the Black Creek and Upper Cape Fear aquifers. Distances from the wells to the lake range from about 700 to 2,750 feet, located to the north, northwest, and south of the lake (distances estimated from a map by GMA and Wooten, 2003 and from Google Maps). **Based on the existing evidence of an effective confining unit, Town well pumping does not likely have any impact upon groundwater inflow to White Lake.**

Wells for the nearby blueberry farms typically utilize deep aquifers (K. White, NC DWR, personal conversation, September 6, 2022). Like the Town wells, any of these wells screened in the deep, confined, Black Creek or Upper Cape Fear aquifers are not likely to have any impact upon groundwater inflow to White Lake. Wells screened in the surficial aquifer could have an impact by lowering water table elevations, as described for ponds and ditches at those elevations.

There is an indirect way that deep confined aquifer wells could affect groundwater inflow to White Lake. Surficial aquifer levels could be drawn down if wells have not been properly sealed at depths of the confining unit. If no bentonite grout has been placed where the confining unit was encountered, the surficial aquifer could drain into the Black Creek aquifer, lowering surficial aquifer heads and thus potentially impacting inflow to the lake.

This can occur through the well's gravel pack, in the annular space between borehole walls and casing. Remnant drilling fluids (drilling "mud") in the gravel pack can act as a seal to some extent for a time, but under the downward hydraulic gradient that is evident near White Lake between the surficial and Black Creek aquifers, the remnant muds may have fully flushed down and out over time, creating a drain. The hydraulic gradient between the aquifers would be amplified in close proximity to the wells because of pumping drawdown in the Black Creek aquifer. Unlike the shallow wells discussed below for residential uses, drawdown in the surficial aquifer would be constant, and recommendations (next section) include ways to address this possibility.

Wells screened in the surficial aquifer at properties surrounding the lake likely have some impact to groundwater inflow to the lake, but pumping rates and durations for residential supply or irrigation purposes are typically low/short and effects are likely to be minor. Larger wells screened in the surficial aquifer with more substantial pumping rates/periods, such as for commercial purposes, would be more impactful, but these wells are more likely screened in the Black Creek and/or Upper Cape Fear aquifers, so that impacts would not be expected unless wells are improperly sealed at confining unit depths, as discussed above.

Recommendations

These recommendations are specifically regarding groundwater inflow to the lake and are meant to accompany the other recommendations in the larger document in which this report is to be presented. Plans for a study to learn more about groundwater flow and the extent of impacts are presented as an appendix and are listed below as a third recommendation, but the first two recommendations are actions that the Town could take in the shorter term to address two of the concerns raised in this report.

Sewer system repairs and hardpan

The Town should meet with sewer system engineers/contractors and discuss concerns about excavations penetrating through the bottom of the hardpan layer, asking if contractors have been breaking through the hard layer and experiencing rising water levels or having to increase dewatering efforts. The rising levels would more likely be evident in winter/spring months and following rainfall periods. If this has happened or is happening now, possibilities for minimizing excavation depths should be discussed. Where breaches have already happened or are necessary, the feasibility of sealing gaps with an impermeable grout should be explored. Perhaps bentonite grout could be used as a base layer (below otherwise permeable backfill materials) across the bottoms of trenches/other excavations to bridge gaps and recreate a continuous layer of impermeable material.

Check Town well records for drilling/geophysical logs and bentonite seals

The Town's public water supply well records should be checked to see if drilling logs or geophysical logs are available. Those logs would reveal more information about the confining unit between the surficial and Black Creek aquifers at locations closer to the lake than the research sites discussed herein. Record searches should also target any logs from test wells or older wells that have been replaced. Depths and thicknesses of the confining unit should be evident from the logs. If no logs are available, gamma logging could be conducted inside the casing, with more logging options if casings are PVC (versus steel).

Records should be checked to see if wells were constructed with bentonite seals in the annular spaces of wells at the depths where the confining unit was encountered. Or the wells may have been constructed with outer casings grouted into the top of the confining unit clay. If neither type of seal is present, the surficial aquifer may be draining to the underlying Black Creek aquifer via well gravel packs (discussed further in the preceding section). If no well records are available or the existence of a seal cannot be determined via other means (cement-bond logging inside the well is a possibility), shallow monitoring wells (in the surficial aquifer) could be installed at well sites to check for water table drawdown in the vicinity of the well. If missing seals are evident at a well, the well should be replaced, not only to reduce surficial aquifer drawdown, but as a wellhead protection measure, preventing shallow groundwater from reaching the source aquifers for the wells.

Further study considerations

Monitoring would be necessary to learn more about the extent to which factors discussed above (the sewer system, ponds, ditches, and wells) affect surficial aquifer levels and especially to try and quantify how much the impacts lessen inflow or increase outflow to/from White Lake. Plans for a study meant to attempt that are outlined in the appendix and incorporate much more of a vertical component to assessing hydraulic gradients than past studies have, with monitoring wells that are deeper, farther from the lake (and nearer to blueberry farms), and also monitoring wells in the lake bottom. Ideally, monitoring would have started before the current program to repair/replace portions of the Town's sewer system had begun to better gauge the effect of those improvements. But there will at least be somewhat of a pre-repairs baseline from the numerous studies done to date.

Further studies can hopefully be done as a cooperative effort with owner/operators of the nearby blueberry farms, north and east of White Lake. If information sharing could be arranged and approvals/access established for conducting monitoring activities on farm properties, far more could be learned about possible impacts to Lake White from the ponds, ditches, and wells at the higher elevations. Study plans in the appendix could proceed without those arrangements, but it is recommended that the Town explore possibilities for conducting a study as a cooperative effort before proceeding with another extensive one.

Note:

Immediately following this report is a section labeled *Sources for Section on Groundwater Supply for the Lake* with a document entitled "**Study Plan and Costs to Further Evaluate Groundwater Flow**" offers a set of plans that could be used to undertake a more thorough examination of groundwater flow around the lake. The plan offers specific criteria, locations, layouts, equipment needs, and other tasks that could be used to gather and evaluate this additional flow data.