

## **EXECUTIVE SUMMARY** **LEGISLATIVE REPORT** 2017



### **RIVERNET: Continuous Monitoring of Water Quality in the Neuse River Basin**

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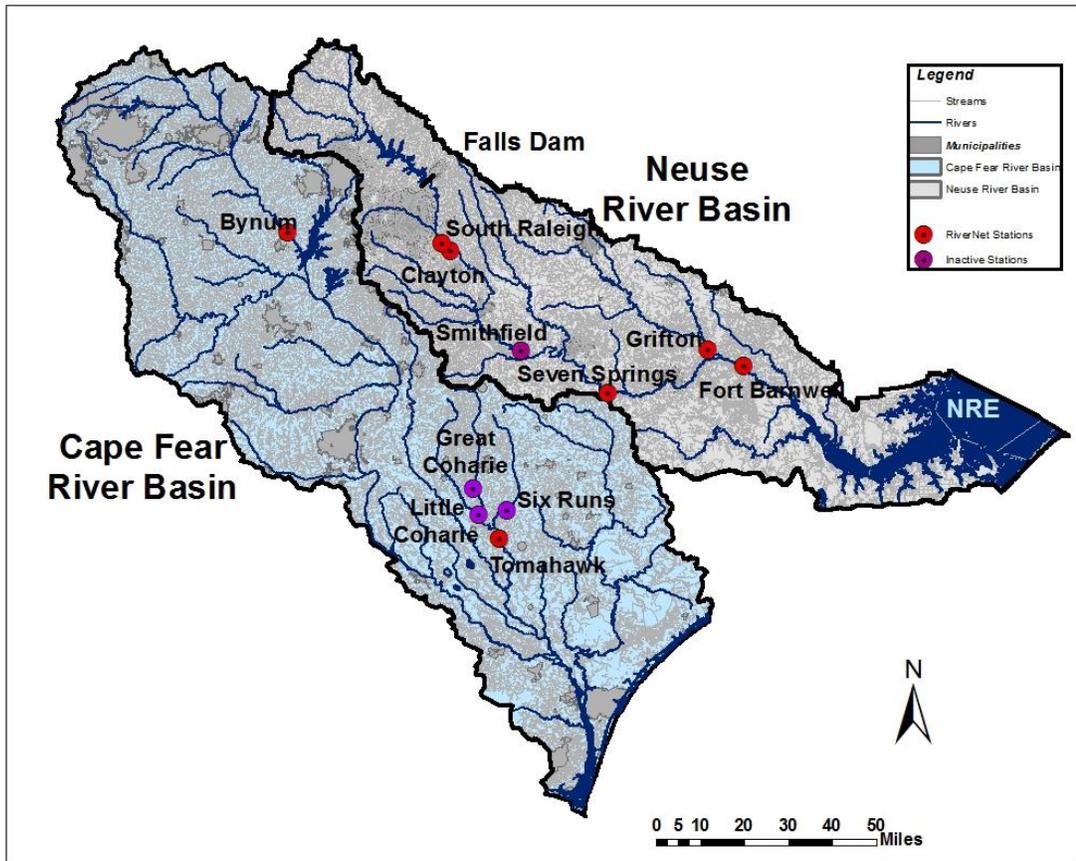
#### **PURPOSE OF PROGRAM**

Agricultural and urban land use has increased the fluxes of nutrients, sediments and different organic/inorganic chemicals into surface water and ground waters. As a consequence, many estuaries and wetlands are under various levels of environmental pressure as a result of diminished water quality (e.g., high nutrient concentrations, sediment loading, low levels of dissolved oxygen). The increased nitrogen flux to estuaries and coastal waters has affected water quality by enhancing phytoplankton blooms as part of the overall eutrophication process. This enhanced production modifies coastal food webs, reduces commercial species abundance, and in extreme cases produces zones of hypoxia and anoxia. Although extensive research has been done to understand nitrate contamination and attenuation processes in ground water, discharge rates of nitrate in streams are commonly not matched to different types of land use or to field application rates. To promote the long-term sustainability of natural and managed watersheds and to develop successful remediation strategies, fundamental processes that control water quality on a watershed scale must be investigated. RiverNet is a program that is designed to understand nitrogen fluxes in watersheds with different land uses, and then provide data to help engineer cost effective solutions to reduce and mitigate the nutrient footprint of businesses, towns and municipalities.

#### **BACKGROUND**

The 2001 Session of the General Assembly appropriated funds to the Department of Environment and Natural Resources (DENR) for transfer to North Carolina State University (NCSU) for the continued operation of the RiverNet Program. RiverNet expanded into the Cape Fear Basin in 2009, and \$288,500 was allocated to the program for operations in the 2017-18 period. The RiverNet Monitoring network has been operated over the past 17 years. During this past year we have deployed a new inexpensive river monitoring techniques to aid farmers who are proactively protecting water quality in their watersheds. Rivernet continues to monitor nitrate flux in the Neuse basin, and continuously operates 1 station in the Cape Fear River Basin where municipalities and agribusinesses are located. Five stations are operating in the basin from Raleigh to Fort Barnwell, with one station in the Contentnea watershed, and four along the Neuse main stem (Figure 1). Two stations (one under construction) are also operating in the Cape Fear watershed on the Black River, and on the Haw River (Figure 1). Physical water quality property measurements with nitrate concentrations are made every 15 minutes. The data is transferred to a server on the NCSU campus via a digital cell network, and mounted on a web site for public access (<http://rivernet.ncsu.edu>). This monitoring will continue for the next year with nutrient mapping in

agricultural watershed buffers and critical drinking water reservoirs. The nutrient mapping technology spatially quantifies nitrate, pH, Eh, temperature, conductivity, Chl a, Phaeophytin, and CDOM in surface waters. During the past year nutrient maps were compiled in Lake Jordan and Falls Lake, which are drinking water sources for Cary and Raleigh, NC (Figure 7).



**Figure 1.** The RiverNet monitoring network with stations located in the Neuse and the Cape Fear River Basins. Stations will monitor water quality in the nutrient sensitive Neuse River Basin and on major rivers in the Cape Fear River Basin. One station was added in the Cape Fear above Jordan Lake, while three stations were damaged by Hurricane Irene in August 2011 and are inactive.

## RiverNet: RESULTS 2017

### *Summary:*

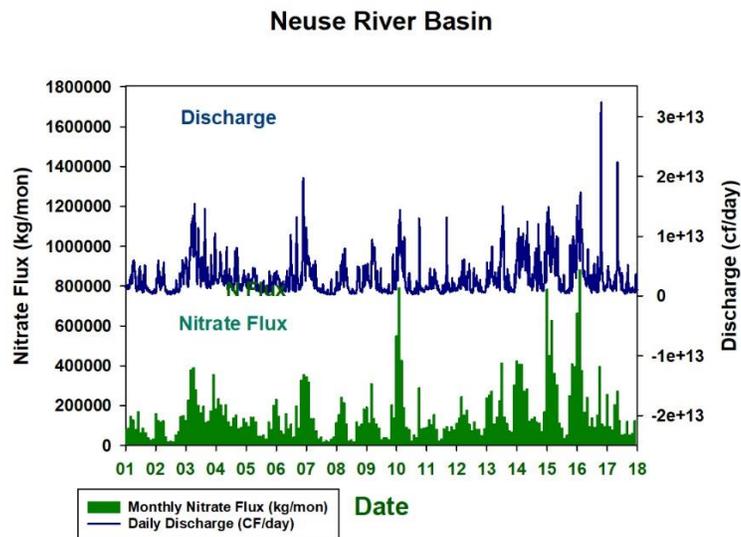
*Previous year's results have shown that there are very rapid nitrate concentration changes in the Neuse River in the upper, middle and lower basin. During the last year the ENSO was in a cold phase and nitrogen fluxes were reduced in the Neuse river Basin, except during Hurricane Matthew. The nitrogen flux in the Neuse River Basin was low after moderate runoff during the spring events. It is likely that there will not be water quality problems this summer in the Neuse River Estuary unless another storm event (hurricane) hits North Carolina, given these low 2017 flux conditions. We have also completed the initial phase of developing a low cost monitoring program for farmers to monitor their individual watersheds. We have used conductivity records in Stockinghead watershed in the Cape Fear River Basin and gotten excellent results for nitrate and chloride concentrations. These results suggest "critical buffers" are important to watershed water quality remediation efforts. Finally we continue to map water quality in drinking water reservoirs and have expanded these efforts from surface water conditions to depth profiles and sediment*

concentrations. Large sediment surface bacterial mats have been found in Falls Lake during summer anoxic conditions, and Chl a concentrations increase in bottom waters after the fall overturning event.

### Significance of Watershed Nitrogen Flux Measurements

To accurately measure nitrate flux to coastal waters, high temporal resolution nitrate concentration measurements must be compiled. The USGS compiles discharge measurements on a 15 minute time interval to capture hydrographic events produced by storm flows. The RiverNet Program has shown that this short time interval is also required to calculate accurate nitrogen flux measurements during storm events (Figure 2). A large proportion of the nitrogen flux to coastal waters occurs during these storm events. But discharge alone does not control water quality in North Carolina rivers, nitrogen flux is also modulated by climate oscillations. These climate oscillations vary over a 1 to ten year period, so long term monitoring programs like RiverNet are needed to understand the efficacy of new regulations by comparing flux during similar climate conditions.

The RiverNet program results indicate that the ENSO (El Niño Southern Oscillation), the Bermuda High Index, and the NAO (North Atlantic Climate Oscillation) modulates water quality in the Neuse River Basin and the downstream estuary (Figure 3). Nitrate flux increases with positive El Niño oscillations or warm water conditions in the equatorial Pacific. Warmer waters in the equatorial Pacific intensify the southern jet stream, which brings Gulf of Mexico moisture to North Carolina. This causes increased precipitation, higher groundwater elevations, and increased N flux in watersheds. North Carolina precipitation is also affected by the North Atlantic Oscillation and the Bermuda High. The North Atlantic oscillation (NAO) is a climatic phenomenon in the Atlantic Ocean that primarily affects northern Europe and Mediterranean climates and is linked to the Bermuda High Index (BHI). When the NAO and BHI indexes are positive, the westerly flow across the North Atlantic and Western Europe is enhanced. For North Carolina, warm ocean waters occur off the eastern US with the BHI/NAO positive phase, and rainfall is enhanced in our region. During the negative phase storm tracks are forced further south, so northern Europe and the east coast of the US are dry. The surface waters of the South Atlantic Bight off the coast of North and South Carolina is cold yielding lesser amounts of rainfall to our region.

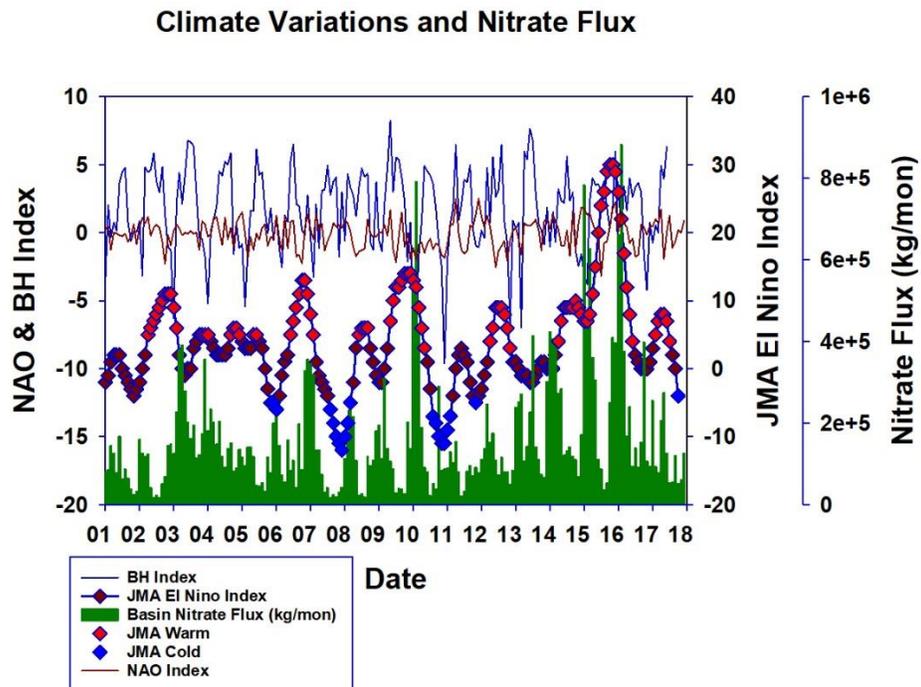


**Figure 2.** Daily discharge and Monthly N flux at Fort Barnwell North Carolina at the bottom of the Neuse River Basin. This graph represents over 500,000 individual measurements at this one station.

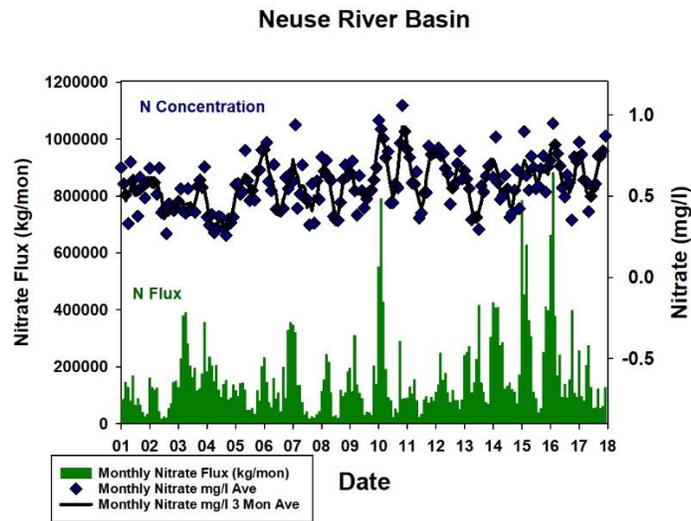
El Nino or warm central Pacific conditions occurred in 2002, 2007, 2010 2012, 2014 and 2016 (Figure 3). Highest annual nitrate fluxes to coastal North Carolina with degraded water quality conditions occurred after these events. The magnitude of flux and water quality degradation correlates to the strength and duration of the El Nino event and the BHI and NAO phases. The largest nitrate flux to coastal waters occurred after the 2016 El Nino event which had a long duration with a positive NAO phase (Figure 2). 2017 started and ended with cool La Nina events, so fluxes were low in 2017 and 2018 should be a good water quality spring period.

### WATER QUALITY FORECAST FOR 2018

Legislative committees and NC voters have asked “why are there good and bad water quality years”? Is water quality improving or degrading in the Neuse Basin, which had massive fish kills in the 1990’s? High nitrate fluxes and bad or good water quality years correlate with the ENSO (El Nino – warm and La Nina – cold) 3-5 year oscillations modulated by the Bermuda High and North Atlantic Oscillation (3 to 6 months). To compare water quality between different years, similar climatic states must be compared. This is why long term high resolution data sets like the RiverNet program are important and need to be continued. There are two indications that water quality conditions in the Neuse are getting better and high resolution monitoring needs to continue to document these trends. The average nitrate concentrations in the basin increased up to 2010 and have been decreasing since in a stepwise fashion (Figure 4). The large nitrate flux of 2010 in the Neuse Basin was associated with a strong El Nino event in the Pacific Ocean, and with increased discharge in the basin (Figure 3). During the winter of 2016 flux of nitrate increased while the NAO was in a negative phase and was high because of the large El Nino event. During 2017 La Nina developed and nitrate fluxes fell to low levels.



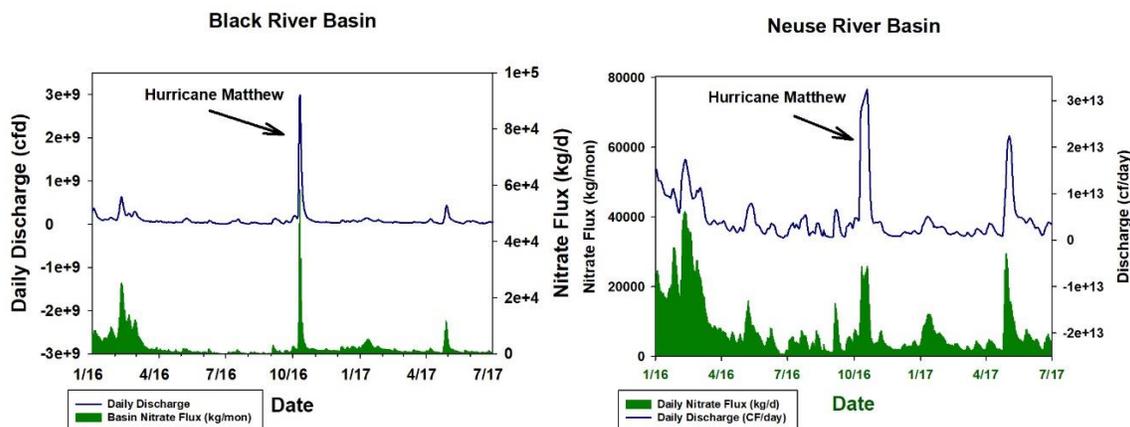
**Figure 3.** Monthly N flux at Fort Barnwell North Carolina versus climate oscillations. El Nino is a good predictor of nitrate flux modulated by the North Atlantic Oscillation and the Bermuda High Index, which have a higher frequency of oscillations than the El Nino periodicity (3-7 years). 2017 was a cool year with low N flux rates.



**Figure 4.** Monthly N flux at Fort Barnwell North Carolina versus nitrate concentration. Nitrate concentration is a poor predictor of water quality trends, but nitrate concentrations in the lower Neuse have increased over the past decade to 2010 and then have been decreasing in a stepwise fashion.

### HURRICANE MATTHEW

Hurricane Matthew grazed the North Carolina coast October 8 as a Category 1 Hurricane. The discharge and N flux response was much larger in the Cape Fear River basin than in the Neuse River Basin. This may be because the Hurricane track was closer to the Cape Fear, or because the Cape Fear basin has more agricultural non-point sources of nitrogen than the Neuse Basin. The storm hysteresis plots show that surface runoff was a significant component of this event and that all the buffers were overwhelmed by the flow of storm water (Figure 5). It took about two weeks longer for the flood waters to recede in the Neuse compared to the Cape Fear River Basin.



**Figure 5.** N flux at Tomahawk, Black River and the Neuse River at Fort Barnwell North Carolina during Hurricane Matthew. The N flux response was much larger in the Cape Fear basin than in the Neuse Basin.

## MONITORING IN THE CAPE FEAR RIVER BASIN

### River Nutrient Mapping

In the Cape Fear, watershed nutrient flux compiled at Tomahawk on the Black River (Figure 6) shows a slightly different flux pattern than in the Neuse River. This nitrogen flux peaks coincide with changes in the NAO oscillation, and the magnitude of the flux peaks are correlated to the ENSO oscillations (Figure 7). Nitrogen flux is low in the Black River prior to 2014. In 2015 and 2016 warm El Nino events and positive NAO phases are associated with large N fluxes. In 2017 ENSO is cool and the NAO becomes negative, and N fluxes are low again (Figure 7). Longer records are needed to see what happens to the Black River during more cool events and during hurricanes.

Tomahawk, Black River, Cape Fear Basin

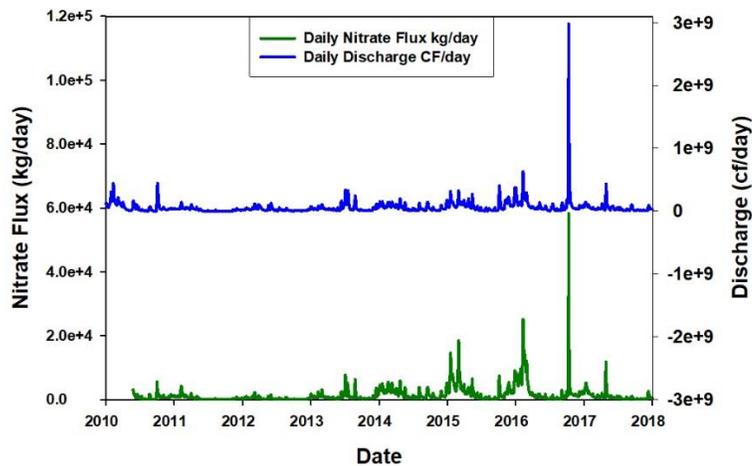


Figure 6. Nutrient flux at the Tomahawk River in the Cape Fear Basin.

Climate Variations and Nitrate Flux  
Cape Fear Watershed, Black River

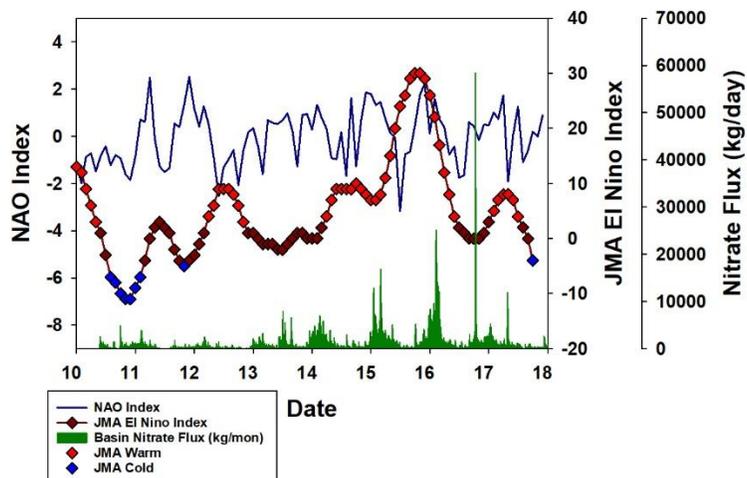
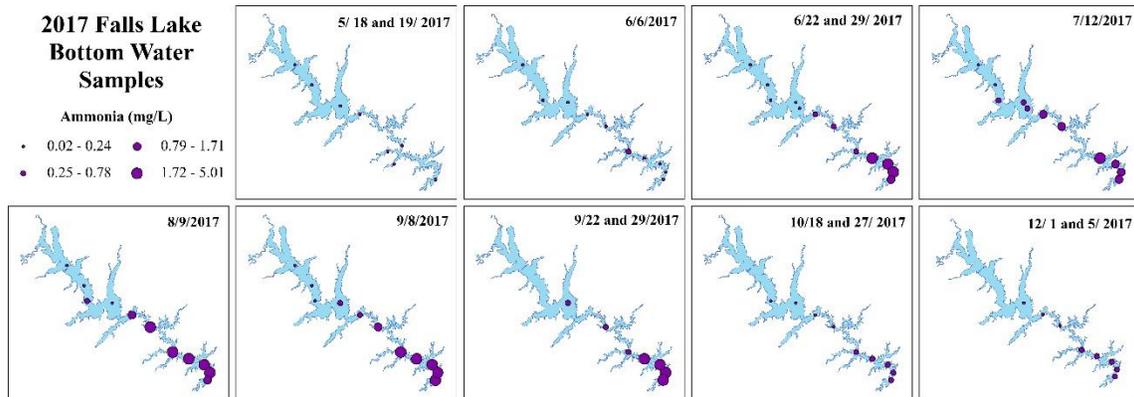


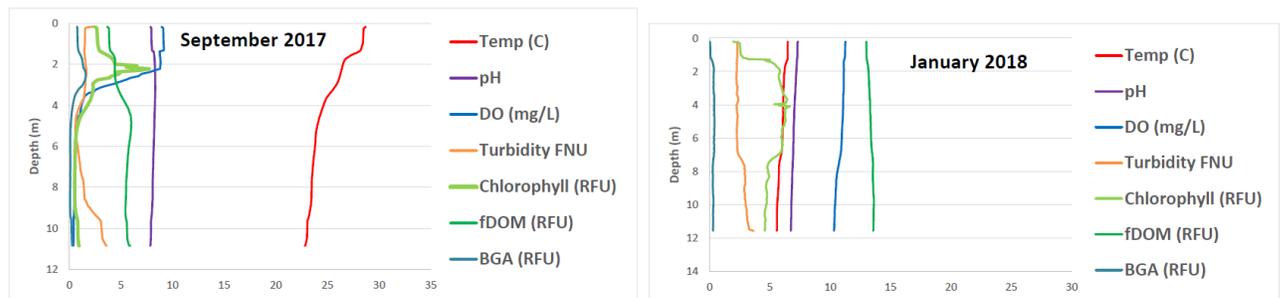
Figure 7. Nutrient flux and the NAO and ENSO climate oscillations in the Cape Fear River Basin.

## Lake/Reservoir Nutrient Mapping

We had monitored the development of stratification, anoxia and nutrient regeneration in Falls lake during 2017 (Figure 8). Carbon isotopic composition and concentrations in lake sediments indicates that organic material is not accumulating in the bottom of the lake. Videos of the lake bottom reveal large bacterial mats develop during the summer anoxic period. Nutrients are generated from the lake bottom during the summer months from June to October, and then the lake overturns in November and a large subsurface Chl a max develops in the lake in the winter months. Over the next year we will sample other North Carolina lakes to see if this stratification and anoxia is a threat to drinking water in other parts of the state.. We will also continue depth profiles to the bottom of the lake to determine when the subsurface algae community appears and quantify the seasonal development of anoxia and bottom sediment nutrient flux into the lake. With new ADCP equipment we can quantify the development of the density stratification and determine circulation in the upper mixed zone and the lower stratified zone. Primary production is highest in the upper part of the lake, but sediment organic content, CDOM, subsurface Chl a, and remineralization rates are highest in the deeper lower portions of the lake where drinking water is extracted by the City of Raleigh. This is a puzzle that can be solved with continued monitoring.



**Figure 8.** Development of anoxia



**Figure 9.** Water column profiles in Sept and January in Falls Lake at station H4 above the water treatment plant. Notice the subsurface Chl a peaks associated with the oxycline (oxygen depletion zone) in the summer.

## Summary:

RiverNet is a river water quality monitoring system that has continued to evolve and given researchers, policy makers, and water quality regulators a new understanding of fundamental processes affecting water quality on a watershed scale. RiverNet data is used by government policy makers, regulators, scientists, environmentalists, and the general public, especially fishermen and communities that live along the river. At the present time we are combining RiverNet monitoring efforts with the USGS to look at nutrient inputs in Jordan Lake and the Haw River. These nutrient mapping efforts in drinking water reservoirs have expanded to surface and deep waters and will support efforts to treat nutrient loads in the lake (*in situ*). The newly redesigned web pages makes this data available to university and government researchers, students, the general public, and policy makers in real time (Figure 10). In the coming year we are looking to partner with the NC Department of Agriculture to monitor nutrient flux in agricultural sub basins. These efforts have so far proven to be very successful in understanding nitrogen transport across landscapes and will aid in efforts to design treatment wetlands and flood buffers to remediate contaminated surface and groundwater nitrate entering our river basins in order to better protect our water resources and water quality.



RiverNet is designed to bring you the latest information on the water quality in select rivers of North Carolina.

Led by Dr. William J. Showers at North Carolina State University's Department of Marine, Earth and Atmospheric Sciences, RiverNet is a program that is designed to understand nitrogen fluxes in watersheds with different land uses. This is achieved through the continual collection of different types of water quality data in an effort to provide the information needed to promote the long-term sustainability of natural and managed watersheds and to develop successful remediation strategies.

## Most Recent Data

### Neuse River

	date	time	depth (ft)	pH	Nitrate (mg/L)		
CLAYTON	January	26	05:00:00	1.846	6.260	1.382	<a href="#">graphs</a> / <a href="#">archive</a>
FORT BARNWELL	January	26	05:15:00	4.451	6.190	0.756	<a href="#">graphs</a> / <a href="#">archive</a>
GRIFTON	January	26	05:00:00	12.460	5.850	0.808	<a href="#">graphs</a> / <a href="#">archive</a>
SEVEN SPRINGS	January	26	05:15:00	1.967	6.340	0.840	<a href="#">graphs</a> / <a href="#">archive</a>
SMITHFIELD	January	26	05:15:00	3.121	6.560	0.675	<a href="#">graphs</a> / <a href="#">archive</a>
AUBURN-KNIGHTDALE	January	26	05:00:00	2.701	6.290	0.531	<a href="#">graphs</a> / <a href="#">archive</a>

### Cape Fear River

	date	time	depth (ft)	pH	Nitrate (mg/L)		
GREAT COHARIE	January	26	05:45:00	5.25	6.3	0.676	<a href="#">graphs</a> / <a href="#">archive</a>
LITTLE COHARIE	January	26	05:45:00	2.32	6.17	0.832	<a href="#">graphs</a> / <a href="#">archive</a>
SIX RUNS	January	26	05:30:00	5.05	5.84	1.308	<a href="#">graphs</a> / <a href="#">archive</a>
TOMAHAWK	January	26	05:30:00	5.105	7.09	1.002	<a href="#">graphs</a> / <a href="#">archive</a>

NCSU RiverNet Program | North Carolina State University | 1125 Jordan Hall, NC State University, Raleigh, NC 27695 | Director: Dr. William J. Showers

Figure 10. The redesigned web page allows easy access to the data generated by this project.



### **Major findings of the program to date include:**

- Nitrate and sediment concentrations in the Neuse River Basin change rapidly with and without stage changes. These variations are correlated to discharge and precipitation variations that are controlled by large scale climate cycles. Nitrate concentrations have increased in the Neuse River Basin until 2010, and have been decreasing since then.
- Long term nutrient fluxes are controlled by the ENSO climate oscillation modulated by the North Atlantic Oscillation and the Bermuda High Index. Hurricanes can cause increased nitrate fluxes for 2 to 4 weeks after they make landfall in North Carolina.
- 15 minute RiverNet flux measurements are significantly more accurate than flux estimates made from daily concentration measurements because they take into account the natural nitrate concentration and discharge variations of hydrographic storm events and wastewater treatment plant conditions. Daily flux estimates have a 10 to 40% error depending upon the location in the river basin.
- River nutrient mapping can identify watershed areas that would benefit from constructed wetlands to protect water quality. Surface water mapping combined with depth profiles indicate that Jordan Lake bottom waters are anoxic below the Haw river outlet, and Falls Lake has strongly developed bottom water anoxia and nutrient remineralization fluxes in the lower portion of the lake.
- Nutrient mapping on a watershed scale can identify where contaminated surface and groundwater enters the river. The groundwater quality in these groundwater discharge zones has a direct effect upon surface water quality downstream from these regions.
- Nutrient mapping in lakes and drinking water reservoirs can identify sources and location of nutrient inputs and lake dynamics as the “biological cascade” stimulates biological productivity and biomass production. Identification of the nutrient inputs and subsequent impact on lake chemistry is crucial to remediation of contamination sources.
- Identification of the location and processes that discharge contaminated groundwater into the river is the crucial first step towards remediation of contaminated surface and ground waters.
- New optical technology can make Chl a BGA, and CDOM mapping possible with nitrate concentrations to define reach and reservoir characteristics that can be related to pollution source. These sources are dynamic and change with space and time, so high resolution data is required to identify and remediate these problems.

By wisely using state and national resources and by emphasizing results focused on the systematic application of research based knowledge, we can expedite the timely resolution of our water quality problems and protect our invaluable water resources and grow our state's economy without environmental impairment. By combining research efforts with industry and with educational outreach programs, we can train the scientists, regulators and policy makers of the future. In the end

we will protect the environment and business development, and improve the public's understanding of water resource issues and the essential social, economic, and environmental value of local water resources for all persons and sectors of society.