Contents

Chapter 9 Water Use Pasquotank 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.

DEQ also 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. The North Carolina Department of Agriculture & Consumer Services (NCDA&CS) plays a critical role in collecting agricultural water use across the state. 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.

9.1 Water Use Reported in the Pasquotank River Basin: North Carolina

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.

9.1.1 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. Per rule, entities or facilities that use over 10,000 gpd of surface water or groundwater must register with the state. Washington County is the only county in the Pasquotank River basin impacted by the CCPCUA rules. Six facilities were permitted in 2018 and two facilities were registered. Annual daily withdraw was not reported by either of the facilities registered with CCPCUA. Total annual daily withdraw was 0.672 mgd for six permitted facilities under

CCPCUA in Washington County with the majority (nearly 69%) being used by the Washington County Water System (Table 9-1).

Table 9-1 Permitted and Registered Facilities CCPCUA (2018)

Permit Number	Facility	Use Type	Average Daily Withdrawal (mgd)
CU1016	NCDA Tidewater Research Station	Irrigation, Agricultural, Aquaculture, Livestock	0.002
CU1113	Washington County Water System	Public Supply	0.464
CU1122	American Turf Grass Corporation	Irrigation, Agricultural	0.127
CU3141	Harris Farms, Inc. (Harris Mine)	Mine Dewatering	0.003
CU3180	3B Farms, Inc. (Lake Phelps Farm)	Irrigation, Agricultural	0.000
CU3253	Mt. Mitchell Farms, LLC (Somerset Farm)	Irrigation, Agricultural	0.077
		Total:	**0.672**
Registration Number	**Facility**	**Use Type**	**Average Daily Withdrawal (mgd)**
CUR0122	Darrell Davenport Sand Mine	Mining	0.000
CUR0181	Douglas Maxwell Farm	Irrigation, Agricultural	0.000
		Total:	**0.000**

9.1.2 Water Withdrawal & Transfer Registration (WWATR) Program

In 2018, 22 facilities withdrew a combined annual average of 3.059 mgd with the majority being used for mining (mineral extraction and dewatering) (Table 9-2). The estimated annual average amount of surface water withdrawn (ponds, streams, canals, rivers) by facilities registered with WWATR was 3.007 mgd, with another 0.053 mgd withdrawn from groundwater sources (Table 9-2). Currituck County has the most registrants, but the most water was withdrawn in Dare County by three golf courses and one mining facility (Table 9-3).

Table 9-2 Total Water Use Reported to the WWATR (2018)

Use Type	Number of Facilities	Ground-water (mgd)*	Surface Water (mgd)*	Total (mgd)	% Ground-water	% Surface Water	% of Total
Agriculture (Row-Crop Farming/Research)	1	-	0.164	0.164	-	100%	5.4%
Mining (Mineral Extraction)	13	-	1.912	1.912	-	100%	62.5%
Recreation (Golf Course)	8	0.053	0.930	0.983	5.4%	94.6%	32.1%
Total	**22**	**0.053**	**3.007**	**3.059**	**1.7%**	**98.3%**	**100%**

* Annual average used (mgd). Calculated based on the average daily amount and the number of days reported in 2018. Surface water includes canals, ponds, rivers and streams.

Table 9-3 Total Water Use of Registered Water Users by County (WWATR, 2018)

County	Number of Facilities/ Registrants	Total (mgd)
Camden	1	0.000
Currituck	11	1.018
Dare	4	1.900
Pasquotank	3	0.126
Perquimans	3	0.016
Total	**22**	**3.059**

9.1.3 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 Pasquotank River basin, data is available for only one of the eleven counties located partially or entirely within the basin (Table 9-4). Data was either not submitted or was non-disclosed for the remaining ten counties located partially or entirely in the basin. DWR also reviewed information on the HUC scale. Data was not disclosed for HUC 03020105 (Table 9-5).

Table 9-4 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]
Bertie	*	*	*	*
Camden	*	*	*	*
Chowan	*	*	*	*
Currituck	*	*	*	*
Dare	*	*	*	*
Gates	9	**	259,254	**
Hyde	*	*	*	*
Pasquotank	*	*	*	*
Perquimans	*	*	*	*
Tyrell	*	*	*	*
Washington	*	*	*	*

* 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 9-5 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]
03020105*	*	*	*	*

* reported as part of "other HUC" which includes non-disclosed data.

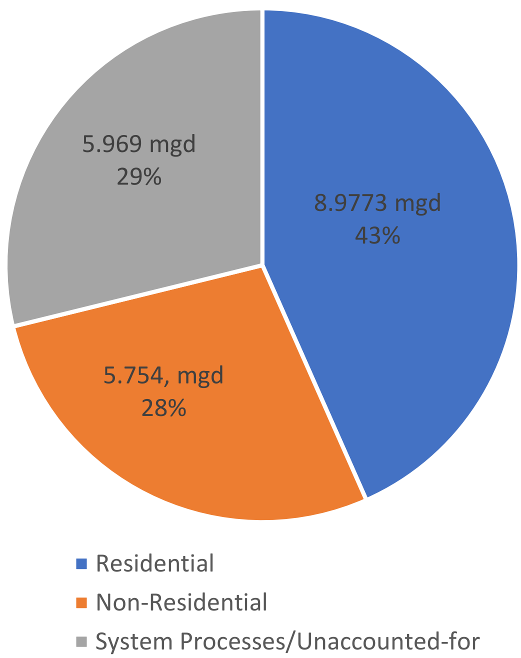
9.1.4 Local Water Supply Plans (LWSP)

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 2018, there are 21 public water supply systems (PWS) in the Pasquotank River basin that submitted a LWSP to DWR (Table 9-6). Combined, the systems supplied an average of 20.701 mgd (Table 9-6) to an estimated year-round population of 128,764. Seasonal population (including year-round population) was estimated to be 237,858. All PWS systems in the basin rely on groundwater to meet current and projected water demand.

Table 9-6 LWSPs Submitted by Public Water Supply (PWS) in the Pasquotank River Basin (LWSP, 2018)

PWSID	Water System Name	Ownership	Year-Round Population	Seasonal Population
04-89-010	Columbia	Municipality	891	891
04-94-020	Creswell	Municipality	482	482
04-27-010	Currituck Co	County	12,775	12,775
04-28-030	Dare Co Regional	County	22,766	52,000
04-28-035	Dare Co Rodanthe-Waves-Salvo	County	1,240	7,620
04-28-025	Dare Co. Cape Hatteras	County	5,486	14,600
04-70-010	Elizabeth City	Municipality	18,683	18,683
04-72-010	Hertford	Municipality	2,124	2,124
04-28-015	Kill Devil Hills	Municipality	7,200	40,000
04-28-020	Manteo	Municipality	1,496	1,557
04-28-010	Nags Head	Municipality	3,125	22,415
04-70-015	Pasquotank County	County	12,000	12,000
60-70-000	Pasquotank County - RO	County	8,200	8,200
04-72-025	Perquimans County	County	11,314	11,314
04-94-015	Roper	Municipality	546	546
04-15-015	South Camden Water and Sewer District	County	5,133	5,133
04-15-010	South Mills	Non-Profit	5,702	5,702
60-27-001	Southern Outer Banks Water	County	600	12,800
60-28-002	Stumpy Point WSD	County	106	121
04-89-015	Tyrrell County Water Department	County	2,482	2,482
04-94-025	Washington County Water System	County	6,413	6,413
		Total	**128,764**	**237,858**

Figure 9-1 Breakdown of Water Use Reported in LWSP (2018)



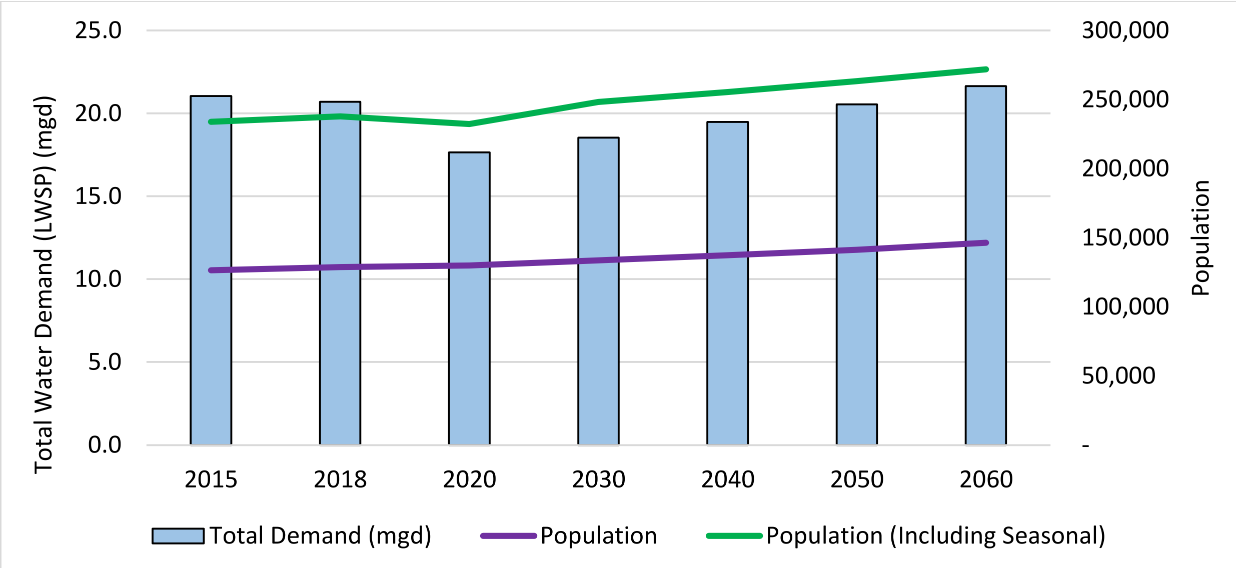
Based on information provided in the LWSPs, residential demand accounted for 43 percent of the total water use in 2018. Non-residential demand accounted for 28 percent. The remaining 29 percent was used for system processing (cleaning and flushing waterlines, backwash, reject water from reverse osmosis water treatment technologies, etc.) or is unaccounted for (Figure 9-1). By 2060, a slight increase in total water demand is expected. Combined, the water systems will supply a projected annual average of 21.665 mgd to a year-round population of 146,432 and a seasonal population of 271,984 in 2060 (Table 9-7).

Table 9-7 Total Average Daily Demand and Population Projections (LWSP, 2018)

Year	Total Demand (mgd)	Population	Population (Including Seasonal)
2015	21.046	126,477	233,891
2018	20.700	128,764	237,858
2020	17.652	130,034	232,279
2030	18.544	133,589	248,350
2040	19.484	137,333	255,455
2050	20.552	141,281	263,479
2060	21.655	146,432	271,984

Water systems are advised to maintain adequate water supplies and manage water demands to ensure that the average daily demands do not exceed 80 percent of the available supply (i.e., demand/supply ratio). Collectively, water systems in the Pasquotank 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 (2018) and projected demands (through 2060) (Figure 9-2) (LWSP, 2018). Based on data from the 2018 LWSPs, there were two water systems who exceeded the 80% demand/supply ratio. Both systems, Dare Regional and South Mills, have demonstrated to DWR that they have secured and have sustainable access to adequate water supplies to meet their current and projected demands through the planning period (2060). The issues related to exceedance of the 80% demand/supply ratio are merely contract issues that have since been largely resolved.

Figure 9-2 Total Average Daily Water Demand and Population Projections (LWSP, 2018)



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

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 Pasquotank River basin. Nationwide, the United States Geological Survey (USGS) has estimated self-supplied withdrawals for domestic use at 3,260 mgd or about 1 percent of 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). DWR is continually working on methodology that would help estimate the amount of water being withdrawn via self-supplied domestic wells in North Carolina.

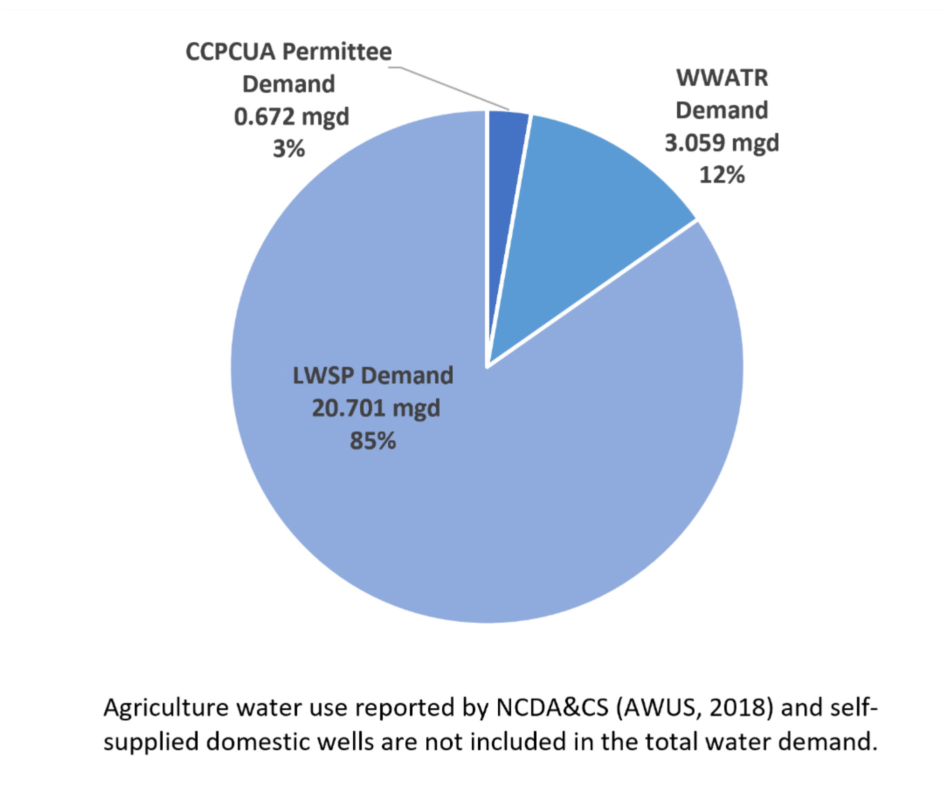
9.1.6 Water Use Summary

Based on information reported by CCPCUA, LWSPs, and WWATR, it is estimated that a total of 24.435 MGD is used in the Pasquotank River basin (Table 9-8; Figure 9-3). This includes both surface and groundwater sources but does not include agriculture demand or the amount of water used by self-supplied domestic wells. **Understanding the total amount of water being used for all activities across the 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.**

Table 9-8 Total Estimated Water Demand in the Pasquotank River Basin (2018)

County	CCPUA Permittee Demand (mgd)	CCPUA Registration Demand (mgd)	WWATR Demand (mgd)	LWSP Demand (mgd)	Total Demand (mgd)
Bertie	-	-	-	-	-
Camden	-	-	-	0.855	0.855
Chowan	-	-	-	-	-
Currituck	-	-	1.018	2.902	3.920
Dare	-	-	1.900	10.971	12.871
Gates	-	-	-	-	-
Hyde	-	-	-	-	-
Pasquotank	-	-	0.126	4.004	4.130
Perquimans	-	-	0.016	0.967	0.982
Tyrrell	-	-	-	0.479	0.479
Washington	0.672	-	-	0.523	1.195
Total	**0.672**	-	**3.059**	**20.701**	**24.432**

Figure 9-3 Estimated Water Use (CCPCUA, LWSP, WWATR) in the Pasquotank River Basin 2018



Since all the public water supply systems that submitted 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.

9.2 Geology

The geology of the Pasquotank River basin consists of interbedded sand, silt, clay, and limestone sediments ranging in age from the early Cretaceous (145 million years ago) to the present. These sediments dip and thicken from west to east and overlie considerably older rock consisting primarily of igneous and metamorphic bedrock. Sediment thickness within the basin ranges from ten feet or less in the western portion of the basin to approximately 9,700 feet in Dare County at Cape Hatteras in the eastern portion of the basin (Figure 9-1).

Potable groundwater supply is available throughout the Pasquotank River basin. Salt water, however, is present within some portions of the aquifers, making proper well design a key factor to assuring a sustainable supply of freshwater. Currently, groundwater is the primary source of water supply for communities and private wells throughout the basin.

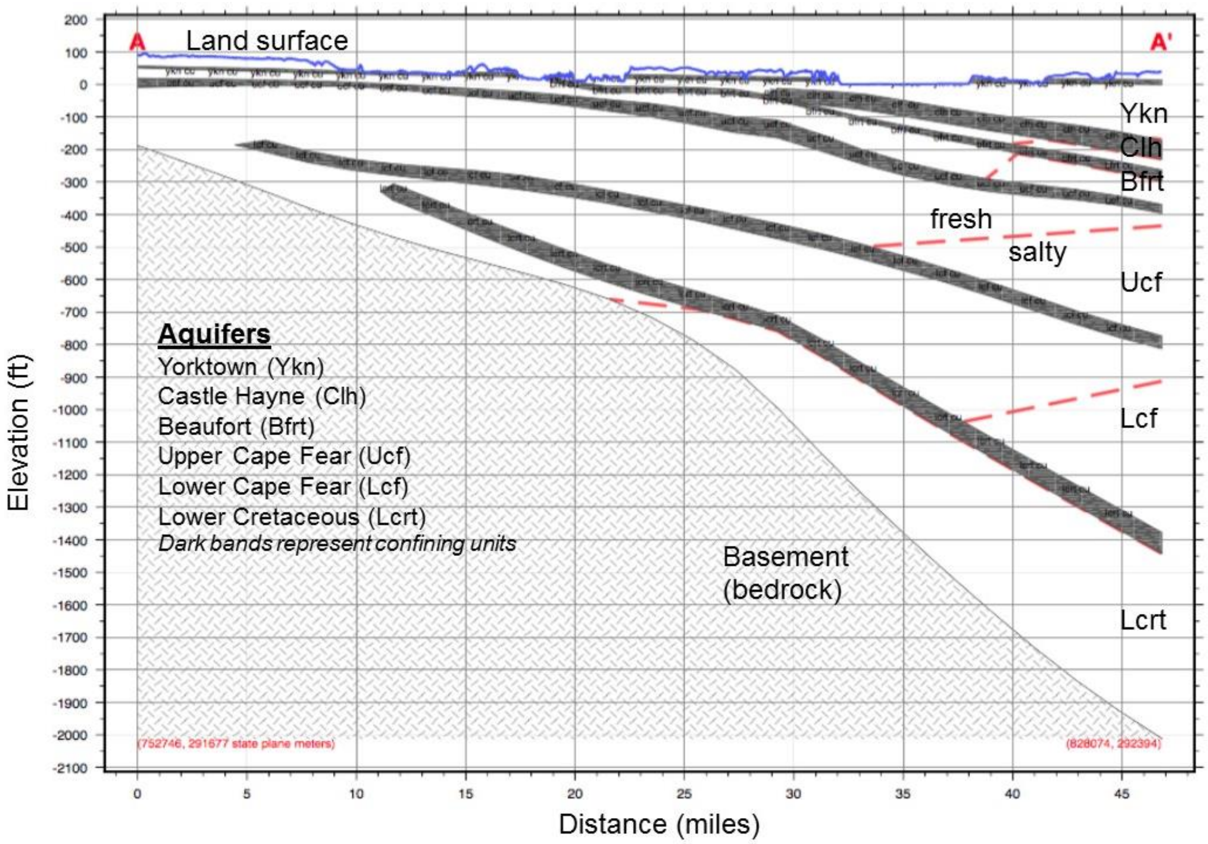
9.2.1 Aquifer Systems

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 thus are limited to the state's coastal plain. 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 to confined aquifers occurs by "leakage" from other aquifers or by direct infiltration where the aquifer outcrops, which is commonly many tens of miles updip from where the aquifer is being utilized for water supply. As recharge rates are much lower than for unconfined aquifers, water level monitoring is necessary to assure that dewatering does not occur as a result of overpumping. Dewatering reduces well yield, increases well operating costs, and causes permanent aquifer compaction and land subsidence.

The primary aquifers within the Pasquotank River basin, from shallowest to deepest, are the surficial, Yorktown, Castle Hayne, Beaufort, Upper Cape Fear, Lower Cape Fear and the Lower Cretaceous aquifers (Figure 9-4). With the exception of the surficial unit, each of these aquifers contains freshwater, transitional, and salt water zones at some depth within the aquifer. In general, these aquifers dip and thicken from west to east. A brief description of each aquifer is provided here. More information about North Carolina's aquifers can also be found on the Ground Water Management Branch's (GWMB) website.

Figure 9-4 Geologic Cross-Section through the Pasquotank River Basin



Surficial Aquifer

The surficial aquifer, or water table, is continuous throughout the study area and is the uppermost aquifer in the Pasquotank River basin. The surficial aquifer is comprised of unconsolidated sediments, which range from several feet to as much as 100 feet or more in thickness.

Water levels in the surficial aquifer rise and fall throughout the year in direct response to precipitation. Changes in water level may range from several inches to a foot or more during precipitation events to tens of feet over a period of a year. Sustained well yields from the surficial aquifer range from several gallons per minute to ten or more gallons per minute depending on aquifer thickness, permeability, and other factors.

The surficial aquifer plays an important role in providing potable water from shallow wells where large quantities are not required. The surficial aquifer is also essential in providing base flow to perennial surface waterbodies and recharge to underlying semi-confined and confined aquifers.

Yorktown Aquifer (Ykn)

The Yorktown aquifer is a fossiliferous, bluish-gray clay with varying amounts of silt and fine-grained sand and shell material. The sandy, shelly portion of the formation is water-bearing and can typically supply enough water to sustain domestic wells. Although usually confined, the Yorktown may act as a surficial aquifer when present at or near land surface. The thickness of the aquifer ranges from around 50 feet (ft) along the western edge of the Pasquotank River basin to over 950 ft along the coast. Groundwater from the aquifer often has high levels of iron.

Castle Hayne Aquifer (Clh)

The Castle Hayne limestone aquifer may be confined or semi-confined, ranges in thickness from tens of feet along the western edge of the Pasquotank River basin to 750 ft or more along the coast. Water yields from the aquifer are typically high, but water is generally hard (i.e., calcium and magnesium carbonates) and can sometimes contain high iron concentrations. As the aquifer commonly has high chlorides, water from the aquifer is often treated by reverse osmosis.

Beaufort Aquifer (Bfrt)

The Beaufort aquifer is primarily comprised of glauconitic, fossiliferous, clayey sands and intermittent limestones, which include sediments from the overlying Castle Hayne formation. The aquifer is typically confined and ranges in thickness from around 50 feet along the western edge of the basin to 200 ft along the coast. Like the Yorktown, the Beaufort can provide potable water where large quantities of water are not required.

Upper and Lower Cape Fear Aquifers (Ucf, Lcf)

The Upper and Lower Cape Fear aquifers are one of the most prolific sources of high-quality groundwater in the western portion of the basin. Consisting of sands with minor silt and clay interbeds, the upper and lower aquifer units are separated from one another by a thick, low-permeability silt and clay confining unit. From west to east, the upper and lower units range in thickness from approximately 250 feet to 650 feet and 900 feet to 2,800 feet, respectively.

Lower Cretaceous Aquifer (Lcrt)

The Lower Cretaceous aquifer is comprised of interbedded sands and clays that lie uncomformably on or over consolidated bedrock. The Lower Cretaceous aquifer is seldom used for water supply within the Pasquotank River basin because of the availability of shallower, high quality aquifers with lower chloride content.

9.2.2 Groundwater Demand and 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.

Groundwater and surface water are hydraulically connected, but the interactions 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 Groundwater Management Branch (GWMB) in the Groundwater Resources Section oversees the assessment, monitoring, and management of the state's groundwater resources with regard to use and availability.

9.2.3 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 over 685 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 to include 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 Pasquotank River basin, from shallowest to deepest, are the Surficial, Yorktown (Figure 9-5), Castle Hayne (Figure 9-6), Beaufort (Figure 9-7), Upper Cape Fear (Figure 9-8), Lower Cape Fear (Figure 9-9) and the Lower Cretaceous (Figure 9-10) aquifers. Chloride sampling within these aquifers allows DWR to monitor salinity levels and trends at the fresh water-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).

Information about the groundwater monitoring well network 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 Pasquotank River basin.

Figure 9-5 Chloride Content within the Yorktown Aquifer

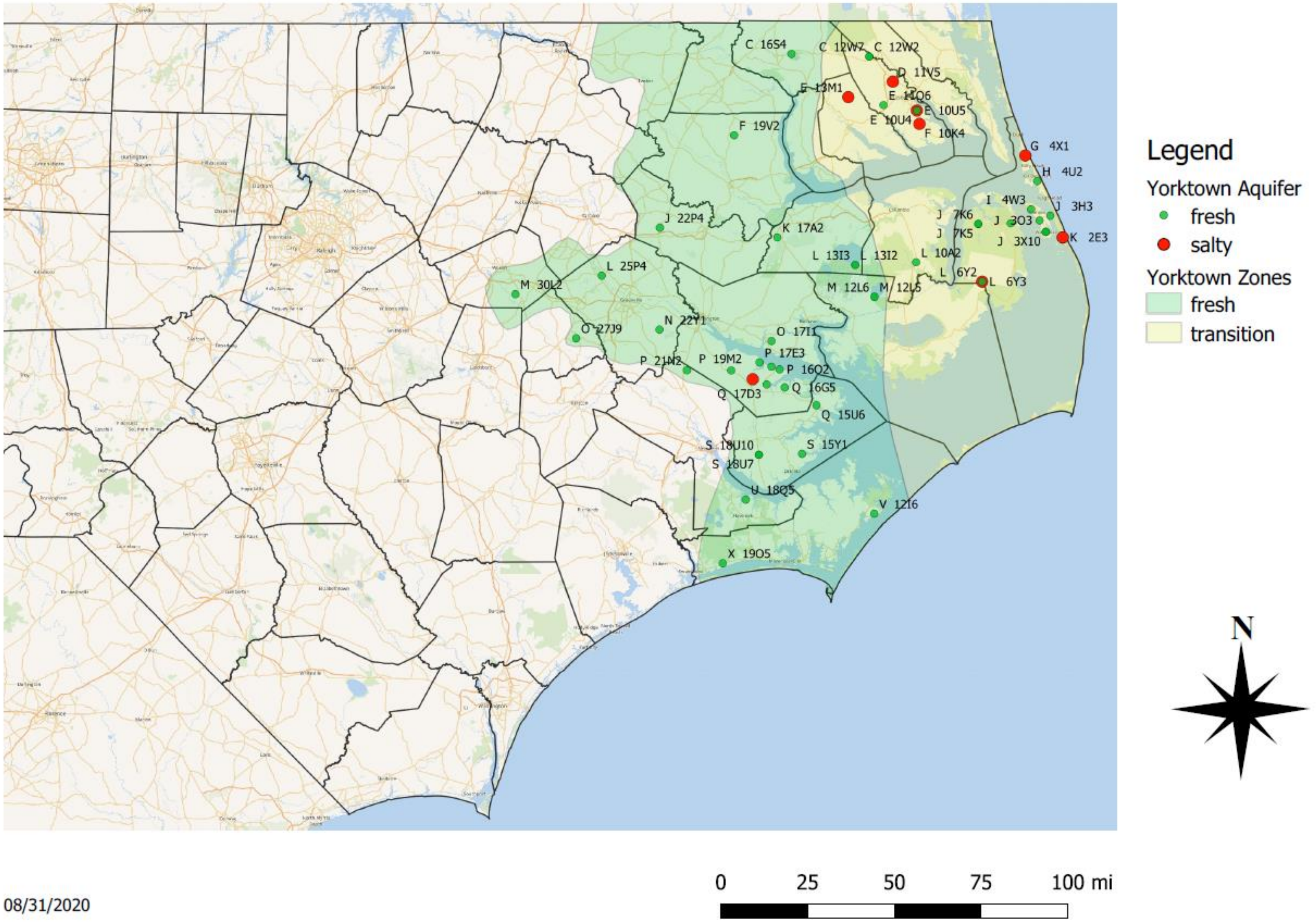


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Figure 9-6 Chloride Content within the Castle Hayne Aquifer

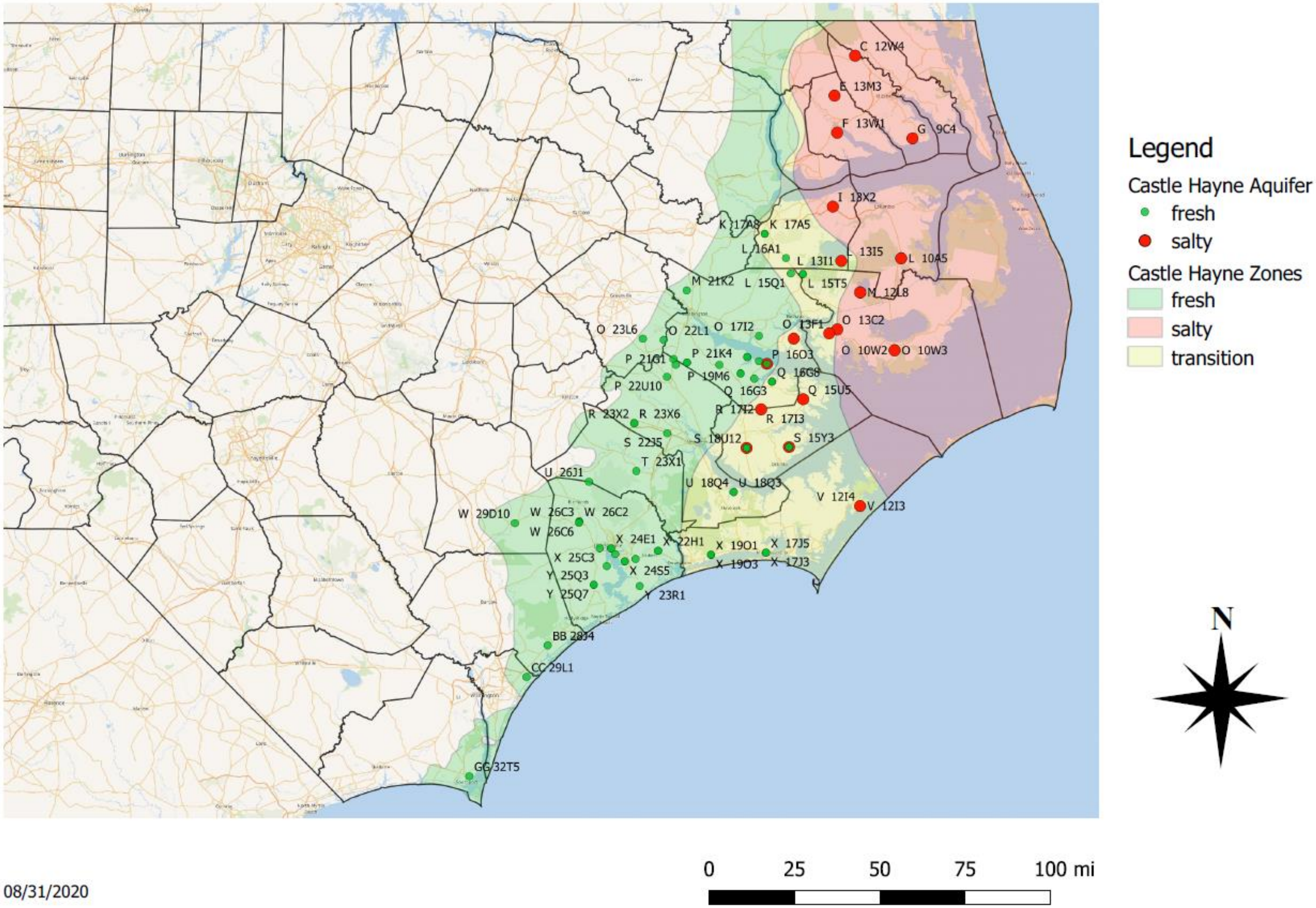

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Figure 9-7 Chloride Content within the Beaufort Aquifer

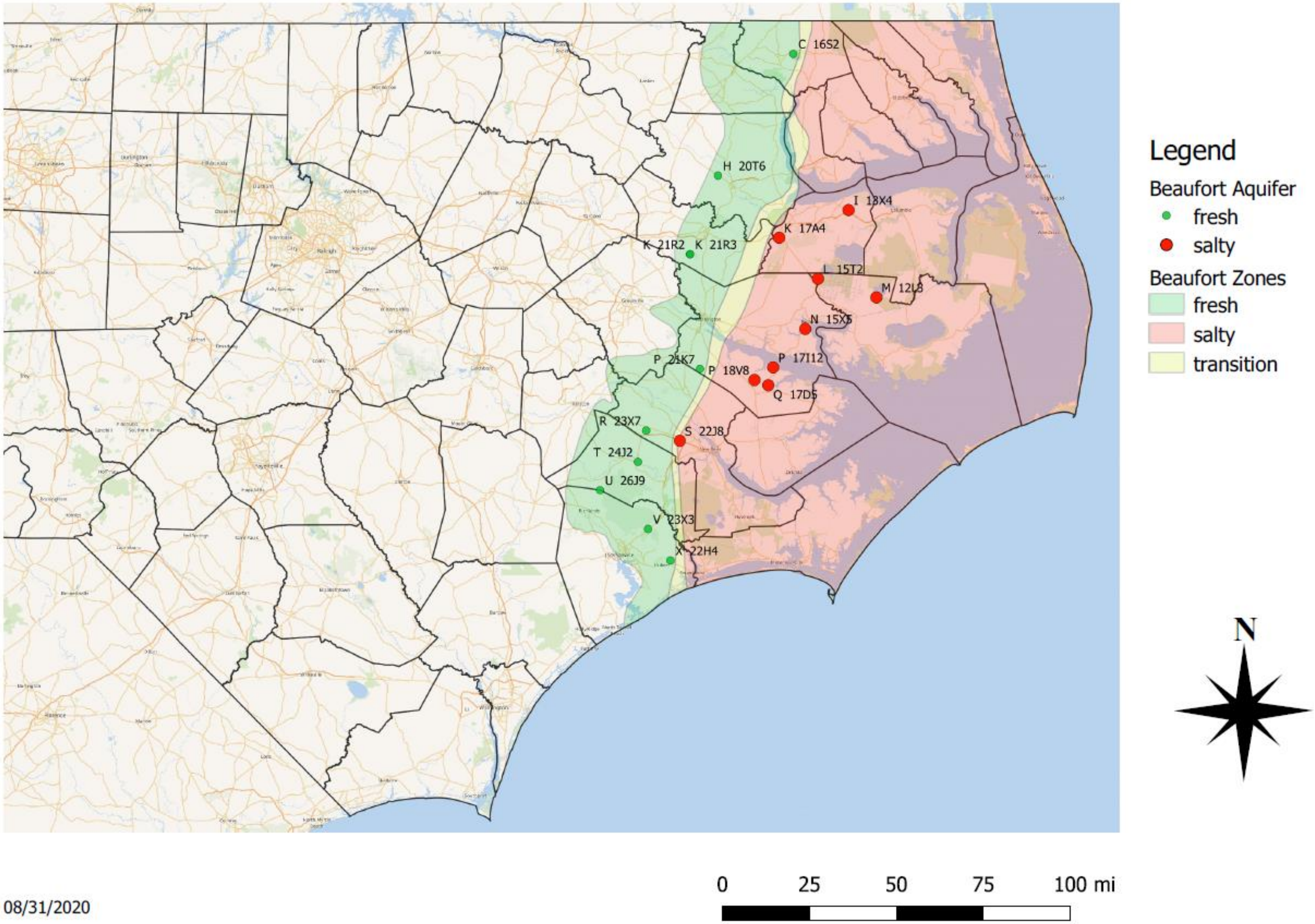

Figure 9-8 Chloride Content within the Upper Cape Fear Aquifer

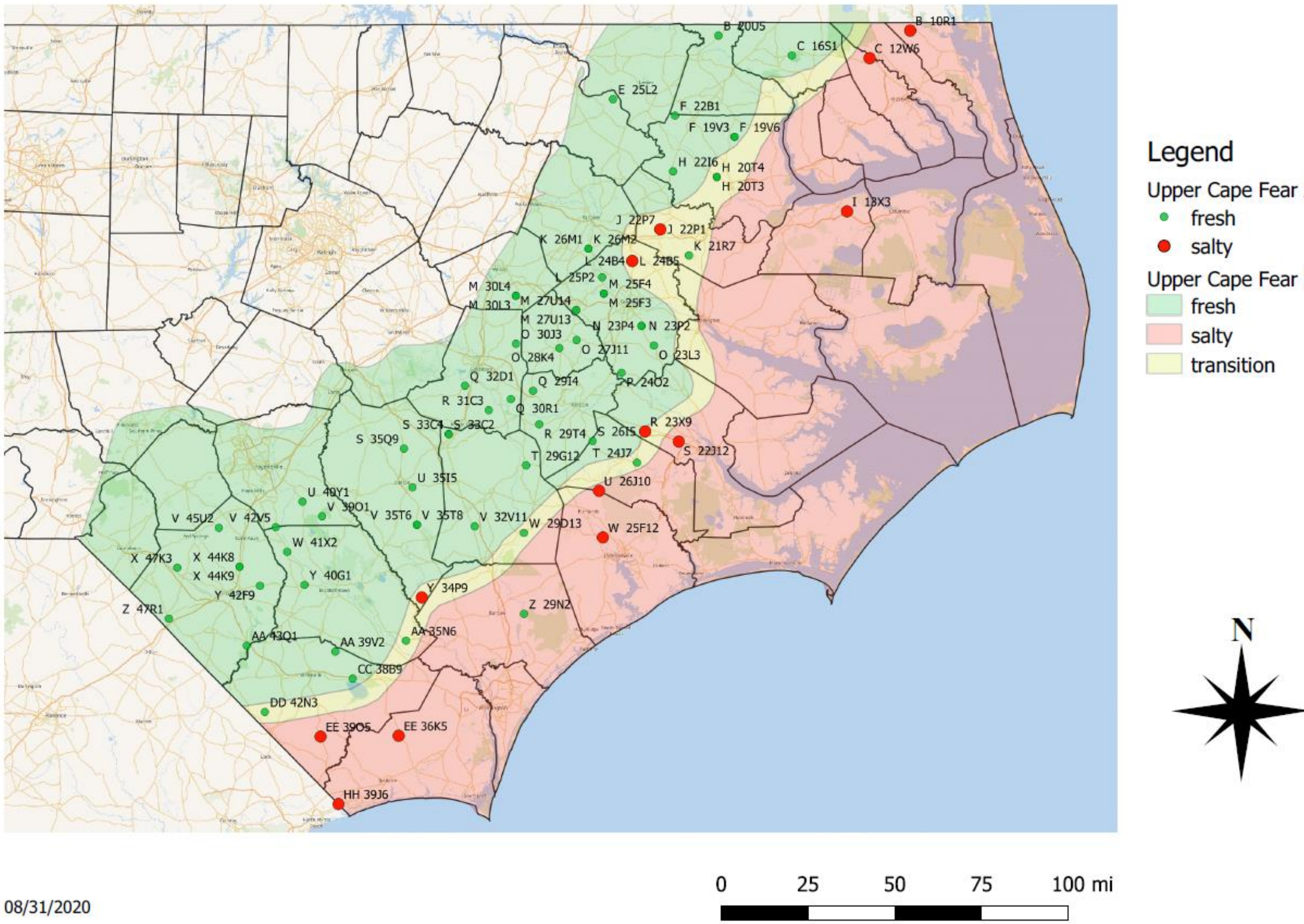

Figure 9-9 Chloride Content within the Lower Cape Fear Aquifer

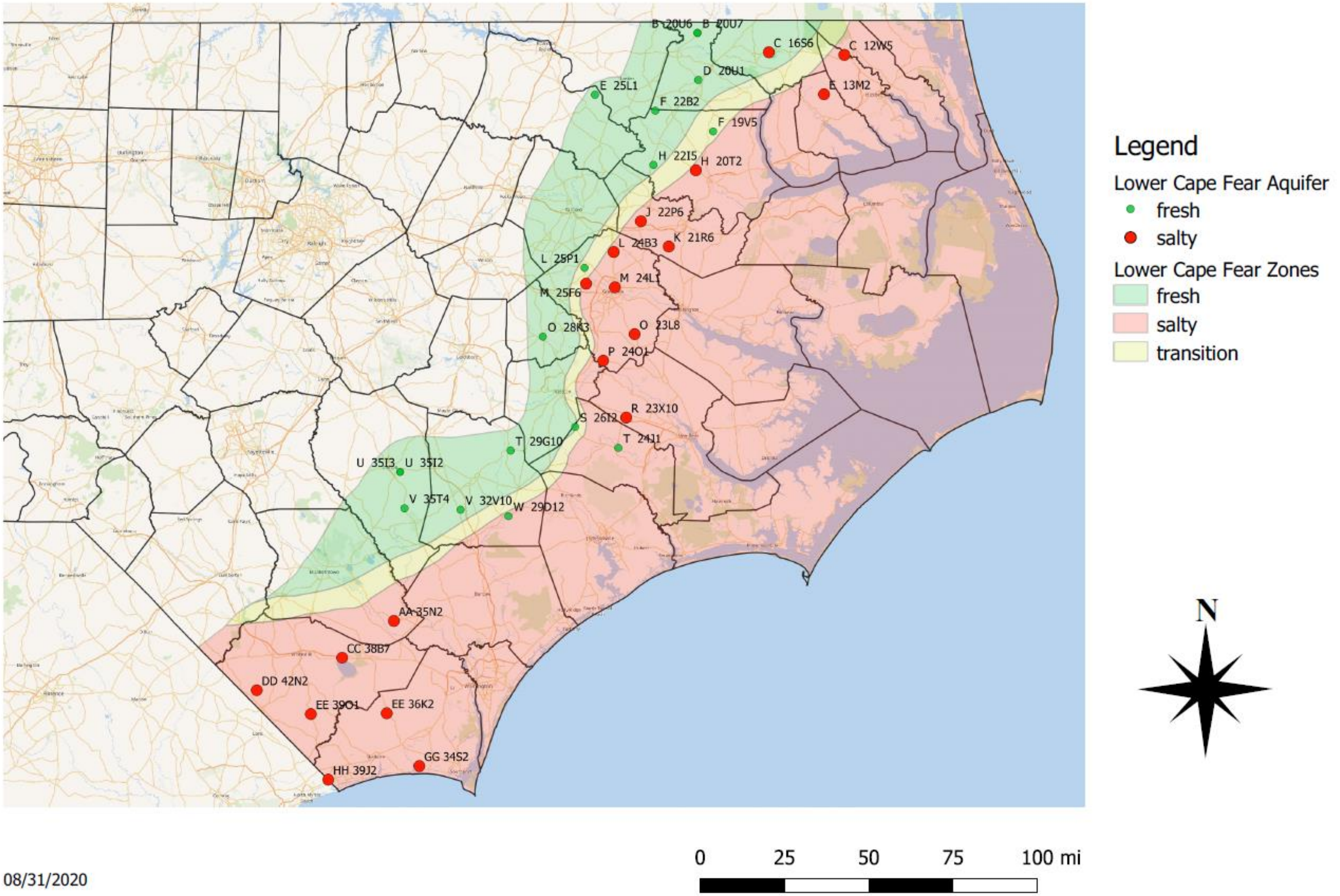

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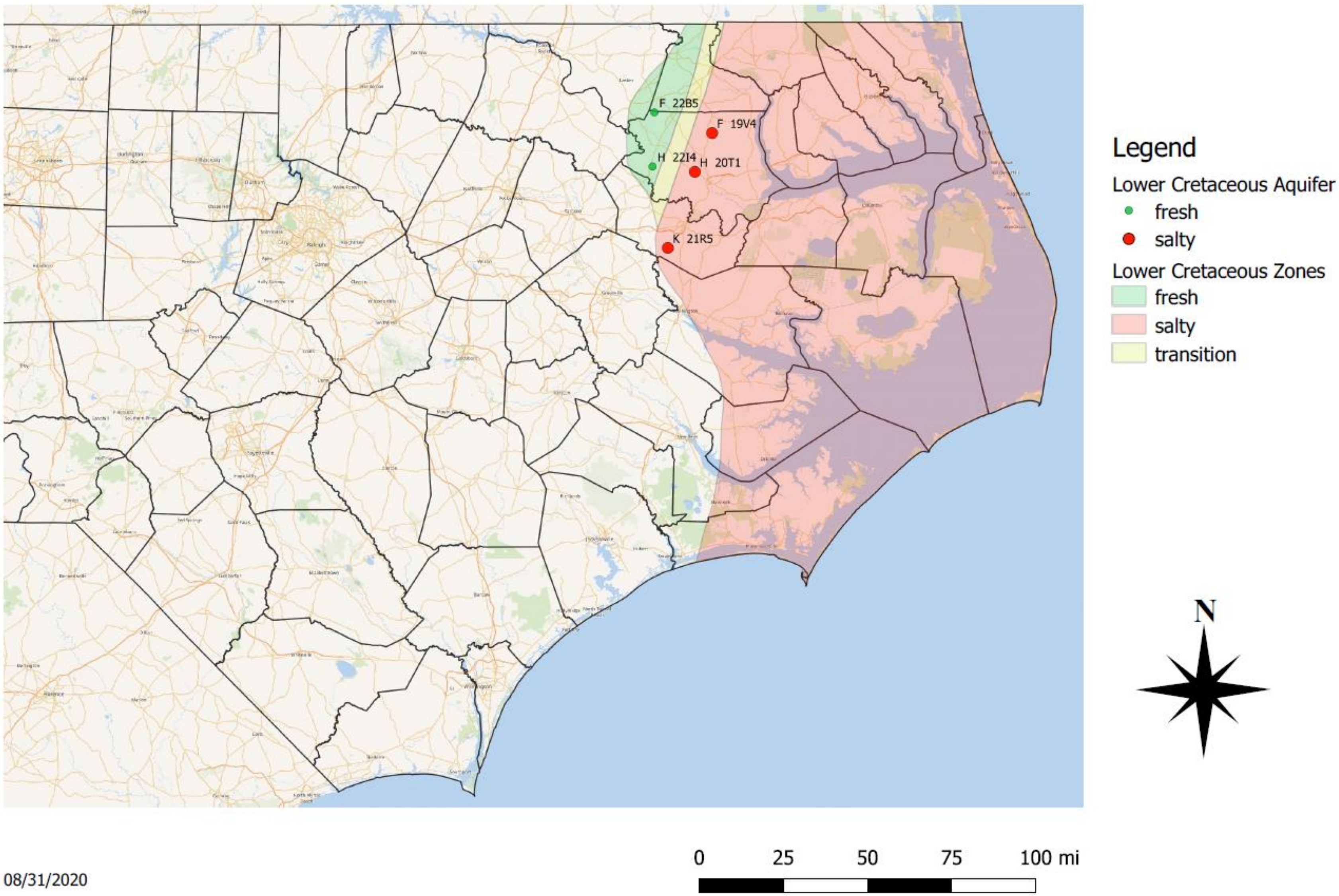
Figure 9-10 Chloride Content within the Lower Cretaceous Aquifer

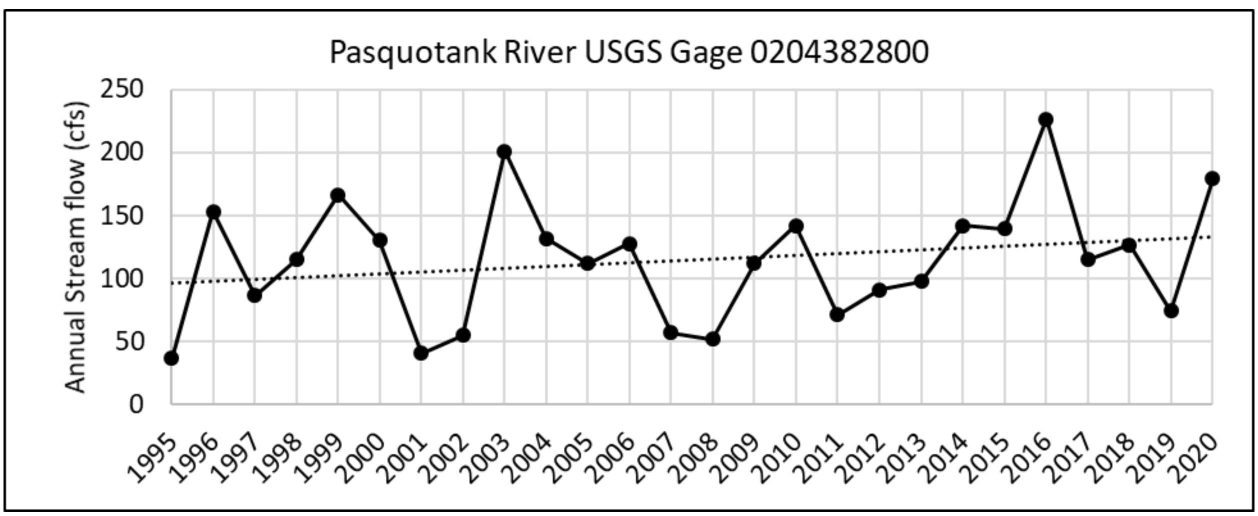


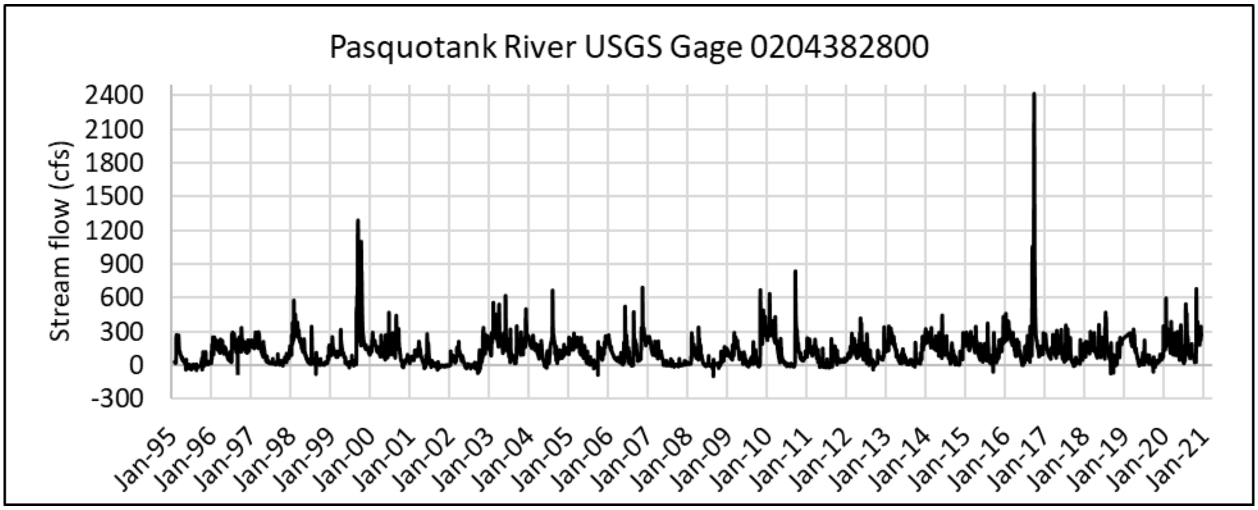
9.3 Streamflow

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.

There are two USGS gaging stations located in the Pasquotank River Basin. One USGS flow gage is located on the east bank of Currituck Sound. Another is located on the Pasquotank River near South Mills, NC. The Pasquotank River USGS gage is used to understand general streamflow patterns throughout the northern portion of the basin and provide some understanding on how drought or wet conditions may be impacting water quality (Figure 9-11). Annual average streamflow and daily streamflow data for this site may be affected by aliasing due to tides and can contain fluctuations that are not representative of net downstream discharge (USGS, 2006).

Figure 9-11 Pasquotank River Annual Average Stream Flow and Daily Stream Flow at USGS Gage 0204382800 Near South Mills, NC.





To protect ecological integrity, critical characteristics of a flow regime (magnitude, timing, frequency, duration, variability and rate of change) need to be considered (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.

9.3.1 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 Pasquotank, however, is a challenge 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.

One challenge when assessing ecological flows 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. Currently, there are only two active surface-water gages in the North Carolina portion of the Pasquotank River basin, Pasquotank River Near South Mills, NC (USGS 0204382800) and Currituck Sound on East Bank at Corolla, NC (USGS 02043433). There are 9 active gages in Virginia, monitoring the North Landing and Northwest river watersheds and the canals of the Great Dismal Swamp (USGS, 2020).

In coastal waters, gages typically collect stage, or water depth, rather than flow values. This is largely due to the difficulty of obtaining accurate flow values in circulating, bidirectional tidal waters and the width of some channels. Water stage 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.

The streamflow data gap and the tidal influence in coastal waters complicates efforts to model streamflow. 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.

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 that have no, or limited, land-cover modification or population growth that often results in additional surface water or groundwater withdrawals. However, 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.

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.

9.3.2 Impacts from Changes in Flow Regime

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. This impact is limited in the Pasquotank River basin since groundwater is the primary source of potable water. Low-flow conditions can also have significant impacts on downstream water quality as waste assimilative capacity is reduced.

9.3.3 Impoundments & Channelization

There are no dam impoundments subject to the Division of Energy, Mineral and Land Resources (DEMLR) Dam Safety Program reported in the Pasquotank River basin (NCDEMLR, 2021). Existing artificial impoundments in the basin are not under DEMLR's Dam Safety Program's jurisdiction. There are, however, other flow-control structures (such as tidal or flood gates, weirs and road culverts) that block access to upstream habitat and alter flows.

Based on data provided by various resource agencies and literature reviews, the 2016 Coastal Habitat Protection Plan (CHPP) Source Document reported that there are more than 80 culverts, dams, and other blockages in the Albemarle Subregion of CHPP Region 1. Culverts, dams, or other blockages are impediments to fish movement in the Pasquotank River basin (NCDEQ 2016). The majority of the impediments are located in the Scuppernong drainage network north of Lake Phelps. Road culverts that are improperly installed or not maintained can hinder upstream fish migration by increasing flow volumes above suitable swimming speeds or the water depth is too shallow to traverse. Culverts can also cause erosion and become elevated above the downstream channel ("perched") making then unnavigable for fish. Culverts may also be installed without consideration to the amount of transported woody debris, which can lead to eventual clogging and require stream debris removal (USACE, 2013). Some fish species may also resist moving through dark road culverts during daytime migration (Moser and Patrick, 2000). Guidance is available for new or replacement culverts to make them more suitable for the passage of anadromous fishes (USACE, 2013).

The removal of structures that impede the movement of migratory fishes can be difficult given the essential uses of these structures, the limited amount of funding, and landowner cooperation. Prioritization tools have become available to identify those structures that would provide the most suitable habitat for the most fish species (SARP, 2019). The development of a prioritization tool requires the input of resource experts to identify, rate and map habitat for target species, to identify impediments in the basin, and an assessment of either the miles of stream network or the area of habitat made available to migrating fish by removal or modification of each structure.

The vast, historical canal drainage network in the Pasquotank River basin has largely been recognized as public waters and have been assigned water quality classifications by the state. The most iconic of the channelization projects in the Pasquotank River basin is the Atlantic Intracoastal Waterway (AIWW). The north-south waterway passes through the Alligator, Pasquotank, North and North Landing river watersheds.

9.4 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.

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.

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

Five drought designations, or classifications, were established by the NCDMAC. A statewide drought assessment is published on a weekly basis. A drought classification is applied to a county when at least 25 percent of the land area of the county is impacted. The drought monitor history (Figure 9-12) provides a graphical representation of the drought designation, and the length of time the basin was in a specific designation. During the twelve-year assessment period (September 2005 - August 2018), the Pasquotank River basin experienced extreme weather conditions that included above average rainfall due to several hurricanes and four levels of drought (January 2000 – December 2020). The designation of Severe to Extreme Drought can first be seen from November 2001 through October 2002 and then again for another year from September 2007 through August 2008. The last severe drought recorded for the basin was the summer of 2010 (Figure 9-13).

Figure 9-12 Drought Monitor History for Pasquotank River Basin (January 2000 – December 2020)

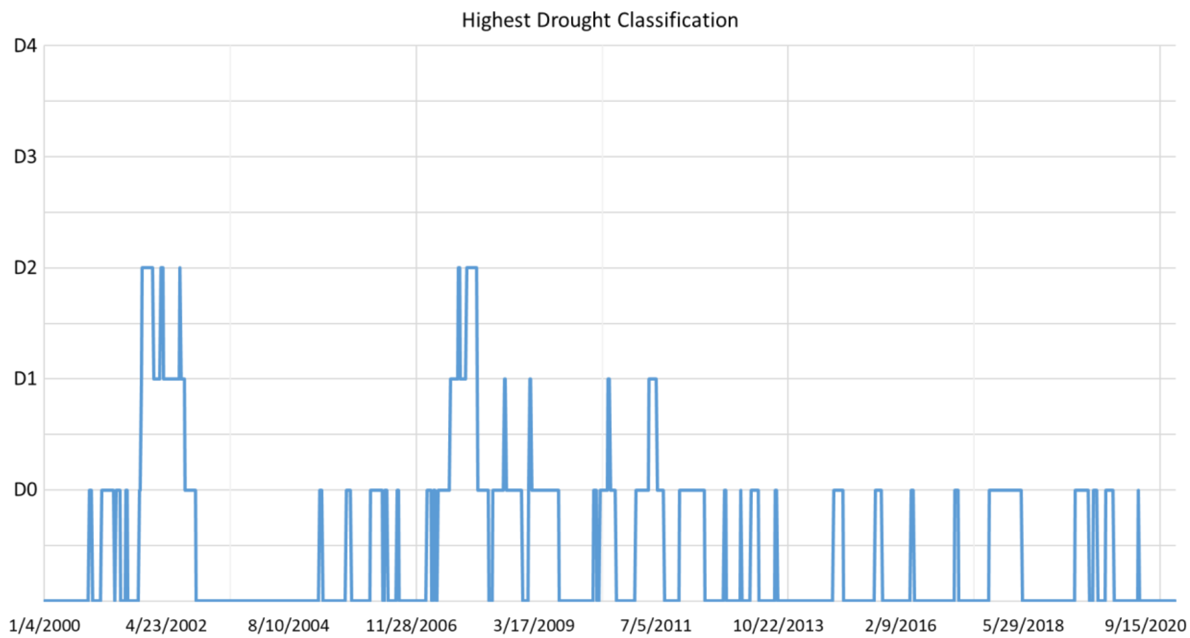
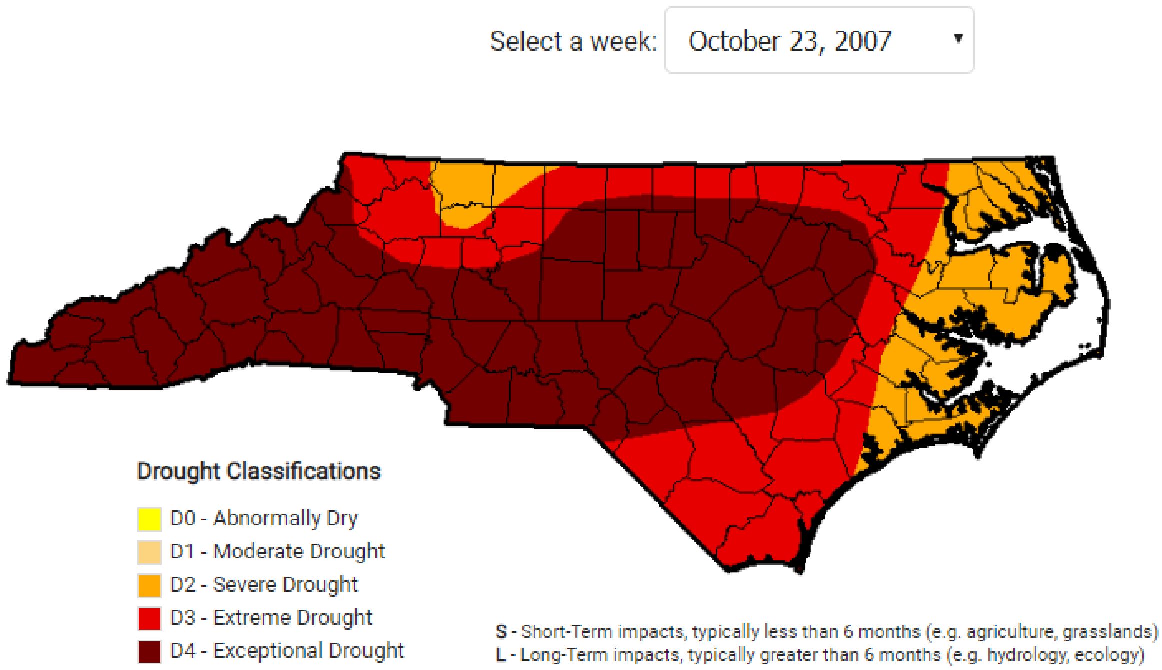
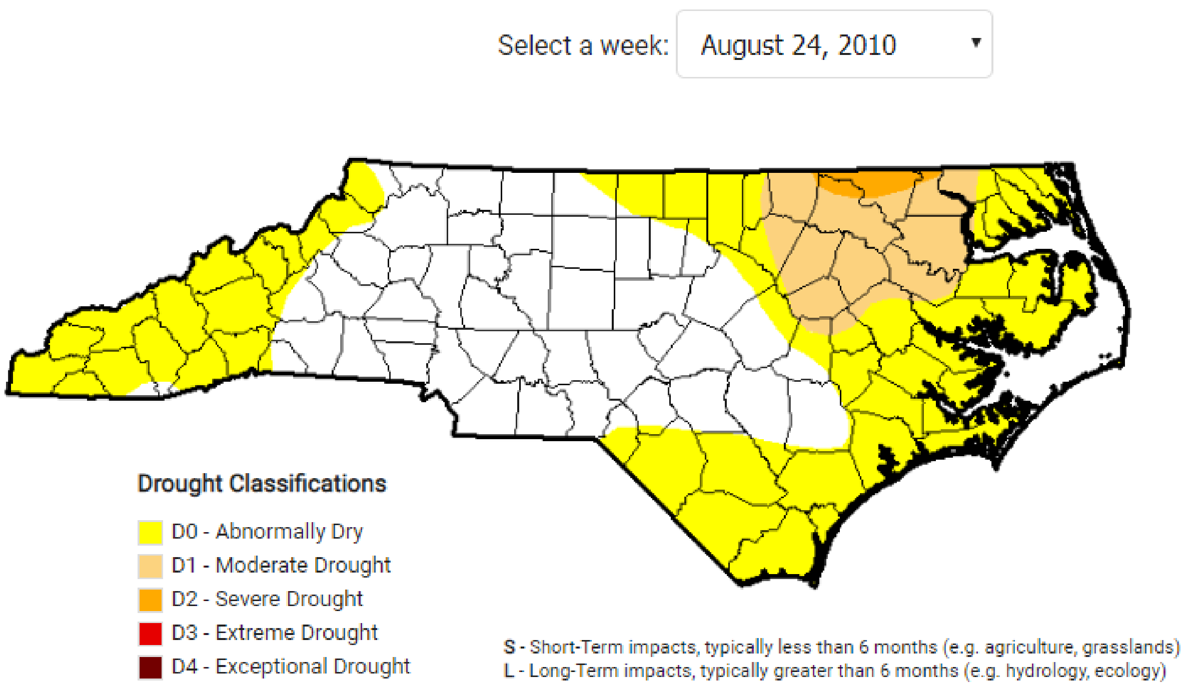


Figure 9-13 North Carolina Drought Monitor Map (October 2007; August 2010)





9.5 Protecting Water Resources & Future Considerations

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.

9.5.1 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.

9.5.2 Agricultural Water Use Data

In the Pasquotank River basin, agricultural water use data is reported for only one of the eleven counties located partially or entirely within the river 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 Pasquotank River basin.

9.5.3 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.

9.5.4 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 baseflows. Lower baseflows 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.

9.5.5 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.

9.5.6 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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