Contents

Chapter 8
Water Use White Oak River Basin

North Carolina has a diverse array of water users throughout the state including: public and private water supply systems that supply drinking water to their customer base; industries such as food production, pharmaceuticals, wood manufacturing and metal processing; and energy production (hydroelectric and thermoelectric). Water is also used statewide for agricultural, mining, and recreational purposes. The availability and continued use of surface water and groundwater by all users is vital to the continued prosperity to the people and communities across the state.

There are several programs within the North Carolina Department of Environmental Quality (DEQ) that provide information about how much water is being used in North Carolina. These include the Water Withdrawal and Transfer Registration (WWATR) Program, the Local Water Supply Planning (LWSP) Program, the Central Coastal Plain Capacity Use Area (CCPCUA), and the Interbasin Transfer (IBT) Certification Program. Several programs are also in place to protect drinking water sources including the Source Water Protection Program (SWAP), the Surface Water Protection Program (SWP), and the Wellhead Protection Program (WHP). More information about these programs can be found in Chapter 7.

In addition to administering programs for water use and protection, DEQ plays a critical role in providing technical and management support for the development and use of surface water and groundwater resources and calculating the volume of water moving through a system. For agriculture water use, the North Carolina Department of Agriculture & Consumer Services (NCDA&CS) plays a critical role in collecting statewide water use data.

The information presented here is based on best available data and includes information about water use and demand, geology and groundwater, and streamflow. The chapter concludes with future considerations to better understand statewide water use and protecting our water resources. Information presented here is not field verified and should not be used for regulatory compliance purposes.

8.1 Water Use Reported in the White Oak River Basin

The White Oak River basin encompasses 1,382 mi^2 along the North Carolina coast reflecting surface water characteristics of the local rivers and streams, including the neighboring barrier islands. The boundary for this analysis extends from the vicinity of Snow Cut and the Carolina Beach State Park in the south to the mouth of Nelson Bay in the Core Sound in the northeast corner of the basin. While the official boundary of the New River subbasin extends south along a narrow strip of ocean beaches to the east to Bald Head Island, reported water withdrawals south of the Carolina Beach State Park area are from outside of the White Oak River basin. Therefore, those areas were not included in this analysis. Portions of Carteret, Jones, New Hanover, Onslow, Pender, Brunswick, Craven, and Dublin counties are located entirely or partially in the basin. Those portions of Carteret, Jones, New Hanover, Onslow, and Pender counties were included in this analysis.

Understanding the total amount of water being used for all activities across a basin is critical for helping agricultural producers, manufactures, municipalities, and utilities plan for future water use while also maintaining or protecting water quality and the ecological integrity of waterbodies throughout the region. The information presented here quantifies water demand on a basin scale. Data was collected from several programs within DWR, as well as the North Carolina Department of Agriculture & Consumer Services (NCDA&CS). The information and data contained within this section is provided by DWR as a service to the public and to stakeholders within the basin. DWR staff does not field verify any data contained within this section. DWR does, however, conduct technical reviews of the LWSPs submitted by the public water supply (PWS) systems to ensure there are no apparent abnormalities in the data. Neither DWR nor any other party involved in the preparation of this data attests that the data is free of errors and/or omissions. Furthermore, data users are cautioned to use the information in this section for planning purposes only and not regulatory compliance. Questions regarding the accuracy or limitations of using this data should be directed to the individual PWS system, registrant, and/or DWR.

8.1.1 Central Coastal Plan Capacity Use Area (CCPCUA)

The Central Coastal Plain Capacity Use Area (CCPCUA) is a 15-county region that is regulated under the 15 NCAC 02E Water Use Registration and Allocation rules. CCPCUA rules require that groundwater users of over 100,000 gallons per day (gpd) or more be permitted. Entities or facilities that use over 10,000 gpd of surface water or groundwater must register. Over 90% of the White Oak River basin (Carteret, Craven, Duplin, Jones, and Onslow counties) are subject to rules associated with CCPCUA. In 2017, 33 facilities were permitted and 16 were registered. Most of the facilities are associated with public water supply (PWS) systems. A list of permitted and registered facilities in the CCPCUA, along with their PWS identification number (ID) and average daily water use, can be found in Appendix VIII.

8.1.2 Water Withdrawal & Transfer Registration (WWATR) Program

In 2017, eight facilities (five golf courses and three PWS systems) withdrew a combined annual average of 1.057 million gallons per day (mgd). The majority was used for recreational purposes (golf courses) (0.976 mgd). The remaining amount was used by public water supply (PWS) systems. Appendix VIII includes a list of entities reporting to WWATR and includes water use reported to WWATR in 2017. The estimates for the PWS systems are based on a presumptive use of 75 gallons per capita day for their reported service population. Population served was acquired from the DWR's Public Water Supply System (PWSS) database of public water systems.

8.1.3 Local Water Supply Plans (LWSP)

Per NCGS §143-355(l), the Local Water Supply Planning (LWSP) Program applies to units of local governments and community water systems that regularly serve 3,000 or more individuals or have 1,000 or more service connections. In 2017, 29 PWS systems in the White Oak River basin submitted a LWSP to DWR. Combined, the systems supplied an average of 48.764 mgd to an estimated year-round population of 320,964. Seasonal population (including year-round population) was estimated to be 458,802 (Table 8-1).

Water systems are advised to maintain adequate water supplies and manage water demands to ensure that the average daily demands do not exceed 80% of the available supply (i.e., demand/supply ratio). Collectively, water systems in the White Oak River basin are expected to have adequate water supplies to meet current and future demands. Nearly all the water systems in the basin are below this 80 percent threshold, indicating that they are able to meet current (2017) and projected demands (through 2060) (LWSP, 2017). Influxes of seasonal visitors, however, can produce significant increases in water demand raising maximum daily water use during popular recreation seasons. Having adequate supplies to meet average daily demands may still require careful management to meet maximum daily water demands. Water withdrawers operating under a permit through CCPCUA have an allowable maximum daily withdrawal amount written into their permit.

Table 8-1 Reported and Estimated Year-Round and Seasonal Populations Served by PWS Systems that Report to the LWSP Program in the White Oak River Basin (LWSP, 2017)

County	2017	2020	2030	2040	2050	2060
Carteret	52,150	53,711	59,180	64,984	47,515	51,385
Jones	1,100	1,142	1,196	1,233	1,345	1,400
New Hanover	10,927	11,365	12,370	13,502	14,778	16,119
Onslow	252,512	280,851	287,005	293,141	301,117	307,380
Pender	4,275	7,055	7,759	8,538	9,203	9,969
Total Year-Round Population	320,964	354,124	367,510	381,398	368,855	380,384
Total Seasonal Population	458,802	477,813	493,736	510,183	529,410	547,838

8.1.4 Self-Supplied Domestic Well Use (Private Well Owners)

Nationwide, the United States Geological Survey (USGS) has estimated self-supplied withdrawals for domestic use at 3,260 mgd, or about 1% of the total withdrawals for all uses in 2015, supporting an estimated 42.5 million people. Similarly, the USGS estimated that self-supplied domestic water use accounted for approximately 5% of the total water withdrawals in North Carolina (USGS, *Estimated Use of Water in the United States in 2015,* Circular 1441, 2018).

Self-supplied domestic water use is primarily household water used by people not serviced by a water supply system. Instead, groundwater well(s) located on the homeowner's property supply groundwater to the residence and associated activities (farm or other commercial business). Water use from individual private wells for household use does not reach the quantities necessary to require reporting to DWR and is therefore not included in the overall demand calculated in the summaries included in this report. DWR, however, recognizes this water usage is likely significant considering the large rural population across North Carolina and in the White Oak River basin. DWR is continually working on methodology that would help estimate the amount of water being withdrawn via self-supplied domestic wells in North Carolina.

8.1.5 Agricultural Water Use

Under legislation enacted in 2008 (Session Law 2008-0143), the North Carolina Department of Agriculture & Consumer Services (NCDA&CS), Agriculture Statistics Division, is required to collect annual information from farmers who withdraw more than 10,000 gpd. Individual responses remain confidential and are only used in combination with other reports, including produce and livestock totals. Operations that withdraw more than 1.0 mgd are required to register and report water use to DWR through the WWATR program. The unique number of operations, annual average daily use of surface water and groundwater, and capacity is published by county and by hydrologic unit code (HUC). The capacity represents the sum of capacities for all reporting operations in that county or HUC. Water is not withdrawn every day of the year. Instead, water use is dependent upon soil moisture, precipitation, and crop. If there were less than three operations in any category, or if one report included more than 60 percent of the total, data at the county or HUC scale was not disclosed (NCDA&CS, 2018).

According to the 2018 NCDA&CS Agricultural Water Use Survey, 1,025 farms statewide withdrew at least 10,000 gpd. Collectively, these farms had an average daily water use of 60.2 mgd and an annual withdrawal capacity that totaled 1.2 billion gpd (NCDA&CS, 2018). In the White Oak River basin, Onslow and Pender counties reported water withdrawal (gpd) and total daily withdrawal capacity (gpd) (Table 8-2). Data was either not submitted or was non-disclosed and included in the cumulative numbers for the remaining three counties. Data was not disclosed for HUC 03020301 or 03020302 (Table 8-3).

Table 8-2 Agriculture Water Use County Summary (NCDA&CS, 2018)

County**	Number of Unique Operations[1]	Annual Average Daily Ground (Gallons) [2]	Annual Average Daily Surface (Gallons) [2]	Daily Withdrawal Capacity (Ground and Surface) (Gallons)[3]
Carteret	*	*	*	*
Jones	*	*	*	*
New Hanover	*	*	*	*
Onslow	6	62,934	*	439,738
Pender	26	435,554	2,276,009	178,340,460

* data was either not disclosed or not reported.
** one operation is greater than 60% of the total or less than three operations reported.
[1] represents the unique number of operations with withdrew surface or groundwater.
[2] represents the average across all days of the year.
[3] includes ground and surface water.

Table 8-3 Agriculture Water Use HUC Summary (NCDA&CS, 2018)

HUC	Number of Unique Operations[1]	Annual Average Daily Ground (Gallons) [2]	Annual Average Daily Surface (Gallons) [2]	Daily Withdrawal Capacity (Ground and Surface) (Gallons)[3]
03020301**	*	*	*	*
03020302**	*	*	*	*

* data was either not disclosed or not reported.
** reported as part of “other HUC” which includes non-disclosed data.

8.1.6 Water Use Summary

Based on information reported by CCPCUA, LWSPs, and WWATR, it is estimated that a total of 52.411 mgd is used in the White Oak River basin. Table 8-4 provides reported (2017) and estimated future demand on the county scale. Table 8-5 provides reported (2017) and estimated future demand on the watershed scale (HUC10). This includes both surface water and groundwater sources as well as the estimated demand used by small community water supply systems that are not required to report to these programs. This number does not include agriculture demand as reported in the AWUS or the amount of water used by self-supplied domestic wells.

Table 8-4 Reported and Estimated Future Water Demands in the White Oak River Basin (2017)

County	Reported Demand (MGD) 2017	Estimated future demands in MGD for County based on 2017 withdrawals				
		2020 Demand	2030 Demand	2040 Demand	2050 Demand	2060 Demand
Carteret	7.359	7.676	7.925	8.238	8.583	8.968
Jones	16.562	16.566	16.570	16.574	16.579	16.583
New Hanover	3.082	3.098	3.291	3.499	3.725	3.960
Onslow	24.722	26.867	27.272	27.706	28.211	28.665
Pender	0.687	1.627	1.810	2.022	2.272	2.573
Total	**52.411**	**55.835**	**56.868**	**58.040**	**59.370**	**60.749**
Notes:	2017 demand figures represent water use reported to DWR under the CCPCUA, LWSP, and WWATR programs. Demand for small community water supply systems that do not report water use under these programs was estimated by using 75 gallons per capita day based on report population served. The total demand does not include agriculture water use or the amount used by self-supplied domestic wells.					
	Demands for 2020 to 2060 reflect a combination of future demand estimates from LWSPs and the amount reported in 2017 by water use for small community water systems and withdrawers, neither of which provide estimates of expected future water needs.					

Table 8-5 Estimated Water Withdrawals by Hydrologic Units (2017)

HUC 10	2017 Demand (MGD)*	2020 Demand (MGD)^	2030 Demand (MGD)^	2040 Demand (MGD)^	2050 Demand (MGD)^	2060 Demand (MGD)^
0302030101	16.562	16.566	16.570	16.574	16.579	16.583
0302030102	0.397	0.429	0.434	0.439	0.446	0.452
0302030103	5.147	5.962	6.055	6.156	6.281	6.381
0302030104	2.704	2.774	2.904	3.086	3.293	3.524
0302030105	0.716	0.757	0.813	0.874	0.944	1.015
0302030107	1.778	1.654	1.700	1.752	1.800	1.865
0302030201	11.958	12.738	12.908	13.087	13.281	13.476
0302030202	9.241	10.088	10.243	10.410	10.608	10.781
0302030203	0.142	0.142	0.142	0.142	0.142	0.142
0302030204	0.771	1.711	1.894	2.106	2.356	2.657
0302030205	2.998	3.014	3.207	3.415	3.641	3.876
Total	**52.413**	**55.836**	**56.870**	**58.042**	**59.372**	**60.751**

* Compiled from reported 2017 water use and estimated for community water systems that do not annually report water use.

^ Future demands are compiled from future demand projections reported in 2017 LWSPs combined with 2017 demands for water withdrawers that do not report projected future demands

Since most of the PWS systems that submitted a LWSP, small community systems not required to submit a LWSP, and self-supplied domestic wells (private wells) rely on groundwater as their drinking water source, it is important to note that groundwater resources are a finite source of water, and in most areas, recharge very slowly. Unlike surface water sources, the state currently has no effective means for quantifying sustainable yields for withdrawal rates for groundwater users. Comprehensive groundwater assessment/modeling programs are needed by water-resource managers to make more informed decisions regarding groundwater availability and allocations.

8.2 Geology and Groundwater

Geology in the White Oak River basin consists of series of eastward sloping and thickening layers of sediments and sedimentary rock that were deposited in shallow seas upon a basement layer of 130-million-year-old Paleozoic age rock. Within the White Oak River basin, the depth to basement rock ranges from 800 feet below sea level in western Onslow County to 5,000 feet below sea level in the vicinity of Harkers Island. The wedges of sediments resting on the basement rock are composed of widespread layers and isolated lenses of silt, clay, sand, gravel, limestone, and shell materials. The nature of the sediment components in the layers determines the ability of the individual layers to allow or inhibit water movement (DWR, n.d.). Within the basin, abundant quantities of potable groundwater reside at depths of up to several hundred feet or more below the land's surface. Beyond the freshwater-saltwater interface, however, chloride levels make the water too saline to drink without treatment.

8.2.1 Aquifers

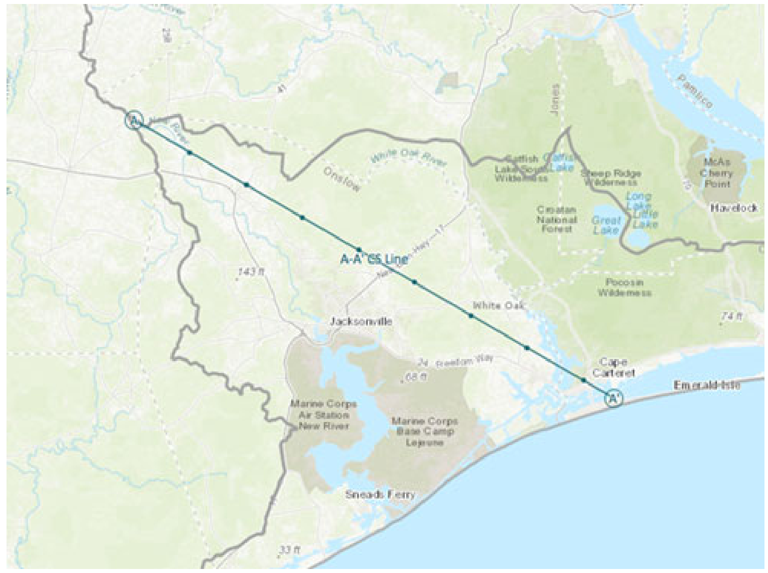
Aquifers are layers of water-bearing permeable and semi-permeable rock and sediment that can store and transmit water through fractures and pore spaces (Hornberger et al., 1998). These fractures and pore spaces exert physical controls on the storage (porosity) and transport (permeability) of groundwater. Aquifers vary significantly in their porosity and permeability, resulting in varying storage capacity and flow rate. In addition to the natural porosity and permeability of an aquifer, groundwater movement and resource sustainability are affected by the hydrologic cycle, physical forces, and human activities.

Aquifers are categorized into two types: unconfined and confined. An unconfined aquifer is referred to as the water table or surficial aquifer. Water within this aquifer type occurs at atmospheric pressure and rises and falls seasonally in response to variations in precipitation and air temperature. Confined aquifers are typically sedimentary and are found in the Coastal Plain of North Carolina. These aquifers consist of thick, water-saturated sand or limestone layers that are confined on top and bottom by impermeable beds of clay and silt. Confined aquifers are referred to as artesian when under enough pressure to flow to the land surface. This pressure is created by the immense weight of water within the aquifer and the downward force of the overlying sediment. Recharge in confined aquifers occurs by "leakage" from other aquifers or by direct infiltration where the aquifer outcrops. Outcrops are often many tens of miles updip[1] from where the aquifer is being utilized as a water supply. Since recharge rates are much lower in unconfined aquifers, water level monitoring is necessary to assure that dewatering does not occur as a result of overpumping. Approximately two percent of average annual rainfall in the Coastal Plain makes its way into the confined aquifer (DWR, 2002.).

[1] The updip is a geologic term that means "located up the slope of a dipping plane or surface" (https://glossary.oilfield.slb.com/Terms/u/updip.aspx).

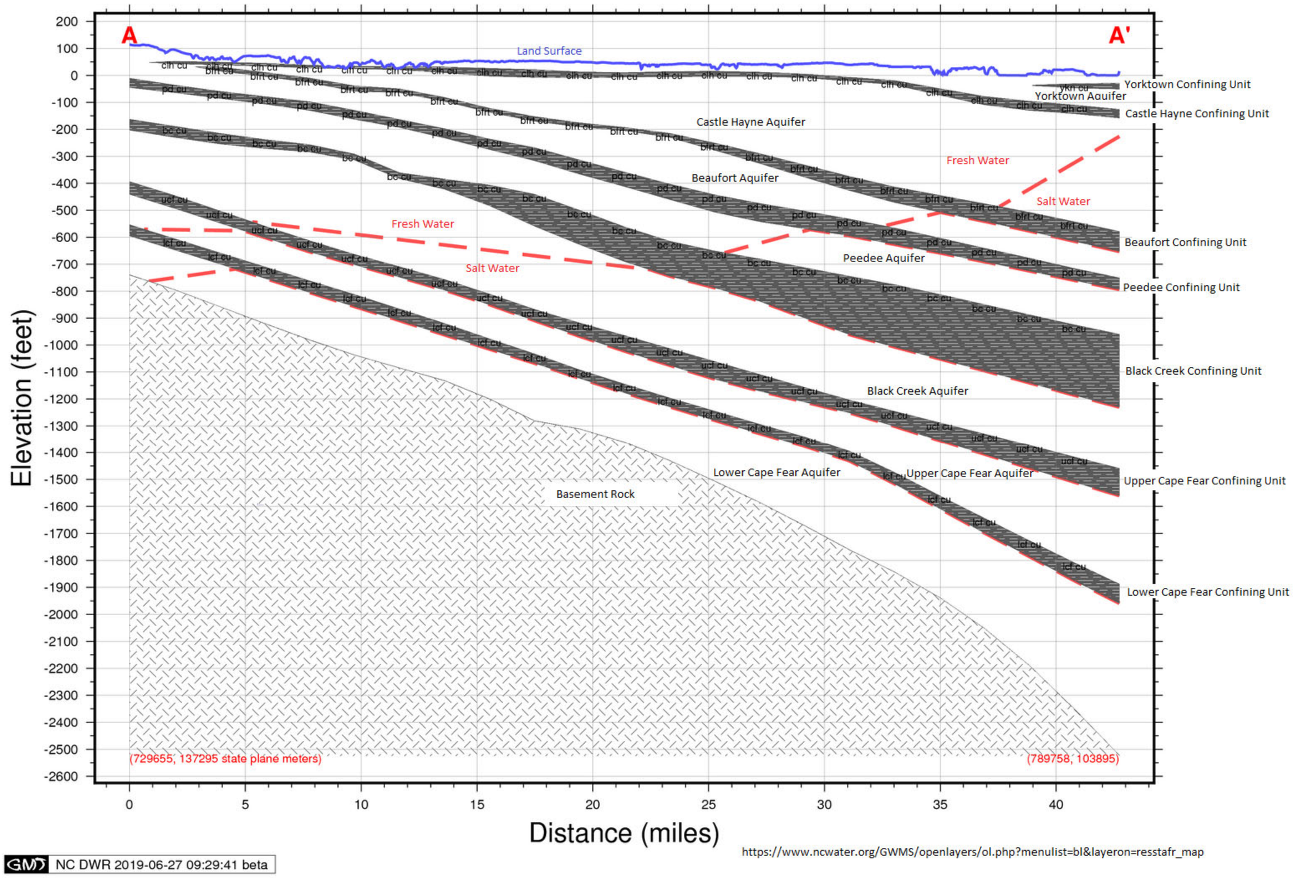
Using interactive mapping tools available on DWR's Ground Water Management Branch's (GWMB) website, a general cross-section of the aquifers in the White Oak River basin can be examined (Figure 8-1). The cross-section shows the relationship between water bearing aquifers and confining units along the A – A' line. The solid dark grey areas shown in Figure 8-2 are the confining units that separate the named aquifers. As the sediments were deposited along the coast, some of the water trapped in the deposits was seawater. Freshwater accumulating after deposition created freshwater-salt water boundary zones in the confined aquifers. The red-dashed line in Figure 8-2 indicates the estimated current positions of the freshwater-salt water interface(s). To the east and below the heavy bars, the groundwater has chloride concentrations of 250 parts per the million (ppm) or more making it is less desirable for potable water purposes.

Figure 8-1 Cross Section Orientation A – A' (Northwest Onslow County to Cape Carteret in Carteret County)



Materials that comprise the aquifers and confining units under the White Oak River basin have accumulated over the last 140 million years. The Lower Cape Fear, Upper Cape Fear, Black Creek, and Peedee aquifers and corresponding confining units shown in Figure 8-2 were deposited between 63 and 130 million years ago during the Cretaceous Period. The major recharge areas for these aquifers lies well inland where the aquifers approach the land surface. The overlying Beaufort, Castle Hayne, Pungo River, and Yorktown surficial aquifers and confining units were deposited between 2 and 63 million years ago during the Tertiary Period. These aquifers are overlain by materials deposited over the last 2 million years forming the Surficial aquifer that absorbs water from precipitation and overland flow events. Infiltrating water replenishes these Surficial and Tertiary aquifers in the Coastal Plain. As a group, Surficial and Tertiary aquifers receive on average about 22% of precipitation as infiltration, with about 2% reaching the deeper confined aquifers. Because of their intimate relationship with the land surface, protecting water quality in the Surficial and Tertiary aquifers is critical to protecting drinking water quality. More information about North Carolina's aquifers can also be found on the Ground Water Management Branch's (GWMB) website (DWR, n.d.b.)

Figure 8-2:Provisional Hydrograph Cross-Section from Northwest Onslow County to Cape Carteret in Carteret County



The age of the sediments in the Cretaceous aquifers and their isolation from activities on the land surface have protected groundwater quality from anthropogenic impacts for thousands of years. In the deeper confined aquifers, freshwater west of the freshwater-saltwater interface typically exhibits high-quality water characteristics (i.e., low in nutrients, metals) making them ideal for supplying water for human consumption and have served as sources of low-cost, high-quality drinking water for decades. As population increased and communities expanded, however, pumping increased which resulted in regional impacts. By the late 1900's, groundwater monitoring indicated that water was being pumped from the Cretaceous aquifers at rates that threatened the long-term sustainability as high-quality groundwater sources in some areas. In 2002, North Carolina designated 15 counties as the Central Coastal Plain Capacity Use Area (CCPCUA) to manage water withdrawals under the authority of the Water Use Act of 1967. The CCPCUA and associated rules were approved by the Environmental Management Commission (EMC) to closely monitor and manage water withdrawals in the designated 15-county area. More information about CCPCUA can be found in Section 8.1.1.

8.2.2 Groundwater Availability

Groundwater availability is a function of an aquifer's ability to store and transmit water. To be sustainable, groundwater pumping must not exceed the recharge rate of the aquifer. When recharge rates are exceeded, dewatering occurs resulting in reduced well flow, porosity loss, land subsidence, and in some cases, upward movement of saline water from deeper within the aquifer. The availability of base flow, which is the continuous supply of groundwater seepage that streams, rivers, and other wetlands rely on, can also be adversely impacted by groundwater overuse. Streamflow during times of drought is entirely dependent on base flow. Precipitation, evapotranspiration, hydrology, geography, land cover, and water withdrawal all impact base flow and the amount of water available for human consumption, irrigation, recreation, and aquatic habitat.

Table 8-6 shows the breakdown of current and estimated future water withdrawals from the Surficial and Tertiary aquifers as well as the Cretaceous aquifers. Withdrawals from the Cretaceous aquifers are regulated by the CCPCUA (Section 8.1.1). In general, the Cretaceous aquifers beneath the White Oak River basin contain salt water with chloride concentrations above 250 parts per million (ppm) making them less desirable as drinking water sources. Because of this, most of the water being withdrawn in the basin are from the more productive and higher quality Surficial and Tertiary aquifers. Of the 89 withdrawers included in this analysis, 15 withdraw from the Cretaceous aquifers and 77 depend on water from the Surficial or Tertiary aquifers with several systems withdrawing water from several aquifers.

Table 8-6 Current and Estimated Future Groundwater Withdrawals in the White Oak River Basin (2017)

Aquifer	2017 Demand	2020 Demand	2030 Demand	2040 Demand	2050 Demand	2060 Demand
Surficial and Tertiary	47.524	50.082	50.912	51.867	52.958	54.090
Cretaceous	4.887	5.753	5.955	6.173	6.412	6.659
Total	52.411	55.835	56.868	58.040	59.370	60.749

Groundwater and surface water are hydraulically connected, but those connections are often difficult to measure. A surface waterbody can gain water from groundwater (gaining stream), lose water to groundwater (losing stream), or it can gain and lose depending on the streambed, hydrology, and geography of the area. In either instance, the interactions between ground- and surface water impact water quality and the availability of both (Winter et al., 1998). Major withdrawals from surface water or groundwater can limit the amount of water available for all uses in the basin. The DWR's GWMB oversees the assessment, monitoring, and management of the state's groundwater resources about use and availability. GWMB is continually working to update statewide methodology to calculate groundwater demand and availability to identify future needs and management measures (where applicable).

8.2.3 Groundwater Monitoring Network

In addition to overseeing the assessment, monitoring, and management of the state's groundwater resources regarding use and availability, DWR's GWMB also manages a statewide groundwater monitoring well network (MWN) consisting of 700 wells. Data from these wells are used to:

- Evaluate effects of recharge, discharge, and drought on water supply;
- Monitor well pumping to assure rates are sustainable;
- Regulate the Central Coastal Plain Capacity Use Area (CCPCUA);
- Monitor chlorides for saltwater intrusion; and
- Provide data to an array of agencies, businesses, and the public.

To protect and optimize the state's groundwater resources calls for balancing withdrawals with recharge. Using the state's groundwater MWN in combination with stream-gage data allows DWR to determine if groundwater supplies are adequate and being used sustainably, especially in highly developed areas where groundwater use is highest.

In 2015, the MWN expanded its scope and it now includes groundwater quality monitoring. This allows the GWMB to characterize ambient groundwater quantity and quality data geographically and geologically. The primary aquifers and their chloride content within the White Oak River basin, from shallowest to deepest, are the Surficial, Yorktown (Figure 8-3), Castle Hayne (Figure 8-4), Beaufort (Figure 8-5), and Upper Cape Fear (Figure 8-6) aquifers. Chloride sampling within these aquifers allows DWR to monitor salinity levels and trends at the freshwater-salt water interface within each of the major coastal plain aquifers (Laughinghouse, 2020). Salinity levels and the location of the interface can change as a result of sea level rise, storm surges during hurricanes, groundwater pumping, and mine dewatering. Chloride levels are used to determine if groundwater is fresh (<250 ppm chloride) or salty (>=250 ppm chloride). Chloride sampling is also used to identify the transition zone between the fresh and salty zones. This transition zone is characterized by a vertical salinity gradient within the aquifer in which salinity increases with depth, from fresh to salty (Laughinghouse, 2020).

Figure 8--3 Chloride Content within the Yorktown Aquifer

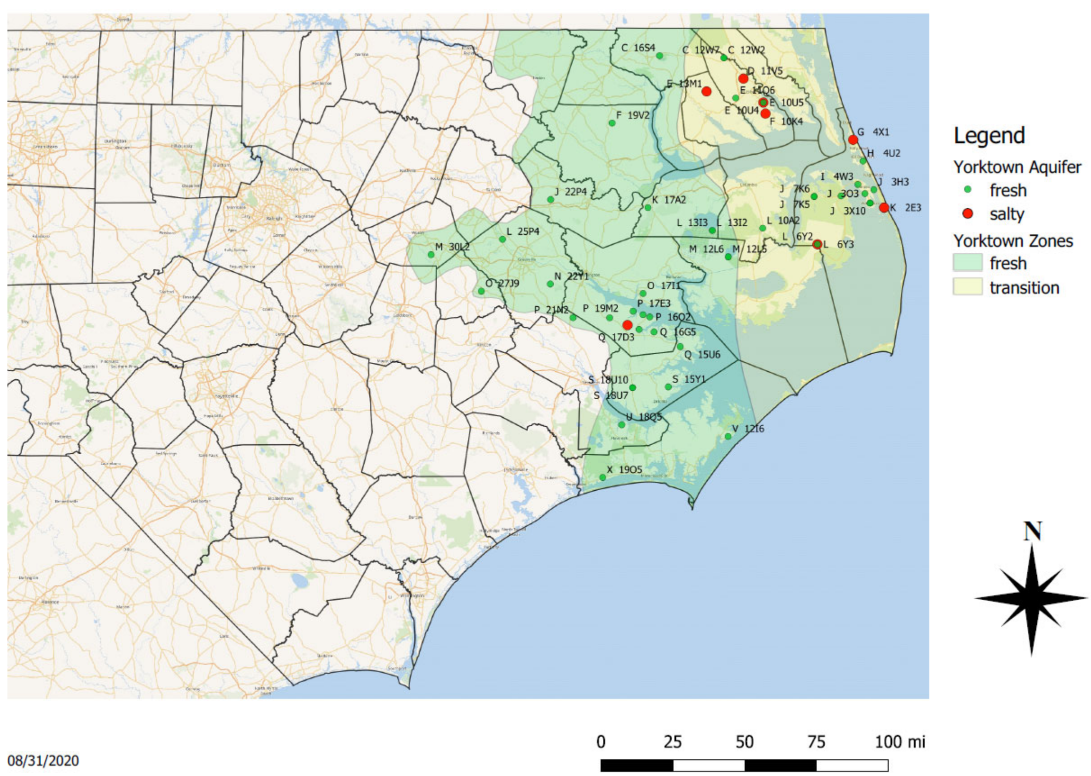


Figure 8--4 Chloride Content within the Castle Hayne Aquifer

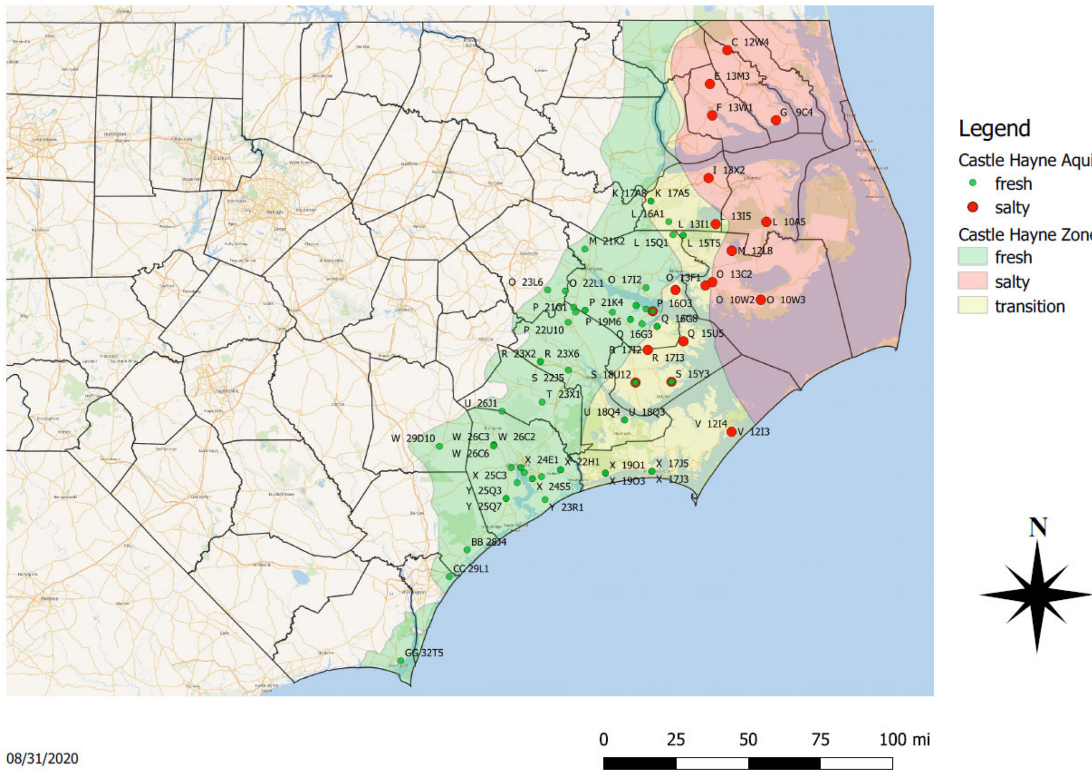


Figure 8--5 Chloride Content within the Beaufort Aquifer

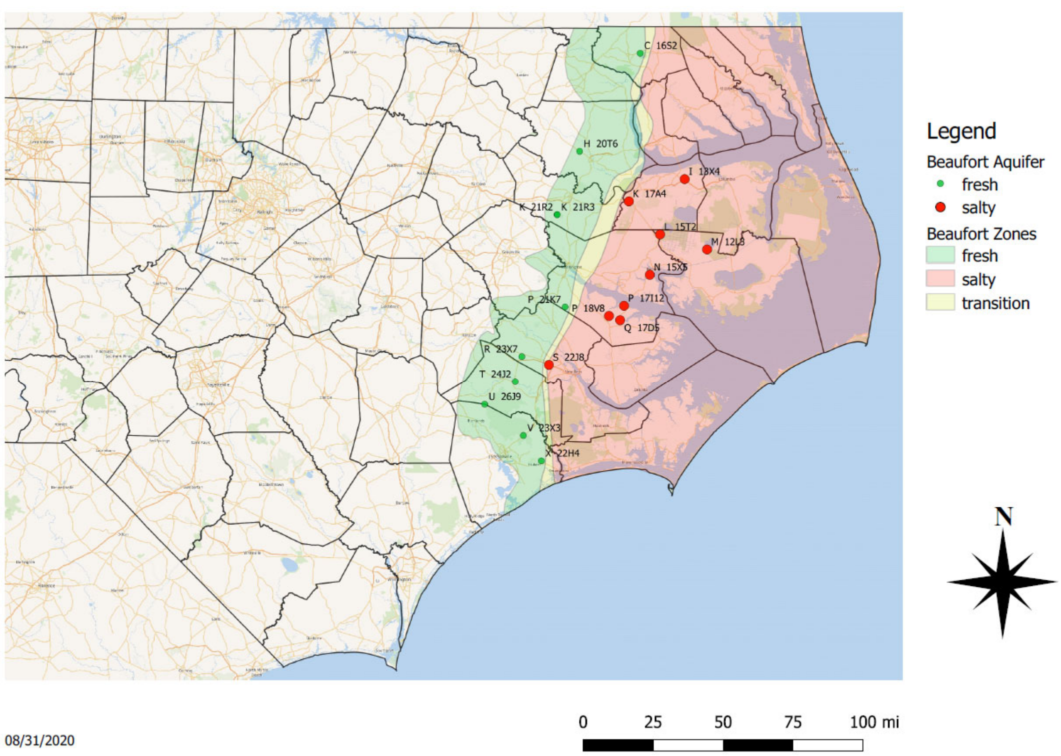
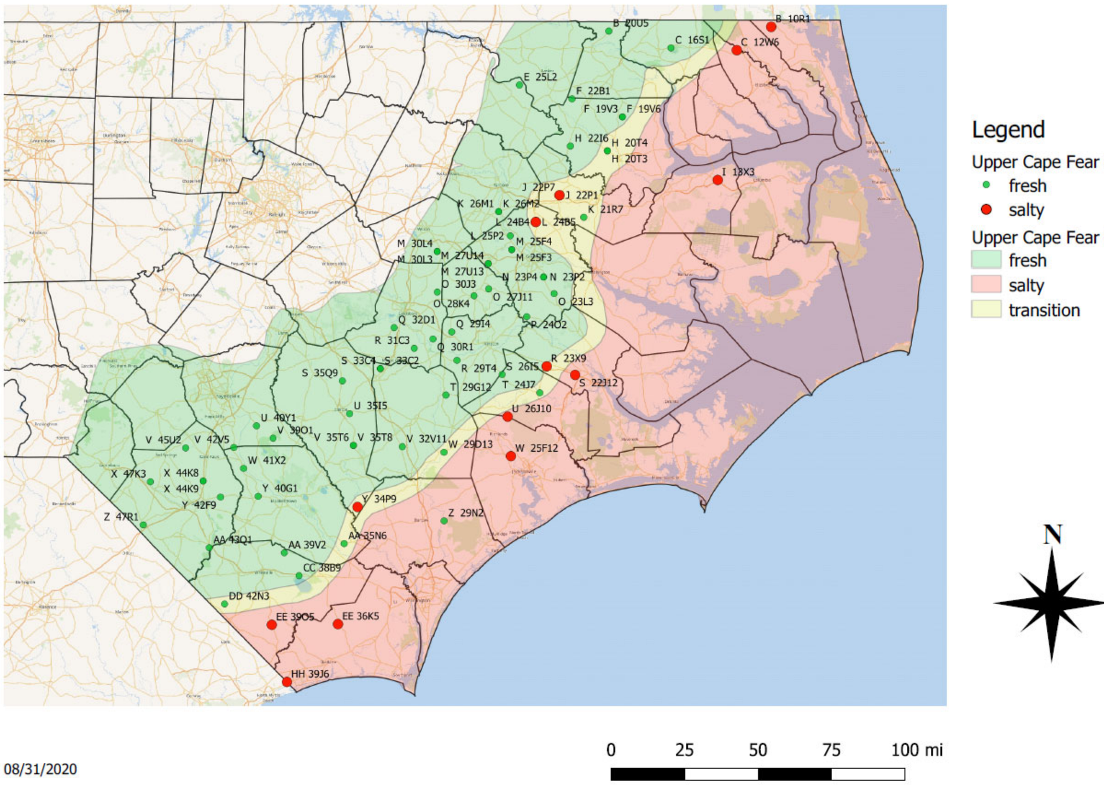


Figure 8--6 Chloride Content within the Upper Cape Fear Aquifer

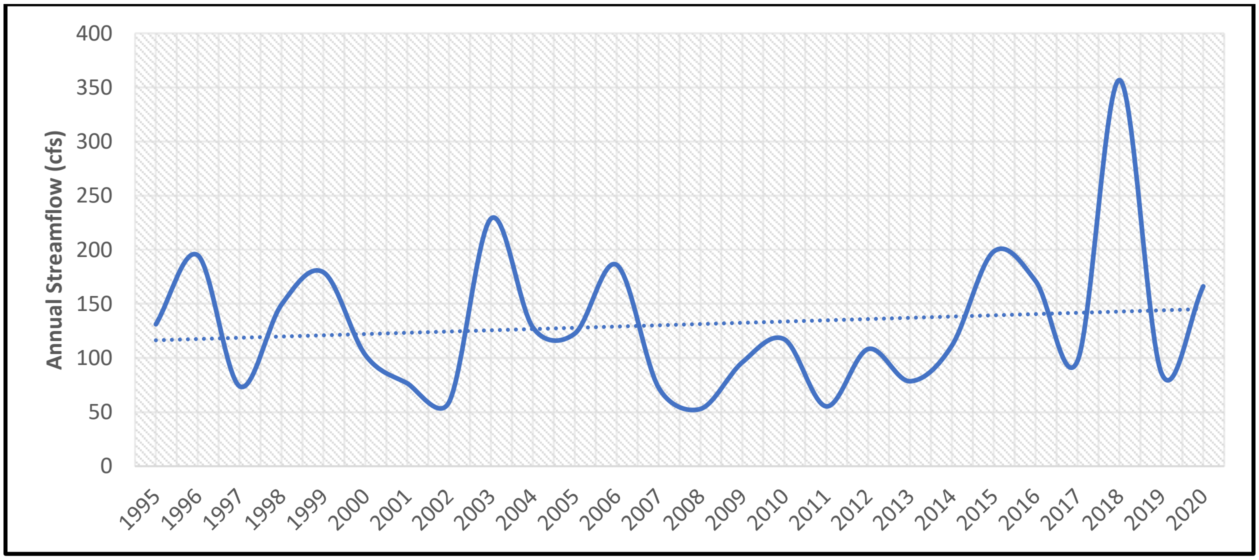


Information about the groundwater MWN can be found on the GWMB's website. Information available on the website includes: location, elevation, screen depth and aquifer for each network well; historic groundwater levels; an extensive interactive map interface with over 30 data layers; chloride analyses showing fresh, transitional, and salt water zones within each aquifer; over 3,500 lithologic and geophysical well logs; aquifer analysis tools; potentiometric surface maps for each aquifer; and the state hydrogeologic framework. Currently, DWR has 21 active, multi-aquifer groundwater monitoring stations in the White Oak River basin.

8.3 Streamflow

Streamflow varies hourly, daily, seasonally, and annually based on changes to its source, including precipitation, groundwater level, evapotranspiration, and upstream uses. Streamflow is monitored by the USGS at constructed gaging stations across the nation, including North Carolina. Flow (Q) is measured in terms of volume of water per unit of time, usually cubic feet per second (cfs). Insight into the flow characteristics of a stream is aided by the presence of USGS gaging stations with a record of flow measurements that spans multiple years or decades. Established gages and long-term flow records can be used to assist in early flood warning, help in the revision of floodplain maps, monitor drought conditions, inform recreational boaters, determine assimilative capacity of a waterbody receiving a permitted discharge, and support decisions on water withdrawal and allocation for drinking water, irrigation, and industry. Long-term flow records also help resource agencies understand environmental changes associated with a changing climate, aid in establishing flow requirements, and assist in monitoring compliance with established flow requirements. Flow statistics are not static but will change over time due to natural and human-caused conditions, and minimum flows often do not take into consideration monthly and seasonal demands or annual climatic variability. One USGS flow gage is located in the White Oak River basin (USGS 020903000). It is in the New River near Gum Branch in Onslow County, between Richlands and Jacksonville.

Figure 8-7 Annual Average Streamflow (Calendar Year) in New River nr Gum Branch USGS 020903000



There are five critical components that need to be considered when assessing streamflow for the protection of aquatic life: magnitude, timing, frequency, duration, variability and rate of change (Poff et al., 1997). The magnitude refers to a particular amount, or height of water, within the range of low to high flows at a moment in time at a particular location within a stream channel. The frequency is how often a particular magnitude occurs during a designated period of time within a period of recorded flows. The duration refers to the length of time that a particular magnitude is sustained during an episode. The timing refers to the predictability of a particular magnitude over a period of record, and the rate of change refers to the deviation above or below a particular magnitude within a given amount of time.

From a planning and water management perspective, it is important to understand flow variability and trends. Trend analysis is useful to detect and attribute long-term flow patterns of a stream to natural climate variability and human interference. Hence, streamflow records remain a key indicator for long-term hydro-climatic variability and changes associated with it. Equally, the length of period over which a stream-flow record is used to estimate the current and future dynamics of the stream system affects the accuracy of calculating estimates and has direct implication on the growing and competing priorities of water uses and management.

8.3.1 Ecological Flow

The term "instream flow" is often used to describe a flow requirement, but it is sometimes used in a more general sense to refer to the amount of water flowing in a stream without providing any established level of protection. A flow regime that protects ecological integrity is often referred to as an “ecological flow”. Ecological integrity is defined in North Carolina General Statute (NCGS) 143-355(o) and means “the ability of an aquatic system to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to prevailing ecological conditions and, when subject to disruption, to recover and continue to provide the natural goods and services that normally accrue from the system" (NCGS, 2017).

Like other aquatic systems, maintaining coastal ecological flows (i.e., approximating the spectrum of low, medium and high flows of a stream's natural hydrograph) is important for many functions, including: aquifer recharge; triggering biological cues; assimilating wastewater discharges; supporting water quality classifications; transporting nutrients, detritus, sediment, eggs and larvae; wetland and flood plain connectivity; and benefits to the economy through recreation and commerce.

Assessing ecological flows in coastal basins like the White Oak, however, is challenging because of the complexity of the fresh and brackish ecosystems and the associated complexity of the hydrology, or the movement of water through the system. The complexity is due in part to the interplay of a location's slope, the proximity to fresh and saline sources, the amount of the source inflow, the percent of salinity in the water column, and the timing and extent of tides.

Adequate freshwater flow regimes are necessary to maintain a suitable environment for organisms, their life-sustaining prey and other nutritional requirements, their various life stages, and their habitats. The consideration of flow regimes should encompass both flow (as it relates to the freshwater environment and the management of the position of the downstream saltwater wedge) and the mixing of the two (freshwater and salt water) to produce a range of sustaining brackish-water concentrations. Mobile organism can relocate in search of suitable water conditions and other less-mobile organisms can tolerate temporary deviations until suitable parameters are re-established, but other less-tolerant species may perish.

Given the low slope of coastal stream channels, low- or drought-flow conditions may not necessarily dewater critical aquatic habitat as is seen in Piedmont streams with steeper slopes. However, coastal streams that become stagnant can lead to warmer temperatures, dissolved oxygen depletion, algal blooms and repositioning of the saltwater wedge and the intervening brackish-water concentrations. The warmer months are when off-stream demands for water are greatest and evaporation and transpiration rates are highest, which can additionally contribute to these deleterious impacts to base flows, water quality and aquatic habitat. Stagnant or reduced base flow waters can also hinder the downstream transport of developing fish eggs and larvae and concentrate fish in deep-water refuges where denser populations can increase predation pressures.

Flow Dynamics : Inland

The apparent lack of anthropological, or human-induced, flow alterations may call into question the necessity of considering ecological flows in coastal watersheds. It is a reasonable assumption that watersheds will be largely unimpacted where there is no, or limited, land-cover modification or population growth both of which result in additional surface water or groundwater withdrawals. Given the unknowns associated with groundwater extraction and spatial impacts within a watershed, or adjoining watersheds, potential surface water demands (such as freshwater purification from brackish waters), and sea level rise, future impacts are a reasonable expectation. Therefore, the need exists for long-range water availability planning and the consideration of these impacts.

One challenge when assessing ecological flows and including them in a hydrologic model is the lack of knowledge regarding a stream's flow characteristics. The absence of gages in the basin collecting decades of flow values in different streams at different drainage areas produces a data gap. In addition to the lack of gages, stage height, or water depth, is typically collected instead of flow values due to the circulating, bidirectional tidal waters and the width of the channels. Stage height may be a suitable surrogate for flow in coastal waters given the importance of flood forecasting, daily wetland inundation patterns associated with tides, the difficulty of measuring flow and understanding sea level rise. The National Weather Service (NWS), through the Advanced Hydrological Prediction Service, partners with federal, state, and local agencies and organizations to use shared data from gage networks to monitor water elevation and to forecast flood events.

Limited data and the tidal influence in coastal waters complicates efforts to model streamflow and flow dynamics. Typical hydrologic models do not adequately represent reality when water can move both upstream and downstream simultaneously in the channel. In the absence of actual flow data, a pseudo-flow record would need to be created from historical flow records in conjunction with precipitation data and runoff models. New and innovative modeling approaches are required in coastal watersheds to adequately replicate the interactions of surface and groundwater withdrawals, modified land use and drainage patterns, climate change and stage-flow relationships.

Between 2006 and 2017, research conducted by the Defense Coastal/Estuarine Research Program (DCERP) noted that historic data from the active surface-water USGS gage in the basin on the New River shows a trend of increasing daily minimum and maximum flows during periods of low flow indicating that flow in the New River is being tidal influenced. The trend was attributed to changes in freshwater discharge and a rise in sea level. The gage has a drainage area of 94 mi^2 and an elevation of 1.51 feet above average mean sea level. It is approximately 35 miles upstream of where the New River discharges into the ocean at the New River Inlet (DOD, 2013).

Flow Dynamics : Sounds and Barrier Islands

The Bogue and Core sounds are not as large as the Albemarle and Pamlico sounds to the north, but there are more inlets which provides additional ways for ocean water to reach freshwater areas. The barrier islands in the basin are closer to the inland shoreline and the freshwater inflow, and the drainage area of the contributing rivers is smaller in comparison to other coastal basins, which reduces the supply of freshwater and sediment that sustains the wetlands and the barrier islands. Core Sound has high salinity concentrations compared to other sounds due to the number of inlets on the ocean side and the limited freshwater inflows (Riggs and Ames, 2003).

South of Bogue Sound the area behind the barrier islands becomes much shallower, more constricted and filled with wetlands and mud flats. The estuarine shorelines in the region are generally resistant to erosion except for the shorelines along the drowned-river estuaries, the Intracoastal Waterway (ICW), and other associated navigation channels where erosion is severe (Riggs and Ames, 2003).

The construction and maintenance dredging of the ICW has modified the hydrology of Bogue and Core sounds due to the presence of dredge spoil islands (Riggs and Ames, 2003). The ICW channel captures both sediment transported downstream with the freshwater flows and materials flushed from the barrier islands and back marshes during storm and overwash events, which hinders replenishment of sediment to the barrier island system (DOD, 2013). This deposited sediment is trapped in the ICW and requires removal during scheduled maintenance dredging to maintain adequate ICW depths and is deposited in designated spoil areas.

Flow Dynamics : Impacts to Habitat and Human Health

The cumulative alterations to flow in coastal streams from surface water and groundwater withdrawals for irrigation and public water supply, agricultural ditching and drainage networks, and stormwater runoff from impervious surfaces can have the greatest impact to freshwater aquatic habitat. Channel scouring and bank erosion from higher, storm-related discharges can deposit sediment loads that cannot be readily transported downstream, blanketing preferred habitat and sessile organisms.

Some of the greatest impacts to water quality are usually associated with high-flow storm events that contribute stormwater runoff, which often increase fecal concentrations, which then typically result in the closure of shellfish waters and swimming areas. The hurricane-related, catastrophic floods can also inundate municipal wastewater and industrial infrastructure and lagoons associated with animal feeding operations (AFOs). Any of these have the potential to release tremendous amounts of untreated waste and chemicals to public waters, contributing to human health risks and the disruption of daily activities. Extended flooding also depletes dissolved oxygen in the stagnant water due to increased biological oxygen demand, and massive fish kills may result from the rapid recession of these flood waters back into river channels.

Concerns related to water supply, on the other hand, are more associated with drought conditions. Drought and low-flow conditions can have a significant impact on how much water is available for consumptive use. Low-flow conditions can also have significant impacts on downstream water quality as waste assimilative capacity is reduced.

8.3.2 Impoundments

Dams have been constructed throughout North Carolina to provide flood control, hydropower generation, water supply, irrigation, navigation, recreation, fish and wildlife ponds, debris and sediment control, and fire protection. Dams affect habitats both upstream and downstream. Upstream habitats may become inaccessible to anadromous fish and downstream habitats receive altered surface water from upstream sources. Many dams in North Carolina are in the upstream portions of estuaries, rivers, and streams. In the coastal plain, dams are most abundant in the upper reaches of the Cape Fear, Neuse, Tar-Pamlico, Roanoke, and Chowan river basins, but there are few in the White Oak and Lumber as well (CHPP, 2016). Currently, there are seven dams in the White Oak River basin. The name of the dam, status, potential hazard description, and purpose as reported by the NCDEQ Division of Energy, Mineral and Land Resources (DEMLR) Dam Safety Program are listed in Table 8-8 (NCDEMLR, 2021).

Table 8-8 Dams in the White Oak River Basin (DEMLR, 2021)

Name	Status	Potential Hazard Description	County	River/ Stream	Purpose
Walker Millpond Dam	IMPOUNDING	High	Carteret	Black Creek	Recreation
Henderson Lake Dam	EXEMPT-DOD	Low	Onslow	Wallace Creek	Recreation
Jacksonville Waste Water Lagoon / Land Treatment Facility Storage	IMPOUNDING	High	Onslow	Southwest Creek	O

Name	Status	Potential Hazard Description	County	River/ Stream	Purpose
Elizabeth Lake / Dewitt Pond / Preston Pond	BREACHED	Low	Onslow	Northwest Creek	Recreation
North Topsail Water & Sewer Lagoon	IMPOUNDING	High	Onslow	Mill Creek	O
Oceanview Farms / Coharie Farms	EXEMPT	Low	Onslow	Haw Branch	O
Jacksonville LTS-South Storage Lagoon	IMPOUNDING	High	Onslow	Southwest Creek	CO

C= flood control, O= other

8.4 Management Under Drought Conditions

Droughts are unpredictable, but their occurrence is inevitable. A drought plan, or water shortage response plan (WSRP), can help reduce the impacts to water resources and minimize disruptions to water withdraws. A WSRP establishes authority for declaring a water shortage, defines different stages of water shortage severity and outlines appropriate responses for each stage. All public and privately-owned water systems subject to General Statute 143-355 (l) are required to prepare and submit a WSRP as part of their LWSP. WSRPs are updated every five years but can be updated more often to address changes to population, water sources and/or additional demands. The plans can also be updated to address any issues that may have been identified when implementing or evaluating the effectiveness of the plan.

Drought Classification
D0 - Abnormally Dry
D1 - Moderate Drought
D2 - Severe Drought
D3 - Extreme Drought
D4 - Exceptional Drought

The North Carolina Drought Management Advisory Council (NCDMAC) has been monitoring drought conditions weekly since 2000 and was given official statutory status and assigned the responsibility for issuing drought advisories in 2003. The NCDMAC assesses drought conditions based on several indices including streamflow, groundwater levels, rainfall, reservoir levels and soil moisture and issues advisories on a county-by-county basis. The council provides consistent and accurate information as it relates to drought and includes representatives from surface water and groundwater hydrology, meteorology, water system operation and management, reservoir management, emergency response as well as local governments, agriculture and agribusiness, forestry, manufacturing, and water utilities. Five drought designations, or classifications, were established by the NCDMAC. A drought classification is applied to a county when at least 25 percent of the land area of the county is impacted. A statewide drought assessment is published on a weekly basis and available online.

8.5 Protecting Water Resources & Future Considerations

Streams and rivers in the White Oak River basin are subject to the ebb and flow of salt water due to tidal activity. The flat terrain is not conducive to constructing reservoirs to store water, therefore, groundwater is the primary source of water for public water systems. Groundwater is also used for irrigation or to maintain dry conditions for mining operations.

While compliance with existing, statewide programs dealing with water resources management is reasonably effective at capturing major water withdraws and uses for most sectors, there are still data gaps that make it difficult for DWR to provide assistance across the state and ensure the long-term sustainability of water resources for all users. Understanding the amount and quality of surface water and groundwater, long-term river and reservoir gages, and long-term streamflow calculations are all critical to understanding how water is being used and how it can be sustained into the future. The following identifies topics for state leaders to consider when answering questions about water resources management.

8.5.1 Groundwater Availability and Trends

North Carolina places considerable demands on its groundwater resources, including domestic drinking-water supplies (i.e., self-supplied private wells), numerous PWS systems, irrigation, livestock management, mining, and self-supplied commercial and industrial uses. Groundwater is a finite resource, and it will continue to be stressed to meet the demands of a growing population.

A key element of properly managing any regional groundwater system is quantifying how much water can be extracted from contributing aquifers without inducing adverse effects. Adverse effects can include aquifer dewatering, saltwater intrusion, water quality degradation, and/or impacts to streamflow and ecological integrity. Groundwater needs to be properly managed to ensure that present withdrawals are sustainable and that ever-increasing projected future demands can be met. For these reasons, it is crucial that North Carolina continue to develop its statewide groundwater monitoring program. Groundwater data collected from a comprehensive groundwater monitoring network can be used to help water resource managers better plan for future water uses to meet all demands. It is recommended that each unit of local government and large community water system certify by testing, evaluating or by other means acceptable to DEQ, the available raw water supply at least once by 2030.

8.5.2 Agricultural Water Use Data

In the White Oak River basin, agricultural water use data is reported for two of the five counties used to report water use in the basin (NCDA&CS, 2018). Data is either not disclosed or not reported, at a county scale, for the remaining ten counties located partially or entirely in the basin. Because of this, agriculture water use is likely underestimated in the basin and was not included in the total water demand calculated in the basin. Understanding how water is being used by all sectors in the basin can help state and county engineers or planning managers plan for future growth and long-term sustainability, ensure commercial, industrial, agriculture and drinking water users are accounted for and that those uses are protected, and allow for better management during drought conditions. The DWR will continue to work collaboratively with federal, state, and local agencies as well as stakeholders in the basin to identify information sharing opportunities to understand and protect water resources for all needs in the White Oak River basin.

8.5.3 Streamflow Gages

Accurately measuring streamflow and reservoir levels is critical to understanding long-term water availability as well as determining real-time instream and lake/impoundment level conditions. Federal and state funding has decreased over time while the demand for gages and the cost of gages capable of monitoring multiple water quality and quantity parameters has increased. Funds are also needed for maintenance to maintain functionality.

The USGS's present network of real-time, surface-water gages in North Carolina is located primarily in non-tidal rivers, the Piedmont and the Piedmont's urban areas. A more diverse gage network would aid federal, state and local agencies in understanding flow characteristics of such diverse locations as headwater streams and tidally influenced creeks. A more diverse gage network would also help water resource managers and planners understand the interactions between surface water and groundwater, long-term changes in weather patterns, climatic conditions, and sea level rise, determining ecological flows for long-range planning, establishing instream flow regimes for projects requiring state action, and the role of land use on flow patterns. As water resources face greater pressures from multiple demands, a more extensive gage network is needed.

8.5.4 Update Long-Term Streamflow Calculations

Many federal and state permitting programs and agency policies rely on flow statistics. The most common flow statistic is the 7Q10, the 7-day lowest average flow in a 10-year period. The last statewide assessment of 7Q10 values was conducted in the early 1990's by the USGS (Giese and Mason, 1993). The most recent assessment of 7Q10 values by USGS in North Carolina focused on select sites in 2015 (Weaver, 2016). The resulting document suggests that 7Q10 values across North Carolina have been declining, some significantly, over time. As a result, streams may have lower base flows. Lower base flows directly impact the assimilative capacity for point and nonpoint discharges and the estimated available yield for water systems. In addition, the potential inaccuracy of these older estimates makes it difficult to calculate an accurate 7Q10 for streams that do not have a gage.

8.5.5 Identifying Data Gaps

North Carolina General Statute §143-355 requires DWR to assure the availability of adequate supplies of water to protect public health and support economic growth. Water supply planning and management requires a basic understanding of both the available water resources and all the demands being placed on those resources. Strides have been made with existing statewide programs to capture water withdrawal from all classes of water users, but data gaps exist. Consequently, these data gaps do not allow DWR to accurately report the amount of water being withdrawn statewide.

Collecting water use information from water users in all sectors is needed to fill in data gaps and allow DWR the ability to identify conflicts or problems that need to be resolved. Complete data sets are also needed to effectively plan, monitor, and manage water resources in North Carolina to ensure future water supply needs can be met. Working collaboratively across all state and federal agencies that have an interest in water resources could help identify and fill in some of the data gaps and identify regional concerns and challenges. Being able to report more completely about water use in the state would add value and more certainty in answering questions about water availability, giving businesses, industries, and citizens more assurance that water needs can be met now and in the future.

8.5.6 Ecological Flow

A critical component of water supply planning and management is not only the amount of water needed and available to supply existing and future water demands but also determining how much flow is needed to support the ecological integrity of the aquatic life present in the region's rivers, streams, and adjacent floodplains. Referred to as ecological flow, or instream flow requirements, it is the amount of water (measured by volume) needed to adequately provide for downstream ecological uses occurring within the stream channel.

Given the increasing off-stream demands on surface waters and the associated flow-altering infrastructure (e.g., intakes and dams), it is unlikely that 100 percent of the natural flow will remain in the stream channel. The challenge is how much can be removed from surface waters without significantly impacting the ecological integrity downstream. Without additional studies, ecological flow remains a largely unknown portion of the overall water demand. It should be considered in any water demand versus available supply analysis and is key to the sustainability of North Carolina's water resources for multiple uses.

In 2010, the General Assembly directed the creation of an Ecological Flows Science Advisory Board (EFSAB) to assist DEQ in characterizing the ecology of the state's river basins and identifying the flows necessary to maintain ecological integrity. When it presented its recommendations to DEQ, the EFSAB recommended the use of adaptive management to protect the ecological integrity of North Carolina streams. This recommendation was based on the realization that the supporting science behind ecological flow advances as more research examines the flow-ecology relationship at various spatial and temporal scales. An adaptive management approach would allow natural resource managers and planners to factor in changes in the state's climate, land-cover, precipitation, and runoff patterns, as well as potential shifts in air and water temperature statistics. Additionally, with time and lessons learned, the flow and biological criteria recommendations will need to be reevaluated to assess their efficacy.

To address data gaps, the EFSAB suggested the following steps:

- Collect additional hydrologic and biologic data in the headwater creeks, the coastal plain and the large, non-wadeable rivers that are underrepresented in DWR datasets. This data will help determine if these waterbodies fit with existing models and assumptions.
- Adopt, design, and develop strategies that:
  - Validate the efficacy of ecological thresholds and adjust these thresholds as necessary based on new data and research.
  - Track the impacts of flow changes when and where they occur.
  - Modify characterizations, target flows and thresholds based on new data and changing conditions like land cover, precipitation, and hydrology.
  - Georeference the hydrologic model nodes to facilitate analysis

The recommendations of the EFSAB represent a starting point for developing ecological flows that protect the integrity of North Carolina streams. By adopting an adaptive management approach, DEQ (formerly referred to as DENR) can ensure that ecological integrity is protected through the refinement and improvement of the recommendations of the EFSAB over time. As data gaps associated with hydrology and biology in the headwater creeks, the coastal plain, and the large, non-wadable rivers are addressed, a more complete representation of flow effects on biological integrity within the state will be available (EFSAB, 2013).

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