# Water Resources Research Institute of the University of North Carolina

# Annual Technical Report

# FY 1999

## Introduction

The North Carolina Water Resources Research Institute program for 1999-2000 (Federal Fiscal Year 99) continued to focus on three broad areas of concern: surface waters, groundwater, and urban water management. The Institute program also emphasized technology transfer in the form of publications, conferences, workshops, forums, seminars, and newsletters. Support from the U.S. Geological Survey through the State Water Resources Institute Program (SWRIP) was supplemented by State Appropriations, Urban Water Consortium, American Water Works Association Research Foundation, and various divisions of the North Carolina Department of Environment and Natural Resources. Fifty-two active research projects were supported with these combined resources. The research program focused on six water quality related projects. These projects involved studies in groundwater, nutrients, swine wastes, pesticides, wetlands, and sediments. Funds for these projects were obtained under the Section 104 RCGP Award. The technology transfer program for the Institute focused on disseminating the results of the Institute's research program; on gathering and disseminating information on emerging water issues, laws, regulations, and problems; and on transferring regulatory and technical information to facilitate changes in North Carolina's water quality related programs. The following strategies were used: (1) reviewed and published eleven reports as part of the Institute report series; (2) evaluated all research projects with research investigators and users to assess progress; (3) published separate brochures describing each of the current research projects and listing Institute publications; (4) published a bi-monthly newsletter summarizing research results, new state and federal water laws, regulations and program changes, and announcements of conferences, workshops, forums and seminars; and (5) organized and co-sponsored eight seminars, four forums, four workshops, one symposium, and four conferences on key water issues. Nineteen ninety-nine continued to bring into focus the need for better scientific information to support and guide policy decisions and regulatory activities regarding water quality and water resource management in North Carolina. The problem is not just one of increasing magnitude. New technology spawns new kinds of potential threats to public health and the environment, and advances in science are making those threats more apparent. Moreover, the mix of agricultural, industrial, and urban activities is affecting the state's water resources in ways that have not been sufficiently explored. Just as the state faces unprecedented demand for water use, it also enjoys unprecedented public support for regulations, arrangements, and technologies to protect that resource. North Carolina's legislature, as well as the press, continue to devote much attention to water-related environmental issues. Among those issues that have drawn the most attention during the year are: 1) hazard mitigation and flood relief from recent hurricanes; 2) restoration of the quality of the state's coastal waters; 3) water quality implications of animal waste operations; and 4) soil erosion and sediment pollution.

## Research Program

## Basic Project Information

| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | An Improved Characterization of a Fractured-Rock Aquifer by the Transient Flowmeter Test (70165) |
| **Project Number** | C-06 |
| **Start Date** | 07/01/1997 |
| **End Date** | 12/31/1998 |
| **Research Category** | Ground-water Flow and Transport |
| **Focus Category #1** | Groundwater |
| **Focus Category #2** | Hydrology |
| **Focus Category #3** | Water Quantity |
| **Lead Institution** | Water Resources Research Institute of The University of North Carolina |

## Principal Investigators

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Zbigniew J. Kabala | Assistant Professor | Duke University | 01 |

## Problem and Research Objectives

The lack of detailed information on the distribution of aquifer parameter sat scales compatible with model grid scales is a major barrier to successful deterministic or stochastic forecasting of the fate of groundwater contamination. Even intermediate-scale hydraulic conductivity estimates from multi-level single-borehole techniques are often insufficient for accurate contaminant transport modeling. There is a need for improved aquifer characterization methodologies. Two such methodologies are considered in this project, the transient flowmeter test (TFMT) and the dipole-flow test with a tracer (DFTT). The first one takes advantage of the fact that before every quasi-steady-state (traditional) flowmeter test is conducted, it has to go through the transient stage, which provides useful information about the formation. The second one, which combines the dipole-flow test with a tracer test, represents the first single-borehole tracer test ever conducted. During the period specified above we have addressed the following objectives of Part I (TFMT) of the project: 1) develop a theory of the TFMT and its interpretation; 2) evaluate the transient flowmeter test in synthetic numerical experiments; 3) evaluate the new test in the field at the Gate 11 Duke Forest Site; and 4) measure the downhole distributions of fracture transmissivity and storativity in a number of the monitoring wells. We have also addressed the following objectives of Part II (DFTT): 1) decide on how to model the local dispersion process; 2) develop a semi-analytic model for the DFTT performed in a homogeneous aquifer; 3) develop an

associated inverse model; and 4) perform and interpret the dipole-flow test with a tracer (DFTT) on a number of wells at the Lizzie site.

**Methodology**

Part I: Transient Flowmeter Test (TFMT) The theory of the TFMT was developed by formulating two initial boundary value problems (IBVP) of different complexity, one neglecting the layer crossflow and one accounting for it. The IBVPs were then solved via integral transforms or other well-established techniques. The models were validated and evaluated by comparing their performance to that of the numerical "truth" model. The two forward models were then employed in the modified Levenberg-Marquard least-squares algorithm for parameter estimation, which allow one to interpret the field tests. The state-of-the-art electromagnetic flowmeter (Tysco, Inc.) was calibrated in our laboratory and re-calibrated in the well before each field test. It was used along with a pressure transducer and (GrundFos RediFlow 2) pump to collect the transient flux and drawdown data at two sites, the Gate 11 Duke Forest Site and the Lizzie Intensive Study Area. The first site, located about one mile south of Route 70 and State Route 751 in Durham County, has a fractured rock aquifer, whereas the second site, located near Greenville, North Carolina, provides access to two coastal aquifers. Part II: Dipole-Flow Test with a Tracer (DFTT) We assumed that the tracer is released after the steady-state dipole-flow pattern is established. For this flow pattern, we used the streamtube modeling approach outlined in the literature to develop a semi-analytical model of the tracer transport in the DFTT. The model, which accounts for the longitudinal dispersion only, was used to develop type curves for parameter estimation and interpretation of field DFTTs. The downhole DFTT device consists of three (Aardvark Corporation) packers, cables, hoses, pressure transducers (0-5 psig transducer above the device, two 0-15 psig transducers for the chambers, and a 0-30 psig transducer below the device), and (Grundfos RediFlow 2) variable speed pump. The above ground equipment consists of a nitrogen cylinder (to inflate the packers), an associated regulator, a mechanical flowmeter, a tripod, (Scientific CR10X)Data Logger, a laptop computer, the dye injection port, the fluorometer isolation valve, and a (Turner Designs Model AU-10) Field Fluorometer with a continuous flow cell set up for optically measuring the concentration of Rhodamine WT. The fluorometer is calibrated before each field test.

**Principal Findings and Significance**

This research consists of two parts. The first one focuses on the transient flowmeter test and its mathematical models. It involves validation, sensitivity analysis, parameter estimation, and field testing. The second part deals with the new single-borehole tracer test. It involves validation, parameter estimation, and field testing. Transient Flowmeter Test (TFMT) A hydrologic analog of a semi-analytic transient flowmeter test (TFMT) petroleum engineering model for confined layered systems is developed and validated by comparing its performance to that of a numerical finite-difference model. It accounts for inter-layer crossflow, wellbore storage, and a thick skin surrounding a fully penetrating well. The initial-boundary value problem is solved in the Laplace domain and the solution is inverted numerically to the dimensionless time domain using the Stehfest algorithm for TFMTs conducted with a constant total pumping rate and the DeHoog algorithm for TFMTs conducted with a step-variable total pumping rate. In conjunction with a modified Levenberg-Marquardt algorithm the semi-analytic TMFT model is used to interpret TFMT measurements in synthetic studies. It produces relatively accurate estimates of the hydraulic conductivity and the specific storativity of each layer in the aquifer zone. The skin hydraulic conductivity estimates are also relatively accurate for damaged (low-conductivity) skins and within an order of magnitude otherwise. The skin specific storativity estimates are highly inaccurate. A sensitivity analysis is performed for three semi-analytic TFMT models. Logarithmic sensitivities are calculated and used to obtain the plausible relative errors as a measure of information content in the well

response from each model. The first TFMT model is a no-crossflow model that accounts for a thick skin surrounding the well. The second is a crossflow model that accounts for an infinitesimal skin. The third is the crossflow model developed in this report. The analysis results for synthetic homogeneous aquifers show that the plausible relative errors in aquifer hydraulic conductivity are generally the smallest compared to other parameters. This suggests that aquifer hydraulic conductivity is the easiest to estimate. In addition, the plausible relative errors in the hydraulic conductivity of a normal skin (skin conductivity greater than aquifer conductivity) may be more than an order of magnitude greater than the plausible relative errors in aquifer hydraulic conductivity. This suggests that when a normal skin is present, only an order of magnitude estimate may be obtained for its conductivity. For damaged skins (skin conductivity smaller than aquifer conductivity), on the other hand, the plausible relative errors in skin hydraulic conductivity are of the same order of magnitude as the plausible relative errors in aquifer hydraulic conductivity. This, in turn, suggests that when a damaged skin is present, accurate estimates of its conductivity may be obtained. Additionally, plausible relative errors in aquifer specific storativities are an order of magnitude or more greater than the plausible relative errors in aquifer hydraulic conductivities. Therefore, estimates for this parameter may be an order of magnitude less accurate than aquifer hydraulic conductivity estimates. Estimates of the skin specific storativities are practically impossible to obtain, the plausible relative errors in this parameter are three or more orders of magnitude greater than the plausible relative errors in the other parameters. It is also found that exponential or continuous piece-wise linear pumping rates have no significant effects on the plausible relative errors in the parameters and hence have no effect on the information content of the well response. For synthetic two-layer aquifers, the sensitivity analysis yields results analogous to those found for homogeneous aquifers. Furthermore, for layers with damaged skins, the plausible relative errors in skin layer horizontal hydraulic conductivities are comparable to those in the aquifer layer horizontal hydraulic conductivities. Whereas for layers with normal skins, these errors may be an order of magnitude greater than the plausible relative errors in aquifer layer horizontal hydraulic conductivities. In addition, the plausible relative errors in aquifer layer vertical hydraulic conductivities may be up to two orders of magnitude larger than the plausible relative errors in aquifer layer horizontal hydraulic conductivities. It is also found that the greater the aquifer layer anisotropy ratios, the smaller are the plausible relative errors in aquifer layer vertical hydraulic conductivities. Dipole-Flow Test With Tracer (DFTT) In addition, the investigator proposes a new aquifer characterization test, the dipole-flow test with a tracer (DFTT), and develop its interpretation methodology. Combining the dipole-flow test (DFT) and a tracer test, the DFTT is a single-borehole, forced gradient tracer test. The DFTT device isolates an injection and an extraction chamber in a well with inflatable packers and utilizes a small pump to create a dipole-flow pattern. After a steady-state flow field is reached and the pumping rate and chamber drawdowns are measured, a tracer is released into the injection chamber, and the concentration breakthrough curve is recorded in the extraction chamber. In developing the DFTT model, the investigator assume that the aquifer is homogeneous on the scale of the test and that the well has no skin zone. He uses a streamtube approach to semianalytically simulate the tracer transport in a DFTT and determine the necessary relationships for estimating the longitudinal dispersivity as well as the radial and vertical hydraulic conductivities. The arrival time of the peak concentration is linearly related to the anisotropy ratio, and the arrival time of the tracer front is related to the longitudinal dispersivity. Preliminary data is presented from DFTTs conducted with Rhodamine WT as a tracer at the Lizzie Field Site located between Farmville and Maury, North Carolina. The results demonstrate that this single-borehole tracer test is feasible and that its estimates of dispersivity are consistent with those reported in literature, whereas its estimates of hydraulic conductivity.

**Descriptors**

Ground water, Hydrology, Aquifer characterization, Well hydraulics, Transient flowmeter test, Solute

transport, Single-borehole tracer test

**Articles in Refereed Scientific Journals**

Kabala, Z.J.; N.C. Ruud; and H.K. El-Sayegh, 1999, Theory and Interpretation of the Transient Flowmeter Test via the No-Layer-Cross Flow Model. J. Hydrology, , . (in press) Ruud, N.C.; Z.J. Kabala; and H.K. El-Sayegh, 1999, Resolution of Vertical Aquifer Heterogeneities Through the Quasi-Steady-State and Transient No-Layer-Cross-Flow Flowmeter Test Models, J. Hydrology, , .(in press) Ruud, N.C.; Z.J. Kabala; and F.J. Molz, 1999, Numerical Evaluation of Head Loss Effects in the Flowmeter Test, J. Hydrology, , . (in press) Sutton, D.J.; Z.J. Kabala; D.E. Schaad; N.C. Ruud; and P. Bannister, 1999, A Single-Borehold Tracer Test for Aquifer Characterization, J. Contaminant Hydrology, , .(in press)

**Book Chapters**

**Dissertations**

Hatem, Khaled, 1999, The Transient Flowmeter Test. Ph.D. Thesis, Dept of Civil Engineering, Duke University, Durham, NC, .(Under the direction of Z. Kabala) Schaad, David, 1998, Dipole-Flow Test with a Tracer: A New Methodology for Aquifer Characterization. Ph.D. Thesis, Dept of Civil Engineering, Duke University, Durham, NC, . (Under the direction of Z. Kabala)

**Water Resources Research Institute Reports**

**Conference Proceedings**

El-Sayegh, H.K.; and Z.J. Kabala, 1998, Transient Flowmeter Tests for Aquifer Characterization, Water Resources Protection: Understanding and Management, In Proceedings of the Annual North Carolina Water Resources Research Conference, WRRI of The University of North Carolina, Raleigh, NC, 32. Sutton, D.J.; D. Schaad; and Z.J. Kabala, 1998, Dipole-Flow Tests with a Tracer for Aquifer Characterization, Water Resources Protection: Understanding and Management, In Proceedings of the Annual North Carolina Water Resources Research Conference, WRRI of The University of North Carolina, Raleigh, NC, 46.

**Other Publications**

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**Basic Project Information**

| Basic Project Information | |
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| **Category** | **Data** |
| **Title** | Eutrophication in the Tar-Pamlico and Neuse River Estuaries of North Carolina (70161, 70167, 70172) |
| **Project Number** | C-07 |
| **Start Date** | 08/01/1998 |
| **End Date** | 02/28/2000 |
| **Research Category** | Water Quality |

| | |
|---|---|
| **Focus Category #1** | Water Quality |
| **Focus Category #2** | Nutrients |
| **Focus Category #3** | None |
| **Lead Institution** | Water Resources Research Institute of The University of North Carolina |

**Principal Investigators**

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Sherri R. Cooper | Assistant Professor | Duke University | 01 |
| Hans W. Paerl | Professor | University of North Carolina at Chapel Hill | 01 |
| Donald W. Stanley | Professor | East Carolina University | 01 |

**Problem and Research Objectives**

For several decades eutrophication has been one of the most important water quality issues for our nation's estuaries. Many citizens, elected officials, and scientists believe that many estuaries are more eutrophic now than they were several years or decades ago. However, previous studies of historical trends in nutrient concentrations, dissolved oxygen and chlorophyll a in some estuaries, including the Tar-Pamlico and Neuse Rivers in North Carolina, do not provide strong support for this hypothesis. Because there are significant contradictions between results of the statistical trend analyses and our perceptions of the history of trophic status of the estuaries, it would seem prudent to continue to examine the accumulating data. Failure to understand whether or not changes are taking place will lead to two serious problems: (1) scientists will formulate and test hypotheses about eutrophication based on misinformation, and (2) legislators and regulatory agencies will have inadequate information upon which to base decisions about implementation of nutrient reduction strategies and to assess the success of those strategies. There are many recent concerns about water quality in North Carolina estuaries (including the Tar-Pamlico River estuary and the Neuse River estuary). The combined drainage area of the Pamlico and Neuse River systems is over 25,000 square kilometers. Algal blooms, toxic algae, eutrophication, low oxygen, shellfish bed closure, decline of submerged aquatic vegetation, and fish kills are just some of the issues. Many of these problems are related, and have not been historically monitored in these systems. The history of algal communities, especially toxic algae, are of particular interest in relation to fish kills and human health concerns in these estuaries, as well as other coastal systems. The proposed research will build on previous work quantifying the degree of anthropogenic disturbance in the estuaries of the Pamlico and Neuse Rivers by providing evidence of changes in abundance and productivity of different algal groups, including toxic algae and other biological and chemical parameters back through time and in relation to specific events. The proposed research will help address specific questions raised about water quality trends through time and provide insights into the effects of nitrogen loading reductions on the algal community in these estuaries. The first component will investigate the effect of a proposed 30% nitrogen reduction on the present phytoplankton community, an evaluation of the N2 fixing potential and rates under reduced N-loading, baseline data for monitoring the effectiveness of N-loading reductions, and identification of other factors that may have to be managed to achieve the desired level of algal productivity and water quality in these

estuaries. The second component will assess trophic status changes in the Tar-Pamlico and Neuse River estuaries during the period 1950-1998. The assessment will be based on three measures including: watershed nutrient production, nutrient loading to the estuaries, and riverine and estuarine water quality. The third component will characterize the environmental conditions (including anoxia), water quality, and algal communities of the Pamlico and Neuse River estuaries as they existed prior to anthropogenic influences, and through time as land use in the watersheds of these systems has evolved with growing populations and industries.

**Methodology**

Paerl et al. (1) Biweekly sampling at eight fixed locations, in situ continuous monitoring of water quality at four locations, routine genetic screening of planktonic diazotrophs, and seasonal mesocosm nutrient addition bioassays provide the necessary infrastructure, complementary data, and historical perspective needed to address the specific project objectives for the proposed research. This component will use nutrient dilution bioassays (Paerl & Bowles 1987, Carrick et al. 1993, Dodds et al. 1993) to determine the effect of DIN reduction on Neuse River phytoplankton communities. Nutrient manipulation experiments will be conducted at the UNC Institute of Marine Sciences (IMS) using bulk water samples from the Neuse River. Bioassays will be run seven times during the project to account for seasonal variations in phytoplankton community composition and response to reductions in the ambient DIN concentrations. The nutrient dilution bioassay technique is a simple manipulative method for reducing the concentrations of ambient dissolved ions in natural water samples. In this assay, concentrations of potential growth-limiting nutrients, chiefly N and P compounds, are reduced while maintaining non-growth limiting ions at naturally occurring levels. For details on the dilution bioassay procedure see Paerl and Bowles 1987. Neuse River water will be obtained from an estuarine site (25.9 km) and riverine site (7.6 km). Treatments will consist of: (1) control (unamended river water); (2) 30% dilution; (3) 30% dilution with P, dissolved inorganic carbon (DIC), and trace metals replenished to ambient levels; and (4) 30% dilution with N, P, DIC, and trace metals replenished to ambient levels. Community composition will be characterized using standard microscopic (direct enumeration) and chemosystematic (photopigment) techniques. For microscopic enumeration, phytoplankton samples (100 ml) will be preserved with Lugol's iodine solution and later concentrated to a 5 ml slurry using settling chambers. For each sample, ca. 1.0 ml of slurry will be dispensed into a counting cell and the phytoplankton enumerated using a Zeiss (research grade) microscope (480x or 750x). Photopigments will be analyzed using high performance liquid chromatography (HPLC). N2 fixation rates (nitrogenase activity) will be estimated using the acetylene reduction assay (Stewart et al. 1967). Water samples (50 ml) will be taken from Cubitainers following bioassays and transferred to serum vials for measurements of N2 fixation rates (nitrogenase activity). Sealed vials will be injected with acetylene and incubated under ambient light and temperature conditions. Nitrogenase activities will be measured for all experimental treatments (controls and nutrient manipulations) as well as under light and dark incubation conditions. Gas samples will be taken at the end of the assay (ca. 3 h) and analyzed using gas chromatography with flame ionization detection (GC FID) to quantify ethylene concentrations. Acetylene is converted to ethylene by the nitrogenase enzyme and is a relative measure of N2 fixation rates. Limitations of the acetylene inhibition technique for measuring denitrification in sediments have recently been documented (Thompson et al. 1995, Seitzinger et al. 1993). Acetylene inhibition of the reduction of N2O to N2 has been shown to be ineffective at low (<10 m M) NO3- concentrations (Kaspar 1982, Oremland et al. 1984, Slater and Capone 1989). Acetylene also inhibits nitrification (Hynes and Knowles 1981), yielding underestimates of denitrification in systems where nitrification is a significant source of NO3- for (i.e. coupled to) denitrification. However, the simplicity of the acetylene inhibition technique allows for greater spatial replication relative to other techniques and the short incubation time (minutes to hours) permits the measure of short-term changes in denitrification. The

acetylene inhibition technique has been adapted for use in estuarine sediments by measuring denitrification rates at incremental NO3- additions to determine saturation kinetics, providing both potential (Vmax) and an estimate of in situ denitrification activity. This technique has been successfully utilized in Dr. Paerl's laboratory during the past several years for measuring denitrification in estuarine headwater creeks and salt marsh sediments. Water samples (surface and bottom) and porewater from surface sediments collected bi-weekly from Neuse transect stations will be analyzed for NOx and NH4+ and for CHN content. Water samples will be filtered through muffled glass fiber filters and analyzed with a Lachat QuickChem automated ion analyzer. Porewater NOx and NH4+ will be extracted from the sediments with 2N KCl, filtered and analyzed with the Lachat autoanalyzer. Filters and surface sediments will be analyzed for CHN with a Perkin Elmer 2400 Series II elemental CHN analyzer. Water samples will be analyzed for dissolved organic N (catalytic oxidation) and dissolved organic C (infrared analysis). Water column parameters including profiles of dissolved oxygen, salinity, temperature, pH and depth will be obtained with a Hydrolab Surveyor 3 data logging system. Biological parameters, including primary productivity (14C Method), phytoplankton species (M3, gravity filtration/centrifugation), photopigments (HPLC-PDAS) and growth rates (Packard 525a Flow Scint Counter) are measured bi-weekly at the same stations as part of USDA project: Nitrogen-Driven Eutrophication of the Neuse River, NC. Surface sediment O2 dynamics in parallel will be determined by using a stirred core technique. Biological and chemical oxygen demand are determined by micro Winkler titration of water overlying sealed sediment cores incubated for 6-48 hrs. This analysis, which is supported by other research funds (USDA) will be of value to this project by helping to clarify temporal and spatial relationships between bottom water hypoxia/anoxia and denitrification dynamics (i.e., PO2 as an environmental regulator of denitrification potential in the Neuse Estuary). The results of the nutrient dilution bioassays will be analyzed using a 2-way ANOVA (factors = nutrient dilution treatment, experiment date; variables = Chl a, productivity, photopigment, nitrogenase activity, etc.). Stepwise multiple regressions will be performed to explain the variation in both potential and calculated in situ denitrification rates in terms of chemical, biological and physical variables. Stanley (2) Calculations of annual total N and P production in the watersheds of the two estuaries will be made using procedures similar to those of Stanley (1993), with several modifications (some of which are based on methods used by McMahon and Woodside 1997). Production will be computed at 2-to-3 year intervals for the period 1950 to present. Details concerning data sources, methods for converting "mixed fertilizer" data to elemental N and P values, methods for estimating production by municipal wastewater treatment plants, etc. are given in Stanley (1992, 1993). Annual nutrient loadings from a large portion of the Tar River will be computed using concentration data collected at a site just above the normal tidal reach (near Grimesland, NC) every other week since 1989. About 85% of the Tar-Pamlico basin is upstream of this site. The first step will be to determine whether the nutrient concentration data are flow dependent. If not, then interpolation will be used to provide daily values. If there is flow dependence, loads will be calculated using the MVUE log-linear regression model described above. In either case, daily flows will be extrapolated from the Tarboro, NC, gauging site by means of land-area ratios. It may be possible to compute loadings for each year, depending on whether or not the MVUE method has to be used and if so, how many concentration values are needed to estimate the regression parameters. The same method will be used for calculating Neuse River loadings from about 80% of the basin above a site on the lower river near Cowpen Landing. The Tar-Pamlico River estuary water quality data to be analyzed for long term trends come from a monitoring program that began in the late 1960s and has continued uninterrupted except for an 18-month period in 1973-74 (Stanley 1993). Data on water temperature, salinity, surface and bottom water dissolved oxygen, phosphorus (three fractions), nitrogen (four fractions), and chlorophyll a are collected approximately every other week at twenty stations spread across the estuary from near Washington, NC, to the mouth at Pamlico Sound. There is considerably less water quality data for the Neuse River estuary, but enough to permit trend analyses. The earliest is from a two-year monitoring project in the early 1970s. Temperature, salinity, dissolved oxygen, nitrogen, phosphorus, and chlorophyll a data from appendices

in the project completion report (Hobbie and Smith 1972) will be transcribed to computer spreadsheets. Since the late 1970s a considerable amount of Neuse River estuary nutrient data have been collected by the North Carolina Department of Environment, Health, and Natural Resources (DEHNR), by the U.S. Geological Survey (e.g., Garrett and Bales (1991) and Garrett (1992, 1994)) and by university investigators (Bob Christian and Don Stanley at East Carolina University and Hans Paerl at the UNC Institute of Marine Science). Most, if not all, of the DEHNR data is available in electronic format through STORET. Most of the data that Christian and Stanley collected is already in spreadsheet format. Some of it is from the 1983-to-1985 period, but the bulk of it was collected between 1985 and 1988. Paerl's data are from the 1980s and 1990s. The seasonal Kendall-tau test will be used to analyze the water quality data for monotonic (one direction) trends over time. This nonparametric procedure, developed by U.S. Geological Survey investigators (Hirsch et al. 1982, 1991; Hirsch and Slack 1984; Helsel 1993), is suitable for application to water quality data, which are often skewed, serially correlated, and affected by seasonality. Also, missing values or values less than the laboratory detection limit present no problems (Hirsch et al. 1991). In addition to establishing the significance of a trend, the test provides a slope estimator, which is the average rate of change over the whole test period. The test cannot detect reversals of direction in trends within a test period. Cooper (3) Sediment cores from seven different sites were collected by standard piston coring methods from the Neuse and Pamlico estuaries during the summer of 1997. Selection of sites was based on personal communications, as well as reports on sedimentation, circulation, depth, and monitoring of bottom water oxygen in the estuaries (Riggs, pers.comm., Benninger, pers. comm., Wells, pers. comm., Bales & Robbins 1995; Robbins & Bales 1995; Treece 1993; Riggs et al. 1992; Garrett 1992, 1994). The cores were 82-148 cm in length and 5-10 cm in diameter. Sediment cores were x-rayed, carefully characterized and subsampled into 2 cm sections. Dating of sediments and determination of sedimentation rates for recent sediments is being accomplished in part using standard Pb-210 and Cs-137 techniques and measured with an Ortec EG&G gamma spectrometer in the Wetland Center at Duke University. Sedimentation rates will also be determined using pollen dated horizons (such as the agricultural horizon characterized by an increase in ragweed percent abundance) and pollen concentration techniques (Brush 1984, 1989). This method is based on the fact that the majority of pollen grains found in estuarine sediments originate from terrestrial vegetation, particularly from plants whose pollen is wind-dispersed (such as oak, pine, ragweed, etc.). The concentration of the tracer particle (pollen in this case) in any interval of sediment will reflect the rate of accumulation of the other particles that make up the sediment. The validity of dating sediments using this method has been demonstrated by identifying historically dated events (Brush 1989). Bulk density, LOI, TOC, P, N, S, acid-soluble Fe, heavy metals, and other chemical parameters are being measured from subsamples in the cores. These data will be correlated to sediment dates, pollen, diatom species, and dinoflagellate cyst abundance. Analyses of sediments at the Duke Wetland Center will follow standard methods of EPA, USGS or other certified approved methods for nutrients, metals or geochemical analysis and follow standard QA/QC protocols on file at the Wetland Center. Accumulation or preservation of parameters will be calculated using appropriate sedimentation rates and bulk density for each subsample of the sediment cores. Heavy metals and other elements of interest are being measured using an inductively coupled plasma-mass spectrometer (ICP-MS) located in the Earth Sciences Division of the Nicholas School of the Environment. This data will provide an alternate dating method for the recent sediments in addition to information on toxic metal concentrations in the sediments. Other elements being analyzed include: Cr, Ni, Cu, Cd, Ti, V, Mn, Co, Zn, Th, U, and Hg. Diatoms and pollen are being extracted and identified at subsampled intervals in the cores (for example, diatoms are being counted at every 10 cm depth interval for the current project). All identifications will be done using light microscopy, according to available taxonomic references (e. g., Faegri & Iverson 1989, Krammer & Lange-Bertalot 1986-1991, Hustedt 1955, Cooper 1995b). Pollen is extracted from sediments following the methods of Faegri & Iverson (1989) and Brush (1989). Slides of pollen are prepared using silicon oil. Dinoflagellate cysts and certain forams are extracted and

preserved with the pollen. The dinoflagellate cysts will be enumerated, as will the forams. All the cyst forms that resemble the cyst stages of Pfiesteria will be enumerated separately. Dr. Peter Leavitt is at the forefront of pigment analysis and paleopigment research using high pressure liquid chromatography (HPLC) methods for separation and characterization of algal pigments and pigment degradation products (Leavitt & Findlay 1994, Leavitt 1993, Leavitt & Carpenter 1990, Leavitt et al. 1989). Further analyses for pigments and pigment degradation products from the Neuse and Pamlico estuarine sediment samples will be done by Dr. Leavitt at his lab. Abundance or concentration of all indicators will be plotted along a time axis in a series of equal time intervals for each of the sediment cores analyzed. Time intervals in relation to depth in each core will depend on sedimentation rates determined for each core. The vertical (time) profiles of changes in paleoecological indicators of water quality will be matched with the history of land use at each site in order to determine the most obvious correlations with each indicator. Diatom species counts will be made at a level to ensure good statistical reproducibility (see section above). Diversity and similarity indices will be employed to evaluate changes in diatom communities over time and between samples. Distance between communities identified at each depth in each core, and between cores, will be computed and used for cluster analysis of the species data. These data will then be compared with other algal indicators, including dinoflagellate cyst abundances, and algal pigments and paleopigments. Mulitvariate techniques such as principal components analysis, canonical correspondence analysis and detrended correspondence analysis will also be used in analyses of the paleoecological data to uncover linkages and patterns among indicators through time and space. This research plan is intended to build on current work that is determining sedimentation rates and chronologies and researching indicators of community structure, water quality and sediment chemistry for sediment cores collected from two sites in each of the Neuse and Pamlico River estuaries. Data will be collected on additional indicators, as well as at three additional sites. The data will also be used for comparisons between the Pamlico and the Neuse estuaries and between the North Carolina estuaries with the Chesapeake Bay.

**Principal Findings and Significance**

Paerl et al. (Progress Report) It is clear that a complete understanding of the role and importance of denitrification in the Neuse River Estuary continues to be hindered by methodological challenges. However, the patterns that have emerged from this study provide insight on regulatory factors and on the seasonal dynamics of denitrification in this estuarine system. Denitrification measured as estimated in situ rates appeared to be regulated by NOx levels, both directly and through competition with benthic and pelagic primary producers. Rates were highest in the fall and winter, coincident with elevated NOx levels. In addition, a positive correlation between estimated in situ denitrification and oxygen levels, suggested an indirect regulation of denitrification via coupled nitrification. Potential rates of denitrification were elevated under conditions of anoxia during the summer and were apparently limited by supplies of labile carbon. Methodological comparisons between the acetylene block and MIMS techniques indicated that true rates of denitrification in the Neuse may be closer to potential rates measured in the current study with an estimated 22 percent of DIN removed via denitrification. Based on the kinetics of nitrate utilization by denitrifyers, a 30% reduction in DIN loading would not be expected to reduce the percentage of N removed via denitrification. Information on rates and dynamics of nitrification is needed to further understanding of N cycling in the Neuse River estuary. To enhance water and habitat quality in the Neuse River Estuary, reduction in nitrogen (N) loading has been selected as means of controlling eutrophication. Dilution bioassays are manipulative experiments that dilute concentrations of limiting nutrients to assess effects on water column processes. Experiments were conducted on samples from a riverine site (Streets Ferry Bridge) and an estuarine site (Marker 15) in the Neuse River Estuary. Thirty percent reductions in concentration of N and both N and P are being used to predict the effects of implementing the Neuse River Nutrient Sensitive Waters Management

Strategy Rules on the native phytoplankton community. This study is examining the effects of reductions in nutrient concentrations on phytoplankton productivity and biomass and the potential for phytoplankton community composition alterations. Reducing N concentrations by 30% decreased phytoplankton productivity. Mean assimilation numbers (productivity/Chl a) after 84 hour incubations were lower than the control (current river conditions) at both sites 11 out of 14 measurements throughout 1997 and 1998. However, reducing N loading unilaterally (i.e. without accompanying P reductions) may lead to decreased N:P ratios in the system and may create conditions conducive to increased dominance by N2 fixing cyanobacteria. Selection for N2 fixers could be problematic for several reasons including trophic perturbation, ineffectiveness of N controls in reducing phytoplankton productivity, and increased biological fixation of N. Results from this study showed that native cyanobacteria fix more N when N alone is reduced as compared to reduction of both N and P and the current conditions in the river. However, N2 fixers were not found to become more prevalent or diverse in response to reductions of N alone. Additionally, N2 fixation was only observed in 2 of the 15 bioassays conducted (both times in the late summer) and only at the estuarine site. Cyanobacteria were present in the river in significant numbers prior to the initiation of the bioassays in which N2 fixation was observed. We directed significant effort toward analysis of the genetic potential for N2 fixation in the Neuse River after the enactment of the 30% reduction in N loading. Molecular assays found that simulated N reduction did not increase the genetic potential for N2 fixation. The majority of the nifH sequences cluster with Anabaena sp., which is among the most commonly observed cyanobacterium in the Neuse River. Microscopic analyses confirmed Anabaena sp. and other heterocystous organisms among the dominant cyanobacteria. Because the activity of N2 fixing cyanobacteria was confined to a narrow temporal window, large changes in activity and abundance of these organisms in response to nutrient load management may not have a major impact on the overall structure and function of the Neuse River phytoplankton community. Stanley (Progress Report) Nitrogen, phosphorus, and chlorophyll a trends in the estuaries do not give clear evidence of increased eutrophication during the past two-to-three decades. Data from three stations in the upper, middle, and lower Pamlico River estuary (1969-1997) were analyzed for trends using the seasonal Kendall test. Ammonium nitrogen levels have decreased throughout the estuary, and nitrate nitrogen decreased in the middle region. Phosphorus levels increased in the 1970s and 1980s but have declined sharply since 1992 when PCS Phosphate reduced their P loading to the estuary by about 90%. Chlorophyll a increased in the upper two-thirds of the estuary, perhaps because of decreased light limitation resulting from decreased TSS loading to the estuary. Bottom water dissolved oxygen decreased in the upper estuary, but the change has been very small. In the Neuse estuary, ammonium nitrogen concentrations appear to have decreased by 50-70% between 1970 and 1980, but they have changed little since then. Phosphorus (both orthophosphate and total phosphorus) has decreased by 25-70% throughout the estuary since the late 1980s following implementation of the phosphate detergent ban. Since the late 1980s chlorophyll a appears to have decreased in the tidal freshwater portion of the estuary, but has shown no trend since the early 1970s in the middle and lower estuary. Total nitrogen and phosphorus production from human-related activities in the Neuse and Pamlico watersheds increased substantially during the past 30 years. Atmospheric nitrogen may be increasing, but there is little historical data. Fertilizer application in these watersheds increased rapidly following World War II, but has stabilized or decreased slightly since the mid-1970s. Point source loadings have risen since 1970 (except that P in the Pamlico has decreased slightly), but this production source is minor compared to the others. Farm animal N and P production has risen sharply in the 1990s. Strong differences in the magnitudes and trends in nutrient production, in-stream loading, and estuarine concentrations for these two estuaries suggest that eutrophication needs to be assessed from as many angles as possible. Only 5-15% of the anthropogenic nitrogen produced in the basins reaches the estuaries (at least via surface runoff). Even less of the anthropogenic phosphorus (2-7%) gets to the estuaries. Apparently there is not a tight coupling between increasing nonpoint source nutrient production and patterns of nutrient concentrations in the estuaries. For example, the great increase in animal nitrogen production in the Neuse basin seems not to have had an

impact on nutrients or algal biomass (as measured by chlorophyll a) in the estuary. This suggests there is a great "buffering" capacity in the watershed for this source. Cooper (Final Report) A two-year study of sediment cores collected from the Pamlico and Neuse River estuaries has been completed. The purpose of this paleoecological study was to begin to re-create the history of water quality in these estuaries by dating sediment core samples and analyzing indicators of water quality, nutrient and trace metal flux, and diatom assemblages through time. The researchers also analyzed the stratigraphic record of pollen found in the sediments for dating purposes. The results indicate that this type of study is not only feasible in these estuarine systems but also very useful. Sediment chronologies have been developed for the sediment cores collected, and the resolution of each 2-cm increment of each core varies from less than 1 year in recent sediments to 36 years in older sediments. Average sedimentation rate in the past 50 years is 0.65 cm yr-1. Sedimentation rates have generally increased three to 10-fold in the past 50 years over previous sedimentation rates based on the data and the models used. Results show that nutrient, metal and sulfur flux to the sediments has increased over the past 50 years. Trace element analyses show that surface sediments often contain heavy metal concentrations that exceed "Threshold Effects Levels" (TEL) as reported by the U. S. Environmental Protection Agency. Cadmium shows highest levels in the Pamlico estuary at the core collection site nearest the phosphate mining operations. Most other metals show higher concentrations in the Neuse River estuary. Diatom valves and pollen grains are well preserved in the sediments of the Neuse and Pamlico. For example, samples analyzed to date from the Pamlico River estuary contain diatom valves in abundances of about 1 to 5 million valves per cubic cm of wet sediment, and pollen grains are present in abundances of about 50,000 to 500,000 per cubic cm of wet sediment. Over 430 diatom species have been identified from subsampled intervals of the Pamlico and Neuse sediment cores to date. Diatom and pollen assemblages have changed through time. The most dramatic assemblage changes in the diatoms appear to have occurred in the past 30-50 years in the Pamlico and Neuse estuaries, possibly associated with industrial activity, increasing population, and land-use changes. Recent assemblages are composed of higher abundances of small planktonic taxa that are often found in large blooms in higher nutrient waters. These samples exhibit relatively low species richness and diversity compared to older (pre-1950) samples. Older diatom assemblages are composed of more benthic and epiphytic taxa. Changes likely reflect eutrophication, increased turbidity and sedimentation, and increased freshwater flow to the estuaries, as well as an increase in industrial activities. They may also reflect declines in submerged aquatic vegetation in these estuaries. Overall trends are similar to those found in the Chesapeake Bay, although the time frame of major changes is different. Similar changes began to occur much earlier in the Chesapeake. Pollen assemblage changes include an increase in ragweed pollen over the past several hundred years signifying increased land disturbance by humans. Pollen count results also show an increase in nut tree pollen (walnut and pecan) over the last several hundred years and an increase in sweetgum tree pollen in the past 50 years. The biogenic silica (BSi) results and the determination of diatom valve flux to the sediments both show that more diatom frustules are being deposited to the sediments in recent years. BSi is primarily a measure of diatom frustules, which are composed of biologically deposited silica. These results indicate higher diatom production, most likely due to increased nutrient inputs to the estuaries. As production increases, dissolved silica in the waters may become limiting, especially if diatoms frustules are preserved in the sediments and not recycled. As silica becomes limiting in the water column, diatoms may be out-competed by other algal species, including dinoflagellates. Diatoms are generally better food sources in the estuarine food web than other algal species, so this change could potentially cause problems in higher trophic levels. Understanding the historical processes of water quality problems is important for managing the continuing impacts of growing populations in North Carolina. These data are useful for providing information on historical changes in estuarine water quality and realistic goals for management.

**Descriptors**

Water quality, Nutrient loading, Eutrophication, Estuarine ecosystems, Algae, Land use, Nitrogen, Historical trends

**Articles in Refereed Scientific Journals**

**Book Chapters**

**Dissertations**

Kim, Sunghea, 1998, Heavy Metal Assessment in the Pamlico and Neuse River Estuaries of North Carolina, Masters Project to partially fulfill the requirements of the Masters of Environmental Management Degree from Nicholas School of the Environment, Duke University, Durham, NC, 47. (Under the direction of S. Cooper)

**Water Resources Research Institute Reports**

**Conference Proceedings**

**Other Publications**

Cooper, S.R., 1999, A Journey Through Time: Paleoecology of Estuaries, Geotimes, 44(5), 14-18.

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**Basic Project Information**

| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | Enviromental and Human Health Impact of Swine Waste Management Practices ( 70170, 70173) |
| **Project Number** | C-08 |
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| **Research Category** | Biological Sciences |
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| **Focus Category #2** | Non Point Pollution |
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**Principal Investigators**

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
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**Problem and Research Objectives**

Nationwide, agriculture is the most important nonpoint source polluter (Sharpley and Meyer 1994). The swine industry is an increasingly important agricultural sector in the Southeastern United States. Rapid regional industry expansion has been accompanied by a shift from family farms to industrial scale animal production in confined quarters. This unprecedented growth presents enormous challenges with regard to disposal of swine manure. For example, swine waste production in North Carolina alone is 8 Tg yr-1, which includes 48 Gg N (Crouse 1995). Regionally, waste is commonly stored in anaerobic lagoons and the liquid phase is land-applied as fertilizer at no more than the agronomic nutrient (in this case N) requirement for the host crop. Improper management may encourage offsite transport, leading to enhanced N loading in adjoining ecosystems, particularly N-sensitive rivers, estuaries and coastal waterways. Clearly, agricultural water quality priorities relative to disposal of swine waste must include development and implementation of Best Management Practices (BMPs) and land use policies that both minimize loss of plant-available N from the site of application and meet the nutritional N requirements of the host crop. This is best accomplished through comprehensive studies that encompass all aspects of N cycling dynamics in spray fields, including simultaneous analysis of changes in pool sizes and rates of microbial and plant N transformations. Regional information of this nature is lacking. Traditional BMPs for agricultural animal wastes have focused primarily on nutrients. However, it is now recognized that these waste materials can harbor numerous enteric human pathogens that will contaminate the environment and pose a human health risk if not properly managed. In particular, the protozoans Cryptosporidium parvum and various species of Salmonella bacteria are present in hog waste. These pathogens have been responsible for numerous outbreaks of gastrointestional illness caused by contaminated drinking water (MMWR 1996). Although Cryptosporidium, Salmonella and other human pathogens of animal origin are widespread in animal wastes, little is known about the relative contribution of agricultural animal wastes to environmental contamination of water resources. On a more basic level, even less is known about the effectiveness of waste treatment systems such as anaerobic lagoons in reducing pathogens or microbial indicators of fecal contamination. In order to better characterize the potential risks to human health and to identify appropriate regional (BMPs), information is needed on: (a) the occurrence, survival and treatment or Cryptosporidium, Salmonella and other human pathogens in stored hog waste; and (b) the effectiveness of current and candidate waste treatment processes at removing and destroying these pathogens before they are discharged into the environment. This two part project is aimed at: (a) obtaining a comprehensive N mass balance for liquid swine effluent applied seasonally to mesoscale (4m X 4m) experimental plots at different loading rates to determine the relative importance and relevant time scales for physical (NH3 volatilization, leaching) and biological (plant and microbial activities) processes involved in N transformations and transfers among reservoirs; and (b) characterizing and quantifying the reductions of pathogens and microbial indicators by conventional and alternative treatment systems for swine waste. These objectives are directly responsive to the several target areas of the 1998 Regional Water Resources Competitive Grants Program (Southeast and Island Region); namely, "problems from non-point sources of both municipal and agricultural sources," "use and user impacts on water quality," and "water quality problems associated with eutrophication and weed control".

## Methodology

Whalen (1) General Experimental Design and Field Sample Collection Triplicate 4 m x 4 m (16 m2) and 2 m x 2 m (4 m2) experimental plots within the spray field will be fertilized with liquid swine effluent at volumes corresponding to 0.63, 1.25 or 2.5 cm additions (one plot each size and volume). These dosages agree with standard facility and industry practices. Collector cups (125 ml) will be positioned along a grid at 0.5 m intervals within plots to ensure homogeneous application with a backpack sprayer. Random samples will be analyzed for NH4+ and total-N. All plots will be spaced at 20 m intervals along a transect perpendicular to the direction of the prevailing wind with the larger plots arranged adjacent to one another along the transect. This spacing and orientation will facilitate utilization of a shared power source at the larger plots (see below, Section 12.1d) and will prevent cross-fertilization with volatilized NH3 via wind drift. Plots will be fertilized no sooner than 7 d following the previous whole field application. The 16 m2 plots will be intensely sampled for 14 d post-fertilization. A tipping bucket rain gauge will be deployed at the site to record precipitation. Installation of permanent sampling devices (gas flux chambers; Section 12.1g) and core collection in each 16 m2 plot will be limited to the area at least 0.5 m interior to the plot boundary to eliminate edge effects (c.f. Weed and Kanwar 1996). Cores removed from the 16 m2 plots will be immediately replaced with cores from similarly fertilized 4 m2 plots to minimize the effect of destructive sampling. The spray field shows no slope and sandy soils to a depth of at least 2 m, hence we expect no lateral post-spray transport of effluent. During each sampling session, a soil temperature profile will be taken at each site with a portable multi-thermister probe (2 cm intervals to 20 cm) and the mean soil temperature will be calculated. Unless noted, cores will be collected with a 5 cm diameter punch auger capable of being fitted with removable stainless steel inserts. Where appropriate (noted below in descriptions of specific methodologies) the following physicochemical determinations will be made on sieved (2 mm mesh), homogenized cores according to standard procedures (Carter 1993): soil pH, organic content, gravimetric moisture content, % water holding capacity (WHC), KCl-extractable NO3--N and NH4+-N (hereafter referred to simply as NO3--N and NH4+-N) and total-C and total-N (dry combustion). Liquid waste samples will be analyzed for NH4+-N and total-N according to Parsons et al. (1984). Soil and liquid waste samples for nutrient analyses will rapidly be frozen in liquid N2 upon collection and transported on ice to the lab. Following are specific methods that will be used to assess N pool sizes and rates of transfer among compartments in Fig. 1. Efforts at assessing internal cycling will focus on the aboveground biomass and soil zone to 20 cm. Our ongoing research at this site shows that microbial activity is confined to this soil zone and soil roots are concentrated in the upper 10 cm. Hereafter, the surface 20 cm soil zone will be referred to as the "active soil zone." Zero Time and Final Time N Pool Sizes Pretreatment (zero time; T0) N pools will be assessed in soil and plant samples collected adjacent to the 16 m2 plots. Quadruplicate soil cores to 100 cm will each be homogenized (10 cm sections in the active zone and 20 cm sections thereafter) and analyzed for NH4+, NO3- and total-N (T0-OUT). Quadruplicate 20 cm diameter cores will be collected in the active zone adjacent to the chambers and cleaned of surface detritus. Roots will be separated from the soil by hydropneumatic elutriation (Smucker et al. 1982). Above- and belowground biomass and detritus will be dried, weighed and assayed for total-N. Soil microbial biomass N in the active zone will be analyzed by the fumigation-extraction procedure (Brookes et al. 1985; Vance et al. 1987). An additional set of samples collected after 14 d (final time; TF) from within (TF-IN) and outside (TF-OUT) each 16 m2 plot after and will be analyzed as described above. Bulk dry mass and concentration data will be used to calculate N pool sizes in soil, plant, detritus and microbial N in the active zone. Data for TF-OUT - T0-OUT will be used to assess changes in pools in the absence of fertilization, while data for TF-IN - T0-OUT will be used to calculate changes that occurred in the fertilized plot. Data will be corrected for changes that occurred outside the plot during the experimental period to evaluate the direct effect of fertilization. These data only evaluate the net change in pool sizes

within the active soil zone. Following are methods used to assess rates of physical and biological processes that mediate N transfers among compartments within the active soil zone or N export from the active soil zone. Soil Emission of NH3 to the Atmosphere A dynamic chamber method (Ruess and McNaughton 1988) will be used to measure NH3 emission from the soil. Air will be drawn with a vacuum pump through a foil-covered chamber (25 cm diameter x 25 cm long ) driven 3 cm into the soil. The flow rate will mimic the mean monthly wind velocity. The foil cover and air flow will minimize the heat load and inhibit formation of a soil surface boundary layer. Each chamber will be fitted with a thermistor to monitor air temperature. The intake will be oriented into the prevailing winds and will consist of a 1 cm diameter tube that extends at ground level to 1 m outside the 16 m2 plot. In-line gas (1 N H2SO4) and distilled water traps will strip NH3 and humidify the incoming air. Five percent of the chamber exhaust will be directed to a gas trap (1 N H2SO4) to collect NH3 emitted from the soil surface. A single chamber will be deployed in each plot and flux measurements will be made for 1 h at 4 h intervals from the time of fertilizer application to 12 h and at 18 and 24 h. Additional measurements of 4 h duration will be made at 48 h and at 2 d intervals thereafter to 14 d. Fresh gas traps will be used for each flux measurement and the NH4+ concentration of each trap will be determined as described above. This original system is 97% efficient at trapping NH3 volatilized in the chamber. We have modified some aspects of the original published method to accommodate the needs of this study after extensive discussion with the senior author, R.W. Ruess. Inorganic-N Export Below the Active Soil Zone Loss of inorganic-N from the active zone will be assessed by comparing soil NO3- and NH4+ concentrations in the 20 cm to 1 m zone in quadruplicate cores collected outside the plots prior to fertilization with similar data for cores collected inside and outside the plots 14 d post-fertilization (Section 12.1c). Bulk density and concentration data will be used as outlined above (Section 12.1c) to calculate mass N loss from the active zone as a result of fertilization. Suction lysimetry in conjunction with the addition of a stable conservative tracer (Cl- or Br-) is frequently employed to assess water and solute transport in the vadose zone. Spatial changes in the NO3-/tracer ratio are used to infer N loss to denitrification or volatilization in mass balance studies (e.g. Kessavalou et al. 1996). This methodology is unacceptable for the proposed research for three reasons. First, Groffman et al. (1995) demonstrated that both Cl- and Br- significantly inhibit N mineralization and nitrification and depress denitrification at typical loading rates. These microbial processes are a primary focus of the proposed research. Second, N loss through volatilization (Section 12.1d) and denitrification (Section 12.1g) will be directly measured here, hence there is no need for a tracer to infer losses from these processes. Third, initial lysimeter deployment disturbs the soil and may influence the region of lysimeter influence (Wu et al. 1995), which are both factors of concern in short duration (<1 yr) experiments. Net Transfers and Transformations Within the Soil Inorganic-N Pool Net transfers and transformations within the soil inorganic-N pool will be assessed by measuring NO3- and NH4+ concentrations in 20 cm cores partitioned into 5 cm sections. Changes in nutrient pools will be computed from concentration and dry soil mass data. These changes will reflect the net influence of processes depicted in Fig. 1 on inorganic-N pools. Duplicate cores will be collected immediately following fertilization and at 3, 6, 12, 24 and 48 h post-fertilization and at 2 d intervals thereafter to 14 d. Many field incubation schemes have been proposed to simultaneously measure net N-mineralization, net nitrification and possibly plant assimilation and leaching loss (Raison et al. 1987; Debosz and Vinther 1989; Hart et al. 1994). To some degree, all involve long-term incubations and soil confinement that can both lead to experimental artifacts and disrupt natural feedbacks and interactions. Further, these methods require high replication to account for field-scale heterogeneity. The technique proposed here involves few samples collected from a relatively small area (heterogeneity minimized) and requires no soil confinement or lengthy incubation. Gaseous N2 and N2O Loss from Denitrification Denitrification rates will be determined by a static core technique (Groffman et al. 1993). Duplicate 20 cm cores will be collected in 30 cm core liners immediately following fertilization and at 3, 6, 12, 24 and 48 h post-fertilization and at 2 d intervals thereafter to 14 d. Liners will be sealed, the headspace will be amended with C2H2 to 10kPa, and the core (plus liner) will be incubated in situ (replaced in the collection hole) for a 1 h equilibration period. Core headspaces

will be syringe-sampled following the equilibration period and at 0.5 and 1 h thereafter. Syringe gas samples will be transported to the laboratory and analyzed for N2O by electron capture gas chromatography (GC-ECD) within 24 h of collection. The internal headspace volume of each core will be determined with a pressure transducer according to Parkin et al. (1984). Acetylene inhibits the reduction of N2O to N2. The rate of N2O accumulation will therefore be used in conjunction with the internal headspace volume to obtain an area-based estimate N2O + N2 production by denitrification. A static chamber technique (Whalen and Reeburgh 1988) will be used to determine rates of N2O emission from denitrification within each plot. Essentially, an inverted cylinder (20 cm diameter X 12 cm height) will be placed over a permanently deployed soil collar (base) to isolate a parcel of air (headspace). The time-linear rate of concentration change of N2O in the headspace over 40 min (samples collected at 10 min intervals) will be used to calculate an area-based flux and the chamber top will be removed between sampling sessions to allow natural soil-atmosphere gas exchange. Flux determinations will be coordinated with core-based denitrification estimates (above) to determine the percent contribution of N2O to total gas (N2 + N2O) emission from denitrification. Duplicate soil collars will be permanently deployed at each plot for N2O flux determinations. Sampling frequency for determinations of N2O flux and denitrification will be increased following any post-fertilization rainfall to match the level proposed for the initial 24 h after fertilizer application. Denitrification is stimulated by rainfall (Tiedje 1988). Data Analysis Experiments are designed to provide a firmly based analysis of N cycling dynamics in response to fertilization, including exports and transformations that influence plant and soil N pools. The scope and labor-intensive nature of the proposed research precludes replication of treatments (loading rates) or soil types. Our ongoing work on various N transformations at this and other spray fields indicates that the proposed methodology is proven and sampling frequencies are adequate to capture anticipated fluxes during each experimental fertilization. Sufficient information will be collected to assign values (rates and mass) to transformations and reservoirs (surface water loss assumed nil). Methods of flux and mass calculation are given above when each technique is discussed. Rate data will be time-integrated to compare observed and predicted TF pool sizes and assess an error of closure. Rates of physical and biological processes affecting N cycling will be correlated with environmental measures such as rainfall, soil temperature and N pool sizes to gain insight into the near-term (single event) importance of these drivers as a function of season and loading rate. Finally, these data can be used to determine whether loading rates or seasonality or combinations of the two promote N accumulation in the soil, which could ultimately lead to offsite transport via surface or groundwater in a time scale beyond the scope of these experiments. Finally, on a regional scale, these experiments will give some indication whether spray fields should be more closely evaluated as a point source of atmospheric N2O. Field-scale, long-term experiments involve considerable labor and expense and are beyond the anticipated funding level of this initiative. This mesoscale (several m2), event-based (individual applications) investigation on a regionally common soil type is less expensive and provides a detailed, conceptual understanding of physicochemical and biological interactions involved in soil N cycling dynamics and soil-atmosphere exchange of gaseous N that are mediated seasonally by a spray event. Data collected here will be the first of its kind and will therefore be invaluable to assess the performance of current BMPs for swine waste disposal and to intelligently modify these BMPs. Sobsey (2) Pathogen Research This research will characterize the pathogen reduction effectiveness of anaerobic lagoons, constructed wetlands, solids separation, and hog house waste collection using state-of-the-art methodology to characterize and quantify the fate of indicator organisms and selected pathogens. Changes in concentrations of total nitrogen, ammonium nitrogen (NH4+-N) and total phosphorous also will be tracked to evaluate how the different treatment techniques and management options affect both pathogen and nutrient removal. Analytical Procedures for Indicator Organisms Fecal coliforms, Eschericia coli, enterococci, Clostridium perfringens, somatic coliphages and male-specific (F+) coliphages are the indicators to be analyzed. Bacterial analyses will be by membrane filtration methods using standard media (Standard Methods for the Examination of Water and Wastewater 1995). Media are: mFC agar for fecal coliforms, nutrient

agar-MUG for identification of which fecal coliforms are E. coli, modified mE agar for enterococci, and mCP agar and anaerobic incubation for C. perfringens followed by ammonium hydroxide fume exposure of presumptive colonies. Somatic and male-specific coliphages are analyzed by double agar layer (DAL) and single agar layer (SAL) plaque assay methods on hosts E. coli CN-13 and Salmonella typhimurium WG-49, respectively (Adams 1959; Grabow and Coubrough 1986; Sobsey et al 1990; 1995). Representative male-specific coliphage plaques in wastewater samples will be tested for RNAse sensitivity and, if RNA phages, they will be serotyped to one of four groups: I (animal origin), II (human origin), III (human origin), or IV (animal origin) (Hsu et al. 1995). Analytical Procedures for Pathogens. Field and laboratory samples will be analyzed for Salmonella spp. as important bacterial pathogens and Cryptosporidium parvum as a key protozoan pathogen. Salmonella spp. will be enriched in modified Rappaport-Vassilidis (RV) enrichment media (Vassilidis 1983; Vassilidis et al. 1978) followed by plating onto XLD, SS, and other Salmonella selective agars. Presumptive Salmonella colonies will be biochemically analyzed using API-20 or Enterotube kits (Oragui et al. 1993), and serologically confirmed (Perales and Audicana 1989; Watson 1985; Emperanza-Knorr and Torrella 1995). Another approach will be enrichment followed by RNA extraction and detection by Salmonella gene probe (non-radioactive 16S ribosomal RNA oligonucleotide probe) and hybrid detection by chemiluminescent methods. Cryptosporidium oocysts are recovered from 1-L wastewater samples by centrifugation, purified by immunomagnetic separation (IMS), and examined microscopically after fluorescent-antibody labeling. Oocyst will be assayed for viability by vital dye staining with DAPI and propidium iodide (Campbell et al. 1992; Grimason et al. 1994; Robertson et al. 1992) and for cell culture infectivity of MDCK cells followed by fluorescent antibody detection with C3C3-monoclonal antibody labeled with rhodamine (Arrowood et al. 1994; 1996). Analytical Methods for Nutrients Total nitrogen, NH4+-N, and phosphorous will be analyzed according to Standard Methods for the Examination of Water and Wastewater (1995). Pathogen and Indicator Reduction Characterization Samples of influent and effluent will be collected monthly for a period of one year from anaerobic lagoons at four hog farms representing differing types of swine operations (small-scale, large-scale, nursery, finishing, etc.) to characterize the effectiveness of currently operating lagoons in reducing levels of indicators, Salmonella spp. and Cryptosporidium. The monthly samples will also be analyzed for TKN, nitrate, NH4+-N, and total phosphorous. These data will be combined with previous data to provide results for an entire year. Hydraulic Studies In order to investigate potential modifications of anaerobic lagoon design to improve pathogen reductions, one or more bench-scale models will be built to model observed field conditions. Tracer studies (fluoride, lithium or fluorescent dyes) will be performed (using these bench-scale units at three hydraulic residence times (HRT) to determine differences between actual and theoretical HRT for the bench-scale units. Wastewater from the field lagoon sites will be collected, transported to the laboratory, and stored at 4EC or -20EC for subsequent use in bench-scale tracer and treatment studies. After the bench-scale tracer studies are completed, the system(s) will continue to be operated. Influent and effluent samples will be collected and analyzed for indicator organisms and nutrients to generate to baseline performance estimate for the bench-scale unit (s). Once a baseline has been developed for the HRT, indicator/pathogen removal, and nutrient reduction achieved by the bench-scale model(s), the effect of installing baffles on the performance of the bench-scale unit(s) will be investigated. Our hypothesis is that the installation of baffles into existing lagoons modifies the hydraulics of the lagoon system from a theoretical complete-mix batch reactor to more of a plug flow system. Plug flow hydraulics may allow for increased, but directed, variation in the composition of the microbial communities in the lagoons. The increased HRT of the baffled lagoons and the differential metabolic activities of the spectrum of microbial communities that from plug flow dynamics may improve pathogen and indicator reductions. After analyzing the indicator and nutrient removal effectiveness of the baffled system(s), the influent to the bench-scale unit(s) will be spiked (in separate studies) with known quantities of Salmonella spp. organisms and Cryptosporidium oocysts to investigate whether installation of baffles in the bench-scale lagoon units improves the removal of these pathogens. If the results of the bench-scale tests demonstrate potential benefits of baffled lagoons,

baffles will be installed in 2 currently operating, full-scale units previously selected for tracer studies. Two tracer studies will be done on each of the baffled full-scale lagoons during the same season(s) that the baseline tracer studies were performed, with monthly samples collected for analysis of microbial indicators and nutrient parameters. Microbial Sedimentation and Survival Studies Sedimentation columns and batch containers will be used in lab studies on sedimentation and survival (die-off). These studies are conducted to associate HRT with pathogen removal due to particle settling/natural die-off in anaerobic lagoons. Test wastewater will be from one or more of the four field sites. Sedimentation studies will be performed to characterize the rates of reduction of microbial indicators as well as added Salmonella bacteria and Cryptosporidium oocysts due to sedimentation/natural die-off by withdrawing wastewater samples from different points in a column of wastewater over time and analyzing for the indicators and the selected pathogens. Die-off Studies Die-off kinetics of microbial indicators, Salmonella spp. and Cryptosporidium will be studies in one or more of the lagoons at the selected study sites using microbial dialysis chambers. These chambers will be filled with lagoon wastewater and spiked with known quantities of Salmonella typhimurium and Cryptosporidium oocysts. The removal and die-off rates of these pathogens will then be tracked over time. Cryptosporidium oocysts viability and infectivity will be enumerated and assayed using previously described methods. Salmonella typhimurium will be assayed by the enrichment MPN methods described previously. Microbial Indicator Reduction Characterization Samples will be collected monthly for a period of one year from the pilot-scale constructed wetlands system at a Duplin County, NC, study site. This system is composed of three sets of parallel wetlands units, each comprised of two cells in series. The constructed wetlands were designed as surface flow (SF). Wastewater samples from two of the parallel SF wetlands units will be analyzed for microbial indicators. These two wetlands units will be operated at different HRTs to investigate the effect of HRT on indicator and nutrient reduction efficiency. Two replicate tracer studies will be performed for both the units, one during the summer and the other during the winter. The measured HRT from these tracer studies will be compared to the theoretical HRT for the units. Pathogen and Indicator Reduction Characterization in Mini-wetlands Small (approximately 1 m by 0.5 m) wetland cells will be used to evaluate the effectiveness of SF and subsurface flow (SSF) constructed wetlands for reducing the concentrations of indicators, Salmonella spp. and Cryptosporidium in effluent from primary treatment (e.g., anaerobic lagoons). These small-scale cells will be planted with vegetation similar to the larger pilot-scale units at the Duplin County site. Wastewater (anaerobic lagoon effluent or solids separated wastewater) from one or more of the study sites will be transported to the lab, stored refrigerated, continuously mixed and pumped into six mini-wetland units (four SF units and 2 SSF units). Pumping rates to the mini-wetland units will be varied to evaluate performance at different HRTs. Units will be operated at selected HRTs for 2 month periods. Samples will be collected weekly (and sometimes daily) to determine how the mini-wetlands perform as they stabilize (over a period of weeks), as well as within a diurnal cycle. In addition to determining mini-wetland performance for reducing microbial indicators and nutrients, influent wastewater to the small-scale cells will be dosed with Salmonella typhimurium and Cryptosporidium parvuum oocysts to determine the removal performance for these pathogens. Solids Separators A field study will be done to evaluate microbial indicator reductions using solids separators for primary treatment of wastewater from hog houses. At swine operations currently using solids separators, influent and effluent wastewater samples will be collected and analyzed for microbial indicators and nutrient parameters. The removal efficiencies for the solids separators will be compared to the removal efficiencies achieved by the currently operating anaerobic lagoons. Pit-Plug vs. Water-Wash House Flushing Systems A laboratory study will be performed to evaluate whether there is a pathogen reduction benefit of pit-plug vs. water-wash systems. Pit-plug systems are those in which the waste collection channels beneath the hog house pig pens are filled with water and collected hog waste is periodically removed from beneath the hog house by 'pulling the plug' and letting the wastewater flow by gravity into the primary treatment unit. Water-wash systems utilize recirculated water from a wastewater lagoon to periodically flush hog waste from

beneath the hog house into the receiving lagoon. Pit plug systems may achieve some pathogen reduction because wastewater sits beneath the hog house for approximately one-half to 1 week before being released to the receiving lagoon. The laboratory study will investigate the die-off rate of microbial indicators under laboratory conditions simulated to be similar to those present in the waste collection channels in pit-plug systems. Data Analysis and Interpretation The data on concentrations of pathogens, indicators and nutrients in treated and untreated wastewater will be analyzed to determine the extent of reduction of these parameters. The frequency and concentrations of pathogens and indicators in raw, untreated wastes will be compared to that of the wastes subjected to specific treatment processes (i.e., lagooning, solids separation, constructed wetlands). By construction of and comparisons between or among the frequency distributions of pathogen concentrations in raw and treated wastes, quantitative reductions of the microbes by the specific treatment processes will be determined. Nonparametric t-tests will be performed on influent and effluent data to determine if the various treatment units achieve significant reductions in mean concentrations of each indicator, pathogen, and nutrient. T-tests also will be performed to determine whether alternative treatment units achieve significantly different reductions of indicators, pathogens,and nutrients. For studies where HRT is varied, regression analysis will be performed to relate indicator, pathogen and nutrient reduction performance to HRT. For constructed wetlands, regression analysis also will be performed to evaluate the significance of hydraulic loading rate, influent concentration, and ambient temperature in predicting wetland performance. Statistical analyses also will be performed to determine which indicators are most reliable in predicting the presence and concentrations of pathogens. Indicators will be evaluated on the basis of sensitivity, specificity, accuracy, reliability, technical difficulty, speed and cost. One goal of the analyses is to determine if levels of indicators (fecal coliforms, enterococci, C. perfringens, coliphages, etc.) in wastewater samples can be used to predict and quantify the presence and levels of the study pathogens (Salmonella spp., Cryptosporidium parvum) in wastewater. A 2x2 table is created to cross tabulate the level of a specific pathogen (high versus zero or low) against levels of an indicator (high versus zero or low). Sensitivity, specificity and measures of agreement (e.g., kappa statistic) will be calculated. This analysis is repeated to compare each pathogen to each indicator, in turn. Data on pathogen and indicator survival (die-off) in swine wastewater will be analyzed by regression methods to determine the rate and extent of pathogen and indicator reduction as a function of time. Data will be expressed as the log10 of initial organisms surviving or remaining as a function of time: log10NtNo where No is the initial concentration of organisms at zero time, and Nt is the concentration of organisms at time = t. If die-off data are first-order, then the slopes of their regression lines can be used to compare die-off rates among the different pathogens and indicators. If the data are not first-order, then alternative regression or other quantitative measures of persistence will be used. These die-off data will be compared among and between indicators and pathogens. These comparisons will make it possible to determine not only how persistent pathogens are under certain waste and incubation conditions, but also which indicators, if any, are adequately predictive of pathogen persistence (or die-off). Similar statistical approaches will be used to determine if there are relationships between microbe reductions and nutrient reductions.

**Principal Findings and Significance**

(1) Whalen (Progress Report) Liquid lagoonal swine waste is repeatedly sprayed as an organic fertilizer on agricultural soils associated with confined animal feeding operations in the southeastern United States. The total-N of the waste is almost entirely NH4+-N (>90%) and thus has a low mineralizatiuon potenial. Application of this liquid fertilizer to warm soils in a form that is both readily volatilized and immediately utilizable by the endogenous N-cycling microbial community ensures a sharp post-fertilization decline in soil NH4+-N and promotes a rapid and short-lived (days) burst of nitrification, denitication and NO2 emission. In contrast, manures and slurries have a higher mineralization potential and therefore show a slower release of nitrogenous nutrients and a more protracted (several months)

period of fertilizer influence. The fractional loss of applied N to N20 found here for liquid lagoon waste (1.4%) agrees with that for mineral fertilizers (1.25%), but further studies of land applied liquid lagoon effiuent are needed to confirm this similarity The increased N2O emission from a representative southeastern U.S. spray field fertilized with swine waste was due to the interactive effects of increases in soil moisture and N. Available C was in adequate supply. High residual soil NO2-N can result in additional episodic N2O efflux in response to rainfall Some unidentified component of liquid swine waste may negatively impact the microbial community, as NO2 emissions were significantly less than for soils amended at a comparable level with a liquid NH4-N fertilizer. Nitrous oxide emission from fertilization was directly related to the levels of fertilization to 150 kg N ha-1. Loss of applied N to N2O (0.005-1.0%) was somewhat lower than previously reported, but these estimates did not include rainfall-simulation emission after fluxes had returned to pre-fertilization levels. An inexpensive modification of the commonly used manual nitrate (NO3)- nitrogen (N) analysis for soil extracts has been developed as a result of this project. The procedure uses multiple reductors of copperized cadmium (Cd) wire threaded through Teflon tubing and a peristaltic pump to rapidly pass a low volume of soil extract through the reductors at a consant flow rate. In excess of 150 prepared samples can be processed daily with minimum waste generation. Efficiency of reduction is >98% and precision of analysis (coefficient of variation) for replicate standards of known NO3-N concentration is excellent, at <0.5% over the concentration range 0.025 to 0.2ug NO3-N mL-1. Column life and storage characteristics are high, at >250 samples per column and one month, respectively. Column activation and regeneration in these wire type reductors are simpler and less tedious than for reductors constructed of copperized Cd granules. (2) Sobsey (Progress Report) The study continues to evaluate microbial reductions in conventional, alternative, and additional swine waste treatment processes, including anaerobic lagoons, constructed wetlands, biofilters, an electro-reactor and UV irradiation systems. This progress report will cover the results from testing the aerobic biofilter system and the UV disinfection system. The aerobic biofilter system was investigated as a treatment alternative to lagoons at swine farms. The results of this study demonstrate that the aerobic biofilter can effectively reduce enteric microbes and nutrients in flushed swine waste, though the effectiveness of the system is lower under cold weather conditions. Enteric microbe reduction efficiencies in the biofilter system were consistent over a wide temperature range (19-32 degrees C) was the highest for vegetative bacteria and coliphages (approximately 98-99% reductions). Geometric mean fecal coliform concentrations in biofilter effluent over this temperature range were 58,000 CFU/100 mL. At these temperatures, concentrations of fecal coliforms and the other enteric microbes studied were lower in biofilter effluent than have been generally measured in single-stage swine waste lagoons, and are comparable to the enteric microbe levels in two-stage lagoon treatment systems (Hill and Sobsey, 1998; Hill and Sobsey, unpublished data). Under the cold weather conditions studied, the biofilter system reduced enteric microbes to levels similar to those in single-stage swine lagoon liquid. Thus, under cold weather conditions the aerobic biofilter can be as effective at reducing enteric microbes in flushed swine waste as single-stage lagoons, which currently are the most common method in the Southeastern United States for storage and treatment of swine waste. The aerobic biofilter system also achieved these relative reductions in less time than lagoons require: swine waste lagoons are typically designed to have HRTs of over 6 months compared to the 18-hour HRT in the aerobic biofilter system. Field studies and laboratory collimated beam testing showed that UV disinfection can achieve an additional 2 log10 reduction of indigenous fecal coliforms and E. coli, and a 2 to 3 log10 reduction of somatic coliphages in swine wastewater. UV disinfection was not as effective against enterococci and C. perfringens spores. Similar collimated beam UV disinfection results were achieved at the same incident UV doses in the three wastewater types studied, although calculated average UV doses were lower in biofilter influent than in biotower #1 or biotower #2 effluents. This may have been due to differences in indigenous enteric microbe populations in the different wastewaters or to other factors. At incident UV doses of approximately 20 to 60 mWs/cm2, fecal coliform and E. coli concentrations in biofilter effluent can be reduced by 1 to 2 log10, achieving final concentrations on the order of 100s to 1000s of CFU/100 mL. Thus, UV disinfection

may be feasible for reducing enteric microbe concentrations in aerobic biofilter effluent, and swine wastewater in general. However, further research is advisable to evaluate the efficacy of UV disinfection during the long-term operation of swine wastewater treatment systems.

**Descriptors**

Soil microbiology, Soil chemistry, Nitrogen, Animal waste, Fertilizer, Pathogens, Viruses, Lagoons

**Articles in Refereed Scientific Journals**

Whalen, S.C., 1999, Simplified Procedure for Rapid Manual Analysis of Nitrate in Soil Extracts by Copper-Cadmium Reduction. Communications in Soil Science and Plant Analysis, 30, 1633-1641.
Whalen, S.C., 1999, Nitrous Oxide Emissions from an Agricultural Field Fertilized with Liquid Lagoonal Swine Effuent. Global Biogeochemical Cycles, , . (in press)

**Book Chapters**

**Dissertations**

Brown, Dan, 1999, The Effect of Environmental Variables on Nitrification in Agricultural Soils Amended with Liquid Lagoonal Swine Waste, M.S. Dissertation, Dept of Environmenal Sciences and Engineering, University of North Carolina at Chapel Hill, Chapel Hill, NC, . (Under the direction of Steve Whalen)

**Water Resources Research Institute Reports**

**Conference Proceedings**

**Other Publications**

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**Basic Project Information**

| Basic Project Information | |
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| **Category** | **Data** |
| **Title** | Soil Processes Impacting Groundwater Quality in the NC Piedmont: Contamination by Organic Agrochemicals (70174) |
| **Project Number** | B-III |
| **Start Date** | 03/01/1999 |
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| **Research Category** | Water Quality |
| **Focus Category #1** | Groundwater |
| **Focus Category #2** | Hydrogeochemistry |

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|---|---|
| **Focus Category #3** | Solute Transport |
| **Lead Institution** | Water Resources Research Institute of The University of North Carolina |

**Principal Investigators**

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Dharni Vasudevan | Assistant Professor | Duke University | 01 |

**Problem and Research Objectives**

Close to 10% of soils in the United States can be classified as ultisols or "red clay soils". Primarily located in the southeast, these soils are strongly weathered, acidic, depleted of organic matter, and enriched in iron and aluminum oxides and low activity clays such as kaolinite. These and other attributes make red clay soils physically and chemically distinct from the more commonly studied temperate soils. Evaluation schemes used to predict soil susceptibility to contaminant leaching are typically based on characteristics of temperate soils; these schemes may not always be successful in red clay soils. Currently, our knowledge of the chemical interactions of polar/ionogenic organic solutes, including many pesticides, in red clay soils is limited. However, research on small organic ligands possessing carboxylic, hydroxyl, and amino groups and pure phase oxides has advanced our understanding of sorption and transformation at the metal oxide-water interface. These studies lend support that interactions between the ligand donor groups on polar/ionogenic organic solutes and surface bound iron and aluminum atoms on red clay soils may play an important role in the assessment of solute fate and transport. The research is aimed at characterizing abiotic interfacial processes that contribute to the attenuation and mobilization of polar/ionogenic pesticides in iron oxide rich North Carolina Piedmont ultisols. The objectives are to: (1) examine and understand the potential for sorption, desorption, and abiotic transformation of polar/ionogenic pesticides at various depths in two unique NC Piedmont soils as a function soil composition and physical-chemical properties and pesticide structure and physical-chemical properties; and (2) evaluate the implication of research results for the prediction of polar/ionogenic pesticide fate in the NC Piedmont. Three heribicides, 2,4-D, norflurazon, and quinmerac, and two representative Piedmont soils, Appling and Georgeville series, were used to achieve the objectives.

**Methodology**

Samples of two related soil series (Appling and Georgeville) were obtained from sites at the Duke forest, Gates 12 and 11, respectively. At each site, samples were taken at 5 depths between 0-200 cm to represent all soil horizons as determined by visual and physical changes in the soil profile. For each soil sample, total elemental composition, mineralogy, soil texture, pH, ECEC, saturated paste conductivity, N2BET surface area, total carbon, nitrogen, dithionate-citrate-bicarobonate (DCB) and acid-ammonium-oxalate extractable Al, Fe, and Mn, and surface site density were measured using techniques outlined by Sparks (1996) and Carter (1993). Batch and continuous flow stirred tank reactors (CFSTRs) were used to evaluate the extent of sorption/desorption and degradation of the test pesticides. Batch studies were used to monitor pesticide loss from bulk solution at regular time intervals for a period of at least 144 h. Pesticide concentrations were measured using HPLC/UV detection.

Standard statistical tools were used to evaluate the relationship between soil properties and extent of pesticide loss from soil solution. CFSTRs were used to study soil processes in non-equilibrium scenarios, confirm the processes observed in batch studies, and determine the kinetics of sorption and desorption. In the CFSTR, influent was pumped at a known flow rate into a stirred chamber containing a constant particle loading. Effluent leaving the chamber was passed through a 0.2mm filter (fitted within the chamber) and into a flow cell of a UV spectrophotometer, where absorbance was recorded at 0.2 minute intervals. For the sorption experiments, an influent of constant pesticide concentration was used, while deionized water was used to evaluate desorption phenomena. Implications of batch and CFSTR results to groundwater quality in the NC Piedmont were then evaluated.

**Principal Findings and Significance**

From the batch studies, the researchers found that loss of pesticide from soil solution occurred rapidly in all soil mineral layers, reaching an apparent plateau by 24-48 h. For the uppermost horizon, a similar plateau was not observed for norflurazon even at 144 h. At 144 h, quinmerac showed the greatest loss from soil solution in the low organic matter-containing layers of both soil profiles, followed by 2,4-D and norflurazon. Norflurazon loss in both Georgeville and Appling systems was only significant in the uppermost organic matter-containing soil horizon. Generally, 2,4-D and quinmerac loss from solution was greater in Georgeville soils as compared with Appling soils. Correlations between pesticide loss and soil properties revealed that 2,4-D and quinmerac loss were strongly correlated with surface area, clay content, total aluminum, total iron, and free iron oxide (operationally defined as DCB extractable iron), while norflurazon loss could only be correlated to total soil carbon. For example, the trend in 2,4-D and quimerac retention as a function of depth mirrored the trend in soil Fe content as free iron oxide. These results suggested that processes that control soil-pesticide interactions for norflurazon differ from those for 2,4-D and quinmerac. Based on pesticide molecular structure and pKa and the strong correlation between pesticide loss and iron content, the researchers speculated that the high retention of 2,4-D and quinmerac in iron-rich mineral horizons was due to both favorable electrostatic interactions with the soil surface and complexation, via the carboxylic acid groups, with the surface-bound electron deficient iron centers. Furthermore, for quinmerac, the researchers speculated that the hetrocylic N group assisted the -COOH group in surface complexation. The importance of iron oxide surfaces was confirmed by the observation of 2,4-D sorption onto pure phase iron oxides, hematite and goethite. In the absence of an ionizable group such as the carboxylic group, as is the case for norflurazon, interaction with mineral horizons was less likely and hydrophobic interactions with soil bound organic matter was the more likely process for pesticide retention. CFSTR studies with 2,4-D demostrated the reversibility of the sorption processes in most cases and confirmed that loss from bulk solution observed in batch studies was largely due to sorption phenomena. Trends with respect to the extent of sorption in various depth samples were similar in both batch and CFSTR studies. The researchers found that the use of lower soil loadings in the CFSTR facilitates greater extent of pesticide sorption and that the initial rate of desorption was consistently greater than the initial sorption rate. In some soil samples, desorption with water failed to recover all the sorbed 2,4-D. From these results the researchers concluded that in some cases sorption involveed both a weakly sorbed and a strongly sorbed phase. They inferred that weak sorption was a result of non-specific electrostatic interaction, while the the strong sorption was the result of either surface complexation, physical entrapment or other physical-chemical processes. Rate of change in concentration of the sorbed pesticide as function time during sorption and desorption scenarios were tol be fitted into established kinetic equations and related rate constants were to be derived. These results suggested that along with traditionally used soil properties (including but not limited to soil organic matter, texture and acidity), total and/or free iron and total aluminum content could be important in determining the fate of carboxylic acid pesticides and phenoxyacetic acid pesticides in iron oxide rich soils. For the soil types examined, it appeared that 2,4-D and quinmerac

were less likely to be retained in the uppermost soil horizon as compared with the mineral horizons, while the opposite were to be expected for norflurazon. The results also suggested that norflurazon that migrates below the uppermost soil horizon and was less likely to be attenuated in the subsoil and was more susceptible to leaching.

**Descriptors**

Sorption, Desorption, Soil Chemistry, Soil Iron Oxides, Pesticides, Herbicides, Organic Compounds, and Water Chemistry.

**Articles in Refereed Scientific Journals**

**Book Chapters**

**Dissertations**

**Water Resources Research Institute Reports**

**Conference Proceedings**

**Other Publications**

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**Basic Project Information**

| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | Predicting Long-Term Wetland Hydrology Using Hydric Soil Field Indicators (70175) |
| **Project Number** | B-IV |
| **Start Date** | 03/01/1999 |
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| **Research Category** | Biological Sciences |
| **Focus Category #1** | Wetlands |
| **Focus Category #2** | Hydrology |
| **Focus Category #3** | None |
| **Lead Institution** | Water Resources Research Institute of The University of North Carolina |

**Principal Investigators**

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
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## Problem and Research Objectives

Jurisdictional wetlands are identified in the field on the basis of three parameters: wetland hydrology, hydric soils, and hydrophytic plants. All three parameters must be identified on-site in order for an area to be declared a jurisdictional wetland. Hydric soils are easily identified by their color patterns which are formed when the soils become saturated and anaerobic. Wetland hydrology can only be confirmed for soils affected by high groundwater when a water table is actually observed within 12 in. of the surface. This restricts wetland identification on such soils to periods of the year when water tables are high. As a result, the boundaries of such wetlands are usually not accurately identified. This research is testing the hypothesis that wetland hydrology can be identified from soil color patterns, called hydric soil field indicators, when the color abundance is calibrated to long-term wetland hydrology at one or two key sites. The objectives of this research are: 1) to estimate the cumulative time that the soils along a transect will be saturated each year for approximately 30 years using historic rainfall data and a hydrologic model; 2) to compute probabilities that each soil along a transect will be saturated at a given depth during a year; 3) to correlate the hydric soil indicators observed in each soil to the probability values determined in objective 2; and 4) to relate the hydric soil indicators to occurrence of iron reduction, sulfate reduction, and denitrification.

## Methodology

Two sites in the NC Coastal Plain are being evaluated. One site consists of thirteen plots while the other contains nine. Each plot contains a well to measure water table fluctuations, redox electrodes to measure redox potential, and piezometers to extract water samples to monitor water chemistry. Water table levels are monitored daily in each plot. Soil redox potential and temperature are evaluated weekly, and soil water chemistry is evaluated monthly during wet periods. Soil properties including particle size distribution, color, saturated hydraulic conductivity, and pore size distribution were evaluated for each plot. Rainfall is measured hourly. The hydrologic model DRAINMOD was used to compute water table fluctuations in each plot. The model is calibrated for each plot by using the soil data noted earlier, water table fluctuations, and rainfall. The calibrated model will then be used to compute a 40-year record of water table fluctuations by using historic rainfall data that have been collected for the counties in which the sites are located.

## Principal Findings and Significance

Data have been collected for three years. In the past year the water table measurements were used to adjust the hydrologic simulation model DRAINMOD to compute water table fluctuations at each plot. For one site the simulation results were successful. The average absolute difference between measured and simulated water tables across all 13 plots was approximately 15 cm. For the second site, the model is taking longer to adjust because rainfall data were found to contain errors. These are slowly being identified. For site one, the adjusted simulation model was used to compute water table fluctuations for 13 plots over a 40-year period using historic rainfall data. Doing this required the researchers to assemble a 40-year record of rainfall from more than one weather station, the daily rainfall totals were broken into hourly values, and then the hourly data were inserted into the simulation model for

computing water table fluctuations. Probability values for the chance that each plot at site one will saturate for periods of 7+, 14+ and 21+ days have been estimated for depths of 15, 30, 45, 60, 75, and 90 cm. These values are now being related to the percentages of red and gray colors in the soils for these depths. This work is significant because it will hopefully show that soil color patterns can be correlated to long-term water table fluctuations that encompass both wet and dry years. By relating the colors to the hydrology, the researchers will be able to calibrate hydric soil field indicators to the requirements for wetland hydrology. This will allow field workers to identify jurisdictional wetlands much more precisely than is currently being done.

**Descriptors**

Wetlands, Groundwater hydrology, Groundwater modeling

**Articles in Refereed Scientific Journals**

**Book Chapters**

**Dissertations**

**Water Resources Research Institute Reports**

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**Basic Project Information**

| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | Impact of Sediment Processes on Water Quality in the Neuse River Estuary (70176) |
| **Project Number** | B-II |
| **Start Date** | 03/01/1999 |
| **End Date** | 06/30/2000 |
| **Research Category** | Water Quality |
| **Focus Category #1** | Nutrients |
| **Focus Category #2** | Sediments |
| **Focus Category #3** | Water Quality |
| **Lead Institution** | Water Resources Research Institute of The University of North Carolina |

**Principal Investigators**

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| James D. Bowen | Assistant Professor | University of North Carolina at Charlotte | 01 |
| Marc Alperin | Assistant Professor | University of North Carolina at Chapel Hill | 01 |

**Problem and Research Objectives**

Numerous studies of estuaries clearly demonstrate that sediment-water exchange plays an important role in regulating water column oxygen and nutrient concentrations. Although most detrital organic matter that becomes incorporated into sediments is eventually remineralized, the sediment oxygen demand and net flux of nitrogen across the sediment-water interface is controlled by both biogeochemical and physical (hydrodynamic) processes. Because these processes interact in a complex, nonlinear way, the magnitude of benthic fluxes are difficult to predict. The goal of this project is to quantify the contribution of bottom sediments to oxygen demand and nutrient loads in the Neuse River estuary. Our specific objectives are to: (1) conduct a detailed field study of sediment carbon and nitrogen cycling at four stations in the mesohaline section of the Neuse River estuary; (2) develop a process-level diagenetic model capable of predicting benthic fluxes of oxygen, nitrate, and ammonium; (3) investigate the decomposition kinetics of sedimentary organic matter to evaluate the lifetime of the sediment oxygen demand and benthic nitrogen pool; and (4) extend the diagenetic model throughout the estuary by linking it to an existing water quality model.

**Methodology**

(1) Benthic flux measurements. The researchers use two complementary approaches to quantify rates of sediment-water exchange: (a) direct measurements of benthic flux with sediment chambers, and (b) calculations of benthic flux using measured porewater concentration gradients. Sediment chambers are made from 25-cm long by 14-cm diameter PVC tubing capped with a Plexiglas lid (O-ring seal) equipped with inlet and outlet ports and magnetic stirring bar. Since benthic fluxes can be extremely sensitive to flow conditions inside the chamber, we have calibrated the stirring rate (alabaster plate method) so that natural hydrodynamic conditions near the floor of the estuary can be simulated. Triplicate sediment cores for the benthic chambers are collected by divers and gently inserting the chamber barrels into the sediment and sealing with a base plate. The chambers are placed in a water bath at in situ temperature; water samples are collected at regular intervals and analyzed for oxygen (micro-Winkler titration), total CO2 (flow injection analysis), and nutrients (ammonium, nitrate, and phosphate; Lachet automated ion analyzer). Bottom-water oxygen demand is measured to provide a control. For calculated fluxes, porewater is collected from sediment gravity cores. Triplicate cores are sliced at high resolution (0.5 cm) to provide the best possible estimate of concentration gradients near the sediment-water interface. Porewater is extracted by centrifugation, filtered, and analyzed for total CO2 and nutrients as described above. High resolution oxygen concentration gradients are calculated by microelectrode (Clark-type) profiling of sediment in the benthic chambers after completion of the flux experiment. Fluxes are calculated from Fick's First Law after correcting diffusion coefficients for porosity. (2) Sediment concentration profiles. Triplicate gravity cores are sectioned at 0.5-cm intervals (0-2 cm) or 3-cm intervals (0-40 cm). Porewater is extracted by centrifugation, filtered, and analyzed for total CO2, nutrients, sulfate and chloride (ion chromatraphy), and total H2S (colorimetry). Whole sediment is analyzed for methane by headspace extraction/gas chromatography. The solid sediment is lyophilized and analyzed for porosity and TOC, C:N, d13C-TOC, and d 15N-TN (elemental analyzer interfaced to isotope ratio mass spectrometer). (3) Rate measurements. All rate measurements are

conducted at in situ temperature using triplicate gravity cores. Sulfate reduction rates are measured by the 35S-SO42- technique. Whole sediment in glass incubation syringes is injected with microliter quantities of radio-sulfate and incubated for 24 hours. The incubation is terminated by freezing the sample and radiosulfide is collected by acidic Cr-distillation and quantified by liquid scintillation counting. Ammonium, total CO2, and methane production rates are measured by the tube incubation technique in custom-built, headspace-free incubators that allow for period, gentle sediment mixing. Five sediment aliquots are sampled from the incubators at 1-day intervals and analyzed for ammonium, total CO2, and methane as described above. Ammonium production rates are corrected for adsorption using KD values measured by the potassium displacement method. Denitrification rates are measured by the isotope pairing technique. Intact subcores are incubated with 15NO3- in the overlying water for 30 min to 3 hr to generate a 4-point time-series. At the end of the incubation, dissolved gas are extracted, transferred to a nitrogen-free serum vial, and analyzed for 14N14N, 15N14N, and 15N15N on a GC-mass spectrometer equipped with triple-beam collector. (4) Diagenetic model. The model used in this project is based on a set of coupled, nonlinear differential equations that describe biological and chemical reactions and diffusive and advective transport in the bottom few centimeters of the water column to a depth of 1-meter in the sediments. The model explicitly links nitrogen, oxygen, and carbon biogeochemical cycles in order to simulate the sequence of diagenetic processes that constitute the sediment microbial food web. The hydrodynamics of the benthic boundary layer are simulated by intense damping of turbulent diffusion through the viscous sublayer. (5) Microcosm study. The "lifetime" of the most reactive sedimentary organic matter is evaluated by measuring changes in sediment oxygen demand and nutrient and total CO2 fluxes (described above) over a 3-month time-series. Sediments in the benthic chambers are stirred and aerated between flux measurements, and overlying water is periodically replaced by fresh estuarine water.

**Principal Findings and Significance**

(1) In the Neuse estuary, approximately 50% of the sub-pycnocline oxygen consumption occurs within the sediment column. Thus, organic matter decomposition in the both the sediment and bottom water are important in producing the hypoxic and anoxic water that blankets the estuarine floor throughout much of the summer. (2) The sediment diagenetic model suggests that sediment oxygen uptake is highly impeded by diffusion through the benthic boundary layer. This implies that changes in estuarine hydrodynamics have a far greater impact on the magnitude of the benthic oxygen flux than changes in the quantity or reactivity of sedimentary organic matter. (3) Benthic ammonium fluxes are high throughout the summer and provide 20-50% of the nitrogen demand of primary producers. (4) Denitrification is limited during the summer by low nitrate concentrations in the bottom water combined with restricted nitrification due to limited oxygen penetration into the sediment. (5) Sediment from the mesohaline section of the Neuse River estuary contains reactive organic matter with two distinct "lifetimes". The highly reactive fraction is responsible for about 50% of the sediment oxygen demand, but has a lifetime of only 7-10 days. This short lifetime suggests that sediment oxygen demand would respond quickly to major changes in deposition of sedimentary organic matter. However, the remainder of the oxygen demand is associated with decomposition of the less reactive fraction. Depth profiles of total CO2 and ammonium production rate combined with sedimentation rates suggest that this fraction will persist for several decades. (6) Our multispecies, coupled diagenetic model accurately predicts sediment oxygen demand, denitrification rates, benthic fluxes of ammonium and total CO2, as well as concentration profiles of total CO2, ammonium, sulfate, and methane. The model appears to be capable of simulating the complex dynamics that characterize estuarine sediment systems.

**Descriptors**

Sediment processes, Estuaries, Nitrogen, Geochemistry, Model studies

**Articles in Refereed Scientific Journals**

**Book Chapters**

**Dissertations**

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# Information Transfer Program

Publications The Institute follows an established review process for all of its publications. It has a stated policy that research completion reports shall be reviewed by at least three peer reviewers prior to publication. An editorial review committee has been created to assist with decisions regarding the inclusion of a report in the WRRI series. Newsletters - The Institute NEWS, a 16-page newsletter, was distributed bimonthly to more than 4,100 federal and state agencies, university personnel, multi-county planning regions, city and local officials, and engineers. The NEWS regularly covers a wide range of water-related topics from current federal and state activities and new research findings to special announcements and listings of new publications. This newsletter can also be electronically obtained through our homepage on the world wide web (URL=http://www2.ncsu.edu/ncsu/CIL/WRRI). The Sediments News, a 6-page newsletter, is published quarterly and 5,500 copies distributed by the Institute for the N.C. Sedimentation Control Commission. The newsletter provides information and assistance to the regulated community and facilitates communication among personnel of state and local erosion and sediment control programs. New Research Reports - A strong demand for Institute reports continues. During the year, the Institute published the following reports for distribution to users throughout the state and nation: WRRI-321 Development of the Technical Basis and a Management Strategy for Reopening a Closed Shellfishing Area WRRI-322 Compliance with EPA's Information Collection Rule for North Carolina Surface Water Supplies: Bench-Scale Testing of the Efficacy of Carbon Adsorption and Membrane Separation WRRI-323 Development of an Environmental Decision Support System (EDSS) for Comparing Drinking Water Treatment Practices and Associated Health Risks WRRI-324 Anaerobic Biodegration in Contaminated Aquifers: Influence of Protozoan Predation and Iron Bioavailability WRRI-325-C Neuse River Estuary Modeling and Monitoring Project Stage 1: Effects of Water Quality on Distribution and Composition of the Fish Community WRRI-325-G Neuse River Estuary Modeling and Monitoring Project Stage 1: Assessment of Stakeholder Interests and Concerns to Inform Long-Term Modeling WRRI-326 Bacterial Regrowth in Drinking Water Distribution Systems: A Comparison of Durham and Raleigh WRRI-327 The History of Algal Communities in North Carolina Estuarine Waters as Documented in Strategraphic Record WRRI-328 Geochemical Tracers of Groundwater Movement Between the Castle Hayne and Associated Coastal Plain Aquifers SRS-20 A Study of Nitrate Movement to Ground Water at the Neuse River Waste Water Treatment Plant SRS-21 Preliminary Investigation on Anaerobic Biodegradation of Benzene in Contaminated Aquifer Sediment 1999-2000 Program - The 35th year edition of the Institute's annual program has been published. This special program provides a history of the Institute and the water-related issues that have been addressed and the new issues that are being addressed through funded research. A 16-page publication describing 11 new and 21 continuing research projects being funded by WRRI and other sources. A

special section describes the 16 Neuse River Modeling and Monitoring projects. These projects are a coordinated effort to monitor and model the Neuse River and improve an estuarine nutrient response model for the State of North Carolina. The annual program defines the other related activities of the Institute including the information dissemination and technology transfer efforts. A separate 2-page program has also been published about the North Carolina Urban Water Consortium. The Consortium is made up of ten of the largest municipalities in North Carolina and includes the departments that deal with water, waste water, and storm water. The Consortium is part of the Institute and the program describes the new and continuing projects being conducted for the Consortium as well as tecnology transfer efforts. Publications List - A 26-page listing of all the publications that the Institute has published to date was revised and made available. This includes 377 individual publications listings. Conferences, Workshops, Forums and Seminars - During the past year the Institute sponsored or co-sponsored four conferences, four workshops, four forums, one symposium, and eight seminars on key water issues. The following information is a brief description of them. Wetland and Stream Restoration/Preservation Program. In April, WRRI and the North Carolina Chapter of the American Water Resources Association conducted a forum on stream restoration and preservation programs. Individuals representing three different organizations gave presentations on the N.C Wetland Restoration Program, N.C. Clean Water Management Trust Fund, and preservation opportunities through the N.C. Conservation Tax Credit and Conservation Easement Programs. These programs emphasise planning, partnership, and project implementation with an emphasize on improving water quality. Mountain Water Resources: Research and Management. Also in April, WRRI, North Carolina Department of Environment and Natural Resources, Land-of-Sky Regional Council, United States Forest Service, City of Asheville, and University of North Carolina at Asheville conducted a conference to discuss the water quality issues and research taking place in Western North Carolina. There were 19 speakers providing information to over 150 conference participants. Presentations were divided into nine themes of: wetland & aquatic habitat, water & wastewater, water quality & storm water, groundwater, atmospheric impacts, erosion & sediment control, flow management & riparian areas, and economic & health issues. The plenary session had three speakers addressing mountain water resources issues. A six-member panel concluded the conference by providing a discussion of water issues and research needs. Effects of the Neuse River Rules on Urban Storm Water. In September, WRRI and the North Carolina Chapter of the American Water Resources Association presented a forum on the Neuse River Rules. The Environmental Management Commission set further storm water rules within the Neuse River Basin because of ongoing water quality problems. Two speakers provided their perspectives on the new rules. One speaker presented the highlights of how the Neuse River Rules will affect designated municipalities throughout the basin and options for storm water controls. The other speaker gave a more specific perspective from an individual cities point of view. Storm Water…Taking the Plunge Conference. In October, WRRI and the North Carolina Chapter of the American Public Works Association conducted a conference on storm water management. There were 14 speakers providing information on different aspects of storm water management and divided into five themes of: regulatory update, monitoring and inspection, mapping, new land development approaches, and streams & wetlands. Erosion and Sediment Control Fall Design Workshop. In November, WRRI, the N.C. Sedimentation Control Commission, Fort Bragg, and the North Carolina Department of Environment and Natural Resources, Division of Land Resources, Land Quality Section, held a 2-day workshop at Fort Bragg on erosion and sediment control design. This workshop was specifically designed for military professionals in the field. Both military and civilian personnel were present at the workshop. Urban Storm Water Management Conference. In November, WRRI, the N.C. Sedimentation Control Commission, the North Carolina Department of Environment and Natural Resources, Division of Land Resources, Land Quality Section, and Division of Water Quality, N.C Sea Grant, Land-of-Sky Regional Council, and N.C. Cooperative Extension held a 2-day workshop on urban storm water management. There were 44 speakers providing information to over 400 conference participants. Presentations were divided into eight themes of: policy and regulations, funding options, stream bank stability, education/ stakeholders, management practices - storm water, management practices - erosion & sediment control, wetlands, and watershed planning. There were also three invited speakers providing their insight on storm water in North Carolina, an overview of urban storm water quality and quantity, and an overview of watershed planning. A roundtable discussion of permitting and beyond concluded the conference. The next day a follow-up symposium was conducted to bring key storm water management stakeholders together to review key aspects of the conference,

discuss current activities by organization, and discuss and recommend future directions of storm water management in North Carolina. A "White Paper" was developed that summarized the symposium and documented the recommendations presented. Water Quality Issues of the Cape Fear River. In December, WRRI and the North Carolina Chapter of the American Water Resources Association presented a forum on issues of the Cape Fear River. The two speakers provide information on the operation of Jordan Lake and the new hydrologic model of the Cape Fear River Basin. The first speaker reviewed the operation of Jordan Lake by the Army Corps of Engineers in light of Hurricanes Dennis and Floyd. The second speaker discussed the new hydrologic model that will be used by the State in allocating water storage, evaluating existing and proposed interbasin transfers, and enhancing future water resources decision-making by the State for the Cape Fear River Basin. Erosion and Sediment Control Workshop for Local Programs. In January, WRRI, the N.C. Sedimentation Control Commission and the North Carolina Department of Environment and Natural Resources, Division of Land Resources, Land Quality Section, held a 2-day workshop to allow local programs across North Carolina to get together and exchange ideas and practices utilized at the local level. Topics such as updates of laws, gray areas and enforcement, wetlands, storm water requirements, and plan design & review were presented. There were also individual topics presented by Cabarrus, Wake, and New Hanover counties and the City of Greenville. Innovative Watershed Restoration Projects. In February, WRRI and the North Carolina Chapter of the American Water Resources Association presented a forum on watershed restoration projects. Two speakers were invited to share their experience with restoration. The first speaker discussed the restoration project on the Michell River in Surry County and included such topics as watershed assessment, natural channel design, and project evaluation practices. The second speaker covered the conceptual design for the restoration work that will take place on Rocky Branch. This impaired creek flows through the North Carolina State University campus in Raleigh. Erosion and Sediment Control Spring Design Workshops. In February and March, WRRI, the N.C. Sedimentation Control Commission and the North Carolina Department of Environment and Natural Resources, Division of Land Resources, Land Quality Section held two, 2-day workshops on erosion and sediment control design. The workshops were held to familiarize design professionals with the erosion and sediment control requirements and design applications. Topics such as new regulations, engineering & planning, storm water management, buffer requirements, new technologies, vegetative cover & regionalization, seeding techniques, channel design, wetlands, and a number of case studies were presented. WRRI Annual Water Resources Research Conference. Also in March, WRRI held their annual conference in Raleigh with the theme - year of the hurricanes. There were 30 speakers providing their research findings to over 300 conference participants. Presentations were divided into six themes of: hypoxia, Piedmont issues, groundwater, economics and public participation, hurricanes, and pathogens. The morning plenary session had two speakers discussing the economic impact and recovery of the three hurricanes and flood plain management. Water Resources Research Seminar Series. WRRI continued a seminar series on current water resource issues and research projects funded by the Institute. The seminars occurred once a month during the year except for the months of June, July, August, and December. The following seminars were given during FY 1999-2000: Remediation of Groundwater Contaminated by Industrial Solvents - Professor Casey Miller, Department of Environmental Sciences and Engineering, University of North Carolina at Chapel Hill Network Analysis for Evaluating the Consequences of Nitrogen Loading - Professor Robert Christian, Department of Biology, East Carolina University Examination of Long-Term Nutrient Data in the Neuse River Watershed - Assistant Professor Craig Stow, Nicholas School of the Environment, Duke University Predicting Long-Term Wetland Hydrology Using Hydric Soil Field Indicators - Professor Michael Vepraskas, Soil Science Department, North Carolina State University Benefits of Quality Improvements in North Carolina's Water Resources - Assistant Professor Dan Phaneuf, Agricultural and Resource Economics, North Carolina State University Impact of Sediment Processes on Water Quality in the Neuse River Estuary - Assistant Professor Marc Alperin, Department of Marine Science, University of North Carolina at Chapel Hill Soil Processes Impacting Groundwater Quality in the North Carolina Piedmont: Contamination by Organic Agrochemicals - Assistant Professor Dharni Vasudevan, Nicholas School of the Environment, Duke University Algal, Bacteria, and BOD Responses to Nutrient Gradients in Coastal Plain Watersheds - Research Associate Michael Mallin, Center for Marine Science Research, University of North Carolina at Wilmington

## Basic Project Information

| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | The Institute NEWS |
| **Description** | A 16-page newsletter that covers a wide range of water-related topics from current federal and state activities and new research findings to special announcements and listings of new publications. This newsletter is published bi-monthly. |
| **Start Date** | 03/01/1999 |
| **End Date** | 02/29/2000 |
| **Type** | Newsletter |
| **Lead Institution** | Water Resources Research Institute of The University of North Carolina |

## Principal Investigators

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Amy B "Jeri" Gray | Professional Staff | North Carolina State University | 01 |

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|---|---|
| **Category** | **Data** |
| **Title** | The Sediments News |
| **Description** | A 6-page newsletter that provides information and assistance to the regulated community and facilitates communication among personnel of state and local erosion and sediment control programs. This newsletter is published quarterly. |
| **Start Date** | 03/01/1999 |
| **End Date** | 02/29/2000 |
| **Type** | Newsletter |
| **Lead Institution** | Water Resources Research Institute of The University of North Carolina |

**Principal Investigators**

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Amy B "Jeri" Gray | Professional Staff | North Carolina State University | 01 |

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|---|---|
| **Category** | **Data** |
| **Title** | Water Resources Research Seminar Series |
| **Description** | This is an annual series of seminars on current water resources issues and research projects funded by the Institute. The seminars occur one afternoon each month during the year except for the months of June, July, August and December. |
| **Start Date** | 03/01/1999 |
| **End Date** | 02/29/2000 |
| **Type** | Conferences |
| **Lead Institution** | Water Resources Research Institute of The University of North Carolina |

**Principal Investigators**

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Robert E. Holman | Assistant Professor | North Carolina State University | 01 |

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|---|---|
| **Category** | **Data** |
| **Title** | NCWRA/WRRI Forums |
| **Description** | Four forums were held jointly by the N.C. American Water Resources Association and N.C. Water Resources Research Institute. Over 250 people attended these forums covering topics such as wetland : stream restoration, Neuse River rules, water quality issues of the Cape Fear River, and watershed restoration. |
| **Start Date** | 03/01/1999 |
| **End Date** | 02/29/2000 |
| **Type** | Conferences |
| **Lead Institution** | Water Resources Research Institute of The University of North Carolina |

**Principal Investigators**

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Robert E. Holman | Assistant Professor | North Carolina State University | 01 |

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## Basic Project Information

| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | Erosion and Sediment Control Design Workshops |
| **Description** | These three, 2-day workshops are jointly conducted by the N.C. Sedimentation Control Commission, N.C. Division of Land Resources - Land Quality Section, and N.C. Water Resources Research Institute. The workshops are held to familiarize design professionals with the erosion and sediment control design. |
| **Start Date** | 03/01/1999 |
| **End Date** | 02/29/2000 |
| **Type** | Conferences |
| **Lead Institution** | Water Resources Research Institute of The University of North Carolina |

## Principal Investigators

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Robert E. Holman | Assistant Professor | North Carolina State University | 01 |

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| Basic Project Information | |
|---|---|
| **Category** | **Data** |
| **Title** | Mountain Water Resources:Research and Management |
| **Description** | This conference brought together over 150 participants to discuss Western North Carolina water resource issues and research. There were 19 speakers providing information on nine themes of:wetland & aquatic habitat, water & wastewater, water quality & storm water, groundwater, atmospheric impacts, erosion & sediment control, flow management & riparian areas, and economic & health. |
| **Start Date** | 04/27/1999 |
| **End Date** | 04/27/1999 |
| **Type** | Conferences |
| **Lead Institution** | Water Resources Research Institute of The University of North Carolina |

**Principal Investigators**

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Robert E. Holman | Assistant Professor | North Carolina State University | 01 |

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|---|---|
| **Category** | **Data** |
| **Title** | Storm Water...Taking the Plunge |
| **Description** | There were 14 speakers providing information on different aspects of storm water management and divided into five themes of: regulatory update, monitoring and inspection, mapping, new land development approaches, and streams & wetlands. |
| **Start Date** | 10/28/1999 |
| **End Date** | 10/29/1999 |
| **Type** | Conferences |
| **Lead Institution** | North Carolina Chapter of the American Public Works Association |

**Principal Investigators**

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Robert E. Holman | Assistant Professor | North Carolina State University | 01 |

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|---|---|
| **Category** | **Data** |
| **Title** | Urban Storm Water Management Conference:Preparing for the 21st Century |
| **Description** | There were 44 speakers providing information to over 400 conference participants. Presentations were divided into eight themes of:colon; policy and regulation, fund options, stream bank stability, education/stackeholders, management practices - storm water, management practices - erosion |
| **Start Date** | 11/01/1999 |
| **End Date** | 11/03/1999 |
| **Type** | Conferences |
| **Lead Institution** | Water Resources Research Institute of The University of North Carolina |

**Principal Investigators**

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Robert E. Holman | Assistant Professor | North Carolina State University | 01 |

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|---|---|
| **Category** | **Data** |
| **Title** | Erosion and Sediment Control Workshop for Local Programs |
| **Description** | This 2-day workshop is jointly conducted by the Sedimentation Control Commission, N.C. Division of Land Resources - Land Quality Section, and N.C. Water Resources Research Institute. The annual workshop allows local erosion and sediment control programs to get together and exchange ideas and practices utilized at the local level. |
| **Start Date** | 01/25/2000 |
| **End Date** | 01/26/2000 |
| **Type** | Conferences |
| **Lead Institution** | Water Resources Research Institute of The University of North Carolina |

**Principal Investigators**

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Robert E. Holman | Assistant Professor | North Carolina State University | 01 |

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|---|---|
| **Category** | **Data** |
| **Title** | North Carolina Resources:Water Quality Trends and Enhancement |
| **Description** | The annual conference drew over 300 people that listened to 30 speakers provide information on their research findings. This year's presentations were divided into six themes:colon; Hypoxia, Piedmont issues, Ground Water, Economics and Public Participation, Hurricanes, and Pathogens |
| **Start Date** | 03/30/2000 |
| **End Date** | 03/30/2000 |
| **Type** | Conferences |
| **Lead Institution** | Water Resources Research Institute of The University of North Carolina |

**Principal Investigators**

| Principal Investigators | | | |
|---|---|---|---|
| **Name** | **Title During Project Period** | **Affiliated Organization** | **Order** |
| Robert E. Holman | Assistant Professor | North Carolina State University | 01 |

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**Principal Findings and Significance**

**Articles in Refereed Scientific Journals**

**Book Chapters**

**Dissertations**

**Water Resources Research Institute Reports**

**Conference Proceedings**

**Other Publications**

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# USGS Internship Program

## Student Support

| Student Support | | | | | |
|---|---|---|---|---|---|
| **Category** | **Section 104 Base Grant** | **Section 104 RCGP Award** | **NIWR-USGS Internship** | **Supplemental Awards** | **Total** |
| **Undergraduate** | 0 | 3 | 4 | 18 | 25 |
| **Masters** | 1 | 3 | 1 | 30 | 35 |
| **Ph.D.** | 1 | 5 | 1 | 15 | 22 |
| **Post-Doc.** | 2 | 0 | 0 | 1 | 3 |
| **Total** | 4 | 11 | 6 | 64 | 85 |

## Awards & Achievements

Dr. R. Wayne Skaggs, Williams Neal Reynolds Professor and Distinguished University Professor of Biological and Agricultural Engineering in the College of Agriculture and Life Sciences, North Carolina State University, won the International Award for Distinguished Service to Agriculture. The Gamma Sigma Delta Honor Society of Agriculture at NC State presented the award. Dr. Jerry R. Miller has been awarded the first Blanton J. Whitmire Distinguished Professor in Environmental Sciences at Western Carolina University. Dr. Miller is a native of Altona, IL and earned his bachelor's degree in geology at Southern Illinois University in 1982 and his master's degree in geology at the University of New Mexico in 1985. He returned to Southern Illinois University and earned his doctorate in geology in 1990. He specializes in fluvial geomorphology. (Individual not involved with Section 104

projects) Dr. David Moreau, March 20, 2000, Recipient of the award "Dedicated and Outstanding Service from the National Institutes of Water Resources. Dr. David Moreau, 2000, reappointed by Gov. James B. Hunt, Jr., Chairman, North Carolina Environmental Management Commission. Dr. Daniel A. Okun received an honorary degree of doctor of science degree at the UNC-CH commencement ceremony. Dr. Okun chaired UNC-CH's department of environmental sciences and engineering from 1955 to 1973. Under his leadership, the department grew from a traditional sanitary engineering program to a prestigious environmental engineering program that is widely regarded as one of the best in the world. Okun's expertise in water supply and pollution control issues contributed heavily to development of environmental sciences and engineering programs for major universities around the globe. His work has influenced organizations such as the World Bank, UNESCO, and the World Health Organization. Mr. Terry Rolan, Director of the City of Durham Environmental Resources is among nine people nationwide to attain Honorary Membership in the American Water Works Association (AWWA). (Indivdual not involved with Section 104 projects) Mr. Doug Sutton received the Outstanding Student Paper Award from the Hydrology Section of the American Geophysical Union (AGU). Doug is a graduate student under the direction of Dr. Zbigniew J. Kabala in the Department of Civil and Environmental Engineering at Duke University. Dr. Fran DiGiano won the Rudolf Hering Medal (1999) for paper in the Journal of Environmental Engineering Division, ASCE with the most valuable contribution to the increase in knowledge in, and to the advancement of, the environmental branch of the engineering profession, with A. Braghetta and W.P. Ball "Nanofiltration of Natural Organic Matter: pH and Ionic Strength Effects" (WRRI-293). Mr. David Briley's MS thesis entitled "Optimization of Coagulation Conditions for the Removal of Algae in Conventioanl Water Treatment" won second prize in the 1999 Montgomery-Watson Master's Thesis Competition, which is co-sponsored by the Association of Environmental Engineering and Science Professors.

# Publications from Prior Projects

### Articles in Refereed Scientific Journals

Aneja, Viney P.; J.P. Chauhan, and J.T. Walker, 2000, Characterization of atmospheric ammonia emissions from swine waste storage and treatment lagoons, J Geophysical Research, 105 (D9), 11,535-11,545. (Publication not part of Section 104) Aneja, Viney P.; Paul A. Roelle, George C. Murray, James Southerland, Jan W. Erisman, David Fowler, Willem A.H. Asman, and Naveen Patni, 2000, Atmospheric Nitrogen Compounds II: Emissions, Transport, Transformation, Deposition and Assessment, Atmospheric Environment, in press. (Publication not part of Section 104) Birgand, F.; G.M. Chescheir, R.W. Skaggs, and J.W. Gilliam, 1999, Quantification and Effects of In-Stream Processes in the Ditches and Canals of the Lower Coastal Plain of North Carolina, in "Proc. of the Mini-conference on Advances in Water Quality Modeling", ASAE Int'l Meeting, Toronto, Canada, July 18-21, 1999, ASAE paper 99-2132. Brinson, M.M.; and R.R. Christian, 1999, Stability and response of Juncus roemerianus patches in a salt marsh. Wetlands, 19, 65-70. (Publication not part of Section 104) Chescheir, G.M.; D.M. Amatya, G.P. Fernandez, J.W. Gilliam, and R.W. Skaggs, 1999, Nutrient Loading from a Lower Coastal Plain Watershed, in "Proc. of the Mini-conference on Advances in Water Quality Modeling", ASAE Int'l Meeting, Toronto, Canada, July 18-21, 1999, ASAE paper 99-2201. Christian, R.R.; and J.J. Luczkovich, 1999, Organizing and understanding a winter's seagrass foodweb network through effective trophic levels, Ecological Modelling, 117, 99-124. (Publication not part of Section 104) Cooper, S.R.; J. Huvane, P Vaithiyanathan and C.J. Richardson, 1999, Calibration of diatoms along a nutirent gradient in Florida Everglades Water Conservation Area-2A, USA, Journal of Paleolimnology 22, 413-437. Fernandez, G.P.; G.M. Chescheir, D.M. Amatya, and R.W. Skaggs, 1999, GIS Based Lumped Parameter Water Quality Model, in "Proc. to the Mini-conference on Advances in Water Quality Modeling", ASAE Int'l Meeting, Toronto, Canada, July 18-21, 1999, ASAE paper 99-2136. Fernandez, G.P.; R.W. Skaggs, G.M., Chescheir, D.M., Amatya, and J.W. Gilliam, 1999, Watershed Scale GIS Based Lumped Parameter Water Quality Model, in Proc of the 2nd Inter-Regional

Conference on Environment - Water 99, September, 1999, Lausanne, Switzerland. Haan, P.; and R.W. Skaggs, 1999, Effect of Parameter Uncertainty on DRAINMOD Predictions for Hydrology and Water Quality, in "Proc. to the Mini-Conference on Advances in Water Quality Modeling", ASAE Int'l Meeting, Toronto, Canada, July 18-21, 1999, ASAE paper 99-2163. Hench, J.L.; J.T. Bircher and R.A. Luettich, Jr., 2000, A Portable Retractable ADCP Boom-Mount for Small Boats, Estuaries, 23 (3), 392-399. (Publication not part of Section 104) Holman, Robert E.; Ross B. Leidy and Ashlee E. Walker, 2000, Evaluation of Selected Pesticides in North Carolina Surface Water Supplies: Intake Study, Journal of the American Water Resources Association, 36 (1) , 75-85. (Publication not part of Section 104) Jensen, J.E.; S.R. Cooper, and C.J. Richardson, 1999, Development of a calibration model of modern pollen along a nutrient gradient in Everglades Water Conservation Area 2A, USA, Wetlands 19, 675-688. Lenihan, H.S.; C.H. Peterson, J.E. Byers, J.H. Grabowski, G.W. Thayer, and D.R. Colby, 2000, Cascading of habitat degradation: oyster reefs invaded by refugee fishes escaping stress, Ecological Applications, in press. (Publication not part of Section 104) Mallin, M.A.; 2000, Impacts of industrial-scale swine and poultry production on rivers and estuaries, American Scientist 88: 26-37. (Publication not part of Section 104) Mallin, M.A.; 2000, L.B. Cahoon, M.R. McIver, D.C. Parsons, and G.C. Shank, 1999, Alternation of factors limiting phytoplankton production in the Cape Fear Estuary, Estuaries 22, 985-996. (Publication not part of Section 104) Olsen, A.; R.J. Sedranski, D. Edwards, C.A. Gotway, W. Liggett, S. Rathbun, K.H. Reckhow, and L.J. Young, 1999, Statistical Issues for Monitoring Ecological and Natural Resources in the United States, Environmental Monitoring and Assessment, 54, 1-45. (Publication not part of Section 104) Pan, Y.; R.J. Stevenson, P. Vaithiyanathan, J. Slate and C.J. Richardson. 2000, Changes in algal assemblages along observed and experimental phosphorus gradients in a subtropical wetland, USA, Freshwater Biology 43:1-15. (Publication not part of Section 104) Pinckney, J.; H. Paerl, M. Harrington, and K. Howe, 1998, Annual cycles of phytoplankton community-structure and bloom dynamics in the Neuse River Estuary, North Carolina, Marine Biology, 131, 371-382. Pinckney, J.; H. Paerl, & M. Harrington, 1999, Phytoplankton community growth rate responses to nutrient pulses in variable estuarine environments, Journal of Phycology, 35, 1455-1464. Pinckney, J.; H. Paerl, E. Haugen & P. Tester, 2000, Responses of phytoplankton and Pfiesteria-like dinoflagellate zoospores to nutrient enrichment in the Neuse River Estuary, NC (USA), Marine Ecology Progress Series 192: 65-78. Reckhow, K.H.; 1999, Water Quality Prediction and Probability Network Models, Canadian Journal of Fisheries and Aquatic Sciences, 56, 1150-1158. (Publication not part of Section 104) Reckhow, K.H.; and S.C. Chapra, 1999, Modeling Excessive Nutrient Loading in the Environment, Environmental Pollution, 1000, 197-207. (Publication not part of Section 104) Reckhow, K.H.; 1999, Lessons from Risk Assessment, Human and Ecological Risk Assessment, 5, 245-253. (Publication not part of Section 104) Richardson, C.J.; G.M. Ferrell and P. Vaithiyanathan, 2000, Nutrient effects on stand structure, resorption efficiency, and secondary compounds in Everglades sawgrass, Ecology 80 (7), 2182-2192. (Publication not part of Section 104) Richardson, C.J.; and S. Qian, 1999, Comments: Limits of phosphorus removal in wetlands (Kadlec, previous issue, pp. 165-175). Wetlands Ecology and Management, 7, 235-238. (Publication not part of Section 104) Richardson, C.J.; and S. Qian, 1999, Long-term phosphorus assimilative capacity in freshwater wetlands: A new paradigm for maintaining ecosystem structure and function, Environmental Science and Technology 33(10), 1545-1551. (Publication not part of Section 104) Ruud, N.C.; Z.J. Kabala, F.J. Molz, 1999, Numerical Evaluation of Head Loss Effects in the Flowmeter Test, J. Hydrology, 224, 55-63. Skaggs, R.W.; and G.M. Chescheir, 1999, Effects of Subsurface Drain Depth on N Losses to Surface Waters, in "Proc. to Mini-Conference on Advances in Water Quality Modeling", ASAE Int'l Meeting, Toronto, Canada, July 18-21, 1999, ASAE paper 99-208. Sutton, D.J.; Z.J. Kabala, D.E. Schaad, and N.C. Ruud, 2000, The Dipole-Flow Test with a Tracer - A New Single-Borehold Tracer Test for Aquifer Characterization, J. Contaminant Hydrology, 44, in press. Tolley, P.M.; and R.R. Christian, 1999, Effects of increased inundation and wrack deposition in a salt marsh: plant community response, Estuaries 22, 944-954. (Publication not part of Section 104) Vaithiyanathan, P.; and C.J. Richardson, 1999, Macrophyte species changes in the Everglades: Examination along the

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Oct. 31-Nov. 4, 1999. Sutton, D.J., Z.J. Kabala, and D. Vasudevan 2000, Rhodamine WT as a reactive tracer: laboratory study and field consequences, in "Proceedings of the International Conference on Tracers and Modelling in Hydrogeology,". Tra'M2000, Liege, Belgium, May 23-26, in press. Sutton, D.J., Z.J. Kabala, D. Vasudevan, and A. Francisco, 2000, Limitations and Potential of a Groundwater Tracer Rhodamine WT, in "Proceedings of the Annual North Carolina Water Resources Research Conference", North Carolina State University, Raleigh, in press. Sutton, D.J., and Z.J. Kabala, 2000, Rhodamine WT as a Reactive Groundwater Tracer, supplement to EOS, in press. Zhang, W., F.A. DiGiano, D. Francisco and L. Todd, 1999, A Statistical Study of the Relationship between Bacterial Growth and Water Quality Parameters. Proceedings of the NC AWWA and WEA Annual Meeting (in press).

**Other Publications**

Mallin, M.A., M.H. Posey, M.L. Moser, L.A. Leonard, T.D. Alphin, S.H. Ensign, M.R. McIver, G.C. Shank, and J.F. Merritt, 1999, Environmental Assessment of the Lower Cape Fear River System, 1998-1999. CMSR Report No. 99-01, Center for Marine Science Research, University of North Carolina at Wilmington, Wilmington, N.C. (Report not part of Section 104)