EXECUTIVE SUMMARY
LEGISLATIVE REPORT
2016

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 2015-16 period. The RiverNet Monitoring network has been operated over the past 15 years. During this past year we have employed novel surface and depth nutrient mapping techniques in critical "at-risk" reservoirs. 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 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).

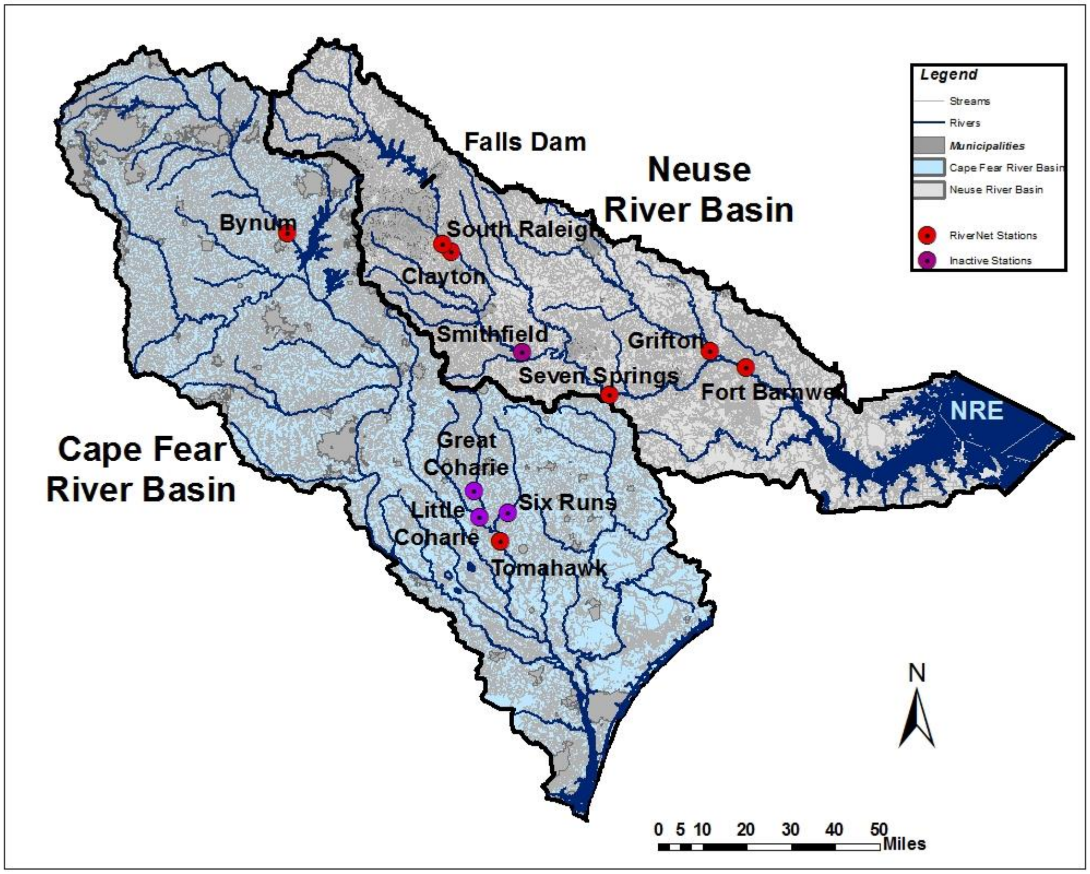

Figure 1. The RiverNet monitoring network with stations located in the Neuse and the Cape Fear River Basins. Stations will monitor water quality in the nutrient sensitive Neuse River Basin and on major rivers in the Cape Fear River Basin. One station was added in the Cape Fear above Jordan Lake, while three stations were damaged by Hurricane Irene in August 2011 and are inactive along with one Cape Fear Station that was vandalized in 2013.

RiverNet: RESULTS 2015

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 warm phase and building into a Super El Nino, and the NAO climate oscillation fell into a negative phase. The nitrogen flux in the Neuse River Basin was high and increasing at the end of the year. The last "Super El Nino" was in 1998, before the start of the RiverNet program. That year there were extensive fish kills in the lower Neuse. It is likely that there will be water quality problems this summer in the Neuse River Estuary unless a storm event (hurricane) hits North Carolina, given these winter flux conditions. It is also to compare similar climate oscillation conditions to evaluate the health of the Neuse River Watershed. Similar flux results are also seen in the Cape Fear Watershed.

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) 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 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 in watersheds. North Carolina precipitation is also affected by the North Atlantic Oscillation. The North Atlantic oscillation (NAO) is a climatic phenomenon in the Atlantic Ocean that primarily affects northern Europe and Mediterranean climates. When the North Atlantic Oscillation index is positive, the westerly flow across the North Atlantic and Western Europe is enhanced. For North Carolina, in the NAO positive phase warm ocean waters occur off the eastern US, and rainfall is enhanced in our region. During the negative phase storm tracks are forced further south and northern Europe and the east coast of the US is 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.

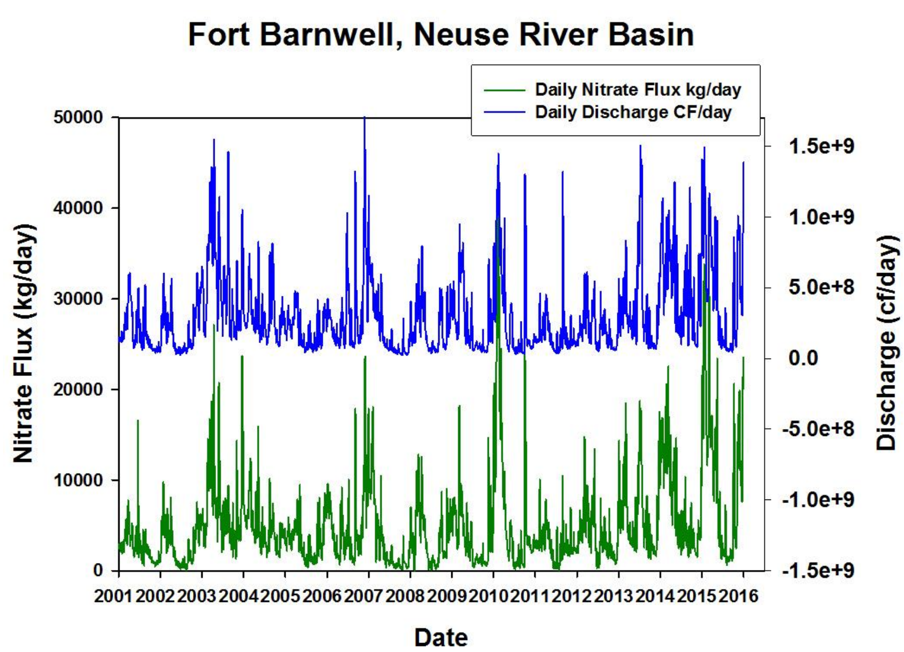

Figure 2. Daily discharge and Monthly N flux at Fort Barnwell North Carolina at the bottom of the Neuse River Basin. This graph represents over 461,000 individual measurements at this one station.

El Nino or warm central Pacific conditions occurred in 2002, 2006, 2009 2012 and 2014 (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 position of the NAO phase. The largest nitrate flux to coastal waters occurred after the 2009-10 El Nino event which had a long duration with a positive NAO phase (Figure 2). In 2014 a small warm event occurred in the equatorial Pacific, but the NAO was in a negative phase and nitrate flux in the basin was low, similar to the 2012 event (Figure 3). However, the largest El Nino is building in the winter of 2015, so fluxes will increase during the spring of 2016.

WATER QUALITY FORCAST FOR 2016

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 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 moderately because the NAO was in a negative phase while ENSO was building into a super warm phase. If the ENSO continues to strengthen in the Pacific water quality may decrease in the Neuse Estuary this summer.

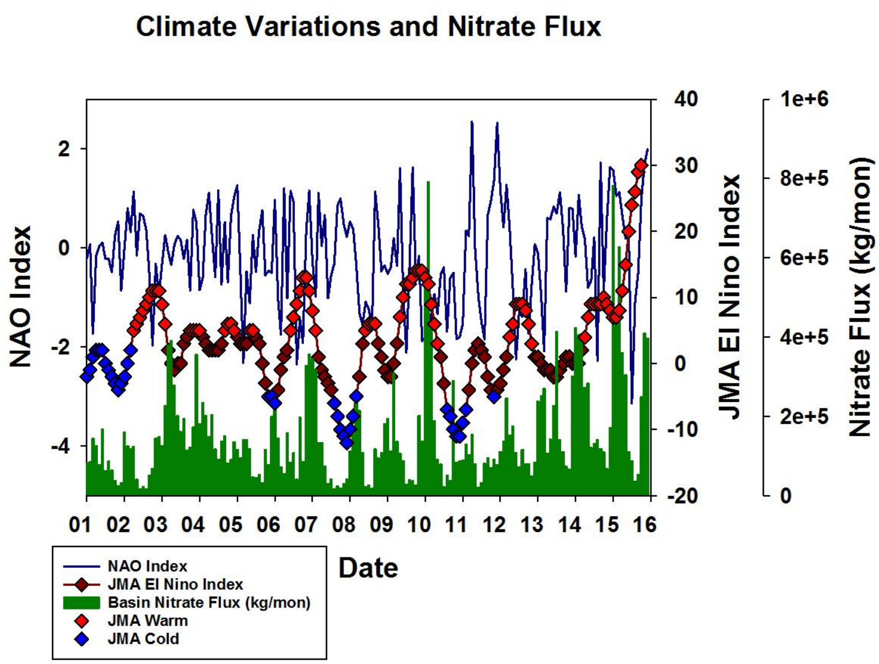

Figure 3. Monthly N flux at Fort Barnwell North Carolina versus nitrate concentration. Nitrate concentration is a poor predictor of water quality trends, but nitrate concentrations have varied in the lower Neuse with the highest values observed after 2010.

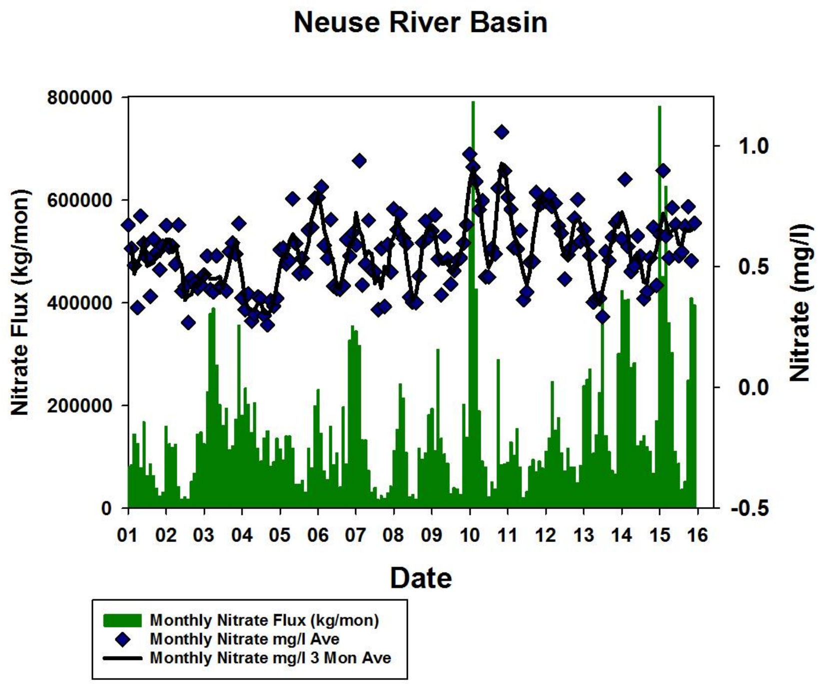

Figure 4. Monthly N flux at Fort Barnwell North Carolina versus nitrate concentration. Nitrate concentration is a poor predictor of water quality trends, but nitrate concentrations in the lower Neuse have increased over the past decade to 2010 and then have been decreasing in a stepwise fashion.

MONITORING IN THE CAPE FEAR RIVER BASIN

River Nutrient Mapping

Four RiverNet Stations have been operated in the Cape Fear #19 sub-basin for the past 5 years in a predominately agricultural basin (Figure 5). Two stations were damaged by Hurricane Irene and one station (Great Cohaire) was vandalized in 2013. These stations have been discontinued since 2014, and a new station is under construction in a secure location at Bynum on the Haw River to support the Lake Jordan nutrient mapping efforts in 2014.

In the Cape Fear, watershed nutrient flux compiled at Tomahawk on the Black River (Figure 5) shows a different flux pattern than in the Neuse River. This basin seems to respond more to the NAO oscillation than ENSO like the Neuse River Basin, but longer records are needed (Figure 6). Nitrogen flux is also lower during low flow conditions, which would be expected from a black water river system because of natural attenuation of nitrogen by wetlands and hydric soils. But as the NAO moves into a positive phase and the ENSO builds into a Super El Nino in the end of 2015, nitrate fluxes are rising, similar to the trend observed in the Neuse River. The effects of a “Super El Nino” will be documented for the first time over the next year.

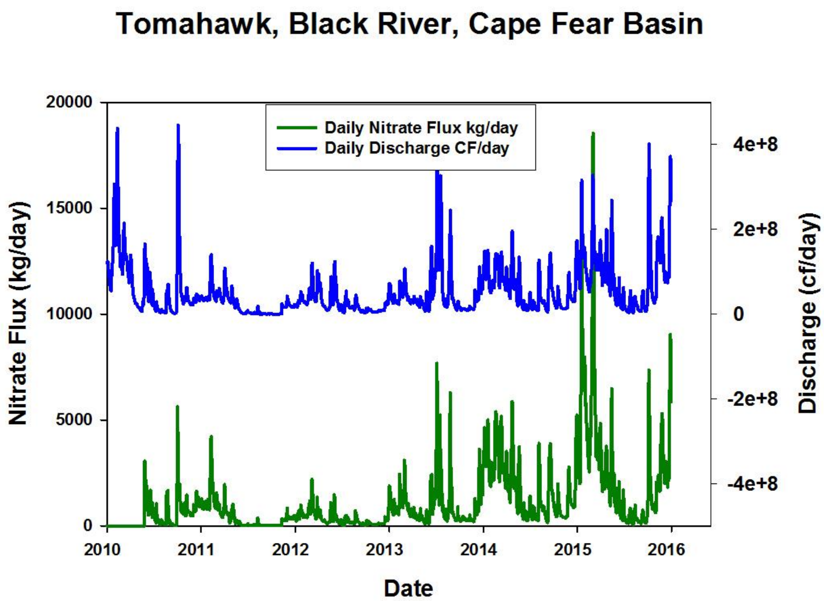

Figure 5. Nutrient flux at the Tomahawk River in the Cape Fear Basin.

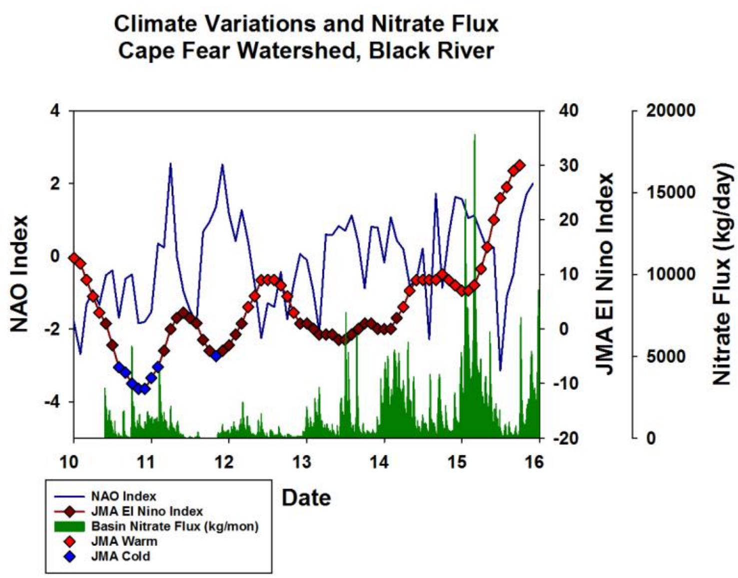

Figure 6. Nutrient flux and the NAO and ENSO climate oscillations in the Cape Fear River Basin.

Lake/Reservoir Nutrient Mapping

We had adapted the nutrient mapping technology to a small boat to efficiently map nutrients at the surface and at depth in lakes that serve as drinking water reservoirs for North Carolina. Chl a in Falls Lake is consistently elevated in the upper shallow portion of the lake. The lower lake surface waters have low Chl a concentrations, but high organic matter in the surface waters after the lake overturns in the fall (Figure 7). Depth profiles reveal that Chl a and blue green algae are elevated at 10-15 feet in the lower portion of Falls Lake, and that the anoxic bottom waters have a high flux of ammonium emitted from bottom sediments that feed this algae bloom (Figure 8). Preliminary data from Falls Lake indicate that nutrient inputs from bottom sediment may exceed nutrient inputs from surface waters. We will sample bottom sediments and evaluate seasonal changes in nutrients fluxes into subsurface waters in 2016 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 seismic equipment the depth of sediment will be measured and the volume and organic content of the sediment will be quantified. This data will be combined with upper lake nutrient concentrations to compare the nutrient flux from the Eno and Knapp of Reeds Rivers to the flux out of the lake bottom sediments.

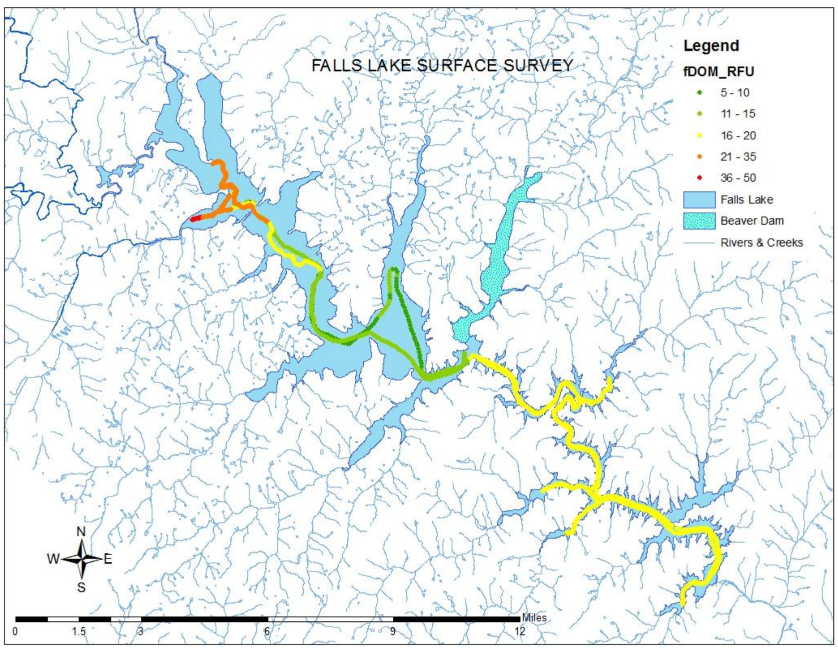

Figure 7. DOM in the surface waters of Falls Lake after the fall overturning event. During the summer anoxic bottom waters feed nutrients into the lower waters of the lake which feeds a subsurface Chl a maximum that builds up DOM concentrations in the lower part of the lake.

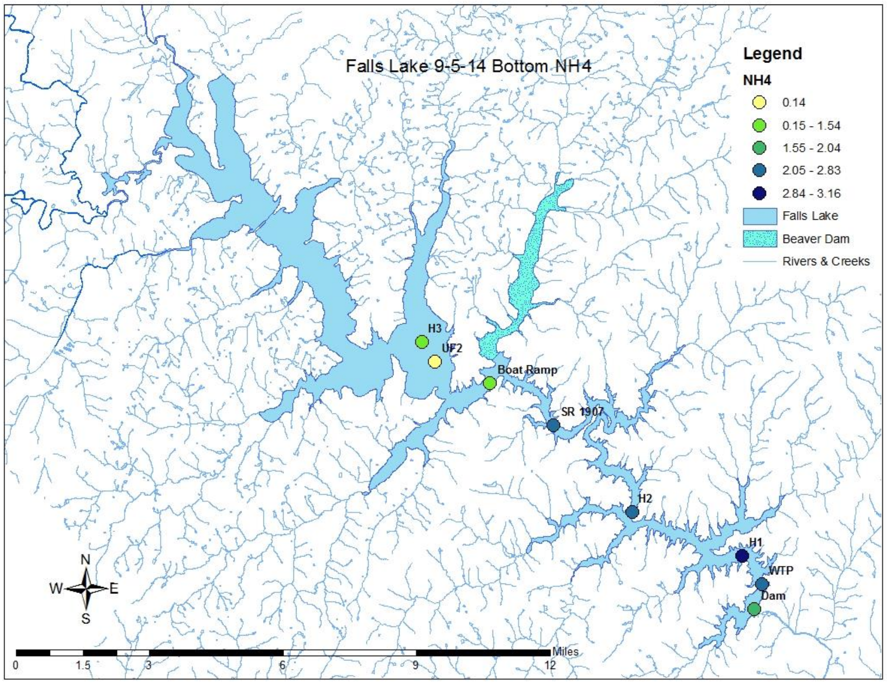

Figure 8. Ammonium concentrations in the bottom waters of Falls Lake, the ammonium nutrient flux from the anoxic bottom sediments builds up in the hot summer months.

Summary:
RiverNet is a river water quality monitoring system that has significantly 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 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 9). 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.

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

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Figure 9. 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 are increased in the Neuse River Basin until 2010, and have been decreasing since then..
- 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 not anoxic and there is no subsurface algae maximum, but Falls Lake has strongly developed bottom water anoxia and nutrient fluxes from the bottom sediments have developed a subsurface algae community the is on the

oxic/anoxic boundary ~10-15 foot depth.

- 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.