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 2007. The RiverNet Monitoring network has been operated over the past eight years. During this past year we converted the data loggers to digital cell phone transmissions. Digital data transmission will allow real time monitoring during storm events in the future. Last year we concluded a co-operative program with the USGS and DENR with a 319 monitoring program to quantify biosolid nitrogen being transported by surface streams into the Neuse River adjacent to the NRWWTP (Neuse River Waste Water Treatment Plant). This 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. 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 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.

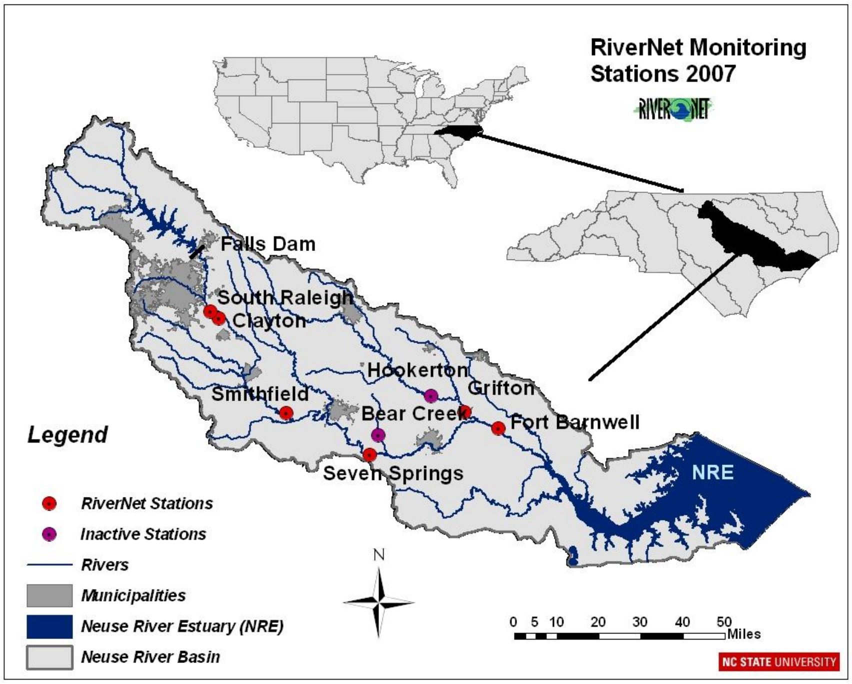

Figure 1. The RiverNet monitoring network with stations located above and below the Neuse River Waste Water Treatment Plant (NRWWTP) to investigate the relationship of groundwater flux from biosolid waste application fields to the river. Due to continued budget restrictions, two lower basins stations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

RiverNet: Results 2007

Previous years 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 are unknown. Rainfall has decreased, and River discharge, groundwater levels, and N flux fell in the second half of 2007 while the SE United States experiences severe drought conditions. Over the past seven years there is a 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. However, nitrate concentration in the river is a poor predictor of water quality trends (Figure 3). During low flux intervals the nitrate concentrations tend to be higher that during high flux intervals, due to the dilution effect. 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

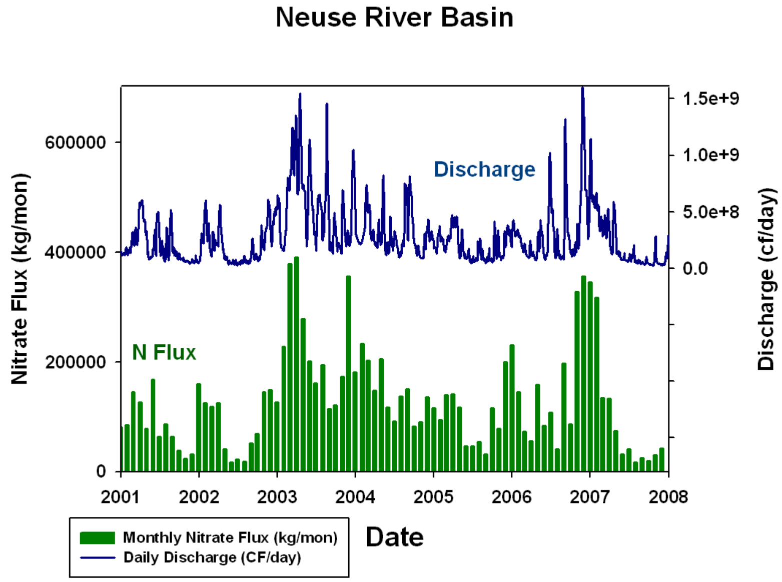

Figure 2. Daily discharge and Monthly N flux at Fort Barnwell North Carolina at the bottom of the Neuse River Basin. This graph represents over 178,000 individual measurements at this one station.

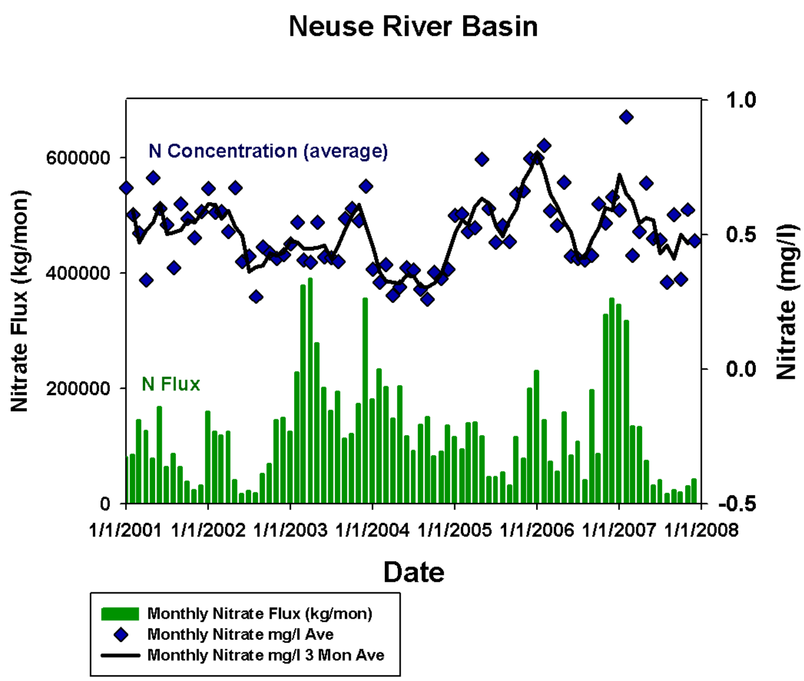

Figure 3. Monthly N flux at Fort Barnwell North Carolina versus nitrate concentration. Nitrate concentration is a poor predictor of water quality trends, during high flux periods concentrations tend to be lower that during low flux intervals.

the negative phase storm tracks are forced further south and northern Europe and the east coast of the US is dry. The 2007 RiveNet flux data document this trend through a full ENSO cycle (Figure 4). In 2008 the effects of the La Nina cold phase will be monitored.

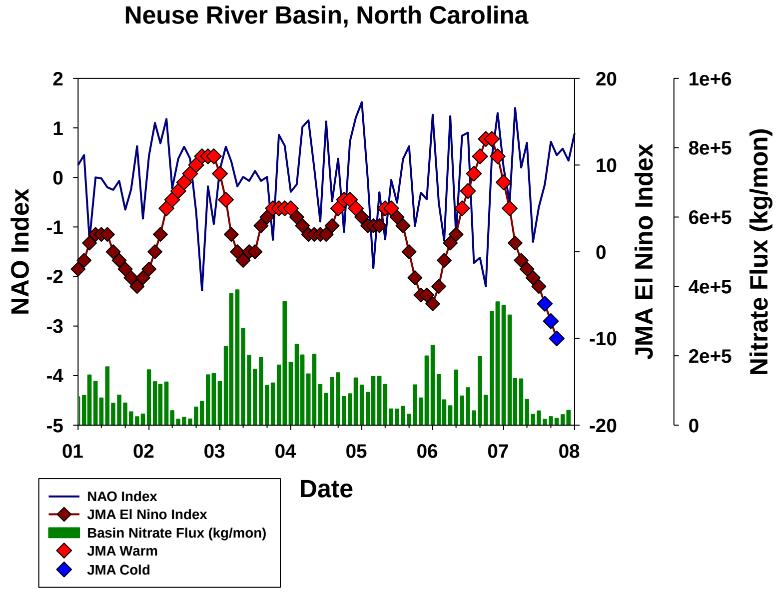

Figure 4. Monthly N flux at Fort Barnwell North Carolina versus two climate oscillations, El Nino and the North Atlantic Oscillation. There has not been a significant La Nina cold phase since 1975.

During the two periods of positive El Nino oscillations (2003 and 2007), enhanced rainfall and nutrient fluxes were moderated by a negative North Atlantic Oscillation index. Nutrient flux did not increase until the NOA became positive. In these two periods of moderate El Nino, the increased flux of nitrate was modulated by the negative NOA phase (Figure 4). During the hypoxic and anoxic

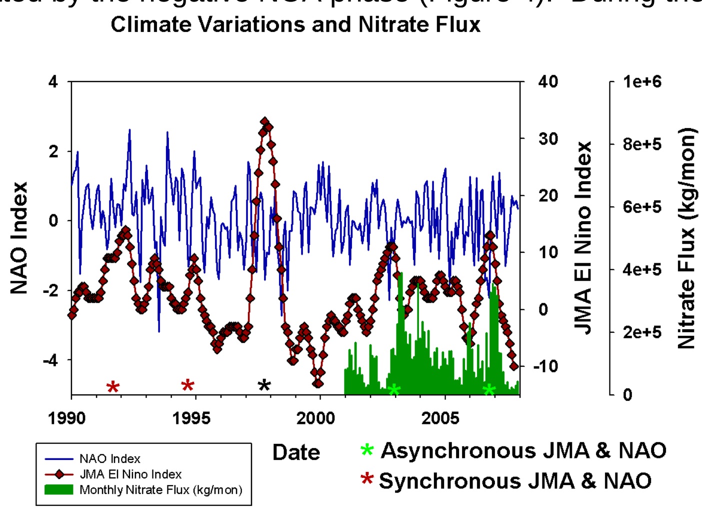

Figure 5. Monthly N flux at Fort Barnwell North Carolina versus two climate oscillations, El Nino and the North Atlantic Oscillation were synchronous in the 1990's and asynchronous after 2000. The nitrate fluxes measured during the El Nino warm phases by the RiverNet program in 2003 and 2007 would be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

events of the 1990's this was not the case. Positive El Nino and NAO phases occurred synchronously during the 1990's, which would have 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 surface waters 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 four years. RiverNet Monitoring Stations have been operated above and below the plant. Groundwater levels were monitored by the USGS in well clusters in the north-western part of the

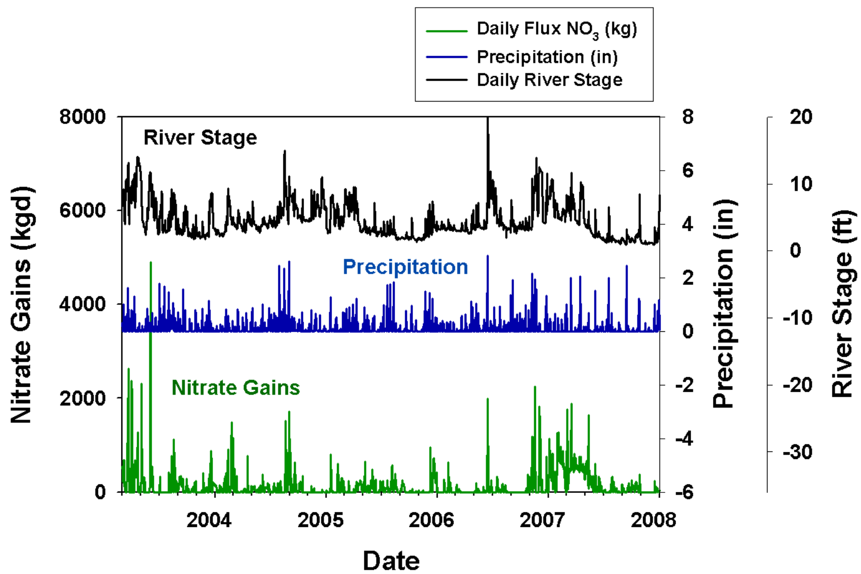

Figure 6. River stage and Nitrate gains at the Neuse River Wastewater Treatment Plant near Clayton, NC. Nitrate gains are not directly correlated to precipitation trends or river stage.

TABLE 1. Nitrate gains in the Neuse River Reach next to the NRWWTP

Calendar Year	Daily Integrated NO3 Gains	% Total NO3 Output NRWWTP	% Total NO3 Output NRCP	Clayton & RDU Precipitation Average (in)	NRWWTP Flux NO3 kg/yr
2003*	58950	59	13	43	140,082
2004	34072	32	11	41	107,262
2005	29065	30	8	38	96,390
2006	27819	33	8	44	84,579
2007	87806	134	30	32	65,610
Average	**47543**	**58**	**14**	**40**	**98785**

* data collected for 9 months from March-December only, note this summary is for calendar years Jan-Dec and not monitoring years (Mar-Mar) as previously reported.

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 4.75 year period (Figure 6, Table 1). 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 (Table 1). The nitrate gains and river discharge are related to the El Nino conditions. During late 2006, there was an El Nino warm phase climate event, and nitrate gains in the river reached an all time high in 2007. The nitrate gains could come from surface drainages or groundwater flowing into the river. To understand how climate cycles affect river discharge and to develop sustainable biosolid waste application practices at this site, the flux of nitrate has been monitored in streams at the site for the past year in co-operation with the USGS.

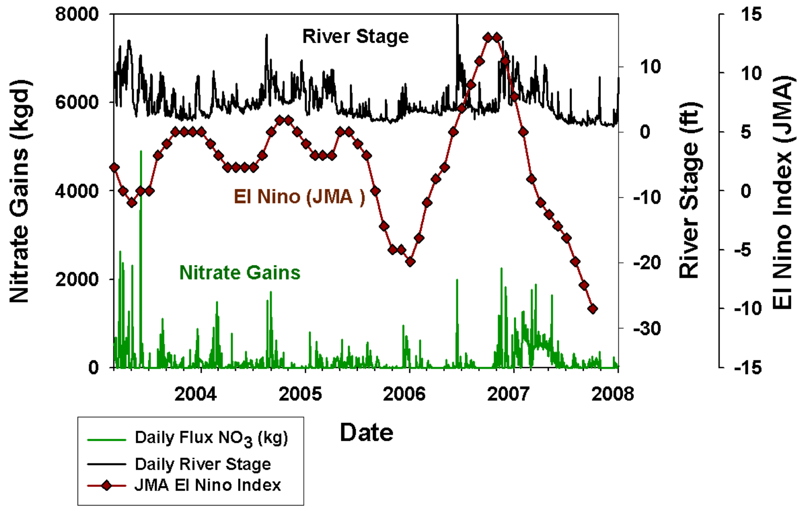

Figure 6. River stage and Nitrate gains at the NRWWTP are related to the state of El Nino in the Pacific ocean, which has a controlling relationship to stream flow and water quality in the Neuse River basin.

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. The lower well cluster groundwater levels are tied to the river stage and do not correlate to nitrate flux in the streams (Figure 7). 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. As part of this years effort, nitrate fluxes were measured in the four streams at the plant that had high nitrate concentrations. Two streams were measured during the entire year, and the other two streams were monitored for six months after June 1, 2007 after the USGS built monitoring stations at the site (Figure 8). The streams have different response times and levels to rainfall events, and stream discharge is modulated by groundwater levels (Figure 9). 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. 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.

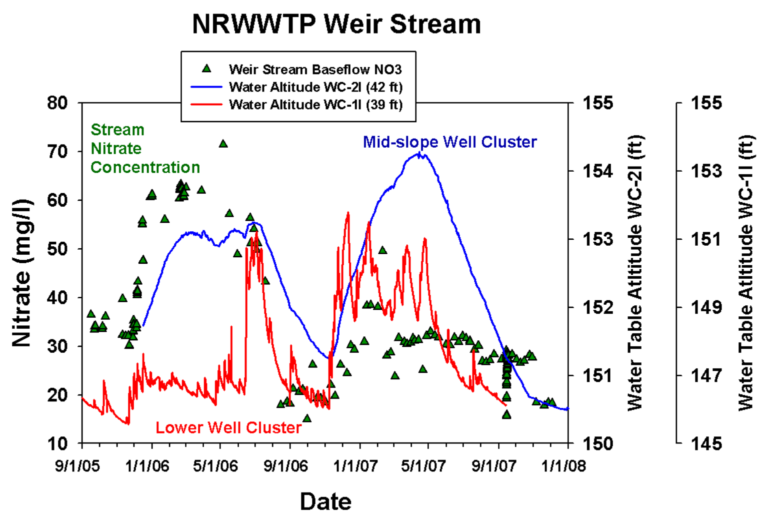

Figure 7. Stream nitrate concentration and water levels at the Neuse River Wastewater Treatment Plant near Clayton, NC. Concentrations and nitrate flux to the Neuse vary with mid-slope water levels, in summer 2007 the water table was elevated and nitrate concentrations dropped in the stream.

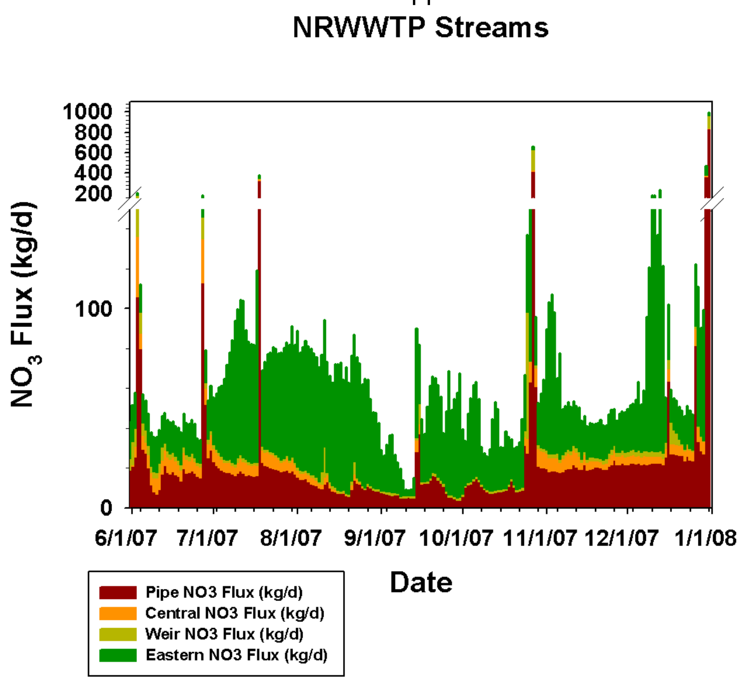

Figure 8. Stream nitrate flux in four streams at the Neuse River Wastewater Treatment Plant near Clayton, NC measured every 15 minutes. Each stream behaves differently to rainfall events.

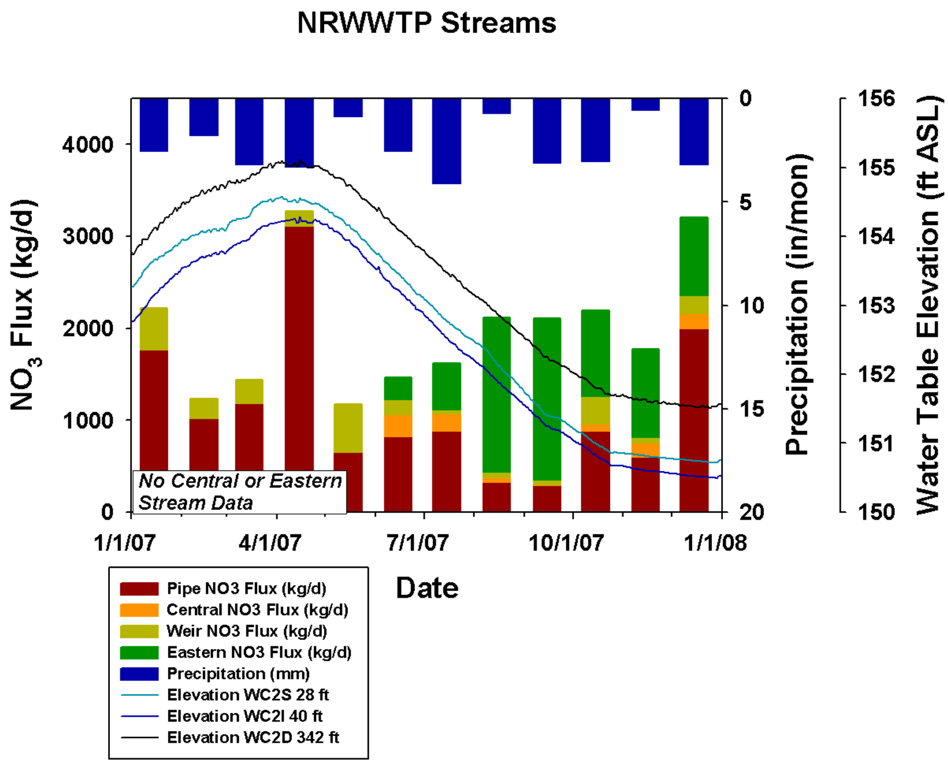

Figure 9. Stream nitrate flux in four streams at the Neuse River Wastewater Treatment Plant near Clayton, NC. Stream flux changes with different groundwater elevations, at lower elevations the smaller streams show large flux variations.

TABLE 2. Daily Average and Maximum Nitrate Flux from NRWWTP Streams

Stream	**N Flux Ave kgd**	**Discharge Average cfd**	**NO3 Flux kg/d Max**
Pipe	37	137022	833
Central	4	5447	30
Weir	7	8816	199
Eastern	39	51494	206

NUTRIENT RIVER MAPPING RESULTS

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 10). There are two large basaltic dike complexes that bisect the NRWWTP biosolid waste application fields in the northeast and northwestern portions of the plant. These are areas where the USGS has measured high nitrate concentrations in groundwater beneath the river and high electrical conductivity in river sediments. More work needs to be completed on the deep groundwater flow paths at this site. These results indicate that the deeper flow paths can account for a significant percentage of the nitrate gains in this reach of the Neuse River. Other areas of the river that are not bisected by basaltic dike complexes may behave differently.

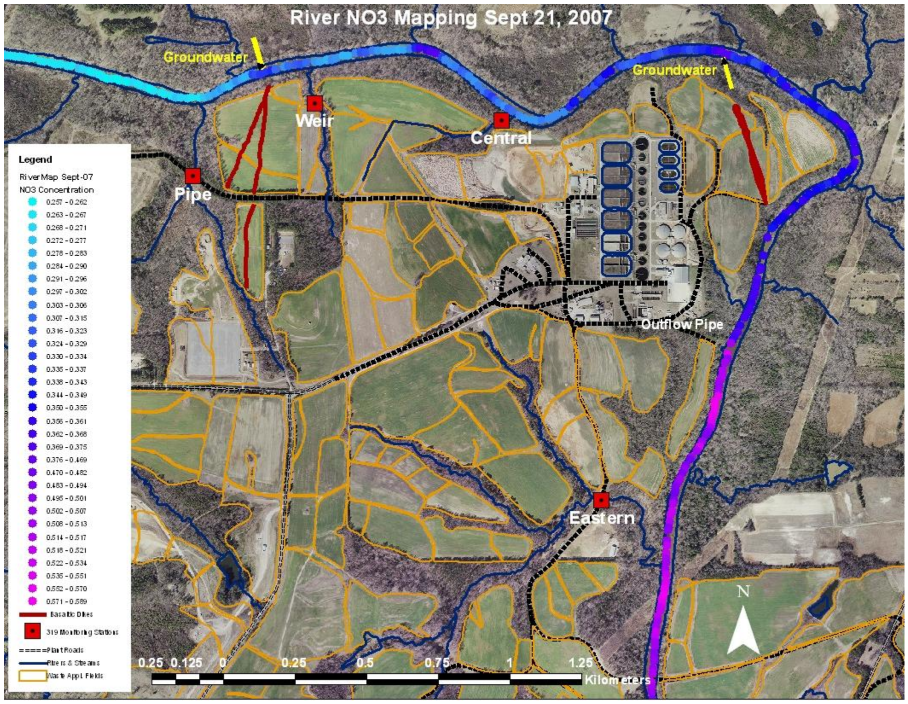

Figure 10. River nutrient mapping of stream nitrate concentrations indicate that deep groundwater contaminated with nitrate enters the Neuse River where large basaltic dikes cross the river. These deep groundwater inputs are minimal at low flow, but increase during high flow conditions.

MONITORING AND MODELING COMPARISON

The City of Raleigh Public Utilities Division has relied upon a Groundwater Nitrate Transport Model to estimate nitrate flux offsite for fifty years into the future. The model was developed by Eagle Resources under contract to ENSR in 2003. The model predicted that nitrate transport offsite would peak in 2005 and then decrease exponentially to 11,000 kg/year in 2053. After 4.75 years of river monitoring we can compare the simplified MODFLOW model predictions with the measured nitrate gains in the river (Figure 11). The initial monitoring year agreed very well with the model estimates (2003). In subsequent years, measured river nitrate gains did not follow the model predictions of declining groundwater nitrate transport over a 50 year period. The problem may be the assumptions the model makes regarding the homogenous underlying rock structure, no nitrate in recharge waters, or groundwater nitrate concentrations that are invariant at 30 mg/l. monitoring results indicate that the river nitrate gains are influenced by climate oscillations and vary significantly year to year. The Eagle-ENSR model has a basic flaw in not taking the varying climatic and groundwater chemistry and elevation conditions in account. Until more complicated spatial and temporal GIS groundwater models are developed and employed with the associated high resolution data sets to put into the models, stream and river nutrient flux monitoring are likely the best way to determine nitrate flux off of the biosolid waste application fields to the Neuse River.

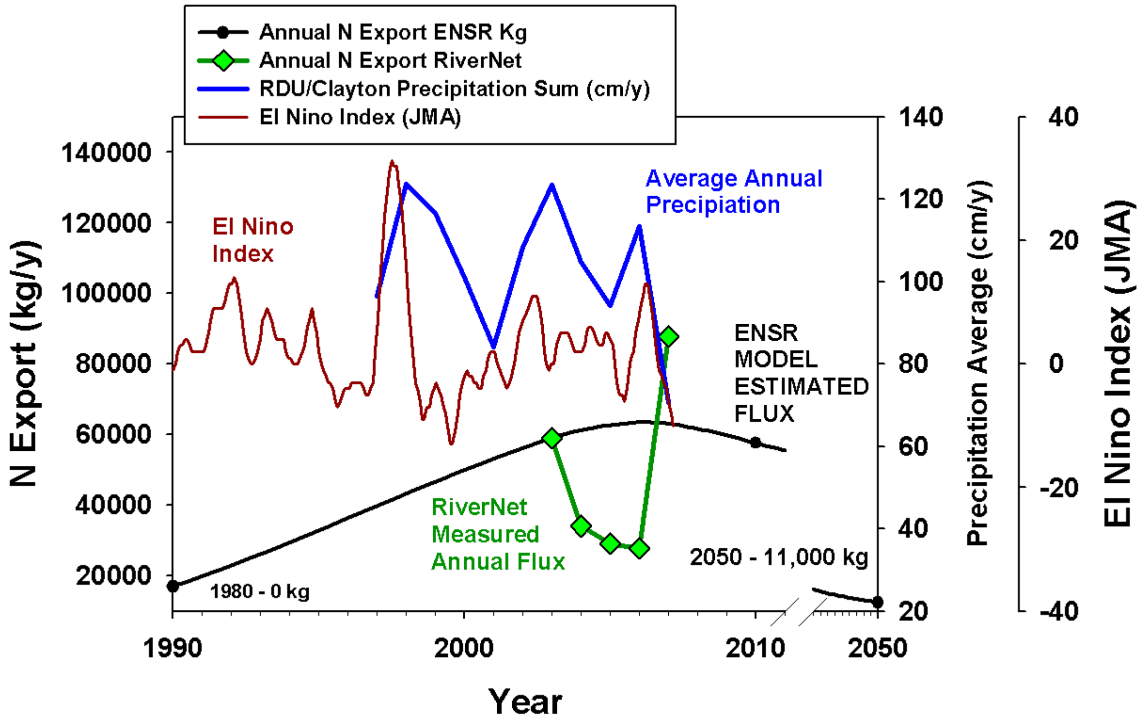

Figure 11. Model versus monitoring comparison of nitrate flux from the biosolid waste application fields into the Neuse River at the NRWWTP>

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 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.