EXECUTIVE SUMMARY
LEGISLATIVE REPORT
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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.

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 2010 and $599,695 was allocated to the program for this period. The RiverNet Monitoring network has been operated over the past nine years. During this past year we have employed novel river nutrient mapping techniques and groundwater flux measurements to quantify deep groundwater flow paths transporting biosolid nitrogen into the river at the Neuse River Wastewater Treatment Plant. Groundwater fluxes were found to be the same magnitude as the surface water stream fluxes at this site. This year we continue monitoring in the Neuse basin, and are installing 4 more stations in the Cape Fear River Basin to monitor water quality in a concentrated swine CAFO area. Six stations are operating in the basin from Raleigh to Fort Barnwell, with one station in the Contentnea watershed, and five are along the Neuse main stem (Figure 1). Four stations are being installed in the Six Runs Creek, the Greater and the Lesser Coharrie watersheds in Sampson County (Figure 2). Physical water quality property measurements with nitrate concentrations are made every 15 minutes. The data is transferred to a server at the NCSU Raleigh 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 watershed mapping in the Neuse and Cape Fear Watersheds.

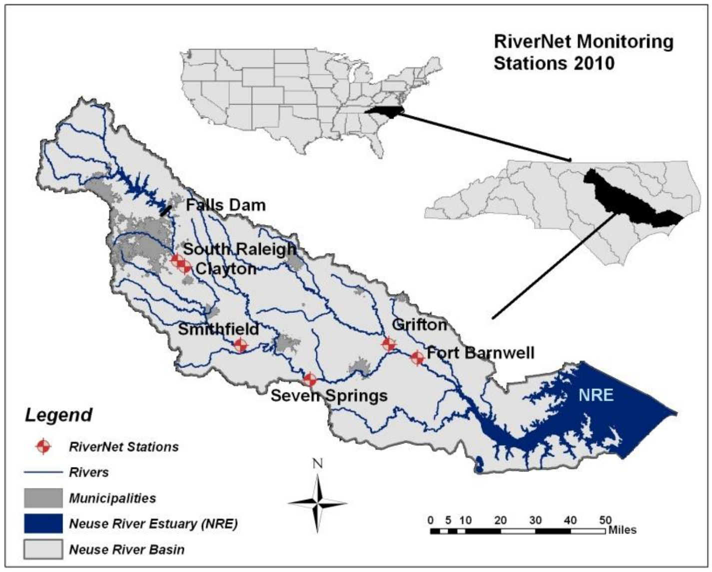

Figure 1. The RiverNet monitoring network with stations located above and below the Neuse River Waste Water Treatment Plant (NRWWTP). Due to continued budget restrictions, two lower basins stations were temporarily closed down at Hookerton and Bear Creek.

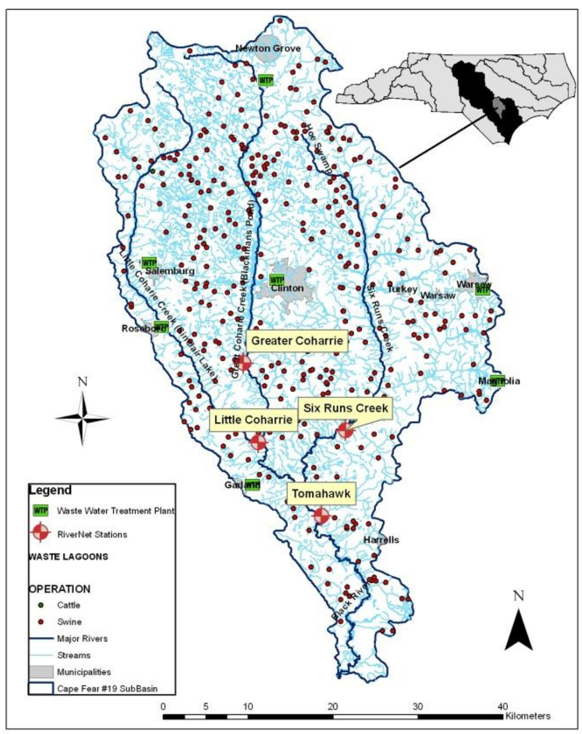

Figure 2. The RiverNet monitoring network with stations located in the Cape Fear River Basin. Stations will monitor water quality on the major rivers in sub-basin #19, river mapping with DNA identification will locate “hot spots” within the basin. There are 7 municipal waste water treatment facilities in the basin with a swine CAFO design capacity of 1.6 million animals.

RiverNet: Results 2009

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. In 2006 an El Nino began to build in the equatorial Pacific that peaked in fall 2006. The 2006 El Nino event and was slightly larger in magnitude than the 2003 El Nino event, and has been followed by the cold phase La Nina that continues to decrease temperatures in the equatorial Pacific. In 2007, the N flux in the Neuse Basin increased with discharge levels similar to the fluxes observed in 2003 (Figure 2). In 2007 the El Nino transitioned in late spring to the La Nina cold phase and fluxes dramatically decreased. There has not been a significant La Nina event since 1975, so the extent of the La Nina effects is not well known. The cold phase in the summer of 2007 resulted in a drought over the entire SE United States. Rainfall has decreased, and river discharge, groundwater levels, and N flux fell in the second half of 2007. 2008 was a neutral year, while during the last half of 2009 an El Nino similar to 2003 appeared, but water and N fluxes remained low as the North Atlantic Oscillation was in a negative phase (Figure 2). Over the past nine years there is an overall trend of increased N flux in the Neuse River basin, and the inter-annual N flux variations are significant and are related to large scale climate oscillations. Nitrate concentration in the river is a poor predictor of water quality trends (Figure 3). Prior to the 2006 El Nino event, during low flux intervals the nitrate concentrations increased. After 2006 concentrations rise with increased discharge and flux. Flux measurements are better indicators of potential eutrophication events in the NRE estuary and coastal waters, but flux/concentration relationships have changed since 2006 (Figure 3).

The two large scale climate oscillations that affect North Carolina precipitation and hydrology are El Nino and the North Atlantic Oscillation. Nitrate flux increases with positive El Nino oscillations. 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. This difference controls the strength and direction of westerly

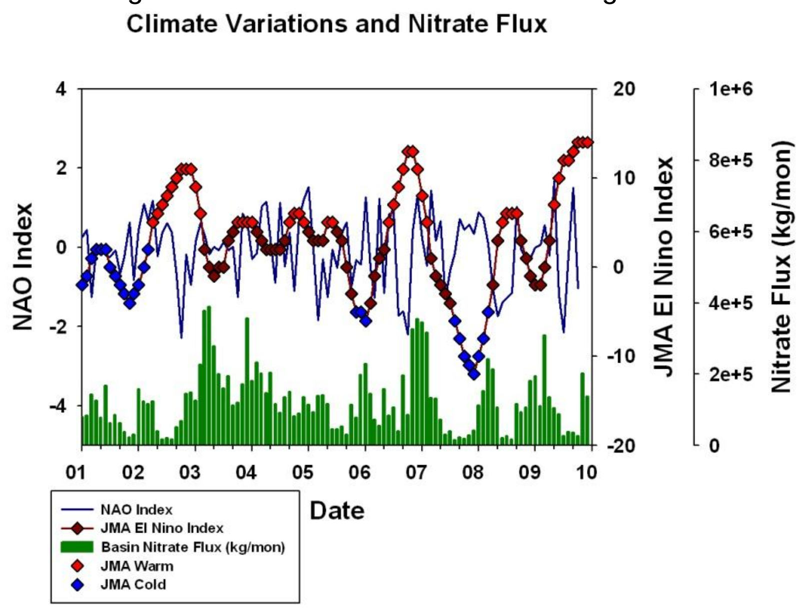

Figure 2. Daily discharge and Monthly N flux at Fort Barnwell North Carolina at the bottom of the Neuse River Basin. This graph represents over 178,000 individual measurements at this one station.

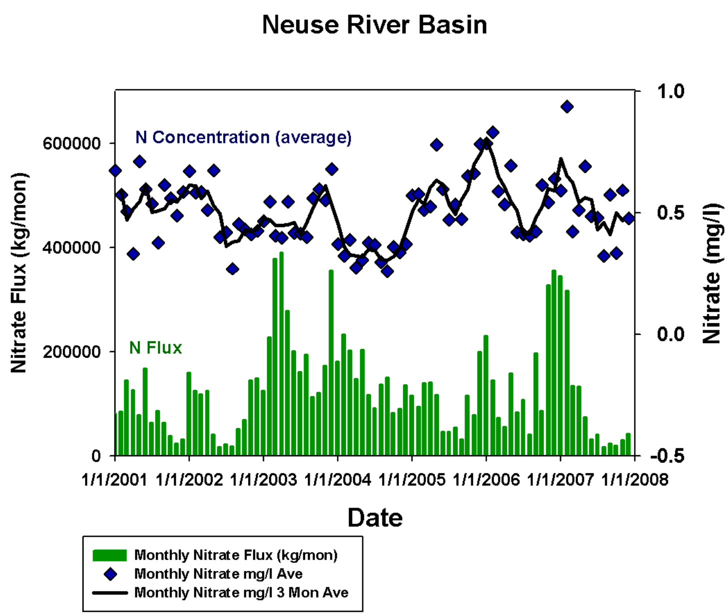

Figure 3. Monthly N flux at Fort Barnwell North Carolina versus nitrate concentration. Nitrate concentration is a poor predictor of water quality trends, during high flux periods concentrations tend to be lower that during low flux intervals.

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 this NAO 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 climate oscillation effects are well illustrated by comparing the discharge, nitrate flux, and JMA El Nino Index (Figures 4). When nitrate flux per year is plotted, there is no apparent

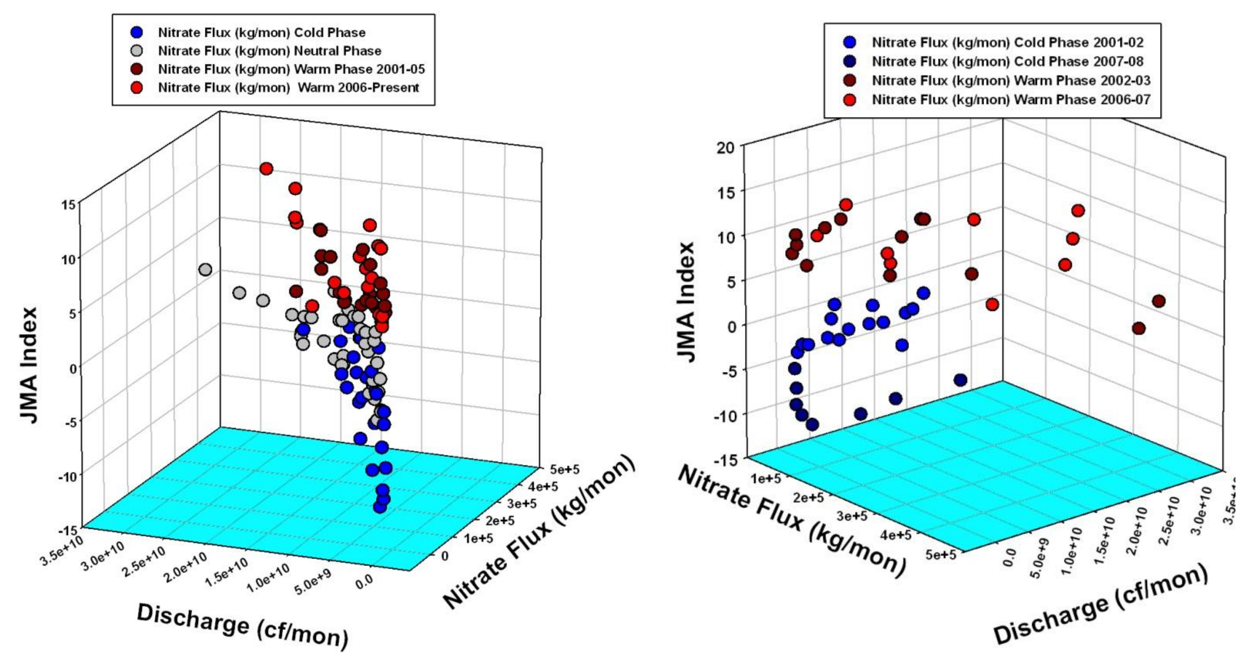

Figure 4. Monthly N flux at Fort Barnwell North Carolina versus Discharge and the El Nino climate index plotted versus warm, neutral and cold years. Highest fluxes are observed during the warm years. N Fluxes for the 2003 El Nino events is greater than the 2006 event, even though the JMA was higher in 2006.

trend, but when the nitrate flux is plotted for the warm, neutral and cold phases, the differences are apparent (Figure 4). There is also a difference in the warm high nitrate fluxes over the last decade. Prior to 2006 the warm periods had higher basin-wide N Fluxes than after the 2006 El Nino Period (Figure 5). This decreased warm phase flux coincides with the change in concentration and flux relationship (Figure 3). The changes in the pre- and post-2006 warm phase N flux may also be the result of differences in land use and indicate changes in agricultural inputs or more improvements of municipal NPDES dischargers as populations increase in the basin. These changes will be documented in the next phase of mapping nutrients in the Neuse and Cape Fear watersheds.

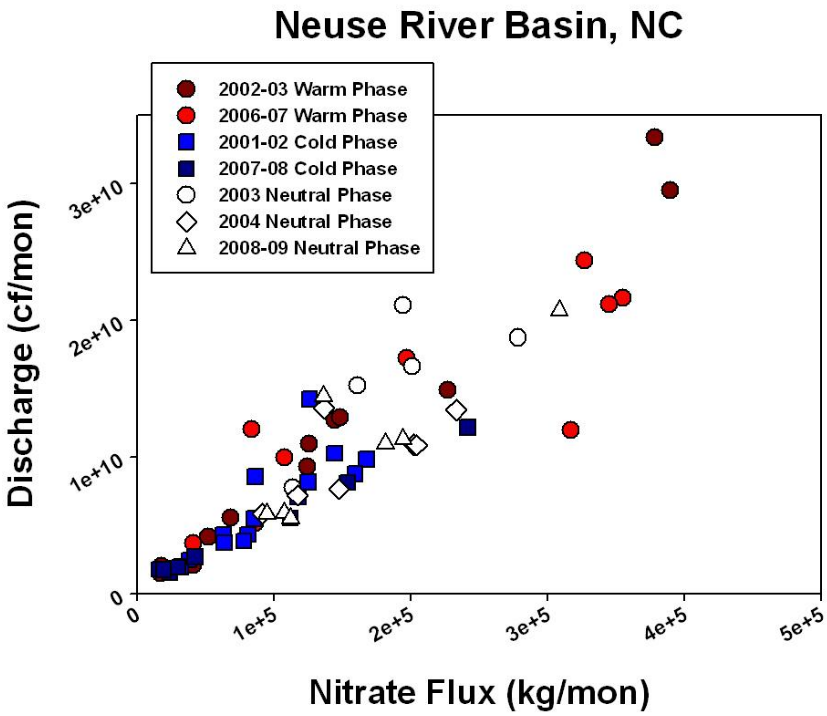

Figure 5. Monthly N flux at Fort Barnwell North Carolina versus Discharge plotted against warm, neutral and cold years with the pre- and post-2006 warm phases separated. Highest fluxes occur prior to the 2006 El Nino event indicating that when like climate phase fluxes are examined, water quality is improving in the Neuse River Basin.

CONTAMINATED GROUNDWATER FLUX OF NITRATE TO THE NEUSE RIVER

Waste application fields accumulate nitrate, but the movement of nitrate from under these fields to surface waters is not well understood. Previous results have shown that the movement of groundwater nitrate from under the Neuse River waste water treatment plant application fields into the Neuse River is significant. The amount of nitrate entering the river from contaminated groundwater is 58% the flux of nitrate released from the plant over a 5 year period. This contaminated groundwater flux is significant to river nitrate flux, and is not directly related to precipitation or river discharge. In the 2007 calendar year, nitrate gains in the reach exceeded the amount of nitrate discharge in the treated effluent from the plant and are related to El Nino climate oscillations. The total stream flux varies from 600 to 800 kg/month, which represents 100 % of the river nitrate gains during low flow conditions and from 20 to 50% of the river nitrate gains during high flow conditions. The missing nitrate flux must be related to deep groundwater discharge into the river, which is exceedingly hard to locate and quantify.

Using the new optical nitrate analyzers with GPS location we can map where the deeper groundwater flux into the river occurs at the NRWWTP. River nitrate concentrations increase where basaltic dike cross the river (Figure 6). There are two large basaltic dike complexes that bisect the NRWWTP biosolid waste application fields in the northeast and northwestern portions of the plant. The riverbed was sampled seasonally (Figure 7) and pieziometers were used to measure the water flux out of the riverbed. Highest flux rates were found in the winter and spring, while the highest groundwater concentrations were observed in the summer and fall periods (Figure 7). The annual flux of deep groundwater nitrogen in these “hot spot” locations was determined to be about equal to the N flux from streams draining the biosolid application fields. The City of Raleigh has contracted ENSR to construct remediation wetlands at three different stream sites at the Neuse River Wastewater Treatment Plant to reduce the “non-point” N flux from plant to the Neuse River. This remediation plan is the direct result of the ongoing research of the RiverNet program. These results indicate that the remediation wetland construction program will only be partially successful at stopping biosolid nitrate leaving the waste application fields and entering the river. River monitoring will continue next year at this site to determine how effective the remediation efforts by the City of Raleigh are at preventing biosolid nitrogen from entering the Neuse River from shallow and deep groundwater paths.

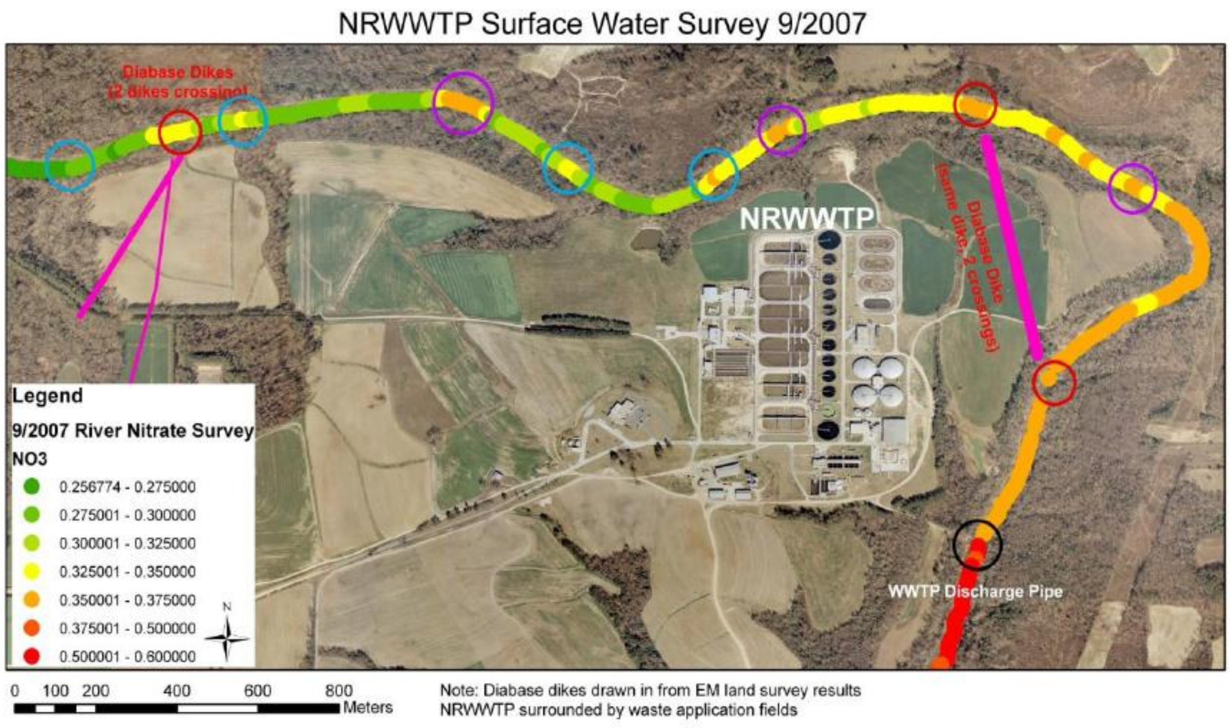

Figure 6. River nutrient mapping of stream nitrate concentrations indicate that deep groundwater contaminated with nitrate enters the Neuse River where large basaltic dikes cross the river (red circles). These deep groundwater inputs are minimal at low flow, but increase during high flow conditions. Blue circles are stream nitrate inputs, purple circles are stream inputs not from the plant, and the black circle represents the WWTP discharge pipe.

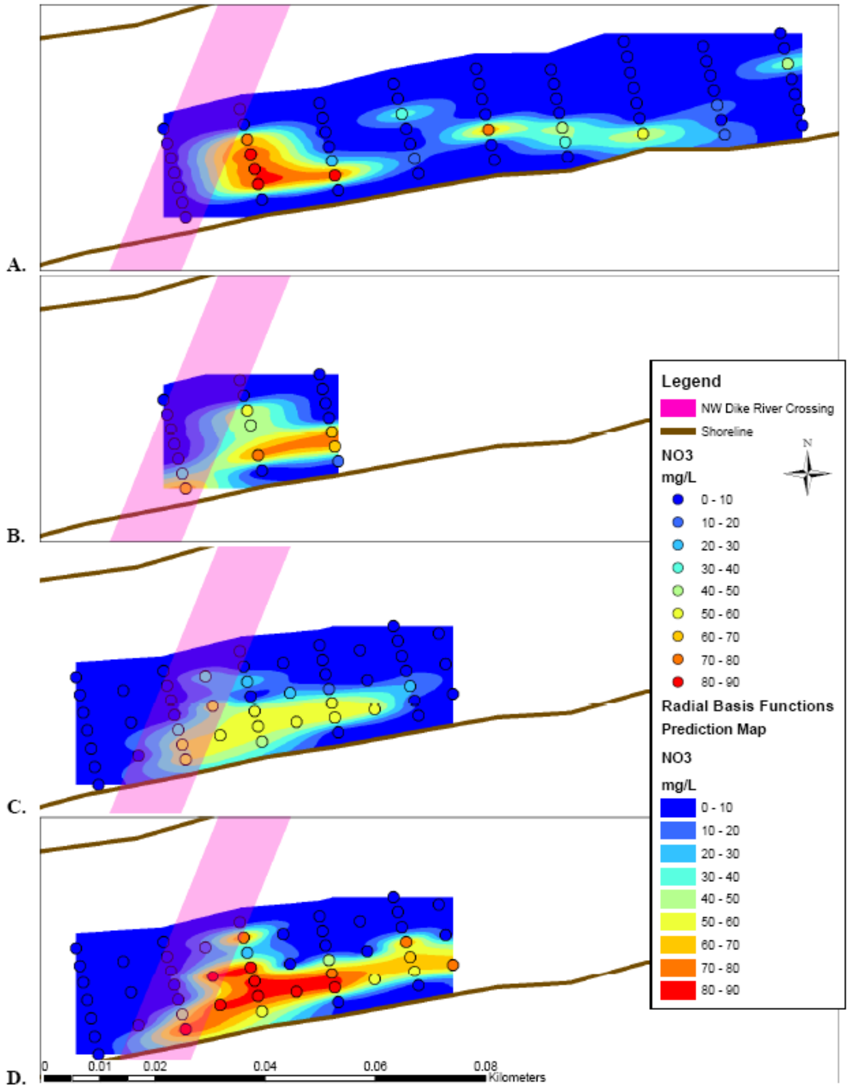

Figure 7. River bed nitrate concentrations that indicate that deep groundwater contaminated enters the river associated with the large basaltic dike {upper right corner of Figure 6) and that this N flux varies seasonally (A. Sept, B. January, C. April, D. July).

MONITORING IN THE CAPE FEAR RIVER BASIN

Monitoring efforts have started in the Cape Fear River basin and stations are currently being installed as equipment is delivered from the manufacturers. We will establish flux stations at bridges in the lower portions of the 6 Runs Creek, Greater and Lesser Coharrie watersheds, and at Tomahawk on the Black River where there is a USGS gauging station. Initial results suggest that the nitrate concentrations are higher in the Cape Fear sub-basin #19 than in the Neuse, and that concentrations decrease downstream (Figure 8). This is different than in the Neuse River basin since nitrate concentrations are lower in the Neuse and increase down basin.

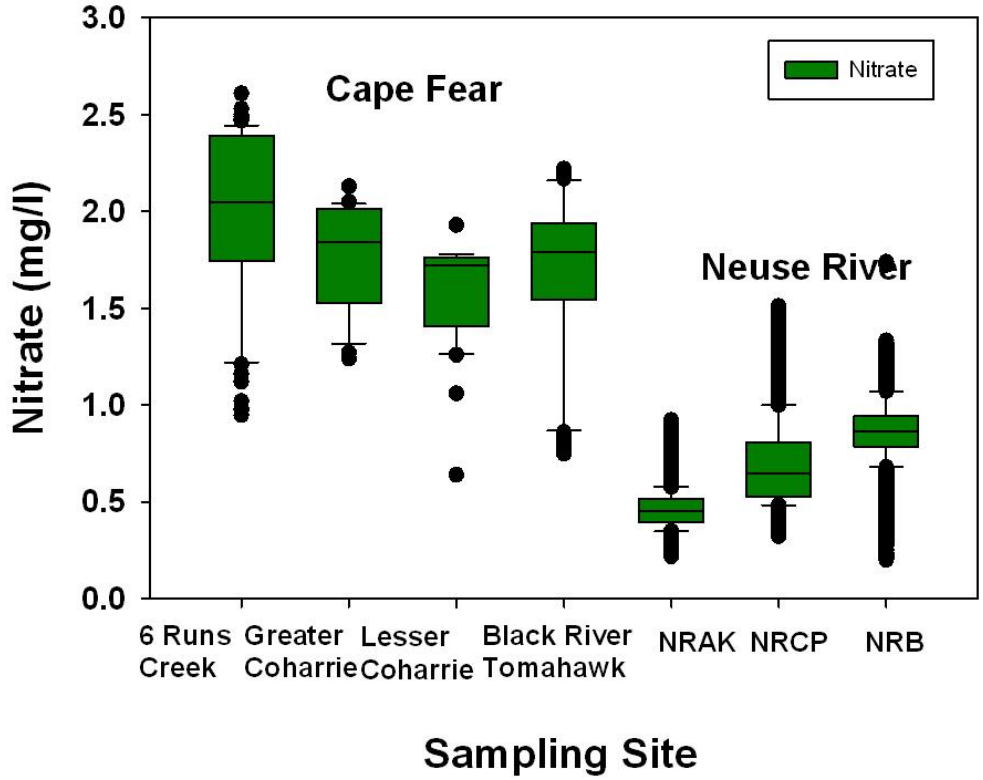

Figure 8. River nitrate concentrations in the Cape Fear and the Neuse River Basin. Nitrate concentrations are higher in the Cape Fear and decrease down the basin (Tomahawk) while concentrations are lower in the Neuse and increase down basin (NRB – Fort Barnwell).

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. At the present time we are combining RiverNet monitoring efforts with the USGS/NC DENR Piedmont Groundwater Observatory at the Neuse River Waste Water Treatment Plant near Clayton NC to understand groundwater nitrate fluxes into the Neuse River. We are also mapping where contaminated groundwater enters the river with a new optical nitrate sensor. These efforts have so far proven to be very successful. These efforts will help design treatment wetlands to remediate some of the groundwater nitrate to protect downstream Neuse River water quality.

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.
- 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 groundwater nitrate fluxes with the RiverNet technology has shown that groundwater N additions are episodic with time periods of hours to days.
- Groundwater nitrate flux at the Raleigh WWTP is about 58% the nitrogen flux from the discharge pipe over a five year period, demonstrating that N groundwater flux is important and cannot be ignored. There are large inter-annual variations that cannot be successfully modeled at this point without more work. Remediation wetlands can reduce about one half of the flux to the Neuse River via surface streams.
- New optical measurement techniques are less expensive than the chemical measurement techniques and will allow the RiverNet program to map nitrate and chl a on a basin or reservoir scale. This next year we will map the Neuse Basin, sub-basin #19 in the Cape Fear, and Falls and Jordan Lakes.
- 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.
- 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.

The progress towards watershed N flux and N mapping that the RiverNet program made this 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 without economic 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 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.