EXECUTIVE SUMMARY
LEGISLATIVE REPORT
2012

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 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 $300,000 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 $286,500 was allocated to the program for operations in the 2012-13 period. The RiverNet Monitoring network has been operated over the past 12 years. During this past year we have employed novel nutrient mapping techniques in water supply lakes as well as critical “at-risk” rivers. Rivernet continues to monitor nitrate flux in the Neuse basin, and continuously operates 2 stations in the Cape Fear River Basin where large numbers of swine CAFO’s are located. Five stations are operating in the basin from Raleigh to Fort Barnwell, with one station in the Contentnea watershed, and four are along the Neuse main stem (Figure 1). Two stations are also operating in the Great Coharie and Black River watersheds in Sampson County (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 rivers and lakes. The nutrient mapping technology spatially quantifies

nitrate, pH, Eh, temperature, conductivity, Chl a, and CDOM in surface waters. During the past year nutrient maps were made of the Great Coharie, Little Coharie and the Black River in the Cape Fear River Basin (Figure 5). Nutrient maps were also compiled in Lake Jordan and Falls Lake which are drinking water sources for Cary and Raleigh, NC (Figure 7, 11, 12).

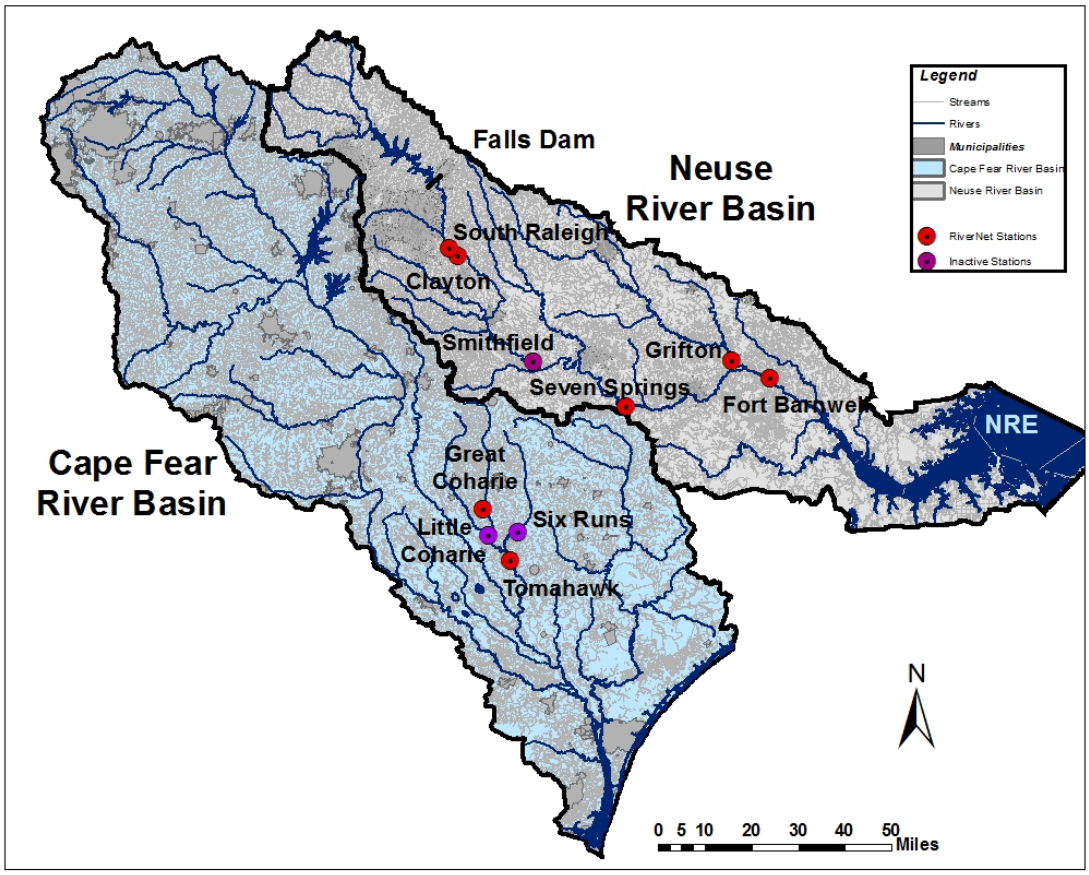

Figure 1. The RiverNet monitoring network with stations located in the Neuse and the Cape Fear River Basins. Stations will monitor water quality in the nutrient sensitive Neuse River Basin and on the major rivers in sub-basin #19 in the Cape Fear River Basin. Three stations were damaged by Hurricane Irene in August 2011 and have been discontinued due to a lack of funding.

RiverNet: RESULTS 2012

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. To accurately measure nitrate flux to coastal waters, high 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. A large proportion of the nitrogen flux to coastal waters occurs during these storm events. But these storm events are modulated by climate oscillations.

The RiverNet program results indicate that the ENSO and North Atlantic Climate Oscillations control discharge and water quality in the Neuse River Basin (Figure 2). 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 where conditions are controlled by the difference of sea-level pressure between the Icelandic Low and the Azores High Pressure zones. This difference controls the strength and direction of westerly winds and storm tracks across the North Atlantic. When the North Atlantic Oscillation index is positive, the westerly flow across the North Atlantic and Western Europe is enhanced. 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 the atmosphere.

El Nino or warm central Pacific conditions occurred in 2002, 2006, and 2009 (Figure 2). 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 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 2012 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 2002 event (Figure 2). However, if the El Nino index stays in a neutral phase and the NAO increases, fluxes will increase during 2013.

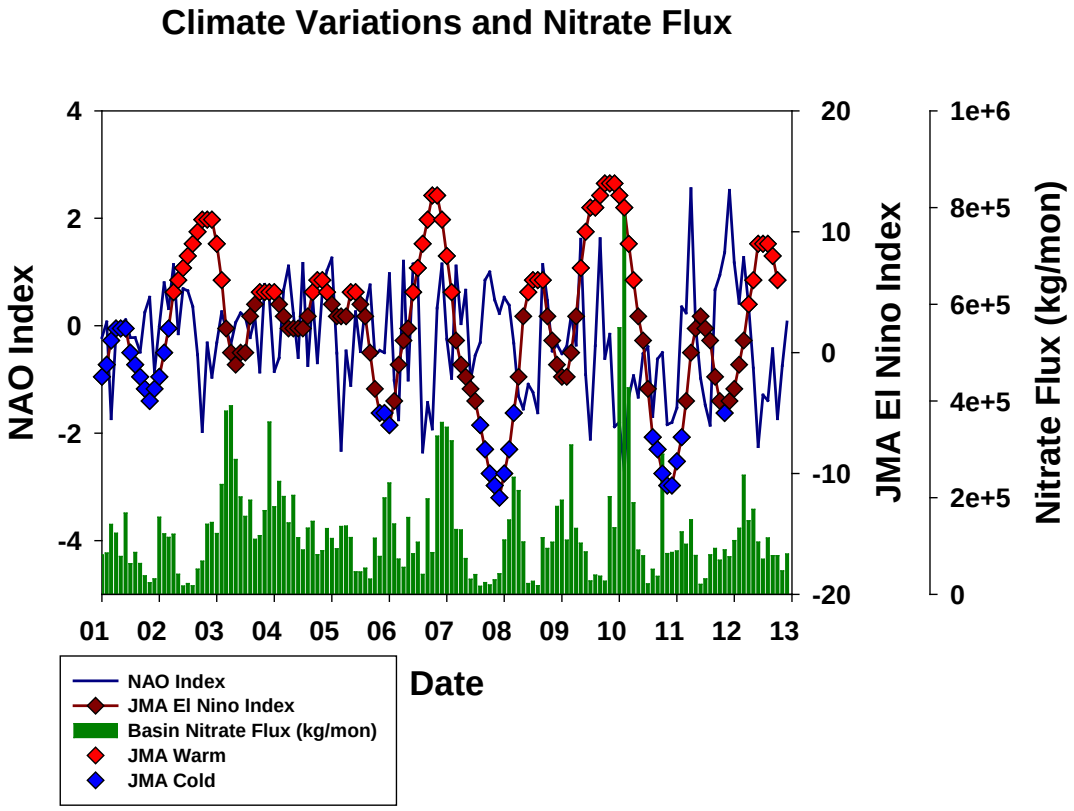

Figure 2. Daily discharge and Monthly N flux at Fort Barnwell North Carolina at the bottom of the Neuse River Basin. This graph represents over 280,000 individual measurements at this one station.

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 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 not getting better so that high resolution monitoring needs to continue. The average nitrate concentrations in the basin have increased over the past decade in a stepwise fashion (Figure 3). Concentrations were lower prior to 2005, increased from 2005 to 2009, and then have increased again in the 2010 to 2012 period. The large nitrate flux of 2010 in the Neuse Basin is also associated with increased discharge in the basin (Figure 4). The cold climate phases show better water quality conditions and lower discharge levels, so the climate oscillation effects are well illustrated by comparing the discharge, nitrate flux, and El Nino Index (Figures 4).

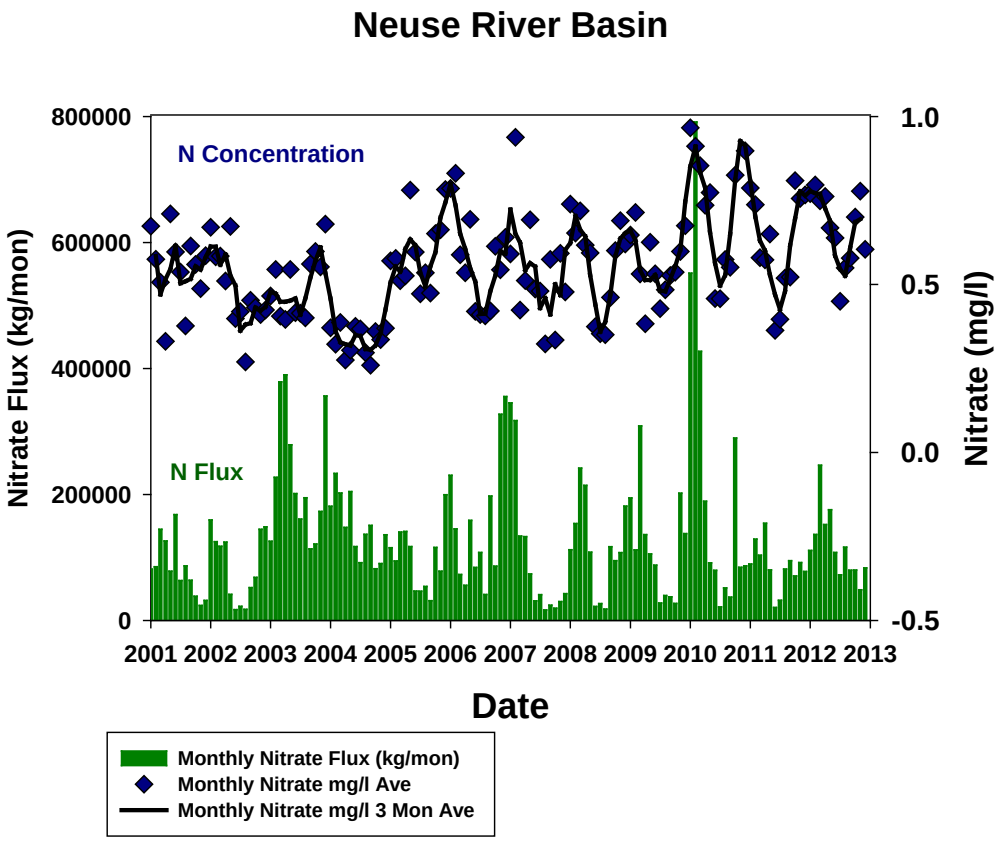

Figure 3. Monthly N flux at Fort Barnwell North Carolina versus nitrate concentration. Nitrate concentration is a poor predictor of water quality trends, but nitrate concentrations in the lower Neuse have increased over the past decade with the highest values observed after 2010.

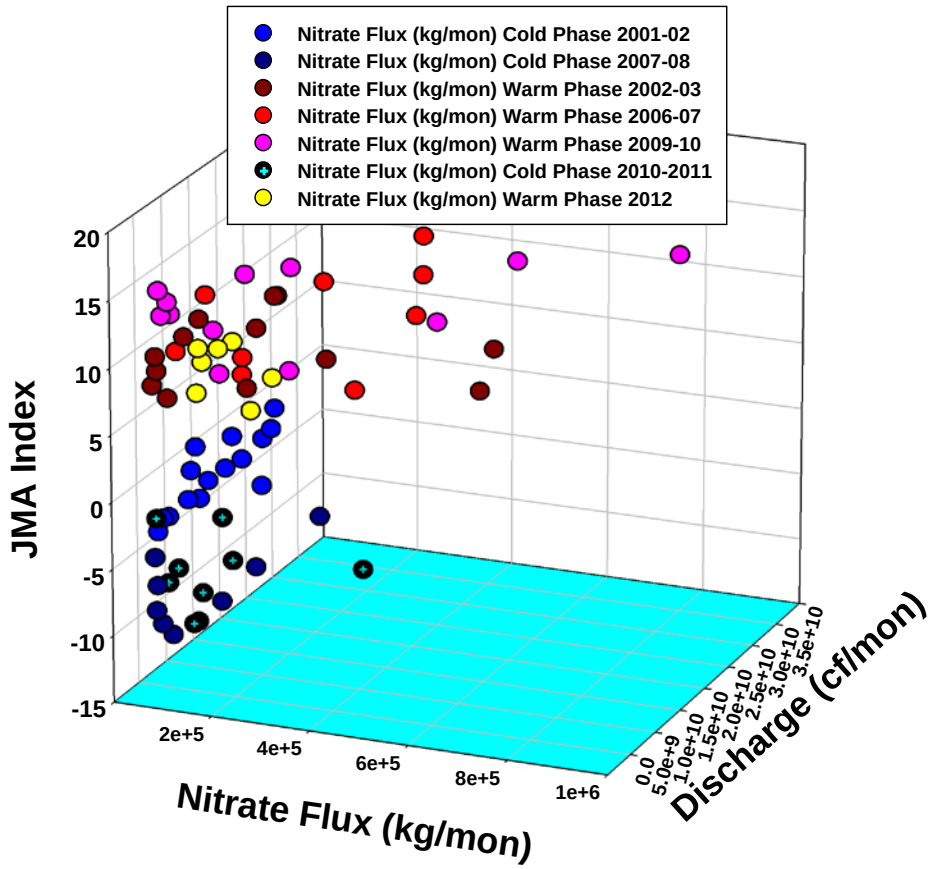

Figure 4. Monthly N flux at Fort Barnwell North Carolina versus Discharge and the El Nino climate index plotted versus warm, neutral and cold years. Highest fluxes are observed during the warm years. N Fluxes for the 2009-10 El Nino events is greater than the 2006 event, N fluxes in the cold phases are increasing as well.

The El Nino and NAO climate oscillations have been antithetic (opposite) since this monitoring program was begun in 2001, in effect canceling the effect of each other out and improving water quality on the North Carolina coastal plain. During the 1990's the two climate oscillations were sympathetic and large fish kills were prevalent in the lower Neuse River Basin and coastal waters. The trend of increasing nitrate flux with increasing average river nitrate concentrations suggests that environmental impacts and problems in the Neuse which were prevalent in the 1990's may reappear in this decade.

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 2 years in a predominately agricultural basin (Figure 5). Two stations were damaged by Hurricane Irene and have been discontinued due to funding restrictions. Watershed nutrient mapping completed in rivers and in lakes (Figure 6) indicates that wetlands control river nitrate levels, not proximity to swine CAFO's in sub-basin #19 (Figure 5). Increases in river nitrate in the Little and Great Coharie Creeks

are found near artificial tile drain systems and near cattle facilities that do not have riparian buffers. Swine operations in this watershed have hydric buffers and do not appear to affect the river nitrate levels except near tile drains. Over the next year we will work with swine CAFO operators to test new tile drain treatment ponds that redirects tile drainage back into hydric soils. This will reduce the environmental nitrogen impact of these farms, and Rivernet monitoring techniques will document these improvements.

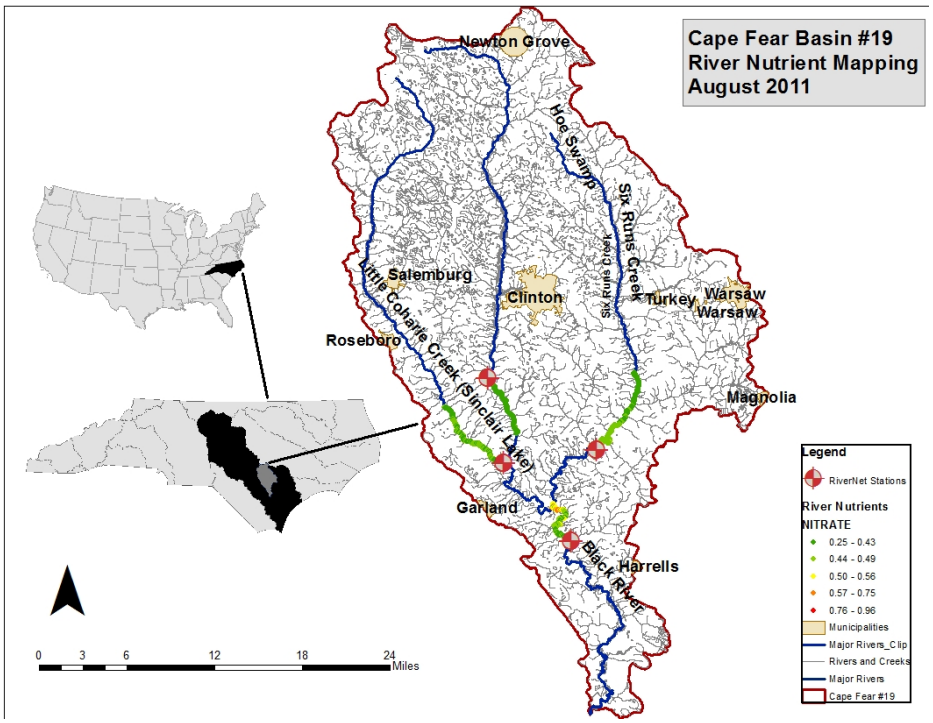

Figure 5. Nutrient watershed mapping sites in the Cape Fear sub-basin #19 during low flow conditions.

Figure 6. Nutrient mapping in rivers (kayak) and drinking water reservoirs (boat in Falls Lake).

Lake/Reservoir Nutrient Mapping

We had adapted the nutrient mapping technology to a Jon boat to efficiently map nutrients in lakes that serve as drinking water reservoirs for North Carolina (Figure 6). Nitrate is elevated in the upper portions of Falls Lake in the spring and summer months, which stimulates Chl a blooms in the upper portion of the lake (Figure 11). Dissolved organic matter is also high in the upper portion of the lake's surface waters (which we measure as CDOM, the optically measured portion of dissolved organic matter - DOM). DOM accumulates in the deeper portion of the lower lake and is a problem for treatment of lake waters for drinking in the fall when the lake overturns.

Nutrient inputs are found in the upper portion of Falls Lake coming from sources in Durham, and from the center of the lake in Barton's Creek (Figure 7). This stimulates phytoplankton growth that results from increased Chl a, and CDOM concentrations in the upper shallow portion of the lake. During the next year,

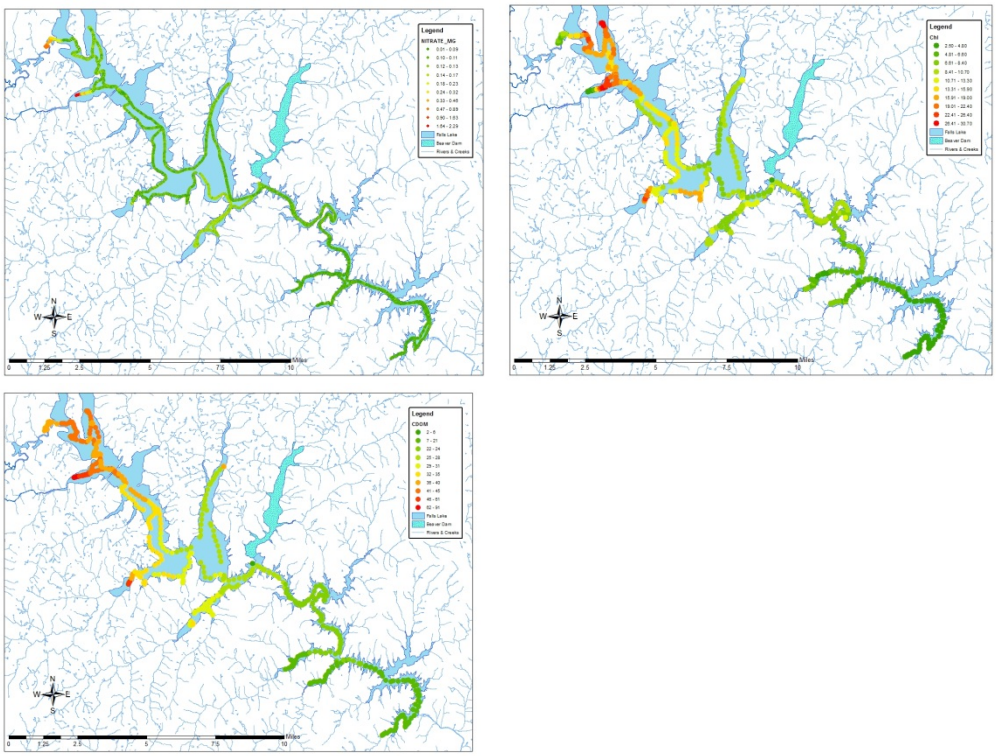

Figure 7. Nutrient maps of Falls Lake for nitrate (upper left), Chl a (upper right) and CDOM (dissolved organic matter, lower left panel). Nutrient inputs are from the upper portion of the lake and Barton Creek.

Rivernet will collaborate with the USGS Raleigh office to investigate nutrient sources in the Eno River Basin. Nutrient sources in the Eno River with be identified with stable nitrogen isotopes, and critical portions of the Eno will have nutrient mapping completed during high and low flow conditions. RiverNet is also working with the Shuying Wang in the Winston Salem NC DENR Regional Office

to apply stable isotope nitrogen techniques available to solve ground and surface water quality problems in the area. This will ensure that the wrong parties are not blamed for water quality problems, and the solutions employed will be cost effective in protecting our water resources.

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 the upper part of Falls Lake from the Eno River. 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 8). 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.

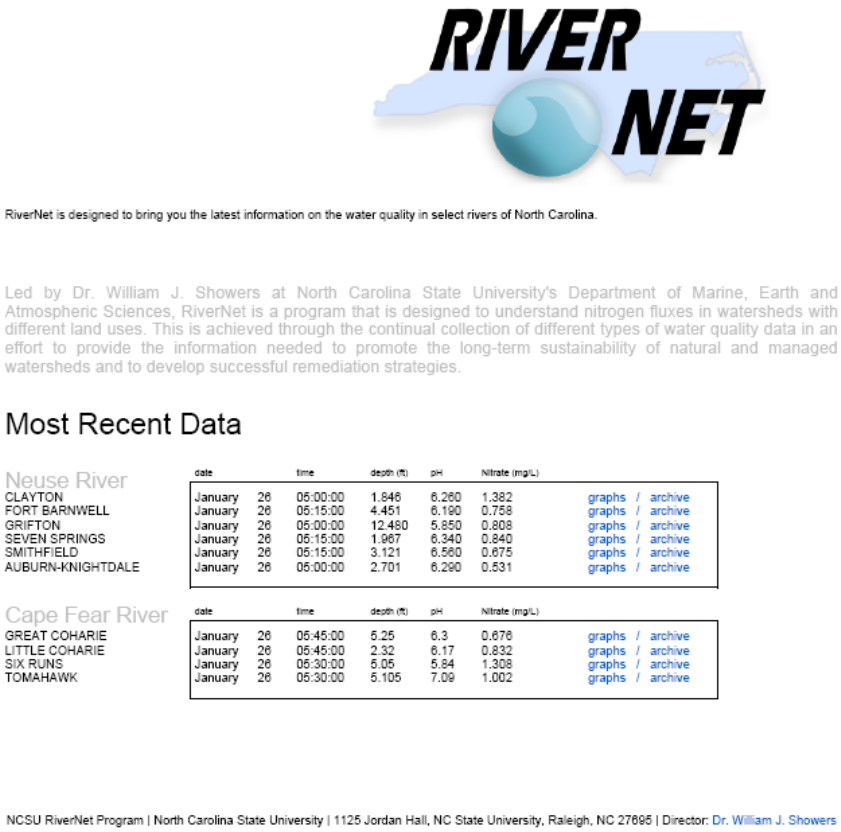

Figure 8. The redesigned web page allows easy access to the data generated by this project.

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. These climate cycles are the El Nino/La Nina oscillation, which has a 5-7 years time period, modulated by the NAO (North Atlantic Oscillation) which has a 1-2 year cycle. These climate cycles must be considered when planning for water quality and water availability. Nitrate concentrations are increasing in the Neuse River Basin over the past decade and fluxes during the comparable different warm and cold phases are getting larger.
- 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.
- Measurement of surface and groundwater nitrate fluxes with the RiverNet technology has shown that groundwater N additions are episodic with time and space and cannot be understood or mapped without high resolution spatial and temporal data.
- Because of this project, remediation wetlands have been installed at the City of Raleigh Neuse River Waste Water Treatment plant, and can reduce about one half of the flux to the Neuse River via surface streams. This technology is now being employed by Smithfield Foods to reduce the nutrient footprint of swine CAFO's by treating tile drain discharges in Waverly, VA. If successful this technology can be employed at low cost in North Carolina.
- New optical measurement techniques are less expensive than the chemical measurement techniques and will allow the RiverNet program to map nitrate, Chl a, and CDOM on a basin or reservoir scale.
- 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 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.

The progress towards watershed N flux and N mapping that the RiverNet program made this past year is an important next step in evaluating and designing remediation strategies to protect our surface, estuarine and coastal water quality. 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 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.