USGS

WATER RESOURCES RESEARCH GRANT PROPOSAL

Title: Impact of Sediment Processes on Water Quality in the Neuse River Estuary

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Critical Water Problem to be Addressed by this Project

The Neuse River regularly exhibits symptoms that are characteristic of an over-productive estuary: nuisance algal blooms, oxygen-depleted waters, and fish kills. Like most coastal aquatic ecosystems, biomass production in the Neuse River is generally limited by the supply of nitrogen (Paerl 1987, Rudek et al. 1991, Paerl et al. 1990). Total nitrogen loading to the Neuse River Basin has increased at least 50% in the past 20 years (Stanley 1988, Harned and Davenport 1990, Dodd et al. 1993) due to rapid growth in urban population and intensive agriculture. In an attempt to restore the Neuse to an "acceptable" level of biomass production, the North Carolina General Assembly has enacted legislation requiring a 30% reduction in anthropogenic nitrogen loading. While there is a general consensus that reduced nitrogen input will translate to lower productivity, the long-term impact and the estuarine response time are difficult to predict. This is because each nitrogen atom cycles through numerous biogeochemical compartments within the estuary before being removed by physical transport, chemical transformation, or burial in the sediment (Christian et al. 1992, Kemp and Boynton 1992, Jørgensen 1996).

One of the primary controls on the estuarine nitrogen cycle involves interactions between the water column and the sediments. These interactions are particularly important in shallow, slow-flowing estuaries like the Neuse where a large portion of the organic matter produced in the water column reaches the sediment surface (Suess 1980, Nixon 1981). Although time delays between deposition and remineralization allow sediments to retain nitrogen over seasonal and annual time scales (Kemp and Boynton 1992), most detrital nitrogen that enters the sediment is ultimately remineralized (burial of organic nitrogen is usually a small component of the benthic nitrogen budget; e.g., Kemp et al. 1990, Jørgensen et al. 1990, Christian et al. 1992). The product of organic nitrogen remineralization-primarily NH_4^+-faces two possible fates: it may diffuse to the overlying water, where it can stimulate algal production, or it may be converted to NO_3^- by aerobic nitrifying bacteria. The production of NO_3^- (nitrification) is of particular interest because it can stimulate denitrification, an anaerobic process whereby NO_3^- is converted to N_2 and rendered unavailable to most algae. Thus, the flux of NH_4^+ and NO_3^- across the sediment-water interface is controlled by a delicate balance between ammonium production, nitrification, and denitrification. These three processes have the properties of a highly nonlinear system: they are tightly coupled and partly regulated by O_2 concentrations that vary in space and time. As a result, the contribution of bottom sediments to nitrogen loading in the estuary is difficult to quantify and even more difficult to predict.

Expected Results, Benefits, and Information

The following study is designed to enhance our understanding of how sediment processes affect water quality in the Neuse River Estuary. Results expected from the proposed research will be used to:

- develop an improved understanding of the biogeochemical processes that control the flux of nutrients across the sediment-water interface in the Neuse River Estuary;
- investigate the decomposition kinetics of sedimentary organic matter to evaluate the lifetime of the benthic nitrogen pool;
- calibrate and validate a process-level diagenetic model capable of predicting benthic fluxes of NH_4^+, NO_3^-, and O_2 given appropriate boundary conditions; · refine estimates of the contribution of bottom sediments to the nitrogen budget of the Neuse River by linking the diagenetic model to an estuarine water quality model; and
- examine the sensitivity of water quality predictions to uncertainty in the rate of sediment-water exchange.

Information from this study will lead to incremental improvements in the way water quality models simulate sediment processes. Such improvements, in combination with advances in other aspects of biogeochemical modeling, will promote the development of models that come closer to simulating the complex dynamics that characterize estuarine systems. Although the practical utility of existing estuarine water quality models is limited by prediction uncertainty, "it is becoming clear that they represent the best avenue toward the future" in terms of making quantitative predictions of how changes in nitrogen loading affect primary productivity and O_2 concentrations (Visser and Kamp-Nielsen 1996). Improvements in the predictive capability of these models will ultimately benefit decision-makers charged with prescribing the most effective nutrient management strategy for the Neuse River.

Nature, Scope, and Objectives of Research

Numerous studies of estuaries throughout the world clearly demonstrate that the release of nutrients from sediments plays an important role in regulating phytoplankton production (e.g., Billen 1978, Kemp and Boynton 1992, Jørgensen 1996). This is because estuarine sediments are rich in organic matter and represent vast nutrient storage reservoirs. In the Neuse River Estuary, the uppermost 2 cm of sediment contains nearly 7800 tons of nitrogen (MODMON in prep.). In contrast, the dissolved inorganic nitrogen (NH_4^+ and NO_3^-) content of the entire 3-4 meter water column is only 130 tons (Christian et al. 1991).

The importance of benthic nutrient recycling in the Neuse River has been recognized for at least 20 years. Fisher et al. (1982) estimated that NH_4^+ released from sediments provides 26% of the phytoplankton nitrogen demand near the mouth of the river. Matson et al. (1983) extended the calculation throughout the entire estuary and arrived at a similar ratio (22%). Haruthunian (1997) considered seasonal and spatial variability in the Neuse Estuary and concluded that the benthic NH_4^+ flux can supply 9-49% of the nitrogen demand of primary producers.

At least five previous studies report measured or calculated values of benthic nitrogen fluxes in the Neuse Estuary (NCDWQ 1998, MODMON in prep., Haruthunian 1997, Matson et al. 1983, Fisher et al. 1982). Measured values were made using in situ or laboratory benthic chambers while calculated values are based on applying Fick's Law of diffusion to measured porewater concentration gradients. The entire data set is collated in Fig. 1. In order to partly remove the effect of temperature, only fluxes determined under summertime conditions are included in the plot. Reported values range from 10 and -4 to +0.5 mmol N m^{-2} d^{-1} for NH_4^+ and NO_3^-, respectively (negative values denote a flux into the sediment).

It is difficult to evaluate the causes of the order-of-magnitude variability in the existing data set because of differences in methodology, the 20-year time span that separates the earliest and most recent studies, and small-scale spatial heterogeneity. In addition, there is an important caveat in the data that warrants discussion. All benthic flux measurements were made under conditions of oxic bottom water (i.e., 1-10 mg O_2 L^{-1}), even though about half the days between June and October experience near-bottom O_2 concentrations of

Despite limitations in the existing data set, there are consistent features that provide guidance for future studies of benthic nitrogen fluxes. First, high rates of NH_4^+ release occur throughout the estuary during the summer, representing a significant input of nitrogen to the system. For example, the average NH_4^+ flux (3.0±2.1 mmol N m^{-2} d^{-1}, n=76) greatly exceeds external loading of particulate and inorganic nitrogen (0.6-1.2 mmol N m^{-2} d^{-1}; Paerl et al. 1998, Christian et al. 1992). Second, sediment uptake of NO_3^- can be significant relative to NH_4^+ release in the upper 20 km of the estuary where water column NO_3^- concentrations are often high (Christian et al. 1991). And third, the relatively large size of the existing data set-and its apparent variability- suggest that a moderate number of additional flux measurements will not lead to a significant improvement in our ability to quantify the contribution of bottom sediments to nutrient loads in the Neuse River. An alternative to the "brute force" approach of conducting additional benthic flux surveys is to develop a process-level diagenetic model based on a fundamental understanding of the key factors that control the sediment nitrogen cycle. Such a model would provide a theoretical framework for scaling-up discrete flux measurements to the size of the estuary.

The overall goal of this project is to improve our understanding of how benthic processes impact water quality in the Neuse River Estuary. Specifically, we propose to:

1. conduct a detailed field study of the sediment nitrogen cycle at selected sites in the estuary to better understand the biogeochemical processes that control the flux of nutrients across the sediment-water interface;
2. establish laboratory microcosms to investigate the decomposition kinetics of sedimentary organic matter;
3. develop and validate a process-level diagenetic model capable of predicting benthic fluxes of NH_4^+, NO_3^-, and O_2;
4. extend the diagenetic model throughout the estuary by linking it to an existing water quality model (Neuse Estuary Eutrophication Model);
5. examine the sensitivity of water quality predictions to uncertainty in the rate of sediment-water exchange.