IPS No. 14

NORTH CAROLINA WATER RESOURCES: THE YEAR OF THE HURRICANES

Abstracts of presentations and posters at the Annual North Carolina Water Resources Research Conference

Jane S. McKimmon Center
North Carolina State University
Raleigh, North Carolina

March 30, 2000

Sponsored by

The Water Resources Research Institute of The University of North Carolina

Abstracts and poster session abstracts appear as submitted by the researchers.

Five hundred and fifty copies of this publication were printed at a cost of $1,333.75 or $2.43 per copy.

Table of Contents

Economics and Public Participation

Hurricanes

Pathogens

Poster abstracts

Agenda

MORNING
7:30- 8:30 AM Registration

8:30- 8:45 Welcome/Conference Overview
Kenneth H. Reckhow
Water Resources Research Institute

8:45- 9:30 Plenary Session:
Economic Impact and Recovery – Billy Ray Hall, N.C. Rural Economic Development Center
Flood Plain Management – W. David Canaan, Mecklenburg County

9:30- 9:45 Break (Poster Session)

9:45-12:30 Concurrent Session I

A. **Hypoxia**: Moderator: Richard A. Luettich, UNC-CH Institute of Marine Sciences
1. *Impacts of Sublethal Hypoxia on Feeding, Growth, and Immunity of Juvenile Estuarine-Dependent Fish*
Regan A. McNatt, N.C. State University
2. *Effects of Hypoxia on Habitat Quality for Juvenile Croaker, Micropogonias undulatus, in the Neuse River Estuary, N.C.*
Lisa A. Eby, Duke Marine Lab
3. *Does the Value of Essential Fish Habitat in the Neuse River Estuary Vary with Annual Severity of Hypoxia?*
Sean P. Powers, UNC-CH Institute of Marine Sciences
4. *Unseen Consequences of Hypoxia in the Neuse River Estuary*
Robert R. Christian, East Carolina University
5. *Winter-Summer Comparison of Suspended, Settling, and Recently Sedimented Particulate Organic Matter in the Neuse River Estuary*
Erika J. Clesceri, UNC-Chapel Hill
6. *A Probability Network Approach to Predicting Hypoxia in the Neuse River Estuary*
Mark E. Borsuk, Duke University

B. **Piedmont Issues** – Moderator: Susan C. Turbak, City of Durham
1. *Watershed Modeling and Management in the Catawba River Basin*
Ty K. Ziegler, Duke Energy Company
2. *An Assessment of Ground Truth Variability Using a "Virtual Field Reference Database"*
Ross S. Lunetta, U.S. Environmental Protection Agency
3. *Metals and Organic Compounds in Storm Water - Charlotte, North Carolina, 1993-1998*
Jerad D. Bales, U.S. Geological Survey
4. *Assessment of a Comprehensive Approach to Water Conservation & Peak Demand Management: Costs and Benefits*
Jennifer L. Platt, Town of Cary, N.C.
5. *Effectiveness of Three "BMPs" for Reducing Non-point Source Pollution from Piedmont Tobacco Fields*
E. Carlyle Franklin, N. C. State University
6. *An Investigation of Stream Origins in the Piedmont of the Neuse River Basin*
Stephen D. Smith, N.C. Division of Water Quality

12:30- 1:30 PM Lunch Provided (Poster Session)

AFTERNOON
1:30- 3:30 PM Concurrent Session II

A. **Ground Water**- Moderator: Harold E. Mew, N.C. Division of Water Quality
1. *Overview of Groundwater Hydrology and Water-Use Regulations in the North Carolina Coastal Plain*
Jeffrey W. Reynolds, Research Triangle Institute
2. *Utilization of Cretaceous Aquifer System for Storage and Recovery of Treated Surface Water in Greenville, N.C.*

Christopher P. Foldesi, East Carolina University

3. *Ground-water and Surface-water Interactions: Potential Effects of Hydrogeology, Riparian Buffers, and Hyporheic Zone on Surface-water Quality and Nutrient Loading*
   Timothy B. Spruill, U.S. Geological Survey
4. *Groundwater Flow and Transport Analysis for the Proposed Martin-Marietta Quarry Site, Water Reclamation Project, City of New Bern, N.C.*
   Kenneth O. Pohlig, N.C. Division of Water Quality

B. **Economics and Public Participation** - Moderator: V. Kerry Smith - N.C. State University

1. *Benefits of Water Quality Improvements in North Carolina*
   Daniel J. Phaneuf, N.C. State University
2. *Economic Value of Water Quality in the Catawba River Basin*
   Randell A. Kramer, Duke University
3. *Trade-Off at the Trough*
   Carol A. Mansfield, N.C. State University
4. *The Role of Decision-Making Authorities in Public Participation Processes: Division of Water Quality and the Tar-Pamlico Rule-making Process*
   Lynn A. Maguire, Duke University

3:30 - 3:45 Break (Poster Session)

3:45 - 6:00 Concurrent Session III

A. **Hurricanes** - Moderator: Donald W. Stanley, East Carolina University

1. *Were Human Impacts Upon Riverine Systems of Coastal N.C. Significant Factors in the Flood of September 1999?*
   Stanley R. Riggs, East Carolina University
2. *Short-term Impacts of Hurricanes Dennis, Floyd and Irene on Water Quality and Fisheries Habitat in Pamlico Sound, N.C.*
   Hans W. Paerl, UNC-CH Institute of Marine Sciences
3. *Effects of Catastrophic Flooding on Hydric Soils of Eastern N.C.*
   Ronald J. Reuter, U.S. Environmental Protection Agency
4. *Effects of Hurricane Floyd Flooding on Coastal Ocean Water Quality*
   Lawrence B. Cahoon, UNC-Wilmington
5. *Impacts from Hurricane Floyd on Water Quality in the Neuse River and Estuary, and Pamlico Sound*
   JoAnn M. Burkholder, N.C. State University

B. **Pathogens** - Moderator: William Kirby-Smith, Duke University

1. *Watershed Factors Associated with Enteric Microbe Concentrations in North Carolina Surface Waters*
   Dana J. Cole, UNC-Chapel Hill
2. *Land Use, Runoff, and the Microbial Pollution of Rivers and Estuaries*
   Michael A. Mallin, UNC-Wilmington
3. *Development of Land Use Change Indicators to Support Watershed Based Restoration of Shellfish Resources Impacted by Fecal Coliform Contamination*
   Nancy M. White, N. C. State University
4. *Reduction of Salmonella and Other Fecal Microbes in Swine Waste Lagoons and Alternative Treatment Systems*
   Vincent R. Hill, UNC-Chapel Hill

Impacts of sublethal hypoxia on feeding, growth, and immunity of juvenile estuarine-dependent fish

Regan A. McNatt *
Dept. of Zoology
North Carolina State University
Raleigh, NC 27695-7617
regan_mcnatt@ncsu.edu
Phone: 919-515-4596
Fax: 919-515-5327

Dr. James A. Rice
Dept. of Zoology
North Carolina State University
Raleigh, NC 27695-7617
jim_rice@ncsu.edu
Phone: 919-515-4592
Fax: 919-515-5327

Dr. Edward J. Noga
Dept. of Clinical Sciences
NCSU College of Veterinary Medicine
Raleigh, NC 27696-8401
ed_noga@ncsu.edu
Phone: 919-513-6236
Fax: 919-513-6336

Juvenile estuarine-dependent fish often experience decreased concentrations of dissolved oxygen, or hypoxia, in tidal bottom-water habitats during the summer growing season. Such sublethal levels of hypoxia may not result in fish mortality but may have a detrimental effect on juvenile fish populations.

A series of experiments was conducted using juvenile spot (*Leiostomus xanthurus*) and juvenile white mullet (*Mugil curema*) to determine whether sublethal levels of hypoxia alter feeding and growth rates and to ascertain whether the stress of chronic hypoxia may lead to a reduction in bacterial immunity.

Juvenile spot and white mullet were exposed to one of three treatment levels of dissolved oxygen (6.5, 4.0, or 2.0 mg O_2 / L) or an oscillating treatment (2.0 – 11.0 mg O_2 / L) for 14 days. Feeding rates were measured daily (for spot only), and at the end of each experiment the final total length, standard length, and wet weight of each fish were compared to the initial measurements. Skin and gill samples were collected and used in a standard diffusion assay to establish antibacterial activity.

The results indicate that sublethal hypoxia does alter the growth rates in juvenile white mullet and the feeding and growth rates in juvenile spot. The antibacterial assays reveal that the amount of antibacterial activity decreases as the level of dissolved oxygen decreases. This experiment is part of a series of experiments to determine how hypoxia affects juvenile estuarine-dependent fish populations in terms of feeding and growth, avoidance behavior, and probability of mortality.

* Indicates speaker

Effects of hypoxia on habitat quality for juvenile croaker, *Micropogonias undulatus*, in the Neuse River Estuary, North Carolina

Eby, Lisa A., and Larry B. Crowder
Duke University Marine Lab
135 Duke Marine Lab Road
Beaufort, NC 28516
(252)504-7571
lae5@duke.edu lcrowder@duke.edu

Landscape modification in coastal watersheds and nutrient loading to coastal rivers often lead to water quality degradation (particularly low oxygen) and associated habitat loss for fishes. We have been attempting to quantify habitat loss and examine possible impacts on the fish community in the Neuse River Estuary, specifically whether hypoxic zones (D.O. concentrations < 2 mg/l) impact habitat quality for juvenile fish.

We examined the hypotheses that hypoxia influences habitat quality for juvenile croaker by changing their distribution (as fish move out of hypoxic areas) and/or by impacting the prey resources exposed to low dissolved oxygen levels. Specifically, the presence of hypoxic zones may (1) force fish to occupy less profitable habitat, (2) crowd fish into a smaller area, increasing competition, and (3) harm the benthic fauna that are prey resources for juvenile fish thus decreasing the profitability areas exposed to hypoxic waters.

Our methods included monthly trawling in an upstream site (Slocum Creek to Clubfoot Creek; '97-'99) and a downstream site (Adam's Creek to Turnagain Bay; '98-'99), associated water quality sampling (temperature, salinity, dissolved oxygen), and *in situ* caging experiments ('99). Hypoxia was more common at our upstream sampling site than downstream. Every year the upper site experienced substantial hypoxia (1/4 - 2/3 of the study site) on one or more of our sampling dates. When large hypoxic zones were present in the system, fish were crowded into the shallower, oxygenated areas. Throughout the season, juvenile croaker captured in waters less than 2 meters deep and those captured in high densities had the lowest stomach fullness, indicating lower feeding rates.

Caging experiments conducted in June 1999 supported our field data, demonstrating that croaker kept either in shallow sites or at high densities did not grow as well as croaker in deeper sites or at lower densities. By August, the deeper waters ($\geq$ 2 m) had been exposed to periodic hypoxia throughout the summer. Subsequently, in our August trawl samples there was no trend in stomach fullness based on where croaker were captured. Similarly in our August caging experiments, there were no significant differences in growth rates between shallow and deeper sites, while high densities of fish in cages still inhibited growth rates.

Based on these data, we conclude that periodic hypoxia may diminish habitat quality for juvenile croaker, both through altering fish distributions and impacting their prey resource.

Does the Value of Essential Fish Habitat in the Neuse River Estuary Vary with Annual Severity of Hypoxia?

Charles H. Peterson[1], Monica Dozier[1], Sean P. Powers[1], Galen A. Johnson[1], and Robert R. Christian[2]

1 University of North Carolina at Chapel Hill, Institute of Marine Sciences, Morehead City, NC 28557
2 Biology Department, East Carolina University, Greenville, NC 27858

Presenter: Sean P. Powers, 252-726-6841, spowers@email.unc.edu

This project evaluates the possibility that the soft-bottom habitat essential for feeding of demersal fishes, blue crabs, and brown shrimp in the lower Neuse River estuary is degraded by the hypoxia/anoxia that results in part from eutrophication of the Neuse River basin. If eutrophication is involved in degrading essential fish habitat in the estuary through effects of oxygen depletion on benthic invertebrate prey, then one would expect to observe the degree of summertime reduction in benthos to vary with the intensity of hypoxia/anoxia. Such information is vital to preparation of fishery habitat management plans as required by the 1997 Fisheries Reform Act of the NC General Assembly.

We present a comparison of changes during summer in the benthic invertebrate prey community in the lower Neuse River estuary between 1997 and 1998, which differed dramatically in intensity of hypoxia/anoxia; and (2) an initial evaluation of the degree to which benthic prey resources are limiting to demersal fish and crab production.

In 1997, the Neuse River estuary experienced intense hypoxia/anoxia extending for more than two weeks. This event had the effect of greatly modifying the composition and abundance of the benthic invertebrate prey community, reducing abundance of *Macoma* clams and other large prey items in deep and mid depths where DO depletion occurred. More than 80% of the bottom of the lower Neuse River estuary experienced this degradation in prey abundance.

The Neuse River estuary did not experience sustained anoxia/hypoxia in summer 1998. The benthic prey community and especially the *Macoma* clams had not recovered from the 1997 events by June 1998 but showed little additional change through the summer of 1998. A preliminary bioenergetics analysis revealed that the demersal fishes and crabs were severely food-limited at the end of summer 1998 following the habitat degradation induced by low DO. Gut contents analyses revealed the significance of clams to both blue crabs and juvenile demersal fishes in this system. Consequently, hypoxia/anoxia events in the Neuse River estuary can reduce the abundance of invertebrate prey for demersal fishes and blue crabs, with likely effects on their productivity. Recovery of value of soft-bottom habitat did not occur within a single year.

These results imply that water quality and eutrophication need to be included in conservation of habitat for demersal fishes and crustaceans of mesohaline portions of the state's estuaries.

Unseen Consequences of Hypoxia in the Neuse River Estuary

Robert R. Christian[1], Daniel Baird[1,2], Steven Roberts[1], Charles H. Peterson[3], and Galen A. Johnson[3],

1. Biology Department, East Carolina University, Greenville, NC 27858
2. Zoology Department, University of Port Elizabeth, P. O. Box 1600, Port Elizabeth, 6000, South Africa
3. University of North Carolina at Chapel Hill, Institute of Marine Sciences, Morehead City, NC 28557

Presenter: Robert R. Christian, 252-328-1835, christianR@mail.ecu.edu

Hypoxia is a common occurrence in the Neuse River Estuary during summers. Much of the focus on its consequences has been the highly visible fish kills, but the benthos is also affected. Benthic fauna are food for nekton and provide a route for the recycling of organic detritus. We constructed and analyzed foodweb networks for the Neuse River Estuary to investigate the impact of hypoxia on trophodynamics. Four networks were constructed, each containing 30 compartments. Field data came largely from ModMon activities and the NC Division of Marine Fisheries trawl surveys. The networks represented food webs in the lower estuary for early and late summer in 1997 and 1998. The networks were analyzed using NETWRK4.2. Hypoxia occurred during each summer, and therefore we assumed that differences between early and late periods of the season were at least partially the result of hypoxia. Here we present results emphasizing benthic/pelagic coupling.

A major shift occurred in the benthic/pelagic coupling from early to late summer during both years. In early summer there were few demersal fish in the estuary, relatively large standing stocks of benthic fauna, and little grazing pressure by the former on the latter. In late summer, the conditions reversed with larger standing stocks of fish, fewer benthos and considerable pressure on the benthos. Suspension feeding bivalves, primarily *Macoma* spp., were the major forms of benthic fauna eaten by demersal fish in all networks. Much of bivalve production was grazed in late summer, and 30 times more of their relative energy flow was grazed in late compared to early summer. Demersal fish fed on deposit feeding polychaetes as their second most important food source in early summer but fewer worms were available in late summer. Effects between periods were also found farther up the food chain. Based on our analyses, reductions in the standing stocks of benthos resulting from hypoxia can have greater effects on the energy flow of the pelagic food web than common kills of pelagic fish. Furthermore, as grazing pressure increases on the stressed benthos, recovery under normoxic conditions may be retarded. Therefore, the unseen effects of hypoxia on the benthos and their link to nekton need better appreciation as potential consequences of eutrophication.

Winter-Summer Comparison of Suspended, Settling, and Recently Sedimented Particulate Organic Matter in the Neuse River Estuary

E.J. Clesceri[1], M.J. Alperin[2] , C.S. Martens[2], and D.B. Albert[2]

1 Dept. of Environmental Sciences and Engineering, School of Public Health, University of North Carolina, Chapel Hill, NC, USA
2 Dept. of Marine Sciences, University of North Carolina, Chapel Hill, NC, USA

Three primary fates exist for photosynthetically produced particulate organic material in river estuarine systems: downstream export to receiving waters, water column recycling (zooplankton grazing, microbial degradation), and deposition to sediments. In a slowly flowing, shallow, highly productive aquatic environment such as the Neuse River Estuary, it is likely that a considerable fraction of the net primary production will be deposited in the sediments. To trace the fraction of the carbon and nitrogen pool that originates in the water column and is deposited in the sediments, sediment traps were employed with simultaneous collection of associated seston and surficial sediments. In July and December 1999, samples of suspended, settling, and recently sedimented POM (particulate organic matter) were collected at four stations spanning the mesohaline reach of the estuary.

Sediment traps capture the downward flux of fresh and detrital particulate material in a natural system. Two sediment trap designs were used for this purpose: a traditional cylindrical sediment trap and a boundary-layer plate sediment trap designed for better flux estimates in flowing water systems. The fresh algal and detrital POM fraction will be chemically traced from water column through sediment traps to the sediment via photosynthetic pigments and stable carbon and nitrogen isotopic ratios. As productivity and phytoplankton community structure varies with ambient solar irradiance, temperature, and nutrient availability, the speciation of photosynthetically derived POM and net deposition will vary proportionally. The percentage of detrital watershed derived organic matter which undergoes suspension and deposition with the fresh algal POM will vary in content and concentration as well. The variability in detrital POM source and in situ biogeochemical processing of bulk (algal + detrital) POM can be evaluated by the signature ratios of naturally occurring levels of stable carbon and nitrogen isotopes. As the biological oxygen demand (BOD) of sediments represents a significant sink for the dissolved oxygen necessary to support estuarine fisheries resources, the dynamics of the deposition of the high BOD demand algal POM must be evaluated and understood for subsequent integration into process-based predictive models.

Clesceri, E.J., CB# 3300, 12-7 Venable Hall, University of North Carolina, Chapel Hill, NC 27599, USA, (919) 962-0014, clesceri@email.unc.edu

Alperin, M.J., CB# 3300, 12-7 Venable Hall, University of North Carolina, Chapel Hill, NC 27599, USA, (919) 962-0298, alperin@marine.unc.edu

Martens, C.S., CB# 3300, 12-7 Venable Hall, University of North Carolina, Chapel Hill, NC 27599, USA, (919) 962-0152, cmartens@marine.unc.edu

Albert, D.B., CB# 3300, 12-7 Venable Hall, University of North Carolina, Chapel Hill, NC 27599, USA, (919) 962-5184, albert@marine.unc.edu

A Probability Network Approach to Predicting Hypoxia in the Neuse River Estuary

Mark Borsuk
Nicholas School of the Environment, Duke University
LSRC, Box 90328, Durham, NC 27708-0328
(919) 613-8054 meb6@duke.edu

In order to demonstrate an improved approach to predictive modeling used for water quality management, a probability network model is being developed and applied to the problem of eutrophication in the Neuse River, NC. Also called a Bayesian probability network, or a "Bayes net", this model consists of the set of variables of interest in the system being modeled as well as a set of assertions concerning the probabilistic relationships among the variables. These relationships are quantified using historical data, process-based models, and expert judgment. Probabilistic predictions of model endpoints are then be made that are based on the entire set of conditional probabilities that have been assessed for each system variable.

Not only does this network structure provide a more integrated approach to uncertainty analysis, but it also allows easy updating of prediction and inference when observations of model variables are made. I demonstrate the development of the conditional probability distributions used in the network using a process-based model of oxygen dynamics and a cross-sectional study of estuarine productivity. While relatively simple, these models are shown to have powerful predictive ability and a full characterization of uncertainty. I believe these qualities to be more beneficial to a management-focused modeling effort than detailed replication of complex processes. The probabilistic predictions generated by the model are also consistent with the risk assessment paradigm and allow decisions to be made based on expected values. In addition, the assessment endpoints are chosen so that they are of vital interest to stakeholders and decision-makers and can be easily conceived in terms of utility for use in a formal decision analysis.

Watershed Modeling and Management in the Catawba River Basin

Ty K. Ziegler
Duke Energy Company
P.O. Box 1006, Mail Code: EC12ZB
Charlotte, NC 28201-1006
Phone: (704) 373-7901 Fax: (704) 382-6240 E-mail: tkziegle@duke-energy.com

WARMF (Watershed Analysis Risk Management Framework) is a decision support system that has been applied to the Catawba River Basin in North and South Carolina. It is an educational tool that stakeholders can use to determine how meteorology generates hydrology and non-point loads; how land use affects non-point loads; how point and non-point loads are spatially distributed; how point and non-point loads translate to water quality in rivers and lakes; and whether the water quality is suitable for intended uses. In short, it is a useful tool that can guide stakeholders in developing a watershed management plan. All necessary databases, simulation models, and graphical software have been integrated into a user friendly Windows-based decision support system. The reliability of the models can be readily checked by comparing simulated results to observed data. WARMF also contains a 7-step roadmap to aid in the organizational and consensus building process. This roadmap provides stakeholders with relevant information concerning water quality so that they can understand and make informed decisions. WARMF also contains a TMDL calculation program that provides a step-by-step procedure to evaluate the total maximum daily load for various pollutants progressing from upstream to downstream control points in a river basin. In addition, the Catawba River Basin application of WARMF is segmented into numerous sub-watersheds. This feature facilitates more in-depth analyses of particular sub-watersheds of interest within reasonable cost and time constraints.

An Assessment of Ground Truth Variability Using a "Virtual Field Reference Database"

Ross S. Lunetta[1]*, John Iiames[1], Joseph Knight[2], Russell G. Congalton[3], and Thomas H. Mace[4]

1 U.S. Environmental Protection Agency, National Exposure Research Laboratory,
Research Triangle Park, NC 27711
2 Center for Earth Observation, North Carolina State University, Raleigh, NC 27695
3 Department of Natural Resources, University of New Hampshire, Durham, NH 03824
4 U.S. Environmental Protection Agency, Enterprise Science and Technology Division,
Research Triangle Park, NC 27711

* Corresponding author (phone: 919.541.4256; FAX: ext.1486; E-MAIL: lunetta.ross@epa.gov)

A "Virtual Field Reference Database (VFRDB)" was developed from field measurement data that included location and time, physical attributes, flora inventory, and digital imagery (camera) documentation for 1,011 sites in the Neuse River basin, North Carolina. The sampling frame incorporated both systematic unaligned and stratified random design elements to provide an even distribution of points across the study area and sufficient sampling site intensification to characterize under represented classes. Field sampling was accomplished during May through September of 1998 and 1999. Field crews navigated to sampling points using Global Positioning Systems (GPS) operating in real-time (satellite broadcast) differential corrected mode. Circular plots with a radius of 36.5 meters were measured and flagged to provide 0.4 hectare plots. Field measurements were made corresponding to location and time, physical parameter and biophysical measurements. Measurements corresponding to physical parameters included, slope, aspect, elevation, percent cover of predominate land-cover type, water regime, and soil moisture condition (descriptive), diameter breast height (DBH) and percent canopy cover were collected, as appropriate. DBH was determined using a refractive lense technique, slope was measured using a clinometer, and percent canopy using both the vertical tube and hemispherical densitometer techniques. Detailed inventory of crop types, ground cover, shrubs, under-story tree and tree canopy constituents and relative abundances were determined for each site, as appropriate. Also, a high resolution (1040 x 840 pixels) natural color imagery series was acquired for each site.

Using the VFRDB two interpreters separately assigned class labels corresponding to a modified Anderson Level 2.5 classification scheme based on their interpretation of field measurement and imagery data. Correspondence between interpreters was 95, 89 (overall average), and 100 percent; corresponding to Level 1, 2, and 3 classes, respectively. High correspondence among Level 1 classes was attributable to the application of the VFRDB provided a high quality source of measurement and imagery data to guide class assignments. The diminished correspondence between many Level 2 classes was attributed to inherent problems associated with the discrete categorization of dynamic landscape characteristics in a biologically diverse environment. The 100 percent correspondence between interpreters for Level 3 classes was attributable to the lack of ambiguity and homogeneity associated with agricultural row crop classes. The results of this research demonstrated the value of field measurement and imagery data to provide high quality reference data to assess the accuracy of remote sensing derived land-cover/land-use (LCLU) products. The concept of a VFRDB provides for a robust source of "ground truth" data that can be applied repeatedly to generate reference data corresponding directly to most user defined LCLU classification systems. Also, the high level of location accuracy (sub-meter) acquired for sampling plots provides an ideal opportunity for subsequent sampling to support change detection methods development and testing. This study identified numerous ambiguities associated with traditional Level 2 LCLU classes. The confusion documented for Level 2 urban types (83 percent agreement), rangeland classes (91 percent agreement), forest classes (90 percent agreement), and barren classes (67 percent agreement) offer a possible explanation for the relatively poor accuracies reported in the literature for studies conducted in diverse urban and biological locations. These result

strongly support the application of field measurement data to provide reliable source of "ground truth" data to support the quantitative assessment of remote sensing derived LCLU products. This research also suggest that many traditional Level 2 classes and definitions be more carefully developed to better provide unambiguous LCLU classes for application biologically diverse locations.

Key Words: field data, "ground truth", reference data, sampling frame, land-cover/land-use, classification schemes, and accuracy assessment.
Notice: The U.S. Environmental Protection Agency funded and conducted the research described in this paper. It has been subject to the Agency's programmatic review and has been approved for publication. Mention of any trade names or commercial products does not constitute endorsement or recommendation for use.

Email/Phone:
John Iiames iiames.john@epa.gov/ 919-541-3039
Russell Congalton congalton@unh.edu/ 603-862-4644
Joseph Knight knight.joe@epa.gov/ 919-835-0746
Thomas Mace mace.tom@epa.gov/ 919-541-0894

Metals and Organic Compounds in Stormwater* Charlotte, North Carolina, 1993-98

Jerad D. Bales (jdbales@usgs.gov) and J.C. Weaver (jcweaver@usgs.gov)
U.S. Geological Survey, 3916 Sunset Ridge Road, Raleigh, North Carolina 27607

Most of the streams in Charlotte either partially support or do not support their designated uses. Most of the use impairment is caused by runoff from developed urban areas or from construction sites in developing areas.

During 1993-98, the U.S. Geological Survey, in cooperation with the City of Charlotte and Mecklenburg County, collected and interpreted data from eight small urban streams in the Charlotte area in order to characterize urban stormwater quantity and quality from selected land uses. Six of the basins were relatively small (0.02 mi2 to 0.27 mi^2 drainage areas) and land use in each basin was relatively homogeneous. Streams from two larger (2.35 mi^2 and 2.67 mi^2) mixed land use basins also were sampled.

A total of about 40 individual stormwater samples from each site were analyzed for 13 metals. Arsenic was detected at all sites, but the State ambient water-quality standard was exceeded only in the heavy industrial and developing basins. Thirty percent of the samples from the developing basin had nickel concentrations in excess of the ambient water-quality standard. Chromium, copper, lead, and zinc occurred at all sites in concentrations that exceeded North Carolina water-quality standards. Median concentrations of these four metals in samples from the developing basin were typically double the median concentrations from the other basins. Silver, cyanide, beryllium, cadmium, and mercury were seldom detected or were detected in low concentrations. Loadings of metals in wet deposition, estimated from weekly measurements of metal concentrations in precipitation, suggest that atmospheric deposition may also be significant source of some metals, including chromium, copper, lead, and zinc, in Charlotte stormwater.

Stormwater samples were analyzed for 121 organic pesticide compounds and 57 volatile organic compounds. Forty five organic compounds and 7 volatile organic compounds were detected. Fifteen or more compounds were detected at all sites except sites in the mixed land use basins. Atrazine, carbaryl, and metolachlor were detected at all sites, with detection frequencies of 90 percent, 60 percent, and 60 percent, respectively. Diazinon and malathion were detected in samples from seven sites, and methyl parathion, chlorpyrifos, alachlor, and 2, 4-D were detected at four or more sites. The high-density residential, medium-density residential, and developing basins had the greatest numbers of detections of organic compounds.

Assessment of a Comprehensive Approach to Water Conservation and Peak Demand Management: Costs and Benefits

Jennifer L. Platt, Water Conservation Coordinator, Town of Cary, NC
P.O. Box 8005, Cary NC 27512-8005
Phone: (919) 462-3872 e-mail: jplatt@ci.cary.nc.us

The population of the Town of Cary has doubled in size (from 43,000 to over 86,000) since 1990. The Cary/Apex Water Treatment Facility, which was projected to meet needs through 2010, must now supplement its supply with water from neighboring municipalities.

The increasing level of summer water demand, which peaked at double the average winter demand in 1997, is compounded by the Town's high appearance standards. The Town's Water Conservation and Peak Demand Management program began in late 1996 with the hiring of a Water Conservation Specialist. To confirm its commitment to efficient use of local resources, the Cary Town Council adopted a policy statement establishing the following goals for the program:

- provide safe, reliable water service while reducing wasteful uses of water;
- reduce costs of infrastructure expansion; and
- conserve a limited natural resource.

The program has implemented a comprehensive management approach, including educational, financial, and regulatory initiatives. These initiatives focus on two areas: reducing per capita water consumption and managing the peak demands that occur during the hottest, driest times of the year.

The Town's application to the State to increase its interbasin transfer from the Cape Fear River to the Neuse River must address the Town's efforts and successes in implementing water conservation savings. As part of the description of the Town's efforts in water conservation, a goal of reducing the average per capita demand by 20% between 2000 and 2015 was established.

The program's second focus area, peak demand management, reduces the Town's reliance on supplemental water supplies. The current initiatives include extensive public information and education programs, (including grassroots neighborhood outreach); close monitoring of municipal use efficiency and unaccounted-for water; water reuse; restrictive watering ordinances; conservation-oriented rate structure; and rebates for purchase of water-saving devices.

This paper provides an evaluation of the costs and benefits associated with the program measures described, and potential for long-term water use reductions and infrastructure savings for the Town.

Effectiveness of Three "Best Management Practices" for Reducing Non-point Source Pollution from Piedmont Tobacco Fields

E. Carlyle Franklin, carlyle_franklin@ncsu.edu
Dennis W. Hazel, dennis_hazel@ncsu.edu
Kathleen T. Summitt, ktsummit@unity.ncsu.edu

Woodlot Forestry R & D Program, Department of Forestry
N.C. State University, Box 8006, Raleigh, NC 27695-8006
(919) 515-3566

Much research has been done exploring ways of reducing non-point source pollution (NSPS) of surface water from agricultural crops. Pollutants include sediment, nutrients, and pesticides. These studies have included use of best management practices (BMPs) including grassed waterways, site-specific application rates and timing of fertilizer and pesticide applications, use of conservation tillage practices, and use of grassed and forested field-side filter zones. As more BMPs are being recommended more data are needed to document NPSP reductions resulting from their use. Documentation of costs of installation and maintenance of BMPs and cost/benefit comparisons of results of a complete in-the-field system is needed. This is especially true for tobacco, because of intensive tillage practices and aggressive fertilizer and pesticide applications.

We evaluated effectiveness of and costs associated with use of three BMPs for tobacco production: conservation tillage, grassed field-side filter zones, and forested filter zones (FFZ). The study was conducted on the Oxford Tobacco Research Station in Granville County. Runoff volumes and nutrient concentrations were measured to evaluate the complete system of three BMPs. Costs and benefits of all practices were documented including impacts on quality, yields and profitability of tobacco.

Several factors contributed to highly variable but low overall yields on both conservation-tillage and conventional-tillage fields. Yield for all fields were a third or less than would be expected for these soils, however, yields on an area basis were about 38 percent higher for conventional tillage when compared with conservation-tillage. Average quality was higher for conservation-tillage fields.

The conservation-tillage treatment was successful in reducing soil loss, with an approximately eight-fold difference between cultivation treatments in soil loss even though well-grassed waterways were established in all fields. Nutrient concentrations in surface runoff for both treatments was sufficiently low that no differences were apparent. The low concentrations may have been related to the same factors which resulted in low yields. Grass field-side filter zones were only modestly effective due to concentrated flow. The recently clear cut forested filter zone was substantially more effective than the adjacent fully-stocked FFZ.

An Investigation of Stream Origins in the Piedmont of the Neuse River Basin

Danny Smith[1]
Joseph Gardner[2]
James Gregory[3]

In order to apply the Neuse Riparian Buffer Rule, it is often necessary to determine the origin of intermittent streams. The inaccuracy of available topographic and soils maps dictates that such regulatory determinations are made in the field by NC Division of Water Quality (NCDWQ) staff. In many instances the transition from ephemeral to intermittent stream is dramatic. However, in other instances the transitions are subtle and determination of stream origin is difficult, requiring extensive field experience and time. The objectives of this research are to determine the factors that influence the formation of first order streams, to conduct extensive field testing of the NCDWQ stream evaluation procedure, and to develop guidelines for map interpretation that may provide for desktop stream origin determinations. The first phase of a study of stream origins throughout the Neuse River Basin has been completed.

It is hypothesized that traits of first order watersheds (stream forming factors) such as geologic substrate, soil type, plant communities, impervious surfaces, watershed shape, watershed area, land use and slope combine on a pedogenic time scale to form an observed intermittent stream origin. A systematic random sample of intermittent streams in the Piedmont portion of the Neuse River Basin was conducted to test this hypothesis. Extensive data on watershed traits and first order stream characteristics were collected. Preliminary analyses of these data show that: (1) stream forming factors influence stream origin locations and first order stream character; (2) first order streams that formed on similar parent material and soil types have similar watershed areas and other factors that affect the stream origin and stream character, and (3) the NCDWQ stream evaluation procedure provides an objective and consistent field tool for stream origin determination.

[1] Environmental Specialist, Wetlands/401 Unit, North Carolina Division of Water Quality, 1621 Mail Service Center, Raleigh, NC 27699-1621, 733-9716, Danny.Smith@ncmail.net; (also Master's Candidate, Hydrology, NCSU Dept. of Forestry)

[2] Master's Candidate, Hydrology; Department of Forestry, North Carolina State University; 3009-F Dorner Circle, Raleigh, NC 27606, 854-2605, jsgncsu@aol.com

[3] Professor, Department of Forestry, North Carolina State University, Box 8008, Raleigh, NC 27695-8008, Jim_Gregory@ncsu.edu

Overview of Groundwater Hydrology and Water-Use Regulations in the North Carolina Coastal Plain

Jeffrey W. Reynolds, Senior Hydrogeologist and Manager, Hydrogeologic Assessments Program
Research Triangle Institute, PO Box 12194, Research Triangle Park, NC 27709
(919)541-7137 jeffr@rti.org

Although groundwater resources as a whole remain plentiful in the majority of coastal-plain aquifers, burgeoning development in some areas of eastern North Carolina has resulted in stresses that are jeopardizing the sustainability of this resource. This presentation provides a brief summary of the hydrogeologic framework of the coastal plain, describes the history of North Carolina's water-use regulations, summarizes current hydrogeologic conditions, and discusses new water-use regulations proposed by the North Carolina Division of Water Resources. Strata beneath the coastal plain comprise an eastward-thickening wedge of marine and transitional sedimentary deposits resting on a crystalline basement.

The Castle Hayne aquifer is the most productive aquifer system in North Carolina and is the primary source of high-quality groundwater for industrial, agricultural, and domestic users in the eastern coastal plain. In the central coastal plain, the Castle Hayne Aquifer is not present and the Cretaceous aquifer system is the primary source of high-quality groundwater. A law to protect coastal-plain groundwater was enacted in the late 1960s in response to large-scale withdrawals of groundwater from the Castle Hayne aquifer for phosphate mine dewatering near the town of Aurora, North Carolina. By authority of the 1967 Water Use Act, North Carolina designated an area surrounding the Aurora mining operations as a Capacity Use Area, encompassing all or part of eight coastal-plain counties. In the Capacity Use Area, a permit is required to withdraw groundwater or surface water in excess of 100,000 gallons per day. Drawdown of water levels in the Castle Hayne Aquifer stabilized several months after mine withdrawals began as a result of a reduction of natural discharge and an increase in recharge. Recently, pumping rates for phosphate-mining activities have decreased, resulting in rising groundwater levels.

In the meantime, groundwater levels in the central coastal plain Cretaceous aquifers have steadily dropped. In addition, dewatering of semiconfining units due to extensive overpumping has resulted in land subsidence in a portion of the central coastal plain. The impacts to the central coastal plain aquifers have prompted the NC Division of Water Resources to propose expansion of the Capacity Use Area to 15 coastal-plain counties. The proposed new rule has been reviewed by the Environmental Management Commission and is currently under review by stakeholder groups. The permanent rule is expected to be in place in 2001. The expanded water-use regulations, combined with rigorous conservation efforts, incentive programs, and innovative coordination between water users are needed to ensure sustainable groundwater supplies for the future.

Utilization of the Cretaceous Aquifer System for Storage and Recovery of Treated Surface Water in Greenville, NC

Christopher P. Foldesi, Department of Geology
East Carolina University, Greenville, NC 27858
cpf1121@mail.ecu.edu

Bryan McDonald, CH2MHILL
3011 SW Williston Road, Gainesville, FL 32608-3928
bmcdonal@CH2M.com

Richard Spruill, Department of Geology
East Carolina University, Greenville, NC 27858
spruillr@mail.ecu.edu

Greenville Utilities Commission (GUC) has experienced steady increases in demand for water supply services due to population growth within their service area. The GUC water treatment plant (WTP) is currently being expanded to treat 22.5 mgd by 2001. This expansion is expected to provide sufficient water supply capacity to meet projected demands until 2010.

GUC recognizes that aquifer storage and recovery (ASR) can provide additional water storage and meet peak demands prior to and beyond 2010. By storing treated drinking water in the natural aquifer system during periods of low demand (winter months), GUC can use this water to meet peak demands in summer months. A total of eight ASR wells may be needed to meet peak demands.

Site selection for the initial ASR site was based on property costs, hydrogeology, proximity to the distribution system and existing production wells. Geological core samples were recovered from 200 to 502 feet below the land surface to determine aquifer and confining layer characteristics. Based on geophysical logs and stratigraphic interpretations, the section (0-516 feet) can be divided into six distinct stratigraphic units containing 3 aquifer zones. Two candidate aquifer zones (Sand 2 and Sand 3) were selected for hydrological evaluation. Sand 2 (depth of 327-379 feet) occurs at the base of the Black Creek Aquifer, and Sand 3 (depth of 419-500 feet) occurs at the top of the Upper Cape Fear Aquifer. The stratigraphic section is sand-rich in comparison to other sites in the Greenville area where wells or borings have been installed in the Black Creek or Upper Cape Fear Aquifers. Reactive minerals identified in Sands 2 and 3 that could deleteriously influence ASR operations include the iron sulfide mineral, pyrite, and mixed layer illite/smectite clays. Pyrite and other iron bearing minerals in the aquifer could react with recharge water and yield dissolved iron to the stored water, possibly elevating levels above primary potable water standards. NaOH added at recharge can reduce dissolved iron in recovered water.

The next phase involves drilling and development of an ASR test well, in which water chemistry and storage capabilities will be tested. The final ASR production well design will be based on test well results. Cycle testing will be completed on the ASR well as a means to measure recharge and recovery production and water quality criteria.

Ground-water and Surface-water Interactions-Potential Effects of Hydrogeology, Riparian Buffers, and Hyporheic Zone on Surface-water Quality And Nutrient Loading

Timothy B. Spruill, Hydrologist
U.S. Geological Survey, 3916 Sunset Ridge Road, Raleigh, NC 27607-6416
(919)571-4088 tspruill@usgs.gov

Surface-water quality is a composite of a variety of chemical inputs from a few major sources-the atmosphere, animals, plants, rocks and soils, and anthropogenic activities. As sources change in abundance through time and space, the aquatic system changes as well. When the changes are great enough to cause undesirable environmental consequences (usually in a human context), a problem is perceived. The Albemarle-Pamlico Drainage has a variety of water-quality problems. Nutrients derived from various point and nonpoint sources are thought by many to be the primary cause of water-quality problems in the basin, including fish kills, algal blooms, and potential hazards to human health. The Neuse River has been the focus of much research addressing nutrient occurrence and distribution and their relation to these problems. Ground water typically provides more than 50% of the annual average discharge of most Coastal Plain streams, which implies that ground water quality is likely to have a major effect on surface-water quality. Four projects are currently being conducted by the U.S. Geological Survey in the Albemarle-Pamlico Drainage that address the identification of sources of nutrients by use of ion ratios, environmental tracers, or isotopes. By using such techniques, the relative contributions from each source may be distinguishable. In addition, these techniques are being used to evaluate chemical and biological processes that take place in the aquifer, riparian buffers, and hyporheic zone and that affect surface-water quality and stream nutrient loads. Preliminary findings from the USGS studies will be presented.

Groundwater Flow and Transport Analysis for the Proposed Martin Marietta Quarry Site Water Reclamation Project, City of New Bern, NC

Kenneth O. Pohlig
NC Division of Water Quality, Construction Grants & Loans Section
1633 Mail Service Center Raleigh, NC 27699-1633
(919) 715-6221 Ken.Pohlig@ncmail.net

A groundwater flow and transport model (MODFLOW) has been developed for the lower portion of the Neuse River basin in order to help address regulatory issues surrounding the proposed use of the abandoned Martin-Marietta quarry site for disposal of tertiary treated wastewater by the City of New Bern. The mutli-layer model considers the interaction of the surficial aquifer with the underlying Castle Hayne aquifer, and their joint interactions with the Neuse and Trent Rivers and major tributaries in the lower portion of the Neuse River basin. Calibration of the regional model was performed by considering water level data from USGS and DENR research wells in the basin. Groundwater pumping at the neighboring Clarks quarry was modeled in order to determine its affect on the transport migration pathways emanating from the Martin-Marietta quarry. The bottom of the quarry was modeled as cutting into the upper portion of the Castle Hayne aquifer. Flow and transport model simulations were conducted assuming a wastewater flow to the quarry of 2, 4, and 6 million gallons per day (MGD) at a total nitrogen concentration of 4 mg/l. To be conservative, nitrogen removal processes (uptake from quarry algae and river bottom sediment denitrification) were not considered in the model.

The model simulations indicate that a small portion of the quarry flux migrates towards Clarks quarry, with the remainder of the quarry flux being discharged into the Neuse River through the surficial and Castle Hayne aquifers along an approximately 2 mile stretch of river/tributary front. The majority of the quarry flux reaches the Neuse River via the Castle Hayne aquifer, being discharged into the river across approximately 1000+ acres of river bottom and flood plain sediments. The total mass of nitrogen discharged into the Neuse River was simulated over time. The nitrogen mass loading rate across the river bottom sediments is found to be comparable to published river bottom sediment denitrification rates. Unfortunately, little research work has been conducted regarding the denitrification effects from river bottom sediments from groundwater seeping into rivers, and therefore much uncertainty exists regarding what levels of denitrification could be expected to occur in this situation.

From a regulatory point of view, this proposed project represents the first of its kind in the State of North Carolina. The immediate effect of the project will be to substantially reduce a nitrogen point source discharge into the Neuse River, which is seen as beneficial. Likewise, a diffuse “non-point” source of nitrogen to the river will develop over time across the river bottom sediments. One benefit of altering a point source of nitrogen into a diffuse “non-point” source of nitrogen will be the increased likelihood of denitrification, as the areal nitrogen mass loading will have been reduced substantially. Whereas nitrogen uptake in the quarry itself from algae and denitrification at the river bottom sediments are processes expected to occur, the actual rates are uncertain. Until a demonstrated nitrogen removal over time can be established, the Division of Water Quality has been reluctant to grant the City of New Bern any additional total nitrogen allocation based on shifting the wastewater discharge from a point source to the quarry discharge. It is apparent that a great opportunity exists to conduct research on denitrification of groundwater as it seeps through river bottom sediments.

Benefits of Water Quality Improvements in North Carolina

Daniel Phaneuf
Department of Agricultural and Resource Economics, North Carolina State University
Box 8109, Raleigh, NC 27695
919-515-4672 dan_phaneuf@ncsu.edu

One way to value the benefits of water quality improvements is to evaluate the non-market benefits of improved quality for water recreation. Using a data set on water recreation in North Carolina, we examine the effect on recreation behavior of water quality measures such as ph and dissolved oxygen, and consider the change in the use of water resources and the associated value from improvements in these quality measures.

Economic Value of Water Quality in the Catawba River Basin

Randall A. Kramer, Nicholas School of the Environment
Box 90328, Duke University, Durham, NC, 27705
(919) 613-8072, kramer@duke.edu

Jonathan I. Eisen-Hecht, Nicholas School of the Environment
Box 90328, Duke University, Durham, NC, 27705
(919) 613-8091, jih1@duke.edu.

The Catawba River is a system of 11 reservoirs originally created by Duke Power Company for the purpose of hydroelectric power generation. Along its course of 224 miles, the river flows through some of the most populated regions of the Carolinas. Many of these areas, including Charlotte NC, are experiencing rapid population growth, which contributes to water quality problems along the river.

An estimation of the economic value of water quality in the Catawba River basin is important for helping stakeholders prioritize present and future actions that could affect area water quality. The primary objective of this study was to estimate the economic value of water quality in the Catawba River basin. Stated preference survey methods were used to estimate the economic benefits associated with the protection of Catawba River basin water quality at its current level over time. Using a combined mail and telephone format, surveys were completed with 1085 households in the basin. Survey results demonstrated the importance of the Catawba River to area residents for a wide variety of uses, including recreation by themselves and others, drinking water, and knowing the resource is being protected regardless of its use. Ninety-eight percent of the respondents stated that protecting water quality in the Catawba basin was at least as important to them as other environmental issues in their state.

After reading an information booklet about water quality in the Catawba River basin, survey respondents were asked about their willingness to pay, through an increase in state income taxes, for a management plan designed to protect area water quality at its current level over time. This willingness to pay was equivalent to the well being area residents receive from the protection of water quality in the basin, and translated to an annual economic benefit of $139 per Catawba basin taxpayer. Aggregating this value across the 16 counties in the Catawba River basin resulted in a total annual economic benefit of over $75 million resulting from the protection of water quality in the region. An econometric analysis showed that several factors had a statistically significant influence on willingness to pay, including respondents' income, educational level and perception of area water quality.

Trade-Off at the Trough

Carol Mansfield, Duke University

V. Kerry Smith, N.C. State University
vksmith@ARE1.CALS.NCSU.EDU

This paper is about two complementary approaches for informing policymakers' choices about animal agriculture in North Carolina.One gauges the income and employment that have been transferred to Eastern North Carolina as a result of the growth in hog production in this area of the state. It attempts to measure the scale of activity generated, directly and indirectly, in meeting the industry's needs. The second focuses on the non-market effects of this increased activity on consumer surplus for activities and public goods whose value is not reflected in market transactions. What is important, under this view, is the set of externality effects not reflected in production costs (and thus omitted >from final goods' prices) or the indirect consequences of industrial activity that are experienced outside markets.

Most economists evaluating policy alternatives ignore the first set of information and focus their attention on the non-market damages. By contrast, many policy makers limit their attention to the output and employment figures, overlooking the second. This paper uses the issues facing North Carolina to illustrate how both can serve in complementary roles to consider the income and environmental consequences of animal agriculture.

Our analysis suggests several conclusions. Hog production is an important source of income and employment in Eastern North Carolina that would be hard to replace in total.

However the same method of analysis suggests that policy makers should take notice of another important source of income to this area of the state. The state's environmental amenities are complementary inputs (if not essential) to many dimensions of tourism. Aggregate analysis of this sector's direct and indirect effects suggest increases (or decreases) in spending on tourism per dollar have larger effects outside the sector than spending that same dollar on hog production. This difference is relevant because public perceptions of the state's environmental quality are especially important to its image as an attractive destination for outdoor recreation.

This response does not include the welfare losses North Carolina households experience from the diminished environmental quality associated with the hog operations. We measure these losses using estimates of households' willingness to pay to reduce the negative effects of hog operations in the state. In a statewide random sample conducted before the widespread polarization in public attitudes we found that North Carolina households are willing to pay significant amounts to enforce regulations on hog operations.

The Role of Decision-Making Authorities in Public Participation Processes: Division of Water Quality and the Tar-Pamlico Rule-making Process

Lynn A. Maguire, Nicholas School of the Environment
Box 90238, Duke University, Durham NC 27708-0328
lmaguire@duke.edu 919-613-8034

E. Allan Lind, Fuqua School of Business
Box 90120, Duke University, Durham NC 27706-0120
alind@duke.edu 919-660-7849

The negative consequences of nutrient overload have prompted new water quality regulations in several North Carolina watersheds. The processes for developing these new regulations have included participation by stakeholders and members of the general public. Among the reasons for enlisting public participation in regulatory rule-making is the desire to formulate rules that will enjoy broad public support. Studies in the theory of procedural justice have shown that process concerns, such as the opportunity to speak up in public meetings and be treated with respect, can have as much, and sometimes even more, influence on public acceptance of the rules that are finally promulgated than the rules' substantive impact.

The behavior of those who are perceived as having positions of decision-making authority is an important component of judgments about fairness of rule-making procedures. We analyzed the role of the North Carolina Division of Water Quality (DWQ) in the process used to propose rules for reducing nutrient inputs to the Tar-Pamlico watershed with an eye to procedural justice concerns. We used a combination of qualitative and quantitative methods to gather and summarize information on the process. We examined the written records of the process (e.g., letters of invitation, workshop minutes, public meeting minutes, final reports) to see who attended, who set the agenda, who proposed topics for discussion, who provided technical information, who drafted reports, and so on. We also noted participants' comments on the process that were included in meeting minutes. DWQ itself conducted a short post-process survey asking participants about their perceptions of the process.

We analyzed those data and supplemented them with a more extensive survey ourselves. Our sample frame included those who participated in some aspect of the rule-making process, those who were invited but did not participate, and members of the public other than those who were invited to participate. We were interested not only in how the process experienced by participants influenced their acceptance of rules, but also in whether secondhand information about the process, or even more general information about the behavior of authorities (in this case, DWQ) influenced acceptance by those who did not participate.

We will present the results of our analysis of the written records and our preliminary analysis of our survey data.

Were Human Impacts upon the Riverine Systems of Coastal North Carolina Significant Factors in the Flood of September 1999?

Stanley R. Riggs
Department of Geology, East Carolina University
Greenville, NC 27858
riggss@mail.ecu.edu 252-328-6360

Was the September 1999 flooding in eastern North Carolina a natural catastrophe or a human disaster?

Rivers move water off the land through drainage basins—-a major portion of the earth's hydrologic plumbing system. Moving water in rivers is among the most powerful and persistent agents in shaping the earth's surface. Rivers are highly variable, extremely dynamic, and dependent upon periodic and sometimes catastrophic flood events. Such floods only become disasters when human activities get in the way of these natural processes.

The flood of September 1999 was a catastrophic event that resulted from the cumulative impact of several large rainfall events associated with hurricanes Dennis and Floyd. However, additional factors led to the severe human disaster that resulted from the extremely high water levels and long duration of the flooding event. From the 1960's to early 1990's, growth in the North Carolina Coastal Plain was rampant with few minor hurricanes. Along with this growth came severe modification of the drainage systems resulting in loss of riverine function and wetland habitats.

Drainage systems have been modified in four general ways. 1) Dams: reservoir dams impound water flow; roads form partial dams across river systems that diminish floodplain size and impede discharge to varying degrees. 2) Stream channelization and dikes: stream flow is altered as channels are straightened and deepened, levees or dikes constructed along stream channels, and floodplains cleared. 3) Marginal wetlands: ditching and draining of secondary floodplains and upland pocosins changes land use and hydrodynamics of associated drainage systems. 4) Urbanization: urban expansion increases areas of impervious surface diminishing infiltration and increasing polluted storm-water runoff.

Each of these modifications impact rates, volumes, and flow patterns of surface-water discharge in different ways within various portions of a drainage basin and in response to specific types of rainfall events. More importantly, these drainage modifications result in riverine habitat alteration and leads directly to significant land-use changes. Escalating human encroachment into the riverine wetlands by agribusiness, industry, and urban sprawl lead to the disastrous human and economic consequences.

Short-term Impacts of Hurricanes Dennis, Floyd and Irene on Water Quality and Fisheries Habitat in Pamlico Sound, North Carolina

Hans W. Paerl*, Christopher P. Buzzelli, Malia Go, Richard A Luettich,
Benjamin L. Peierls, Tammi L. Richardson
Institute of Marine Sciences, UNC-CH, 3431 Arendell Street, Morehead City, NC 28557,

Joseph S. Ramus, Larry B. Crowder, Lisa A. Eby
Duke University Marine Laboratory, Beaufort, NC 28516

Larry Ausley and Jimmie Overton
Water Quality Division, N.C. Dept. of Environment and Natural Resources, Raleigh, NC 27699-1621

Jerad Bales, U.S. Geological Survey, Raleigh, NC 27607

North Carolina has experienced six major hurricanes over the past 4 years, including four visits from three hurricanes (Dennis, Floyd and Irene within 4 weeks in September/October 1999. Floyd alone led to an unprecedented 200 to 500 year (depending on location in the watershed) flood event, inundating coastal rivers and the Pamlico Sound, the Nation's 2nd largest estuary and North Carolina's most valuable aquatic resource. The Sound processes nearly half of the State's freshwater runoff via its subestuaries (Neuse, Pamlico, Roanoke-Chowan-Albemarle) and has a mean water retention time of approximately 1 year. The huge pulse of nutrient-laden runoff from Dennis, Floyd and Irene completely "freshened" the Neuse estuary and caused excessive oxygen consumption (hypoxia), reducing the habitat for estuarine-dependent fish and shellfish species. Water and nutrient discharge from this single event approached annual loads, and turned the estuaries into conduits for freshwater and nutrient discharge directly to the Sound.

In response to the unprecedented environmental changes taking place in the Sound, an emergency water quality and fisheries habitat assessment was launched in cooperation with NC DENR's Div. Water Quality & Marine Fisheries, the Neuse River Modeling and Monitoring Program (ModMon), and NOAA's Beaufort Fisheries Lab. We found dramatic reductions in system salinity, the formation of a 3 week-long low oxygen bottom water region (80-100 km2), accompanied by longer term elevated inorganic nitrogen (especially ammonium) and algal production (as chlorophyll a) levels in the western Pamlico Sound. Trawls of the low oxygen region recovered dead and dying shrimp and blue crabs, and bloated fish with tail rot, skin sloughing and lesions. These are the recognizable short-term effects. A portion of the soluble nutrients and organic materials not processed and particulate nutrients sedimented during fall 1999 will remain in the Sound through the spring and summer of 2000 and beyond, potentially enhancing algal production and blooms. This, combined with continued elevated freshwater discharge may enhance the potential for water column stratification, and low oxygen bottom water conditions. There is a need to assess the longer-term (multi-annual) impacts in the Sound, yet currently there is no long-term water monitoring and assessment program in place to evaluate impacts and facilitate water quality and fisheries management strategies. Proposed is the use of the State's and considerable scientific infrastructure and resources and national agency (EPA, NOAA) support to assess the effects of hurricanes and man-made watershed nutrient manipulations, including: 1) NC DOT's ferry system for space and time-intensive automated water quality sampling, 2) satellite-and aircraft-flown ocean color and infrared sensors, 3) moored instrument packages at indicator river estuary mouths and inlets, 4) a network of atmospheric deposition collectors, 5) sediment-water column nutrient cycling, algal productivity and bloom studies, 6) fisheries resource and habitat assessments, 7) developing stratigraphic records of the geological and ecological history in the sediments, 8) predictive water quality and fisheries resource modeling.

*(252) 726 6841, hans_paerl@unc.edu

Effects of catastrophic flooding on hydric soils of eastern North Carolina

Ronald J. Reuter, reuter.ronald@epa.gov, 919.541.1483
U.S.EPA NERL/ESD, MD75, Research Triangle Park, NC 27711

C. William Zanner, bill_zanner@ncsu.edu, 919-515-7154
N. C. State University, Soil Science Department, 3403 Williams Hall, Campus Box 7619
Raleigh NC 27695-7619

Michael J. Vepraskas, michael_vepraskas@ncsu.edu, 919-515-1458
N. C. State University, Soil Science Department, 3412 Williams Hall, Campus Box 7619, 9
Raleigh NC 27695-7619

Recent catastrophic flooding in the lower coastal plain of North Carolina inundated both wetlands and their adjacent uplands. The transition between hydric (wetland) and upland soils in the floodplains of the Coastal Plain is difficult to delineate because flooding produces little direct affect on soil properties. We hypothesized that the extended inundation (> 3 weeks) would produce changes in soil properties that would suggest new indicators of hydric soils that could be used to delineate wetland boundaries in these areas. Field and laboratory studies have shown that some hydric soil field indicators can form in the length of time some of these floodplain soils were inundated.

The purpose of this study is to identify morphological changes in these flooded soils that might be used to aid in identification hydric soils on floodplains. Three sites have been identified for the study. Two sites are in the Neuse River Basin and one in the Tar River Basin. Soil transects at each site include upland and wetland soils. Soil profiles were described to a depth of 30 cm. Samples were obtained for representative horizons and will be analyzed for texture, pH, organic matter content, and extractable Mn. In addition, upland and hydric soils at Site I were described and sampled to a depth of 2 m to determine Mn distribution within the profile. Examination of soils showed little or no visible effect of flooding on soil color patterns. However, soils that had been inundated for 3+ weeks reacted to dilute (3%) H_2O_2 while soils that were flooded for shorter durations had minimal reaction. This suggests that the concentration of MnO_2 was high in soils subjected to long-term flooding. Data collected in 1996 after hurricane Fran support the movement of MnO_2 within soil horizons following flooding. It is likely that the high concentration of MnO_2 in soils subject to flooding minimizes changes in soil color due to reduction and oxidation of Fe. We speculate that use of dilute (3%) H_2O_2 can be used to identify elevated Mn concentrations in soils, and may be a useful tool for identifying hydric soils on floodplains.

This project has been funded in part by the U.S. EPA. It has been subjected to Agency review and approved for publication

Effects of Hurricane Floyd flooding on coastal ocean water quality

Lawrence B. Cahoon[1], Frederick M. Bingham[2], Michael A. Mallin[3],
Sharon A. Kissling[1], and Janice E. Nearhoof[1]

1 Dept. of Biological Sciences, UNC Wilmington, Wilmington, N.C. 28403

2 Dept. of Physics and Physical Oceanography, UNC Wilmington, Wilmington, N.C. 28403

3 Center for Marine Science, UNC Wilmington, Wilmington, N.C. 28403

Hurricane Floyd struck eastern North Carolina Sept. 15-16, 1999, with rainfall totals up to 19" over a 40 hour period, causing record flooding and the highest single daily discharge of the Cape Fear River in the last 50 years. A large volume of turbid, highly colored river water formed a plume in the coastal ocean extending from the mouth of the Cape Fear River westward along the Brunswick County beaches into South Carolina waters. Five cruises sampled the river and its plume between Sept. 23 and Oct. 14, 1999 to examine the impacts of this floodwater plume. Dissolved oxygen levels, although lower than normal in the plume, were only rarely below 5.0 ppm. Chlorophyll a concentrations averaged about 1.0 µg/l and did not exceed 5.0 µg/l in the plume water. Nutrient concentrations (N, P and Si) in relation to salinity were comparable to average values for the river and estuary during the period July, 1998-June, 1999. Although large quantities of animal and human waste were likely washed into the Cape Fear River by hurricane flooding, the large rainfall volume diluted these contaminants, preventing more serious water impacts on the coastal ocean.

Impacts from Hurricane Floyd on Water Quality in the Neuse River and Estuary, and the Pamlico Sound

JoAnn M. Burkholder, Howard B. Glasgow Jr., and Robert Reed
Box 7510, North Carolina State University, Raleigh, NC 27695-7510

As part of an intensive, 8-year, ongoing monitoring effort of the Neuse River and Estuary, we have characterized the impacts of Hurricane Floyd on physical, chemical, and biological conditions in the river and estuary, extending into Pamlico Sound (36 stations; ca. 3,000 samples from Sept.-Dec. 1999). We have also used a boat-mounted acoustic Doppler current profiler in the river and estuary, and across ca. 100 km2 of the Sound, to characterize flow patterns and quantify volume of flow for improved nutrient loading estimates. Post-hurricane, the Neuse from Kinston to below Oriental was at ca. 0 psu salinity; and after 4 weeks, salinity in the Sound was still depressed by ca. 70% relative to pre-storm conditions. Normally freshwater segments from Kinston to New Bern recovered to pre-hurricane suspended solids, dissolved oxygen, and nutrient levels within 2 weeks post-Floyd. However, SS remained high (at ca. 30 mg/L in the estuary, and at ca. 20 mg/L in the Sound) for 6 weeks post-Floyd, with significant declines documented after 8 weeks. Dissolved oxygen (DO) was depressed to 3-4.7 mg/L for 3 weeks post-Floyd in the river and estuary, but had recovered to > 5 mg/L after 4 weeks (late Oct.). Contrary to widespread reports at ca. 4 weeks, there was no 'established, massive dead zone' in the Sound after the hurricane. Mild to moderate hypoxia occurred in some areas (ca. 3-4.5 mg/L) at depth 5-7 m or 6-7 m, depending on the location – that is, in the bottom water only. About 1 week later, DO had recovered to > 5 mg/L throughout the water column of the Sound. In fact, DO was at supersaturation (ca. 120% saturation from surface to bottom), coincident with an increase in phytoplankton biomass (chlorophyll a, 4-22 µg/L, mostly as dinoflagellates). Patches of increased algal production also were detected in the estuary at 6 weeks, and high incidence of diseased fish occurred in the western Sound. Major increases in N and P were documented at all sites after 3 weeks post-Floyd, and concentrations remained high in freshwater and estuarine segments for 8 weeks. In the Sound after 4 weeks, nitrate had increased to > 300 µg/L, 10-fold higher than normal, with significant declines by week 8.

Fecal coliforms and other fecal bacteria were elevated in freshwater segments for 8-weeks post-Floyd, with a maximum at 60,000 colony-forming units [CFU]/100 mL at week 8. Highest densities were measured after the water level had begun to recede (about 6 wk post-Floyd), when smaller volumes of flanking floodwaters (much of which had become septic) began to move down-stream. In contrast, the mesohaline Neuse and the Sound did not exceed the State standard for human health (200 CFU/100 mL) in the water column or surficial sediments (1 cm-depth) at any time during the 8-week period. We will continue to track water and biological quality in the Neuse and western Sound during the coming year, with major focus on the Estuary in evaluating the extent of delayed impacts that may be sustained from the hurricane.

Watershed factors associated with enteric microbe concentrations in North Carolina surface waters

Dana Cole[1], Vincent Hill[2], Daniel Line[3], William Harman[3], Greg Jennings[3], Mark Sobsey[2]

1. Dept. of Environmental Sciences and Engineering, UNC School of Public Health, Chapel Hill NC 27599-7400; tel. (919) 966-7316; email: dcole@email.unc.edu2

2. Dept. of Environmental Sciences and Engineering, UNC School of Public Health, Chapel Hill NC 27599-74003

3. Dept. of Biological & Agricultural Engineering, North Carolina State University, Raleigh NC 27695-7637

Fecally contaminated water continues to be a problem in the United States despite regulations intended to protect recreational and drinking waters. However, specific risk factors of waterway contamination are poorly characterized. This study analyzed surface water samples quarterly for three years in Gaston County and Wake County, North Carolina in watersheds having different levels of agricultural, residential, and urban development. Factors influencing the levels of enteric microbes in surface water collected near livestock facilities, a municipal biosolids land application site and an urbanized region were investigated. Geometric mean microbial concentrations varied with land usage, sampling site, season, total suspended solids (TSS) measurements, and rainfall events. The magnitude of these impacts on observed microbial densities were variable, depending on the microbial indicator. Geometric mean concentrations of fecal coliforms, E. coli, and somatic coliphages were generally higher at sites impacted by animal and human inputs compared to rural residential and background stations. Urban-impacted sites had significantly ($p<0.05$) more Group II F+ RNA coliphages than both the livestock-impacted and the rural/background stations, suggesting primarily human fecal contamination. Livestock-impacted sites had more Group I coliphages than the other three F+ RNA coliphage serogroups, but the F+ RNA coliphage densities were lowest at these sites. Fecal coliform levels declined at the Gaston County dairy site after implementing best management practices (BMPs) for animal wastes. Runoff from a cattle pasture and feedlot at Lake Wheeler Road Farm contained high concentrations of microbial indicators; concentrations in feedlot runoff approached those in raw animal wastewater. The levels of all microbial indicators increased significantly during rainfall events at all tested sites, as did TSS. Microbial indicators were positively correlated with TSS, but correlation strengths differed for base flow and storm samples. Compared to the other indicators, the concentrations of enterococci and somatic coliphages were most influenced by season and were highest in the summer. The results of this study suggest that surface water quality in North Carolina can be degraded by human and animal fecal waste sources and that BMPs as well as source water protection programs are needed to minimize waterborne microbe levels and risks to public health.

Land Use, Runoff, and the Microbial Pollution of Rivers and Estuaries

Michael A. Mallin, Scott H. Ensign, Matthew R. McIver, G. Christopher Shank
Center for Marine Science Research, University of North Carolina at Wilmington
Wilmington, N.C. 28403, phone 910 256-3721, mallinm@uncwil.edu

Patricia K. Fowler
Shellfish Sanitation Section, North Carolina Department of Environment and Natural Resources
Morehead City, N.C. 28557

Coastal areas in the United States and many other countries are considered to be desirable regions to live and recreate. However, as human use of coastal land and water increases, so does the incidence of aquatic borne disease from contact with contaminated water and eating contaminated shellfish. Movement of humans into coastal areas both greatly increases the number of sources of microbial pathogens and radically alters the landscape through increased construction activity and paving of former natural areas.

On a regional scale, increases in human population over a 14 year period in coastal North Carolina were strongly correlated with increases in shellfish bed closures due to high fecal coliform bacterial counts. On a watershed scale, an analysis of several tidal creeks found strong correlations between average estuarine fecal coliform bacterial counts and watershed population, percent developed area, and especially with percent impervious surface coverage. Conversion of natural landscapes to impervious surfaces (roads, drives, sidewalks, parking lots, and roofs) removes the land's natural filtration capability, allows for increased concentration of pollutants at the land's surface, and provides a means of rapid conveyance of pollutants to downstream waterways. These findings suggest that waterborne microbial pathogen abundance can be minimized in urbanizing coastal areas through reduced use of impervious surfaces and maximal use of natural or constructed wetlands for passive stormwater runoff treatment.

Water bodies draining agricultural areas are also subject to severe microbiological contamination. Analysis of four years of data from a mainstem Cape Fear River station found very strong correlations between turbidity and fecal coliform counts, and river flow and both turbidity and fecal coliform counts. This indicates a significant non-point source pollution problem along the Cape Fear River. An analysis of 11 rural watersheds in the Coastal Plain found that stream fecal coliform counts and turbidity were both strongly correlated with rainfall in the previous 24 hr in watersheds containing extensive swine and poultry production facilities, as well as those with more traditional agriculture. In contrast, in those watersheds containing greater than 13.5% wetlands coverage these relationships were not significant. In animal husbandry areas retention of natural wetlands and management practices designed to minimize sediment runoff can reduce inputs of pathogenic microbes into streams and rivers.

Development of Land Use Change Indicators to Support Watershed Based Restoration of Shellfish Resources Impacted by Fecal Coliform Contamination

Nancy White, Michael Holmes* and Leon Danielson

* Research Associate, Design Research Laboratory, School of Design,
Box 7701, N.C. State University, Raleigh, NC 27695--7701
(919) 515-8951 mvholmes@unity.ncsu.edu

Jumping Run Creek in North Carolina is the focus of a multi disciplinary, multi-agency, watershed- based project that combines in column water quality data, stormwater monitoring, stream flow measurements, with watershed assessment techniques, and community involvement to investigate causes of and solutions to reduce bacterial loading to shellfish beds. Field data indicate that stormwater flows are the primary transport vector: however, total “impervious surface” area in the water shed, a popular indicator of stormwater threats to water quality, is lass that 5%. This is well below the threshold of 12% -25% cited as the level which cause water quality degradation. Very little is understood with regards to the effects of land use change and bacterial loading. This effort reports on approach to measure change to land cover and relate it to bacterial loading rates.

Current parcel data was overlain onto scanned images of aerial photos of the watershed ranging from 1967 to 1994. Classification ranks were assigned to each parcel indicating the degree of land use / cover change for three categories — clearing, ditching, and impervious surface area. These data were organized in a GIS database to facilitate spatial as well as temporal analysis. using correlation and regression techniques, the variables were analyzed against thirty years of bacterial data. Increased ditching in the watershed was positively correlated and statistically significant with increased bacterial loading. Imperviousness and cleared areas were not good indicators of bacterial densities. These results imply that time of concentration of rainfall in the watershed is an important factor in delivery of viable bacterial loads to shellfish resources in the sound.

Reduction of *Salmonella* and Other Fecal Microbes in Swine Waste Lagoons and Alternative Treatment Systems

Vincent R. Hill and Mark D. Sobsey
Department of Environmental Sciences and Engineering, School of Public Health
University of North Carolina at Chapel Hill, CB#7400, Chapel Hill, NC 27599
(919) 966-7316 vrhill@email.unc.edu; Mark_Sobsey@unc.edu

Salmonella and other enteric microbes have been quantified in flushed swine waste and their levels of reduction measured in lagoons at four North Carolina hog farms, an aerated biological filtration system (Ekokan), a bioreactor system utilizing aeration and solids settling (Bion), a field-scale constructed wetland system, and laboratory experimental wetland reactors. *Salmonella* were measured in flushed swine waste at farm-specific geometric mean concentrations ranging from 3 to 280 000 MPN/100 mL. In single-stage lagoon systems, *Salmonella* were reduced by approximately 89%, to geometric mean concentrations of 60 to 160 MPN/100 mL. In lagoon systems having two cells, a further reduction of approximately 97% was measured in the second cells. Associated geometric mean *Salmonella* concentrations were 2 to 3 MPN/100 mL. Candidate enteric bacterial indicators (fecal coliforms, *Eschericia coli* and enterococci) were reduced to a greater extent than *Salmonella* in primary lagoons (97, 97 and 98%, respectively) and similar to or less than *Salmonella* in secondary lagoons (96, 96 and 91%, respectively). Geometric mean fecal coliform concentrations ranged from 140 000 to 710 000 CFU/100 mL in primary lagoons and 6700 to 11 000 CFU/100 mL in secondary lagoons. *Salmonella* and microbial indicator concentrations in swine waste lagoon systems appear to vary seasonally, with the highest concentrations generally occurring during colder, winter months. In the Ekokan system, *Salmonella* were reduced by 95%, and fecal coliforms, *E. coli* and enterococci by 98, 98, and 97%, respectively. The Ekokan system was more effective at reducing enteric microbe concentrations during warmer months than colder months. In the Bion system, *Salmonella*, fecal coliforms, *E. coli* and enterococci were all reduced by approximately 99%, with the reduction efficiencies varying slightly with temperature. In a field-scale constructed wetlands system treating primary lagoon liquid, *Salmonella* were reduced by 92% at a total nitrogen loading rate of 25 kg/ha/d. Corresponding fecal coliform, *E. coli* and enterococci reductions were 96, 97 and 79%, respectively. In laboratory experiments using primary lagoon liquid spiked with *S. typhimurium*, *S. typhimurium* was reduced by 73, 99.4 and 98% in a surface flow wetland reactor, a subsurface flow wetland reactor, and an unplanted subsurface flow reactor, respectively, at 30°C and a TKN loading rate of 25 kg/ha/d. Reactor treatment efficiencies were lower at a higher TKN loading rate of 40 kg/ha/d. Overall, *Salmonella* are ubiquitous in swine waste and are reduced but not eliminated by current and candidate biological treatment systems.

Investigation of the across and along-channel circulation in the Neuse River Estuary

Richard A Luettich, Jr., Janelle V. Reynolds-Fleming
University of North Carolina - Chapel Hill Institute of Marine Sciences
Morehead City, NC 28557
janelle@email.unc.edu

We have been participating in the cross-institutional modeling and monitoring program of the Neuse River Estuary, called MODMON. In order to quantify the role that physical circulation plays in the occurrence of hypoxia and water quality, a section of the estuary has been targeted for concentrated study. Both a moored and a survey experiment were conducted in the summer of 1999. The moored experiment consists of two acoustic Doppler current profilers (ADCPs) and two vertical profiling stands. These stands are located on opposite sides of the estuary. The ADCPs provide detailed current information throughout the water column at a specific location. The vertical profiling stands record conductivity, temperature, depth and dissolved oxygen throughout the water column in 15-minute intervals. The survey experiment consists of following a cross section of the estuary with a boom-mounted ADCP. Detailed current velocity information of the entire water column was collected along a cross section every 2-3 hours for a 24-hour period. In addition, hydrographic information, such as conductivity, temperature and D.O., was collected at five stations along this transect. Preliminary evidence suggests the advection of high salinity, low D.O. water into shallower regions can occur within minutes and may last for a few hours.

Zoospore Production by Two Toxic *Pfiesteria* Species and the Benign "Lookalike" Species, *Cryptoperidiniopsis*, Given Algal Prey

Matthew Parrow, Howard Glasgow, JoAnn Burkholder & Cheng Zhang
North Carolina State University, Raleigh, NC
mwparrow@unity.ncsu.edu

Zoospore production was experimentally examined during grazing on three species of algal prey (*Rhodomonas, Prorocentrum minimum*, or *Synechococcus* in single-species trials) by Neuse Estuary clonal isolates of *Pfiesteria piscicida*, the second known toxic *Pfiesteria* species ('B'), and the benign taxon *Cryptoperidiniopsis* nov. gen. (lacks bioactive compounds that cause fish stress, disease or death based on fish bioassays of multiple strains and species from the Chesapeake Bay, the Albemarle-Pamlico system, and three Florida estuaries). Prior to the experiments, strains of *P. piscicida* from the same clone had been maintained for 4 months in fish-killing mode (TOX - toxic; fish death at 12- to 24-hour intervals with 5,000 cells/mL), temporarily nontoxic mode (NONTOX, on cryptomonad prey). An older clone of kleptochloroplastidic, 'never-toxic' strain (NEVTOX, grown on cryptomonad prey) that had lost its ichthyotoxic activity was also compared. TOX (toxic; fish death at 1- to 2-hour intervals with 800 cells/mL) and NONTOX strains of *Pfiesteria* B were compared as well. The *Cryptoperidiniopsis* strain was kleptochloroplastidic, and had been maintained similarly as NONTOX Pfiesteria spp.

Zoospore production by all species and strains was highest with cryptomonads among the algal prey tested. TOX strains attained lower zoospore production on algal prey than NONTOX and NEVTOX strains. Both NONTOX *Pfiesteria* spp. attained significantly higher zoospore production on cryptomonad prey than did *Cryptoperidiniopsis*. The data indicate that zoospore production on algal prey differs among *Pfiesteria* species and strains, depending on the history of toxic activity.

For concerned citizens and policy makers, concerns about the response of *Pfiesteria* to nutrient pollution focus on the response of strains that have the ability to stress and kill fish. Unfortunately, many laboratories recently have focused research on benign ('never-toxic') strains of *Pfiesteria* because they are easily cultured without need of biohazard III facilities. However, when not allowed access to live fish and given only algal prey, most *Pfiesteria* clones lose their ability to produce toxin after several weeks in culture. This phenomenon probably does not occur in nature. It is believed to be an artifact of the highly artificial conditions encountered in a laboratory culture setting, where various organic substances that *Pfiesteria* likely requires are lacking.

The present research and other supporting data from our laboratory demonstrate that in experiments to understand the nutritional ecology of potentially toxic *Pfiesteria* species (for example, their response to algal prey; or their stimulation by nutrient enrichment directly, versus indirectly when mediated through algal prey abundance), it is important to avoid use of strains for which toxicity cannot be induced (that is, the so-called 'never-toxic' strains that show no ability to stress or kill fish). This study also demonstrates that benign lookalike species such as *Cryptoperidiniopsis*, like benign or 'never-toxic' strains of *Pfiesteria*, should not be considered as ecologically comparable to toxic and potentially toxic *Pfiesteria* species. That is, they may 'look like' toxic *Pfiesteria*, but they are not like toxic *Pfiesteria* – they lack toxicity and they differ, as well, in other important ecological traits.

Interactions between Two Commercially Important Shellfish Species and *Pfiesteria Piscicida*

Jeffrey Springer[1], JoAnn Burkholder[1], and Sandra Shumway[2]
1 North Carolina State University, Raleigh, NC, and
2 Southampton College, Southampton, NY
jjspring@unity.ncsu.edu

The toxic estuarine dinoflagellate, *Pfiesteria piscicida*, is a causative agent of major fish kills in the Albemarle-Pamlico Estuarine System and Chesapeake Bay. Here, we compared the response of larval pediveliger and adult life history stages of the bay scallop (*Argopecten irradians*) and the eastern oyster (*Crassostrea virginica*) to *Pfiesteria* zoospores. Rather than being eaten by pediveligers, the *Pfiesteria* zoospores attacked them. Within 5 minutes of zoospore introduction into cultures with larval pediveligers, the zoospores congregated around individual larvae and attached via their peduncles. Within 15 minutes, the zoospores had penetrated into the visceral cavity of the shellfish larvae and had begun to feed aggressively upon exposed tissue. After 30 minutes, all shellfish tissues except the adductor muscle had been consumed, leaving a hollow cavity in which the zoospores encysted. Pediveligers that had discarded their velums were preyed upon by the zoospores, whereas larvae with active, extended velums appeared to discourage *Pfiesteria* attack and feeding behavior. In contrast to these observations with larvae, adult shellfish were observed to actively filter Pfiesteria zoospores out of suspension and consume them. However, examination of the faeces produced by the shellfish indicated that the zoospores had formed temporary cysts and passed through the digestive tract with no apparent adverse affects on cell viability. Within three hours, 90% of the cysts excysted and regained motility. The data indicate that *Pfiesteria* zoospores have the potential to adversely affect shellfish larval recruitment and survival. This study also documented that *P. piscicida* survives passage through the gut tract of these shellfish.

The Toxic Pfiesteria Complex: Confirmation of a Second Toxic *Pfiesteria* Species

Howard Glasgow[1], JoAnn Burkholder[1], Steve Morton[2] & Jeffrey Springer[1]
1 North Carolina State University, Raleigh, NC
2 Center for Coastal Environmental Health and Biomolecular Research
National Ocean Service - Charleston, Charleston, SC

We describe a second ichthyotoxic species within the genus *Pfiesteria* from the Albemarle-Pamlico and Chesapeake Estuaries of the eastern U.S., ranging south at least to the Gulf Coast. At this symposium we will also present its soon-to-be-formal species name, in honor of a scientist who has contributed greatly to toxic dinoflagellate research.

The 2nd known toxic *Pfiesteria* species has a complex life cycle with an array of flagellated, amoeboid, and cyst stages. Its life cycle and behavior are, thus far, identical to those of *Pfiesteria piscicida*, except that it responds more strongly to N enrichment and less strongly to P enrichment than *P. piscicida*. This species is a heterotroph that can become mixotrophic with kleptochloro-plasts. Like Pfiesteria and other toxic dinoflagellate species, it includes toxic as well as nontoxic (that is, capable of producing toxin but in a temporarily nontoxic mode) and 'never-toxic' strains (that is, strains that cannot be induced to produce toxin with fish or other stimuli that have been tested).

Zoospores (7-12 μm in diameter, with permanently condensed chromosomes) contain thin deposits of cellulose (plates) within layers of outer cell membranes. The plate number, shape and arrangement, or the plate formula, must be discerned for speciation (from suture-swollen cells using scanning electron microscopy). In the 2nd toxic *Pfiesteria* species, these plates are arranged in a Kofoidian series as Po, cp, X, 4', la, 6'', 6c, 4s, 5''', 2''''. The 2nd species differs morphologically from *P. piscicida* in having two additional plates in its upper cell covering or epitheca. In addition, its 1 anterior intercalary plate is large and diamond-shaped, whereas that of *P. piscicida* is small and triangular. Zoospores of the 2nd toxic *Pfiesteria* species produce chrysophyte-like cysts with organic scales and bracts. They can also form temporary mucoid cysts. Benthic amoeboid stages (thus far with length ranging from 5-380 μm, without permanently condensed chromosomes) may be filopodial, lobopodial, or rhizopodial, with reticulated cysts. Anisogamous gametes (flagellated but dissimilar in size) fuse to form swimming zygotes (planozygotes) with one transverse and two longitudinal flagella, which can become thick-walled sexual resting cysts or hypnozygotes.

The 2nd toxic *Pfiesteria* species is distinguishable from *P. piscicida* both morphologically (plate structure) and genetically (18S ribosomal DNA sequence). Like *P. piscicida*, it shows strong preference for certain species of algal prey when fish are not available, and its toxicity varies depending on its history of access to live fish. Its distribution thus far overlaps that of *P. piscicida* (which was also first reported in Florida and Gulf Coast waters by Burkholder et al. 1995, and recently confirmed there by Steidinger and colleagues as well). *P. piscicida* and the 2nd species are toxic to fish, based on both fish bioassays and toxin assays. In contrast, all other 'pfiesteria lookalike' species tested to date (including taxa reported by other laboratories such as the unofficially named 'shepherd's crook,' *Gyrodinium galetheanum*, and the unofficially named '*Cryptoperidiniopsis*' from NC, MD, and FL waters) have been confirmed as benign, that is, unable to stress or kill fish (data of our laboratory, cross-confirmed by the laboratory of Dr. H. Marshall, Old Dominion Univ.). Thus, at present the toxic *Pfiesteria* complex consists of these two toxic *Pfiesteria* species.

Effect of Riparian Buffers on Shallow Groundwater Nitrogen in the Neuse River Basin

Michael D. Dukes* and Robert O. Evans
Biological and Agricultural Engineering Department
* Corresponding author: Campus Box 7625, Raleigh, NC 27695-7625
(919) 515-8595 mddukes@eos.ncsu.edu

J. Wendell Gilliam and Sheryl H. Kunickis
Soil Science Department

North Carolina State University

Due to recent regulations in North Carolina, controlled drainage and or riparian buffer Best Management Practices (BMPs) will be used to minimize agricultural nonpoint source nitrogen loss to surface waters. Controlled drainage has successfully reduced field scale nitrogen losses in regions with high water tables drained by shallow ditches or tile drains. Riparian buffers have been shown effective at removing groundwater nitrogen via uptake or denitrification on landscapes having an impermeable layer and drained by shallow streams or ditches. Controlled drainage is less economical on the sloping landscape common to agricultural land in the Middle Coastal Plain of North Carolina due to the excessive number of control structures required to maintain high water table conditions. Groundwater nitrogen removal by riparian buffers has not been evaluated on gently sloping landscapes drained by deeply incised field ditches and channelized streams. A combination of controlled drainage, several buffer vegetation types, and two buffer widths are being evaluated to minimize groundwater nitrate loss to surface waters. Preliminary findings indicate that the type of buffer vegetation, buffer width (25 versus 50 foot width) or streamside landscape features had little effect on removal of shallow groundwater nitrate as it traveled beneath the buffer. The direction of groundwater flow across a particular riparian buffer location seems to have the largest impact on shallow groundwater nitrate removal.

BasinPro: Low Cost Desktop Environmental GIS for NC

Betsy Johnson Pearce
NC Center for Geographic Information & Analysis
301 N. Wilmington St., Suite 700
Raleigh, NC 27601
(919) 733-2090
betsy@cgia.state.nc.us

- **An easy-to-use environmental GIS extension for North Carolina**
- **A visual companion to the *North Carolina Basinwide Water Quality Plans***
- **A watershed planning tool for local government planners and non-profit groups**

***"BasinPro** has proven to be an extremely valuable tool for accessing geographically- based water quality information. I use the program almost every day in my job!"*

—Beth McGee, Water Quality Advisor, Clean Water Management Trust Fund

BasinPro is a custom desktop GIS project that features a comprehensive set of geospatial data related to water quality. The project, created by the Center for Geographic Information and Analysis (CGIA) for the Clean Water Management Trust Fund, is now available to you. *BasinPro* allows non-GIS or infrequent GIS users to easily navigate a multitude of spatial data without needing GIS expertise. This desktop tool is essential for water quality professionals, water resource specialists, grant applicants, educators, and interested citizens.

BasinPro consists of one CD-ROM over 75 data layers (a $2,000 value if ordered separately), an ArcView® (Environmental Systems Research Institute or ESRI) project with 10 pre-set map views, custom ArcView tools built into the project, a user guide, metadata, and up to one hour of technical support from CGIA. The ArcView GIS software must be purchased separately. The cost of *BasinPro* is $285.00 per copy.

The data are in North Carolina state plane coordinates, NAD 1983 meters. System requirements are a PC with Windows 95 or 98 or Windows NT or a UNIX workstation, running ArcView 3.1 software. Approximately 415 MB of storage are needed for housing the data. For information about using water quality data with other GIS software, call CGIA.

Views available in the project include statewide maps of the 17 North Carolina river basins, protected lands, water and sewer system service areas, wetlands, pollutant sources and water quality monitoring information. In addition, through tools and buttons the user can get a detailed view of hydrography with stream name annotation, use-support ratings, and stream classifications.

CGIA developed *BasinPro* using the ESRI's AVENUE® programming language to write scripts that simplify user navigation of the data. The project has a slimmed-down set of tools and buttons to perform the most useful functions and new pull-down menus and on-screen lists to get you where you want to go — fast!

The ready-made views and custom interface enable quick and easy access to geospatial data. This project places an extensive library of data at the fingertips of environmental planners, watershed planners, grant applicants, teachers and ordinary citizens interested in water quality protection, restoration and enhancement.

Design, Cost, and Effectiveness of Level Spreaders for Dispersion and Treatment of Agricultural Runoff in Vegetated Filter Zones

Dennis W. Hazel, dennis_hazel@ncsu.edu
E. Carlyle Franklin, carlyle_franklin@ncsu.edu
Kathleen T. Summitt, ktsummit@unity.ncsu.edu

Woodlot Forestry R & D Program, Department of Forestry, N.C. State University
Box 8006, Raleigh, NC 27695-8006 (919) 515-3566

Recent studies of agricultural watersheds have indicated that vegetated filter zones often do not function optimally because of concentrated surface runoff through the zone. One successfully demonstrated solution has been to use level spreaders to disperse concentrated surface runoff in the receiving portion of the filter zone. Our initial feasibility study demonstrated that level spreaders can substantially improve filter strip performance and reduce non-point source (NPSP) outputs to surface water. However, widespread adoption of level spreaders as a best management practice requires designs that are both functional and cost effective over a variety of conditions including filter zone (FZ) condition and with differing sources of NPSP and under varying rates of loading.

The overall objective of this research was to evaluate different level spreader designs for dispersing concentrated agricultural runoff and to evaluate their effectiveness for enhancing FZ effectiveness on several sites with greatly differing watershed characteristics. Other objectives included estimating construction and maintenance costs for several level spreader designs and developing design criteria for level spreaders for specific watershed and FZ conditions for acceptable reductions in non-point source pollution.

Level spreaders with associated instrumentation were constructed on nine watersheds from 1989 to 1997 representing a wide variety of watershed and FZ conditions. Source areas included crops under both conventional and conservation tillage, pasture, a dry lot for dairy cattle, and a paved and partly roofed cattle containment area. All spreaders tested were designed to essentially be permanent. Designs tested included commercial galvanized gutters, treated wood, fabric-lined ditches with gravel just above and below the ditch, and vegetated soil.

Reductions in NPSP through-puts were more a function of the ratio of filter zone area to watershed area and of peak flow rates of individual storm events than spreader design. All spreader designs improved FZ performance. Level spreaders with larger cross-sectional areas were more effective for high peak-flow events. However, spreaders with limited cross sectional area such as gutters are an option where excavation of ditches or shaping of spreaders with large equipment is a problem such as in mature forests or on inaccessible but potentially effective filter zones. The least-cost design to install is a trenched vegetated spreader shaped from soil and hardened with rocks as needed.. However, its use is practical only where tree roots are minimum and where farm equipment can maneuver during installation. This design also allows limited vehicle traffic over the spreader, once it is stabilized.

Phytoplankton Dynamics as a Barometer of Water Quality Changes in the Water Supply Reservoir and Treatment Plant for the City of Raleigh, North Carolina

L.C. Ehrlich, Spirogyra Diversified Environmental Services
2232 Holland Avenue, Burlington, NC 27217
spirogyra@juno.com

L. McMillan, Public Utilities Department, City of Raleigh, P.O. Box 590, Raleigh, NC 27602.

Monitoring algal productivity and species composition can provide a useful supplement to chemical-specific measurements of water quality in surface freshwater systems. Algal populations respond quickly to changing environmental conditions, and the character of a particular algal assemblage can be a sensitive indicator of an entire matrix of factors: N:P ratios, overall fertility, temperature, toxicants, etc. Further, direct cell counts are an effective means of tracking algal removal efficiencies progressively through water treatment processes. Phytoplankton community structure was monitored over a two year period at four sites on Falls Reservoir east of Highway 50 and in the water plant after critical treatment processes. In the reservoir, composite water samples were collected integrated over the euphotic zone; surface grab samples were collected within the plant. Phytoplankton were identified and enumerated using the Utermöhl inverted microscope technique. Direct cell counts were obtained, from which, biomass estimates were calculated. *In vitro* chlorophyll a and pheophytin were determined for the reservoir samples. Vertical profiles were produced at the four reservoir sites including *in situ* measurements of chlorophyll a, temperature, dissolved oxygen, pH, and specific conductance. The phytoplankton community exhibited seasonal patterns of dominance typical of a eutrophic lake, i.e. diatom/chlorophyte dominance shifted to nuisance Cyanobacterial dominance during periods of high temperature, low flow and epilimnetic nutrient depletion. The predominance of the N-fixing taxon *Cylindrospermopsis* indicated conditions of low nitrogen:phosphorus ratio during the summer when nutrients were not measured above detection limits. In fall, cooling water temperatures and a slight increase in ammonia and silica stimulated a resurgence of the green algae, diatoms, euglenoids, cryptomonads, and dinoflagellates. Spatially, changes in community structure appeared to originate upstream and proceed toward the dam in a plug-flow fashion. The site at Bayleaf Mile Mkr. #6 appears to be a pivotal point where water quality changes begin to be reflected in the biological community. Biomass at several sites exceeded 10 mg/L in August, though peak chlorophyll values occurred in November. Chlorophyll a appeared to be related to total phosphorus and TKN. Within the plant, potassium permanganate was an effective treatment against Cyanobacteria, but not against green algae (Chlorophyta) and diatoms (Bacillariophyta). Most algal cells, including the Bacillariophyta, were removed in the settling basin.

Linda C. Ehrlich
Spirogyra Diversified Environmental Services
2232 Holland Avenue
Burlington, NC 27217
Tel: 336-570-2520
Fax: 336-570-2520
E-mail: spirogyra@juno.com

The Hydrology of a Lower Coastal Plain Watershed during the Hurricanes and Related Storms of 1999

George M. Chescheir, Jennifer L. Duvall, Devendra M. Amatya, Glenn Fernandez, R. Wayne Skaggs
North Carolina State University, Dept of Bio & Ag Engineering
P. O. Box 7625, N. C. State University
Raleigh, NC 27695-7625
Phone: (919) 515-6741 Fax: (919) 515-7760 Email: cheschei@eos.ncsu.edu

The hurricanes and related storms during September of 1999 brought rainfall amounts in excess of 20 inches to many parts of the North Carolina coastal plain. These extreme hydrologic events brought unprecedented flooding to the eastern part of the state. This presentation will document and analyze the hydrology of a 24,700 acre lower coastal plain watershed during the summer and fall of 1999. The watershed is located in Washington County near Plymouth, NC, and has been heavily instrumented with over 40 gauging stations since 1996. Maximum stages and peak flow rates measured in September 1999 on the watershed were the highest recorded during our monitoring study which has included the active 1996 hurricane season and the 1998 El Nino winter. Since the summer of 1999 was drier than average, the hydrologic conditions changed over a three week period from some of the drier we have observed to the wettest we have observed. Profound changes of this scale are of particular interest since they provide some of the most challenging scenarios for hydrology models to simulate with accuracy. We are testing our hydrology models (DRAINWAT and DRAINMOD/DUFLOW) with field measured data to determine how well the models can simulate the response of the watershed to the 1999 storms. Hydrology models that can accurately simulate these conditions will be very useful for determining the impacts of land use and management practices on watershed hydrology during extreme events

Delineating Hydrologic Boundaries in Open-Water Estuarine Areas

Randolph L. Ferguson[1], H. E. Mew, Jr.[2], Charles W. Hoffman[3], and Kathleen M. Farrell[4]

1 NOAA, Center for Coastal Fisheries and Habitat Research, 101 Pivers Island Road, Beaufort, NC 28516; Randy.Ferguson@noaa.gov
2 DENR, DWQ-Groundwater Section, 2728 Capital Blvd., Raleigh, NC 27604; Ted.Mew@ncmail.net
3 DENR, N.C. Geological Survey, Coastal Plains Office, 4100A Reedy Creek Road, Raleigh, NC 27607; Bill.Hoffman@ncmail.net
4 DENR, N.C. Geological Survey, 1612 Mail Service Center, Raleigh, N.C., 27699; Kathleen.Farrell@ncmail.net

Increasingly, water resource decisions involving stream restoration, regulatory controls, research initiatives, and fund allocation, are targeting officially delineated hydrologic units (HUs). These units are also becoming fundamental accounting units and database entities for a variety of resource management programs and research projects. However, in North Carolina's estuaries, previous delineations of over-water HU boundaries lacked a defensible scientific foundation, limiting their utility as a tool for both research and management. Under the auspices of the Natural Resources Conservation Service, USDA (NC Office), a coastal HU team* of resource and GIS specialists is revising over-water HU boundaries in the estuarine areas of North Carolina. Historically, the criteria used to establish land-based hydrologic units included: (1) delineating drainage areas along topographic ridgelines; (2) preserving the stream-network hierarchy; and (3) assuring drainage to a point. In North Carolina's low-relief, estuarine areas, however, the expedient solution had been to simply delineate hydrologic units using the centerline of estuaries, and to divide sounds and barrier islands at inlets. This approach negated the network hierarchy and drainage-to-a-point criteria, and lacked any scientific rationale. The team is proposing a revised methodology that uses geomorphology as a basis for defining HU boundaries. Bathymetric maps allow delineation of submerged geomorphic features, such as shoals, tidal deltas, inlets, and shoreface limits, that control the flow of water. Our research has shown that the location of these features reflects Pre-Holocene (>10,000 years BP) drainage patterns that still control today's coastal topography. These features were extracted from digital NOAA Nautical Charts by heads-up digitizing. Digitized features include coastal-lagoon shoals, which outline drowned river basin boundaries, and flood-tidal deltas at inlets, where estuarine waters drain to the ocean. Topographically delineated (land-based) HU boundaries were extended to a depth of six feet in adjoining estuarine waters—the approximate limit for light penetration sufficient to support submersed aquatic vegetation that might be impacted by waterborne nutrients and waste applied to the adjoining land. Within larger water bodies, deeper estuarine mixing basins were delineated based on shoals. Barrier island HUs were mapped to the toe of the shoreface (approximated by 30-foot contour) in order to include the dynamic, submerged portion of these islands. Adopting these proposed changes will reconcile the bases for land and over-water HU delineations, and will facilitate integration of land, water, and biotic research and management in coastal North Carolina. We believe these improvements are necessary and timely and seek stakeholder support.

* Randy Ferguson, Chairman (NOAA), Bill Hoffman and Kathleen Farrell (NCGS), Silvia Terziotti and Lloyd Edwards (USGS), Chase Barnard and Sheila Balsdon (DENR-CM), Ted Mew and Brannon Ketcham (DENR-DWQ), Elizabeth Noble (DENR-MF), and Sherman Biggerstaff (NRCS HU project coordinator)

Water Quality Monitoring in the Neuse River Estuary, NC: Links with Modeling Efforts

Luettich, R. A., Buzzelli, C. P., Richardson, T. A., Paerl, H. W.
University of North Carolina at Chapel Hill Institute of Marine Sciences
3431 Arendell St., Morehead City, NC 28557
252 726 6841, x1137 rick_luettich@unc.edu

Watershed-derived inputs of inorganic nitrogen (N) and organic carbon have been directly and indirectly linked to algal blooms, bottom water hypoxia and anoxia, and fish mortality in the Neuse River Estuary. In an effort to curb these symptoms of eutrophication, the state of North Carolina mandated a 30% reduction in N loading in 1997 and has provided financial support to monitor physical and biogeochemical dynamics in this system.

As part of the WRRI-funded Neuse River Modeling and Monitoring Program (ModMon), we are studying estuarine circulation, water quality, phytoplankton community structure and function, and sediment-water column linkages. Results of monitoring efforts are being directly coupled to numerical modeling studies that simulate estuarine processes in an attempt to understand observed trends. Our studies of estuarine circulation use an observational system that consists of bottom-mounted current and hydrographic instruments and platform mounted vertical profilers. We continuously monitor conditions near Oriental, NC to establish the downstream boundary condition for the simulation model. The downstream boundary condition sets the transport and volume characteristics that are pivotal in the simulation of water quality. Investigation of the relationships between nutrients, light availability, and algal growth are necessary so that the simulation model can couple biological responses to nutrient inputs and physical transport processes. We have generated a multi-year record of mid-estuary hydrography and biological and chemical attributes that is essential in model calibration and long term data analysis. Since the primary repository for water column material is the sediment environment, we monitor the vertical flux of phytoplankton-derived material and nutrient exchange at the sediment interface. These data are used to derive sinking coefficients, provide sediment boundary conditions, and simulate sediment geochemistry and exchange with water column pools. Reliable prediction of the interactions between watershed practices, biological dynamics, and ecological responses requires the continued development of a comprehensive and integrative data set.

Nitrogen Isotope Tracing of Eutrophication Sources on a Watershed Scale: Differences between the Cape Fear and Neuse River Basins, North Carolina

W.J. Showers[1], Jon Karr[2], Bernie Genna[1]

[1]Dept. of MEAS, N.C. State University, Box 8208, Raleigh, NC 27695-8208, USA
[2]Dept of Geology and Physics, Lock Haven University of Pennsylvania, Lock Haven, PA 17745

Increased nitrogen flux to coastal and estuarine ecosystems through atmospheric and groundwater/surface water transport stimulates exogenous or new production that alters the composition of the primary producer phytoplankton communities, and may be linked to the expansion of harmful algae blooms (HABs) and fish kills. We have examined river discharge data for the past 48 years in the coastal river basins of North Carolina and have found that river discharge is controlled by ENSO activity. Since 1972 "super El Ninos' have the greatest impact on river discharge. The mass flux of nitrate in these watersheds since 1985 is controlled by river discharge. Nutrient fluxes and fish kill periodicity are related to ENSO events.

The stable isotopes of nitrogen can be used to distinguish between different eutrophication sources and sinks utilizing new CF-IRMS combustion and pyrolysis techniques. Animal wastes concentrate the heavier isotope of nitrogen (^{15}N) in liquid wastes (lagoons) and elevated levels of ^{15}N are found in groundwater under animal waste application fields. Nitrogen that is volatilized to the atmosphere from animal waste lagoons concentrates the lighter isotope of nitrogen (^{14}N). Rainfall is enriched in ^{14}N in the areas of concentrated animal populations compared to urban areas such as Raleigh. These sources are isotopically distinct from chemical fertilizers used in row crop agriculture, and from Municipal Sewage Treatment Plant point sources. $\delta^{15}N$ isotopic tracing of nutrient inputs on a basin wide scale indicates that non-point sources are the most important eutrophication source in these watersheds, and that the nature of non-point sources has changed over the past decade. Heavier nitrogen is coming into the central part of the Neuse basin. 10 years ago this was not observed in the Neuse River Basin. The Black River Basin in the Cape Fear shows enriched heavy nitrogen during all discharge states, yet nitrate concentrations are low in the main river and rise only in small tributaries draining intensive animal operation.

A GIS analysis of the Cape Fear, Neuse River Basin and Tar Pam River Basins show that the location of animal waste lagoons in the Neuse have the highest overlap with groundwater recharge/discharge areas. In the Neuse there are only 650 animal waste lagoons, but 30% of these lagoons are located in groundwater discharge areas, as opposed to 5% of the 1350 lagoons in the Cape Fear and 12% of the 200 lagoons located in the Tar Pamlico River Basin. Long term controls of the connection between groundwater nutrient pools and surface waters nutrient flux to coastal estuaries is not well understood. Time domain analysis indicate that inter-annual weather, precipitation, and river discharge in eastern North Carolina is linked to the ENSO state and hurricane impacts during non-ENSO years. During the past 5 years hurricane impacts have dramatically increased. We postulate that in addition to these long term ENSO modulated inter-annual climate variability changes, the location of large scale animal operations in relationship to groundwater geology is the key to understanding spatial and temporal differences in nutrient flux in eastern North Carolina River Basins and estuaries water quality.

Evaluation of an In-Stream Constructed Wetland in the Chowan River Basin

Kristopher Bass* and Robert Evans
NCSU Department of Biological and Agricultural Engineering

*1702 Bickett blvd. Raleigh 27608
(919) 833-5682 klbass@eos.ncsu.edu

The use of constructed wetlands for storm and wastewater management has been the topic of recent environmental research. Although wetlands have exhibited the potential to provide water quality benefits, effectiveness is sensitive to variables such as location and hydrodynamics. Design recommendations for constructed wetlands typically involve surface area, retention times, or other hydrologic requirements. Economic and space limitations frequently make meeting these suggestions impractical.

A free water surface constructed wetland was built to intercept two ditches, which carry waters from approximately 600 acres of agricultural and urban watershed. In addition to the two inlet ditches, one small side ditch, several tile drains, and surface runoff contribute to the wetland. The 2.5-acre wetland surface area is less than half the minimum recommended size.

The project assessed the abilities of this in-stream constructed wetland to control water flows and improve water quality. Monitoring included continuous flow recording and a combination of grab and automatic sampling on interval and storm basis. Water quality samples were analyzed for TKN, NH4, NO3, TP, and OP. The influence of other variables such as temperature and dissolved oxygen on wetland performance was also considered. The data and analysis from this project provides information on the potential for wetlands in an urban setting. Monitoring at the site began in early 1996 and continued through December 1999.

Application of UV Disinfection for Water Treatment

Karl G. Linden, Department of Civil and Environmental Engineering
Duke University, Durham, NC
(919) 660-5196; Fax (919) 660-5219; email: kglinden@duke.edu

In March of 1999, the US Environmental Protection Agency (EPA) established an advisory committee to negotiate regulatory options for the upcoming Disinfection By-product Rule (DBPR) and the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). These rules, (termed the Stage 2 Microbial and Disinfectants/Disinfection By-products (M-DBP) rules), are concerned with controlling risks from microorganisms and the use of disinfectants in drinking water. The advisory committee's role is to examine health risks associated with disinfectants, DBPs, and microorganisms under current regulatory requirements, and to evaluate whether more stringent requirements are warranted. Because of the emergence of UV as a viable control technology for the inactivation of *Cryptosporidium parvum*, UV applications are being seriously considered as compliance technologies under these rules. The Stage 2 M-DBP rules are both scheduled for proposal in February 2001, and for promulgation in May 2002. Recent research has illustrated that UV is an effective technology for inactivation of *Cryptosporidium parvum* and *Giardia lamblia* – two of the most chlorine resistant pathogens. Use of UV as a technology under the Stage 2 M-DBP rules holds potential for improving disinfection performance and eliminating many concerns around disinfection by-product formation. However, how UV might fit in to the existing water treatment plant processes is not very clear. There are a number of important questions that need to be addressed. What types of upstream processes would best benefit a UV disinfection system? What, if any, would be the role of chemical disinfection under a UV disinfection scenario? What types of data would need to be collected for a utility to begin considering the use of UV? How will UV systems be regulated? What types of monitoring requirements would there be? These questions will be addressed, along with recent research results, to provide a clearer picture of the potential for UV as a viable disinfection technology for water treatment.

Effects of Timber Harvesting on Water Quality of the Goshen Swamp

Scott H. Ensign* and Michael A. Mallin
Center for Marine Science Research
University of North Carolina at Wilmington, Wilmington, NC 28403
*Corresponding author (ensigns@uncwil.edu) phone (910) 256-3721 ext 249

Coastal North Carolina contains numerous blackwater creeks and rivers with extensive riparian swamp forests. The effects of timber removal in these lowland riparian habitats have not been well studied. The Goshen Swamp, a 4th order blackwater creek located in the Northeast Cape Fear River watershed in southeastern North Carolina, was clearcut of 130 acres of riparian and seasonally flooded forest in late May through September 1998. This clearcut is located immediately upstream of a long-term water quality monitoring station monitored by the Lower Cape Fear River Program. Fourteen physical, chemical and biologic parameters have been monitored monthly at this site since February 1996. Historical data from this station were compared with data gathered during and after clearcutting occurred. Statistical comparisons of water quality between one year of pre-clearcut and one year of post-clearcut data showed significant increases in specific conductance and ammonium-N, accompanied by statistically significant decreases in pH and nitrate-N. Short-term impacts (<6 months) consisted of increases in total suspended solids, turbidity, total nitrogen and total phosphorus. Long-term impacts (>1 year) consisted of recurring phytoplankton blooms and periodic fecal coliform pollution events. Phytoplankton blooms, unique to the Goshen Swamp after the clearcut, were followed by periods of water-column hypoxia. Though a 30 foot-wide riparian buffer zone was employed by timber harvesters to protect water quality, the data indicate that it was inadequate to maintain downstream water quality in the Goshen Swamp.

The Neuse River Estuary Modeling and Monitoring (ModMon) Program

Buzzelli, C. P., Luettich, R. A., Richardson, T. L., Powers, S., Alperin, M.
University of North Carolina at Chapel Hill Institute of Marine Sciences
3431 Arendell St., Morehead City, NC 28557
252 726 6841, x161 Email: buzzelli@email.unc.edu

The Neuse River Estuary (NRE) in North Carolina exhibits symptoms of eutrophication including widespread anoxia, algal blooms, and fish kills. The NRE Modeling and Monitoring (ModMon) Program is tracking circulation & hydrodynamics, nutrients & phytoplankton, sediment-water interactions, and benthic fauna over the course of the N reduction. The monitoring component assesses ecological trends, identifies possible mechanisms in the estuary, and provides data for model development and testing. Our in situ observational system is used to characterize longitudinal and lateral transport and to quantify across-estuary sloshing, upwelling processes, and the specific physical conditions that precede significant fish kills in the NRE. We are building a long term mid-estuary database of critical water quality variables in the NRE. The database is a valuable tool to calibrate models, to detect biogeochemical patterns, and to compare estuarine characteristics during normal vs. high discharge periods. Because the models are used to examine the effects of nitrogen input on biological responses (e.g. algal blooms) in the estuary, we determine rates of phytoplankton productivity and nutrient uptake at bi-weekly intervals. These experiments are used to examine the interactions between submarine light and nitrogen availability and to establish model biological transfer coefficients. We are using state-of-the-art particulate collectors to measure the composition, rates, and mass of material flux from the water column to the sediment. Coupled with the in situ analysis of particulate settling, we incubate sediment-water cores to assess rates of dissolved oxygen and nitrogen exchange under different material input scenarios. Included are sophisticated methods to determine rates of denitrification, which is a potentially substantial loss pathway for nitrogen introduced to the estuary. Finally, benthic fauna and the fishes that prey upon them are highly influenced by the frequency, extent, and duration of bottom water hypoxia. We are monitoring the composition and biomass of benthic habitats at different stages during the recovery from hypoxia and conducting manipulative experiments to better understand the potential effects on higher trophic levels.

For more information on monitoring activities in the NRE visit http://marine.unc.edu/neuse/modmon

Biological Monitoring in Greensboro, NC: A different look at urban water quality?

Kim Yandora and Peter Schneider
City of Greensboro - Storm Water Services
401 Patton Ave., Greensboro, NC 27406
(336) 373-2741 & (336) 373-2737
kim.yandora@ci.greensboro.nc.us
peter.schneider@ci.greensboro.nc.us

To truly assess the health of urban water resources, the chemical, biological and physical processes that affect urban watersheds must be examined. Chemical monitoring has traditionally been almost exclusively used for determining the water quality of a water body. Biologists have traditionally argued that the life that exists within that water body must be assessed to truly determine its health or impairment.

The City of Greensboro Storm Water Services has recently conducted a study of both the macroinvertebrate and fish communities that exist within its jurisdictional and watershed boundaries. This effort was designed to compliment and support existing chemical monitoring efforts in area lakes and streams under both ambient and storm impacted conditions.

The fish community monitoring effort was conducted using standard NC DWQ sampling and collection protocol/methodology for the production of the NC IBI (Index of Biotic Integrity). Sampling, collection, and identification was conducted by Storm Water Services staff with assistance from Dr. Menhineke, a fisheries biologist from UNC-Charlotte.

The macroinvertebrate monitoring effort was conducted using standard NC DWQ sampling and collection protocol/methodology as well. Results from the study will be used to produce the standard and EPT classifications of the NCBI (Biotic Index). Storm Water Services staff conducted the sampling and collection, and the identification was completed by Pennington and Associates, Inc. out of Cookeville, Tn.

This poster presentation illustrates the results from both the macroinvertebrate and fish community sampling effort in Greensboro, NC. For more information about chemical or physical monitoring efforts in Greensboro, NC, please contact Storm Water Services at (336) 373-2812.

Spatial patterns in sediment oxygen and nutrient (NH_4, NO_3 and PO_4) dynamics in the Neuse River Estuary, including MIMS denitrification experiments

John Fear, Suzanne Thompson, Hans Paerl

UNC-Chapel Hill Institute of Marine Sciences, 3431 Arendell St., Morehead City, NC 28557
(252)-726-6841 ext.135, Email: jfear@email.unc.edu

The Neuse River Estuary, a key tributary of the Albemarle-Pamlico Estuarine System, drains a watershed of ~16,000 km^2 and is the recipient of nutrient loading from agricultural runoff, municipal wastewater and industrial discharge. Primary production in this estuary is strongly controlled by nitrogen (N) supply rates. Nitrogen (N)-driven eutrophication has been identified as the most significant cause of water quality impairment in this estuary. Accelerated eutrophication has fueled episodic reductions in water column oxygen (DO) levels. One of the main drivers in DO depression is sediment oxygen demand (SOD). This study examined Neuse estuary sediment oxygen and nutrient (NH_4, NO_3, PO_4) flux dynamics at three sites (M-9, M-17 and M-38) in the oligo-mesohaline portion of the estuary. Neuse estuary SOD ranged between 0.31 and 2.03 g O_2/m^2*day, with an average around 1 g O_2/m^2*day. Nutrient fluxes were also extremely variable. Significant (ANOVA $\mu = .05$) spatial differences in SOD and nutrient fluxes were observed between each of the three stations. Furthermore, NH_4 and PO_4 release was correlated with SOD. Sediments from station M-17 contained the highest sedimentary carbon and nitrogen levels, and had the highest SOD and nutrient release rates.

Recently a membrane inlet mass spectrophotometer (MIMS) has been used to monitor oxygen flux rates. A beneficial characteristic of the MIMS system is the ability to simultaneously monitor both oxygen and nitrogen concentrations in a single sample. This allows denitrification rates to be obtained concurrently with SOD rates during the same experiment. Results from preliminary experiments show that the SOD rates from the MIMS match up very well with previous rates measured using micro-Winkler titrations. Denitrification rates ranged between 1813 mmoles N/m^2*day and 4178.8 mmoles N/m^2*day. Results are linked to ecosystem level nitrogen and oxygen cycle discussions.

Residues of Selected Pesticides in Surface Waters Collected in 1999 from North Carolina Rural and Urban Watersheds

S.J. Jones[a], R. B. Leidy[a] and R. E. Holman[b]
a Department of Toxicology
b Water Resources Research Institute
North Carolina State University Raleigh, NC 27695-8604

Surface water samples were collected monthly or following significant storm events (>2.5 cm of rainfall) over a 12-month period and analyzed for the following pesticides: atrazine, chlorothalonil, chlorpyrifos, 2,4-D and simazine. Samples were screened by immunoassay, and any residue level greater than 1.0 ppb was extracted by SPE and quantitated by GC/MS. Residues of atrazine and 2,4-D were found in both types of watersheds at levels up to 7 and 15 ppb, respectively. Small quantities of chlorothalonil, chlorpyrifos and simazine were found urban watersheds indicating runoff from lawn care, either from commercial or resident use. The data generally indicate that applications are made according to label directions.

Chemical Fate of Polar/Ionogenic Herbicides in North Carolina Piedmont Soils

Dharni Vasudevan and Ellen M. Cooper
Nicholas School of the Environment, Duke University, Box 90328, Durham, NC 27708
Phone: 919-613-8039; Email: dharni@duke.edu

Our ability to evaluate the soil and groundwater contamination by pesticides/herbicides in the Coastal Plain is relatively well advanced. However, our capability to do the same in the North Carolina (NC) Piedmont, especially with respect to polar/ionogenic herbicides, is limited at the present time. Several soils systems of the NC Piedmont are distinct from the sandier Coastal Plain soils in that they are depleted of soil organic matter and are enriched in iron oxides and low activity clays. As a result of the extremely small size of clay and iron oxide particles and the reactivity of the electron deficient surface bound iron atoms, B-horizons of these soils are the seat of important physical-chemical activity. Within these soils, polar/ionogenic herbicide fate is governed, in part, by interactions between polar functional groups on the herbicide and the electron deficient metal atoms on soil mineral surfaces.

This research explores abiotic interfacial processes that contribute to the attenuation of three polar/ionogenic herbicides in two common soils of the NC Piedmont. More specifically, we have examined the potential for sorption and transformation of 2,4-dichlorophenoxyacetic acid (2,4-D), norflurazon, and quinmerac in Appling and Georgeville soils as a function of (1) molecular structure and physical-chemical properties of the herbicide, and (2) mineralogy and physical-chemical properties of the soil/subsoil. Samples of Appling and Georgeville soils were obtained from two sites at the Duke forest Gates 12 and 11, respectively. At each site, samples were taken at 5 depths between 0-200cms 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, CEC/ECEC, saturated paste conductivity, BET surface area, and surface site density were measured. With each soil sample, well-controlled batch laboratory experiments were conducted to evaluate the extent of sorption/desorption and degradation of the test herbicides. Mechanisms of herbicide-soil interactions were explored based on correlations with measured soil properties. We find that the extent of 2,4-D sorption and degradation in Appling soils is distinct from that observed in Georgeville soils. Furthermore, when considered on a surface area normalized basis, these processes seem to be influenced by soil composition and mineralogy, surface site density, and iron content. Our results provide increasing evidence that evaluations of the fate of polar ionogenic contaminants in NC red clay soils should account for soil mineralogy and soil iron content, in addition to traditionally considered soil properties such as organic matter content, acidity, and texture.

Ground-Water Quality in Orange County, North Carolina

William L. Cunningham and Jason M. Fine
U.S. Geological Survey, 3916 Sunset Ridge Road, Raleigh, NC 27607
(919)571-4000 wcunning@usgs.gov, jmfine@usgs.gov

From November 1998 through January 1999, the U.S. Geological Survey (USGS) sampled 51 domestic wells in Orange County, North Carolina, as part of a more comprehensive evaluation of the county's ground-water resources. Wells were selected among wells inspected by county staff during 1996-1998 based on (a) countywide areal distribution, (b) weighted distribution among hydrogeologic units, and (c) permission from the homeowner. Wells were located by using a global positioning system and plotted on a hydrogeologic unit map.

Water samples were collected from wells in the following hydrogeologic units: felsic metavolcanic (45 percent of the county land area, 41 percent of the samples collected), felsic metaigneous (26 percent area, 26 percent samples), intermediate metavolcanic (14 percent area, 17 percent samples), phyllite (7 percent area, 4 percent samples), mafic metaigneous (3 percent area, 4 percent samples), epiclastic metavolcanic (2 percent, 6 percent samples), and intermediate metaigneous (<1 percent area, 2 percent samples).

Samples were screened for benzene, toluene, ethylbenzene, and xylene (BTEX), and atrazine by using an immunoassay technique and analyzed by USGS laboratories for major ions (dissolved and total), nutrients, and radon. Samples from 31 wells also were analyzed for dissolved trace metals. Results were compared to State and Federal standards, and compared among hydrogeologic units. None of the BTEX or atrazine compounds were detected in any of the samples. Nitrogen concentrations up to 7.2 milligrams per liter (mg/L) were observed, with a median concentration of 0.49 mg/L. Exceedances of State or U.S. Environmental Protection Agency (USEPA) drinking water standards were observed for iron (3 exceedances of 51 analyses, detection up to 1,100 µg/L), lead (8 of 31, up to 3.5 µg/L), manganese (12 of 51, up to 890 µg/L), and zinc (4 of 31, up to 4,900 µg/L).

Total radon 222 was collected by using a specialized technique to prevent sample degassing. Radon activity ranged from 38 to 4,462 picocuries per liter (pCi/L) countywide, with a median activity of 405 (pCi/L). Median radon activities were highest in felsic rocks (487 pCi/L), and lowest in mafic rocks (357 pCi/L). USEPA has proposed a radon maximum contaminant level (MCL) of 300 pCi/L, and an alternative MCL (AMCL) of 4,000 pCi/L. Sixty-seven percent of the samples exceeded the USEPA proposed MCL, and one sample exceeded the proposed AMCL. Radon activities in Orange County were lower than those measured during similar work in nearby Guilford County, where the median activity was 735 pCi/L.

Limitations and Potential of a Groundwater Tracer Rhodamine WT

D.J. Sutton and Z.J. Kabala
Department of Civil and Environmental Engineering,
Duke University, Durham, North Carolina

D. Vasudevan and A. Francisco
Nicholas School of the Environment, Duke University, Durham, North Carolina

We conducted chemical characterization, batch, column, and modeling studies to elucidate the sorption and transport of RWT in the subsurface. As a representative porous media we selected the sand used to fill the sand packs around the monitoring wells at the Lizzie Field Site near Greenville, North Carolina. As part of the chemical characterization study, we separated the two isomers of Rhodamine WT (RWT) from a commercially available RWT solution and found that the emission spectra of the two isomers are distinct.

Our batch studies confirm earlier results that the two RWT isomers have different sorption properties. We found that one RWT isomer (isomer 1) has a partitioning coefficient and a time to equilibrium an order of magnitude lower than those of the other isomer (isomer 2). The combination of two isomers with \ \ i) different sorption properties and \ \ ii) distinct emission spectra, introduces errors in measuring the RWT concentrations with fluorometers during porous media tracer studies. The two isomers become chromatographically separated (due to traveling at different velocities) and thus arrive in a different concentration ratio than that of the RWT solution used in injection and fluorometer calibration.

Based on the emission spectra of the two isomers we found that these errors could be as high as 7.8%. We fit six different reactive-solute transport models of varying complexity to our four column experiments. To accurately describe RWT transport in this sand sample at time scales less than one hour we found it essential to account for nonequilibrium sorption. A two-solute, two-site sorption transport model that accounts for nonequilibrium sorption accurately describes the breakthrough curves from the two column experiments conducted on shorter time scales, and the resulting parameter estimates agree with the sorption parameters measured by the batch experiments. However, we were unable to accurately model the transport of the RWT injection solution for the column experiments conducted on longer time scales with either the same model or a similar one that accounted for a nonlinear Freundlich isotherm for one of the solutes. This could be due to experimental errors such as maintaining and measuring a steady flow rate. We also conclude that isomer 1 of RWT can be accurately modeled with a one-solute, two-site, nonequilibrium sorption model. This conclusion and the results from our batch studies suggest that RWT isomer 1 is an effective groundwater tracer, but that the presence of isomer 2 hampers this effectiveness.

Sensitivity Analysis of the Transient Flowmeter Test

H.K. El-Sayegh and Z.J. Kabala
Department of Civil and Environmental Engineering
Duke University, North Carolina, Durham

We consider the transient flowmeter test (TFMT) model that accounts for inter-layer crossflow, wellbore storage, and a thick skin surrounding a fully penetrating well situated in a confined multi-layer aquifer to estimate layered aquifer parameters. Its sensitivity analysis yields a number of practically useful conclusions. The sensitivities of wellbore drawdown and wellface flowrate to aquifer and skin parameters and the corresponding plausible errors are correlated with the wellbore storage effects. Minimum plausible errors in aquifer and skin layer parameters generally occur towards the end of the wellbore storage phase or after that. It is impossible to obtain accurate estimates of the skin specific storativity for confined aquifers using the transient flowmeter test. This is because the minimum plausible errors in that parameter are several orders of magnitude larger than the corresponding plausible errors in the other parameters. However, accurate estimates can be obtained for aquifer conductivity, and order-of-magnitude estimates can be obtained for aquifer specific storativity and skin conductivity. Although the plausible errors in the vertical hydraulic conductivities from wellbore drawdown data are usually small, they may be up to four orders of magnitude larger when using the flowrate data. This suggests that obtaining estimates of the layer hydraulic conductivities in a flowmeter test is hindered by the limited information content in the flowrate signal. The development and use of more accurate flowmeters should improve the flowrate measurement and the information content about the formation parameters.

The Neuse Estuary Eutrophication Model (NEEM): Circulation and Transport Model Calibration

Jeff Hieronymus[1,2] and Jim Bowen[1]

The Neuse Estuary Eutrophication Model (NEEM) is an application of the coupled hydrodynamic/water quality model CE-QUAL-W2. The NEEM is being developed to predict the water quality impact of reduced nutrient loading to the estuary. Here we report on the calibration of the model's hydrodynamic and conservative transport simulation routines.

The NEEM was calibrated to weekly and continuous monitoring data collected from June 1997 through December 1998 as part of the Neuse River Estuary Modeling and Monitoring Project (MODMON). Mid-river vertical profiles of salinity and water temperature were collected weekly from as many as seventeen stations in the Neuse Estuary. The calibration data set also included continuous measurements of water elevation, salinity, and water velocity collected at four stations in the estuary. During calibration, these data were quantitatively compared to model predictions using various sets of model parameters. Comparisons of observed and predicted salinity distributions were used to assess the model's ability to simulate conservative transport within the estuary. Of particular interest was the model's ability to simulate the observed stratification and circulation dynamics in the Cherry Point area during periods of shifting wind direction. Model predictions of water elevation were generally within 10 cm of the observed data. Over the entire data set, the model predictions accounted for 88% of the variance in observed salinity. Mean absolute errors in predicted salinity were approximately 20%. Compared to observed data, the model predictions of salinity appeared somewhat less stratified in the upper estuary. Time histories of model predictions and observed data during July 1998 both show increased stratification and enhanced estuarine circulation during periods of southwesterly winds, although the model's predictions of salinity are somewhat less dynamic than the observed data.

[1] Department of Civil Engineering, UNC Charlotte, Charlotte NC 28223
[2] Corresponding Author - Phone: 704-547-4345, Email: jwhieron@uncc.edu

Predictions of Water Quality Improvement in the Neuse River Estuary Using a Mechanistic Eutrophication Model

Jim Bowen[1,2] and Jeff Hieronymus[1]

Eutrophication modeling of the estuarine portion of the Neuse River, North Carolina is being conducted to predict the water quality improvements associated with nutrient loading reductions to the estuary. An existing two-dimensional, laterally-averaged, coupled hydrodynamics/water quality model (CE-QUAL-W2) is being applied to predict water quality conditions in the lower 80-km of the estuary. This model application, the Neuse Estuary Eutrophication Model (NEEM), simulates longitudinal and vertical dynamics of water motion, salinity, nutrients, dissolved oxygen, phytoplankton abundance. The model also includes a sediment diagenesis sub-model that simulates sediment/water-column exchanges of nutrients, dissolved oxygen, and organic matter.

Two data sets have been utilized to date for calibration and scenario testing. The NEEM was calibrated to weekly and continuous monitoring data collected from June 1997 through December 1998 as part of the Neuse River Estuary Modeling and Monitoring Project (MODMON). The MODMON data set, although relatively short in duration, is one of the most comprehensive data sets available for calibration of a estuarine eutrophication model. A less extensive data set of 1991 conditions, used for calibration of an earlier version of the model, is now used for model verification. Scenarios that reduce nitrogen, phosphorus, or nitrogen and phosphorus loading to the estuary produce similar model results. In each case the largest reduction in phytoplankton biomass is predicted to occur in the lower estuary where nutrient limitation of phytoplankton growth is expected. Because of non-limiting growth conditions and shorter residence times in the upper oligohaline portion of the estuary, nutrient loading reductions are predicted to result in only minor decreases in phytoplankton biomass. The model also predicts that in the short-term, dissolved oxygen concentrations will increase only very slightly by nutrient reduction, which is indicative of the important role that sediment processes play in determining water column dissolved oxygen concentrations.

[1] Department of Civil Engineering, UNC Charlotte, Charlotte NC 28223
[2] Corresponding Author - Phone: 704-547-3130, Email: jdbowen@uncc.edu

Land Use Impacts of Rapid Urbanization in the Neuse River Basin

Ronald Matheny
U. S. Environmental Protection Agency
Landscape Characterization Branch MD-56
Research Triangle Park, NC 27711
(919) 54122983
matheny.ron@epamail.epa.gov

Urban development in the Neuse River Basin, North Carolina is rapidly increasing, causing immense changes in land cover. As part of the U.S. Environmental Protection Agency's Mid Atlantic Integrated Assessment (MAIA), this study used the Urban Growth Model (UGM) to estimate the regional and broader impact of urbanization in the basin. UGM is based on a cellular automaton (CA) simulation technique developed at the University of California, Santa Barbara to predict urban growth. The model was calibrated using multiple data sources including topography, road networks, and changes in land-use / land-cover (LULC) at four different time periods from 1950, 1970, 1980, and 1990 A.D. LULC data at the 1-kilometer-squared scale were used for calibration and the best parameters were selected from a suite of model runs made using Monte Carlo methods. The control parameters of the model "self modify" during model runs to best match the pattern of urban growth and other LULC changes observed over time. Probabilistic predictions were then made using Monte Carlo techniques based on the parameter estimates obtained from the calibration runs and 1992 A.D. LULC data at the 30-meter-squared resolution until 2050 A.D. If previous trends continue, nearly full-scale urbanization of the region will occur. Ecological implications of such urbanization will be significant. A 75 year animation of urban growth from 1975 through 2050 will be shown.

Thermophilic Anaerobic Digestion for Treating Swine Waste

C.M. (Mike) Williams
Animal & Poultry Waste Management Center
Box 7608 North Carolina State University, Raleigh, NC 27695-7608
phone: 919-515-5386
mike_williams@ncsu.edu

Numerous alternative animal waste treatment technologies are under development and consideration for implementation in North Carolina to address water and air quality concerns. One such technology involves thermophilic anaerobic (TAD) digestion of swine manure. Under proper design and management systems, full-scale TAD systems have been shown to enhance nutrient recovery, reduce ammonia and greenhouse gas emissions, reduce pathogens and odor, and generate fuel from animal wastes substrates. However, these systems often combine substrates (such as food waste, etc.) with the animal manure to be codigested. It has been suggested that this practice reduces the potential of ammonia toxicity to the digester microbial population under high temperature treatment conditions. In this study, the potential for biological methane production from swine manure as the sole substrate, under thermophilic (50°C) conditions, was investigated. A methanogenic culture was systematically enriched from a variety of environments including swine manure, primary treatment swine lagoon sediment and rumen fluid. The culture was successful in producing a biogas yield of approximately 300 l/kg volatile solids (VS) fed. The methane fraction of biogas produced exceeded 60% and biogas yields were consistently stable. Subsequently, the established methanogenic culture was challenged under varying conditions of urea (provided in swine urine) concentrations. Toxicity, as determined by severe decline in biogas production, was observed when the urine concentration exceed approximately 50% in the batch fed manure substrate.

Controls on estuarine sediment oxygen demand: Impact of bottom current and oxygen transport through the diffusive boundary layer

Marc J. Alperin
Department of Marine Sciences
12-7 Venable Hall
University of North Carolina
Chapel Hill, NC 27599-3300
Tel: 919-962-5184
Email: alperin@marine.unc.edu

Oxygen-depleted bottom-water (hypoxia) is a common condition in the mesohaline portion of the Neuse River Estuary during the summer and fall. Persistent hypoxia reduces the habitat area available for demermersal fish and benthic invertebrates, and may be a contributing factor in fish kills. Bottom-water hypoxia occurs when the water column is stratified and oxygen consumption exceeds re-supply from turbulent mixing. In the Neuse Estuary, a significant portion of the oxygen consumption occurs within the sediments. Sediments are rich in organic matter, and estimated oxygen consumption rates exceed those in the overlying water by three orders-of-magnitude. However, the benthic oxygen flux is in part controlled by transport through a stagnant boundary layer immediately above the sediment-water interface. Within this layer, the flow of bottom water is retarded by friction, and molecular diffusion becomes the dominant transport process. The thickness of the diffusive boundary layer (z) is a function of the bottom current ($z\mu U^{-1}$), and ranges from ~3-mm at 1 cm/s to ~0.3-mm at 10 cm/s. Bottom currents in the Neuse Estuary near Minnesott Beach oscillate between upstream and downstream flow with a magnitude of ~10 cm/s. A transport-reaction model applied to the benthic boundary layer suggests that oscillating bottom currents play an important role in regulating sediment oxygen demand: fluxes range from 1.2 g $m^{-2} d^{-1}$ during period of maximum flow to <0.2 g $m^{-2} d^{-1}$ during periods of relatively stagnant water. Furthermore, the oxygen penetration depth in the sediment is sensitive to bottom current velocity. Variations in oxygen penetration may play an important role in regulating coupled nitrification-denitrification: during low flow periods, oxygen is depleted 100-µm below the sediment surface and nitrification may be limited by the rapid diffusion time for ammonium through the thin oxic layer (0.1 second).

Development of a Habitat Evaluation Methodology for Use in Watershed Assessments in Mecklenburg County

Tony Roux [1], Rusty Rozzelle[1], Phil Sacco[2], Paige Baker[2] and Bill Kreutzberger[2]

In the past 10 to 15 years, the Mecklenburg County Department of Environmental Protection (MCDEP) has initiated comprehensive efforts to assess the streams within the County by monitoring biological indicators and water quality data from streams, point sources, and nonpoint sources. However, one component that was not previously addressed by MCDEP's biological and water quality programs was the physical conditions of the streams and riparian zones. In 1997, the Mecklenburg County Commissioners adopted a Creek Use Policy Statement requiring MCDEP to develop a strategy to protect and restore the County's surface waters to supporting swimming, balanced aquatic life and other uses. In developing their Surface Waters Improvement and Management (SWIM) strategy, protection of riparian areas and restoration of stream habitat were determined to be critical factors.

The effort to develop stream habitat and riparian assessment methodology (s) included several steps:

- Literature review of available methodologies
- Screening of methodologies in conjunction with MCDEP and the Division of Water Quality (DWQ)
- Pilot watershed testing of selected approaches
- Selection of methodology and implementation Countywide

A number of protocols were reviewed by MCDEP for consideration for further testing. DWQ staff participated in a workshop. The three protocols selected for evaluation in the field Pilot Study were the Georgia Department of Natural Resources protocol (GDNR, 1997) (which is based on the EPA Rapid Bioassessment Protocols), the DWQ protocol (1997), and the Ohio Environmental Protection Agency's (Ohio EPA's) Qualitative Habitat Evaluation Index (QHEI) protocol (Rankin, 1989).

The study areas for the pilot watershed studies included Gar Creek, a predominantly rural watershed located in the northwest portion of the County and McMullen Creek, a heavily urbanized watershed located in the southern part of the County, primarily within the City of Charlotte. Each of the streams and tributaries were surveyed by several scientists using each of the protocols. The approach allowed comparison of the various protocols as well as potential differences in use of the methodologies between scientists.

Based on assessment results, the three methodologies were evaluated based on eight criteria. While each methodology had strengths and weaknesses, the GDNR protocol was selected as the basis for habitat assessment in Mecklenburg County primarily because the protocol minimized subjectivity and seemed to be most responsive over the wide range of habitat conditions encountered in the two watersheds. The DWQ protocol, while the easiest (and quickest) to use was determined to be subjective (wide differences between scientists) the results were bi-modal (i.e. streams were either good or poor – with little gradation between these ratings). The GDNR protocol was used as the basis for a Mecklenburg Habitat Assessment Protocol (MHAP) with several changes to the definition, conventions and assessment forms to adapt the protocol to the piedmont conditions in the county.

A county-wide implementation strategy is currently being developed to assess all the streams. In addition, a training manual and program for MCDEP filed staff are underway. Testing of MHAP within the Edwards Branch watershed, which is currently being evaluated for a wide range of stream restoration and stormwater management BMPs, showed that the protocol provided habitat ratings which were extremely consistent with recommended stream restoration activities.