EXECUTIVE SUMMARY
LEGISLATIVE REPORT
2018

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

Dr. William J. Showers
Dept. of Marine, Earth & Atmospheric Sciences, North Carolina State University

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 started to monitor agricultural basins in the 2014 period. The RiverNet Monitoring network has been operated over the past 18 years. Over the course of the program new technologies have been employed to measure nitrate fluxes in different watersheds. During the past three years 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 and 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). One stations is operating in the Cape Fear watershed on the Black River, and one under construction on the Haw River (Figure 1). Physical water quality property measurements with nitrate concentrations are made every 15 minutes. The data 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.

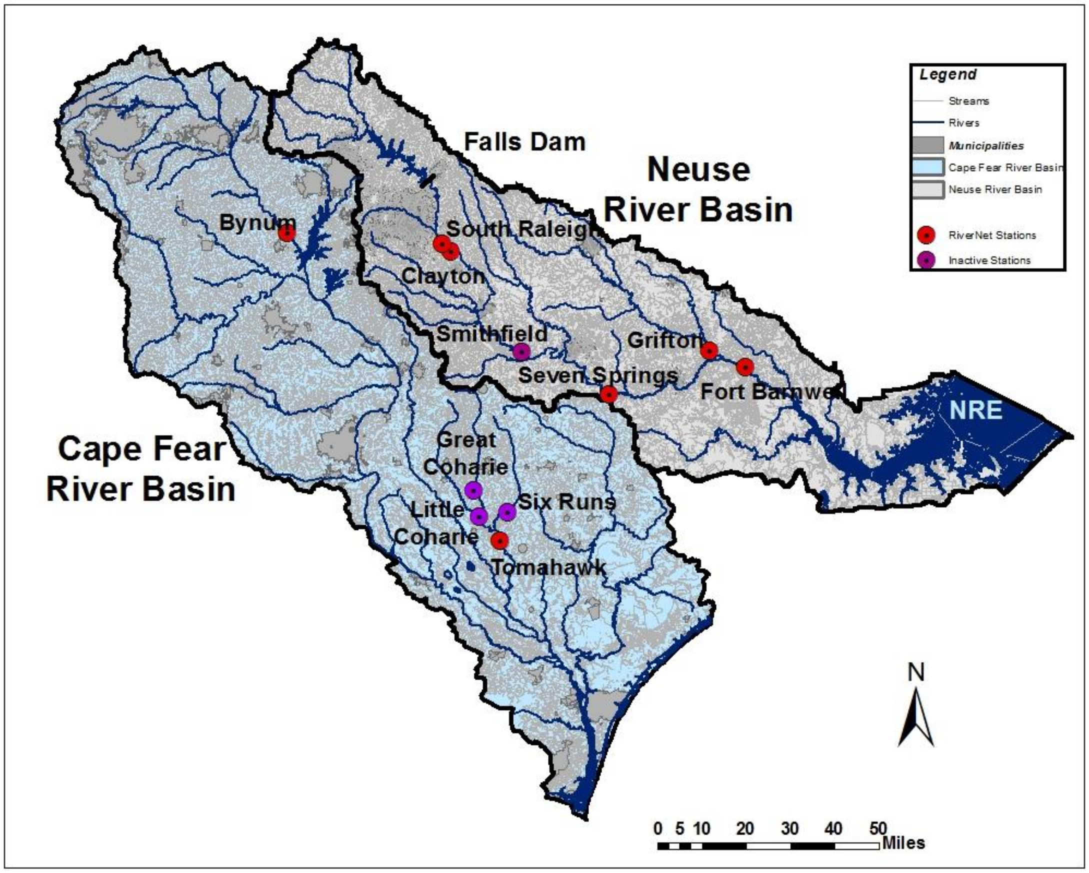

Figure 1. The RiverNet monitoring network with stations located in the Neuse and the Cape Fear River Basins. Stations will monitor water quality in the nutrient sensitive Neuse River Basin and on major rivers in the Cape Fear River Basin. One station was added in the Cape Fear above Jordan Lake, while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

RiverNet: RESULTS 2018

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 Pacific ENSO transitioned from a cold phase and reduced nitrogen fluxes to a warm phase and increased nitrogen fluxes in the Neuse river Basin. The nitrogen flux in the Neuse River Basin has increased 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 building 2019 flux conditions. We have also completed the development of 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 toxic algae concentrations are found under the oxycline during the summer months.*

Significance of Watershed Nitrogen Flux Measurements

To accurately measure nitrate flux to coastal waters, high temporal resolution nitrate concentration measurements must 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 Nino Southern Oscillation) modulated by the Bermuda High Index, and the NAO (North Atlantic Climate Oscillation) best correlates to water quality variations in the Neuse River Basin and the downstream estuary (Figure 3). Nitrate flux increases with positive El Nino 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 into 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 and the ocean southern bight is warm. For North Carolina, warm ocean waters occur off the eastern US enhances rainfall 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 and the southern bight is cold yielding lesser amounts of rainfall to our region.

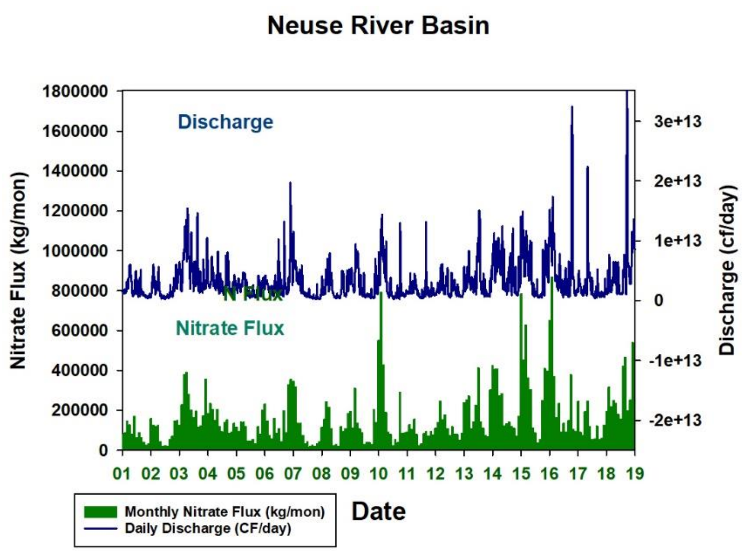

Figure 2. Daily discharge and Monthly N flux at Fort Barnwell North Carolina at the bottom of the Neuse River Basin. This graph represents over 500,000 individual measurements at this one station.

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 3). In 2019 there is a warm phase building in the Pacific, so fluxes will increase in 2019 during the spring and summer months.

WATER QUALITY FORCAST FOR 2019

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. The average nitrate concentrations in the basin increased up to 2010, decreased in 2013, and has been increasing ever since (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 2016 and 2018 two hurricanes and a large tropical storm also increased the flux of nitrate to the estuary. During 2019 El Nino developed and nitrate fluxes have been steadily rising (Figure 3).

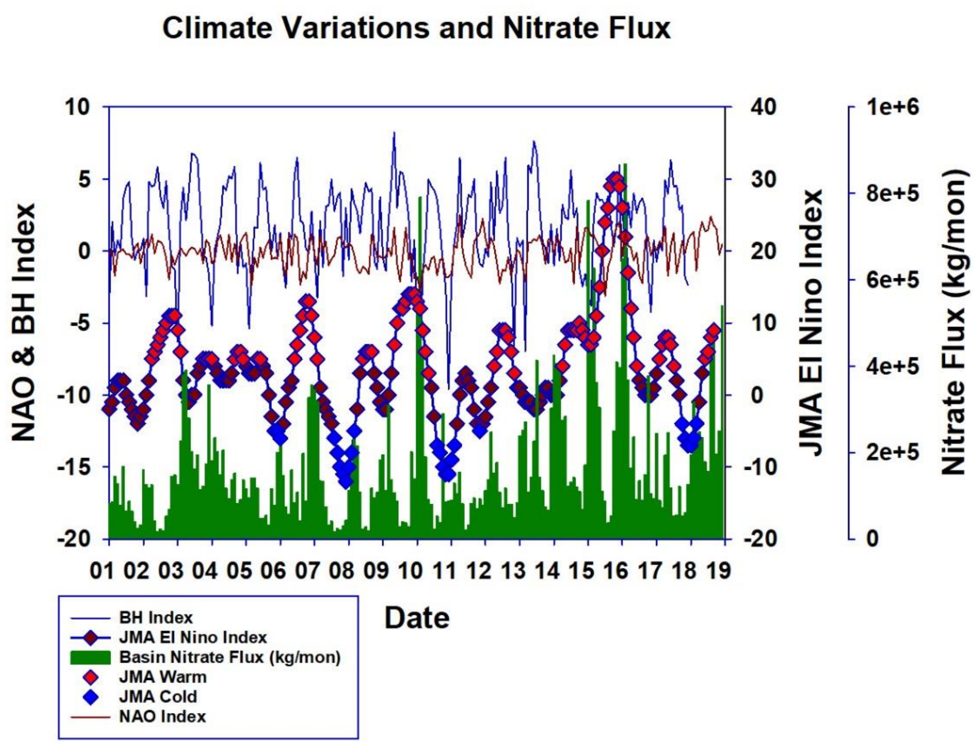

Figure 3. Monthly N flux at Fort Barnwell North Carolina versus climate oscillations. El Nino is a good predictor or nitrate flux modulated by the North Atlantic Oscillation and the Bermuda High Index, which have a higher frequency of oscillations than the El Nino periodicity (3-7 years). 2017 was a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

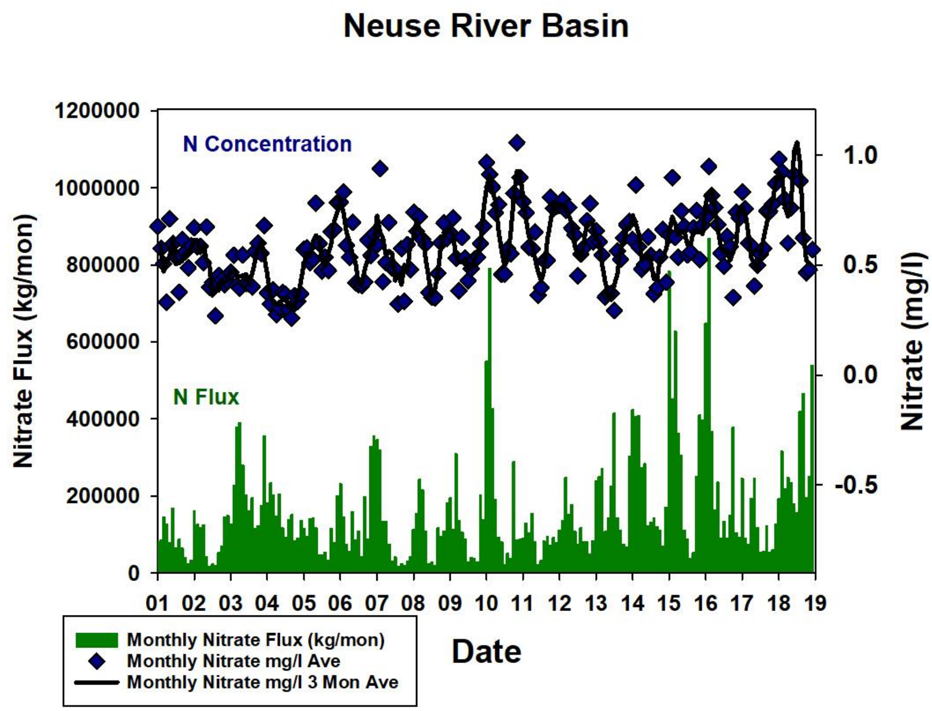

Figure 4. Monthly N flux at Fort Barnwell North Carolina versus nitrate concentration. Nitrate concentration is a poor predictor of water quality trends, but nitrate concentrations in the lower Neuse have increased over the past decade to 2010 and then have been decreasing in a stepwise fashion.

HURRICANE MATTHEW AND FLORENCE, TROPICAL STORM ALBERTO

Hurricane Matthew grazed the North Carolina coast October 8, 2016 as a Category 1 Hurricane but dumped an incredible amount to rainfall on eastern North Carolina. Hurricane Florence turned westward into South Carolina in September 2018, but moved slowly and also deposited a significant amount of rainfall on the NC Coastal plain. Rainfall from Tropical Storm Alberto was concentrated in the NC Mountains, but also delivered a large amount of rainfall to selected regions of the lower coastal plain (Figure 5). The N flux response was different in the Cape Fear River basin than from the Neuse Basin (Figure 6). In the Neuse basin all three storms had large discharge and N flux responses. In the Cape Fear basin Tropical Storm Alberto did not have as large a response as the hurricanes. Matthew had a greater N Flux in the Cape Fear, but a lower discharge total than Florence. It took longer for the flood waters to recede in the Neuse compared to the Cape Fear River Basin.

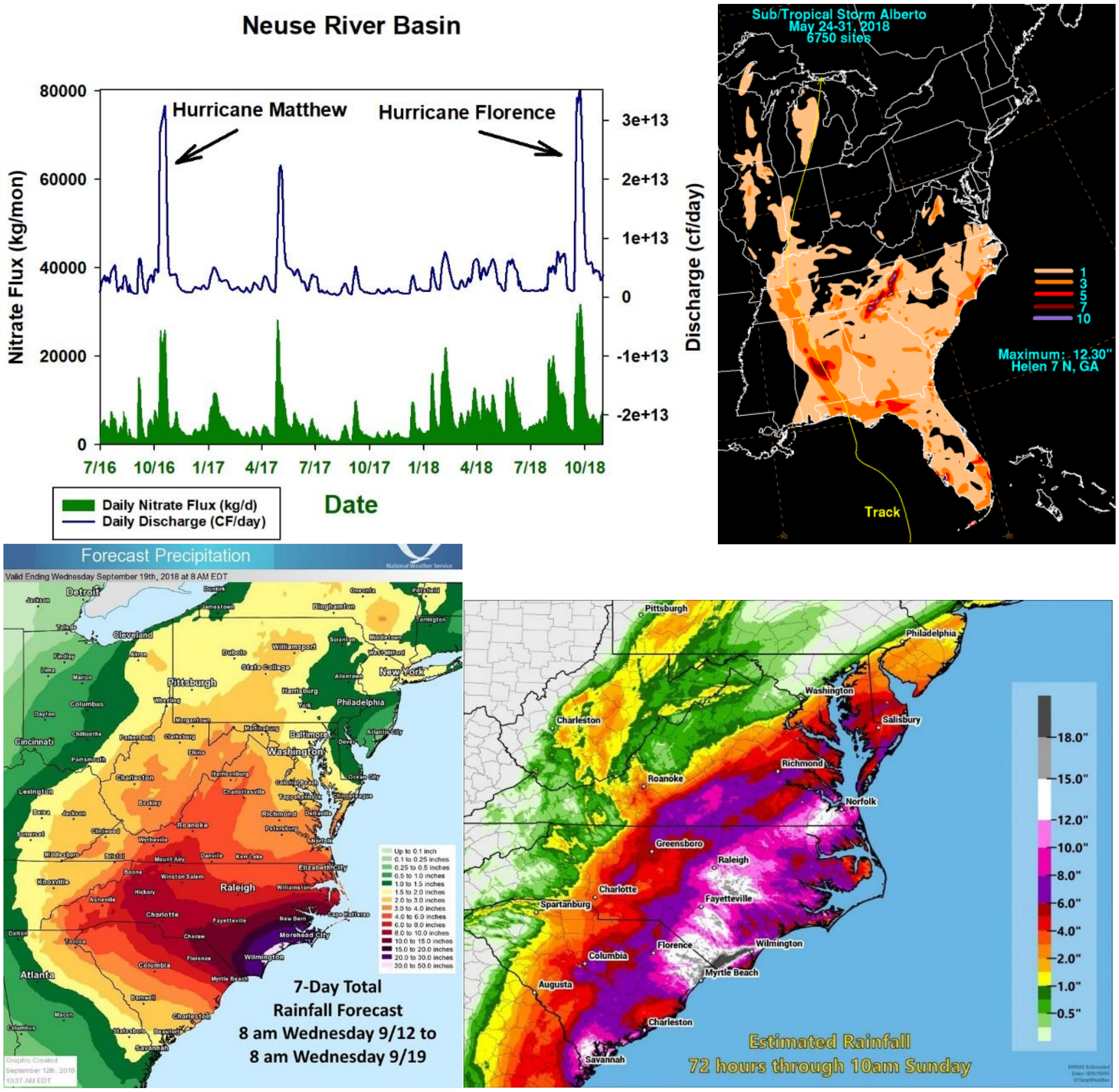

Figure 5. N Flux at Fort Barnwell for 2016 to 2018 and rainfall maps for Tropical Storm Alberto, Hurricane Florence, and Hurricane Matthew.

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 7) shows a slightly different flux pattern than in the Neuse River. The 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 NOA 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). Tropical Storm Alberto had less of an impact on the Black River than in the Neuse. The Bermuda High precipitation effect is known to be centered just north of Atlanta Georgia. This may partially explain the difference between the two basins.

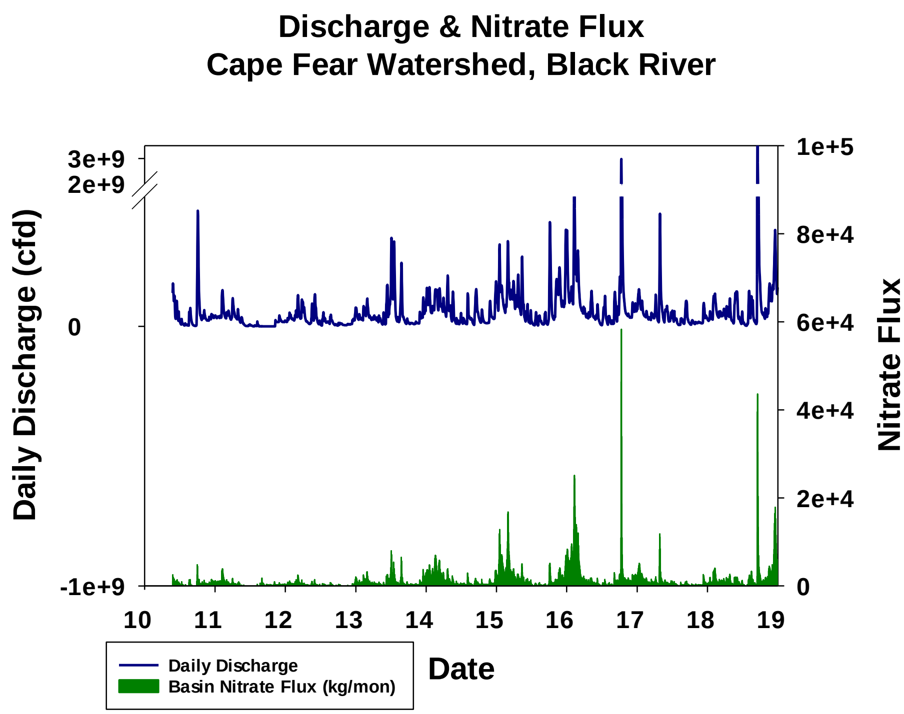

Figure 6. Nutrient flux in the Black River in the Cape Fear Basin.

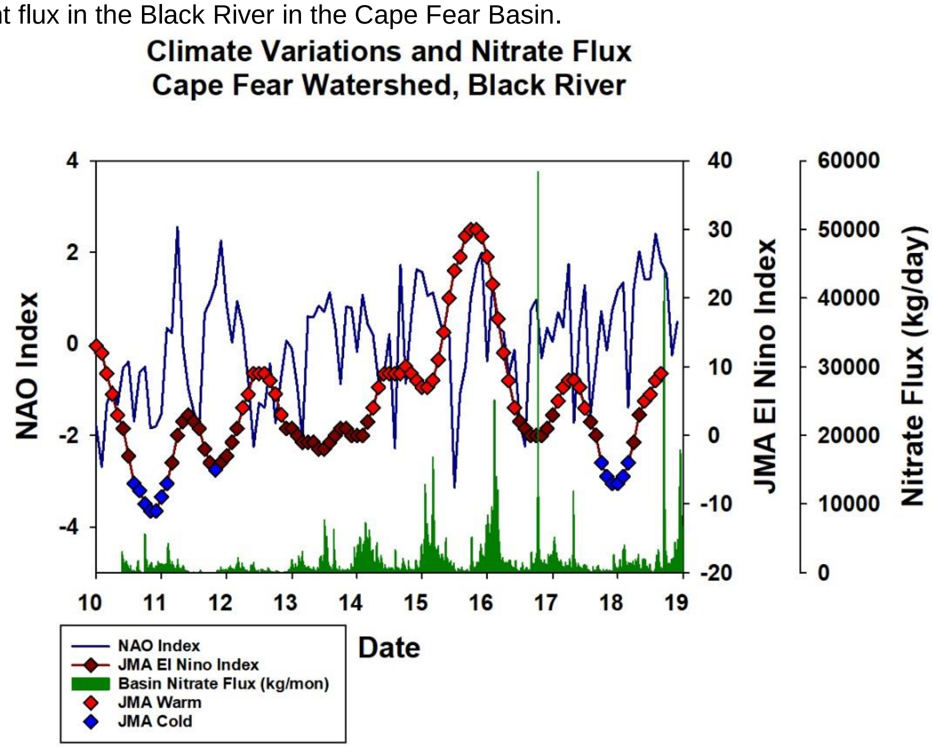

Figure 7. Nutrient flux and the NAO and ENSO climate oscillations in the Cape Fear River Basin.

Agricultural Watershed Monitoring – Critical Buffers

We had monitored Stockinghead watershed in Duplin County with inexpensive level loggers, the specific conductivity has excellent relationships with nitrate and chloride concentrations in the river. We can use these continuous measurements to reconstruct storm events. The continuous measurements are calibrated every two weeks with discrete samples. The best explanation for the nitrate variations in the streams is the amount of area in the river buffers (100’) that are cultivated and underlain by non-wetland soils. We call these critical buffer intersection zones (CBIZ, see figure 8 & 9). These finding suggest that water quality in agricultural watersheds can be greatly improved if these critical buffers are restored. We don’t have to restore all buffers to make major improvements basin in water quality.

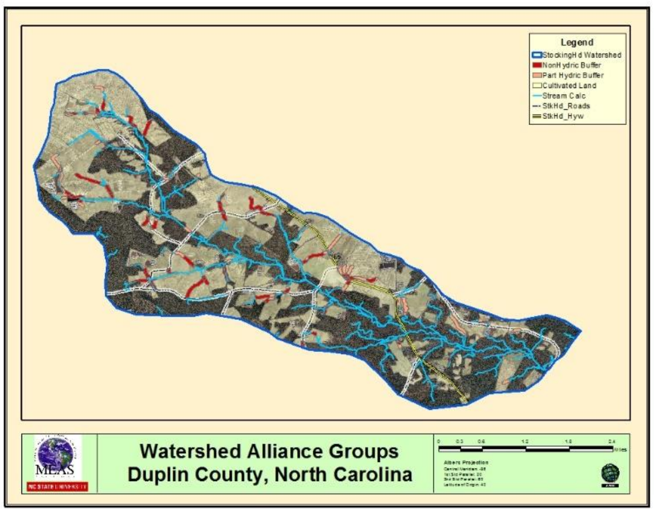

Figure 8. Critical buffer zones (red) in Stockinghead watershed.

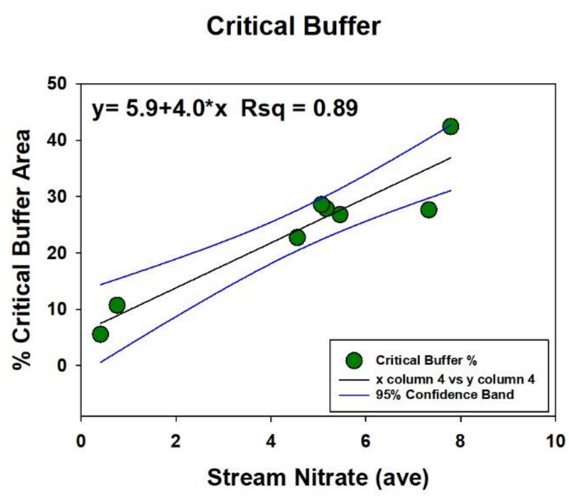

Figure 9. % critical buffer area in the 100 foot river buffer best explains the average nitrate concentration in the streams in Stockinghead watershed.

Summary:
RiverNet is a river water quality monitoring system that has continued to evolved 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 using new technology to nutrient map watersheds. These nutrient mapping efforts in agricultural watershed are expanding to encompass watersheds with different land use. We are changing over to optical sondes this year, which will yield better data during storm events. 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). During the next year we look to continue collaborations with NC DEQ and look at other watersheds that they are monitoring. 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.

RIVER NET

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	graphs / archive
FORT BARNWELL	January	26	05:15:00	4.451	6.190	0.758	graphs / archive
GRIFTON	January	26	05:00:00	12.480	5.850	0.808	graphs / archive
SEVEN SPRINGS	January	26	05:15:00	1.967	6.340	0.840	graphs / archive
SMITHFIELD	January	26	05:15:00	3.121	6.560	0.675	graphs / archive
AUBURN-KNIGHTDALE	January	26	05:00:00	2.701	6.290	0.531	graphs / archive

Cape Fear River	date		time	depth (ft)	pH	Nitrate (mg/L)	
GREAT COHARIE	January	26	05:45:00	5.25	6.3	0.676	graphs / archive
LITTLE COHARIE	January	26	05:45:00	2.32	6.17	0.832	graphs / archive
SIX RUNS	January	26	05:30:00	5.05	5.84	1.308	graphs / archive
TOMAHAWK	January	26	05:30:00	5.105	7.09	1.002	graphs / archive

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 to 2013, and are increasing again.
- Long term nutrient fluxes are controlled by the ENSO climate oscillation modulated by other oscillations. 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. Critical buffers, areas where there is cultivated land within the 100 foot buffer underlain by non-hydric soils correlate well with average stream nitrate concentraitons.
- 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.