Contents

Chapter 5 Chowan NSW History and Current Nutrient Conditions

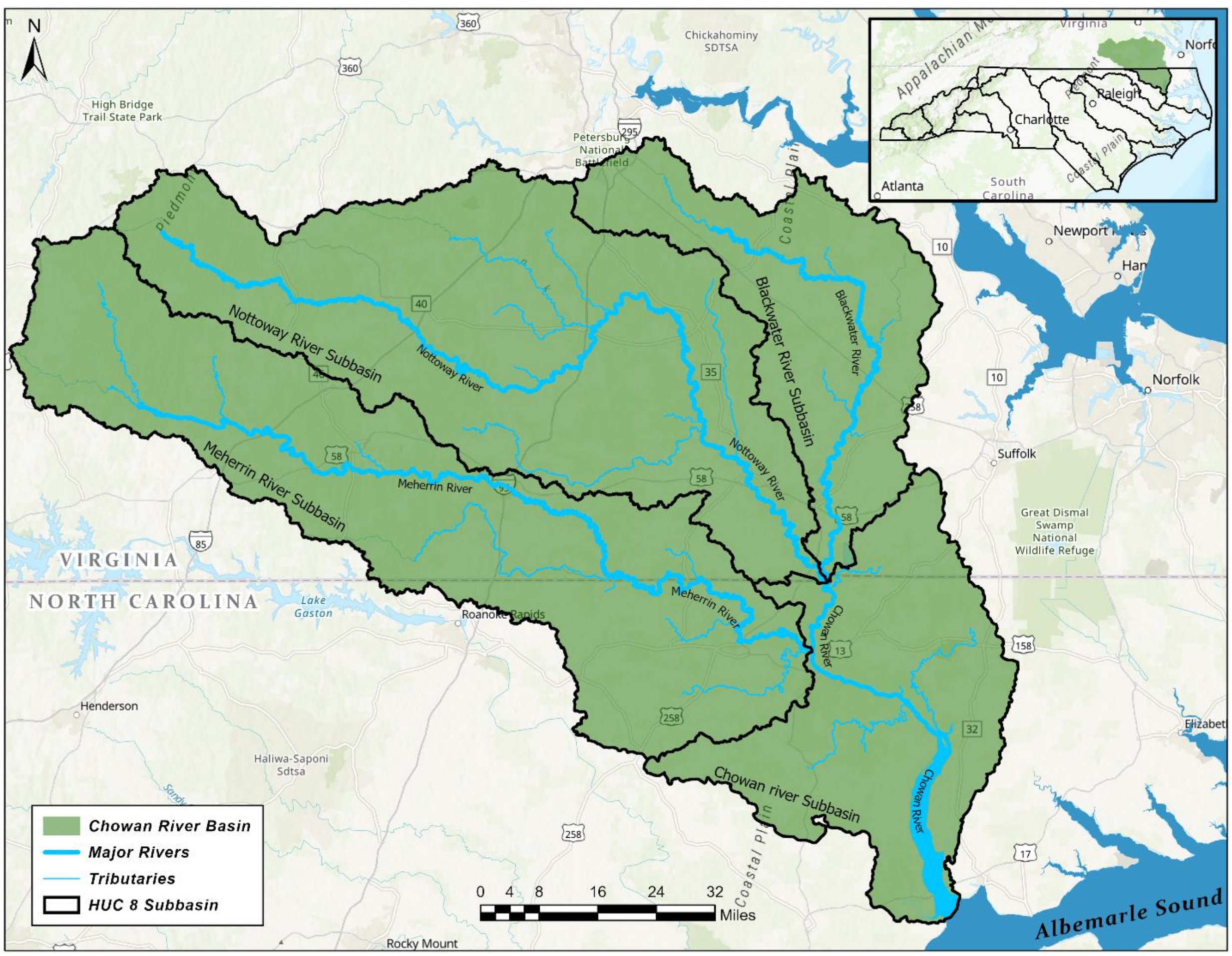
Dolichospermum bloom, Chowan River (7/2/18)

5.1 Historical Review

5.1.1 Nutrient Reduction Management Goals: Strategic Plan Development (1970's – 1980's)

The Chowan River was the first coastal river in North Carolina (NC) recognized to experience problems with nutrient enrichment, or eutrophication (Figure 5-1). Early reports indicated that major nuisance algal blooms occurred in 1972 and 1978 in the lower portion of the Chowan River. In addition to algal blooms, the occurrence of fish kills also indicated water quality problems.

Figure 5-1 Chowan River Basin Watershed



Nuisance algal blooms are the growth of microscopic or macroscopic vegetation due to an excess amount of nutrients in a river system. The nutrient sources in the Chowan River were identified as wastewater from municipal and industrial dischargers, overland flow, and drainage from agricultural and urban areas (Stanley and Hobbie, 1977; Daniel, 1977; NCDNRCD, 1979). The largest contributors of nutrients were a fertilizer plant (C. F. Industries Inc.) in Tunis, NC and a bleached pulp and paper and building products complex (Union Camp/International Paper) in Franklin, Virginia (VA). C. F. Industries Inc. may have contributed as much as 4,000 pounds per day (Howells, 1990) and Union Camp/International Paper was estimated to contribute 5,565 pounds of nitrogen per day (NCDNRCD, 1979). C. F. Industries Inc. stopped discharging in 1972 and no severe algal blooms developed in the river during the next few years. There was continued concern that high nitrogen-laden water continued to seep into the river from storage ponds at the fertilizer plant as blooms began to appear in 1976 (See Chapter 7, Groundwater Remediation Non-Discharge Permitting section for additional information). Union Camp was limited to discharging only during the winter months (Bond et al., 1978).

In response to the deteriorating water quality in the Chowan River, the Chowan River Project was established in 1973. This was the first management program which led to multidisciplinary studies of the hydrodynamics and eutrophication issues. The goal was to establish the basis for a water quality management plan which would help resource managers prevent these algal blooms and preserve the water quality for present and future water uses (Bond et al., 1978). The highlights from three of these studies conducted in the 1970's and one study in the 1980's are listed below with additional study summaries in the Chowan River Restoration Project:

1. A one-dimensional deterministic flow model of the Chowan River was developed by Daniel (1977). This model served as a common reference for other investigators by providing daily average discharge for nine sites along the river for the period of April 1974 to March 1976. The study also described the influence of both lunar tides and wind tides which are present within the Chowan River system. The lunar tides are small causing only about 1 foot of change in the water surface and are buffered by the Outer Banks. During periods of low flow, these tides may exert an influence as far upstream as six miles north of Franklin, VA on the Blackwater River. The wind tides exert more influence on the surface water level resulting in a change of as much as 4 feet. The residence time in the lower portion of the river averaged about 50 days and is often in excess of 100 days during the summer and fall (Daniel, 1977). Currently, DWR does not have flow data and there is no USGS flow gage on the mainstem Chowan River, so additional understanding of flow throughout this system is not readily available.
2. A study focused on the relationship between nutrients and algal growth was undertaken by Stanley and Hobbie (1977). They reported that nitrogen was clearly implicated as a cause of the algal blooms. Their study concluded that the release of nitrogen from decomposing organic matter in the sediments deposited on the river bottom would provide much of the nitrogen needed to sustain algal growth, during the summer months. This means that even though dissolved inorganic nitrogen (the form of nitrogen most readily available for biological uptake) was often undetectable during the summer, dischargers of organic matter and nutrients during the winter months could sustain summer algal growths through recycled nitrogen. Additionally, river flow was found to exert a strong negative influence on algal biomass during the winter when flow rates are high.

3. A study of the response of phytoplankton to water quality was conducted between 1974 and 1977 by Witherspoon, et al. (1979). Their study found three periods of relatively high algal growth: 1) a short-lived, late winter peak, 2) a mid-spring peak, and 3) a summer peak that was sustained through September to early October. They also reported that the river could be divided into an upper and lower biotic section. The upper river usually contains concentrations of nutrients sufficient to support algal biomass. However, river flow rates usually were high enough to prevent large accumulations of algal biomass, i.e. blooms. The lower river has more stagnant flows that provide conditions for nutrient and algal interactions and that bluegreen algae were dominate in the lower section of the Chowan River system. One of their main conclusions stated that "low nutrient levels coupled with high algal biomass during the mid-summer indicted that when environmental conditions are favorable, algal growth quickly depletes nitrogen and phosphorus; yet algal growth during this season continues. Nutrient recycling, nitrogen fixation, physiological utilization or organic nitrogen and/or phosphorus in high concentration in the river or a combination of all three processes may be providing these essential nutrients during that period".
4. Studies continued in the 1980's to better understand the drivers of the bluegreen algal blooms. In 1982, Hans Paerl confirmed that both nitrogen and phosphorus were important nutrients that contributed to the development of bluegreen algal blooms. In particular, high nitrogen inputs during the spring were identified as creating a potential for spring algal blooms (non bluegreen algae). These blooms would subsequently sink and deplete oxygen from bottom water as they decomposed triggering the release of phosphorus and stimulating the growth of bluegreen algae during the summer. Additional studies concluded that controls of nitrogen and phosphorus inputs were necessary to reduce the frequency and magnitude of algal blooms and that the reductions should be done simultaneously. It was also suggested that the ratio between nitrogen and phosphorus should promote competition for each nutrient such that no one species would gain dominance and would promote conditions favorable to a balanced algal community.

In response to nuisance algal blooms, fish kills and "red sore disease" (fungus *Aphanomyces*) in North Carolina's waters, the North Carolina Environmental Management Commission (EMC) established the Nutrient Sensitive Water (NSW) supplemental classification on May 10, 1979 as a legal basis for controlling the discharge of nutrients (nitrogen and phosphorus) into surface waters. Nutrient Sensitive Waters were defined as waters subject to excessive growths of microscopic or macroscopic vegetation requiring limitations on nutrient inputs. This classification was applied to the Chowan River and took effect in September 1979. This enabled nutrient limits to be included in NPDES wastewater permits discharging to the surface waters of the Chowan River basin (1 mg/L total phosphorus and 3 mg/L nitrogen as a 30-day average).

In 1982, the North Carolina Department of Natural Resources and Community Development developed the Chowan/Albemarle Action Plan and the Chowan River Water Quality Management Plan. These plans addressed the water quality problems in the area by constructing a strategic plan with specific management goals focused on the Chowan River. Goals included nutrient reduction of 30 to 40 percent in phosphorus inputs and 15 to 25 percent reduction in nitrogen inputs. To meet these goals, a combination of point and nonpoint source controls were required. Given that approximately 75 percent of the Chowan River basin is in Virginia, these control measures would also need to be implemented in

Virginia in order to meet the nutrient reduction goals. Achieving these nutrient reduction goals would substantially reduce the probability of nuisance algal blooms.

Chlorophyll *a* concentration was a metric for achieving the 1982 management reduction goals. The reductions in nitrogen and phosphorus loads should result in chlorophyll *a* concentrations with peak levels not to exceed 40 µg/L. In order to ensure that peak summer levels of chlorophyll *a* not exceed the 40 µg/L standard, a target range for average summer chlorophyll *a* was established to be 25 to 30 µg/L. The 1982 report indicated that the 1977 to 1980 average summer (June-September) chlorophyll *a* levels for the Chowan River near Colerain, ranged from 34 to 132 µg/L with peak summer chlorophyll *a* values ranging from 63 to 1,300 µg/L. This section of the lower Chowan River generally had the worst surface blooms and maximum levels of chlorophyll *a* concentrations recorded at that time.

5.1.2 Implementation of the Strategic Plans in the Chowan River Basin (1980's – 1990's)

Agriculture and Best Management Practices:

In 1983, Craig and Kuenzler reported on a mass balance model which found that agriculture, forests and wetlands, and point sources contributed 62%, 21% and 7% respectively the annual nitrogen inputs to the Chowan basin. The respective annual phosphorus inputs were estimated to be 72%, 22% and 6%. Swamp forests were estimated to remove 83% of the total nitrogen and 51% of the total phosphorus from streams passing through these wetlands. This study highlighted the **need to reduce agriculture inputs of nitrogen and phosphorus.**

Humenik, et al. (1983) measured the water quality changes resulting from implementation of best management practices (BMPs) to reduce agricultural nonpoint sources concluded there was a need for educational and technical assistance on soil testing for farmers in the Chowan River basin. The EMC found that there were no practical regulatory means to specifically address agricultural sources of nutrients. This necessitated the **need for a voluntary program and/or economic incentives to achieve implementation of agricultural BMPs**. In 1985, the North Carolina Agricultural Cost Share Program (NCACSP) was implemented in the Chowan River watershed. The purpose of the NCACSP was to assist agricultural landowners in reducing nutrient, sediment, and pesticide runoff through the application of best management practices.

Municipal and Industrial Dischargers converting to Non-Discharge Land Application:

While the limitation on surface water discharged of effluents will continue to allow point sources to discharge, it was the Division's position that non-discharge land application was the more desirable treatment methodology for the removal of nutrient from the Chowan River System. The thirteen towns in the Chowan River basin initially committed to voluntary actions to reduce discharges into the Chowan in 1979 and municipal wastewater discharges were largely eliminated by 1990. The industrial discharge which all took steps to reduce their nutrient loads to the Chowan River included C. F. Industries Inc., United Piece Dye Works and Union Camp/International Paper.

Summary:

In 1990, North Carolina Department of Environment, Health and Natural Resources updated the 1982 management plan and concluded that NC achieved its goal of a 20 percent reduction in nitrogen and reduced phosphorus loading by 29 percent (goal of 35 percent). These reductions were largely due to the elimination of most municipal wastewater discharges, one industrial discharger (the Tunis fertilizer plant) and through the implementation of agricultural BMPs.

5.1.3 Continued Monitoring of the Chowan River (1990's – 2000's)

Nutrients:

Between 1988 and 1991, the North Carolina Division of Water Quality participated in the Albemarle-Pamlico Estuarine Study. Nutrient data showed high mean total nitrogen concentrations, relative to other Chowan River stations, for stations located on the Blackwater River near Wyanoke, VA and Ahoskie Creek near Ahoskie, NC. The Blackwater River near Wyanoke had the highest concentration of total nitrogen, ammonia, total kjeldahl nitrogen, total phosphorus and orthophosphorus. This station is located just downstream of a discharge canal from Union Camp (now International Paper). This facility stores waste in settling ponds and then releases wastewater during the winter months when flow is generally the highest. The report also showed that the highest mean concentrations of total nitrogen and nitrite-nitrate nitrogen are found in Ahoskie Creek near Ahoskie. The 1988 – 1991 study found many slow-moving tributaries to the Chowan had thick surface growths of algae. Many of these blooms were accompanied by elevated chlorophyll a levels ranging from 54 µg/L to 400 µg/L in 1989 and 100 µg/L to 400 µg/L in 1990.

For the 1997 Chowan River Basinwide Water Quality Plan, a nutrient budget was developed to assess the relative contributions of nutrients to the Chowan River basin from different sources within the entire watershed (Table 5-1). Point source loads represent the annual loads from permitted dischargers in the basin at that time. Nonpoint source loads represented the net export of nutrients from areas of varying land use or land cover within each subbasin. The nonpoint source loads were calculated using an export coefficient model utilizing land cover information (derived from 1988 Landsat data) and nutrient export estimates derived from previous studies in central and eastern NC. It is important to note that this method of calculating nutrient loads does not estimate the amount of a nutrient delivered to a certain point in the river and did not account for any BMP implementation that occurred in the basin. The 1997 loading estimates did not consider any contributions from the VA portions of the watersheds, which is approximately 75% percent of the land area.

As seen in Table 5-1, the 1997 nutrient budget indicates that nutrient loading from the NC portion of the basin is dominated by contributions from agriculture; these finding concur with the reported results by Craig and Kuenzler (1983). It is important to recognize that the 1997 nutrient budget specific analysis did not account for specific land management practices put in place over the time-period between the development of the Chowan Management Plan in 1982 and the 1997 nutrient budget modeling effort. As a result, reductions obtained during that timeframe are not reflected in the load estimates, however, even with such reductions, agriculture would remain the dominate source of nitrogen and phosphorus in the Chowan River basin due to the prevalence of the agricultural land use area in the watershed (Table 5-2).

Due to the elimination of most municipal wastewater discharges in favor of non-discharge land application systems and the closure of most of the industrial dischargers over the years (C. F. Industries Inc. and United Piece Dye Works/Edenton Dyeing and Finishing LLC) the portion of nutrient load from point sources has declined over the last 35 to 40 years to what is likely less than one percent of the total nutrient load to the NC portion of the watershed (Table 5-3). The nitrogen load from point sources have continued to decline and in 2019 the total nitrogen load is estimated to be about 6,216 pounds per year which is a

98.99 percent reduction from the 1982 estimated load of 612,880 pounds per year (Table 5-3). Total phosphorus has remained relatively stable over the years and in 2019 there was a 95.8 percent reduction from the 1982 load (Table 5-3).

Table 5-1 1997 Estimated Annual Total Nitrogen and Total Phosphorus Load to the NC Portion of the Chowan River Basin.

Nutrient Sources	Nitrogen Load		Phosphorus Load		Source Information
	percent	lbs/yr	percent	lbs/yr	
Point Sources	1%	40,065	1%	2,926	Based off average daily discharge load (1996)
Agriculture	62%	2,406,873	75%	242,340	Includes: cropland and animal operations
Forest/Wetland	23%	891,707	16%	51,444	Includes: natural and managed forest and wetlands
Urban	<1%	11,138	<1%	1,577	Includes: stormwater runoff, on-site wastewater disposal
Atmospheric Deposition	13%	501,803	8%	26,315	
Total NC Load	100%	3,851,586	100%	324,602	

A nutrient loading budget was developed in 1997 (Chowan River Basinwide Water Quality Management Plan, 1997 Appendix VII). Loads were estimated using an export coefficient model utilizing land cover data (1988) and nutrient export estimates derived from literature values. Point source loads estimated from 1996 annual loads.

Table 5-2 Range of land cover percentages from 1982 and 2016 (Note: the different land cover source information between the two dates. A full land use change evaluation can be found in Chapter 1).

Land Cover Type	1982 Totals[1]		Land Cover Type	2016 Totals[2]	
	Area (mi^2)	Percent of Total		Area (mi^2)	Percent of Total
Cultivated Crop	412.7	32.8%	Cultivated Crops/Pasture/Hay	381.3	29.4%
Uncultivated Crop	0	0.0%			
Pasture	16.4	1.3%			
Forest	696.7	55.4%	Forest/Wetland	730.6	56.3%
Urban & Built-Up	21.9	1.7%	Developed	55.4	4.3%
Other	109.8	8.7%	Open Water/Barren/ Grassland/Shrubland	131.0	10.1%
Totals	1257.5	100%	Totals	1298.3	100%

[1]Data from the National Resources Inventory.
[2]Data from the National Land Cover Dataset.

It is accepted that converting a point source to a non-discharge land application waste disposal system reduces direct nutrient contribution to surface waters. While there is no direct discharge of nutrients, our understanding of the groundwater contribution of nutrient to surface waters from these systems in this region of NC is not well-understood. Non-discharge systems require a state permit and must comply with groundwater standards. Failing and leaking on-site septic systems also have the potential to contribute nutrients to groundwater. More information is needed on the location, age, and type of septic systems in the Chowan River basin. Monitoring and research is needed to better understand the possible nutrient contributions to ground and surface water from these types of wastewater practices. Chapter 7 includes additional information about wastewater systems.

Table 5-3 Chowan River Basin NC NPDES Point Source Discharge Total Nitrogen and Total Phosphorus Loading Estimates and Percent Reduction from 1982 Load.

Year	Nitrogen		Phosphorus		Notes
	Load (lbs/yr)	% reduction from 1982	Load (lbs/yr)	% reduction from 1982	
1982	612,880		55,556		
1989	39,680	93.53	1,323	97.62	
1996	40,065	93.46	2,926	94.73	1 Major Discharger – Union Piece Dye Works (1.5 MGD)
2019	6,216	98.99	2,321	95.82	1 Major Discharger - Ahoskie WWTP (1.3 MGD with NSW Limits of 3 mg/L-N & 1 mg/L-P)
-1982, 1989 and 1996 loading from 1997 Chowan River Basinwide Water Quality Management Plan page 3-6 (https://deq.nc.gov/about/divisions/water-resources/planning/basin-planning/water-resource-plans/chowan-1997). -2019 load, see Appendix V-I Table V-I.5. for specific 2019 NPDES permit loading details by discharger.					

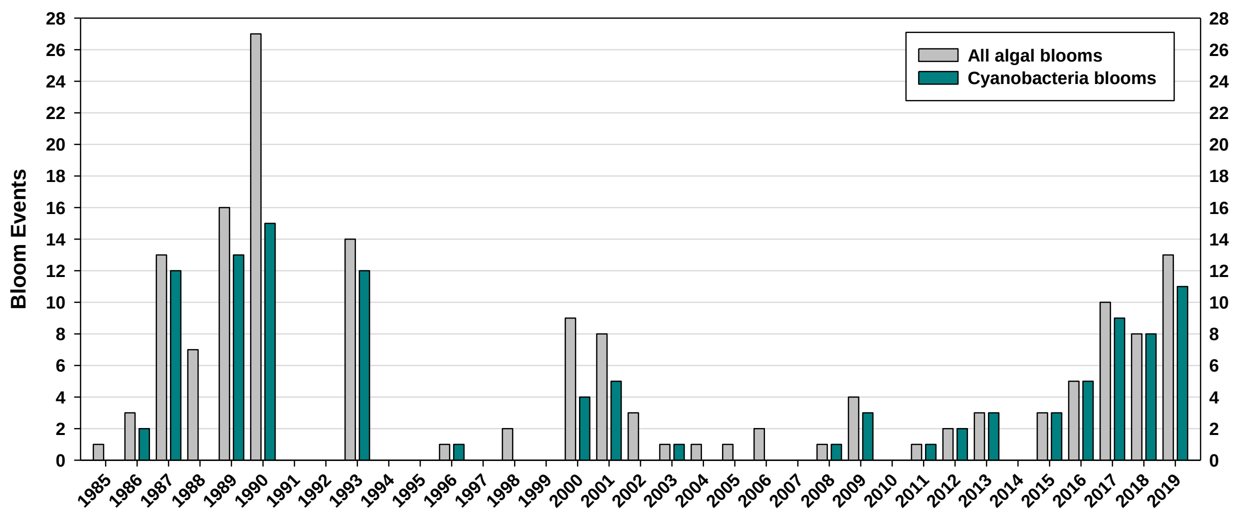
Biological:

There are additional factors that have been reported over the years that could affect algal bloom development in the Chowan River basin. The 1997 Chowan River basin plan suggested that there is a possible temporal relationship between flow and chlorophyll *a* concentration indicating that years of high flow, particularly high spring flows, are the same years of high chlorophyll *a* concentrations. Paerl et al., reported a similar finding in the Neuse River Estuary in 1998 (Paerl et al., 1998). The 1997 basin report also indicated that bluegreen algal blooms are more severe, cover wider areas and lasted longer during years of heavy winter and spring rains and dry summers, with 1990 and 1993 given as examples in which both of these years recorded significant flows in the winter and late spring providing nutrient delivery, followed by low flow periods, enabling bloom development.

The 2002 and 2007 Chowan River Basinwide Water Quality Management Plans reported on data collected between September 1, 1995 and August 31, 2000 and between September 1, 2000 and August 31, 2005, respectively. Both reports indicated there was a reduction in nutrient inputs which led to a steady decline in both the frequency and intensity of algal blooms. There were very few reported chlorophyll *a* readings over the state standard of 40 µg/L. It was later determined that there was an issue with the chlorophyll *a* data collected between September 1996 and March 2001. This data was later removed for use in water quality assessments across the state. Both basin plans continued to recommend the implementation of nutrient reducing BMPs throughout the watershed in order reduce nutrient inputs and avoid nuisance algal blooms.

An important concerns associated with bluegreen algal blooms was potential disruption of the food chain. Evidence suggests that bluegreen algae, which are not a suitable food source for small aquatic animals, can disrupt the food chain by replacing normal algal populations (c.f. Paerl et al., 2001). Small aquatic animals are the basic food item for important fish species in the Chowan River. Therefore, bluegreen algal blooms can have a negative impact on fisheries populations by affecting the food source of the small aquatic animals upon which fish feed (1979 Basinwide Management Plan). The number of episodic algal blooms reported to the division over the years and those identified as bluegreen algal blooms can be seen in Figure 5-2.

Figure 5-2 Chowan River Basin Episodic Algal Bloom Reports 1985-2019.



5.1.4 Summary of the Mainstem Chowan River Impaired Waters Listings

In 1998, the lower Chowan River was placed on the EPA approved 303(d) list of impaired waters for North Carolina. "Nutrients" were identified as the cause of the impairment with municipal and industrial point sources of pollution identified as the potential cause of the impairment (1998 EPA approved 303(d) list). In 2002, assessment methodology changed. Surface waterbodies identified on the 303(d) list of impaired waters were the result of North Carolina water quality standards being violated, whereas previously, the waterbody was listed based on problem parameters. The lower Chowan River remained on the 2002, 2004 and 2006 303(d) list with the reason for listing being identified as "historical listing decision" for "nutrients" (Table 5-4).

In 2008, the lower segment of the Chowan River was removed from the 303(d) list of impaired waters. Data collected between 2002 and 2006 demonstrated that "the applicable water quality standard is being met." North Carolina does not have water quality standards for nitrogen or phosphorus. Consequently, it was determined that the "historic listing decision" for nutrients could no longer be justified as a cause for impairment (2008 North Carolina's Removal of Waterbodies from 2008 Section 303(d) List – See Appendix V-I.3). Since 2008, the lower segment of the Chowan River has been assessed and determined to fall into Category 1 (water quality standards are being met or supporting the intended use of the waterbody) and/or Category 3 (data inconclusive) for chlorophyll *a*. See Table 5-4 for a full description of the Chowan River nutrient/chlorophyll *a* impaired waters list (303(d)) history.

Table 5-4 Chowan River Nutrient/Chlorophyll a 303(d) Impairment History 1998-2020.

303(d) Listing Year	Chowan River AU	AU Segment Description	Stream Length (Miles)	Integrated Report Category	Cause of Impairment/ Reason for Listing	Potential Sources
1998	25e	From Below Holladay Island near Harrellsville	5.5	5	Nutrients	Industrial; Municipal
	25f	From Colerain to US Hwy 17 at Edenhouse	14.5	5	Nutrients	NA
2000	25e *	From Below Holladay Island near Harrellsville	5.5	5	Nutrients	Industrial; Municipal
	25f *	From Colerain to US Hwy 17 at Edenhouse	14.5	5	Nutrients	NA
2002	25b	From Below Holladay Island near Harrellsville to subbasin 03-01-03/03/01/04 boundary	12.2	5	Nutrients	Industrial; Municipal
	25c	+ From subbasin 03-01-03/03/01/04 boundary to mouth defined by a line extending in a southerly direction from Reedy Point on the north shore of Albemarle Sound to a point of land on the south side of the mouth of Black Walnut Swamp	7.8	5	Nutrients	NA
2004	25b	From Below Holladay Island near Harrellsville to subbasin 03-01-03/03/01/04 boundary	12.2	5	Historical listing decision: Nutrients	Industrial; Municipal
	25c	+ From subbasin 03-01-03/03/01/04 boundary to …. mouth of Black Walnut Swamp	7.8	5	Historical listing decision: Nutrients	NA
2006	25b	From Below Holladay Island near Harrellsville to subbasin 03-01-03/03/01/04 boundary	14.1	5	Historical listing decision: Nutrients	Industrial; Municipal
	25c	+ From subbasin 03-01-03/03/01/04 boundary to …. mouth of Black Walnut Swamp	7.8	5	Historical listing decision: Nutrients	NA
2008	25b	From Below Holladay Island near Harrellsville to subbasin 03-01-03/03/01/04 boundary	14.1	1^	Delisted	
	25c	+ From subbasin 03-01-03/03/01/04 boundary to …. mouth of Black Walnut Swamp	7.8	1^	Delisted	
2010	25b	From Below Holladay Island near Harrellsville to subbasin 03-01-03/03/01/04 boundary	14.1	1		
	25c	+ From subbasin 03-01-03/03/01/04 boundary to …. mouth of Black Walnut Swamp	7.8	1		

303(d) Listing Year	Chowan River AU	AU Segment Description	Stream Length (Miles)	Integrated Report Category	Cause of Impairment/ Reason for Listing	Potential Sources
2012	25b	From Below Holladay Island near Harrellsville to subbasin 03-01-03/03/01/04 boundary	14.1	1		
	25c	**+** From subbasin 03-01-03/03/01/04 boundary to …. mouth of Black Walnut Swamp	7.8	1		
2014	25b	From Below Holladay Island near Harrellsville to subbasin 03-01-03/03/01/04 boundary	14.1	1		
	25c	**+** From subbasin 03-01-03/03/01/04 boundary to …. mouth of Black Walnut Swamp	7.8	1		
2016	25b	From Below Holladay Island near Harrellsville to subbasin 03-01-03/03/01/04 boundary	14.1	1		
	25c	**+** From subbasin 03-01-03/03/01/04 boundary to …. mouth of Black Walnut Swamp	7.8	1		
2018	25b	From Below Holladay Island near Harrellsville to subbasin 03-01-03/03/01/04 boundary	14.1	1		
	25c	**+** From subbasin 03-01-03/03/01/04 boundary to …. mouth of Black Walnut Swamp	7.8	3a Inconclusive	Chlorophyll *a*	
2020	25b	From Below Holladay Island near Harrellsville to subbasin 03-01-03/03/01/04 boundary	14.1	TBD		
	25c	**+** From subbasin 03-01-03/03/01/04 boundary to …. mouth of Black Walnut Swamp	7.8	TBD		

See Appendix V-I Table V-I.1 for corresponding data window periods.
*2002 note: As a result of implementation of the nutrient sensitive waters (NSW) management strategy, substantial reductions in total phosphorus and total nitrogen loads are reported. DWQ will assess the continued implementation of the NSW strategy prior to TMDL development.
+ AU Segment Description - From subbasin 03-01-03/03/01/04 boundary to mouth defined by a line extending in a southerly direction from Reedy Point on the north shore of Albemarle Sound to a point of land on the south side of the mouth of Black Walnut Swamp
^ Category 1 in 2008 – Segment of Chowan River removed from the impaired 303 (d) list/category 5. Reason for delisting was "the assessment and interpretation of more recent or more accurate data in the record demonstrate that the applicable water quality standard is being met".
TBD – To be determined as part of the 2020 water quality assessment process which is underway.
Link to 303(d)/305(b) Integrated Report lists - https://deq.nc.gov/about/divisions/water-resources/planning/modeling-assessment/water-quality-data-assessment/integrated-report-files

5.2 Current Nutrient Conditions and Trends

5.2.1 Introduction

The 1982 Chowan River Water Quality Management Plan goals included nutrient reductions of 30 to 40 percent for phosphorus and 15 to 25 percent in nitrogen to achieve a reduction in chlorophyll *a* concentration with peak levels not to exceed 40 µg/L (NCDNRCD, 1982). The implementation measures put in place to achieve these reductions mainly included converting point source dischargers to land application where possible and installation of agricultural BMPs throughout the basin.

In time the algal blooms diminished, and the Chowan River appeared to improve through the early 2000's. The 2002 and 2007 basinwide management plans reported on data collected between September 1, 1995 and August 31, 2000 and between September 1, 2000 and August 31, 2005, respectively. Both reports indicated there was a reduction in nutrient inputs which led to a steady decline in both the frequency and intensity of algal blooms. There were very few reported chlorophyll *a* readings over the state standard of 40 µg/L. The lower Chowan River segments near Colerain (Assessment Unit: 25b) and Edenhouse (Assessment Unit: 25c) were also determined to be meeting the chlorophyll *a* water quality standard of 40 µg/L and these Assessment Units were subsequently delisted from the impaired waters list in 2008 (Table 5-4). It was later determined that there were analytical problems with the chlorophyll *a* data between September 1996 and March 2001. This data was later removed from use in water quality assessments across the state.

Figure 5-3 Chowan River Basin Ambient Monitoring Stations.

Over the last several years a resurgence of algal bloom and potentially harmful algal bloom (pHAB) activity in the Chowan River has occurred (Figure 5-2). As part of the basin planning process, the need to evaluate what changes have occurred in the watershed to supports the rapid growth of bluegreen algal blooms was recognized as well as the need for additional research into the sources of nutrients and what environmental factors are driving the reoccurrence of the blooms.

Since about 2015, the Chowan River has experienced recurrent summer algal blooms which lead to the Department of Environmental Quality to issue press releases “urging the public to avoid contact with the green or blue water in the Chowan River due to algal blooms that has lingered in the area” mainly south of Harrellsville (near station D8356200) down to the Edenhouse Bridge (near station D9490000) (Figure 5-3). Many of the bluegreen algal bloom species detected have been identified as potentially harmful such as *Dilochospermum* and *Microcystis*. The blooms evaluated in 2019 were widespread throughout the Chowan River system but were most intense between Indian Creek (Dillard Millpond) downstream to Rockyhock Creek. These intense blooms were associated with elevated microcystin cyanotoxin concentrations.

(Photo: Chowan River, June 2015)

Algal blooms and water quality issues do not stop at the basin boundary between the Chowan and Pasquotank River basins. The water quality conditions directly impact the Albemarle Sound and will be presented in the Pasquotank basin plan, which will be completed in 2021. A joint Story Map will be developed that will better show the direct connections and interactions between these two river basins. In recognition of the intimate link between the two systems, the division added the Chowan River to the Nutrient Criteria Development Plan process that is underway for the Albemarle Sound. More information on this critical process can be found in section 5.4.1.

5.2.2 Water Quality Monitoring

The Division of Water Resources (DWR) Ambient Monitoring System (AMS) program has continued to sample five mainstem Chowan River stations in North Carolina (NC) and two stations in Virginia (VA), just above the VA/NC state line in the Nottoway and Blackwater Rivers (Figure 5-3). The two VA rivers join to form the Chowan River as it enters NC (Figure 5-3). There are also two long-term monitoring stations located in Potecasi Creek and the Meherrin River which drains into the Chowan River about two miles upstream of the Winton ambient monitoring station (D6250000).

D0000050 – Nottoway River (VA)
D0001800 – Blackwater River (VA)
D0010000 – Chowan River near Riddicksville (NC)
D6250000 – Chowan River at Winton (NC)
D8356200 – Chowan River near Gatesville (NC)
D8950000 – Chowan River near Colerain (NC)
D9490000 – Chowan River near Edenhouse/US17 Bridge (NC)
D4150000 – Potecasi Creek near Union (NC)
D5000000 – Meherrin River near Como (NC)

Due to staffing shortages, resource issues, and/or extreme weather conditions over the years, the Chowan River basin stations have not always been monitored on a monthly basis. Monitoring inconsistencies present a limitation when interpreting the water quality data and these inconsistencies should be taken into consideration when reviewing the water quality data (Figure 5-4).

Nutrients

There is a need to better understand the different nutrient contributions in the VA and NC watersheds which form the Chowan River and flows into the Albemarle Sound. One of the goals of this assessment is to better understand the changes that have occurred over time and if there is a specific turning point or shift in environmental conditions which have resulted in the Chowan River becoming increasingly susceptible to the development of algal blooms and/or potentially harmful algal blooms. Reviewing the changes in nutrient concentrations and loading is just the first step in understanding possible changes in the watershed. To understand the changing conditions throughout the Chowan River system this report will present the nitrogen species [nitrate (NO_x), ammonia (NH_3) and total Kjeldahl nitrogen (TKN)], total phosphorus (TP) and chlorophyll *a* (Chl *a*) data over time throughout the Chowan River basin. The goal is to communicate the changes in the instream nutrient concentrations and loads and relate those changes to the management strategy, land-use and other watershed implementation efforts that have taken place since the early 1980's. A summary of the most current nutrient statistics from 2010 – 2018 is presented in Table 5-5 and Figure 5-5 (a and b) with explanation for each parameter in subsequent sections.

Figure 5-4 Yearly and Summer (May-October) Chlorophyll a Monitoring Frequency at Station D8950000 near Colerain Which is Representative of All Stations in the Chowan River Basin.

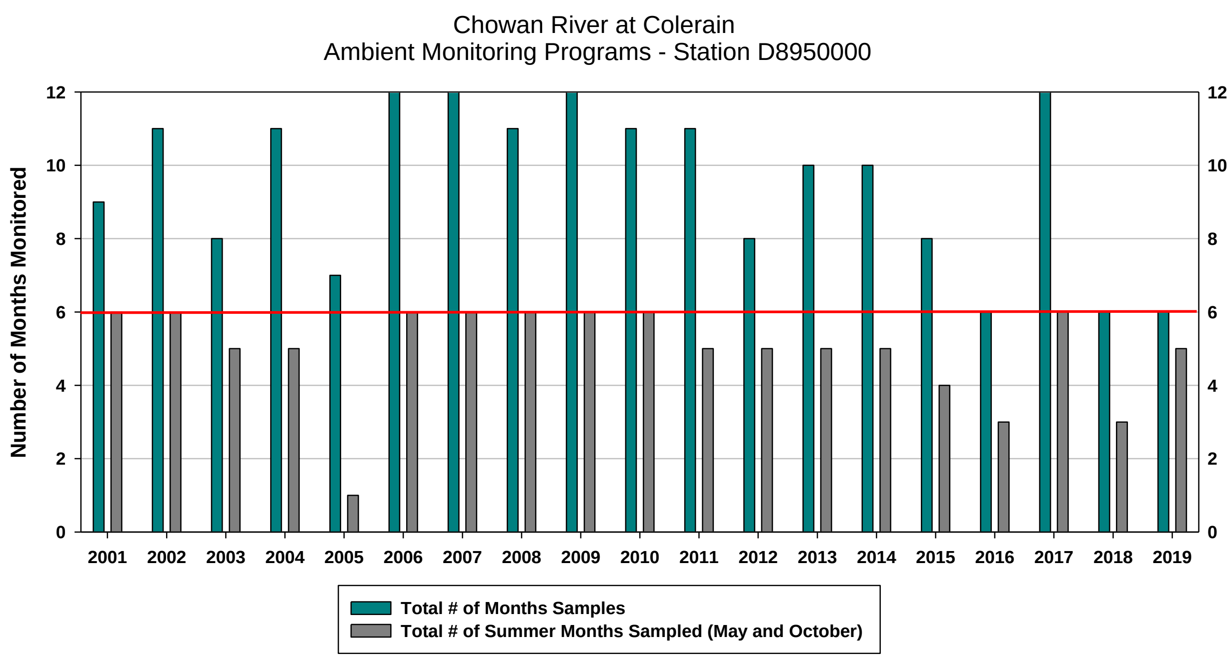


Table 5-5 2010-2018 Yearly Weighted Mean and Median Concentration Range with the Reporting Level by Date or PQL (Practical Quantitation Limit).

Nutrient	Chowan River Watershed			Meherrin River Watershed			Current PQL
	Mean Range	Median Range	Max Mean Station (Year)	Mean Range	Median Range	Max Mean Station (Year)	
NH3^ (mg/L)	0.020*-0.068	0.020-0.065	D0001800 (2011)	0.026-0.095	0.020-0.060	D4150000 (2010)	0.02
NO3 (mg/L)	0.063-0.230	0.050-0.220	D0001800 (2016)	0.076-0.246	0.050-0.260	D5000000 (2018)	0.02
TKN (mg/L)	0.520-0.847	0.470-0.805	D0001800 (2011) & D8950000 (2018)	0.544-1.100	0.53-1.200	D4150000 (2012)	0.20
TP (mg/L)	0.053-0.099	0.040-0.095	D0001800 (2015)	0.064-0.164	0.050-0.160	D4150000 (2012)	0.02
Chl a (µg/L)	1.22-35.19	1.00-8.00	D8950000 (2017)	1.23-7.12	1.00-3.35	D5000000 (2015)	1.0

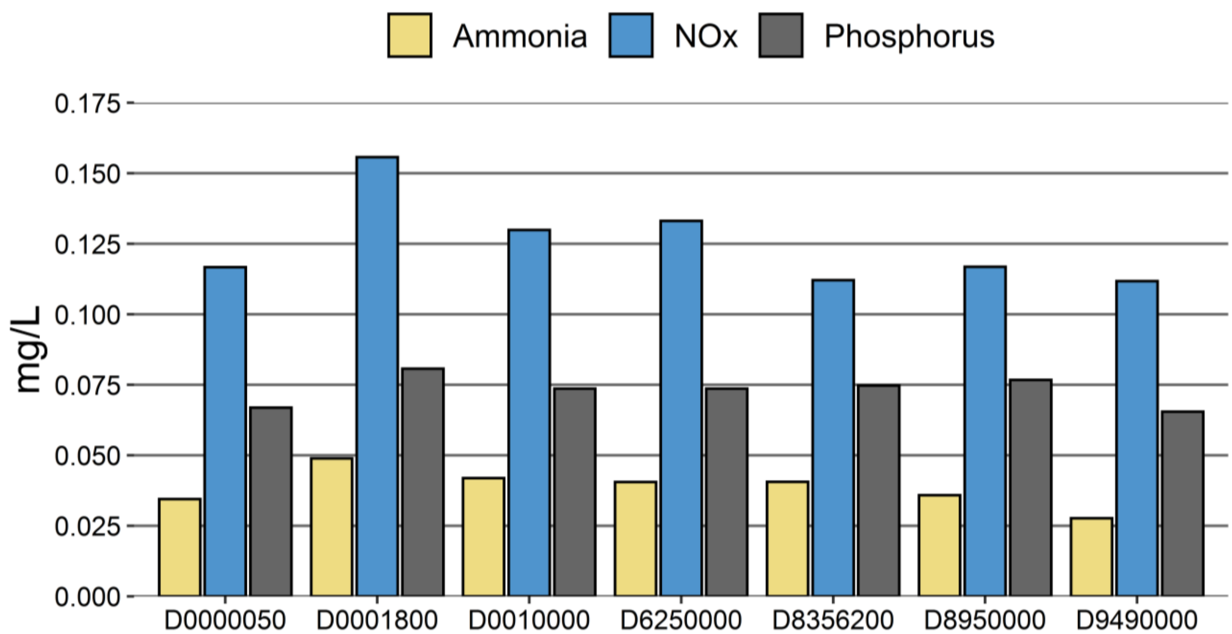
*Minimum is equal to the PQL or detection limit. The value used for assessment purposes is equal to the PQL or detection limit.
NH3^ is equal to the total of $NH_3 + NH_4^+$.

	Reporting Level by Date* (mg/L)				
Parameter	Pre-2001	3/13/2001 to 3/29/2001	3/30/2001 to 7/24/2001	7/25/2001 to 2/28/2009	3/01/2009 to Present
NH_3	0.01	0.50	0.20	0.01	0.02
TKN	0.10	1.00	0.60	0.20	0.20
NO_2+NO_3	0.01	0.50	0.15	0.01	0.02
TP	0.01	0.50	0.10	0.02	0.02

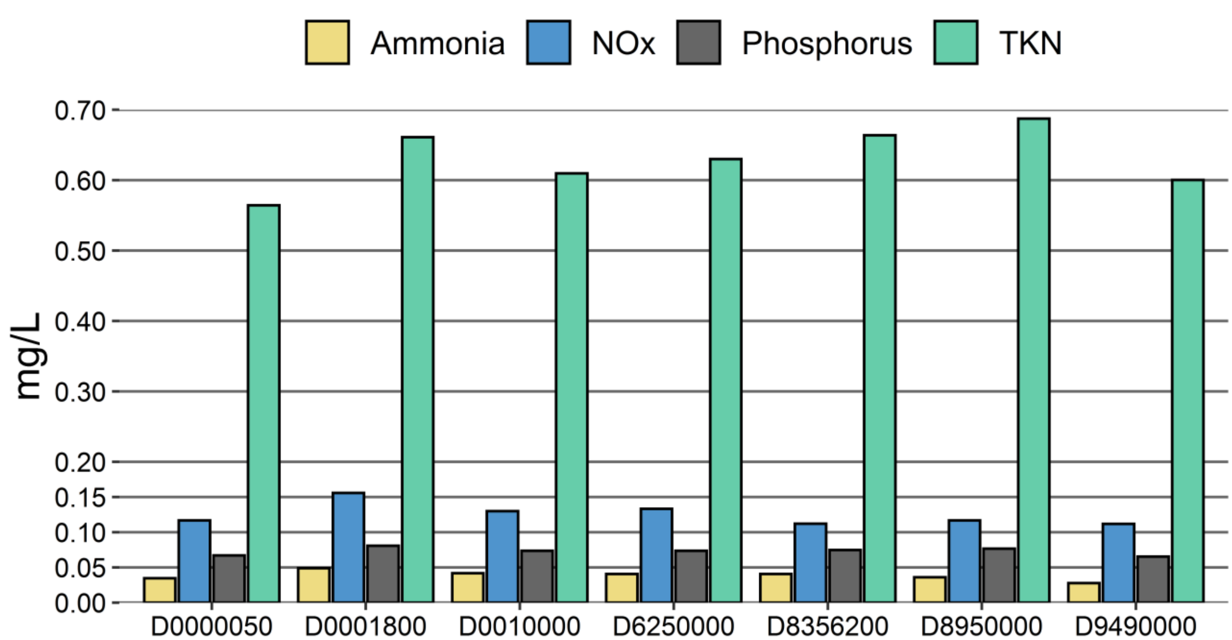
*In early 2001, the DWQ Laboratory Section reviewed its internal Quality Assurance/Quality Control (QA/QC) programs and analytical methods. This effort resulted in a marked increase in reporting levels for certain parameters. New analytical equipment and methods were subsequently acquired to establish new lower reporting levels and more scientifically supportable quality assurance. As a result, the reporting levels quickly dropped back down to at or near the previous reporting levels.

Figure 5-5 The 2010 – 2018 Weighted Mean Nutrient Concentrations for Mainstem Stations Including the Virginia Stations (D0000050 & D0001800).

(a) Ammonia, Nitrate (NOx) and Phosphorus



(b) Ammonia, Nitrate (NOx), Phosphorus and Total Kjeldahl Nitrogen (TKN).



When evaluating nutrients in a watershed it is important to understand the impacts of nutrient loading as well as the changes in instream concentrations when possible. Flow-normalized loading trends analysis was conducted on the data collected between 1981 and 2016 for the Nottoway and Blackwater rivers which make up the Chowan River and for Potecasi Creek. There is a USGS gage stations in close proximity to the AMS stations on the Nottoway (D0000050) and Blackwater River (D0001800). There are no USGS flow gaging stations on the mainstem Chowan River which precludes the development of a loading assessment. There is however, a USGS gage and a co-located AMS station on Potecasi Creek (D4150000), a smaller subwatershed that drains to the Meherrin River (Table 5-6). This allows for some additional understanding of nutrient loading changes coming into the Chowan River from a smaller, mostly agricultural, and forested watershed.

Table 5-6 Flow-Normalized Load Station Information. Baseline Period Used 1981-1985.

Station ID	USGS Station	Waterbody	Drainage Area Ratio	USGS SQML	AMS SQML
D0000050	2047000	Nottoway River	1.19	1440	1722
D0001800	2049500	Blackwater River	1.21	610	740
D4150000	2053200	Potecasi Creek	1	224	224

These flow-normalized loading trends are used to estimate the changes in nutrient loads computed using a flow-normalized loading method (Lebo, et al. 2011). Nutrient loads were computed by 5-year moving averages and compared with the corresponding value for the 1981-1985 baseline period. Each data point reflects a percent change in a 5-year moving average flow-normalized load from the estimated 1981-1985 baseline load (example: the percent change for the year 2000 data point is the mean flow-normalized 1996-2000 load from the 1981-1985 baseline load). It should be noted that these are only estimates and all the methods used for load estimation have associated errors in their estimates; therefore, caution should be exercised when interpreting the results. All the results discussed below should be interpreted in light of the limitations of the approaches and the existing data.

5.2.3 Total Nitrogen

Total nitrogen (TN) is made up of nitrate/nitrite-nitrogen, ammonia/ammonium-nitrogen, and organic-nitrogen (TN = (NO_2+NO_3) + TKN). To understand what is happening throughout the watershed, it is important to understand the changes occurring in the different nitrogen components. These different nitrogen components are discussed in subsequent sections. The management strategy put in place for the Chowan called for a **total nitrogen reduction of 15 to 25 %** to achieve a reduction in chlorophyll *a* concentration with peak levels not to exceed 40 µg/L.

Nottoway River

The estimated flow-normalized loads varied over time and over space in relation to the 1981-1985 baseline period. The Nottoway River watershed at D0000050 showed that the total nitrogen loading remained fairly stable until the early 2000's where is began to increase. As of 2016 (2012-2016), the total nitrogen load had increased about 24%, mainly due to the increase in TKN loading (Figure 5-6 (a)).

Blackwater River

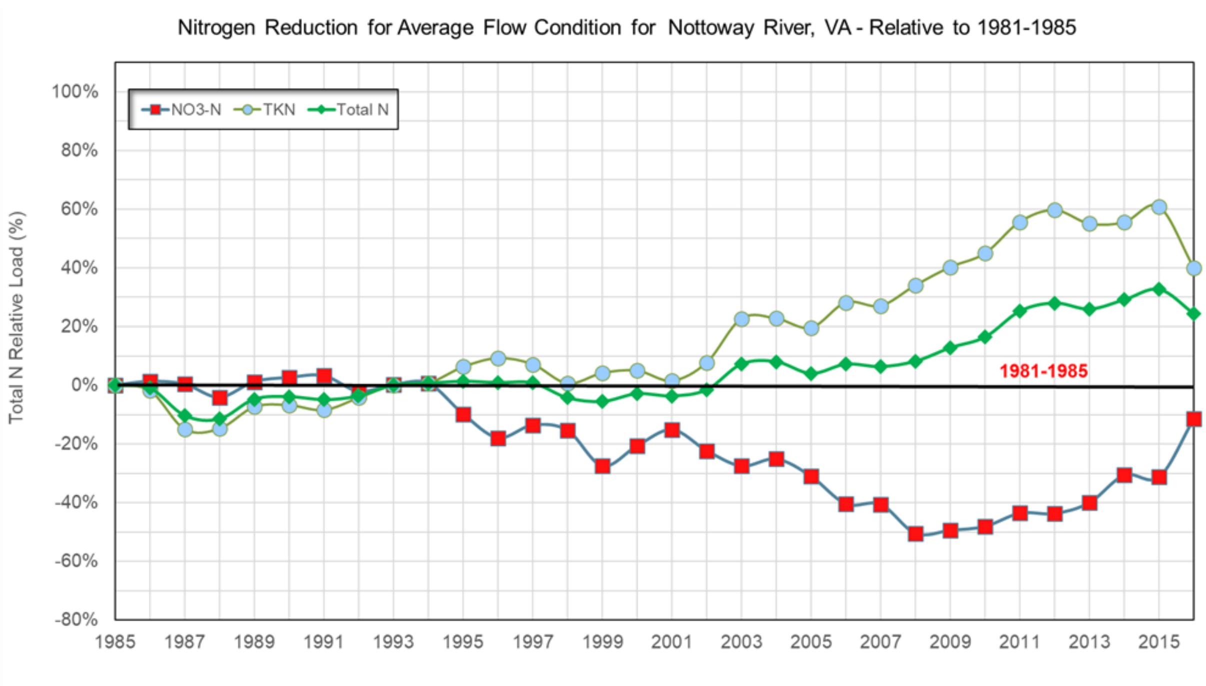
The Blackwater River watershed at D0001800 showed a steady decline in the total nitrogen load through 1999 (1995-1999) where it has fluctuated since. In 2016, the total nitrogen load had decreased about 29%. It is apparent that some type of implementation effort was successful at reducing the nitrogen load in the Blackwater River watershed. The overall load reduction was achieved by reducing both nitrate and TKN loading (Figure 5-6 (b)). It is important to maintain the load reduction as the climate patterns change. The loads have oscillated over the last few years and are currently still below the 1981-1985 baseline levels. Information related to the implementation efforts taken by the State of Virginia have been challenging to obtain to date. However, Basinwide Planning Branch and APNEP have a concerted effort underway to develop a relationship with our counterparts in the VA Department of Environmental Quality with the goal of understanding what has been done in the past and how we can work together to implement additional nutrient reductions needed in order to meet appropriate water quality standards throughout the basin.

Potecasi Creek

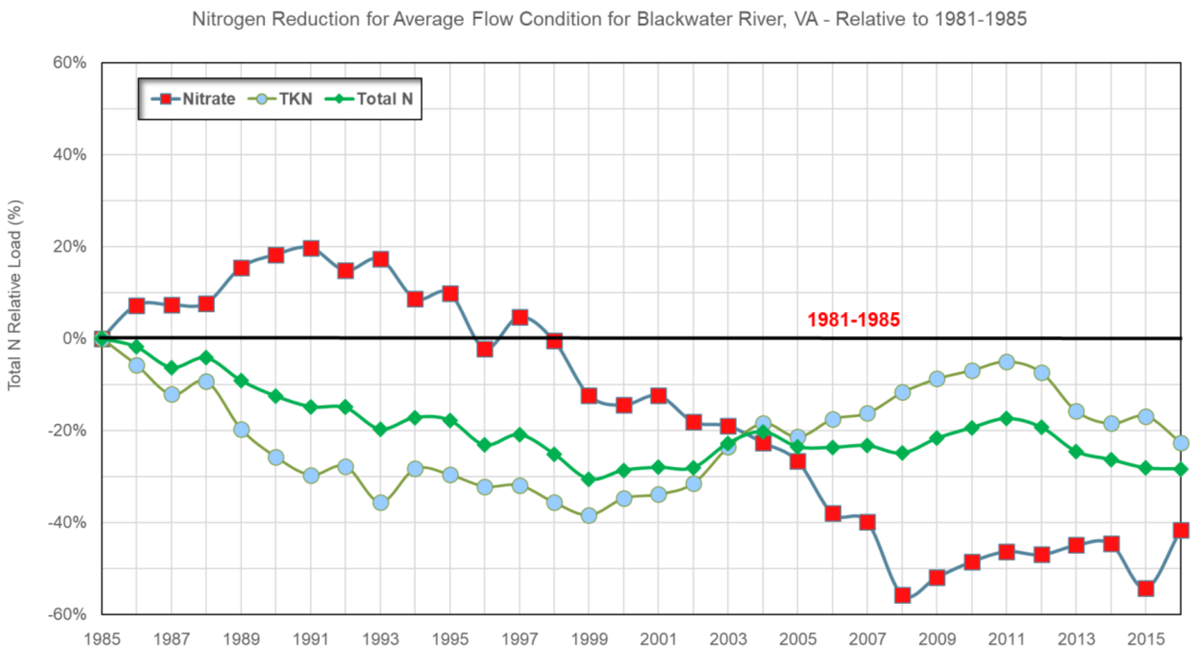
The total nitrogen loading in the Potecasi Creek watershed at D4150000, was fairly stable through the mid-1990's and declined to about a 20% reduction as of 1998 (1994-1998) (Figure 5-6 (c)). The total nitrogen loading began to increase at that point mainly as result of the dramatic increase in TKN loading to that system. As of 2016, the total nitrogen load was about 53% higher than the 1981-1985 baseline load. This is over the same time frame that the organic signature has increased throughout the basin, but these data provide evidence that it is occurring at a very fast rate in some of the smaller watersheds.

Figure 5-6 Flow-Normalized Total Nitrogen, Total Kjeldahl Nitrogen, and Nitrate-Nitrogen Load at (a) D0000050 Nottoway River, (b) D0001800 Blackwater River and (c) D4150000 Potecasi Creek Stations relative to the 1981-1985 Baseline Load.

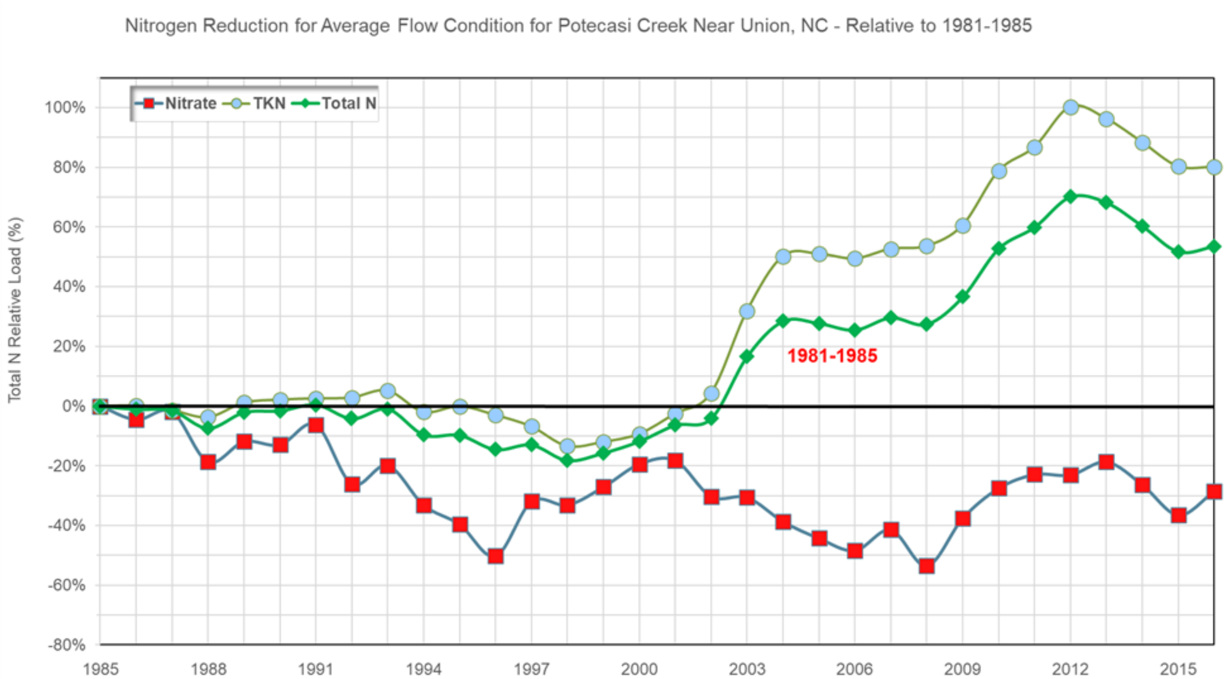
(a) Nottoway River (D0000050)



(*b*) Blackwater River (D0001800)



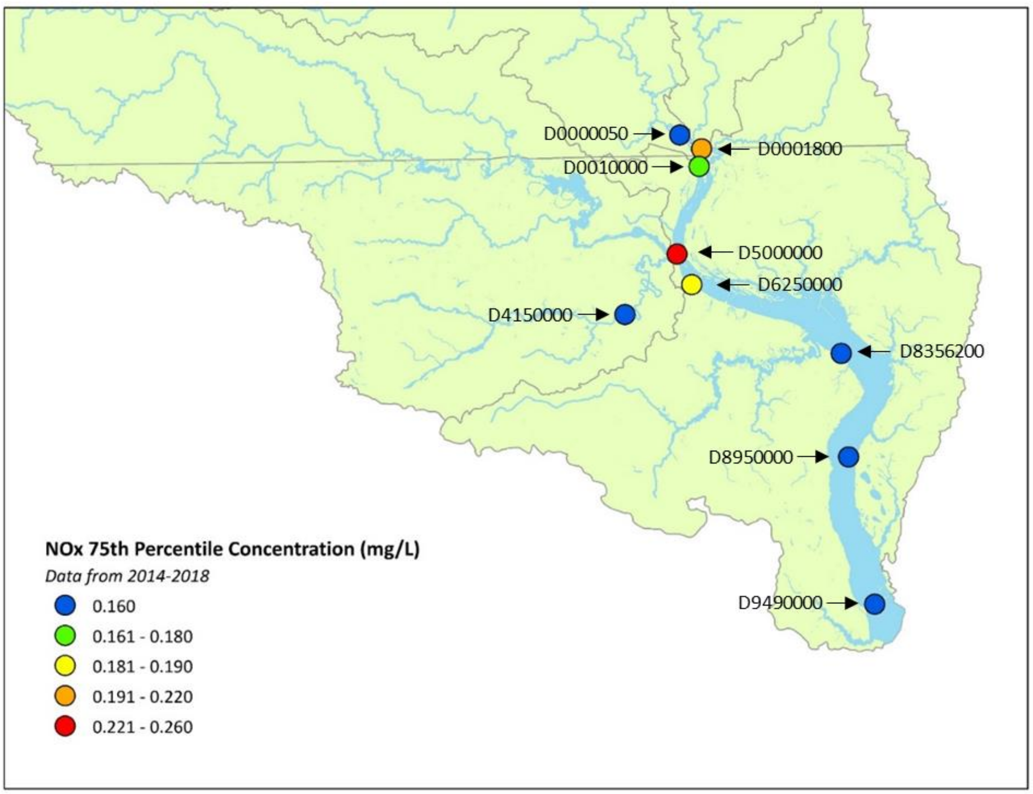
(*c*) Potecasi Creek (D4150000)



5.2.4 Nitrate Nitrogen

Over the last five years (2014-2018; 2020IR period) the two stations with the highest, 75th percentile nitrate (NO_x) concentrations in the Chowan River basin are the Blackwater River (D0001800) and Meherrin River stations (D5000000) (Figure 5-7). There were declines in the nitrate concentrations where the Blackwater River meets the Nottoway River to form the Chowan River. There are also declines where the Wiccacon meets the Chowan River (D8356200) (Figure 5-7). The nitrate concentrations increase where the Meherrin flows into the Chowan River (Figure 5-7). The range in the mean nitrate concentration between 2010-2018 was 0.063 – 0.246 mg/L with the highest annual means at the Meherrin River station (D5000000) in 2018 and the Blackwater River station (D0001800) in 2016 (Table 5-5). These stations with relatively high nitrate concentrations are addressed later in this section after reviewing the historical trends.

Figure 5-7 Chowan River Basin AMS Stations for the 2020 IR Period 75th Percentile Nitrate Concentrations.



In reviewing the historical nitrate data from 1975 through 2018, the instream nitrate concentrations throughout the Chowan, Nottoway and Blackwater rivers have generally declined since the end of the 1980's until about 2005-2009 (Figure 5-8, Figure 5-9 (a) and Figure 5-9 (b)). This decline can likely be attributed to the 1982 management strategy. Around 2007 to 2008, these three rivers began to display an increasing trend in annual instream nitrate concentrations (Figure 5-9 (b)). Moving downstream, the nitrate concentrations generally decline possibly due to biological uptake, however there are year to year fluctuations (Figure 5-9 (c)). The contribution of nitrate with respect to the total nitrogen signature is small in proportion to the organic nitrogen fraction (TKN-NH_3) (Figure 5-5 (b)).

Figure 5-8 Five Year Weighted Mean Nitrate Concentrations and Nottoway River Flow (1975-2018).

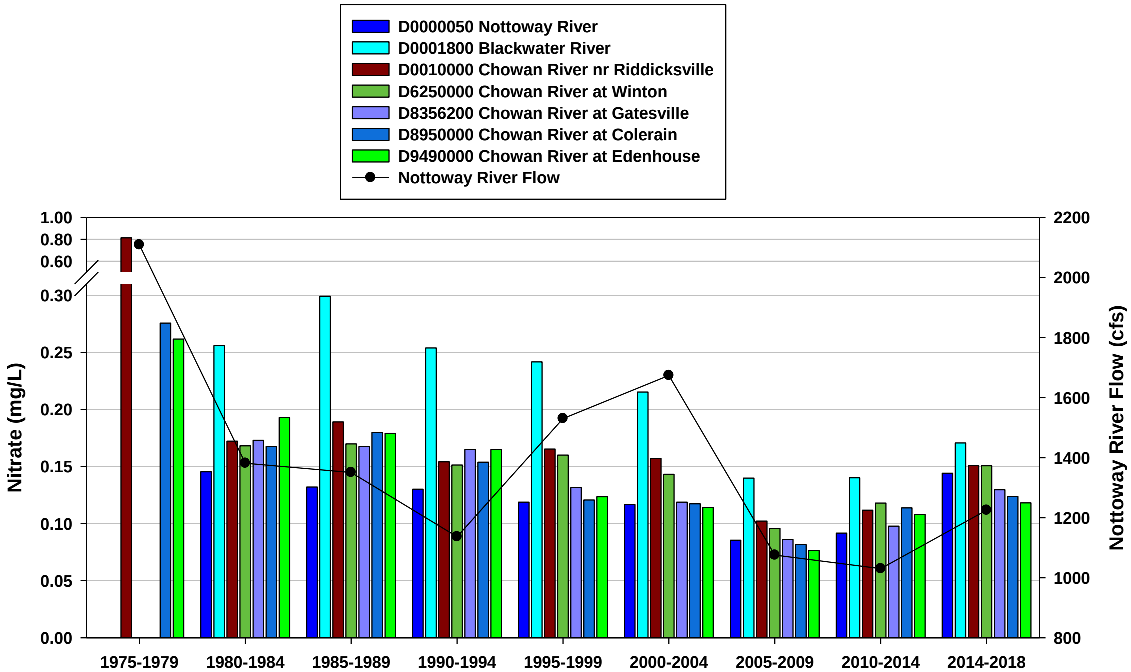
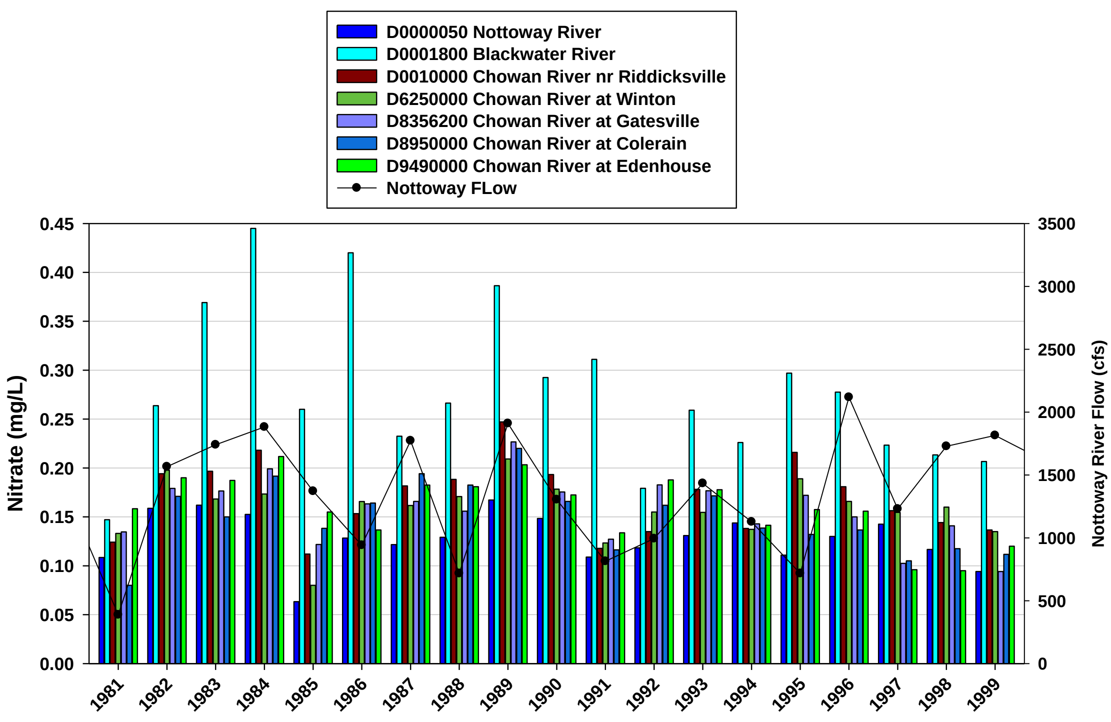
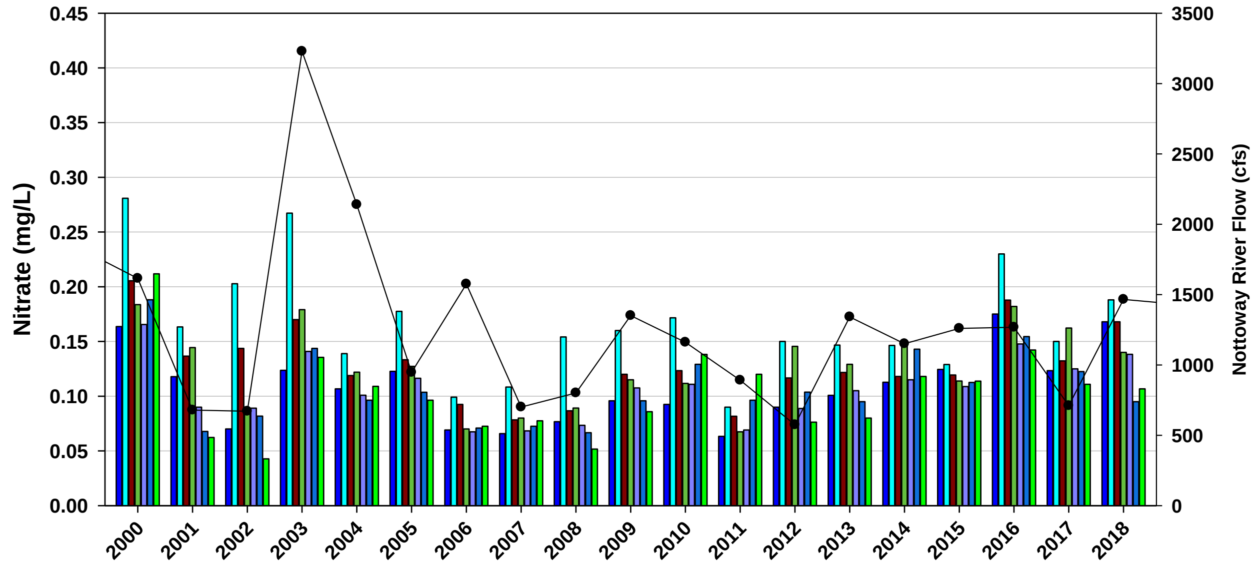


Figure 5-9 Annual Weighted Mean Nitrate Concentrations and Nottoway River Flow (a) 1981-1999, (b) 2000-2018 and (c) 2006-2018 (This time frame focuses on the increase in the instream nitrate concentration over the last decade, note both Y-axis change to allow for better visual evaluation of the change that has occurred over this time period).

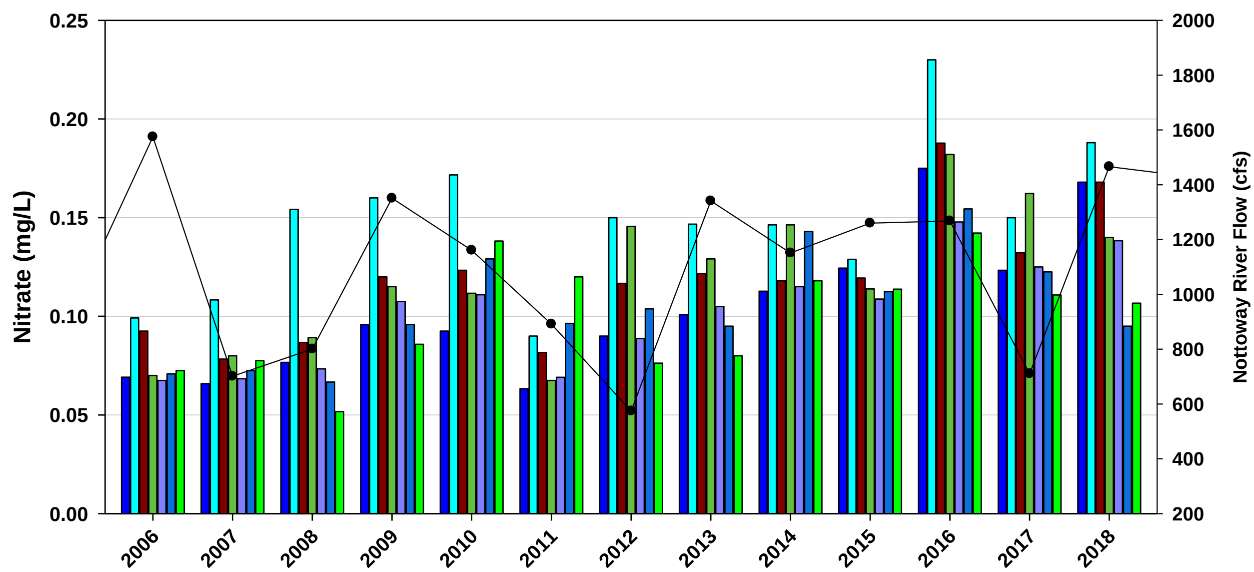
(a) 1981-1999



(b) 2000-2018



(c) 2006-2018



The flow-normalized nitrate loading trends are similar to the nitrate concentrations observed in the Blackwater River, the Nottoway River and Potecasi Creek stations (Figure 5-6). Between 1985 and 2008, these watersheds showed substantial reductions (50 to 60%) in nitrate load; however, in 2008 nitrate loads began to increase in all three watersheds which continued through the end of the modeled period (Figure 5-6).

Nottoway River

The nitrate concentrations are consistently lower in the Nottoway River than in the Blackwater River; however, these two rivers follow a similar pattern (Figure 5-10). This pattern could indicate a watershed-wide driver like climate or nutrient sources (i.e. land-use, permitting strategies, atmospheric deposition, land-use). The flow in the Nottoway River is generally higher than the Blackwater which will directly impact the overall loading to the Chowan River (Figure 5-11).

Figure 5-10 Annual Weighted Mean Nitrate Concentrations, 1981-2018 for the Nottoway River (D0000050), Blackwater River (D0001800) and the Chowan River near Riddicksville (D0010000).

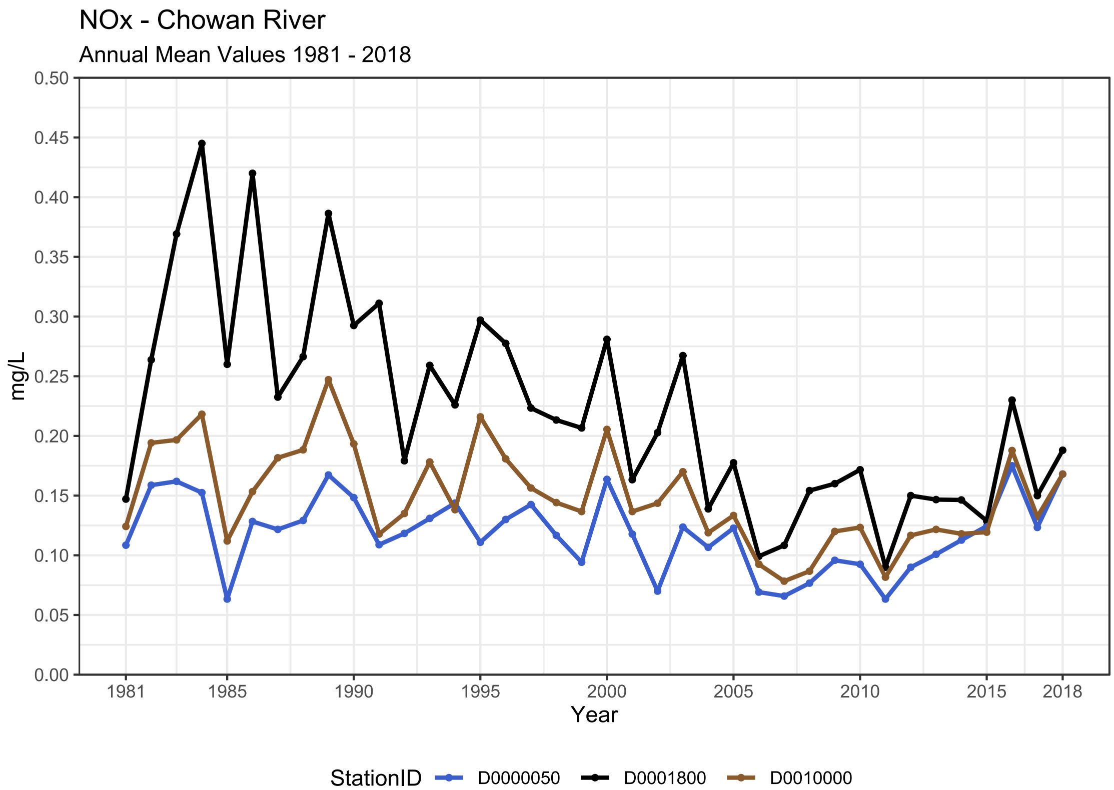
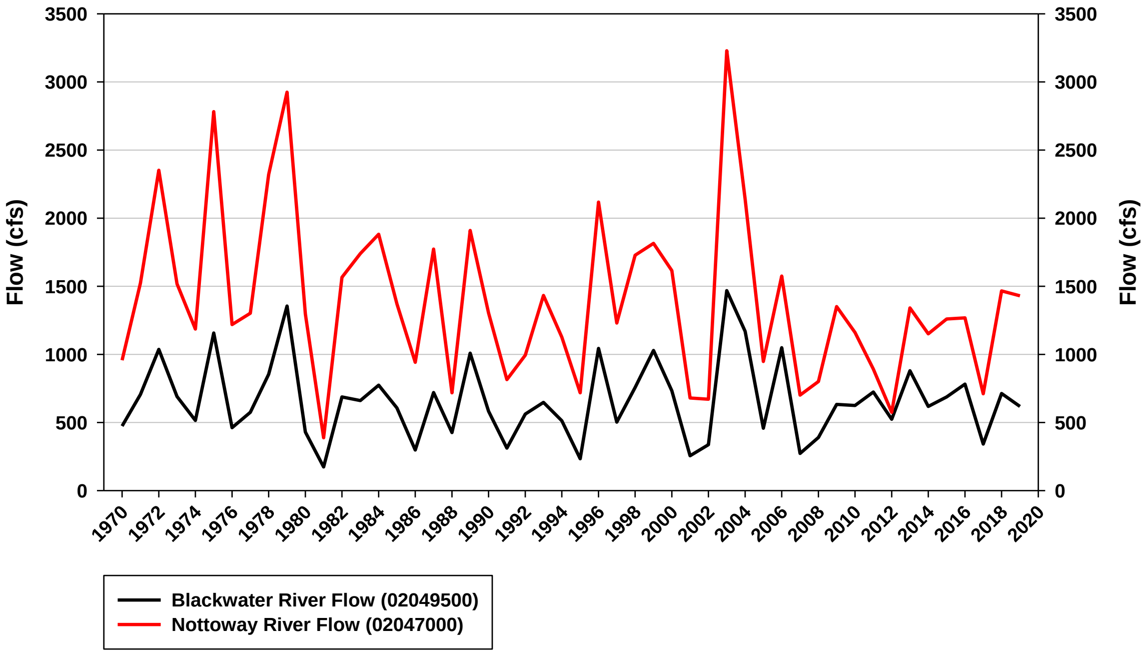


Figure 5-11 USGS Annual Mean Stream Flow in the Nottoway and Blackwater rivers (1970-2019).



Blackwater River

The Chowan River watershed is likely influenced by the Blackwater River (D0001800) as reflected in the nitrate concentrations (Figure 5-10). The Blackwater River had the highest instream annual mean nitrate concentration 87% of the time on a yearly annual basis (1981-2018) (Figure 5-9; the exceptions were 1981, 1992, 2011, 2014, 2017) and for each five-year averaged period as seen in Figure 5-8. One significant contributor of nutrients to the Blackwater River (D0001800) is International Paper (IP), formerly Union Camp. This NPDES permitted facility has an effluent discharge point located upstream of the AMS monitoring station. Their NPDES permit allows IP to discharge only during the winter months (November-April) when the river flow is generally higher (NPDES permit winter 7Q10 is 1.36 MGD). For the past several years, IP discharged waste only in February and March of each year. There is no nitrate, TKN or total nitrogen discharge limit. The plant was closed in 2009 and half the plant was reopened in 2012 and the other half in 2013. The total nitrogen (TN) and total phosphorus (TP) loads from the plant dropped substantially following the closure and has increased to a fraction of what was discharged between 2005 and 2009 (Figure 5-12). The instream ambient nitrate data (D0001800) was separated into the DWR sampling seasons and the highest yearly nitrate concentrations were observed to occur during the winter months (Figure 5-13). The higher overall annual mean nitrate concentrations at the Blackwater station in the early to mid-1980's (Figure 5-8, Figure 5-9, and Figure 5-10) are partially the result of limited, to no summer samples to offset the high winter instream concentrations as part of the annual mean concentration (see Figure 5-13 for missing summer data points in the 1980's; the same is true for the other nutrient constituents).

Figure 5-12 International Paper Winter Nutrient Effluent TN and TP Concentration, Load, and Total Annual Flow (Permitted Winter Season Discharge Flow Maximum of 14,000 MG).

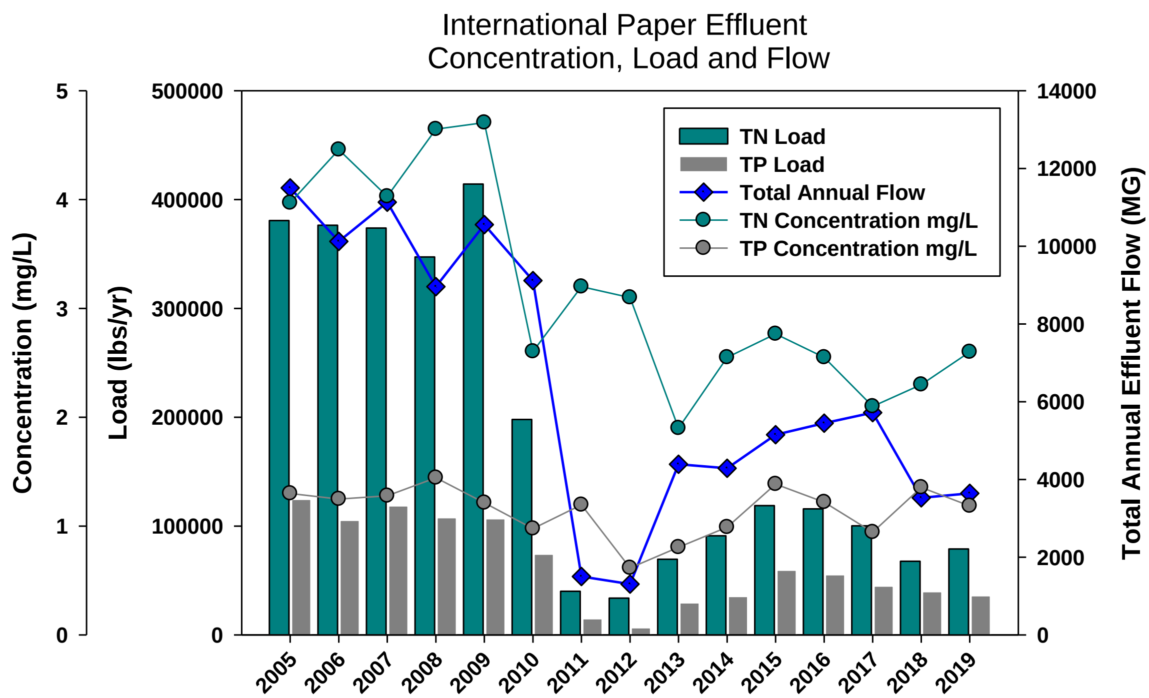
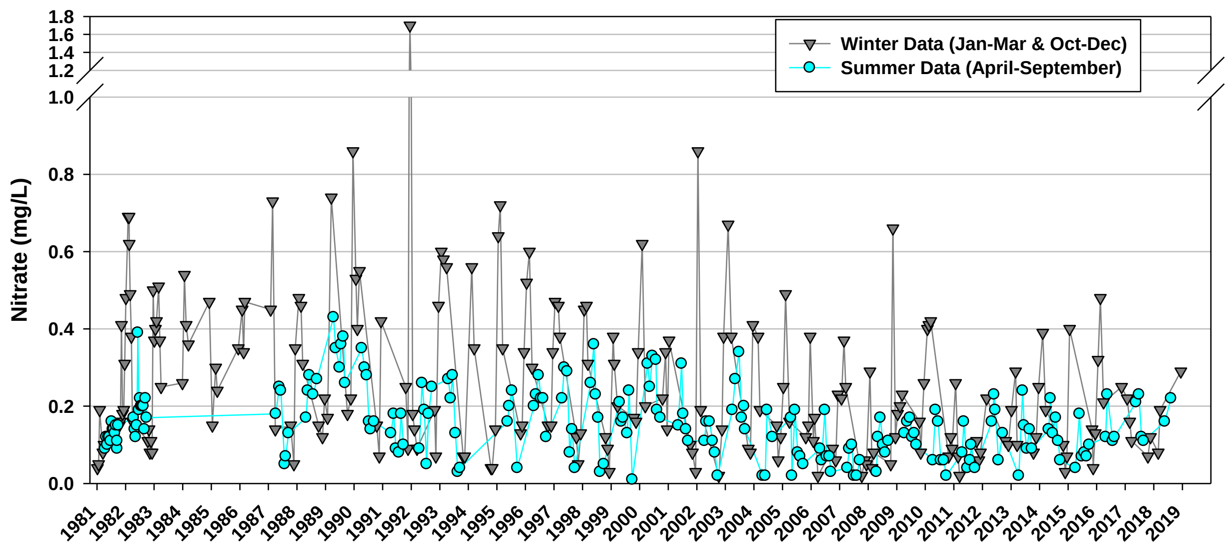


Figure 5-13 Monthly Ambient Monitoring Nitrate Concentration Data for the Blackwater River VA Station D0001800. Data is Separated into DWR Sampling Seasons.



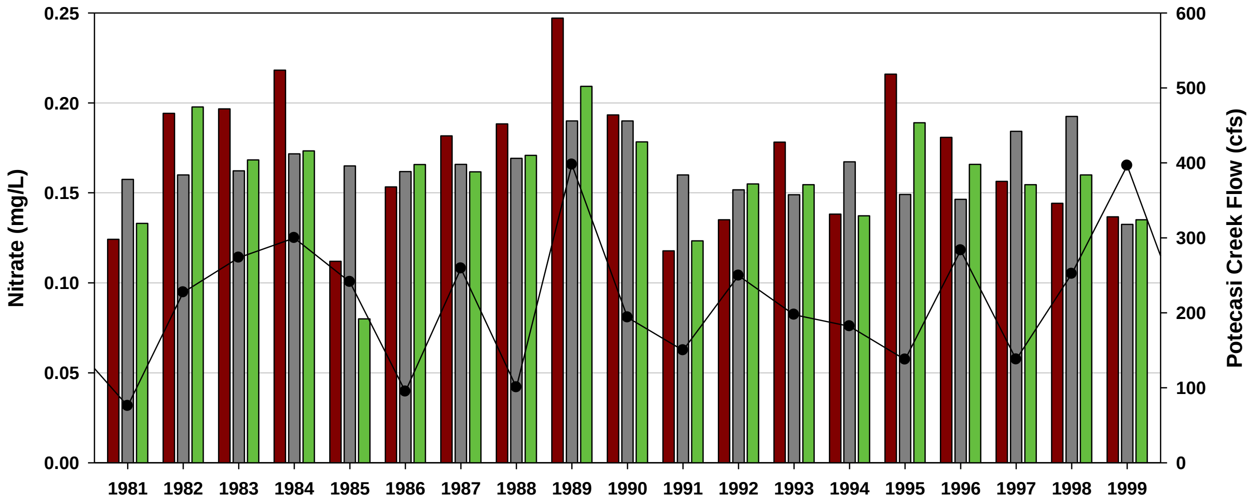
Meherrin River

The Meherrin River watershed drains to the Chowan River between station D0010000 near Riddicksville and D6250000 at Winton (Figure 5-3). The Meherrin River station (D5000000) has higher yearly mean nitrate concentrations relative to the upstream Chowan River station (D0010000) more than half the time since these stations were established in 1981 (Figure 5-14). This phenomenon has happened more frequently and with the largest differences between these two stations observed during the more recent period of monitoring (Figure 5-14 (b)). The drainage from the Meherrin River watershed appears to influence the instream nitrate concentrations at station D6250000. Several of the more recent years (2007, 2008, 2012, 2013, 2014, 2017) have mean nitrate concentrations which are elevated at D625000 relative to D0010000 (Figure 5-14).

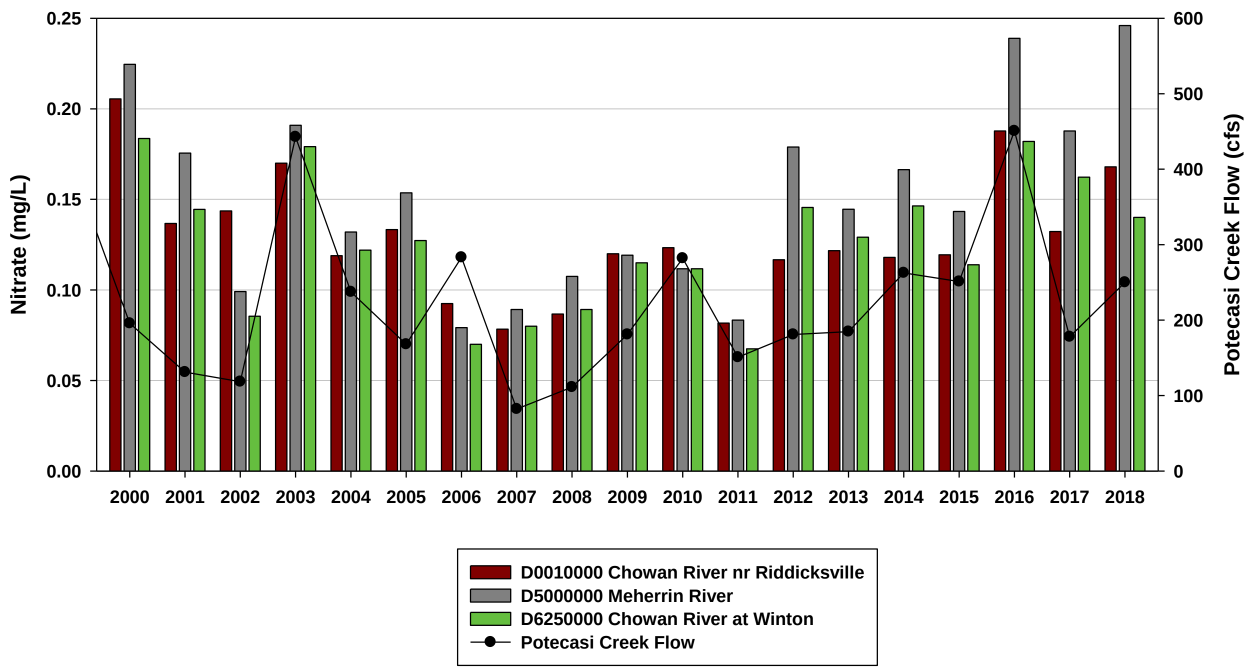
The overall loading from the Meherrin watershed is lower since the volume is lower, but the data indicate that the nutrient load from smaller watersheds like the Meherrin are likely contributing substantial nitrogen loads to the Chowan River system (Hall and Paerl, 2020). Since there are no flow data available in the lower portion of the Meherrin River, an actual loading estimates cannot be directly calculated. In order to understand the overall eutrophication process and contributions from the smaller watershed like the Meherrin River watershed, additional nutrient and flow data would be required.

Figure 5-14 Annual Weighted Mean Nitrate Concentrations Comparison Between the Meherrin River Station and the Chowan River Upstream and Downstream Confluence Stations for (a) Years 1981-1999 and (b) Years 2000-2018.

(a) Years 1981-1999



(b) Years 2000-2018



Potecasi Creek

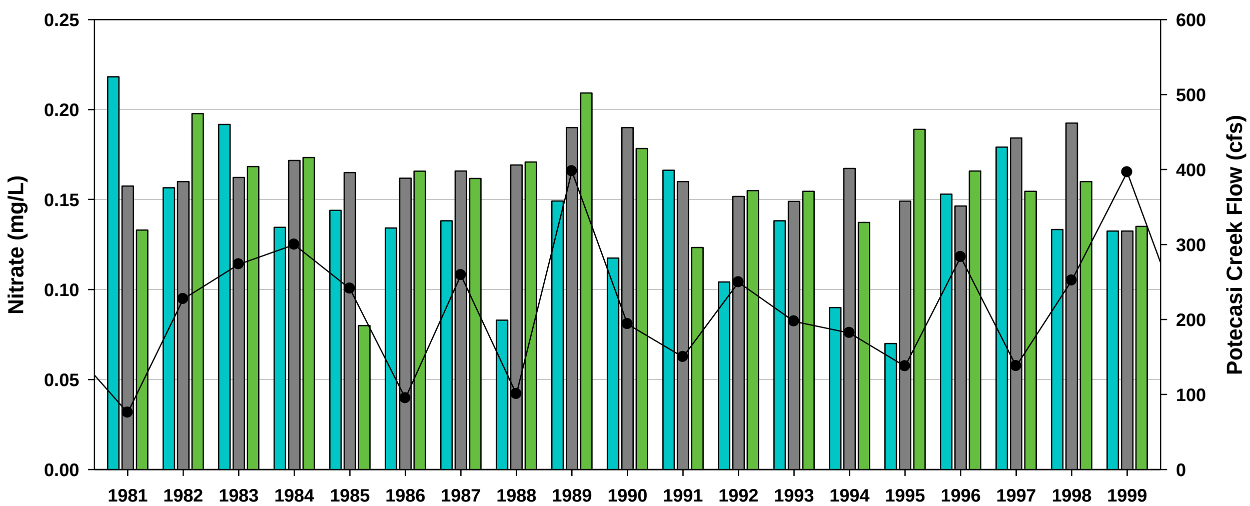
Similar to the pattern seen in the Chowan and Meherrin River, the annual mean nitrate concentrations in Potecasi Creek have varied somewhat and declined until about 2006, at which point the concentrations gradually increased over time (Figure 5-15). The range in annual nitrate concentrations since 2010 is 0.076-0.148 mg/L with the highest annual concentration recorded in 2010. The range for the Meherrin River watershed since 2010 was 0.076-0.246 mg/L with the highest annual concentration at the Meherrin

River station (D5000000) in 2018 (Table 5-5; Figure 5-15)). The five-year nitrate means also demonstrates that the overall decline in nitrate concentrations occurred until about the 2005-2009 (Figure 5-16) similar to what was reported for the Chowan River mainstem (Figure 5-8).

The long-term flow-normalized nitrate loading trend results are similar to those described for the Potecasi Creek concentration response. The nitrate loads have varied but have been increasing since 2008 as well (Figure 5-6). Nutrient loading in the Potecasi Creek is driven by nonpoint sources, since the point source dischargers have been eliminated (Figure 5-15). There is a need to better understand the contribution from groundwater/base flow in this system. There is some evidence that groundwater nitrate concentrations in the Chowan are elevated near current and historic agricultural sites that have routinely applied animal waste or fertilizers which could contribute to surface water nutrient loads (for more groundwater quality discussion see Chapter 4, Wiccacon River and Chowan River Watershed sections). The reason for the upward trajectory in nitrate concentration in the 2010's is unknown at this time. It is not clear if this is an inflection point or the point in time in which a shift occurred resulting in elevated biological productivity and increased occurrence in pHABs in the lower Chowan River.

Figure 5-15 Annual Weighted Mean Nitrate Concentrations and Flow at the Potecasi Creek (D4150000), Meherrin River (D5000000) and Chowan River at Winton (D6250000) AMS Stations for Comparison for (a) Years 1981-1999 and (b) Years 2000-2018. (Flow at USGS Gage 02053200; Co-located with AMS Station D4150000.)

(a) Years 1981-1999



(b) Years 2000-2018

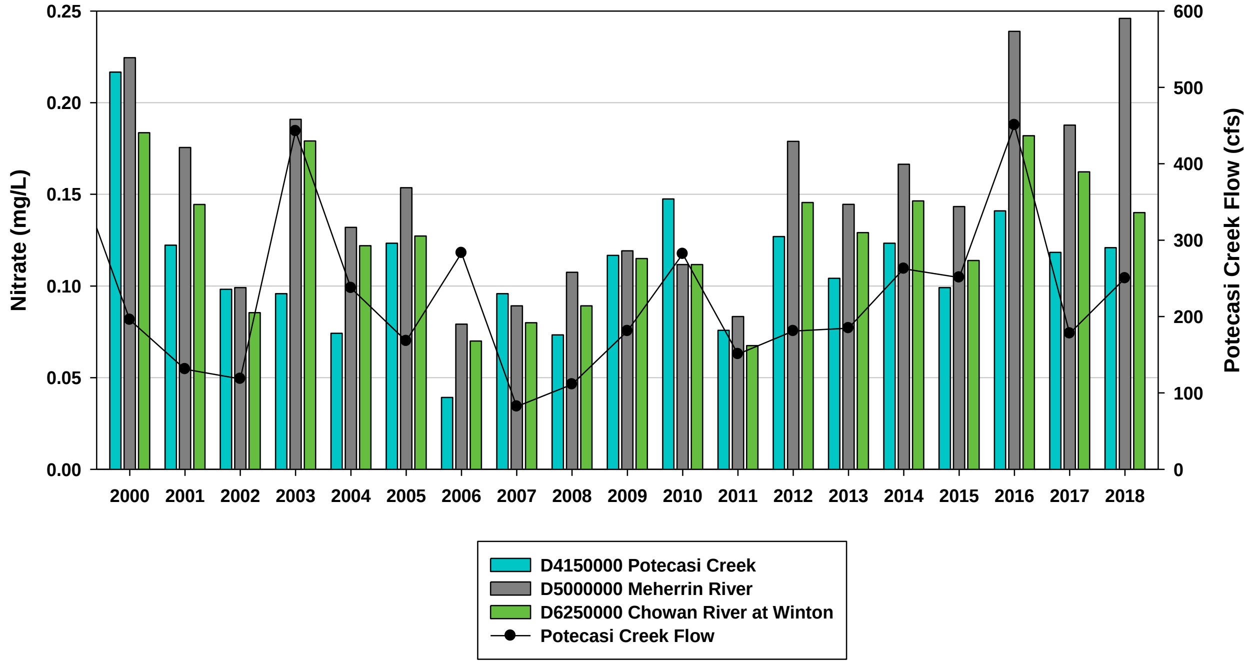
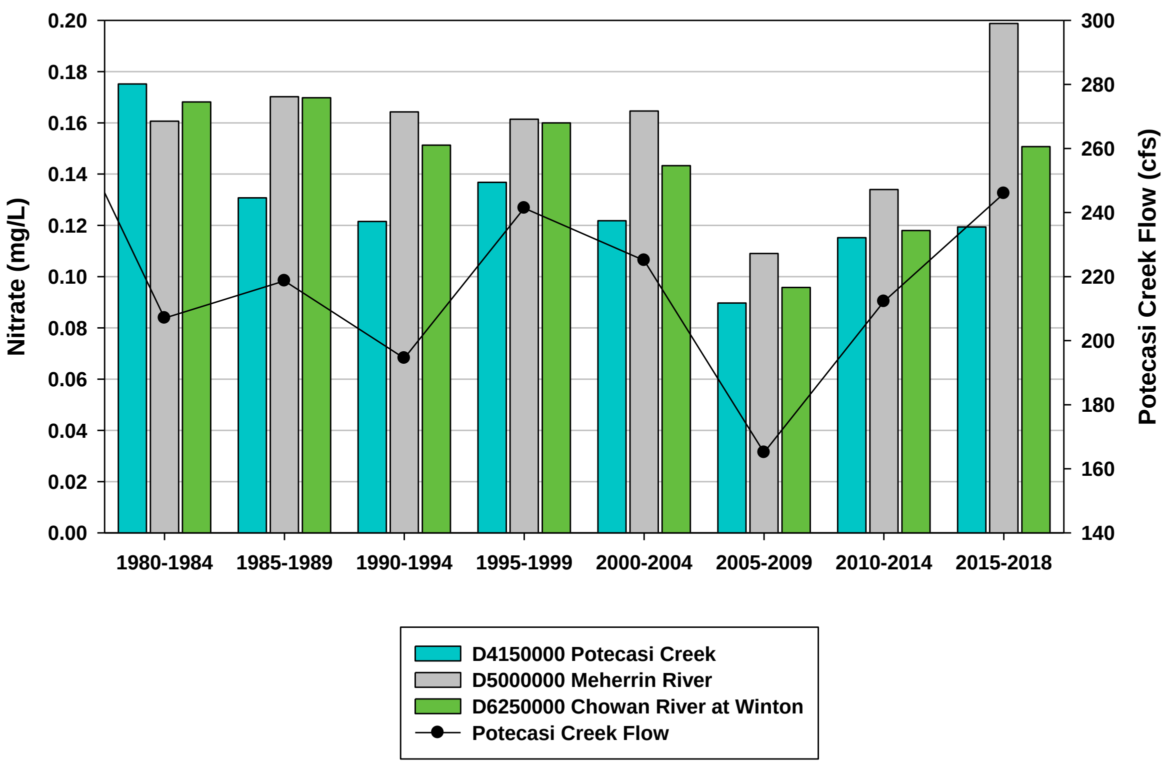


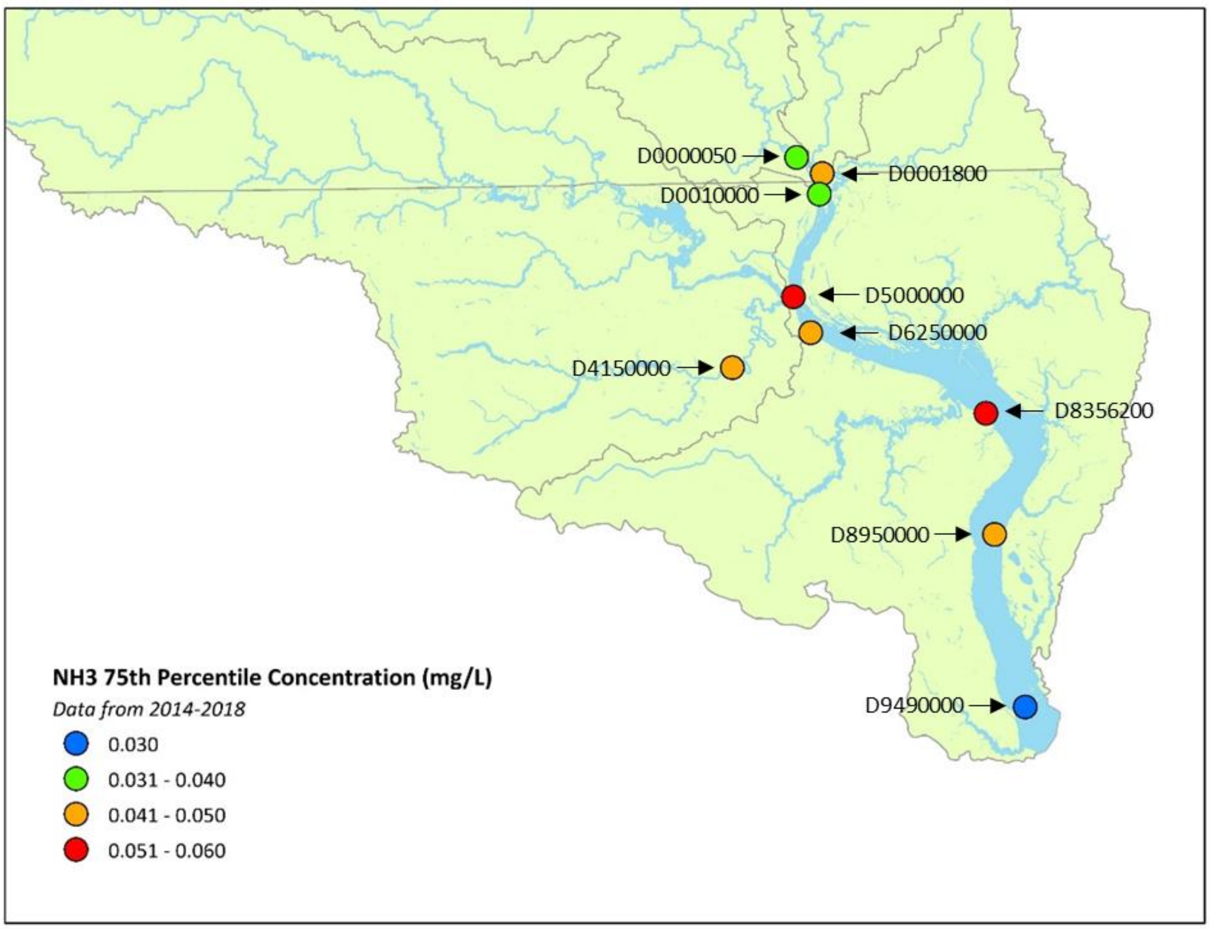
Figure 5-16 Five-Year Weighted Mean Nitrate Concentrations and Flow at the Potecasi Creek (D4150000), Meherrin River (D5000000) and Chowan River at Winton (D6250000) AMS Stations. (Flow at USGS Gage 02053200; Co-located with AMS Station D4150000.)



5.2.5 Ammonia Nitrogen

Ammonia (NH_3 + NH_4^+; reported as ammonia) is the nutrient parameter most often found at low concentrations (at or below detection levels) in our natural aquatic ecosystems in North Carolina. Ammonia is readily utilized by the algal communities, especially in highly productive environments. In the Chowan River basin, ammonia is most often the smallest fraction of a total nitrogen signature (Figure 5-5). Over the last five years (2014-2018; 2020IR period) the two stations with the highest, 75th percentile ammonia (NH_3) concentrations are the Meherrin River (D5000000) and the Gatesville (D8356200) station in the Chowan River (Figure 5-17Figure 5-17). The range in the annual mean ammonia concentration between 2010-2018 is 0.02 mg/L (minimum reported value) to 0.095mg/L with the highest annual mean at the Potecasi Creek station (D4150000) in 2010 and the Blackwater River station (D0001800) in 2011 (Table 5-5). These stations with relatively high ammonia concentrations are addressed later in this section after reviewing the historical trends.

Figure 5-17 Chowan River Basin AMS Stations for the 2020 IR Period 75th Percentile Ammonia Concentrations.



The ammonia concentrations throughout the basins seven mainstem stations have declined since the 1980's and have been relatively consistent at each station since about 2006 (Figure 5-18 and Figure 5-19). The annual mean ammonia concentrations between 2010-2018 drop slightly with each successive station moving downstream from the Blackwater River station to the Chowan River Edenhouse station near Eden NC (Figure 5-5). This is likely due to the increased biological activity that occurs in the lower segments of the Chowan River. The elevated concentrations reported in 2000 and 2001 in (Figure 5-19) are likely the result of laboratory equipment and methodological adjustments made during that time period, resulting in a large fluctuation in the reported PQLs (practical quantitation limit). The PQL or the minimum detection value is used throughout this assessment and can influence the overall data interpretation (Table 5-5: PQL portion). The source of the increased ammonia concentration in the Chowan River between Winton (D6250000) and Gatesville (D8356200) needs to be investigated. Ahoskie Creek/Wiccacon River watershed as well as Cofield drains to this section from the west side of the river and Buckhorn Creek/Sarem Creek watershed drain to the east side of the river. This area has a few of the remaining surface water dischargers in the basin. The Town of Ahoskie, the largest town in the river basin lies in this portion of the watershed. The dominate land cover type is however agriculture and forest.

Figure 5-18 Five Year Weighted Mean Ammonia Concentrations and Nottoway River Flow (1975-2018). (Note the Y-axis scale break).

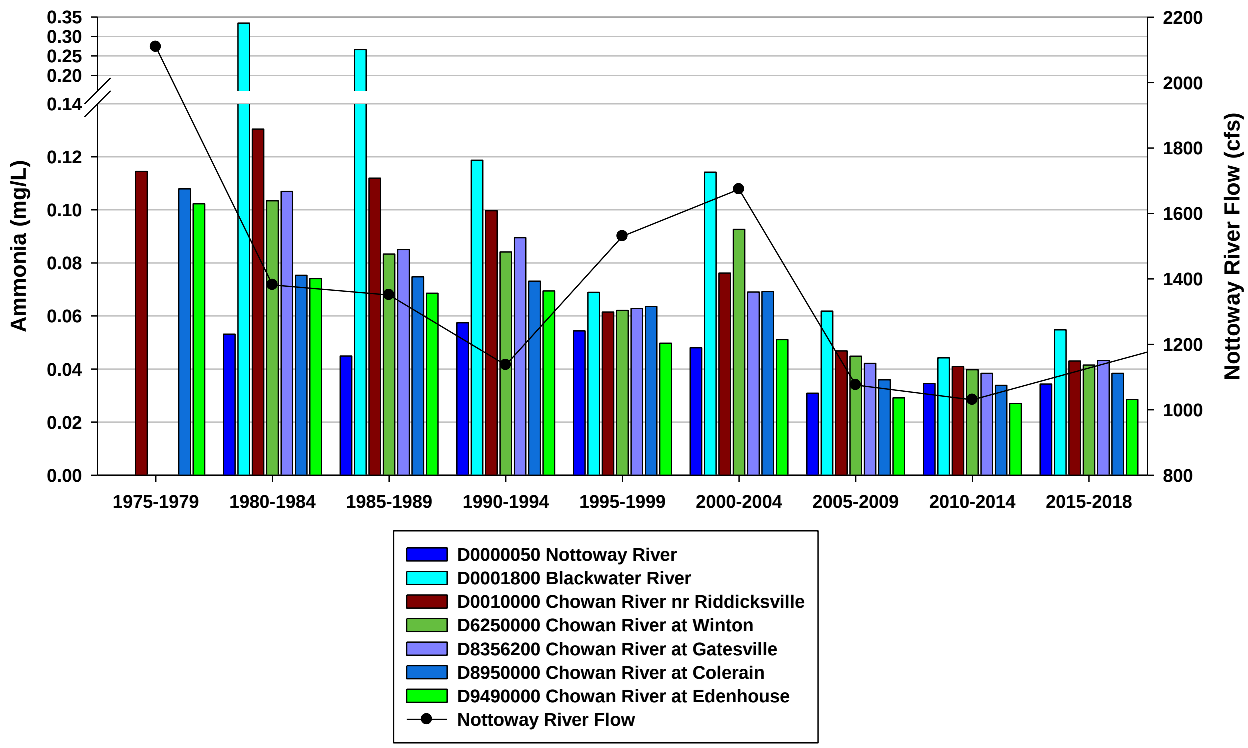
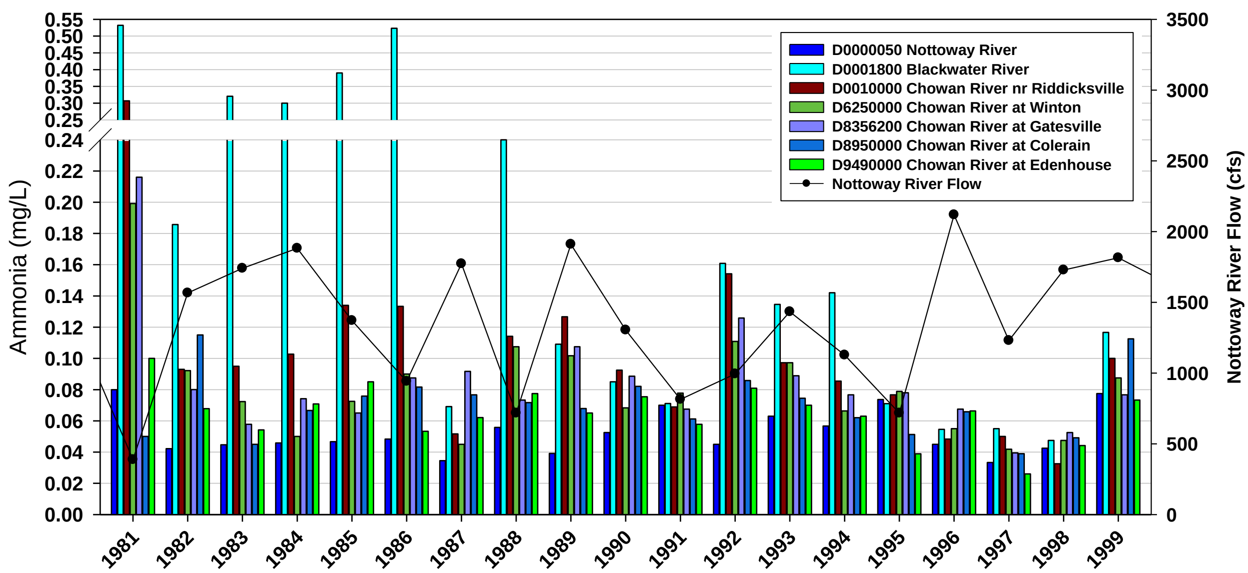
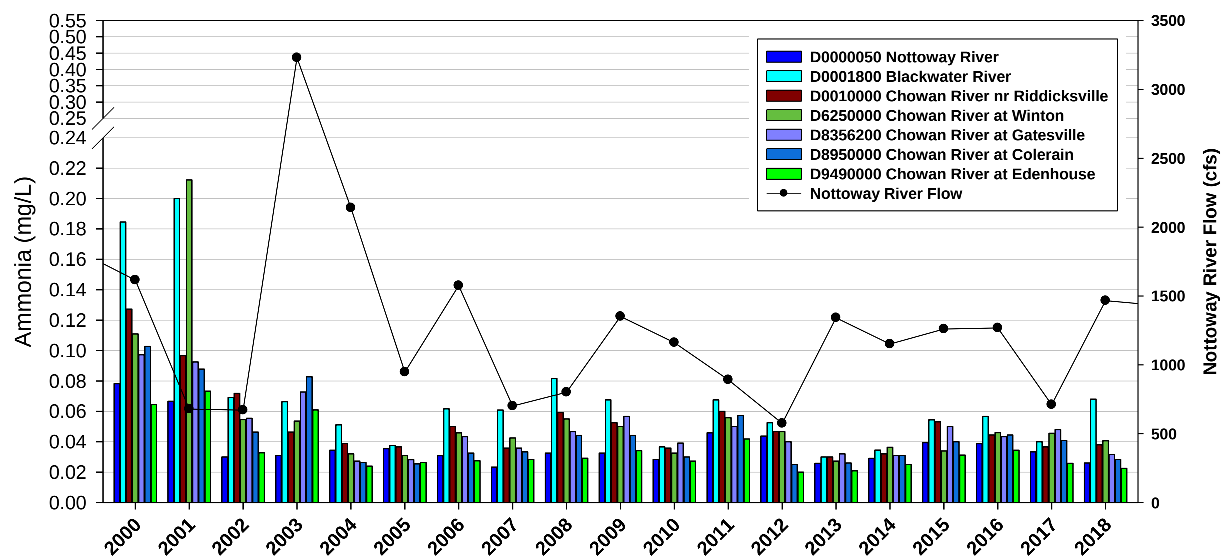


Figure 5-19 Annual Weighted Mean Ammonia Concentrations with Annual Nottoway River Flow ((a) 1981-1999 and (b) 2000-2018) (Note the ammonia axis scale break, this is the same axis for both a and b) (c) 2006-2018 (This time frame focuses on the most recent instream ammonia concentration, note both Y-axis change to allow for better visual evaluation of the change that has occurred over this time period).

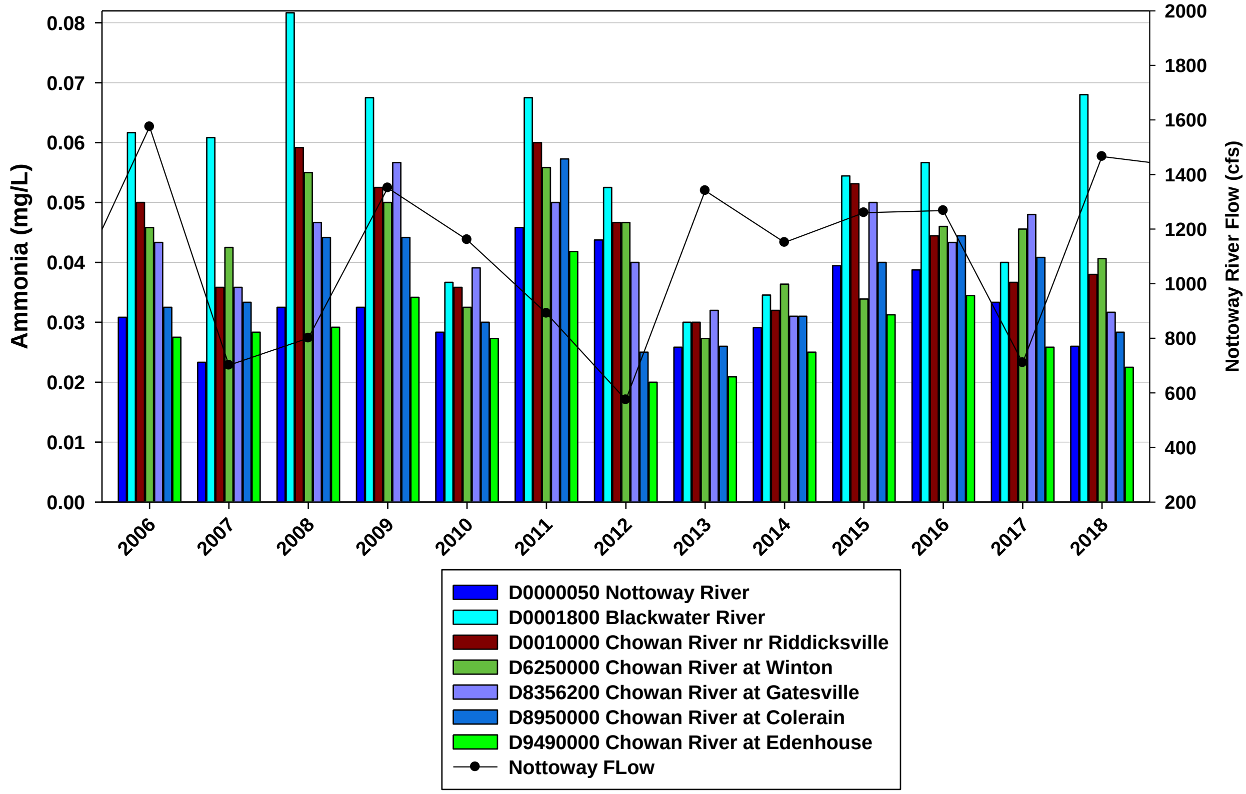
(a) 1981-1999



(b) 2000-2018



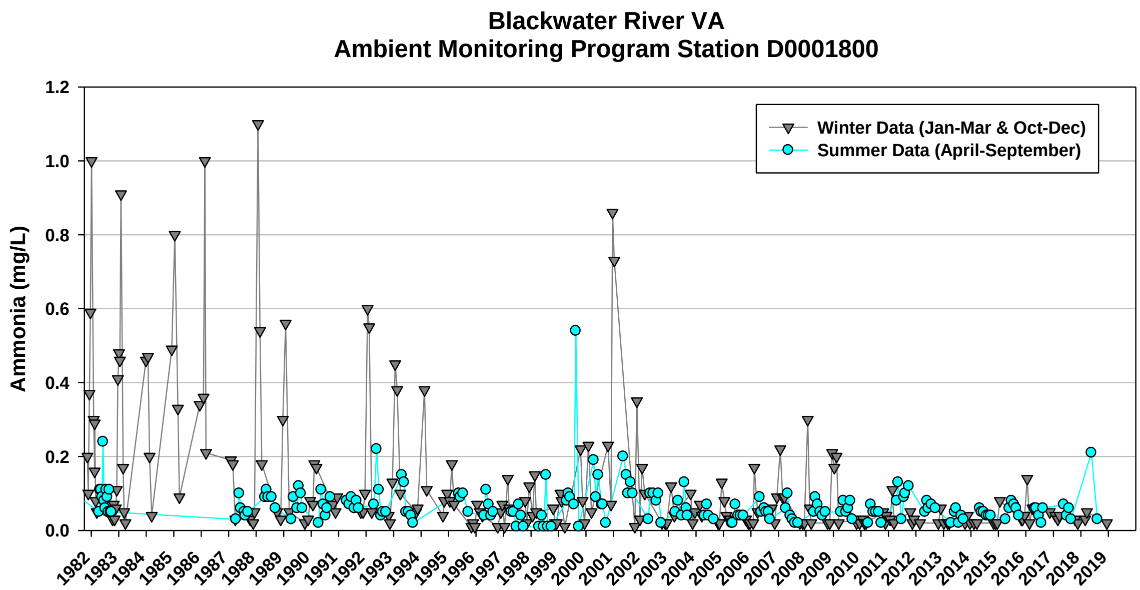
(c) 2006-2018



Blackwater River

Fifty-seven percent of the time, the highest annual mean ammonia concentrations were recorded at the Blackwater River station D0001800 which is located downstream from the IP discharge point (Figure 5-18 and Figure 5-19). The highest yearly readings have generally occurred during the winter months when IP is permitted to discharge their wastewater (Figure 5-20). From the information currently available (as of May 2020), IP has had an ammonia discharge limit of no more than a monthly average of 2.15 mg/L and a daily maximum of 3.19 mg/L since at least 2005 (unable to confirm IP NPDES permit information prior to 2005). It is important to note that there was no summer ammonia data available at the Blackwater River station in the early to mid-1980's. This likely resulted in artificially high annual mean concentrations for those years (Figure 5-18 and Figure 5-19). Since 2010, the summer and winter instream ammonia concentrations in the Blackwater River have been fairly consistent (Figure 5-20), however the Blackwater River still had the highest annual mean concentrations more than have of the time (Figure 5-19 (c); 5 out of the 9 years since 2010).

Figure 5-20 Monthly Ambient Monitoring Ammonia Concentration Data for the Blackwater River VA Station D0001800. Data is Separated into DWR Sampling Seasons.

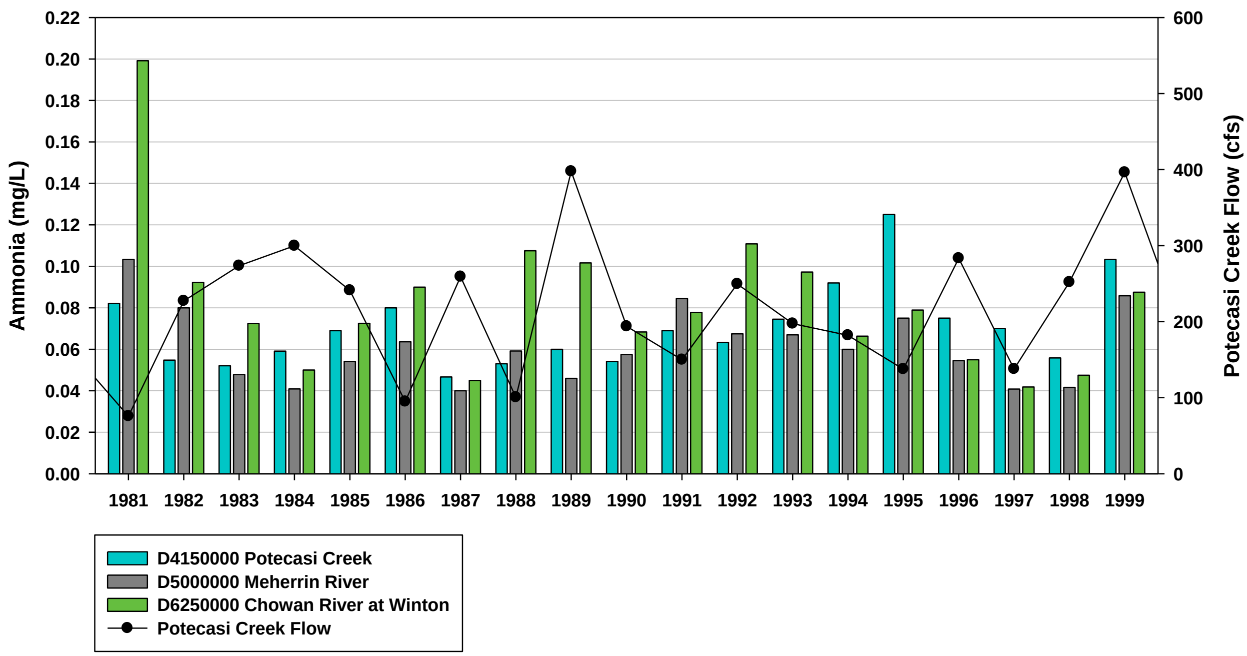


Meherrin River and Potecasi Creek

The ammonia concentration draining from the Meherrin River watershed was generally lower than mainstem Chowan River until the mid-1990’s (Figure 5-21 and Figure 5-22). The concentration dropped and remained fairly stable since 2002 with the exception of elevated concentration in the Potecasi Creek in 2010 and 2011 (Figure 5-21). Stream flow does not appear to influence to overall instream concentration in the Meherrin River watershed (Figure 5-21). It would be helpful to understand the base flow contribution of ammonia throughout this system.

Figure 5-21 Annual Weighted Mean Ammonia Concentration and Flow at the Potecasi Creek (D4150000), Meherrin River (D5000000) and Chowan River at Winton (D6250000) AMS Stations for Comparison for (a) Years 1981-1999 and (b) Years 2000-2018. (Flow at USGS Gage 02053200; Co-located with AMS Station D4150000).

(a) Years 1981-1999



(b) Years 2000-2018

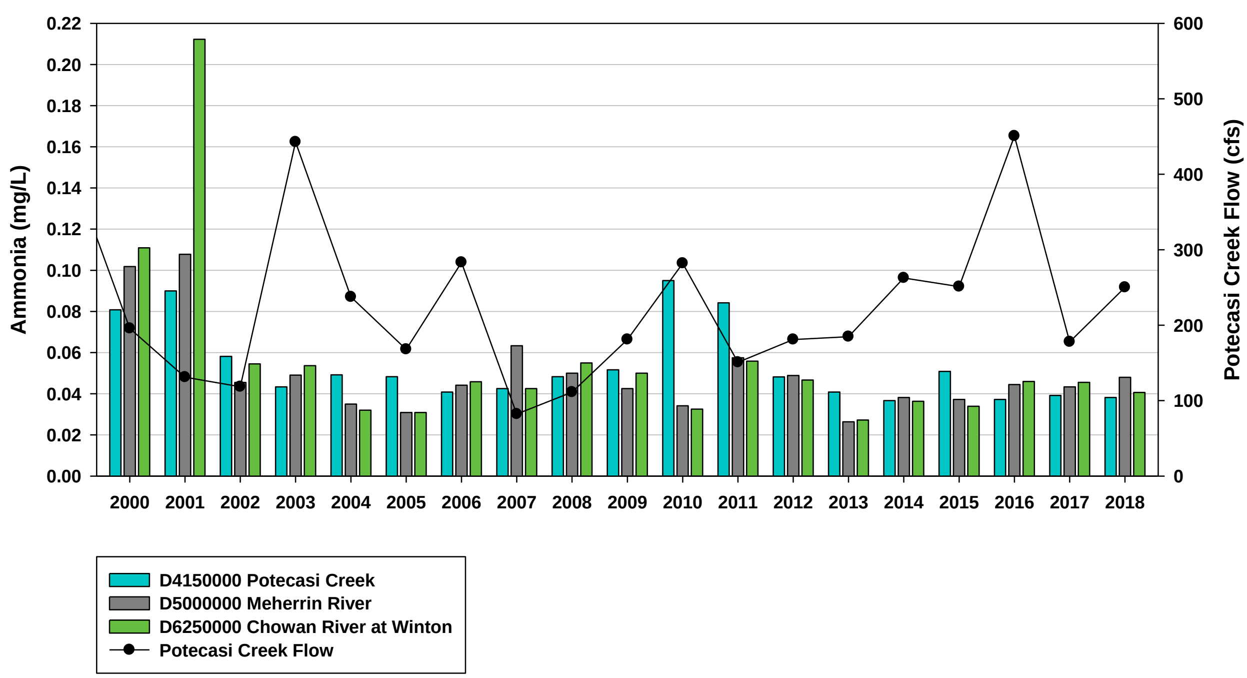
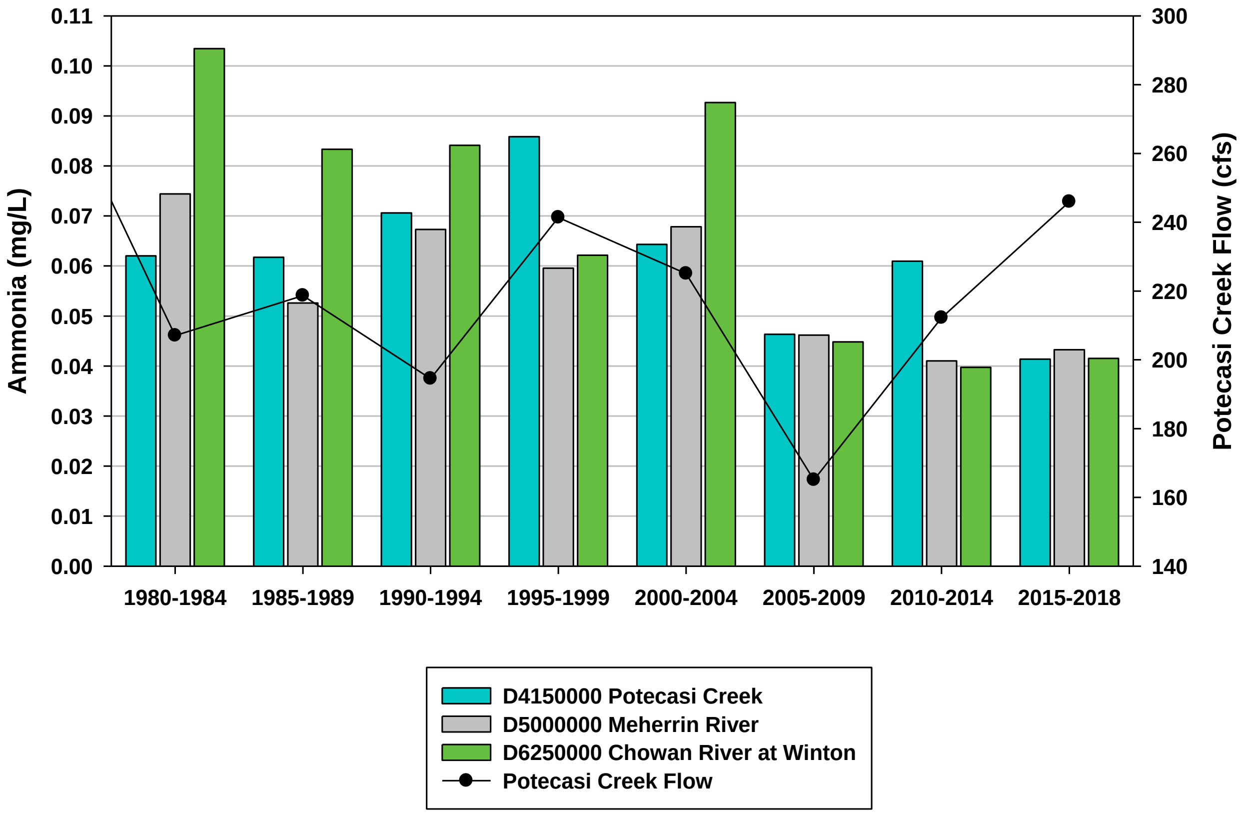


Figure 5-22 Five-Year Weighted Mean Ammonia Concentrations and Flow at the Potecasi Creek (D4150000), Meherrin River (D5000000) and Chowan River at Winton (D6250000) AMS Stations. (Flow at USGS Gage 02053200; Co-located with AMS Station D4150000).



5.2.6 Total Kjeldahl Nitrogen (TKN)

Total Kjeldahl Nitrogen (TKN) is ammonia/ammonium nitrogen + organic nitrogen. As can be seen in Figure 5-5, the ammonia component is a very small fraction of the overall TKN concentration. Organic nitrogen is the dominate form of nitrogen throughout the Chowan River system (Figure 5-5). Over the last five years (2014-2018; 2020IR period) the two stations with the highest, 75th percentile TKN concentrations are the Potecasi Creek (D4150000) and Chowan River at Colerain (D8950000) (Figure 5-23).

Since 2015, the annual mean TKN concentrations in the mainstem Chowan River has increased moving downstream from the Chowan River station near Riddicksville (D0010000) at the top of the watershed, down the Chowan River to the Colerain station (D8950000) (Figure 5-24 (c)) and this pattern can be clearly seen in the 2015-2018 mean bar graph (Figure 5-25). During this time frame, the increasing TKN is likely the result of the increasing algal blooms that are occurring throughout this system and have dominated the lower portion of the Chowan River over the last several summers.

The range in the mean TKN concentration between 2010-2018 for the 7 mainstem stations is 0.52 to 0.84 mg/L with the highest annual mean at the Blackwater River station (D0001800) in 2011 and Colerain station (D8950000) in 2018 (Table 5-5). In the Meherrin River watershed, the TKN concentration ranged between 0.54-1.10 mg/L with the highest annual mean at the Potecasi Creek station (D4150000) in 2011.

These stations with relatively high TKN concentrations are addressed later in this section after reviewing the historical trends.

Figure 5-23 Chowan River Basin AMS Stations for the 2020 IR Period 75th Percentile TKN Concentrations.

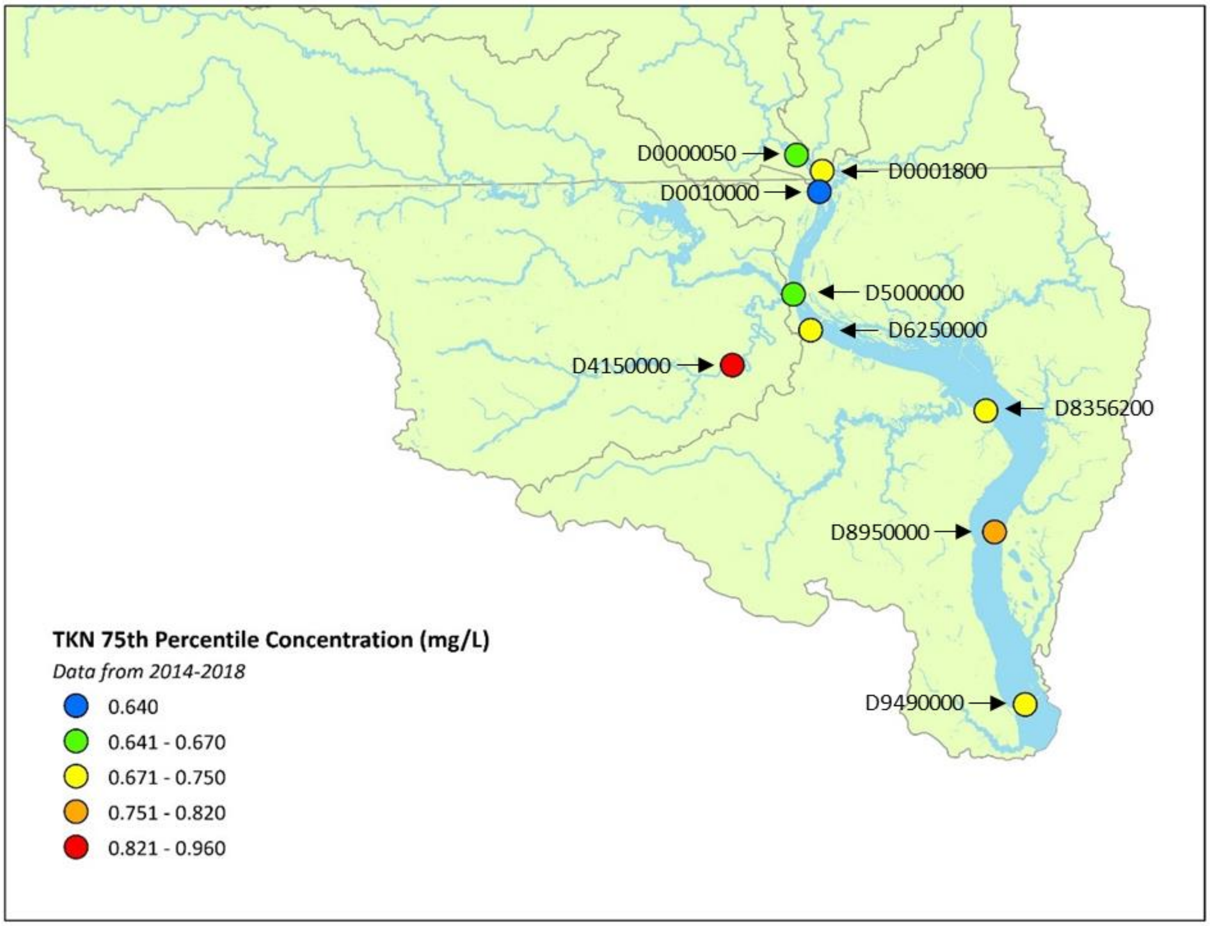
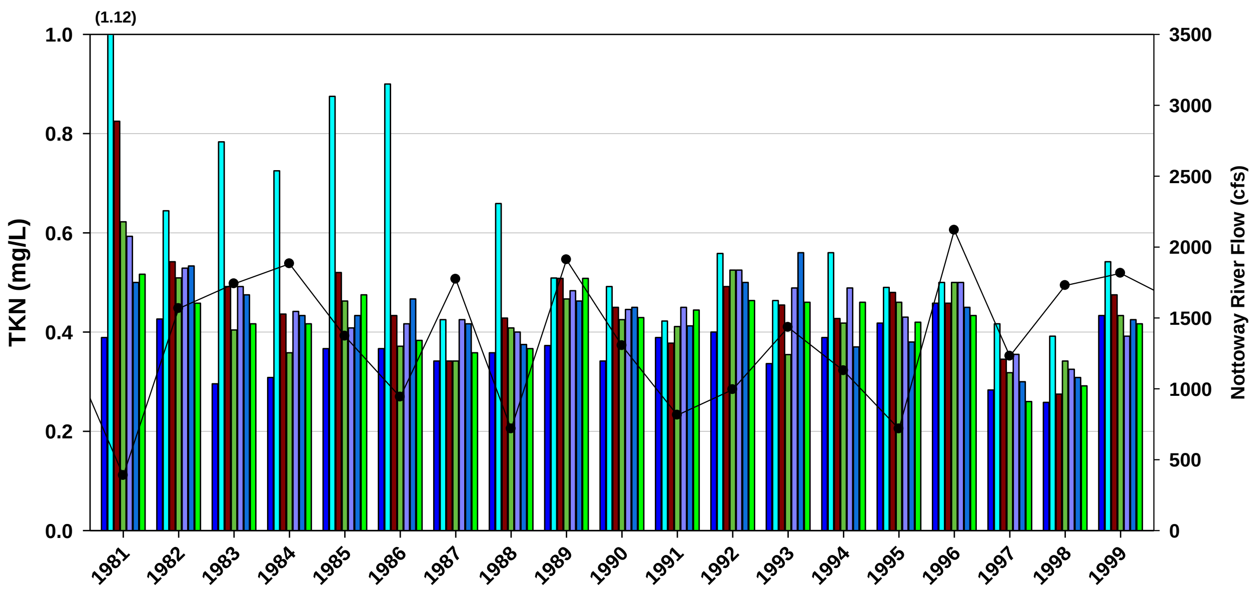
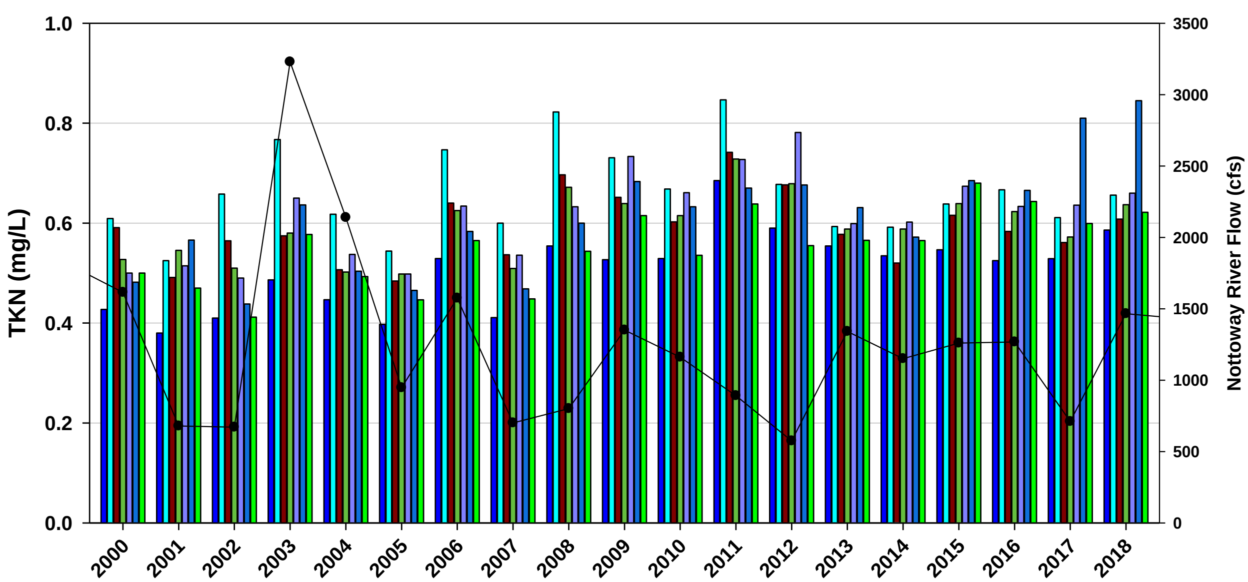


Figure 5-24 Annual Weighted Mean TKN Concentrations with Annual Nottoway River Flow ((a) 1981-1999, (b) 2000-2018) and (c) 2006-2018 (This time frame focuses on the most recent instream TKN concentration).

(a) 1981-1999



(b) 2000-2018



(c) 2006-2018

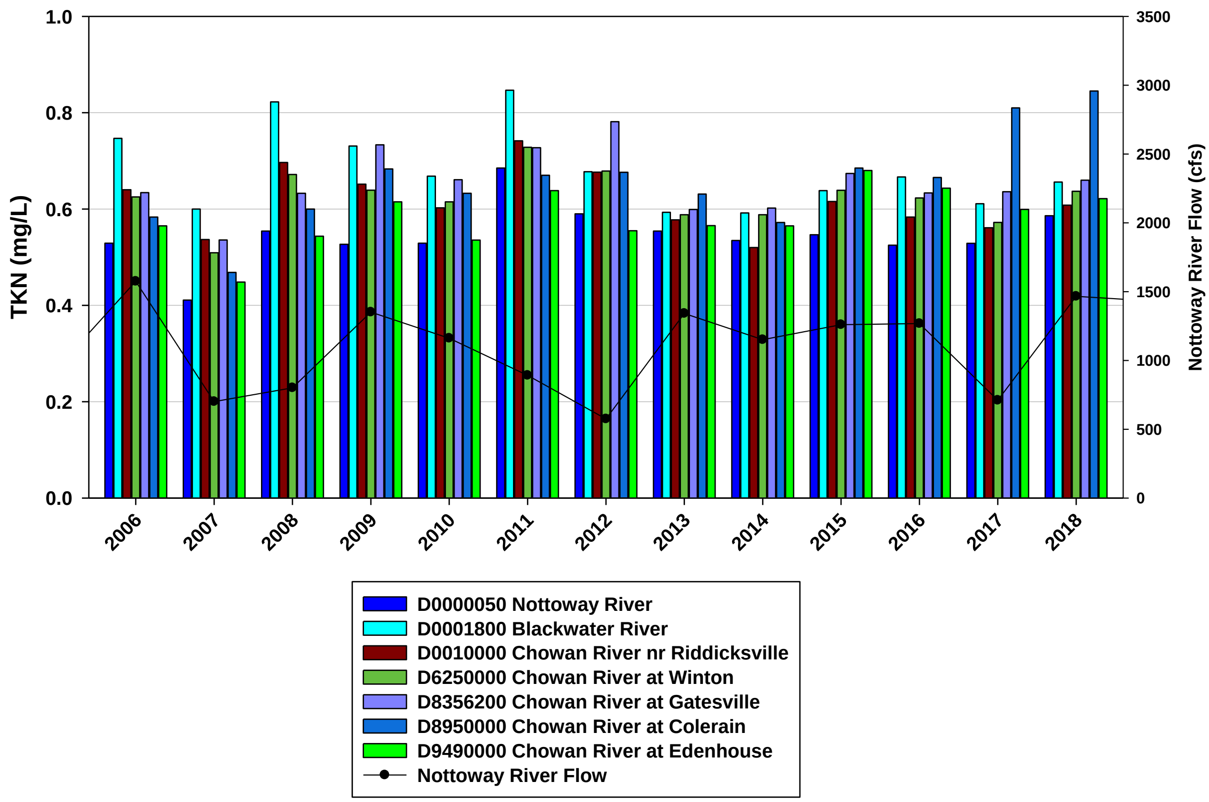


Figure 5-25 Five Year Weighted Mean TKN Concentrations and Nottoway River Flow (1975-2018).

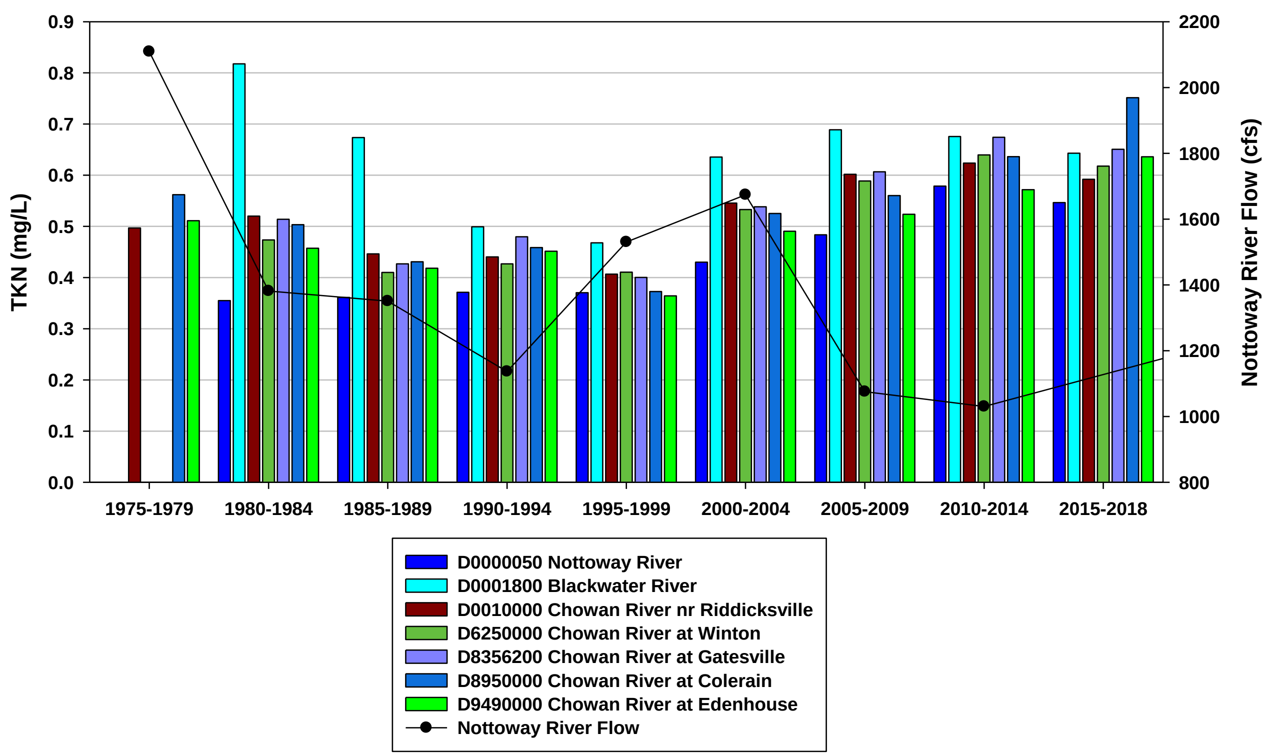
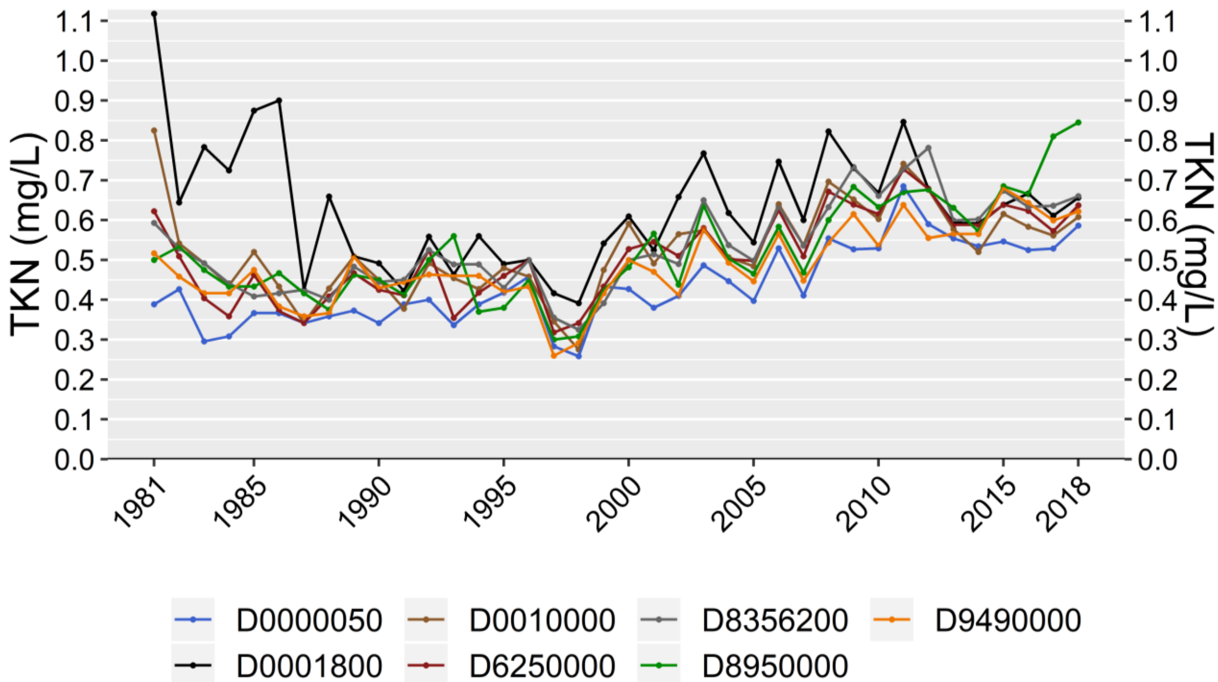
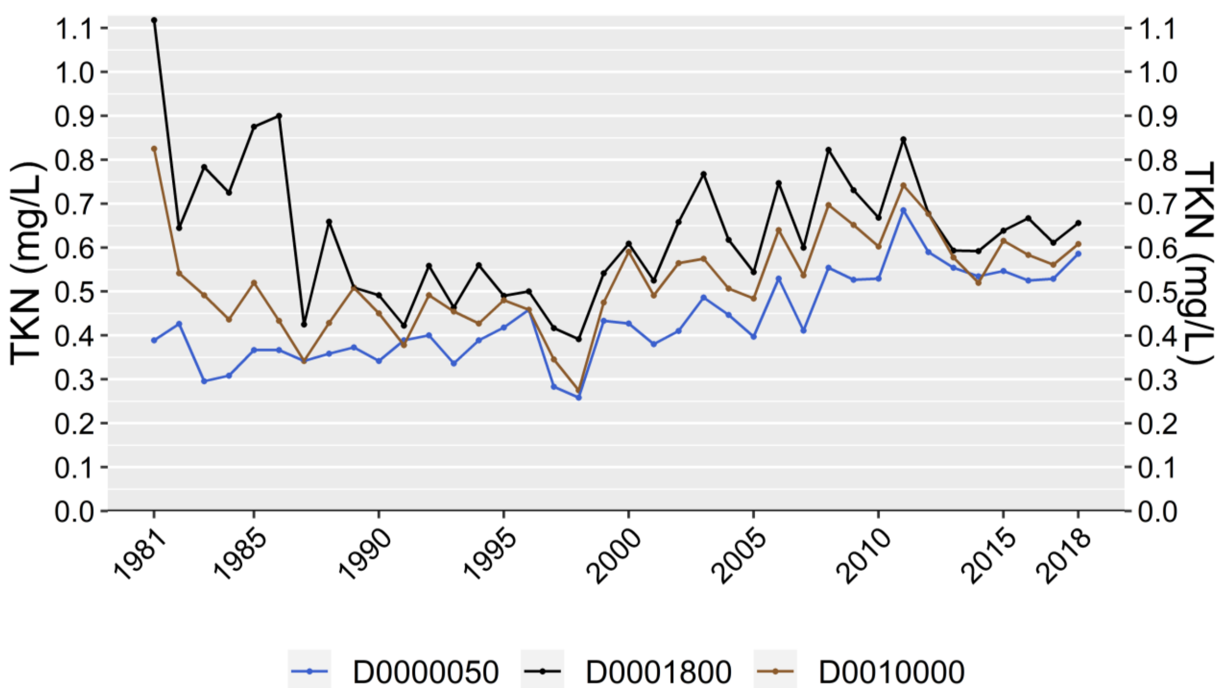


Figure 5-26 Annual Weighted Mean Total Kjeldahl Nitrogen Concentration (1981-2018) at (a) Two Virginia and Five Chowan River Mainstem AMS stations, (b) the Upper Three Station Only, (c) the Chowan River Station Only, and (d) Meherrin River Watershed Stations and the Chowan D6250000 at Winton.

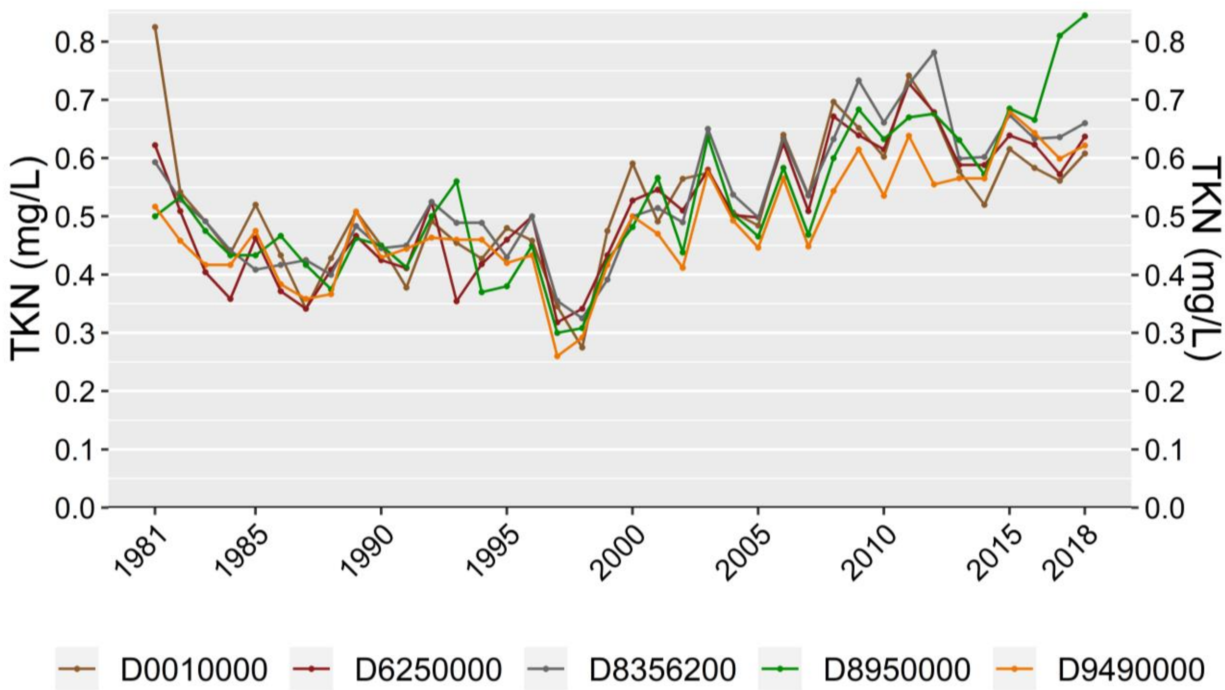
(a) Two Virginia and Five Chowan River Mainstem AMS stations



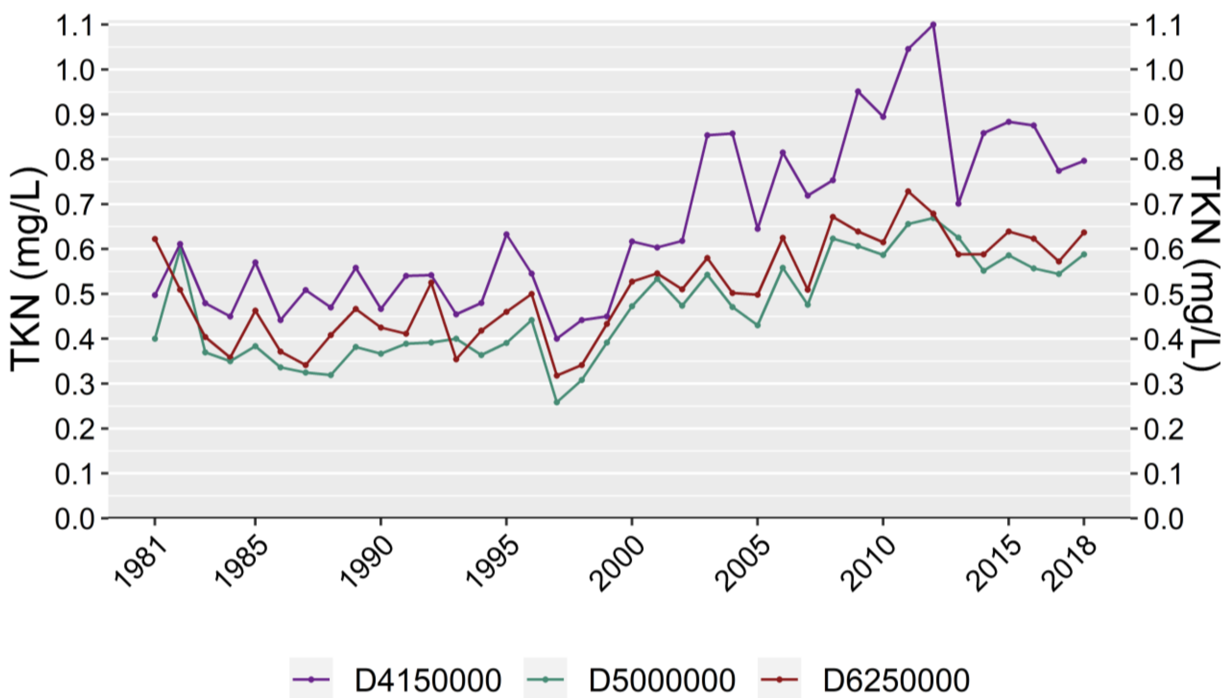
(b) the Upper Three Station Only



(c) the Chowan River Station Only



(d) Meherrin River Watershed Stations and the Chowan D6250000 at Winton



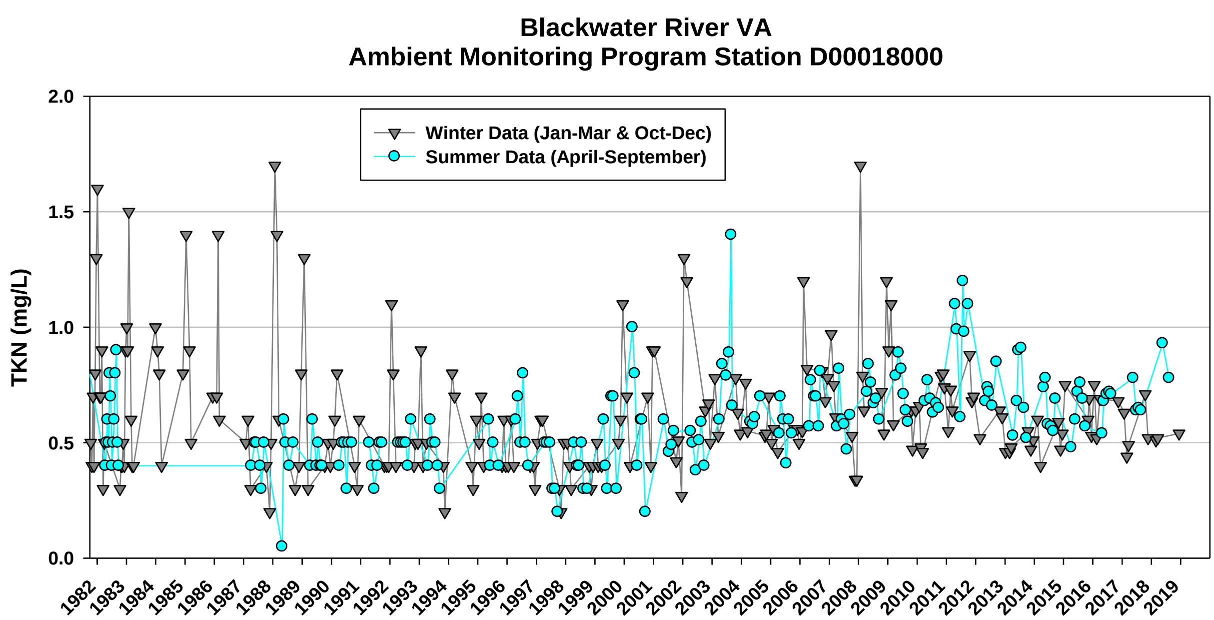
Historically, the instream TKN concentrations throughout the Chowan River, Meherrin River and the Nottoway River watersheds remain fairly steady through the 1980's and mid-1990's (Figure 5-25 and

Figure 5-26). The TKN concentration in the Blackwater River (D0001800) declined in the 1980's and 1990's and was likely the result of some type of direct implementation efforts taking place in that watershed (Figure 5-24, Figure 5-25, and Figure 5-26). In 1999, the TKN instream concentration began to increase at all 9 stations across the basin.

Blackwater River

The long-term flow-normalized TKN loading trend results are similar to those described for Blackwater River instream concentrations with a sharp decline in load in the 1980's and early 1990's, followed by a slow decline in loading through 1999 before reversing the trend with a steady increase through 2011 (Figure 5-6). The load has declined somewhat since 2011 and in 2016 the TKN load was about 23% lower than the 1981-1985 baseline load. The concentrations and load estimates in the early 1980's are likely skewed as a result of not having summer ambient samples between 1983-1986 (Figure 5-27). There is clearly a decline in the winter TKN concentrations through the 1990's. This could be the result of some type of implementation measure in the Blackwater River watershed. This trend however clearly reverses and begins to slowly increase over time which is similar to the other stations monitored throughout the Chowan River watershed.

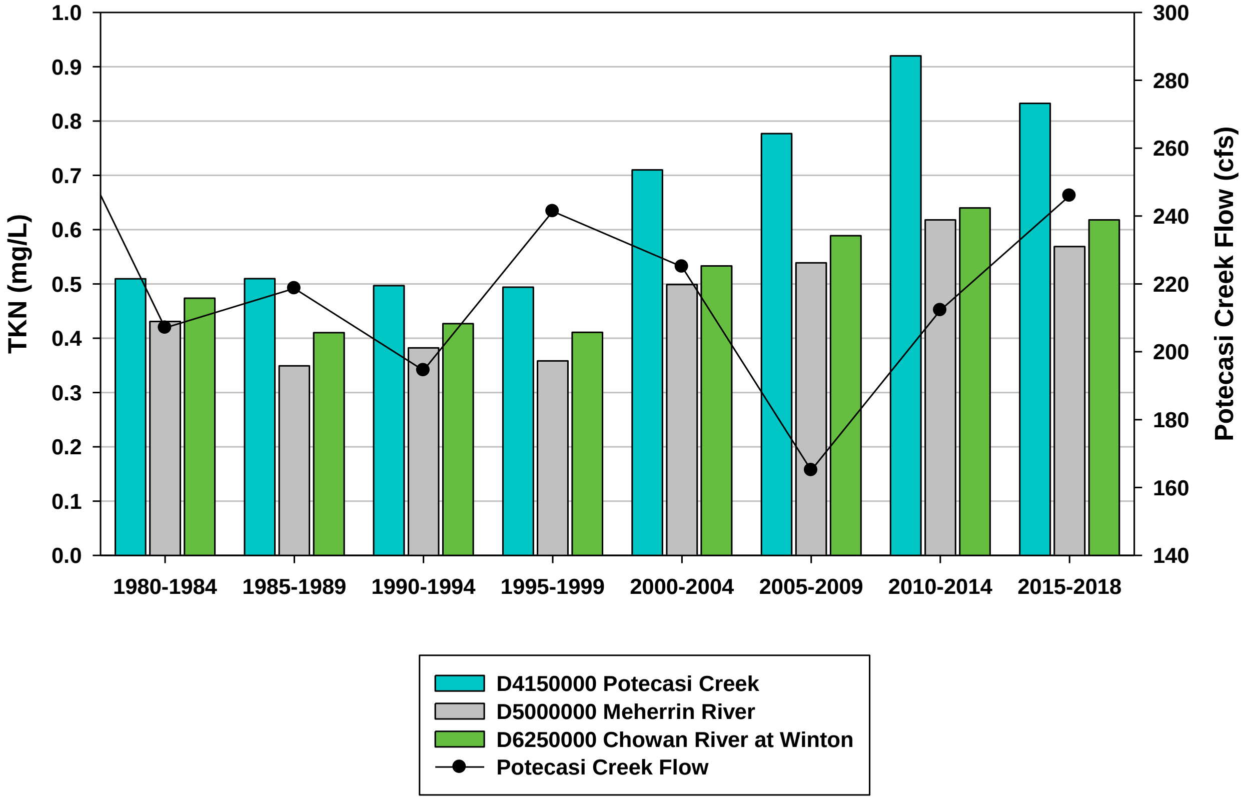
Figure 5-27 Monthly Ambient Monitoring TKN Concentration Data for the Blackwater River VA Station D0001800. Data is Separated into DWR Sampling Seasons.



Nottoway River

The long-term flow-normalized TKN loading trend results are similar to those described for Nottoway River instream concentrations described above (Figure 5-6 and Figure 5-26(b)). The loading remained steady until about 2002 where the concentration and loads began to climb over time. The estimated load increase in 2016 was 40 % higher than the 1981-1985 baseline load.

Figure 5-28 Five-Year Weighted Mean TKN Concentrations and Flow at the Potecasi Creek (D4150000), Meherrin River (D5000000) and Chowan River at Winton (D6250000) AMS Stations. (Potecasi Creek Flow at USGS Gage 02053200; Co-located with AMS Station D4150000).



Potecasi Creek

The instream TKN concentration in Potecasi Creek (D4150000) follows the same pattern described for the watershed which was fairly stable though 1999 (Figure 5-26(d) and Figure 5-28). There was however a dramatic increase in both instream concentrations and long-term flow-normalized TKN loading trend in Potecasi Creek (D4150000) (Figure 5-6, Figure 5-26(d), and Figure 5-28). The load began to increase slowly in 1999 and increased dramatically in 2003 and continued to increase until 2012 with the estimated load registered a 100% increase (representing data for years 2008-2012, relative to the 1981-1985 load). The estimated load increase in 2016 was 80 % higher than the 1981-1985 baseline load. The highest annual mean TKN concentration was 1.10 mg/L in 2011 (Table 5-5 and Figure 5-26(d)). An increase in the Meherrin River was also seen but not to the extent documented in Potecasi Creek watershed (Figure 5-28). The source of the increasing TKN is unknown but is not likely linked to increasing algal concentrations like those in the mainstem Chowan River between 2015 and 2018.

Chowan River

As described above, the general pattern throughout the Chowan River mainstem has been an increasing TKN concentration since the early 2000's. There was distinct shift in 2015 with the concentrations increasing as you move down the river towards the Albemarle Sound (Figure 5-24, Figure 5-25, and Figure 5-26 (c)). A large increase in TKN concentrations can be seen at the Colerain station (D8950000) in 2017 and 2018 (Figure 5-24 (c) and Figure 5-26 (c)). This is likely associated with an increase in biological productivity as seen by a corresponding increase in the chlorophyll *a* concentrations (Figure 5-29). The algal blooms have been concentrated near the Colerain region of the river but have occurred as far upstream as Harrellsville/Gatesville station (D8356200) and stretched down into the Albemarle Sound (see chlorophyll *a* sections below for more algal bloom related details; Appendix V-II DWR Chowan River Basin Algal Bloom Assessment for Years 2015-2019 Table).

DWR has identified a similar pattern of increasing TKN/organic nitrogen in other river basins across the state. At this time, it is unclear as to the reason for this basinwide shift in increasing organic nitrogen concentrations since the early 2000's.

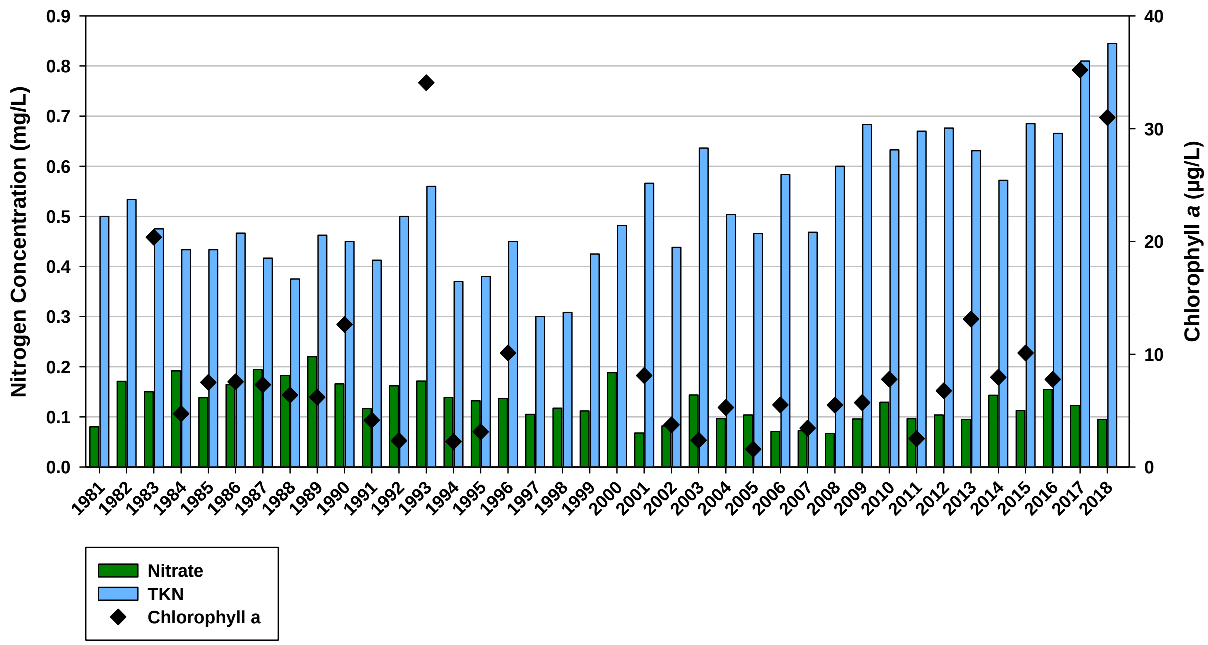
Recommendations related to organic nitrogen

There is a need to understand the sources of the organic nitrogen (ON) to the Chowan River system and across the state of NC. There are very few point sources discharger remaining in the Chowan River basin, as most point sources were converted to land application to reduce the overall nitrogen and phosphorus loading to surface waters back in the 1980's. Therefore, nonpoint discharges are suspected of being important ON sources.

There is a critical need for technology that can identify and quantify nitrogen inputs from specific sources such as agricultural animal wastes, domestic waste or a background forest/sediments. DWR encourages researchers to continue to work toward methods applicable for use on a large-scale system. This would assist in the development of appropriate best management practices to reduce the load of organic nitrogen into this system and across the state.

In the Chowan River basin, it appears important to understand the land use and changes in agricultural/urban/industrial activities that have occurred as it is clear that over time a shift to increasing organic nitrogen loading has occurred. There is a need to determine how this might play a role in the overall shift in environmental conditions which have resulted in the Chowan River becoming increasingly susceptible to the development of algal blooms and/or pHABs. There are different fractions of organic nitrogen that DWR does not currently sample. The dissolved fraction likely becomes more readily bioavailable and could feed into the algal and other microbial cycles. The particulate organic nitrogen fraction, when no longer part of a living organism, takes time to break down before it is once again becomes bioavailable. Some of this likely occurs in the sediments through nutrient recycling throughout the system, while the rest likely occurs downstream in the longer residence time estuary/Albemarle Sound. Understanding the ratios of these different organic nitrogen fractions may help in understanding what role TKN/organic nitrogen plays in the increasing biological productivity of the entire Chowan-Albemarle Sound continuum. As the Chowan River system becomes more productive, the TKN concentrations will continue to increase in response.

Figure 5-29 Annual Weighted Mean TKN, Nitrate and Chlorophyll a Concentrations at D8950000, Chowan River at Colerain.

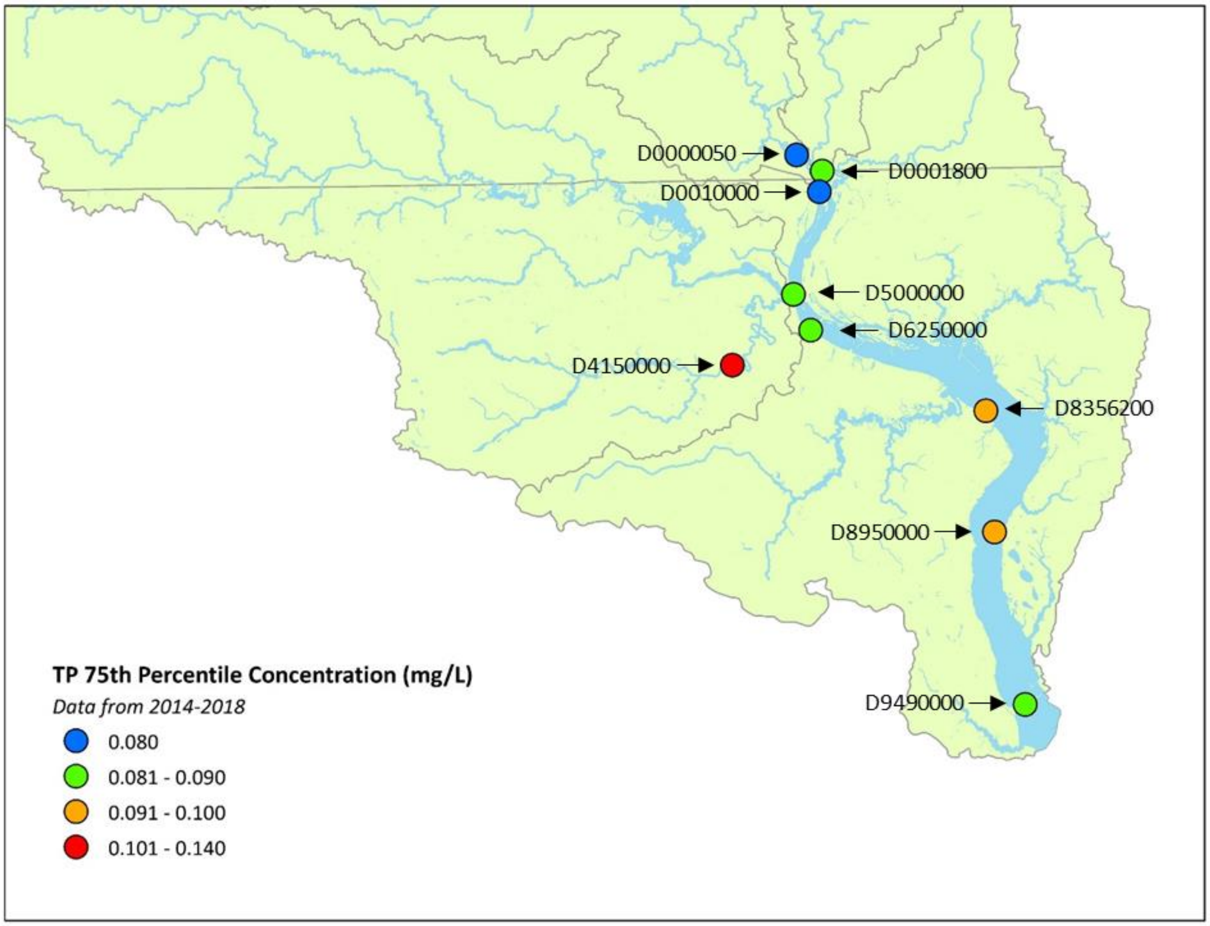


5.2.7 Phosphorus

Over the last five years (2014-2018; 2020IR period) the three segments with the highest, 75th percentile total phosphorus (TP) concentrations are Potecasi Creek (D4150000), Chowan River at Colerain (D8950000) and at Gatesville (D8356200) (Figure 5-30).

The range in the mean TP concentration between 2010-2018 for the 7 mainstem stations in the Chowan River watershed is 0.053 to 0.099 mg/L with the highest annual mean at the Blackwater River station (D0001800) in 2015 (Table 5-5). The range in the Meherrin River watershed was higher at 0.064-0.164 mg/L with the highest annual mean at the Potecasi Creek station (D4150000) in 2012 (Table 5-5). These stations with relatively high TP concentrations are addressed later in this section after reviewing the historical trends.

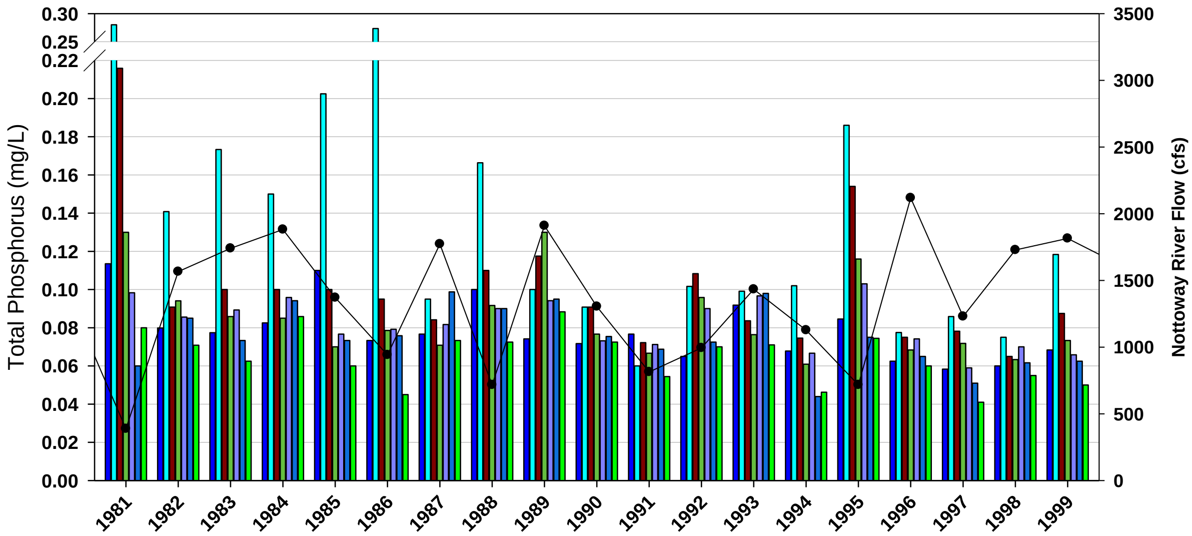
Figure 5-30 Chowan River Basin AMS Stations for the 2020 IR Period 75th Percentile Total Phosphorus Concentrations.



The 1982 management strategy put in place a **total phosphorus reduction goal of 30 to 40 %** to achieve a reduction in chlorophyll *a* concentration with peak levels not to exceed 40 µg/L. Between 1981 and 2016, instream TP concentrations throughout the Chowan River mainstem have remained fairly stable with annual means between 0.04-0.12 mg/L (Figure 5-31 and Figure 5-32 (c)). The Blackwater River station (D0001800) and Chowan River station at Riddicksville (D0010000) are the exceptions to this pattern with frequent peak annual mean TP concentrations above 0.12 mg/L (Figure 5-31 and Figure 5-32 (b)). The five year mean TP concentration demonstrates that these two stations remained elevated relative to the other mainstem stations through the 2005-2009 period (Figure 5-33).

Figure 5-31 Annual Weighted Mean TP Concentrations with Nottoway River Flow (a) 1981-1999, (b) 2000-2018 with the 2008 Year Inset to Display a High Spike in the Blackwater River and the Corresponding Watershed Response. (Note the TP axis scale break, this is the same axis for both graphs).

(a) 1981-1999



(b) 2000-2018

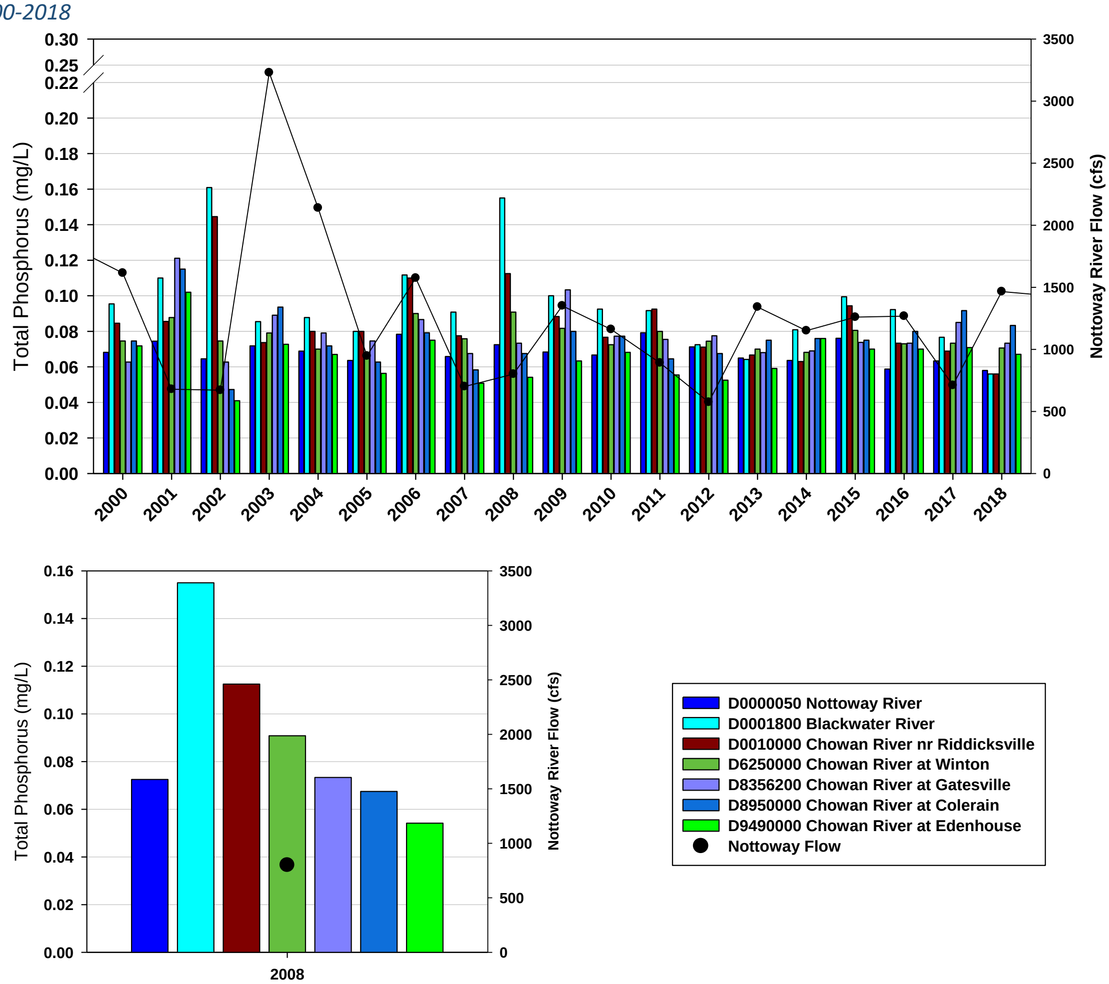
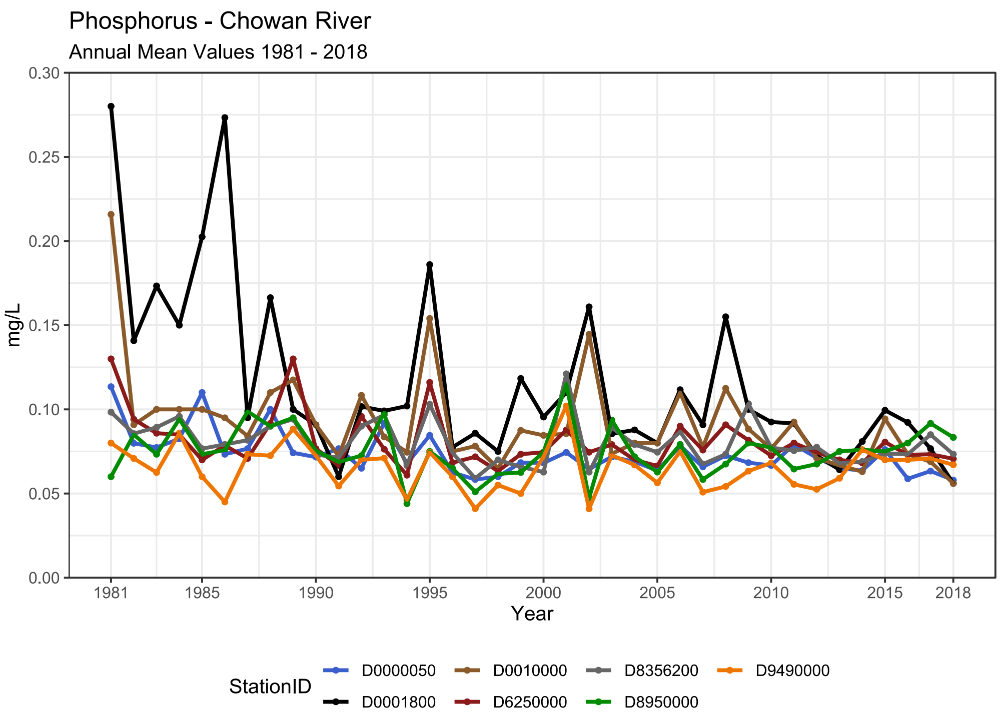
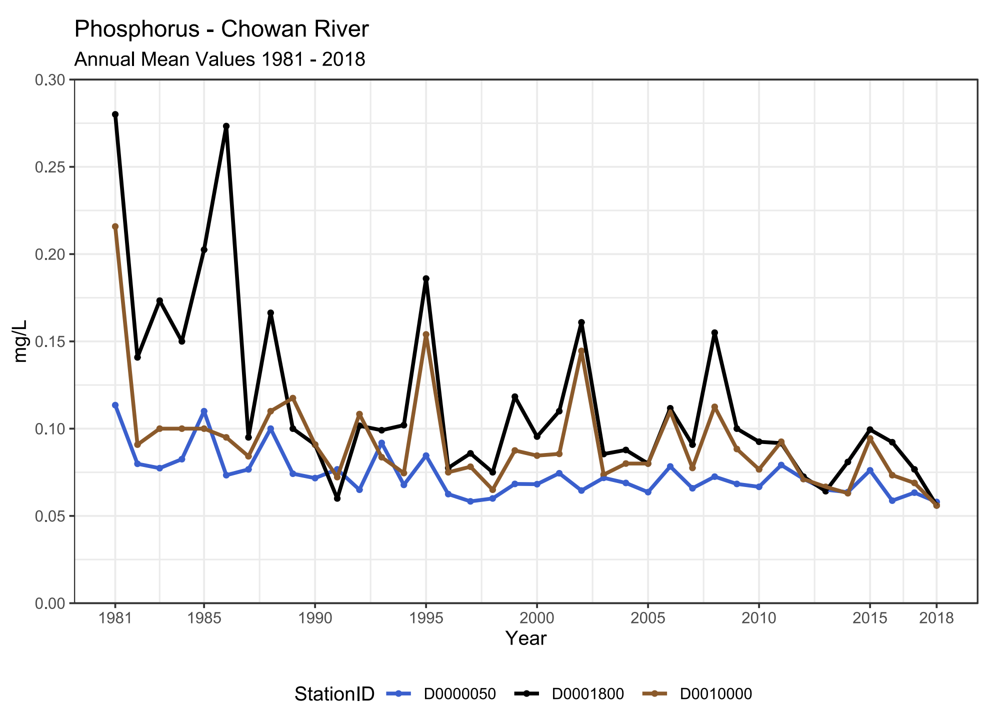


Figure 5-32 Annual Weighted Mean Total Phosphorus Concentration (1981-2018) at (a) Two Virginia and Five Chowan River Mainstem AMS stations, (b) the Upper Three Station Only, (c) the Chowan River Station Only, and (d) Meherrin River Watershed Stations and the Chowan D6250000 at Winton.

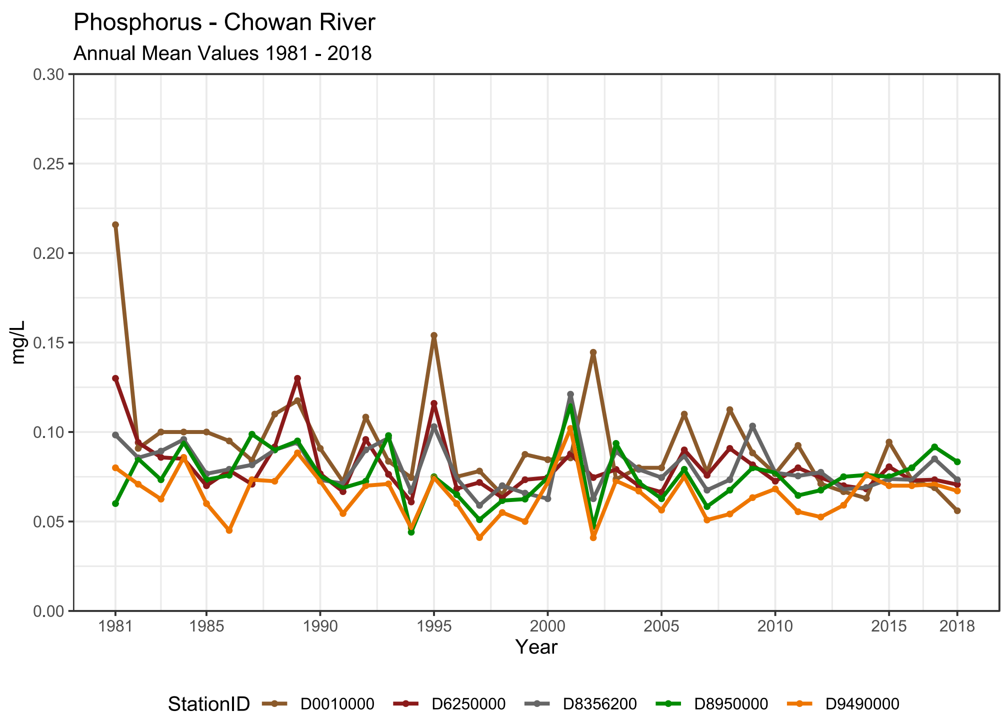
(a) Two Virginia and Five Chowan River Mainstem AMS stations



(b) the Upper Three Station Only



(c) the Chowan River Station Only



(d) Meherrin River Watershed Stations and the Chowan D6250000 at Winton

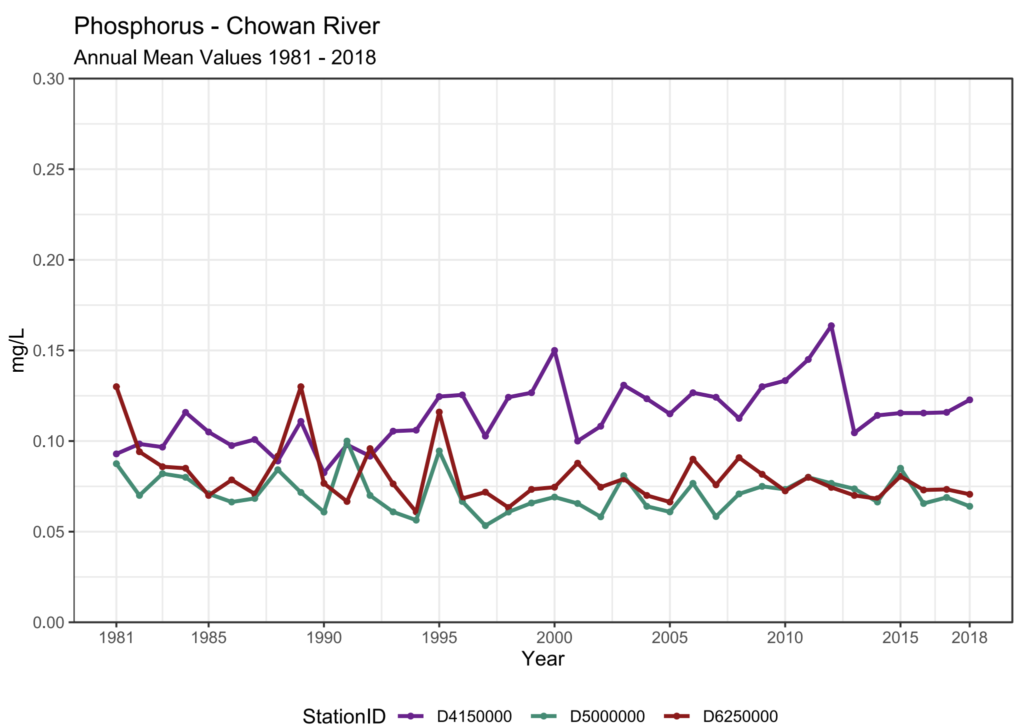
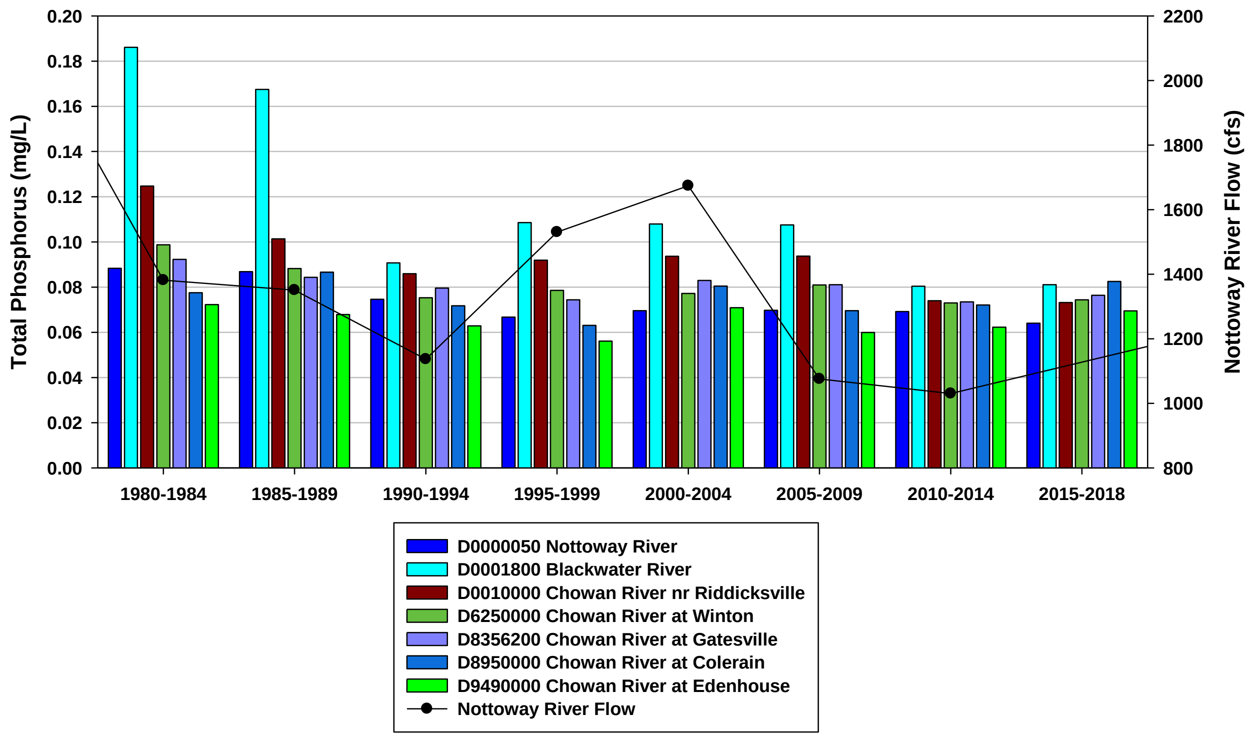


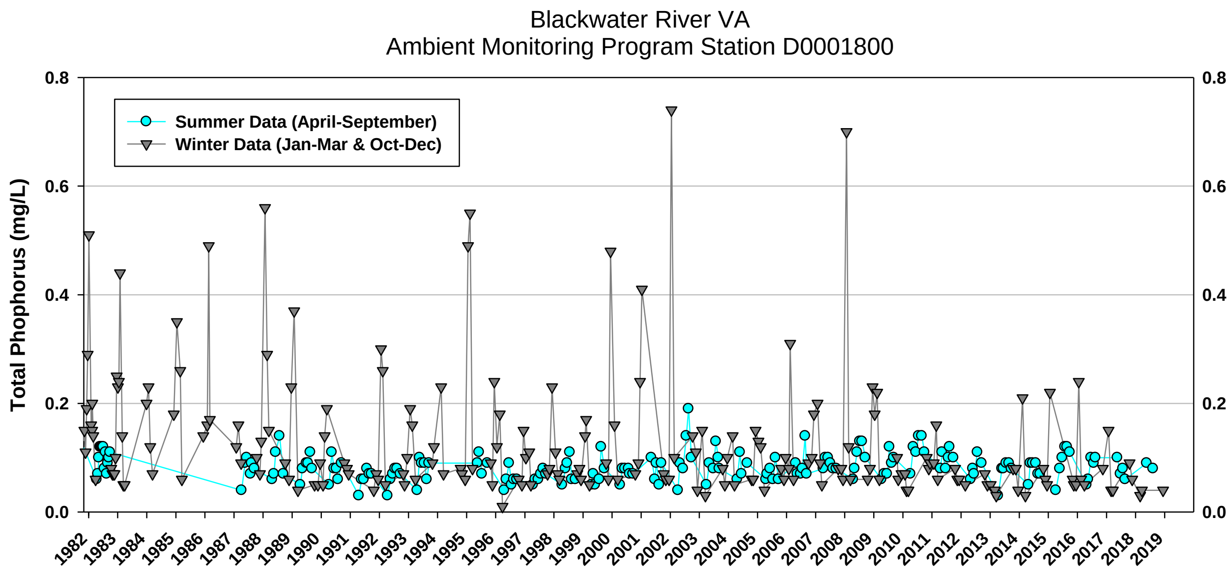
Figure 5-33 Five Year Weighted Mean TP Concentrations and Nottoway River Flow (1980-2018).



Blackwater River

It appears that the Blackwater River TP concentration often influenced the concentrations downstream in the Chowan River as spikes in annual mean TP concentration were conveyed downstream (Figure 5-32 (a) and (b)). These peaks correspond to winter spikes in TP and are likely associated with IP wastewater effluent discharge (Figure 5-34). IP has a monthly winter discharge TP limit of 2.0 mg/L (no daily limit included in the permit). These peaks also tended to occur during years with low flows (1981, 1986, 1988, 1995, 2002, 2008) (Figure 5-31, Figure 5-32 (b), and Figure 5-34). The Blackwater River TP declined initially and remained fairly stable since the early 1990's with the exception of the peaks discussed above. The large decline from the 1980's is once again likely due to the fact the annual mean concentrations for the mid-1980's did not include summer TP samples (Figure 5-34). Based on the seasonal data at D0001800, the summer TP concentrations are generally much lower (Figure 5-34). Winter TP concentrations have dropped over time as well which is likely the result of discharge permit limits in the Blackwater River watershed in VA. Virginia established a monthly average effluent limit of 2 mg/L in waters classified as nutrient enriched (2015 International Paper Franklin Mill, NPDES permit fact sheet – VA0004162). In 1997, VA officially classified a section of the Blackwater River and Nottoway River as nutrient enriched (The Virginia Register of Regulations, Nov. 10, 1997, Vol 14, No 4 - http://register.dls.virginia.gov/vol14/iss04/v14i04.pdf).

Figure 5-34 Monthly Ambient Monitoring TP Concentration Data for the Blackwater River VA Station D0001800. Data is Separated into DWR Sampling Season.



The Blackwater River watershed at D0001800 showed a significant decline (~50%) in the flow-normalized TP load between 1988 and 1993 (1989-1993) where it has fluctuated since (Figure 5-35 (b)). In 2016, the TP load decreased to about 58% from the 1981-1985 baseline load. It is apparent that some type of implementation effort was successful at reducing the overall phosphorus load in the Blackwater River watershed.

Nottoway River

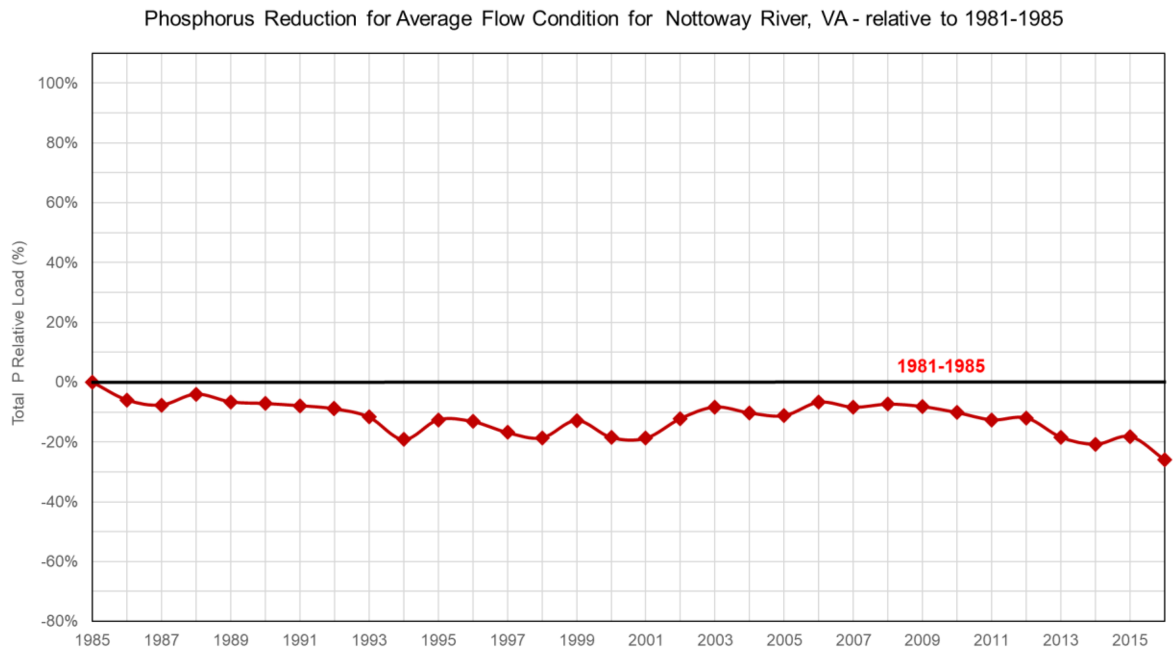
The estimated flow-normalized loads varied over time and over space in relation to the 1981-1985 baseline period. The Nottoway River watershed at D0000050 showed that the TP loading has declined and stayed fairly stable since 1986. As of 2016 (2012-2016), the total phosphorus load decreased about 27% (Figure 5-35(a)).

Potecasi Creek

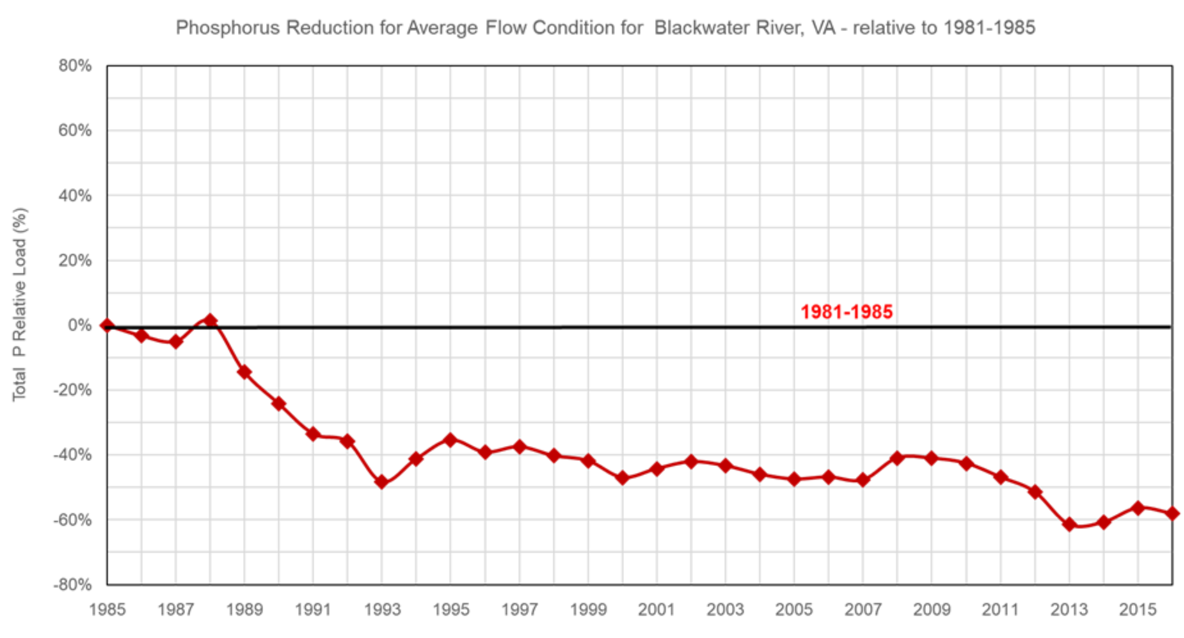
The Potecasi Creek watershed TP concentrations began to increase in the mid-1990's and has remained elevated relative to the Meherrin River (D5000000) and Chowan River at Winton (D6500000) (Figure 5-32 (d) and Figure 5-36). The TP increase in Potecasi Creek (D4150000) is reflected in the long-term flow-normalized trend's analysis. The TP loading in the Potecasi Creek watershed at D4150000, has been higher than the 1981-1985 basin line years with the exception of 1994 and 1995 at which point the increase in TP loading increased quickly to 50% over the base line period. The loading has remained elevated and has fluctuated overtime. In 2016, the load was estimated to be 26% percent higher than the base line period (Figure 5-35 (c)).

Figure 5-35 Flow-Normalized Total Phosphorus Load at (a) D0000050 Nottoway River, (b) D0001800 Blackwater River and (c) D4150000 Potecasi Creek Stations relative to the 1981-1985 Baseline Load.

(a) D0000050 Nottoway River



(b) D0001800 Blackwater River



(c) D4150000 Potecasi Creek Stations relative to the 1981-1985 Baseline Load

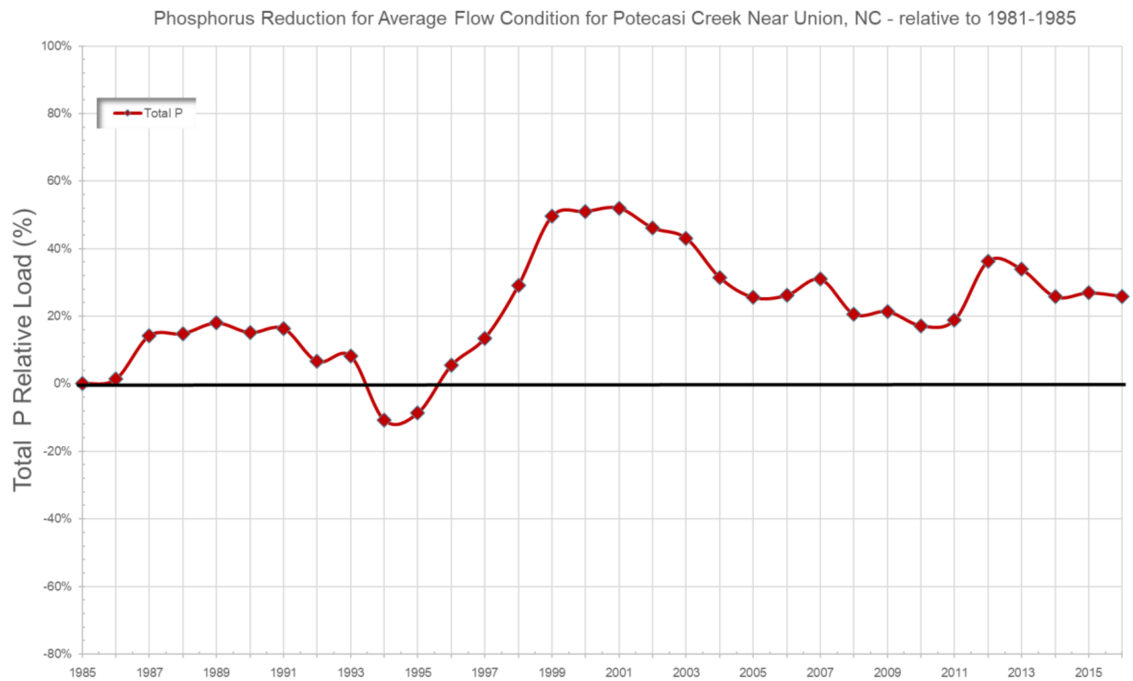
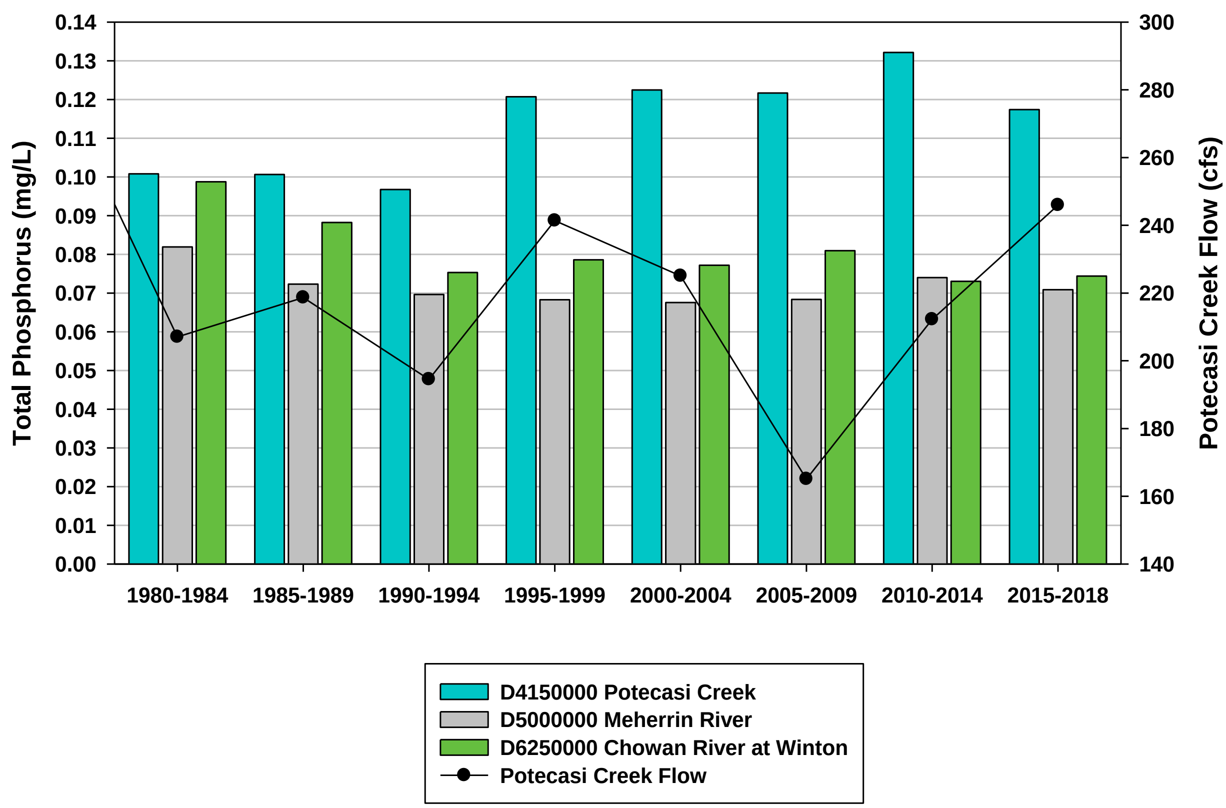


Figure 5-36 Five-Year Weighted Mean TP Concentrations and Flow at the Potecasi Creek (D4150000), Meherrin River (D5000000) and Chowan River at Winton (D6250000) AMS Stations. (Potecasi Creek Flow at USGS Gage 02053200; Co-located with AMS Station D4150000.)



Recommendations in relation to total phosphorus

The source of nutrients in the Potecasi Creek are from nonpoint sources. It is well known that phosphorus binds to soils and is often associated with runoff events resulting in elevated instream TP concentrations. There is a need for BMPs to reduce the loading of phosphorus into the whole Chowan River system.

In order to better understand what role TP plays in the increasing biological productivity occurring in the Chowan River, additional data may be needed. DWR mainly samples for TP but in order to understand how much of the TP signature is bioavailable there is a need to quantify the dissolved fraction (soluble reactive phosphorus (SRP)).

5.3 Chowan River Biological Productivity

5.3.1 Chlorophyll *a* and Algal Blooms

Chlorophyll *a* is an algal pigment that is used as a surrogate for measuring how biologically productive an aquatic ecosystem is at a specific point in time. Algae is the base of the food chain and is a required component of a healthy system. However, systems that become nutrient over enriched (eutrophic), can lead to over production of algae, resulting in high chlorophyll *a* concentrations (algal bloom). The state of North Carolina has an instream chlorophyll *a* standard of 40 µg/L. Over the last five years (2014-2018; 2020IR period) the three segments of the Chowan River with the highest, 75th percentile chlorophyll *a* concentrations and percent exceedances of the 40 µg/L standard are the three most downstream stations (Figure 5-37). These stations are located near Gatesville (D8356200), Colerain (D8950000) and Edenhouse (D9490000) on the mainstem of the Chowan River. These stations currently have the highest concentrations and the only violations of the chlorophyll *a* standard. These stations with relatively high chlorophyll *a* concentrations are addressed later in this section after reviewing the historical trends. Special attention is given to the Colerain Station (D895000), as this AMS station best captures the changes in the algal community and the bloom intensities as of 2018 and 2019.

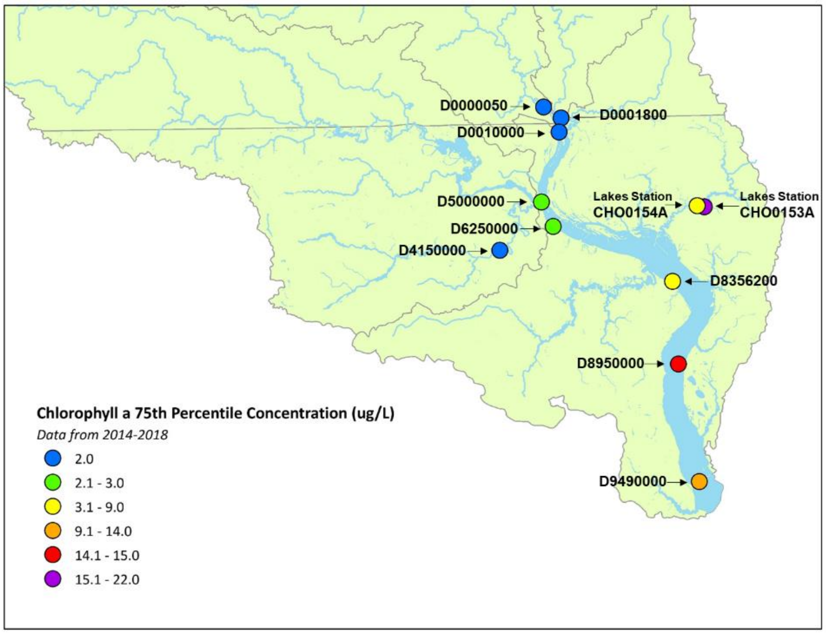
Historically, major nuisance algal blooms occurred in the lower Chowan River in 1972 and 1978. In 1979, as a result of these bloom and fish kill events, the EMC designated the Chowan River basin as Nutrient Sensitive Waters (NSW). A water quality management plan was established with the goal to reduce nutrients in order to insure that peak summer levels of chlorophyll *a* not exceed the 40 µg/L standard, a target range for average summer chlorophyll *a* of 25 to 30 µg/L was developed (1982, NC DNRCD).

The 1982 report indicated that the 1977 to 1980 average summer (June-September) chlorophyll *a* levels for the Chowan River near Colerain, ranged from 34 to 132 µg/L with peak summer chlorophyll *a* values ranging from 63 to 1300 µg/L. This section of the lower Chowan River generally had the worst surface blooms and maximum levels of chlorophyll *a* concentrations recorded at that time. The data provided here indicates that the actual range was 34 to 213 µg/L for 1977 to 1980 at the Colerain station (D8950000) (Figure 5-38).

As can be seen in Figure 5-38, the summer chlorophyll *a* concentrations declined and remained below the target of 25-30 µg/L from 1994-2012. It is important to note that the chlorophyll *a* data collected between September 1996 and March 2001 was removed due to analytical issues, therefore these years are not represented in the overall evaluation or the following figures. The summer mean chlorophyll *a* concentrations began to increase slowly over time from about 2006 and exceeded the summer target in 2013 at the Colerain station (D8950000) (Figure 5-38). The year 2015 has been identified by many in the basin as the turning point when algal blooms in the Chowan River system began to occur on a persistent basis with a recorded summer mean of 66 µg/L and 26 µg/L at the Edenhouse (D9490000) and Colerain (D8950000) stations, respectively. Higher summer means returned to the Colerain station in 2017 and 2018 with values of 93 and 87 µg/L, respectively.

Figure 5-37 Chowan River Basin AMS and Lake Stations 2020 IR Period (2014-2018) Chlorophyll a (a) 75th Percentile Concentrations and (b) Percent Exceedances of the Standard (40 µg/L).

(a) 75th Percentile Concentrations



(b) Percent Exceedances of the Standard (40 µg/L).

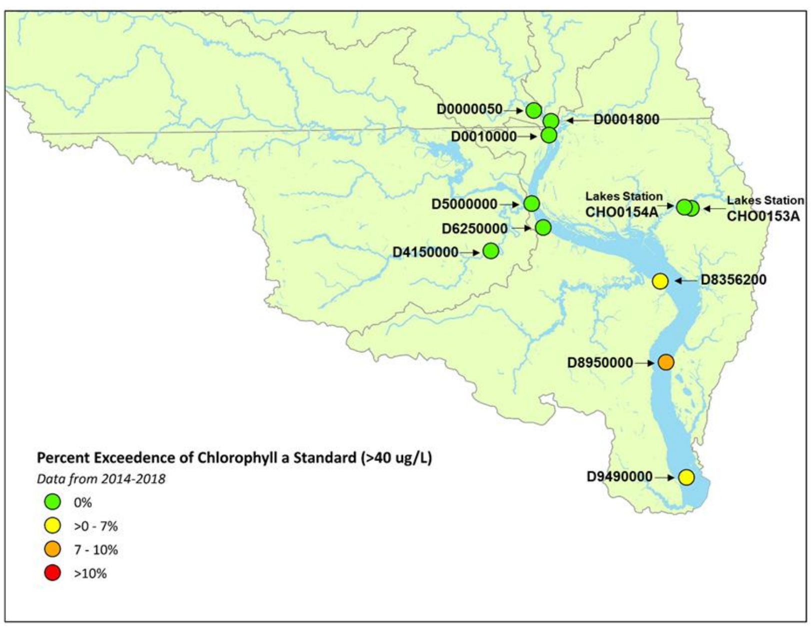
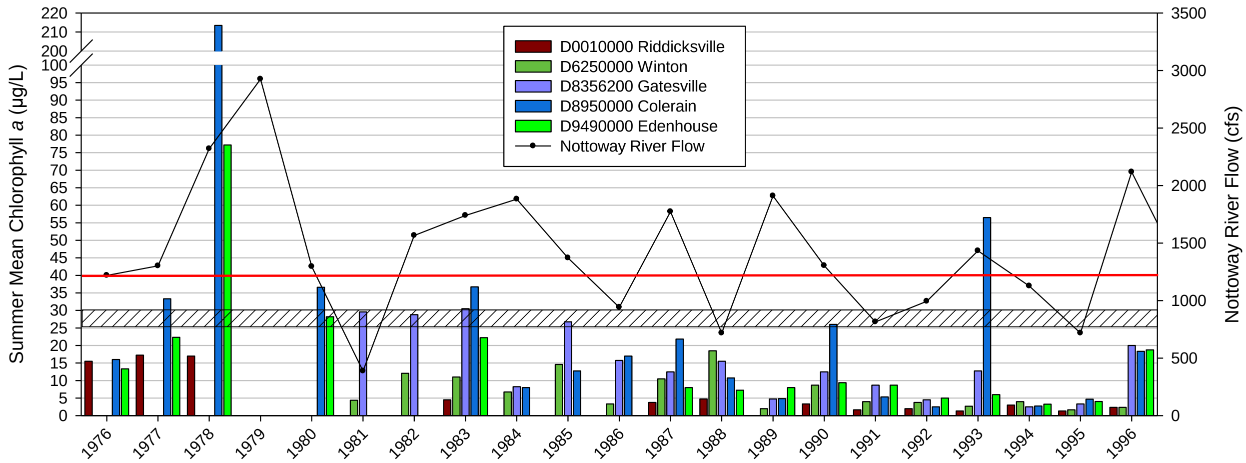
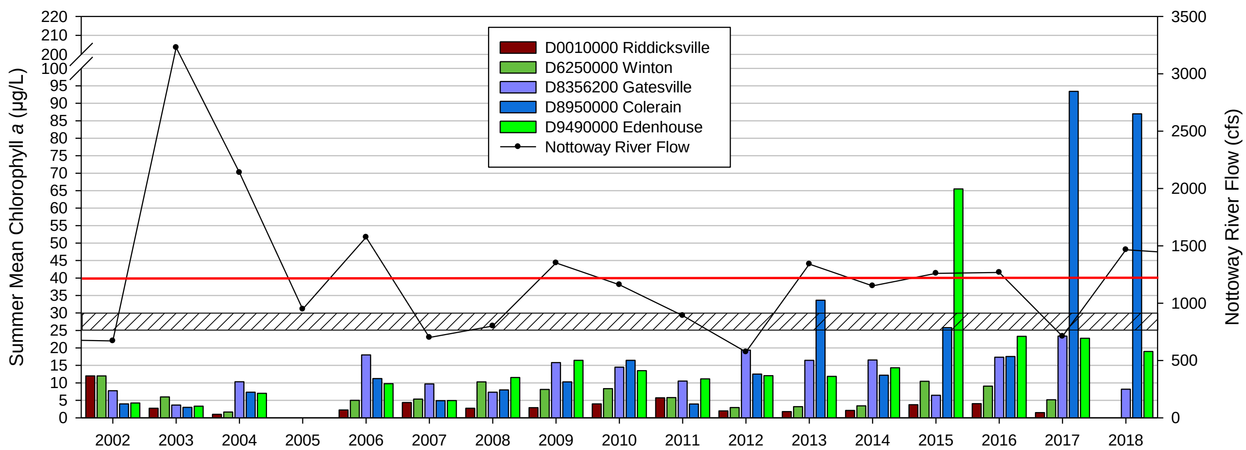


Figure 5-38 Chowan River Annual Weighted Mean Summer (June-September) Chlorophyll a Concentrations at the AMS Stations in the Basin (a) 1976-1996 and (b) 2002-2018. (Summer corresponds to the 1982 management plan goal of a target summer mean of no more than 25 to 30 µg/L Chlorophyll a (Hatched Zone); Red Line Indicates the 40 µg/L Chlorophyll a Standard; Note the Chlorophyll a Y-axis break needed to show the extreme 1978 concentration).

(a) 1976-1996



(b) 2002-2018

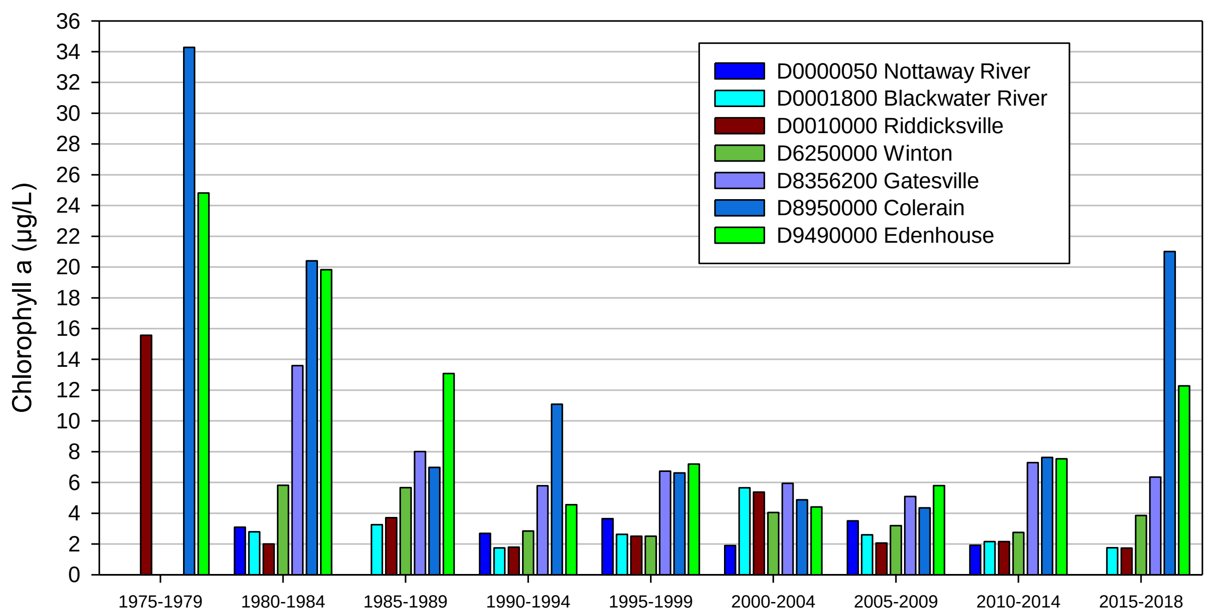


The five-year mean chlorophyll *a* concentration graph clearly shows the pattern of decreasing concentrations until the 2010-2014 time period and the shifting peak concentration between the lower three stations (D8356200 at Gatesville, D8950000 at Colerain and D9490000 at Edenhouse) (Figure 5-39). The two VA stations and the upper two NC Chowan River station had relatively low five-year mean chlorophyll *a* concentrations through the entire period (1981-2018) (Figure 5-39).

The location of algal blooms in a large river system like the Chowan are highly dependent on many environmental factors such as nitrogen and phosphorus (nutrients) availability, stream flow and climate impacts like temperature, light intensity, precipitation, wind driven tides and storm events. The location of blooms shifts constantly with these changing conditions.

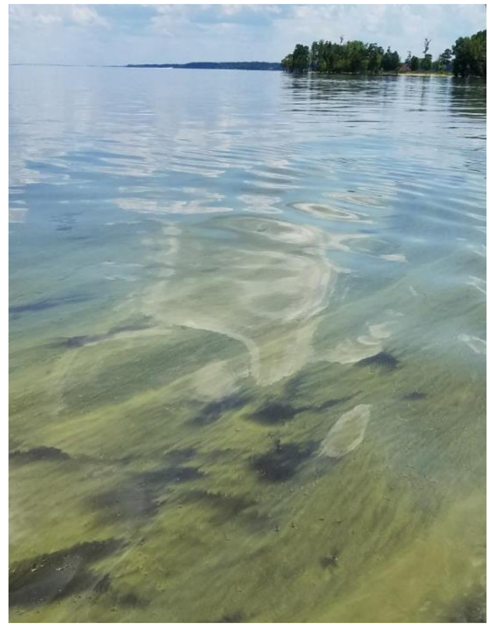
Dr. Nathan Hall has estimated that instream water temperatures in the mainstem Chowan River have increased since 1980 based on a Seasonal Kendall test. This statistical test is used to determine if there is a trend in temperatures between 1980 and 2019. This trend is based on surface water (depth less than 0.1 m) temperatures recorded in the Chowan River near Winton (D6250000), Colerain (D8950000) and at Edenhouse (D9490000) (Figure 5-3). The results indicated a significant increasing temperature of 1.69°C (3.04°F) at station D6250000 (p=0.0064), 1.77°C (3.19°F) at station D8950000 (p=0.0009) and 1.87°C (3.37°F) at D9490000 (p=0.0002) (Nathan Hall, personal communication, December 4, 2020; based on an empirical model involving a 24-hour cycle using a standard regression analysis (least squares error minimization) to find the best fit mathematical curve (sine wave). The corrected temperature (temperature at 12:00 pm) is calculated for comparison purposes). The influence of the increasing temperature is not well understood at this time. Additional analysis is needed to understand how temperatures have changed throughout the entire watershed and the implication these changes have on the ecosystem. The Chesapeake Bay has also experienced warming water temperatures over time resulting from the influence of urbanization and industrialization, as well as the impact of global change in the form of increasing water temperature (Ding and Elmore, 2015).

Figure 5-39 Chowan River Five Year Weighted Mean Chlorophyll a Concentrations at Two VA and Five NC Mainstem Chowan River Stations. (No Chlorophyll a Data Available Between September 1996 - March 2001.)



5.3.2 Chowan River near Colerain (D8950000)

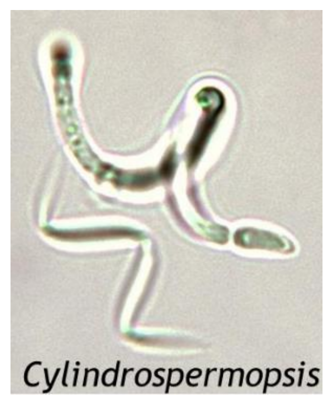
As part of the routine ambient monitoring program, phytoplankton samples have been collected and algal species quantified along with chlorophyll *a* concentrations at the station D8950000. Station D8950000 is located in the center channel of the Chowan River near Colerain. This is a section of the Chowan River system that has experienced severe algal blooms in the last few years and the best station to reflect the ongoing changes in the basin (Figure 5-38). While the algal blooms tend to accumulate closer to the banks and coves of the river, they are often distributed across the river and move around due to changes in stream flow velocity and direction, wind, sunlight intensity and precipitation events. While the algal blooms tend to concentrate in the shallower portions of the river, an evaluation at AMS station D8950000 allowed us to understand changes overtime in algal species present along with the chlorophyll *a* concentration, as this station is sampled on a routine basis and as part of an episodic event if appropriate.



(Photo: Chowan River near Colerain, July 13, 2020; Steve Chesson)

The integrated reporting period chlorophyll *a* mean has increased from 7.6 to 18.6 µg/L between the 2016 and the 2020 draft report respectively and the percent exceedance of standard also increased from 2 to 8.9 % (Table 5-7). The range in the annual mean chlorophyll *a* concentrations between 2010-2018 for the Chowan River basin was 1.22-35.19 µg/L (Table 5-5) with a maximum chlorophyll *a* concentration of 320 µg/L at the Colerain station (D8950000) in 2017.

Chlorophyll *a* concentrations increase in the summer months which is normal, but in late summer 2010 the chlorophyll *a* concentration reached 36 µg/L (approximately 97% of this algal bloom was identified as a bluegreen alga/cyanobacteria, *Dolichospermum (formerly Anabaena) planctonica*) (Figure 5-40 and Figure 5-41). This appears to be the starting point for higher summer chlorophyll *a* concentrations and associated algal blooms with high cell counts of bloom forming bluegreen algal (cyanobacteria) taxa that can produce toxins also known as pHABs (Figure 5-41). These pHAB taxa include *Dolichospermum*, *Aphanizomenon*, *Microcystis*, *Cylindrospermopsis*.



The blooms formed since 2010 have generally shifted to these pHAB category of blooms with potential human health concerns. As the chlorophyll *a* concentrations have risen over the last several years, the algal cell counts of these pHABs have also increased. Although these two metrics have increased concurrently, chlorophyll *a* does not always reflect the intensity of the bloom. This can be the result of sampling method differences, type of species present, if a bloom is dying off or being dispersed. Since 2000 at the Colerain station (D8950000), 61% of the blooms greater than 20,000

cells/mL and 86% of the extreme blooms (> 100,000 cells/mL) occurred in the last 10 years (2010-2019) with the majority of the taxa being pHABs (Figure 5-41).

Table 5-7 Chowan River Chlorophyll a Integrated Report Summaries for IR 2016, 2018, Draft 2020 and Partial 2022 (Missing Year 2020).

Integrated Report Period	2016 IR	2018 IR	Draft 2020 IR	2022* IR Partial Set Only
Mean Chl a Conc. (µg/L)	7.6	9.2	18.6	24.9
Number of Samples	50	45	45	33
Number > 40 µg/L Chl a	1	2	4	5
% > 40 µg/L	2	4.4	8.9	15.2
IR Date Window	2010-2014	2012-2016	2014-2018	2016-2020
*The data as of June 2020 for the partial 2022 IR is for 2016-2019. It is missing data for 2020. Final 2022 IR values will be different than what is presented here.				

Figure 5-40 Chowan River Chlorophyll a Concentration at Colerain (D8950000) Between 2001-2019.

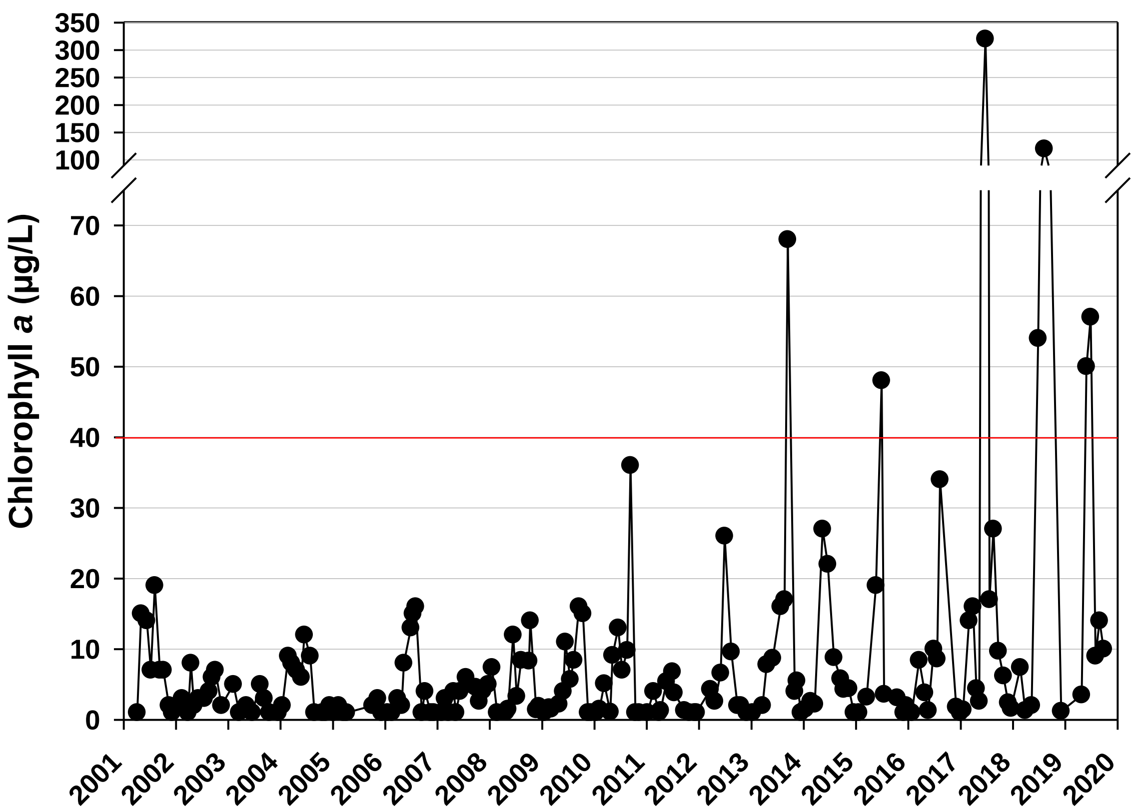
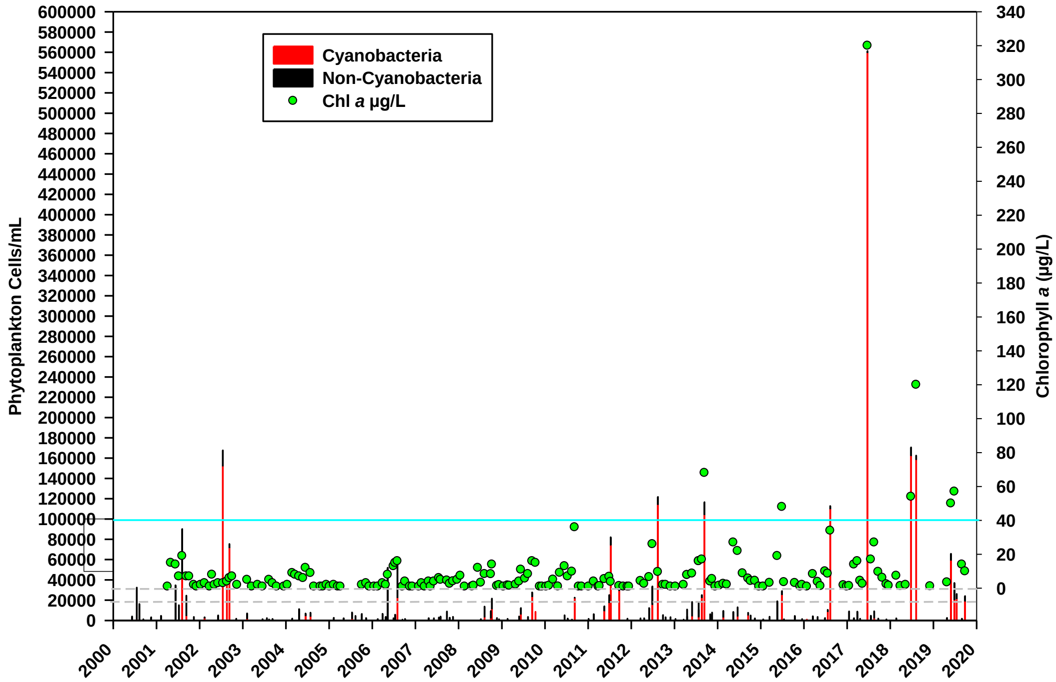
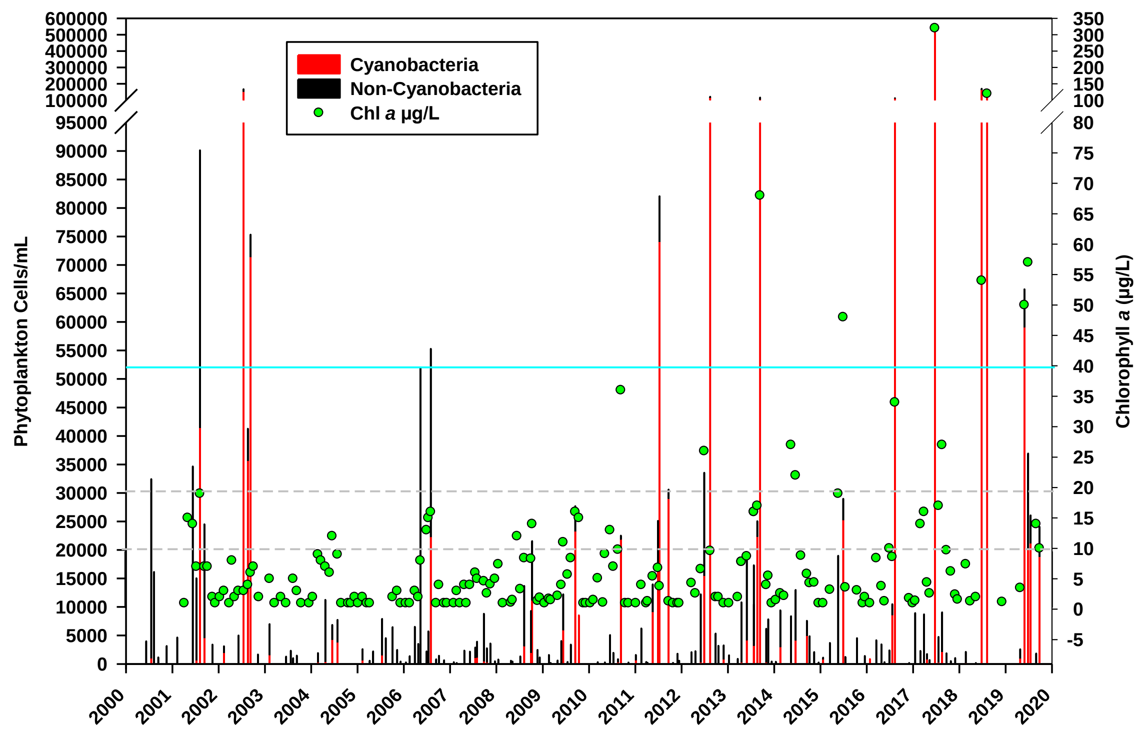


Figure 5-41 Chowan River at Colerain (D8950000) Chlorophyll a Concentration and Phytoplankton Counts (Cyanobacteria and Non-Cyanobacteria Cell Densities). (a) 2000-2019 (No Axis Break), (b) 2000-2019 with Y-Axis Breaks, (c) 2010-2019 with Y-Axis Breaks.

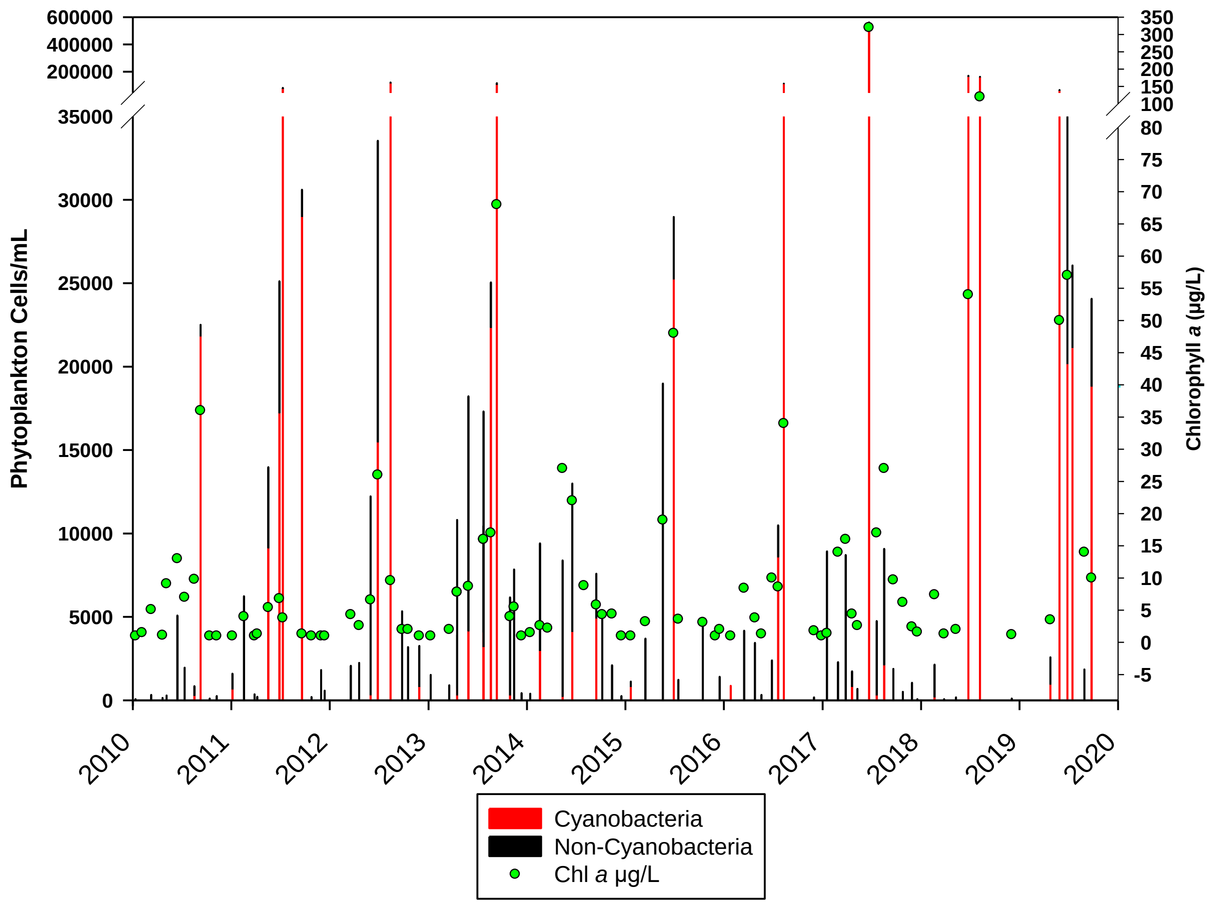
(a) 2000-2019 (No Axis Break)



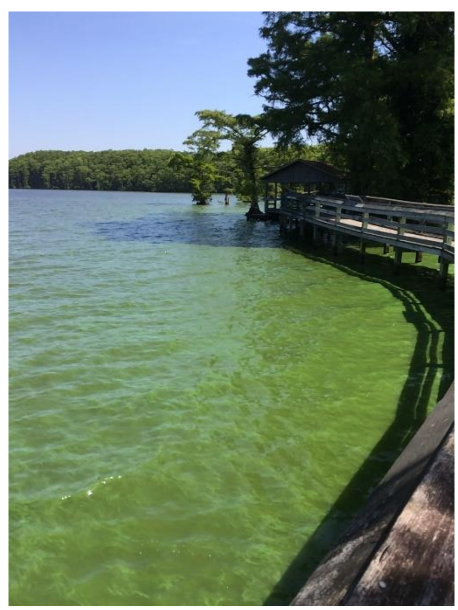
(b) 2000-2019 with Y-Axis Breaks



(c) 2010-2019 with Y-Axis Breaks



5.3.3 Chowan River Episodic Algal Blooms



(Photo: Chowan River at Cannon's Ferry, June 29, 2020; CEEG).

There were three reported algal blooms in 2013 and 2015 (Figure 5-2 (1985-2019 Episodic Algal Bloom Reports)). The reported blooms increased to 13 in 2019, 11 of which were identified as bluegreen/cyanobacteria blooms and several where reported to have *microcystin* toxin associated with them (Table 5-8 (a subset of the full bloom table found Appendix V-II). These episodic blooms were reported at numerous locations throughout the lower half of the watershed from Harrellsville to Edenton and the Albemarle Sound.

DWR's Ecosystem Branch developed an algal toxin program in 2018 and began monitoring algal blooms for *microcystin* toxin in the Chowan River in late 2018 (Table 5-8). The division is still developing the capacity to analyze algal blooms around the state and hoping to expand the program to include other algal toxins as resources allow. There were several blooms with toxin above the WHO moderate risk level (Cyanobacteria (cells/mL) 20,000-100,000; Microcystin-LR (µg/L) 10-20; Chlorophyll a (µg/L) 10-50;

See Appendix V-II (Table V-II.3) for WHO Risk Table). On July 17, 2019, an algal bloom in Shawnee Trail Canal near Arrowhead Beach had a Microcystis bloom with a 310 µg/L *microcystin* toxin concentration and an associated 984 µg/L chlorophyll *a* concentration. The bluegreen cell count and biovolume was 852,000 cells/mL and 31,000 mm^3/m^3 respectively. The highest *microcystin* concentration was recorded on August 13, 2019 with 620 µg/L toxin concentration and a cell count and biovolume of 18,570,000 cells/mL and 557,000 mm^3/m^3, respectively (Table 5-8). DEQ and DHHS issued a press release regarding these algal bloom events, as well as several others since 2015. The press release urged the public to avoid contact with the blooms in order to eliminate the risks associated with exposure to *microcystin* toxin (Link to DHHS August 16, 2019 Health Advisory based on the August 13, 2019 algal bloom results; see Appendix V-II for links to other published health advisories and health related information).

Table 5-8 2018 and 2019 Bloom Events with Associated Microcystin Toxin Concentrations, Chlorophyll a Concentrations, and Dominate Algal Group Identification and Quantification (This is a subset of the available data, full 2015-2019 DWR Chowan River Basin Algal Bloom Assessment Table V-II.1 in Appendix V-II).

Location	Date	Micro cystin µg/L	Chl a µg/L	Cell Density+ cells/mL	Cell Density+ units/mL	Biovolume mm^3/m^3	Algal Group/ Dominant Taxa	County
Chowan River near Leary Landing	6/27/18	0.44	5,400^	T-7,334,000 C-7,334,000	T-259,000 C-259,000	T-474,000 C-474,000	CYA Dolichospermum, Aphanizomenon	Bertie
Chowan River near Colerain D8950000	8/7/18	1.40	120	T-162,000 C-158,000	T-5,800 C-2,100	T-8,400 C-6,700	CYA Dolichospermum, Microcystis	Chowan
Chowan River Edenhouse/Wharf Landing	8/7/18	14.0*	ND	T-918,000 C-913,000	T-25,000 C-20,000	T-61,000 C-60,000	CYA/ Dolichospermum, Microcystis	Chowan
Chowan River Edenhouse/Wharf Landing	8/27/18	6.4	120	T-118,000 C-114,000	T-4,700 C-2,300	T-4,500 C-3,600	CYA Pseudanabaena, Dolichospermum	Chowan
Chowan River nr Arrowhead Beach Shawnee Trail Canal	7/17/19	310*	984	T-853,000 C-852,000	T-7,900 C-7,200	T-32,000 C-31,000	CYA/ Microcystis	Chowan
Chowan River nr Arrowhead Beach Shawnee Trail Canal	7/23/19	21*	72	T-338,000 C-332,000	T-5,600 C-2,700	T-12,000 C-9,800	CYA/ Microcystis	Chowan
Chowan River Leary Landing	7/29/19	190*	630	T-9,097,000 C-9,093,000	T-9,600 C-6,797	T-280,000 C-273,000	CYA/ Microcystis	Bertie
Chowan River / Indian Cr. (Dillard Cr)	8/13/19	620*	ND	T- 18,570,000 C-18,596,000	T-13,4000 C-13,300	T-557,000 C-557,000	CYA/ Microcystis	Chowan
Chowan River/ Indian Cr (Dillard Cr)	8/19/19	9.3	32	T-235,000 C-231,000	T-2,600 C-400	T-7,900 C-6,900	CYA/ Microcystis	Chowan

*** WHO (World Health Organization): Exceeds guideline of 10 ug/L indicating moderate probability of acute health effects from recreational exposure;**
+ T=Total Algae & C=Cyanobacteria/Bluegreen Algae;
^ Verified Chl a concentration with DWR laboratory (April Williams, personal communication, May 18, 2020);
ND = Data sheet was found, but no analytical data was found;
CYA = Cyanobacteria Algal Group (Cyanobacteria is also known as bluegreen algae).

5.3.4 Chowan River Submerged Aquatic Vegetation

Submerged aquatic vegetation (SAV) are rooted aquatic vascular plants that grow in estuarine and marine environments forming vast habitat beds underwater. In North Carolina (NC), SAV occurs coastwide, including the sounds and rivers of the Albemarle-Pamlico Estuarine System, but not beyond the extent of the outer banks (Figure 5-42 and Figure 5-43; DEQ, 2021; Ferguson and Wood, 1994). There are two distinct groups of SAV habitats in NC that are distributed according to the estuarine salinity. One group thrives in fresh and low salinity riverine waters (<10 ppt), referred to as low salinity SAV, and includes species such as Redhead grass (*Potamogeton perfoliatus*), Wild celery (*Vallisneria Americana*), and Sago pondweed (*Stuckenia pectinate*), etc. The second group occurs in moderate to high (>10 ppt) salinity estuarine waters of the bays, sounds, and tidal creeks, referred to as high salinity SAV or seagrasses, and includes three species, temperate eelgrass (*Zostera marina*), tropical shoal grass (*Halodule wrightii*), and cosmopolitan widgeon grass (*Ruppia maritima*). These SAV beds provide critical habitat for nursery and feeding for fish, shellfish, and wading birds (Ferguson and Wood, 1994; DEQ, 2021).

There have been many efforts over the last 40 years to map the distribution of SAV along the NC coast and it is estimated that the known historic extent (1981-2015) covered approximately 191,155 acres, of which 12,872 acres are in the Albemarle/Chowan system (Figure 5-42 and Figure 5-43; DEQ, 2021). Low salinity SAV have historically been found in the shallow portions of the lower Chowan River up to about Colerain and along the shorelines of the Albemarle Sound (Figure 5-43; DEQ, 2021). “The primary factors controlling SAV distribution are water depth, sediment composition, wave energy, and the penetration of light through the water column” (DEQ, 2021); Goldsborough and Kemp, 1988).

SAV is a sensitive bioindicator of environmental health and can become stressed due to eutrophication and other environmental conditions which reduces water clarity such as algal blooms and sedimentation (DEQ, 2021). The current extent of SAV in the Chowan River basin is unknown, but a significant decline in native grass species has been documented in the Albemarle Sound through recent hydroacoustic surveys. This is likely due to the decline in the water quality resulting in a reduction in the water clarity.

SAV in NC also includes an invasive non-native species known as Hydrilla (*Hydrilla verticillata)*. This invasive aquatic plant species was identified in the Chowan and Albemarle Sound regions through local efforts by the Chowan Edenton Environmental Group, Chowan Soil and Water Conservation District, and NC Sea Grant (Riddle, 2015). Their work aimed to survey and reduce the presence of Hydrilla appears to have been successful (CEEG, personal communication 2020). The effort to eliminate Hydrilla succeeded through the formation of the Hydrilla Citizen Science Project. More information about this effort can be found in Chapter 6.

The Coastal Habitat Protection Plan (CHPP) is a requirement of the 1997 NC Fisheries Reform Act (G.S. 143B-279.8). The legislative goal of the CHPP is long-term enhancement of coastal fisheries by addressing habitat and water quality needs of fishery species. The CHPP aims to identify threats and recommend management actions to protect and restore habitats critical to NC’s coastal fishery resources. The CHPP is currently being updated and will likely be adopted in 2021. The 2021 version is focusing on five priority issues, one being “submerged aquatic vegetation protection and restoration with focus on water quality improvements" (October 30, 2020 NCDP presentation). An SAV specific focused paper is being produced and includes recommended actions to be considered by three commissions (EMC, CRC, MFC). Many of these direct the EMC to develop several criteria and water quality standards through the Nutrient Criteria Development Plan (NCDP) process, with the specific goal of protecting and restoring SAV. More information on the 2021 Amendment and earlier versions of the CHPP can be found [here](#) (Figure 5-42).

Figure 5-42 Known historic extent of SAV in North Carolina, mapped from 1981 to 2015. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not reflect current state, as data dates to 1981 (DEQ, 2021).

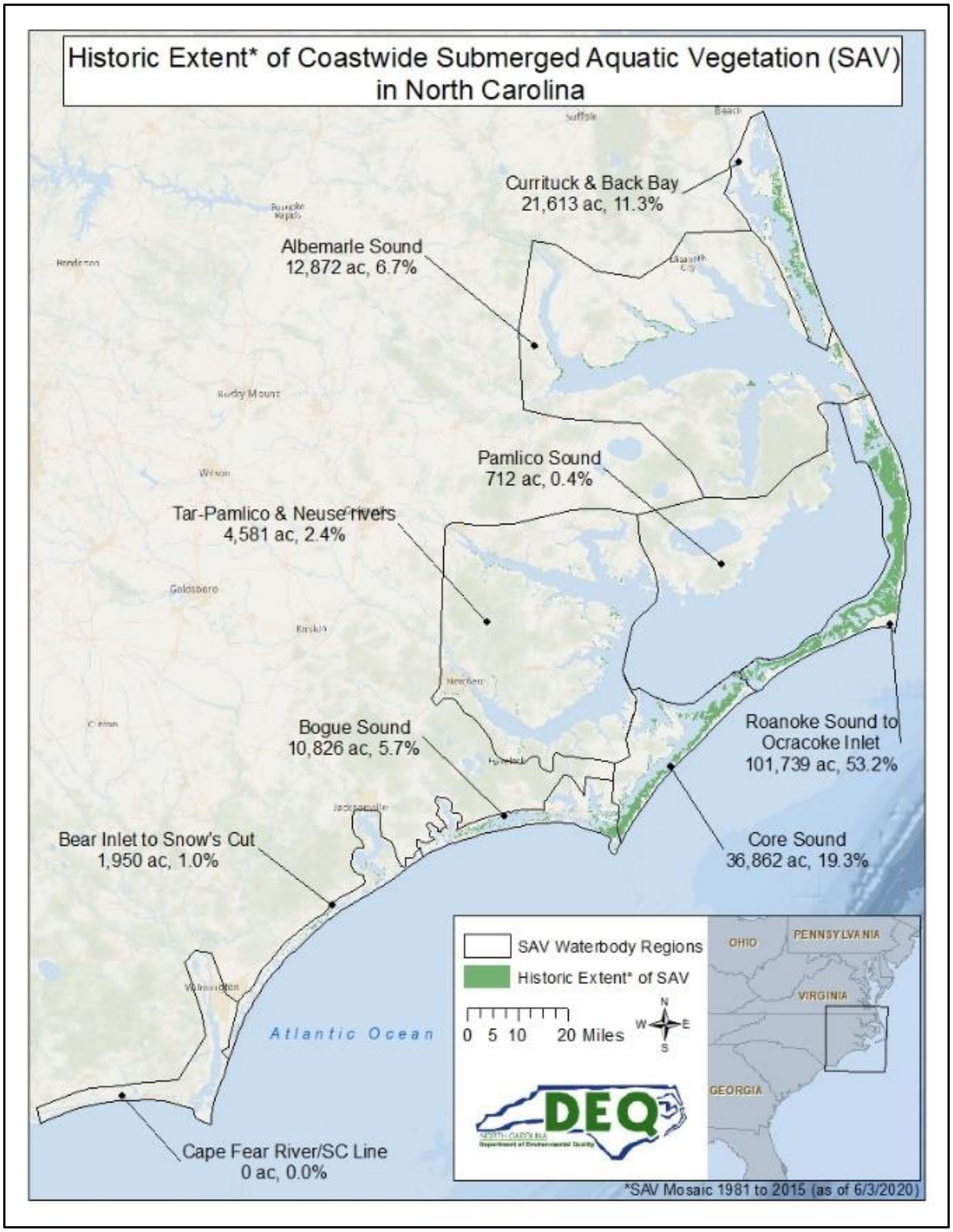
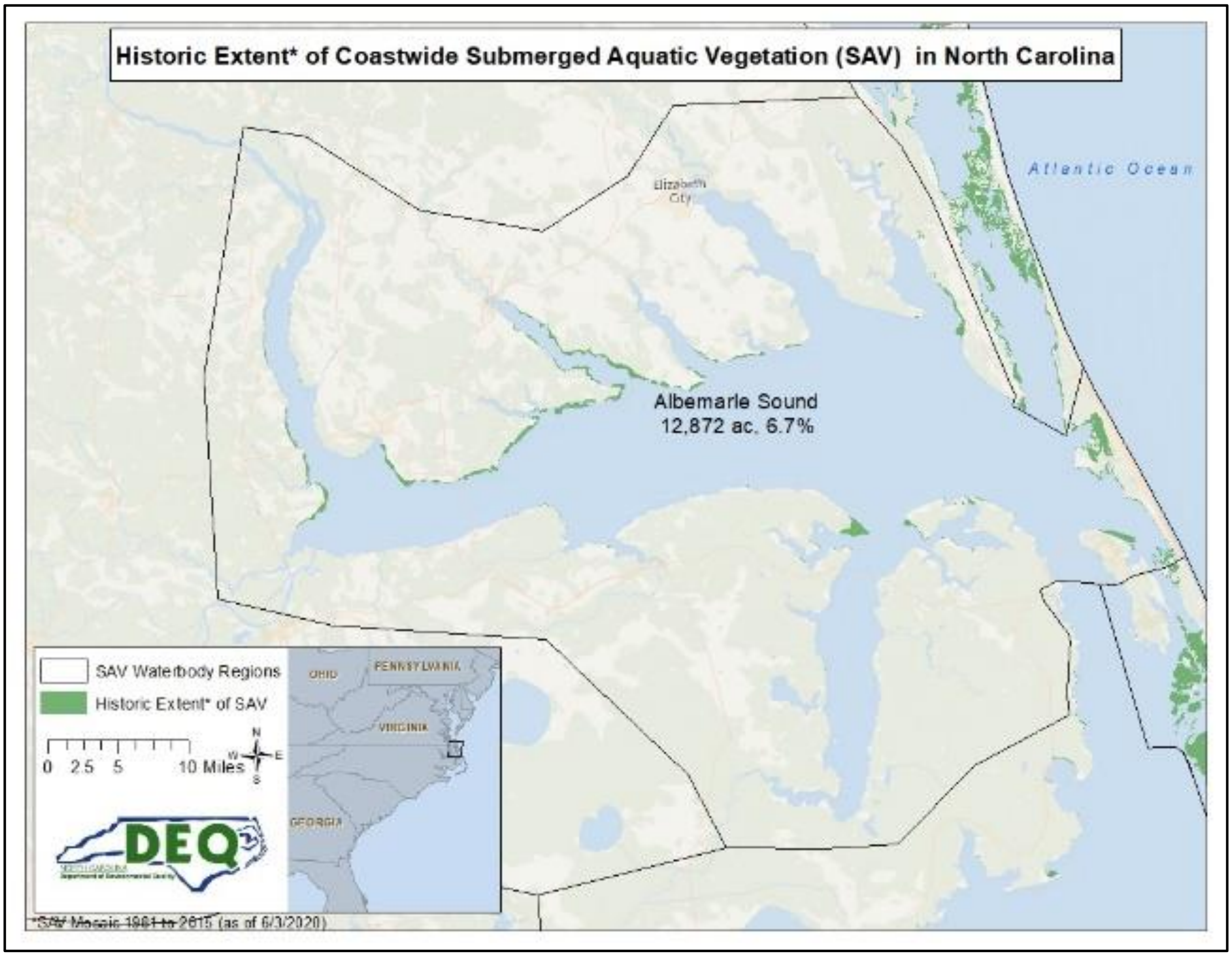


Figure 5-43 Known historic extent of SAV in NC, mapped from 1981 to 2015 in Albemarle Sound. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not reflect current state, as data dates to 1981 (DEQ, 2021).



5.4 Current and Proposed Actions and Recommendations

5.4.1 Nutrient Criteria Development Plan

In 2001, the US EPA strongly encouraged every state to develop nutrient criteria if states did not currently have site specific criteria in place to protect waterbodies from nutrient over enrichment (eutrophication) issues. In 2014, NC developed a Nutrient Criteria Development Plan (NCDP) which laid out the approach NC would take to achieve this requirement. The goal is to develop scientifically defensible criteria based primarily on the linkage between nutrient concentrations and protection of designated uses. The EPA-approved North Carolina NCDP identified three specific waterbody types and prioritized the development of criteria in three pilot watersheds. These watersheds where identified as possibly experiencing impacts from excess nutrients and where chosen in order to facilitate appropriate management actions by the division based on any new criteria developed. The specific waterbody type and pilot watersheds were:

1.) Reservoir and Lakes – High Rock Lake in the Yadkin-Pee Dee River basin;
2.) Rivers and Streams – Central portion of the Cape Fear River in the Cape Fear River basin;
3.) Estuaries - Albemarle Sound in the Pasquotank River basin.

The NCDP was approved by the EPA in 2014 which was followed by the development of a 12-member Science Advisory Council (SAC). The SAC is composed of experts in the areas specifically related to water quality, nutrient response variables, nutrient management, and point and non-point nutrient abatement and is meant to help provide scientific guidance to the division for the development of appropriate nutrient related criteria. The first NCDP meeting was held on May 6, 2015 with the focus on developing criteria for High Rock Lake.

During this same time period, the Albemarle-Pamlico National Estuary Partnership (APNEP), guided by their Comprehensive Conservation Management Plan (CCMP) to maintain ecological integrity in the estuary by ensuring that "nutrients and pathogens do not harm species that depend on the water", evaluated nutrient-related criteria and determine additional data and research needs in order to fulfill the mandate. The Albemarle Sound Nutrient Criteria Development Workgroup consisted of subject-matter experts/scientist, resource agency staff, environmental groups, municipal and concerned citizens, which met nine times between August 2014 and September 2016. The group successfully secured resources for several targeted initiatives, identified additional research needs and developed list of criteria proposals for parameters including pH, DO, chlorophyll *a*, nitrogen and phosphorus. While the group did not come to consensus on criteria recommendations, priority research efforts were identified. (Proceedings of the Albemarle Sound Nutrient Criteria Development Workgroup: Phase I, February 8, 2018 document https://files.nc.gov/apnep/documents/files/past-committees/Albemarle-Sound-Report_combined.pdf)

In 2019, as result of the ongoing algal blooms in the Chowan River, DWR modified the NCDP to pair the Albemarle Sound and Chowan River waterbodies for development of numeric nutrient criteria. This will allow for a more holistic nutrient criteria development strategy for the watershed since the Chowan River directly influence the condition of the Albemarle Sound. EPA approved the modification in May 2019 and the Albemarle/Chowan SAC NCDP kick off meeting was held on October 30, 2019.

To develop an appropriate numeric nutrient criterion for any waterbody, many steps must occur prior to this determination. These initial steps minimally include, identification of designated uses to protect, which response variable (i.e. chlorophyll a, pH, DO, water clarity, phytoplankton) is affected by nitrogen or phosphorus concentrations or loading, and which is the most sensitive species or use for a specific parameter under consideration.

The DWR has worked with the SAC to identify the designated use in need of protection, developed a list of the most sensitive organism to consider throughout this process and currently is in the process of determining the appropriate response variables to assess in the Chowan River and Albemarle Sound. Depending on needs for additional research and continued availability of staff resources, the goal is to complete adoption of nutrient criteria for the Chowan River/Albemarle Sound by January 2024. For more information see the NCDP webpage https://deq.nc.gov/about/divisions/water-resources/water-resources-data/water-sciences-home-page/nutrient-criteria-development-plan.

5.4.2 Proposed Actions and Recommendations

DWR proposes the following actions and recommendations to address nutrients in the Chowan River basin.

- Reevaluate appropriate nutrient-related criteria and assessment protocols in the Chowan River basin and Albemarle Sound.

  - DWR will continue to work with the Nutrient Criteria Development Plan (NCDP) Scientific Advisory Council (SAC) to develop appropriate protective criteria (which could be response and/or causal variables) for the Chowan River and Albemarle Sound. This may include modifications to current criteria such as chlorophyll *a* and/or the development of an instream nitrogen and/or phosphorus criterion, which could result in the need for additional nutrient reductions to meet a new criterion. There is some debate as to whether the 40 µg/L level for chlorophyll *a* is an appropriate criteria level to protect the designated uses of the Chowan River, including aquatic life and recreational uses. For more information on this process see the Nutrient Criteria Development Plan (NCDP) webpage.

- Reevaluate monitoring needs throughout the basin for water quality assessment purposes and algal bloom response.
  - The Chowan River is not listed as impaired for nutrient-related parameters despite clear indications that use of the water has been affected. There is a need to better characterize the instream water quality conditions. The current monitoring schema does not appear to appropriately capture the magnitude, frequency, or the geographic extent of the ongoing water quality problems in the region. A review of the Chowan River basin AMS program is needed to insure the program is capturing the algal blooms, algal toxin production, nutrients and physical characteristics needed to understand current water quality conditions and algal bloom development (e.g., dissolved fractions of N and P, algal limiting constituents, sediment recycling, nutrient source identification, river flow, sample locations, algal bloom response time, etc.).
  - Develop/expand local capacity to monitor for algal blooms and algal toxins. Chowan and Pasquotank River systems are far from the DWR regional and central offices. Blooms shift quickly and swift response is needed in order to capture a bloom in progress. A local entity in the region would be better positioned to monitor the situation (County health department, special monitoring group, citizen scientist organizations, others).
  - Expand local education and outreach on algal blooms and improve local stakeholder digital bloom reporting.
  - Support research and use of new monitoring techniques and technology to improve understanding of algal blooms in the hard to reach sections of the Chowan and Albemarle Sound region (e.g. remote sensing/satellite imagery, drones, etc.).
  - Expand/initiate groundwater quality monitoring in the Chowan River basin to understand the contribution nutrients from baseflow and nonpoint nutrient sources.

- Riparian Buffers:
  - Consider financial incentives (i.e., grants or tax credits) to promote strategic preservation or restoration of riparian areas.
  - Consider implementation of nonpoint source management strategies (e.g. buffer rules) analogous to those in other nutrient-impaired watersheds.

- Use existing state and federal cost share programs to identify ways to maximize voluntary implementation of buffers, filter strips, or other effective nutrient reducing BMPs on agricultural lands.

- Best Management Practices (BMPs): Agriculture, Forestry and Urban
    - Identify existing nutrient reducing BMPs and evaluate potential opportunities to continue promoting and implementing those BMPs in the watershed. Enroll the support of academic researchers to identify new, effective nutrient reducing BMPs for the region based on soil type, current and future crop rotations and specialty crops, organic and inorganic fertilizer management, etc.
    - Review and reevaluate existing policies that may limit a BMP's use in the basin (i.e., maximum amount of cost share funds available per cooperator or limit on the number of acres or contracts per cooperator).
    - Encourage the use of nutrient management plans to ensure appropriate and efficient use of fertilizers.
    - Encourage the use of green infrastructure and sustainable development, forestry, and agricultural practices to reduce and eliminate nutrient runoff.
    - Information is needed about the location of nutrient producing animal operations and land application sites to assist DWR in assess potential nutrient impacts to aquatic ecosystems and water quality.
    - Provide financial support to state and local agencies, as well as individual cooperators/landowners, to conduct these nutrient reducing activities:
        - Identify and expand educational opportunities to work with private landowners on nutrient management and the benefits of implementing BMPs, maintaining riparian buffers and conducting soil tests.
        - Identify new funding to hire personnel at the local (SWCD) and state (DSWC) level to promote BMPs in the region and work with landowners on new and innovative practices that can reduce nutrients, manage water levels in the field, and explore the benefits of forested buffers and wetlands to reduce nutrients and mitigate flood damage.
        - Identify additional funding to add to existing cost share programs to address nutrient management in the region.
        - Working with APNEP, identify ways to collaborate and engage with the agricultural communities in VA.
        - Identify how best to capture water quality data and BMP benefits to model nutrient loads throughout the entire basin (VA and NC). Establish a baseline and characterize agricultural land use in the region.

- Interstate Cooperation:
    - There are concerted efforts underway to improve the communications between our two state water quality agencies. DWR is attempting to work with VA to better understand changes that have occurred at the IP plant as well as other steps that the state has taken to control nutrients and improve water quality flowing into NC. When this information becomes available, we will provide an update to the basin plan.
    - Coordinate with Virginia to ensure proportionate nutrient-reduction measures are in place.
    - Identify how to improve, manage, and share water quality data across the basin and how best to capture BMP benefits (agriculture, stormwater, etc.). Information could be used to model nutrient loads through the entire basin.
- Administration, Communication, and Public Relations:
    - Establish a Chowan Strategy web page on NPS website with key historical documents, summary of historical issues, and summary of current conditions and ongoing work.
    - Consider accepting third-party algal reporting as a separate layer on the NC algal bloom tracker. Already underway at county level with active community participation.
    - Contribute to community education and local forums on this topic.

5.4.3 Nutrient Related Research Needs

DWR has identified the following research needs for the Chowan River basin.

- Research in determining if the Chowan River system is nitrogen or phosphorus limited.
    - Conduct bioassays throughout the Chowan River and Albemarle Sound region to understand response of algae to nitrogen and phosphorus.
    - Conduct preliminary assessment of nutrient modeling needs in the basin.
    - If warranted, finance external nutrient model for the Chowan Basin to characterize the degree of nutrient reductions needed to achieve water quality goals.
    - Establish if there is a need to modify the current NSW strategy to include additional actions to reduce nutrient contributions to the system.

- Research into nutrient source identification
    - Conduct research into the role of nitrogen fixation as a source of new nitrogen into the Chowan River/Albemarle Sound.
    - DWR has identified a pattern of increasing TKN concentrations in the Chowan River basin as well as in other river basins across the state. The reason for this basinwide shift in increasing organic nitrogen concentrations is not known. There is a need, however, to understand the sources of the organic nitrogen to the Chowan River system and across the state of NC.

- There is a critical need for technology that can distinguish a specific nitrogen signature in order to identify a specific source such as agricultural animal types, domestic waste or a background forest/sediment signature. DWR encourages researchers to continue to work toward a method viable to use on a large-scale system. Using bioassays, assess algal growth responses to specific organic nitrogen sources, as these are increasing as part of the N load to the Chowan River system. This would assist in the development of appropriate best management practices to reduce the load of organic nitrogen into the system.
- It is recommended that research be conducted to better establish and understand the relationship between groundwater and surface water in eastern North Carolina. Such understanding would provide for more accurate assessment of surface water impairments resulting from groundwater discharges and enable the state to make sound permitting judgments and recommendations to better protect ground and surface water quality.

- Scientific Research for Streamflow and Chlorophyll *a*:
  - The 1997 basin plan suggested that there is a possible temporal relationship between flow and chlorophyll *a* concentration indicating that years of high flow, particularly high spring flows, are the same years of high chlorophyll *a* concentrations. This report also indicated that bluegreen algal blooms are more severe, cover wider areas and lasted longer during years of heavy winter and spring rains and dry summers, with 1990 and 1993 given as examples in which both of these years recorded significant flows in the winter and late spring providing nutrient delivery, followed by low flow periods, enabling bloom development. This assumption needs to be investigated further now that algal blooms have once again returned to the Chowan River on a regular basis. This seasonal flow relationship has been shown to stimulate blooms in other parts of the state and the nation (Paerl et al., 1998).
  - Currently there is a lack of available stream flow data throughout the North Carolina portion of the Chowan River basin. DWR has identified a need for bi-directional instream flow data that would allow for loading estimates and better understand of nutrient cycling in the Chowan River mainstem and coastal creeks. Research needs include identification of appropriate tools, monitoring locations and data assessment to improve the overall understanding of the Chowan River system and enhance future management decisions.

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