EXECUTIVE SUMMARY
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Water quality is important to the health of the people that live in the State of North Carolina, and to the economic well being of the our state. Fish kills and harmful alga blooms are conspicuous end-members of water quality degradation and these events are the source of the concern to the public regarding the impact on our water resources of rapidly growing urban centers and the expansion of agri-business operations. We face serious challenges as we enter the 21st century if we are to protect our environmental quality. To meet these challenges we have used stable isotopes to trace the sources and fate of nutrients in surface and ground waters. In addition we have installed a system of automated real-time monitoring stations that continuously collect, archive and disseminate water quality data from the coastal plain of North Carolina.

Isotopic Tracers of Nutrient Sources to the Neuse River Basin Surface Waters

The concentration and the isotopic composition of nutrients in surface waters have been monitored for 3 to 4 years at 17 stations in the Neuse River Basin. New analytical methods have been developed to rapidly process the large number of isotopic samples required by this project. The major findings of this project are:

1. *The isotopic composition of river nitrate varies with river discharge*. During low discharge periods the isotopic composition of river nitrate is similar to point source nitrate (municipal sewage). When river discharge rises, the isotopic composition of river nitrate decreases, indicating non-point source nitrogen is dominated by fertilizer runoff. Most of the nitrogen flux to our estuaries and sounds occurs during high discharge periods, and fertilizer nitrogen is the predominate source.

2. *The high discharge nutrient loading has changed during the last decade*. Over the past 10 years the isotopic composition of the high discharge end member at the head of the estuary (Streets Ferry Bridge) has become more positive (more ^{15}N). ^{15}N, the heavier isotope of nitrogen is concentrated in both human and animal waste. Stations in the upper parts of the basin do not show this high discharge ^{15}N shift, indicating municipal sewage from the upper basin is not the cause. The middle and lower Neuse Basin stations do show the high discharge ^{15}N shift. The central sub-basin is also an area of groundwater recharge and an area of increased density of animal populations. Migration of this animal waste nitrogen is controlled by the residence time of groundwater in the discharge areas. In the Neuse basin there are only 650 animal waste lagoons, but 30% of these lagoons are located in groundwater discharge areas. Only 5% of the 1350 lagoons in the Cape Fear basin and 12% of the 200 lagoons located in the Tar Pamlico River Basin are in groundwater discharge areas.

3. *Groundwater residence time in these areas is on the order of 5-30 years*. The residence time and groundwater pathways are not well understood, yet this information is crucial for policy changes that will protect our rivers, lakes, and streams. The preliminary data suggests that any changes in land use will not be reflected in surface water chemistry for 5 to 15 years. The results of the RiverNet project indicate that groundwater recharge and surface water runoff result in a complicated loading process that can change river concentrations hourly. This points to the need for continuous river monitoring and multiple isotopic techniques to pull apart this process that controls nutrient flux in our rivers. It also suggests that in addition to flood plain geography, hydro-geologic properties (movement of groundwater up or down) should be taken into account in the location of animal operations.

4. *The Isotopic Signatures of Nutrients in the River are not significantly altered by Biochemical Processes*. Several researchers have asked if the biological processes alter the nitrogen isotope signals in our surface and ground waters. In other words is the high discharge ^{15}N shift caused by waste pollution or natural processes in the river (denitrification). We have developed a new technique to simultaneously measure oxygen and nitrogen isotopes in nitrate. By examining both isotopes, the amount of denitrification can be assessed. This technique shows that the ^{15}N signals in the Neuse River are not significantly altered. This technique can be used to characterize areas where nitrogen is consumed by natural processes such as riparian buffers and wetlands. These natural processes can then be enhanced to protect our water resources.

5. *Atmospheric deposition of nitrogen is highest in the middle portion of the Neuse Basin*. The rate and isotopic character of ammonium deposited from in rainfall has been monitored at a farm site in Sampson County and at several sites in the upper, middle and lower Neuse Basin. The middle portion of the Neuse Basin and Sampson County are similar during the year in isotopic character, indicating that volatilized (evaporated) animal waste ammonium is the predominate source of wet deposition in these areas. The upper portion of the basin (Raleigh) is not similar to Sampson county. Coastal areas (New Bern & Morehead City) are similar to the Sampson County farm site only during the late summer early fall period. Isotopic measurements take from ammonia collected immediately over a swine lagoon is slightly different than the ammonium that is deposited in rainfall at the same site. This indicates that even in the center of the coastal plain swine belt, about $1/5^{th}$ of the ammonium deposited in rainfall is from external sources.

6. Long term nutrient fluxes in the Neuse Basin are related to ENSO (El Nino/La Nina) climate cycles. ENSO cycles control precipitation in North Carolina and the number of hurricanes that approach our coastline. Increased precipitation leads to increased river discharge and increased nutrient fluxes. Since 1972 the "Super El Ninos" (1972, 1982, 1997) have the largest impact of all other climate variations. Number of fish kills is related to changes in river nutrient flux to the estuary. When hurricanes and ENSO events occur back to back, the most severe water quality events occur. It is therefore important that high quality long term monitoring of nutrient fluxes be continued on the coastal plain. Shorter records may be biased by climate events that have 5-7 year cycles.

RIVERNET: Continuous Monitoring of Water Quality in the Neuse River Basin

Long term monitoring needs to be completed in the watersheds where nutrients enter the aquatic systems and where regulations will be enacted to improve water quality. Climate factors can also cause nutrient flux variations (see #6 above). Rapid advances in monitoring technology and information management systems with web based data dissemination makes a project such as RiverNet not only possible, but important to the prudent management of our state water resources in the future. I have attached the RiverNet 2001 Legislative Report to this document describing the progress and results that have made over the past year in this program (see attached).

RiverNet: Results

The results during the first year of monitoring show significant variation in nitrogen nutrient loading in the lower portion of the basin (Seven Spring, Grifton & Fort Barnwell) in the Neuse and Contentnea watersheds (Figure 1). This concentration variability occurs during low flow and high flow conditions. This type of variability has not been observed before because the high frequency of sampling has not been possible with previously existing techniques. There are two important implications of this data.

1. Nutrient loading and river fluxes of nitrogen are the product of a complicated mixing of shallow ground waters contaminated with nitrogen and deeper ground waters without nitrogen that dilute the concentration in the surface waters. To understand this mixing process in different parts of the basin, isotopic separation techniques can be used.
2. Calculation of compliance with TMDL limits set by EPA will be extremely difficult without high frequency monitoring techniques because these fluxes can change over a 12 to 24 hour period. These results demonstrate the importance of having long term high resolution water quality monitoring records to understand nutrient loading variability, and for accurate calculations of nutrient fluxes to the Neuse River estuary.

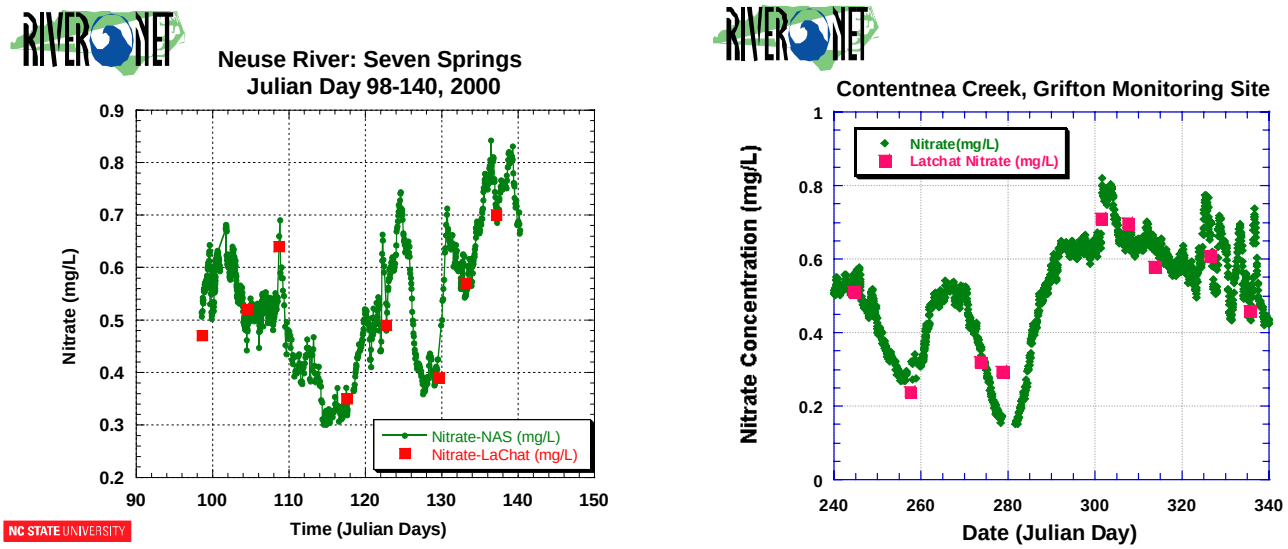

Figure 1. Nitrate concentration in the Neuse River above at the Seven Springs site above Kinston NC during low flow conditions and at Grifton on the Contentnea Creek during high flow conditions. The rapid concentration changes during this period are associated with groundwater discharge variation. These data demonstrate that estimates of nutrient flux calculated from weekly or daily measurements can contain significant error, since these concentrations change on an hourly basis.

CONCLUSIONS:

This continuous monitoring system will give researchers and water quality regulators a new understand of the processes effecting water quality. The results are available at the RiverNet web site (http://rivernet.ncsu.edu/) and are available to researchers, legislators and public policy makers as well as middle and high school teachers and students. In combination with university extension and educational outreach groups, this data can be used to raise public awareness water quality issues. Most important, data will be available to policy makers in real time to answer questions about water quality problems. By installing a network of stations, spatial and temporal variability in nutrient loading and water quality can be assessed over the entire river basin. Operating this monitoring network over a period of time will assist in documenting the effect of new regulations enacted to improve water quality in North Carolina, and assist in the US EPA basin-wide model that is requested under the reauthorization of the Clean Water Act.