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. Due to budget reductions, $285,000 was available to operate the RiverNet program in 2008. The RiverNet Monitoring network has been operated over the past eight years. During this past year we have converted to digital cell phone transmissions. Digital data transmission will allow real time monitoring during storm events in the future. Last year we completed a co-operative 319 monitoring program with the USGS and DENR to quantify biosolid nitrogen being transported by surface streams into the Neuse River adjacent to the NRWWTP (Neuse River Waste Water Treatment Plant). This project finished in June of 2008, and found that a significant amount of nitrate is transported from the biosolid application fields to the Neuse River, about 50% of what is discharged from the plant on an annual basis. Most of this nitrate is delivered to the Neuse River via surface drainages, but not all the nitrate gains in the river can be accounted by surface water flux and is related to river stage. This year we have investigated deep groundwater biosolid nitrate inputs into the river and determined that basaltic dikes control contaminated groundwater flow (see below). 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 Mainstem (Figure 1). 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 phone 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 and groundwater monitoring at the Raleigh WWTP.

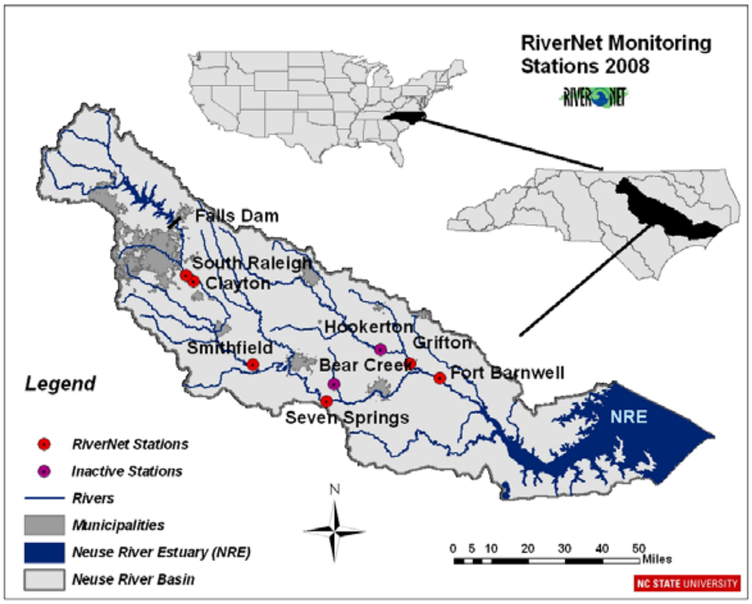

Figure 1. The RiverNet monitoring network with stations located above and below the Neuse River Waste Water Treatment Plant (NRWWTP) to investigate the relationship of groundwater flux from biosolid waste application fields to the river. Due to continued budget restrictions, two lower basins stations were closed down.

RiverNet: Results 2008

Previous years results have shown that there are very rapid nitrate concentration changes and fluxes in the Neuse River in the upper, middle and lower basin (Figure 2 & 3). In 2006 an El Nino began to build in the equatorial Pacific that peaked in Fall 2006 (Figure 4). The 2006 El Nino event and was slightly larger in magnitude than the 2003 El Nino event, demonstrating the important link between global climate indexes and local water quality. In 2008, the N flux in the Neuse Basin decreased from 2007 levels with discharge levels similar to the fluxes observed in 2005 (Figure 2). During this past year the 2007 El Nino transitioned in to a La Nina cold phase and N fluxes dramatically decreased in late 2007. Rainfall decreased, river discharge and groundwater levels fell in the second half of 2007 while the SE United States experiences severe drought conditions. In the spring of 2008 El Nino returned to a neutral phase, but the North Atlantic Oscillation fell which reduced the spring and summer rainfall and N flux in the basin. In the summer both the El Nino and NAO indexes rose, increasing N flux in the late summer as precipitation and river discharge returned to normal levels, but in the fall the El Nino index fell as the NAO rose reducing N flux in the basin during the winter period of this year (see Figure 4).

Over the past eight years there has been a change in the trend in N flux in the Neuse River basin. Up to 2007 there was an increasing trend of N flux in the basin, and the inter-annual N flux variations were significant and are related to large scale climate oscillations. Since the El Nino peak of 2007, there has been a decreasing trend of N flux in the basin. River nitrate concentration remains a poor predictor of water quality trends (Figure 3). Flux measurements are better indicators of potential eutrophication events in the NRE estuary and coastal waters.

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 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

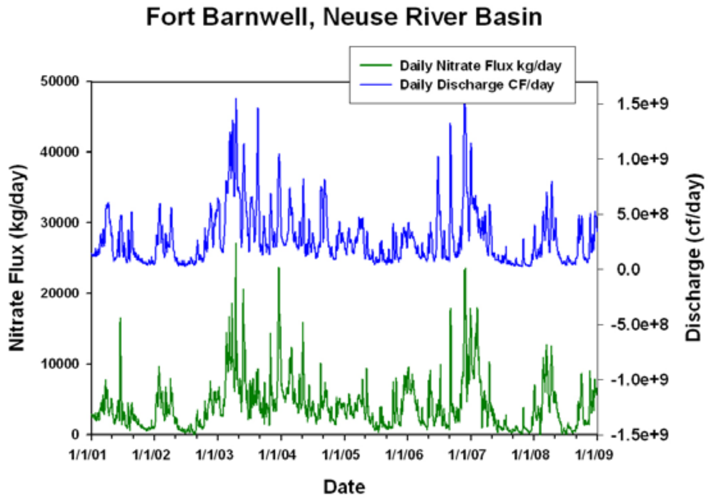

Figure 2. Daily discharge and Monthly N flux at Fort Barnwell North Carolina at the bottom of the Neuse River Basin. This graph represents over 178,000 individual measurements at this one station.

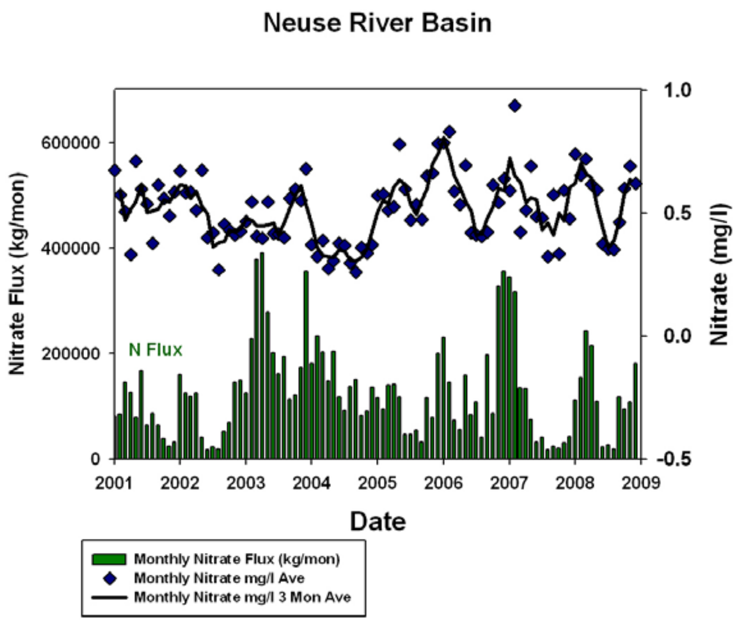

Figure 3. Monthly N flux at Fort Barnwell North Carolina versus nitrate concentration. Nitrate concentration is a poor predictor of water quality trends, during high flux periods concentrations tend to be lower that during low flux intervals.

the negative phase storm tracks are forced further south and northern Europe and the east coast of the US is dry. The 2006-08 RiveNet flux data document this trend through a full ENSO cycle (Figure 4). In 2008 the effects of the La Nina cold phase reduced discharge and N flux in the basin, and normal discharge patterns did not return until the El Nino index returned to a neutral phase in the spring.

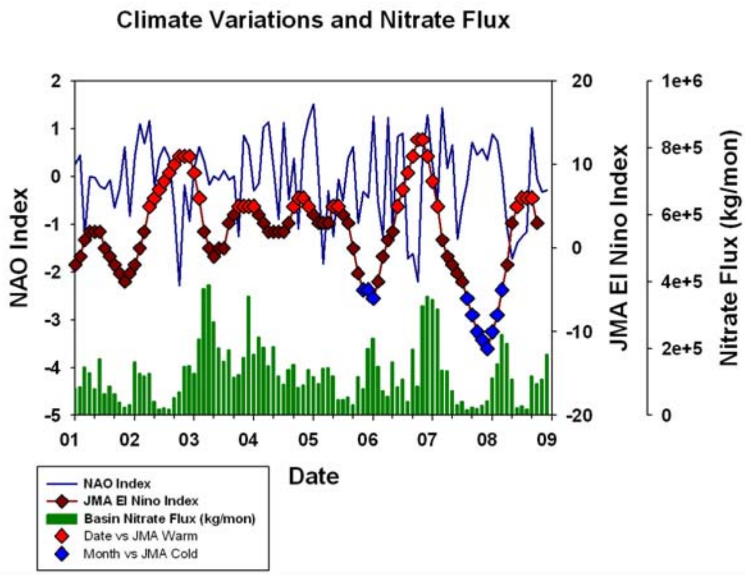

Figure 4. Monthly N flux at Fort Barnwell North Carolina versus two climate oscillations, El Nino and the North Atlantic Oscillation. There has not been a significant La Nina cold phase since 1975.

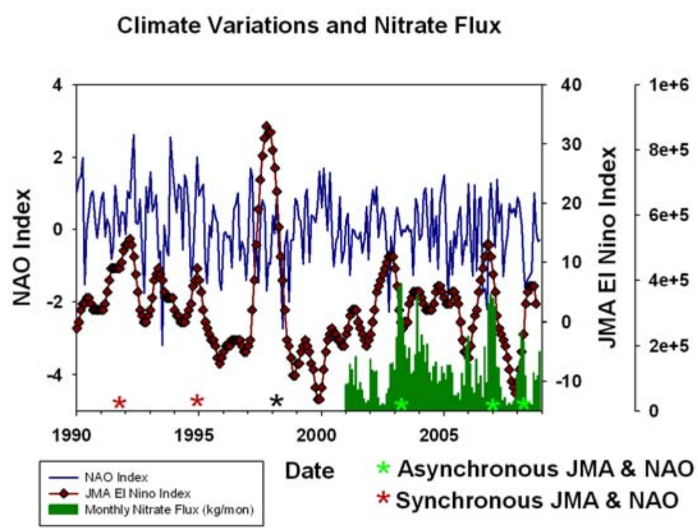

Figure 5. Monthly N flux at Fort Barnwell North Carolina versus two climate oscillations, El Nino and the North Atlantic Oscillation were synchronous in the 1990's and asynchronous after 2000. The nitrate fluxes measured during the El Nino warm phases by the RiverNet program in 2003 and 2007 would be smaller than warm phase fluxes during the 1990's when the NRE experienced large fish kills.

The difference between N flux in the 1990's when large fish kills were present in the basin, and N flux in the current decade is that the El Nino and NOA were synchronous in the previous decade and are asynchronous in the present decade. This asynchronous oscillation between the El Nino the NAO now observed reduces N flux in the basin and leads to an apparent improved water quality in the Neuse Estuary. Positive El Nino and NAO phases occurred synchronously during the 1990's, which enhanced nutrient transport in the basin and led to the negative water quality events, fish kills, hypoxia and anoxia observed in the Neuse River Estuary at this time (Figure 5).

CONTAMINATED GROUNDWATER FLUX OF NITRATE TO THE NEUSE RIVER

Waste application fields accumulate nitrate, but the movement of nitrate from under these fields to the adjacent Neuse River is not well understood. We have investigated the movement of groundwater nitrate from under the Neuse River waste water treatment plant application fields into the Neuse River over the past five years. RiverNet Monitoring Stations have been operated above and below the plant. Groundwater levels were monitored in USGS well clusters in the north-

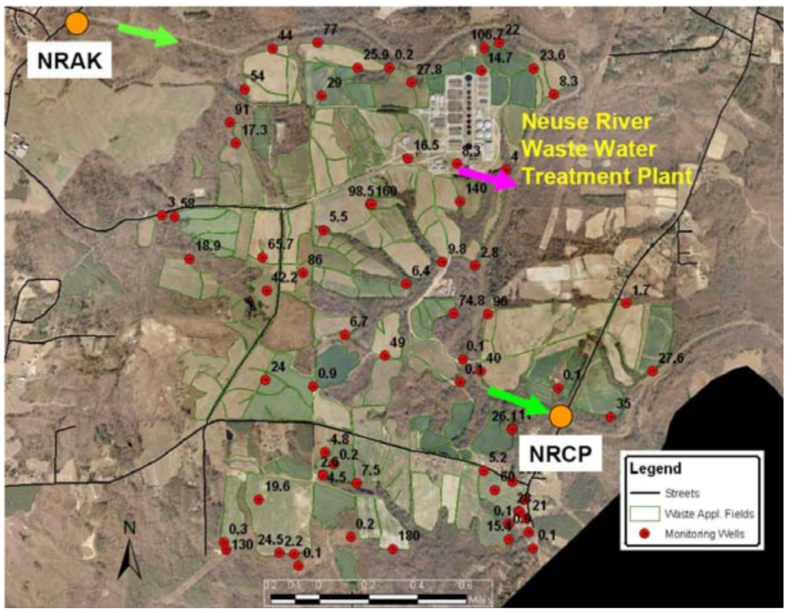

Figure 6. Measuring non-point nitrate gains at the Neuse River Wastewater Treatment Plant near Clayton, NC. Nitrate gains are transported to the river via surface drainages and groundwater and equal about 50% of the nitrogen discharge from the plant on an annual basis.

western part of the plant near the Neuse River. Biosolids have been land applied at this site for the past 24 years, but applications ceased in 2002. The amount of nitrate entering the river from contaminated groundwater is 58% the flux of nitrate released from the plant via the discharge pipe over a 5 year period (Figure 6, Table 1). An EPA funded 319 project measured the nitrate flux from surface drainages at the plant Not all the nitrate gains in the Neuse River can be attributed to these surface drainages. This past year we have developed novel methods to sample and measure groundwater flux out of the Neuse River bed near the plant. Contaminated groundwater enters the river via deep groundwater flow paths controlled by intrusive basaltic dikes in the fractured granite rock that underlies the plant. We have developed and are deploying differential pressure transducers that will record groundwater flux into the river during storm events.

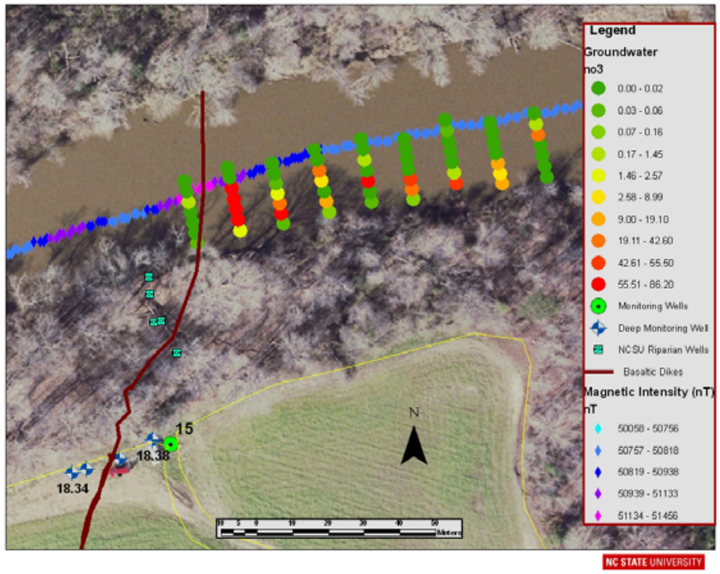

Figure 6. Nitrate contaminated deep groundwater that enters the Neuse River adjacent to the biosolid application fields at the Neuse River Waste Water Treatment Plant.

NRWWTP STREAM NITRATE FLUX RESULTS

Monitoring the stream nitrate flux at the NRWWTP has shown that the nitrate concentrations in the streams are related to the groundwater levels in the mid-slope area (Figure 7). The lower well cluster groundwater levels are tied to the river stage and do not correlate to nitrate flux in the streams. In the summer of 2007, after the high flux El Nino period, groundwater levels were high and the stream nitrate concentrations fell to lower levels than observed during the previous summer period. The streams have different response times to rainfall events, and stream discharge is modulated by groundwater levels. 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 average nitrate flux per day varies from 3 to 14 kg/day (Table 2), while maximum nitrate fluxes can reach over 40 kg/day.

Biosolids have not been applied at the site since 2002, and the stream nitrate concentrations are falling 5-6 years after the last application. USGS age dating in the piedmont of groundwater suggest that the shallowest ground water reservoirs have ages of 3-5 years. This would fit with these nitrate concentration observations. Stream concentrations will rise again if biosolid application was resumed at the site over a similar time frame.

Treatment wetlands constructed onsite should be able to attenuate a large portion of this surface water nitrate flux, which will have a significant impact during low flow conditions on river water quality when downstream conditions are most affected by biosolid nitrate flux from the NRWWTP. During low flow conditions nitrate is flux is reduced in the river because water is lost from the river to the groundwater. Nitrate gains in the river is therefore an underestimate of how much nitrate is exported from the biosolid application fields to the river.

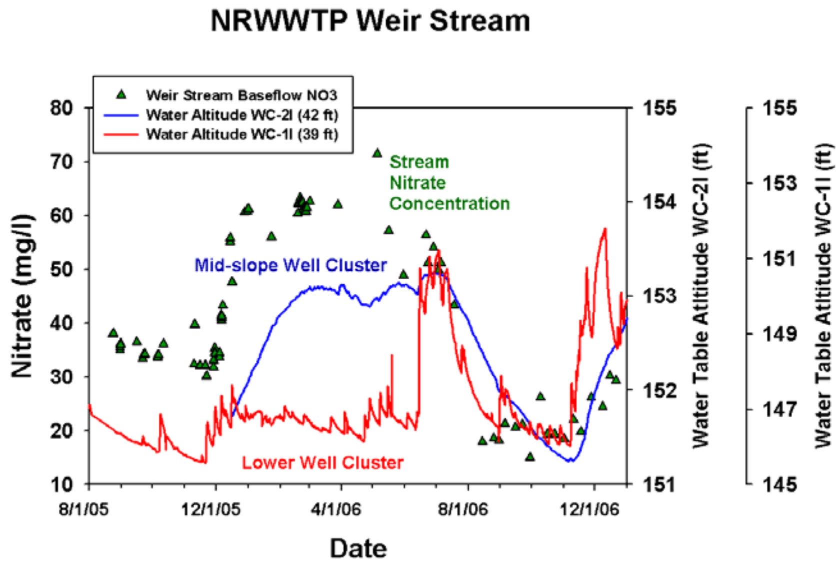

Figure 7. Nitrate concentration in streams draining the biosolid application fields at the Neuse River Waste Water Treatment Plant varies seasonally and is related to the depth of the water table and the water source to the streams. Concentrations are decreasing in the streams since biosolids have not been applied at the site since 2002.

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 and with portable groundwater piezometers. 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 year 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 can not be successfully modeled at this point.
- New optical measurement techniques are less expensive than the chemical measurement techniques and will allow the RiverNet program to expand statewide for reasonable costs. With the advent of digital cell phone services continuous monitoring of river conditions is now possible similar to the GOES satellite technology used by the USGS.
- Nutrient mapping on a watershed scale can identify where contaminated 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.