IPS No. 16

Setting the Agenda for Water Resources Research

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

Jane S. McKimmon Center
North Carolina State University
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Abstracts and poster session abstracts appear as submitted by the researchers.

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Laura Ehlers, National Research Council's Water Science and Technology Board

9:00 — 9:30 "Availability and use of freshwater in the United States: Concepts for an ongoing national water resource assessment"
Robert Hirsch, Associate Director for Water, U.S. Geological Survey

9:30 — 10:00 "Research needs related to TMDL's," Kenneth H. Reckhow, Director, WRR, and Professor, Nicholas School of the Environment and Earth Sciences, Duke University

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Peter J. Robinson, UNC-Chapel Hill

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Joel J. Ducoste, Veronica Ortiz and Yanjin Liu, NC State University

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Amy Poe, Suzanne Thompson, Michael Piehler and Hans Paerl, UNC-CH Institute of Marine Sciences

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V. Kerry Smith, NC State University

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Suzanne Klimek, N.C. Division of Water Quality, Wetlands Restoration Program

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Jim Blose, N.C. Division of Water Quality, Watershed Assessment and Restoration Project

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Gordon H. Small, Haywood Waterways Association, Inc.

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4:15- 4:30 The Use of the Natural Abundance of ^{15}N to Evaluate the Effect of Anthropogenic N on the Components of a Headwater Urban Stream
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4:30 - 4:45 Can Geochemical Fingerprinting Be Used to Determine the Relative Contributions of Sediment through Time from Different Source Areas?—A Pilot Study in the Southern Appalachians, North Carolina
Jerry R. Miller, Mark L. Lord, Steve P. Yurkovich, Larry G. Kolenbrander and Gail Mackin, Western Carolina University

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Ground Water Stewardship: The Need for Science-based Regulations to Prevent Nitrogen Contamination

Ted Mew[1] and Kirsten Hofmockel[2]

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2.Nicholas School of the Environment, Duke University, Durham, NC 27708

A continuing public-policy challenge is to base regulations governing the disposal of waste on the best available scientific information. In North Carolina regulations controlling waste discharged to air and surface water resources are based on the assimilative capacity of the media, as determined through modeling, with concentrations not to exceed an environmental standard at some predetermined compliance boundary. Compliance with these regulations is determined through monitoring. Determining the assimilative capacity for ground water is a more complex undertaking due to the heterogeneity of the subsurface environment. Models must account not only for these heterogeneities, but also for the transient, episodic pattern of rainfall that drives the movement of pollutants through the ground water system. This problem is particularly acute for the regulation of nutrients being applied across the Coastal Plain landscape from lagoon and sprayfield waste treatment systems.

Historically nutrient application to agricultural fields has been regulated by "agronomic rates," that are based on the capacity of plants to take up or assimilate these nutrients. However, these regulations do not account for the "functional loss" of excess nutrients, which are not assimilated by plants but that leach to ground water and may contaminate surficial aquifers. Experience in the European Union, where excess nitrogen has been a problem for about 30 years longer than in North Carolina, indicates that extensive ground water contamination may result if nutrients are not controlled at the source, before being applied to the land. While North Carolina has developed a commendable riparian buffer program to denitrify nitrogen-laden ground water before it discharges to the stream network, additional pollution prevention criteria are needed to control nutrients at the source before they enter the ground water system.

In protecting air and surface water resources, the State is developing a sustainable strategy to foster sound stewardship and maintain these resources for future generations. The challenge we face today is to develop defensible, science-based criteria that can be incorporated into regulations to control the "functional loss" of nutrients, primarily nitrogen, which is contaminating near surface aquifers in the Coastal Plain. One candidate criterion that merits investigation is the notion of "nitrogen saturation," an environmental indicator signaling when nitrogen levels in the soil and ground water have exceeded the capacity of the plants and microbes to take up or process excess nitrogen inputs. Nitrogen saturation offers a potential science-based indicator upon which to base a sustainable ground water protection strategy. The European Union uses a "critical load" criterion as a limit on nutrient application to prevent nitrogen saturation, and employs vulnerability mapping to identify areas most susceptible to nitrate contamination. Continuing research is needed to determine whether the notions of nitrogen saturation and critical load can provide a science-based foundation for North Carolina's ground water regulations.

Potential Effects of Tile Drains on Offsite Nutrient Transport from Different Agricultural Settings

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The use of artificial drainage in agricultural fields may influence surface-water nutrient loads that drain from the fields to adjacent watersheds. Tile drains and drainage ditches are used to lower the water table and drain saturated soils to allow farming on land that otherwise could not be cultivated. This process redirects nitrate-laden ground water beneath agricultural fields away from the usual ground-water flow paths to field drainage ditches, and this rerouting may increase the offsite transport of surface-water nitrate loads.

The principal goal of this study is to estimate the relative contribution of tile drains and drainage ditches to total annual nitrogen and phosphorus loads transported from artificially drained agricultural land to selected streams in the Neuse River drainage basin. A total of 12 tile drains and 12 surface-water locations in three watersheds (Sandy Run, Middle Swamp, and Bear Creek) were selected for investigation. Study sites include farms that have animal operations and farms that have row-crop agriculture in which inorganic and(or) organic fertilizers are used.

Preliminary water-quality data for the Sandy Run and Middle Swamp watersheds, which include sampling sites at fields fertilized with hog waste (4 tile drains and 3 drainage ditches) and fields fertilized with inorganic fertilizer (6 tile drains and 6 drainage ditches), are summarized as follows. At fields fertilized with hog waste, the average concentration of dissolved nitrite plus nitrate was 34.6 mg/L as nitrogen in tile drains (34 samples) and 7.4 mg/L in ditches (32 samples). Concentrations of dissolved ammonia averaged 0.14 mg/L as nitrogen in tile drains (25 samples) and 0.27 mg/L in ditches (33 samples). Concentrations of total phosphorus averaged 0.03 mg/L in tile drains (6 samples) and 0.16 mg/L in ditches (23 samples). Dissolved phosphorus concentrations in the tile-drain samples were less than the analytical reporting level of 0.02 mg/L. The average concentration of dissolved phosphorus in seven water samples from drainage ditches was 0.09 mg/L.

At fields fertilized with inorganic fertilizer, the average concentration of dissolved nitrite plus nitrate was 7.1 mg/L in water samples from tile drains (48 samples) and 2.6 mg/L in samples from ditches (60 samples). Concentrations of dissolved ammonia averaged 0.05 mg/L in tile drains (15 samples) and 0.07 mg/L in ditches (54 samples). Total and dissolved phosphorus concentrations in the tile-drain samples typically were less than the analytical reporting level of 0.02 mg/L. In ditches, the average concentration was 0.06 mg/L for total phosphorus (43 samples) and 0.06 mg/L for dissolved phosphorus (7 samples).

These preliminary data indicate that nutrient concentrations in samples from tile drains and drainage ditches tend to be higher at fields fertilized with hog waste than at fields fertilized with inorganic fertilizer. At both field types, samples from tile drains tend to have higher dissolved nitrite plus nitrate concentrations and lower dissolved ammonia, total phosphorus, and dissolved phosphorus concentrations than samples from the drainage ditches. Nutrient load transport from the tile drains and drainage ditches for the different study sites will be estimated by combining discharge monitoring data with the nutrient concentration data.

Environmentally Superior Animal Waste Management Technologies for Implementation in North Carolina

C.M. Williams and Leonard S. Bull

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Advances in animal waste treatment technology considered "environmentally superior" (to existing systems) must be evaluated for their ability to address their impact on both water and air quality. A landmark model establishing appropriate criteria for considering a technology or process for swine waste management to be "environmentally superior" is underway as a part of the agreements between the office of the North Carolina Attorney General, Smithfield Foods and Premium Standard Farms. The criteria being applied to the evaluation of 18 separate systems (individual technologies or combinations of technologies) in that program are: a. able to be permitted by appropriate governmental authority; b. technically, operationally, and economically feasible; c. eliminates discharge of animal waste to surface and ground waters through direct discharge, seepage and runoff; d. substantially eliminate atmospheric emissions of ammonia; e. substantially eliminate emission of odor detectable beyond the boundaries of the parcel or tract of land on which the farm is located; f. substantially eliminate the release of disease-transmitting vectors and airborne pathogens; and g. substantially eliminate nutrient and heavy metal contamination of soil and ground water. The technologies under consideration in the program includes (grouped by type and in some cases combined): anaerobic digestion (mesophilic, ambient and thermophilic temperatures) with energy recovery; constructed wetland; biofilter systems; sequencing batch reactor; gasification/combustion of waste solids with energy recovery; nitrification and denitrification systems; covered (permeable and impermeable) treatment basins with microbial cultures and mesophilic digestion; isolation and recovery of fertilizer nutrients (N, P, K, S) and heavy metals by numerous processes including stripping, precipitation, desalinization and dewatering; activated sludge with fertilizer recovery; separated solids processing as compost and other value added forms; belt systems for elimination of flushing; alcohol production from waste; ultrasonic resonation/high temperature treatment of waste; fly larvae conversion of waste to animal feed. A complete overview will be presented and discussed at the conference.

Changes in Nutrient Concentrations In Shallow Ground Water Beneath Agricultural Fields Caused by Hog Wastes Spraying

Timothy B. Spruill [1], Anthony J. Tesoriero[1], and William J. Showers[2]

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The U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) Program began a ground-water flow-path study near Lizzie, North Carolina, in 1995. The Lizzie Research Site is located in Greene County in the Contentnea Creek Basin. Contentnea Creek is a major tributary to the Neuse River. The North Carolina Department of Environment and Natural Resources (NCDENR) installed about 40 wells on the site prior to 1995. Four of these wells were selected by the Albemarle-Pamlico NAWQA Study Unit to investigate changes in shallow ground-water chemistry along a flow path and effects on water quality of pesticide and inorganic fertilizer applications on corn and soybean fields on the site. Two of these wells were sampled during 1999-2001 as part of an ongoing study conducted by the U.S. Environmental Protection Agency (USEPA), USGS, and NCDENR. This paper discusses the effects of switching from inorganic fertilizer to sprayed hog wastes on dissolved nitrate-nitrogen and phosphorus concentrations in shallow ground water beneath the corn and soybean fields.

In the summer of 1995, the nitrate-nitrogen concentration in a ground-water sample from a well upgradient from corn and soybean fields at the Lizzie site was 4.1 milligrams per liter (mg/L). The dissolved phosphorus concentration in this well was < 0.01 mg/L. The nitrate concentration in a ground water sample from a well in the corn and soybean field, where inorganic fertilizer had been applied, was 10 mg/L. Dissolved phosphorus in this well was < 0.01. Following the 1995 sampling, a 5000-head swine operation was established at the site. Like other large swine operations in North Carolina, the liquid swine wastes, stored in lagoons, were sprayed on crops as fertilizer and to maintain adequate storage in the lagoon to prevent uncontrolled environmental release. These two wells were included in a new investigation that began in 1999. Nitrate concentrations in samples from the upgradient well did not change in 1999 and remained approximately 5 mg/L. The $\delta^{15}N$ value of 8.7 per mil in nitrate from this well indicated primary sources to be soil organic nitrogen or inorganic fertilizer, with possibly some nitrogen from septic systems located farther upgradient. By May 2000, however, nitrate concentrations in ground- water samples from beneath the sprayed field, had increased to almost 50 mg/L, nearly 5 times the 1995 nitrate concentration. Chemical characteristics of ground water from the field well, including a $\delta^{15}N$ value of 21.8 per mil, indicate the primary source of nitrate to be hog wastes. However, little or no change in concentrations of dissolved phosphorus occurred in ground-water samples from either the field well or the upgradient well between 1995 and 2001. In samples collected since 1999, dissolved phosphorus concentrations in both wells were less than 0.02 mg/L.

A Re-Evaluation of the Water Balance Methodology used in Design of Wastewater Lagoon/Spray Irrigation Systems

Derek Lewis[1] and Kenneth O. Pohlig[2]

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Spray irrigation of treated municipal, industrial and intensive animal agricultural operation wastewater is a disposal practice in North Carolina that is gaining in popularity especially because of the desire to eliminate point discharges to surface waters. The permits necessary for these non-discharge disposal operations are issued by the Division of Water Quality.

All wastewater treatment systems that incorporate spray irrigation as their primary disposal mechanism require temporary storage for those conditions when irrigation cannot take place (typically wet weather conditions). The proper sizing of the irrigation field, the hydraulic loading rate, and the storage lagoon is accomplished in part by utilizing a standard water balance methodology. The water balance procedure accounts for all the gains and losses of water at the irrigation field: rainfall, evapotranspiration, subsurface vertical drainage, and the applied spray loading that is distributed over the irrigation field. This water balance evaluation, along with the corresponding soils investigation, is part of the permit application for a particular proposed disposal site that is submitted to the Division for review and permitting.

Experience and analysis reveals that the current water balance methodology can lead to inadequately sized storage lagoons and/or excessive spray irrigation hydraulic loading rates, which do not allow for proper additional wastewater treatment in the soil, and can ultimately lead to surface runoff. We demonstrate using sensitivity analysis that the subsurface drainage parameter is a primary source of this error. The standard methodology, as recommended by EPA, for calculating the subsurface drainage parameter is to multiply the vertical saturated hydraulic conductivity (Kvsat) of the most limiting soil horizon by 4 to 10 %. This standard approach ignores many key physical soil and groundwater properties. For sites in the coastal plain, the subsurface drainage term should vary seasonally, with a variable rate calculated using a combined soil moisture and groundwater mounding approach. We are currently developing an overall soils model of the coastal plain which we are combining into a groundwater model to develop a new approach for calculating the appropriate subsurface drainage terms, which should lead to a more accurate water balance methodology.

Tracing Nitrate Movement from Swine-Lagoon-Effluent Spray Fields Toward an Adjacent Stream

Daniel W. Israel[1] and William Showers[2]

USDA-ARS[1] and NC State University[1,2]

Movement of NO_3 from lagoon-effluent spray fields managed under .0200 regulations toward an adjacent first order stream in shallow groundwater is being evaluated. The study is in a 260 hectare watershed in which swine production increased from 3,750 to 43,000 animals per year between 1993 and 1998. Transects of monitoring wells were installed and sampled in two spray fields and in riparian areas between these fields and an adjacent stream. The spray fields received 300 kg of plant available N /ha/yr from effluent for four years. Receiver crops were coastal bermudagrass either cut for hay or grazed.

Nitrate comprised more than 95% of the inorganic N in groundwater under spray fields and riparian areas. Nitrate concentrations averaged 12 mg/L in groundwater sampled monthly for 17 months from all wells in the spray fields. Nitrate concentrations averaged 25 to 30 mg/L at the top of the water table and decreased to an average of 8 mg/L at 1.2 to 2.4 m into the water table. These NO_3 levels measured in the uppermost part of water table were about 2 fold higher than those measured in shallow groundwater under coastal plain fields in row crop production.

For the six transects, NO_3 concentrations in groundwater from riparian wells screened at 1 to 1.8 meters into the water table averaged 12 mg/L. In four of six transects, NO_3 concentrations in groundwater at the edge of the stream decreased 98% compared to that under the spray fields and were less than 0.3 mg/L. In two transects, groundwater NO_3 concentrations at the stream edge were 10 to 15 mg/L. ^{15}N natural abundances of NO_3 from fertilizer and soil sources range from -5 to 8 per mil and that of N in lagoon effluent ranges from 20 to 30 per mil. Thus, measurement of ^{15}N natural abundances can be used to determine which N sources contribute NO_3 to groundwater beneath the riparian zone and to the stream if denitrification in the system is negligible. The correlation between ^{18}O and ^{15}N natural abundances in NO_3 from shallow groundwater wells throughout the spray field-riparian-stream system was not significant. This indicates that denitrification did not contribute to the ^{15}N enrichment of NO_3 as it moved through the shallow groundwater system. $\delta^{15}N$ values $\geq$ 10 per mil showed that N from applied effluent was moving through the riparian zone in shallow groundwater at rates of 4.5 to 12.5 m/yr. $\delta^{15}N$ values for NO_3 in groundwater from stream side wells of two transects were similar to that for NO_3 in groundwater beneath the spray fields (20 to 25 per mil) indicating that most of the NO_3 in these wells was derived from effluent N. $\delta^{15}N$ values for NO_3 in stream samples ranged from 9.6 to 12.8 per mil. These values are just above values expected for NO_3 derived from fertilizer and soil sources and at the lower end of the range observed for NO_3 derived from effluent. Therefore, after four years of application only a small amount of effluent N has accumulated in the stream. Determinations of ^{15}N natural abundances of NO_3 in groundwater beneath the riparian zone and in the stream will continue at six month intervals to evaluate how rapidly the spray field-riparian-stream system is approaching hydrologic equilibrium.

Evaluation of Soil Properties and Processes in Mitigation and Natural Forested Wetlands in the Coastal Plain

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Mitigation involves the creation or restoration of wetland structure and function that were lost during development. As mandated by Section 404 of the CWA, the Army Corps of Engineers (ACoE) requires that the hydrology and vegetation of mitigation wetlands meet hydrologic and vegetative success criteria during a 5 year monitoring period following creation or restoration. Typically, hydrologic success criteria involves saturation to within 30 cm of the soil surface for 12.5% percent of the growing season while vegetative success criteria involves survival of 320 planted species per acre. However, the ACoE monitoring process does not require any monitoring of soil properties or processes. This is a cause for concern for various reasons because: (1) soil forms the foundation of these developing ecosystems, (2) soil properties can be limiting to vegetative growth and survival due to lack of nutrients and compaction, and (3) soil is the medium for biogeochemical processes that transform and retain nutrients. Furthermore, very little research has been attempted to examine how differences in soil properties leads to differences in critical wetland soil processes such as decomposition, phosphorus (P) sorption, and denitrification. Thus, the objectives of this study are to: (1) quantify differences in soil properties (bulk density, texture, moisture, organic matter, pH, and microbial biomass) of mitigation and natural wetlands, (2) examine how differences in soil properties lead to differences in soil process (decomposition, P sorption, denitrification), and (3) compare soil properties and processes of created wetland to those of restored wetlands. Results to date indicate that the soils of mitigation wetlands generally have higher bulk density, sand content, and pH, and lower silt and clay content, moisture, organic matter, and microbial biomass than their natural counterparts. This is turn can lead to lower decomposition rates, P sorption, and denitrification in mitigation wetlands. Additionally, soil properties of restored wetlands, especially those on prior-converted (PC) agricultural land, appear to be more similar to natural wetlands, than those of created wetlands or non-agricultural restored wetlands. Thus, while forested mitigation wetlands may meet the ACoE's hydrologic and vegetative success criteria in the early years of development, soil properties and processes in certain types of mitigation sites may not functionally replace those of the natural wetlands that were lost due to development.

Methodologies to Characterize Sediment Stratigraphy of a Carolina Bay Wetland Prior to Restoration

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Juniper Bay is a 300 ha Carolina Bay in Robeson County, NC, that was ditched and drained for agriculture approximately 40 years ago. The NC Dept. of Transportation will attempt to restore wetland hydrology in the Bay to support pocosin vegetation similar to that found in undrained bays in surrounding counties. This study focuses on ways to characterize the Bay's stratigraphy in order to help predict the likelihood that wetland hydrology can be restored. Twenty-nine cores (7.6-cm diam.) were collected across the bay and in the surrounding area to depths of 6 or 15 m to characterize the stratigraphy, and identify clay layers that would prevent ground water leakage. Sediment layers were correlated among cores using ground penetrating radar surveys. Results to date show that the Bay stratigraphy is complex and consists of alternating layers of sand and clay. The water-restricting "clay layers" had clay contents between 25 to 73%. Soil pH values of oven-dried materials ranged from 2.2 to 6.5. The low pH values developed from oxidation of sulfide minerals that were present. At least two buried soil surfaces were identified. The Bay formed in sediments believed to be members of the Yorktown formation. Radiocarbon (RC) dates indicate that the depression under the Bay may have existed as long as 44,000 years ago. The RC dates also indicate that there have been several times, the last about 3,700 years ago, when there was no standing water in the Bay. After 3,700 years ago, the Bay filled in with sandy and clayey sediments, and organic soils formed on those sediments. Ground penetrating radar surveys have identified the shallowest clay layers across the bay. The clay layers vary in depth and have an irregular surface topography probably as a result of stream channels that are now buried. A series of overlapping clay layers at depths of 0.3 to 6 m. will probably retard drainage of ground water out of the restored bay and allow restoration of wetland hydrology once ditches are filled. The clay layers have low saturated hydraulic conductivity, and the essentially flat landscape has a low hydraulic gradient. Ground penetrating radar was effective in tracing clay layer continuity to depths of 6 m. However, the radar images can only be interpreted if adequate borings are made to provide accurate ground-truth data.

Toward a More Flexible Approach to Wetland Restoration

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Wetland restoration has become stereotyped to some degree because of the simultaneous needs for regulators to establish standards of performance and for project proponents to achieve short-term results of success. With roughly 20 years of collective experience in compensatory mitigation using restoration, the institutional framework has had time to mature and the knowledge base has expanded greatly. We suggest that the practice of restoration is at a critical juncture for significant change. Methods developed over the past 10 years are available for implementation. They take into account the large variation in wetland types and have the capacity to estimate condition. The three areas for implementation are the use of reference, ecosystem condition, and experimentation. Reference provides a powerful way to set standards, communicate restoration goals, and recognize the breadth of natural variability. Ecosystem condition can be assessed using indicators that are sensitive to human-induced alterations. Experimentation provides a way to explore new and varied practices without subjecting whole projects to a single treatment. These initiatives were uncommon in a recent review of a large restoration program in North Carolina. They are consistent with technical recommendations in a National Research Council report released last year.

Methods to Determine Lateral Effects of a Drainage Ditch on Wetland Hydrology

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A method was developed to estimate the lateral effects of a single drainage ditch on wetland hydrology. The method can be used to calculate the distance of influence of a single ditch constructed through a wetland, where the distance of influence is defined as the width of a strip adjacent to the ditch that is drained such that it no longer satisfies wetland hydrologic criteria. Simulation analyses were conducted with DRAINMOD to define the minimum, or threshold, drainage intensity that would result in failure of a wetland site to satisfy the wetland hydrologic criterion. Analyses were conducted for five hydric soils spanning a wide range of profile hydraulic transmissivities for climatological conditions near Wilmington, NC. Results of the analyses showed that the threshold drainage intensities would result in water table drawdown from an initially ponded surface of 25 cm in approximately 6 days. That is, a drainage intensity sufficient to lower the water table from the surface to a depth of 25 cm in about 6 days would result in hydrologic conditions that would just barely fail to satisfy the wetland hydrologic criterion. The time required to lower the water table to 25 cm depends somewhat on drain depth, but it was the same for all five of the soils examined. Water table drawdown can be predicted as a function of distance from a single ditch using methods previously published. Therefore it is possible to estimate the lateral effect of a single drainage ditch by a relatively simple analysis based on previously published solutions to the Boussinesq equation. The method will be described and examples presented to demonstrate their application. Field experiments to test the methods will be briefly discussed.

The North Carolina Department of Transportation Compensatory Mitigation Program

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The North Carolina Department of Transportation provides compensatory wetland and stream mitigation by three methods; (1) an in-house program, (2) payment into the North Carolina Wetlands Restoration Program, and (3), a Full Delivery Program. The in-house program is comprised of mitigation sites planned and constructed on properties acquired by the Department and constitutes the majority of our wetland mitigation acreage. In specified watersheds throughout the state, the Wetlands Restoration Program provides all of the Department's compensatory stream and wetland mitigation at a standard fee schedule. The Full Delivery Program consists of the acquisition of compensatory mitigation that is planned, designed, constructed, and monitored by a private firm on property acquired by that firm under contract to the Department.

A Preliminary Analysis of Stream Restoration Costs in the North Carolina Wetlands Restoration Program

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The North Carolina Wetlands Restoration Program (NCWRP) is an innovative program charged with the restoration of wetlands, streams, and riparian buffers for the protection and improvement of water quality and habitat in each of the seventeen river basins in the state. Payment to the NCWRP is an option for applicants who must provide compensatory mitigation as a condition to receive a Section 404 Permit or 401 Water Quality Certification for impacts to streams, wetlands, and riparian buffers. Currently, applicants pay the NCWRP $125 per linear foot for stream impacts. The Program is responsible for using this money to implement stream restoration projects that are both ecologically functional and cost efficient. The purpose of this study is to determine whether the $125 per linear foot fee is adequate to meet these goals.

The NCWRP analyzed thirteen stream restoration projects (58,864 total linear feet) that are either in final design, under construction, or constructed. The stream restoration projects were divided into urban and rural groupings. The stream restoration costs were divided into categories: site acquisition, design, construction management, site restoration, monitoring, and long-term management. Costs analyses were performed on a per linear foot basis for total costs of the projects as well as in each category.

Five projects were analyzed through the site restoration phase, and eight projects were analyzed through the design and construction management phase. Monitoring and long-term management costs were estimated for the five completed projects. Three of the five completed stream restoration projects are rural and two are urban. The mean cost of these five projects is $118 per linear foot, with a mean for rural and urban projects of $106 and $218 per linear foot, respectively. The average construction cost for the five completed projects is $67 per linear foot. The construction costs for the rural projects average $58 per linear foot and the urban projects average $109 per linear foot. For all thirteen projects, design costs average $25 per linear foot while construction management costs average $11 per linear foot. The design costs for the eight rural projects average $22 per linear foot and construction management costs average $11 per linear foot. In urban areas, average costs for design and construction management are $32 per linear foot and $12 per linear foot, respectively.

The analysis of the current fee schedule of $125 per linear foot shows that the NCWRP can implement projects in rural areas within this budget (the average cost of the completed stream projects is $118 linear foot). However, urban stream projects showed a significantly higher cost as compared to the rural projects ($218 per linear foot as compared to $106 per linear foot, respectively). The NCWRP anticipates the need to restore more urban streams since most of the mitigation payments accepted are from urban areas. Based on the analysis of these costs, the Water Quality Commission of the Environmental Management Commission has authorized the publication of a notice of intent to initiate rule making to increase the fee for stream restoration to $180 per linear foot. Public comments will be accepted through mid-January, 2002.

The Current and Future North Carolina Erosion and Sediment Control Program

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The North Carolina Sedimentation Pollution Control Act of 1973 affects anyone who is involved in construction or other land-disturbing activities. It covers all aspects of such activities with the exception of agriculture and mining. All disturbances over 1 acre are required to submit an erosion and sediment (E&S) control plan which has to be approved prior to initiating construction. Most of the larger cities and some counties as well as the Department of Transportation have their own E&S program and the authority to approve plans is delegated to them, otherwise the plans go to the regional office of the Land Quality Section. The law requires that disturbed areas are stabilized and non-erosive within 15 working days or 90 calendar days, whichever is shorter, for most sites. A sufficient buffer zone is needed around water bodies to allow sediment to settle out of runoff in the first 25% of the buffer. Overall, the law is performance oriented in that plans must show that off-site movement of sediment is prevented. It is the responsibility of the owner and developer to determine the best combination of structural or other management practices to achieve this goal. Combinations of devices such as silt fence, sediment traps and basins, check dams, and others are commonly used. The maintenance of these practices is the responsibility of the owner and developer, as well. Periodic inspections are made to insure that the practices are in place and being maintained. Violations can lead to fines and stop-work orders being issued until the problem is addressed.

Evaluations of Polyacrylamide for Erosion and Sediment Control

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There are many devices and systems designed to reduce the amount of sediment in runoff from construction sites. In most cases, little if any data is available on their "real life" effectiveness. We've been gathering data on a variety of systems, including standard traps, skimmer basins, baffles, level spreaders, check dams, and silt fences. We are able to perform these tests at our Sediment and Erosion Control Research and Education Facility (SECREF) in Raleigh. There we can generate "storm events" including flows up to 6 cubic feet/second and sediment loads as high as desired. We will present our initial findings from these tests, focusing on sediment removal efficiency. While some of these systems can retain over 90% of entrained sediment, the resulting discharge water is usually highly turbid, resulting in substantial impacts on receiving waters. One of the more promising and practical approaches to reducing turbidity is to add polyacrylamide (PAM) to flocculate the suspended particles and improve settling. We tested several PAMs for their effectiveness in reducing turbidity in sediment traps and basins under simulated runoff conditions. The PAMs were commercially available as formulated blocks of approximately 4 kg of anionic PAM. The test system involved water flowing under gravity in a 30 cm pipe at variable rates of 850 – 2500 L/min with soil added approximately 10 m above the discharge into the sediment basins. Both flow and sediment concentrations were designed to simulate a 2.5 cm storm event. The PAM blocks were placed inside the pipe below the point where the soil was added. Turbidities within the basin ranged up to 5,000 nephelometric turbidity units (NTU) during the peak of the events, and dropped to 200-400 NTU toward the end of the discharge period. Adding PAM to the system dropped the turbidity in the discharge at all points of discharge and NTU values were often near 100. Modifying the basins to slow the discharge or reduce turbulence further reduced the discharge turbidity. Increasing the PAM dosage by adding blocks to the system did not improve performance. In field tests of PAM on a 2:1 slope, no reduction in erosion was found. Standard straw and seeding methods reduced erosion to 5-10% of bare ground, and adding PAM may have provided some reductions in erosion. PAMs with different molecular weights and charge densities have shown a wide range of capacities to reduce turbidity under laboratory conditions. No one was the best performer for all 13 soils tested, but several worked well for many of the soils.

Watershed Disturbance and Stream Instability: A Weak Link In North Carolina's Sediment Erosion Control Program

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1st to 3rd order stream channels in the Piedmont represent one of the least understood sources of sediment pollution in North Carolina. While a quasi-stable, "in-regime," stream channel commonly can absorb as much sediment as it generates, an "out-of-regime" channel can generate the watershed equivalent of several tons/acre/year. In this abstract we review five classes of disturbance that can create channel instability: agricultural practices, urban stormwater management practices, in-stream wet detention basins, landuse changes, and stream channelization.

1st to 3rd order stream channels are those most vulnerable to disturbance. In the North Carolina Piedmont these streams have channels running along a cohesive bed of saprolite interspersed with nickpoints of various bedrock lithologies, and smaller restricted zones of alluvial soils. Sinuosity in these systems is typically 1.1 to 1.6, but with natural rates of meander growth from mm to a few cm/yr. A series of recently completed stream assessments show that any process which triggers accelerated meander growth, constricts or redirects flow at any point in the channel, adds or removes sediment at an unnatural rate from the stream system, or decreases bank cohesion, can destabilize the existing planform. This destabilization produces periods of rapid sediment flux in the watershed. A second cause of increased in-stream sediment production is when the channel dimensions are inappropriately too large, or too small. An undersized channel will undergo a period of rapid enlargement; producing events near the bankfull stage with large fluxes of sediment. An oversized channel will in-fill with fine sediment, developing a nested channel system. In the latter case, however, very large flow events can remobilize or flush the channel of the in-filled sediments. Past channelization in agricultural areas commonly resulted in undersized channels, and many urban areas have had programs which dredged and dramatically enlarged channels in order to lower flood elevations. Finally, in-stream ponds or wet detention basins can be 90+% effective in trapping sediment from upstream sources. However, these sediment traps promote downstream degradation, due to the lack of sediment to armor and protect the stream bed. Pond out-fall reaches commonly become degraded and entrenched. These degrading reaches can produce as much new in-stream sediment as is being removed by settling within the upstream pond.

Sediment Transport Analyses in Natural Channel Designs and the Need for Further Research

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Natural channel designs are undertaken with the objective of establishing stable stream reaches that maintain their dimension, pattern, and profile without aggrading or degrading over time. Natural channel designs are based on the bankfull discharge and corresponding floodplain elevation. Bankfull discharge is assumed to be the effective discharge, which by definition is the flow that transports the most sediment over a long period of time. Effective discharge is calculated as the product of the flow duration curve and the sediment transport rating curve. Since few sediment rating curves have been established for streams in the Southeastern U.S., designers often rely on the bankfull stage and corresponding discharge along with critical shear stress calculations to ensure that design channels do not aggrade or degrade.

The purpose of this presentation is to provide an overview of sediment transport analyses commonly used in natural channel designs while describing their strengths and weaknesses. Further, the need for additional sediment transport research will be described with an emphasis on the following topics:

- The assumption that bankfull and effective discharge are equal needs to be examined for streams in the Southeastern U.S. This is especially important due to the incised nature of most alluvial streams.
- Empirical critical shear stress equations need to be "calibrated" for natural systems and the Southeastern U.S.
- Interpretation of the modified Shields Curve needs to better represent natural stream data rather than flume studies.
- The "Rosgen Method" for entrainment calculations and sediment sampling methods need further testing in the Southeastern U.S.
- Empirical equations used in natural channel design should better represent the population of streams being described, e.g. alluvial channels in 0.5 to 20 mi^2 drainage areas.

Relationships among Turbidity, Suspended Sediments, and Other Pollutants in Urban and Rural Watersheds

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Turbidity is a widespread pollution problem in the coastal area of North Carolina. Turbidity itself causes a number of water quality problems, such as increasing light attenuation to levels that reduce aquatic plant photosynthesis, interfering with the nutrition of shellfish and other filter-feeders, impairing the feeding of sight feeding fishes, and altering sediment composition. However, turbidity particles also serve as vectors that transport other pollutants well downstream form their points of origin. These pollutants can include ammonium, phosphorus, heavy metals, and fecal coliform bacteria. The UNC Wilmington Aquatic Ecology Laboratory is conducting several long-term programs that involve sampling of marine, estuarine, and freshwater locations in rural, urban, and suburban locations. This affords us an opportunity to explore the relationship among turbidity and other pollutants at several scales.

Our data indicate that turbidity and suspended sediments are significantly related to various pollutants, depending on the situation. At a Cape Fear River location downstream from Lock and Dam #1, turbidity was strongly correlated with fecal coliform bacterial counts and weakly correlated with BOD, and both turbidity and fecal coliforms were significantly correlated with river flow. In a set of rural agriculturally influenced steams in the Cape Fear River basin, turbidity was strongly correlated with fecal coliform bacterial counts. Both of these pollutant parameters were also significantly correlated with rainfall within the previous 24 hr. However, in watersheds with extensive wetlands coverage these correlations were non-significant.

In a set of three urban streams within the City of Wilmington, turbidity and suspended sediments were both significantly related to rainfall within the previous 48 hrs. Additionally, in all three streams turbidity and suspended sediments were strongly correlated with total phosphorus and orthophosphate. In a set of urbanized tidal creeks in New Hanover County, turbidity was significantly correlated with concentrations of both fecal coliform bacteria and *Escherichia coli* counts. Tidal cycle sampling in these same creeks revealed that turbidity was likewise correlated with fecal coliform bacterial counts and orthophosphate concentrations. Collectively, these data demonstrate that sedimentation and turbidity problems caused by land disturbing activities have the potential to considerably increase the transport and concentrations of other pollutants even in distant downstream areas of a watershed. Control of sedimentation and turbidity can likely best be achieved by maintaining natural wetlands and constructing new wetlands, utilizing vegetated buffer zones along streams and ditches, and building effective wet detention ponds.

Present and Historical Water Quality on the Cape Fear River: Effects of Lock and Dam Structures

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We compared relative trends in historical nutrient loads and present water quality parameters at three lock and dam sites on the Cape Fear River (CFR). Data indicate that there are differences in water quality parameters among the three Lock and Dam structures. Surface water nutrient concentrations were highest at Lock and Dam 2. ^{137}Cs dating of sediment cores from the floodplains at the three lock and dam locations reveal that the sedimentation rates vary from 0.5 cm/yr at Lock and Dam 3 to 1.5 cm/yr and 1.3 cm/yr at Lock and Dam 2 and 3, respectively. These rates correspond well to the total sediment phosphorus concentrations, which indicate that sediment deposition during the recent decades has caused an increase in nutrient loading to the CFR. Furthermore, the concentration of mineral elements such as Fe, Al and Ca, do not show any significant trend with depth and occur at similar concentration at all three sites. This suggests that the differences in phosphorus accumulation are not due to the differences in these important mineral elements and are most likely a function of recent changes in sedimentation rates and nutrient additions due to varying land-use practices. We assessed current land use patterns within the sub-basins of each of our sampling sites and found associations between current water quality trends and land use patterns within these three sub-basins. At least at one site (Lock and Dam 3) there are marked differences in nutrient accumulation rates between pre and post 1964 periods. Additionally, sediments appear to be very important in controlling water quality in the Cape Fear River Basin. Further studies are needed to estimate the relative portioning of nutrients such as nitrogen and phosphorus into sediment-bound and dissolved phases. Understanding the relative sources of sediment load and sediment nutrient interactions will allow for optimum selection of problem sites to better target Best Management Practice efforts.

The Importance of Rainfall as a Source of "New" Nitrogen in the Neuse River Estuary, NC

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Atmospheric deposition of nitrogen (AD-N), as NH_4^+, NO_3^- and organic N contributes a significant portion of the total externally-supplied or "new" N flux to the Neuse River Estuary, NC. Excessive N loading to N-sensitive waters such as the Neuse River Estuary has been linked to symptoms of eutrophication, including changes in microbial and algal community composition and function (harmful algal blooms), hypoxia/anoxia, and fish kills. In a four-year study beginning in July 1996, we quantified the weekly wet deposition of NH_4^+, NO_3^- and dissolved organic N, using concentration and precipitation measurements made at eleven sites on a northwest-southeast transect in the watershed. These data indicate that the mean annual wet AD-N flux was 11 kg ha^{-1} yr^{-1}. Deposition was fairly evenly distributed between nitrate, ammonium and organics (32%, 32% and 36% respectively). In urban and industrial regions, nitrate usually exceeds ammonium in AD-N by at least 2:1. The fact that AD-ammonium equaled AD-nitrate in the Neuse basin reflects the relatively-important role that agricultural emission (volatilization of ammonia from animal waste and fertilizers) play. This has also been observed in regions of western Europe (i.e., Netherlands, Denmark) where intensive animal operations are concentrated. The organic component of the AD-N was larger than previously reported for North Carolina, but fell within the range of reported values elsewhere. Seasonally, the summer (June-August) months contained the highest weekly wet total N deposition; this trend was not driven by precipitation amount. Estimates of watershed N retention and in-stream riverine processing revealed that the AD-N flux contributed an estimated 20% (range of 15-51%) of the total "new" N flux to the estuary, with direct deposition of N to the estuary surface accounting for another 6% of the total "new" N flux. This study has not measured the dry depositional flux, which may up to double the contribution of AD-N to the estuary. AD-N is an important source of "new" N to the Neuse River Estuary as well as other estuarine and coastal ecosystems downwind of major emission sources. As such, AD-N should be included in effective nutrient mitigation and management efforts for these N-sensitive waters.

Ammonia Emission and Dry Deposition Fluxes from an Animal Agricultural Facility in Eastern North Carolina

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The primary focus of our experimental and modeling study is on the emission and dry deposition fluxes of atmospheric ammonia, using a micrometeorological technique over different types of agricultural and natural surfaces in North Carolina where animal farms and waste storage and treatment lagoons (which are known to emit ammonia) are located. Ammonia concentrations are measured at two heights (2 and 6m) above the surface employing an arrangement of a Thermo Environmental Instruments, Inc. (TEI) Model 42S (modified to a Model 17) and Model 17C chemiluminescent nitrogen oxides (NO_X)-ammonia (NH_3) analyzers along with a solenoid for each analyzer to alternate measurements between the two elevations. A switching frequency of 10 minutes allows hourly gradient measurements of three 10-minute intervals for each height. An average of the last 6 minutes of concentration data is considered in order to minimize measurement errors related to the analyzer's response time (~2 to 3 minutes). A scatterplot and linear regression of the measured NH_3 concentrations by the two chemiluminescent analyzers showed good agreement between the two with significant correlations during both daytime ($r^2 = 0.91$) and nighttime ($r^2 = 0.89$) periods. Simultaneously, mean winds and temperatures are also measured at the same two heights. Micrometeorological gradient and modified Bowen-ratio methods are used, in conjunction with the Monin-Obukhov similarity theory, to estimate the vertical flux and dry deposition velocity of ammonia under different meteorological conditions. Gradient measurements will also be made over different types of natural surfaces near ammonia sources under a wide range of wind and atmospheric stability conditions. We will also study diurnal and seasonal variations of ammonia flux and dry deposition velocity.

The Behavior of Atmospheric and Rainwater Mercury in North Carolina's Eastern Coastal Plain

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The eastern coastal plain of NC is known to have elevated levels of methylmercury in several species of freshwater fish consumed by recreational and subsistence fishermen. The DAQ has collected data on total gaseous mercury, as well as speciated data on elemental mercury vapor and reactive gaseous mercury from several sites across southeastern North Carolina. This session will describe the results from these studies, discuss additional data on mercury in rainwater from Lake Waccamaw and Pettigrew State Parks, and explore the potential relationship between atmospheric and freshwater mercury levels in this region of the State.

Modeling Regional Evapotranspiration for Forested Watersheds across the Southern US

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Evapotranspiration (ET) is the process that returns water to the atmosphere and therefore completes the hydrologic cycle. Evapotranspiration is the largest hydrologic component in the water budgets for watersheds in the Southern US, and therefore are important to understanding forest water yield, sediment and nutrient. However, direct measurement of forest evapotranspiration is not possible. Therefore, using long-term hydrologic and climatic data from experimental watersheds and USGS monitored watersheds across the Southern US including North Carolina, We developed generalized empirical models that can be implemented to predict annual actual ET at a regional scale. Independent variables in the model include temperature, precipitation, potential evapotranspiration, and others. Six potential evapotranspiration methods (Thornthwaite, Hamon, Turc, Priestley-Taylor, Makkink, and Hargreaves-Samani) are compared in this paper.

Trends in North Carolina's Atmospheric Water Availability over the Last Century

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For North Carolina, a state with a rather small riverine water inflow, the difference between precipitation and evaporation largely determines the water directly available to the state. Recently there appears to have been an increase in precipitation variability and possibly in evaporation amounts. The implications of current global climate change projections are that these trends will continue and may increase. With a rising demand for water within the state, this is cause for concern. The currently available precipitation and evaporation data are used here to show statewide annual trends for the past 100 years. The volume of precipitation falling on the state as a whole, and on its major basins separately, can be specified for most of the century with reasonable confidence. There is no clear trend in annual total amounts for any major region of the state. Interannual variability and seasonal contrasts, however, are increasing, particularly in the west. Evaporation values and patterns are much less certain. Three methods of estimation are used here, one based on the rather sporadic observational record stretching back some 50 years, one using a well-established empirical estimation formula, and the third treating evaporation as the residual from water budget calculations. Statewide the observational record suggests a marked increase in evaporation over the last 50 years, the empirical method suggests little overall change throughout the century, while the water budget indicates an increased evaporation early in the century, a slight decrease in the second half. These various results indicate the uncertainty in the evaporation estimates, but are partly a function of the areal weighting used in each method to derive statewide values. The observational data, regarded as the most reliable, suggest increasing evaporation in the east, a slight decrease in the western mountains. A new set of observational data is being developed as part of the NC-ECONET monitoring system operated by the State Climate Office of North Carolina. Implementation plans and site locations are described. It is anticipated that early information will clarify some issues surrounding the spatial variability of evaporation. Meanwhile, the current data suggest that there has been an overall decrease in water available in the last few decades. Climate projections suggest this will continue.

Bioterrorism Scenarios in Public Water Supplies: Modeling Concepts to Predict Impacts

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The tragic terrorist attacks of September 11, 2001 have dramatically heightened the nation's concern over the vulnerability of public water supplies. The American Water Works Association, for example, has quickly organized a seminar "Counter Terrorism and Security in the Water Industry: A Manager's Guide to Keeping Your Utility Safe" soon to be offered at six locations across the U.S. The emphasis of the seminar agenda is, as in other national discussions thus far, on ways to increase security in order to prevent the introduction of toxins. However, the development of a conceptual framework upon which to analyze the consequences of a successful terrorist attack on a water supply demands as much attention as heightened security to prevent the event. A few technical articles (e.g., Clark and Deninger 2000) address the routes by which toxins could be introduced into water supplies and the general nature of countermeasures. It is clear from these articles that much more research is needed to characterize the threat, to predict the toxin concentration-time profile, and to design effective countermeasures.

The purpose of this paper is provide general mathematical modeling concepts that could be used to predict the spatial and temporal pattern of a toxin concentration after introduction into a public water supply. In broad terms, a toxin could be introduced at three locations: (1) into the raw water supply (e.g., a reservoir); (2) into the water treatment plant (e.g., at a chemical feed tank); or (3) into the distribution system (e.g., injection at a location where the system pressure could be easily overcome). The analysis of system response at each location would demand a different mathematical model of water movement (hydrodynamic models) and the forcing function (i.e., the introduction of a toxin as an instantaneous pulse input or as a step input over a fixed time). The models would lead to prediction of a time response in toxin concentration at the intake to the treatment plant, within the treatment plant and within the distribution system. The presentation will discuss the available mathematical modeling tools in generic terms, from simple to complex. Some example responses will be included along with ideas for how model results could be used to design countermeasures such as increased security and monitoring at critical locations and to link with more general risk assessment models.

Approaches to Determining Whether Pharmaceutical Residues are Present in NC Drinking Waters

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Natural and synthetic antimicrobials are one class of prescribed pharmaceutical compounds that are of human health concern because of increased bacterial resistance. More than 50 million pounds of antibiotics are produced in the United States per year approximately one-half of these are prescribed for human use and one-half for agriculture. Approximately 40 percent of the antibiotics that are produced are used for livestock (for example, swine, poultry, and cattle) and the majority of these antibiotics are given in subtheraputic doses as feed additives to enhance growth. Antibiotics are also used in aquaculture and sprayed on fruit trees to inhibit fungal growth. The interest in pharmaceutical compounds in the environment is fairly new, and for the most part suitable methods have only recently been developed to concentrate and analyze these compounds at levels at which they probably occur in the environment. Due to the bioactivity of antimicrobials, their presence even at the sub nanomolar level will pose a long-term health threat to consumers that has not yet been evaluated. The extent to which drinking water supplies and drinking water-treatment facilities are impacted from upstream sources, such as hospitals, pharmaceutical manufacturers, and animal feeding operations that have the potential to release pharmaceutical compounds into the environment is for the most part not known. Yet each of these sources impact the drinking water supply watersheds for many of the larger cities in North Carolina.

With currently little information on the levels of antibiotic residues and antibiotic resistant bacteria in the drinking water supplies across the State, we are studying selected treatment facilities drawing water from vulnerable water supplies to examine the occurrence of selected antibiotics in these supplies, and track their fate through the corresponding water treatment plants. This is no simple task since methods for the detection of these compounds are a challenge as is identifying the exact group of compounds that are likely to be present in any drinking water source.

This presentation will discuss the approaches we are employing to address some of these challenges and describe a project that will provide the first snapshot of the pharmaceutical residue issue in North Carolina drinking waters.

A Multifluid Modeling Approach to Characterizing Chemical Dispersion in Drinking Water Treatment

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A research study has been done to evaluate the use of Computational Fluid Dynamics (CFD) for analyzing the mixing effectiveness of low energy mixers used in drinking water treatment processes. Low energy systems are used when there is not a process need for instantaneous mixing. This is in contrast to those processes that require higher mixing intensities such as primary coagulant mixing for particle destabilization. Low energy mixing is often associated with the addition of chlorine, ammonia, fluoride, and stabilization chemicals. However, poorly mixed chemicals prior to flow splits or subsequent unit process may result in undesirable conditions such as disproportionate chemical concentrations after flow splits and non-reacted chemicals prior to additional treatment steps. CFD models of chemical mixing offer unique and promising opportunities for process improvements in the drinking water field. The challenge will be to find the best utilization of CFD models to help determine the optimal mixing strategy currently met through engineering experience. In this study, CFD was used to predict the downstream mean tracer concentration and segregation of intensity for different reactor geometries. These reactor geometries include plane mixing and a plane jet in square conduits, a round jet in a tubular reactor, and a hydraulic jet mixer in a 1 in. and 6 in. pipe. In addition, the impact of turbulence model selection (single fluid approximation with standard k-ε, Chen-Kim k-ε, RNG k-ε, and Multi-fluid approximation with standard k-ε), wall roughness model, and turbulent Schmidt number (σ_{sc}) on the average downstream tracer concentration and the segregation intensity parameter were also investigated. The results show that the single fluid models are slightly sensitive to the turbulence model selection, σ_{sc} , and wall roughness function for plane mixing shear flows. The multifluid model was found to predict the mean concentration and the downstream segregation intensity values reasonably well. Overall, the results show that CFD has the potential to enhance engineering experience by permitting the evaluation of different low energy mixer alternatives.

Water Quality in the Lower Falls Lake Reservoir 1999 - 2001: Consistency and Change

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Regular monitoring of chemical and biological parameters in recreational and drinking water reservoirs provides information important for long term water quality management and assessment of source water quality for utilities. A quarterly monitoring program for the lower reach of Falls Lake Reservoir has been underway for three years. Surface water samples have been analyzed for a broad suite of parameters, including EPA organics and disinfection byproduct (DBP) parameters, major ions, metals, nutrients, chlorophyll a, phytoplankton, fecal coliform bacteria, enterococci, and cyanotoxins. The results indicate general consistency in chemical water quality in the lower reach: mineral content remains relatively stable; barium is the only ubiquitous primary metal contaminant; the secondary metal contaminants, aluminum, iron, and manganese, are continually present at levels above EPA SMCL standards. Certain seasonal patterns are emerging: the triazine pesticide Simazine is present each spring, persisting through May; turbidity tends to be lowest in August, while total organic halides (TOX) are highest. There are indications that nutrient levels, though still following typical seasonal patterns, may be slowly increasing. Nitrate has reached detectable levels during spring. Phosphorus has become detectable in all seasons. Phytoplankton dynamics and chlorophyll concentrations also follow seasonal patterns. Chlorophyll maxima approaching or exceeding 40 µg/L generally occur upstream during spring or fall, not coincident with August peaks in phytoplankton biomass. The seasonal depletion of bioavailable nitrogen in summer may favor recurring August blooms of the diazotrophic cyanobacterium, *Cylindrospermopsis*. The cyanotoxins cylindrospermopsin, anatoxin-a, and microcystin have been detected in raw water samples in 2000 and 2001. Fecal coliform bacteria and enterococci sporadically reach high levels, most often upstream.

Coastal Wetland Formation Since 1940: Core Banks, Cape Lookout National Seashore, NC

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Interpretation of georeferenced aerial photography since 1940, reveals significant development of back-barrier low marsh and barrier island high marsh marsh along Core Banks, NC. Core Banks was initially surveyed by the US Army Corps of Engineers in 1960-1962 and again by the National Park Service (P. and M. Godfrey) in 1972-1974. In 2001, 70 of the original 77 control sites were located and resurveyed using high precision GPS mapping techniques. USGS digital orthophoto quarter quadrangles were acquired for 1993 and 1998 and aerial photo sets for 1940, 1945, 1962, 1974 and 1983 were acquired for Core Banks and georeferenced using ArcGIS software. Integrating physical surveys with aerial photo interpretations provide an understanding of horizontal and vertical landscape change and vegetation community succession through time.

Surveyed transects across the barrier islands demonstrate a general increase in elevation of the beach berm and foredune over the past several decades. It is hypothesized that this increase in ocean-side elevation is at least partially responsible for the documented decrease in frequency of oceanic overwash events. Evidence of active overwash dynamics during the earlier history is indicated by vast areas of nonvegetated sand flats and fan deltas containing well-developed and active drainage systems across the barrier islands. The drainage systems flowed off the overwash fans between isolated estuarine shoreline islands and formed fan deltas into the estuaries. Absence of periodic overwash of sand led to the growth of marsh vegetation on barrier island overwash flats and back-barrier fan-delta lobes. The decrease in overwash events allowed the reworked fan-delta lobes to evolve from barren sand flats to low marshes dominated by *Spartina alternaflora*. Lower portions of overwash flats and estuarine shoreline islands evolved from barren flats to high marshes dominated by *Juncas roemarianus* on the lower fan morphologies and to *Baccharis halimifolia* and *Myrica cerifera* shrub scrub communities on the slightly higher sand morphologies. The preliminary research results indicate that the back-barrier environments of Core Banks experienced a significant formation of marsh wetlands over the past several decades. This is critical considering that most NC estuarine shorelines dominated by wetland marshes are experiencing severe shoreline erosion and wetland loss.

Effectiveness of a Constructed Wetland at Removing Nitrogen From Agricultural Runoff in the Neuse River Estuary Watershed

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Water quality concerns in the Neuse River Estuary, NC have necessitated enactment of a 30% reduction in nitrogen loading accompanied by a N loading cap. Open Grounds Farm (OGF) is an 18,210 ha row crop farm located in the Neuse River Watershed. In 1999, a tidal wetland was constructed to remove nutrients (N+P), sediment and pathogens in surface water draining from an 809 ha area of OGF. The wetland area is 5.1 ha with alternating sections of emergent marsh and open water. Nineteen wetland cells, each 31 m by 19.8 m are planted in monoculture of *Spartina alterniflora*, *Juncus roemerianus*, *Cladium jamaicense* or unplanted controls in a randomized block design. Nitrogen removal from the wetland via denitrification was measured monthly by analysis of dissolved N_2, O_2, and Ar in sediment incubation chambers with a Membrane Inlet Mass Spectrometer. Variables likely affecting denitrification, including benthic microalgal biomass (chlorophyll *a*), organic carbon content and nutrient concentrations, were measured concurrently. In addition, nutrient loading and removal from the wetland were determined from bi-weekly nutrient collection at 24 sites within the wetland watershed and continuous flow measurements at the entrance and exit of the wetland. For 2000 and 2001 inorganic nitrogen removal was 52% from the wetland. Maximum nitrogen removal from the wetland occurred in June for both years when loading was the highest. In 2000, 13.28% of the N removed was via denitrification, in 2001 this increased to 27.44%. Comparison of denitrification rates within the wetland showed no difference between those sites planted with *Juncus roemerianus* and those left unplanted. Nitrate concentration appeared to be a key variable controlling denitrification rates. Spatial and temporal differences in denitrification rates were strongly affected by the overlying nitrate concentration in the wetland. Light/dark experiments were conducted to investigate the differences in denitrification on a diel cycle. The results suggest the wetland effectively removed nitrogen from the runoff. Removal rates approached the 30% mandated N reduction value. Additional work will determine long-term effectiveness of the wetland from a management perspective.

Estuarine Shoreline Erosion and Wetland Loss, Albemarle-Pamlico Sound, North Carolina

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The Albemarle-Pamlico estuary of North Carolina's northeastern coastal zone is the second largest estuarine system in the US, and all shorelines are generally eroding in response to a worldwide rise is sea level. However, the specific rate and amount of shoreline recession is highly variable and depends upon a local set of variables. These variables include shoreline type, geometry and composition, geographic location, size and shape of associated estuary, storm fetch, type and abundance of vegetation, and frequency and intensity of storm patterns. Organic or wetland shorelines (marsh and swamp forest) comprise 62% of the estuarine margins in northeastern NC, whereas sediment banks constitute 38%. The goal of this study is to characterize the erosional processes occurring along these shorelines in response to local controlling variables.

Shoreline recession rates for 14 wetland sites with either marsh or swamp-forest segments were calculated using high precision GPS mapping techniques, digital orthographic quarter quadrangles, and other georeferenced aerial photographs from the early 1950's to 2001. Field mapping of each site provided data on shoreline characteristics and erosional processes. An open marsh site on western Pamlico Sound with a significant fetch erodes at 12 ft/yr in contrast to a marsh on the inner Pamlico River with a limited fetch erodes at 3 ft/yr. Wade's Point marshes erode at 4 ft/yr, whereas adjacent low-sediment banks erode at rates greater than 6 ft/yr, suggesting that low-sediment banks are more susceptible to erosion. Back-barrier marshes erode irregularly at rates varying from 0 to 20 ft/yr and depend upon the interactions between oceanic overwash processes, Pamlico Sound dynamics, and human modification of the barrier island, which determine sand supplies to the shoreline. A Tyrell County pocosin swamp-forest shoreline on Albemarle Sound erodes irregularly at rates between 2 and 6 ft/yr. However several hurricanes impacted the area between 1998 and 2000 and the shoreline receded over 16 ft in two years. Preliminary data suggest that estuarine erosion rates are extremely variable and often are up to an order of magnitude greater than previously reported. If 62% of estuarine shorelines consist of wetlands and the erosion rates for the 14 wetland study sites are representative, NC is experiencing a significant and ongoing loss of coastal wetlands at the land-estuarine interface.

Patterns in Neuse River Estuary Sediment Oxygen Demand and Nutrient Flux over a Three-year Period (1998 to 2000)

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The sediment oxygen demand (SOD) and nutrient (NH_4^+, NO_3^-, and PO_4^{-3}) flux were monitored at three locations M-9, M-15 and M-38 spanning the salinity gradient in the Neuse River Estuary (NRE) from New Bern, NC, to Minnesott Beach, NC. Sedimentary organic matter (OM) content was quantified for each station via percent carbon and nitrogen values as well as sediment surface chlorophyll *a* concentration. For comparative purposes, water quality data were collected at each site during the study. SOD ranged from 0.4 to 3.4 mmoles O_2/m^2 hr with an average of 1.2 mmoles O_2/m^2 hr. Sedimentary carbon and nitrogen content were highest at the mid-transect site M-15 and lowest in the upper (M-38) site. SOD followed this pattern during all three years however, differences in SOD between sampling stations and years were extremely small and for all practical purposes negligible, possibly suggesting a diffusional limitation to SOD in the system. Nutrient flux was much more variable ranging from –10,000 to 7500 mg/m^2 hr. Generally NH_4 and PO_4 were released from the sediments, while NO_3 was consistently taken up. NH_4 fluxes were positively correlated with SOD and sedimentary OM content. NO_3 and PO_4 were not related to SOD or OM content, suggesting processes other than aerobic remineralization were influencing these fluxes. Both SOD and nutrient fluxes were found to be quite stable across all three years despite major interannual differences in hydrology, suggesting spatial and temporal independence of water column processes and benthic fluxes.

Comparative Impacts from Hurricanes Floyd and Fran on Water Quality in the Neuse River Estuary

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More hurricanes and tropical storms made landfall in North Carolina from 1996-1999 than in the previous 35 years combined. Impacts of floods caused by the most severe of these storms, Hurricane Fran (4-6 Sept. 1996) and Hurricanes Dennis/Floyd/Irene (DFI, 4 Sept. - 18 Oct. 1999) were evaluated. Physical, chemical, and biological conditions were compared for the 1996 and the 1999 storms as opposed to non-hurricane years. During hurricane Fran the Neuse watershed received ~14% of the mean annual precipitation, and the normally mesohaline estuary decreased in salinity from 2-12 pre-Fran to near 0 in the from 2 weeks after peak flood waters reached the mesohaline Neuse through 7 weeks post-Fran. SS reached 15-mg/L 5 weeks post-Fran with return to pre-storm conditions (~5-mg/L) after 8 weeks. Dissolved oxygen was ~0-2 mg DO/L from Kinston to New Bern for two weeks post-Fran, coinciding with high NH_4^+N, high TP, high enteric bacteria densities, and massive fish kills. In the estuary, DO ranged from 3-6 mg/L in surface waters and 0-5 mg/L in the lower water column for the three weeks following the Fran event. This was followed by a system-wide recovery to 6-8 mg/L. Flooding and pollutant dilution from the 1999 hurricane season was much greater, as the watershed received ~50% of the mean annual precipitation. Negative effects on fish populations were also significantly less. Salinity in the mesohaline decreased from 2-16 pre-DFI to near 0 for more than 10 weeks post-DFI. SS was maximal at 30-mg/L 2 weeks post-Irene, with significant declines after 7 weeks. DO was not depressed post-Dennis or post-Irene, but decreased to 3-5 mg/L 2 weeks post-Floyd, with recovery to >5 mg/L after 4 weeks. No fish kills were reported post-DFI in the estuary, although incidence of fish disease was reportedly elevated in Pamlico Sound. Estuarine phytoplankton biomass (chlorophyll *a*) was at moderate levels prior to both Fran and DFI (18-25 mg/L); post-DFI conditions reflected washout (~0-3 mg/L), with greatest effects from Floyd (~90 days for chl*a* to increase to 50% of pre-storm concentrations). Increased TN (1200 and 1000 mg/L post-Fran and post-DFI, respectively) and TP (125 and 155 mg/L post-Fran and post-DFI, respectively) occurred after these storms, but ca. 2-fold longer recovery was required post-DFI (90 days). TN and TP loadings into the mesohaline estuary were calculated and compared for Fran and Floyd. Although Fran was shorter in duration, with less precipitation than Floyd, both TN and TP loadings that were significantly higher for Fran by approximately 20% and 10%, respectively.

Using Modern Sediment Chronology to Recognize Impacts of Hurricane-induced Flood Discharges on Muds of the Neuse River Estuary and Pamlico Sound, North Carolina

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Precipitation from major hurricanes in 1996 (Hurricane Fran) and 1999 (Hurricanes Dennis, Floyd, and Irene) produced peak discharges in Coastal Plain streams, including the Neuse River. Highest discharges followed Hurricane Floyd, during mid-September through early October, 1999. At peak flow, daily average discharge in the Neuse River at Kinston (USGS Station Number 02089500) exceeded 35,000ft^3/s (ca 1000 m^3/s), well above any other discharge recorded since March 1930. In addition, satellite imagery from late September 1999 shows turbid water discharging into Pamlico Sound. Given these circumstances, we should anticipate substantial redistribution of muds within the Neuse estuary and Pamlico Sound. We are testing for sediment redistribution by comparing pre-hurricane and post-hurricane sediment chronologies, using excess ^{210}Pb and weapons-fallout radionuclides (^{137}Cs or Pu) as chronometric tracers. In the Neuse estuary we have re-occupied five stations where we previously (1982, 1988, 1993) conducted studies of modern sediment chronology. Divers using SCUBA collected push-cores at these sites during November 1999 (two stations) or July 2000 (three stations). Sediment porosity profiles are very similar in pre-hurricane and post-hurricane cores, indicating that any sediment redistribution did not substantially change lithologies at our stations. At one station, the most landward, post-hurricane and pre-hurricane profiles of chronometric tracers differ so markedly as to exclude any simple interpretation of flood impact. Two other stations in the upper estuary show evidence of slight (ca 1 cm) to moderate (ca 6 cm) net erosion. We interpret net deposition of 10-20 cm at one station in the lower estuary; in this case the presence of red mud at the core top (6 cm) confirms introduction of new sediment from the drainage basin. At the mouth of the estuary we see evidence of both erosion and deposition within the top 20 cm of the sediment column, producing only minor net change. Extending our approach into Pamlico Sound, we have sampled six sites in the western Sound during October 2001. Four of these sites were sampled previously (1990 or 1994) for sediment chronology. We expect to complete chronologic studies on these cores within the next three months.

Measuring the Benefits of Nutrient Reduction in Coastal Waters with Calibration Methods

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Measures of the potential benefits arising from improved water quality due to a proposed policy rely on simple adaptations of past estimates of people's willingness to pay for an observed reduction in waterborne pollutants. Because these analyses are conducted to inform policy, they are undertaken before there is any improvement in water quality at the intended location to be influenced by policy. Experience at other locations is assumed to provide a basis for gauging the benefits in the new area.

The most common practice is to compute the average, per capita, benefit per unit change in water quality (or pollution concentration) and transfer this "unit value" to the policy site. Multiplying the unit benefit times the potential quality change and the number of people hypothesized to experience it provides the annual benefit measure.

Nearly all discussions of the theory of benefit-cost analysis conclude that this practice is incorrect on conceptual grounds. Moreover, the best overall summary of the research evaluating its performance in practice indicates that it is very unreliable. Until recently, there have been no new methods proposed to address the limitations in established practice.

Smith, Van Houtven, and Pattananak [2002] have proposed a new calibration methodology for transfers that assures consistent economic measures of the benefits of change in environmental quality. This paper reports the first application of the method to policies intended to reduce nutrient loadings to coastal estuaries. Based on results from the Chesapeake Bay Watershed and Estuary Models, the 1972 Clean Water Act and ensuring regulations and management actions are estimated to have lead to a 60% improvement in total nitrogen and phosphorus by bay segment (Morgan and Owens [2001]). Using their results along with estimates of the benefits of estuarine water quality improvements (Bockstael et al. [1989] and Lindsay et al. [1995]) we calibrate a representative household's preference function and develop consistent estimates of the benefits from the improvement that reconcile the results from existing studies. The paper also outlines how the method could be applied to evaluate nutrient policy for the Albemarle-Pamlico Estuary.

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Did EPA Get the Arsenic Rule Right?

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After delaying a rule issued initially by the Environmental Protection Agency on the final day of the Clinton Presidency to reduce arsenic in drinking water from 50 mg/l to 10 mg/l by 2006, the Bush EPA maintained the stringent new standard (on October 31, 2001). The rule continues to be a source of controversy and confusion. Some prominent economists have argued that

"EPA's new arsenic standard and even its current 50 mg/l standard makes no economic sense . . . . " (Burnett and Hahn [2001] pg. 48)

Regardless of the assumptions made about the severity of the risk, these authors find negative net benefits with costs exceeding benefits by $190 million dollars annually. By contrast, an advocate of the more stringent rule seems to imply it was warranted based on a benefit cost analysis, noting that

"One of the most important features of the 10 mg/l arsenic rule that EPA wants to implement is that it resulted from the first use of a cost-benefit analysis for a drinking water pollutant" (Wilson [2001] pg. 53)

It is not clear how Wilson arrived at this endorsement since even the EPA assessment finds a clear likelihood of negative net benefits (see U.S. Environmental Protection Agency [2000]). Moreover, the recent Science Advisory Board review found the Agency's benefit-cost analysis was flawed both in the estimates of benefits and in costs. These mistakes were identified and their potential impacts on the benefit-cost analysis were discussed. This critique is especially important because a benefit-cost analysis is required to be part of the regulatory decision process under the Safe Drinking Water Act.

This paper argues action was not warranted and that a national standard cannot be justified. Overall risk is likely to increase, not decrease, as a result of the new rule.

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Analytical Issues of Spatial Econometrics in Watershed Analysis of Geographically Referenced Data

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Spatial structure can arise in the analysis of geographically referenced data of a regional watershed with complex relationships between water quality and pollution sources. A novel analytical framework is necessary for integrating the study of factors affecting water quality within the spatial econometric analysis. The purpose here is to provide a method to apply the spatial econometrics framework to the specific analysis of a watershed model to develop new methodology for watershed analysis. We show what spatial econometric analysis problems are faced when trying to analyze the intricate relationship between measures of spatial association of water quality and land uses / economic activities in a watershed. Methods are proposed to correct those analytical problems in the econometric analysis framework to estimate the model appropriately. Spatial autocorrelation and heterogeneity are identified in the econometric analysis of watershed. Spatial process in a watershed is preserved in administratively defined areas and we expect to see the possible effects of spatial autocorrelation and heterogeneity of responses between the geographic units, counties or sub-basins. Data sets aggregated over the spatial units for the empirical linear model lead to the methodological problems violating the assumptions of the conventional model. Spatial autocorrelation might occur because the water quality measurements in each monitoring station are related through their geographical units. Ignoring such spatial dependence can cause inefficient estimates leading to inaccurate prediction. Application of the spatial econometrics concept that takes into account the complex spatial structure of the data will provide more realistic inference, more efficient parameter estimation and better forecasting.

Ex Ante Economic Losses Due to Hurricane Risk: A Preliminary Analysis

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This paper reports the findings of an analysis of the determinants of changes in housing prices over time in response to a spatially and temporally differentiated pattern of hurricanes as well as the changes in the terms for flood insurance. Economic models of behavior suggest asset prices should reflect a consumer's expectations about the risks of loss (or gain) over the time horizon relevant to the assets involved. We test this model using a spatially delineated set of sales prices for houses. These geographic distributions make it possible to observe differences in storms and policy changes over time. There is a different pattern of storms and insurance changes for different sets of homes. By pooling information on how sales prices change across different groups of homes we can isolate the effects of the climate and policy events.

To implement the framework we have developed a panel data set covering over 20 years of residential sales for Collier and Lee Counties in Florida. By using differences in the sales prices for the same homes (i.e., repeat sales) it is possible to control for the heterogeneity in different homes and isolate the effects of perceived storm risks.

Preliminary analysis with the data for Lee County supports a clear connection between severe storm events and the capitalization of updated perceptions of the risk of these hazards into property values. We are in the process of acquiring information on changes in insurance rates over the same time span.

The framework has broad relevance and can be readily adopted to consider the impact of storm risks for North Carolina as well.

The NC Wetlands Restoration Program's Local Watershed Planning Initiative

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The NC Wetlands Restoration Program has embarked on an innovative approach to identifying stream and wetland mitigation opportunities. Focusing on small watersheds, Local Watershed Planning combines the use of technical data with stakeholder involvement to generate practical solutions to identified water quality and habitat problems. This approach allows the NCWRP to further its mission of implementing mitigation projects that have maximum ecological benefit. Currently, eleven Local Watershed Planning efforts are underway statewide, with four additional efforts set to begin this year. Although funding for these efforts comes from the NC Department of Transportation to address future mitigation requirements, the focus of these efforts extends beyond this scope to identify a comprehensive suite of solutions to watershed issues. Key concepts behind the local watershed planning initiative include:

· Multiple projects concentrated in small watersheds generate greater environmental benefit than multiple projects spread across several watersheds;
· Stakeholder involvement is critical to the development of viable watershed plans;
· A watershed approach to the identification and implementation of mitigation projects is preferable.

Identifying Causes and Sources of Biological Impairment: Current Studies of North Carolina Streams

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North Carolina's 303(d) list currently includes several hundred stream segments which are considered impaired because they are unable to support adequate communities of fish or benthic macroinvertebrates. For the vast majority of these waterbodies the reasons for impairment are unknown, inhibiting efforts to improve stream integrity.

Within this context the Division of Water Quality has initiated the Watershed Assessment and Restoration Project (WARP) to evaluate the causes and sources of biological impairment in eleven watersheds across the state during 2000-2002. The goal of this effort is to provide the foundation for future water quality restoration activities in the eleven watersheds by: 1) identifying the most likely causes of biological impairment (such as degraded habitat or specific pollutants); 2) identifying the major watershed activities and sources of pollution contributing to those causes (such as stormwater runoff from particular urban or rural areas, streambank erosion, or hydrologic modification); 3) outlining a watershed strategy that recommends restoration activities and best management practices (BMPs) to address these problems and improve the biological condition of the impaired streams.

The general approach used to evaluate causes of impairment involves three steps:
1) identification of the most plausible candidate causes of impairment in the watershed, based upon existing data and initial watershed reconnaissance activities; 2) collection of multiple types of data bearing on the nature and impacts of those potential causes; 3) characterization of the causes of impairment by evaluating all available information using a strength of evidence approach.

Data collection approaches vary depending upon needs in each watershed but most often include:
· Benthic macroinvertebrate community sampling;
· Assessment of stream habitat, morphology, and riparian zone condition;
·Stream surveys—walking stream channels to identify potential pollution inputs and obtain a broad scale perspective on channel condition;
· Chemical sampling of stream water quality;
· Laboratory bioassays to assess water column toxicity;
· Bed sediment chemistry and laboratory bioassay;
· Watershed characterization—evaluation of watershed hydrologic conditions, land use, land management activities, and potential pollution sources.

Investigations are still in progress, but the overall approach will be described and preliminary results presented for selected watersheds.

Using Geographic Information Systems to Address Nonpoint Pollution in the Pigeon River Watershed, Haywood Co, NC

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Watershed associations often have difficulty planning, prioritizing and funding projects to address sources of nonpoint pollution. This is particularly true when dealing with watersheds that are hundreds of thousands of acres in size. The Haywood Waterways Association, Inc. addressed this issue through the use of the TVA Integrated Pollutant Source Identification (IPSI) model. Using color infrared leaf off photography, a team of skilled photo interpreters, ground truthing, and local USLE parameters, a GIS database was developed within ArcView to identify and quantify nonpoint pollution sources in the Pigeon River Watershed. As a result of this work, the sources of nonpoint pollution in the Pigeon River Watershed have been mapped. The relative significance of the various sources has been identified and charted. The limitations inherent in the interpreted data have been recognized. This information has been a key component of a watershed action plan, successful grant applications, and public information and education forums. The equipment and training required to use this GIS data has changed the way conservation work is accomplished in Haywood County. Other themes have been added to the initial data (property record information, soils data, GPS data, and orthophotos) to expand the usefulness of the data. Other planning efforts within the County make use of this information. Small watershed analysis starts with this GIS information. The Haywood Soil and Water Conservation District uses GIS and GPS to map and analyze conservation plan information. HWA newsletters, brochures, and presentations are developed within this digital environment. The demonstrated success of the use of this technology has enhanced public interest and support for watershed protection efforts.

Wake County's Comprehensive Watershed Management Plan

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As one of America's *Best Places to Live* (Money, 2000), Wake County has experienced significant changes in terms of economic development and population growth since 1990. This growth and development is expected to continue in the foreseeable future, and 500,000 new residents are expected to move into the region within the next twenty years. Though numerous benefits are associated with the gains in economic development and population growth, there are also accompanying pressures on the County's water resources.
The Wake County Commissioners recognized these pressures on the County's natural resources and unanimously approved to develop a comprehensive watershed management plan in November 2000. County staff are working with a consultant and a Task Force made up of an elected official from each local government and stakeholders to develop the plan. In addition, monthly meetings with local government staff occur to ensure the plan can be implemented. The goal of the plan is to protect and restore the uses of the County's streams in a manner that balances economic development with environmental protection. This plan is scheduled for completion in July 2002, and it will serve as a basis for future decisions concerning land use planning, open space protection, and stormwater control to protect the area's aquatic resources.

The County was delineated into 80 subwatersheds based on available water quality data, land cover information, and other watershed attributes. Benthic, habitat and geomorphology data were collected to assess the current conditions of the County's waters. These data along with data collected by the Division of Water Quality and others are being used to classify the County's watersheds into one of the following categories: healthy, impacted, impacted/restorable, degraded, and degraded/restorable. The watersheds will then be prioritized based on criteria that include the designated uses of the waters; how vulnerable the watershed is to development based on zoning, slopes and soils; the presence of special protection areas; and the ease of implementation.
The Center for Watershed Protection's Eight Tools of Watershed Protection will be applied to the County. These tools include land use planning, land conservation, riparian buffers, better site design for development, erosion and sediment control, stormwater control, non-stormwater discharge control (such as septic tanks), and environmental stewardship. The final plan will likely include recommendations for ordinance changes as well as incentive-based approaches to protect the County's water resources. A funding mechanism will also be included in the plan.

Developing Locally Driven Performance Standards for the Upper Neuse Basin Watersheds

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Tetra Tech (Tt) developed a Watershed Management Plan for the Upper Neuse River Basin Association (UNRBA) comprising 14 jurisdictions in the watershed above Falls Lake Dam. Early in the process, Tt facilitated prioritization of issues to be addressed in the plan, as well as regional and local water quality and habitat targets linked to the management issues. The groups' "most important" management priority was drinking water safety, while limits on recreational uses and threats to aquatic and riparian habitat were considered "very important". Based on these priorities, the TAC and Board directed Tt to focus the watershed assessment and planning effort on three types of stressors (1) nutrients and algae, (2) erosion and sedimentation, and (3) hydromodification. Chlorophyll *a* and imperviousness were selected as measurable and modelable indicators to assess these top three stressors. Tt conducted a baseline modeling assessment comparing current and predicted future watershed conditions (year 2025 and buildout conditions) to identify areas at greatest risk of not meeting management objectives for the nine drinking water supply watersheds in the Upper Neuse Watershed. Watershed modeling analyses were also used to evaluate the relative effectiveness of management alternatives for the key indicators. Early in the screening of potentially feasible management strategies, the UNRBA Board determined its number one strategy as shaping where growth occurs through more distinct urban areas and planned conservation areas. Consistent with this, the recommended Plan has three distinct zones: urban; suburban; and conservation. The TAC and Board directed Tt to evaluate two different approaches to shaping growth: zoning and on-site performance standards for new development. Working with the TAC and Board, Tt developed zoning density scenarios for each jurisdiction that could be evaluated using the model and considered by local governments. Alternatively, local governments can choose to use the performance standard approach. Under this approach, the urban areas and suburban areas would implement the existing nitrogen performance standard for new development in the NC NSW rules (3.6 lbs/ac/yr), while new development in the conservation areas would need to meet a much higher standard: 1.7 lbs/ac/yr. Since phosphorus is the primary nutrient of limiting concern in the Upper Neuse Watershed, urban and suburban areas would need to implement a new phosphorus loading limit standard of 0.6 lbs/ac/yr for new development, while new developments in the conservation area would need to meet a more stringent standard of 0.3 lbs/ac/yr. The plan also recommends an enhanced peak flow management standard for all new developments $\geq$10% imperviousness. A management plan was developed for each of the 9 drinking water supply watersheds that gives 3 or more management options for each local government to consider. Each option meets the UNRBA water quality and habitat targets while also meeting its objective of wisely shaping where growth occurs in the watersheds.

Choices of Scale and Process Complexity in Hillslope Models

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Water flow in the subsurface partially determines the response of a watershed to a variety of events, such as rainfall or irrigation. Accurately representing flow in a well-chosen fundamental geological unit of the watershed's subsurface environment is, therefore, a precondition for accurately representing watershed response as a whole. In this work we focus on hillslopes as the fundamental geological units of the watershed's subsurface processes and investigate the effect of modeling decisions about scale and process complexity on the representation of hillslope hydrological response. As porous medium continuum scale models can include a high degree of process complexity and provide resolution at scales much smaller than hillslopes, we first formulate a model of the hillslope unit based on the theory of porous medium continuum dynamics. We incorporate the irregular three-dimensional geometry of the hillslope, nonlinear and hysteretic submodels of multiphase flow processes, and the heterogeneity and anisotropy of soil parameters. We then compare the behavior of our complex, high-resolution hillslope model to a variety of simplifications in order to understand the degree to which the hillslope representation can be simplified while retaining sufficient resolution for watershed modeling applications.

Applications of Systems Analytic Tools in Integrated Watershed Management

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The need for protection and management of watersheds is identified as a critical task, especially in the presence of rapid growth as seen in North Carolina in the recent past. The challenges facing this issue are multi faceted. At one level, proper watershed water quality monitoring as well as modeling studies are needed to characterize and understand the existing and impending watershed water quality problems in NC. Most studies focus on this activity. At another level, akin to planning and management activities, tools and methods are needed to identify good management strategies that protect the watershed while allowing for sustainable development. Numerous watershed management issues that challenge environmental management agencies are yet to be addressed systematically. For example: what are allowable land use development plans in a watershed that would not violate specified water quality targets; where would it be most effective to require buffer zones or changes is agricultural practice to improve water quality; how do cost effectiveness and water quality effectiveness tradeoff among point source controls and nonpoint source management; what are feasible and cost-effective total maximum daily load (TMDL) allocations that would meet specified water quality targets; what is the tradeoff between cost and water quality improvement; are there alternative management strategies or TMDLs to achieve the same water quality at similar costs, and if so, what are those alternatives; and how will any of these management alternatives perform under conditions of uncertainty.

To assist decision-makers address these questions, ongoing research by the authors focus on developing and implementing a set of systems analytic tools within a computer-based decision support framework for integrated watershed management. Proven methods and procedures for uncertainty analysis, mathematical programming and optimization form the core set of tools that are employed to search for “good” solutions. This framework is designed sufficiently general to allow easy linkage with a variety of watershed water quality models. Building upon this framework, a prototype decision support tool is implemented within a GIS-based watershed management system, coupling a genetic algorithm-based search and Latin hypercube sampling procedures with a watershed water quality model. This talk will summarize these implementations, their functions and features, as well as the results obtained by applying it to illustrative, but realistic, case studies. Also, this talk will briefly describe a recently initiated research project on incorporating these tools within a multi-media, integrated, modular modeling framework that is being developed by US EPA.

Detection and Occurrence of Antibiotic-Resistant Enteric Bacteria in Groundwater around Swine Farms in Eastern North Carolina

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The substantial use of antibiotics for growth promotion and disease treatment by the commercial swine industry in the United States has led to high proportions of multiply antibiotic-resistant enteric bacteria fecally shed by these animals and growing concerns about the spread of these enteric bacteria into environmental media. A study was conducted to understand and quantify the extent of release of antibiotic-resistant enteric bacteria from swine farms into the groundwater environment. Four study sites with known groundwater flow paths were screened for enteric bacteria and coliphages. These sites include two hog farms with lagoons and land application of the swine waste, one farm with land application of swine wastes but no animals, and a farm with only crops and no land application of swine wastes or animals. Of a total of 48 study wells, 25% were positive for enterococci, 17% were positive for *E. coli* and only one well (~2%) was positive for both somatic and male-specific coliphages. Of the total of 114 enterococci isolates, 34% were *Enterococcus faecium*, and 5% were *E. faecalis*, both of which are species associated with fecal contamination, and can be pathogenic. Of 35 *Escherichia coli* isolates, 89% were confirmed by further biochemical testing. The bacterial isolates were tested for antibiotic resistance using a panel of 17 drugs that are typical of human and veterinary use. The enterococci isolates were predominantly resistant to four antimicrobials or less, although a few were pan-resistant. For example, one isolate from a swine farm site was resistant to ten antimicrobials: vancomycin, chlortetracycline, tetracycline, trimethoprim, chloramphenicol, erythromycin, ampicillin, florfenicol, tylosin base, and clindamycin. The majority of the *E. coli* isolates were resistant to three or more antimicrobials, with a few also showing pan-resistance to eight or nine drugs. This study demonstrated that antibiotic-resistant enteric bacteria are being found in groundwaters associated with hog farms that have the lagoon and land application system for waste management. The extent to which such contamination of groundwater with multiple antibiotic-resistant enteric bacteria poses risks to human health is uncertain and deserves further investigation.

Greening Development to Protect Watersheds: Is New Urbanism the Answer?

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New urbanism has been touted as an environmentally sustainable form of development. Proponents of new urbanism contend that compared to low-density conventional sprawl, new urban development patterns require considerably less open space and impervious surfaces, and are more supportive of conservation goals, including water quality protection and flood mitigation. This two-year study involves a comparative evaluation of the watershed impacts of new urban and conventional low-density developments based on: 1) a cross-sectional survey of 50 matched pairs of new urban and conventional developments in five states (Georgia, Maryland, North Carolina, South Carolina, and Virginia); 2) case studies of six new urban developments; and 3) simulations of impacts of new urban and conventional low-density development scenarios that would occur at build-out in the demonstration sub-basin of Lake Ellen in Chapel Hill, North Carolina. At the end of the first year of study, preliminary findings from the survey and case studies indicate that new urban developments reveal a complex array of benefits and deficits associated with watershed impacts. First, in "greenfield" (suburban fringe) sites, compared to conventional developments, new urban developments more successfully incorporate techniques that reduce impervious surfaces, protect hydrologically sensitive areas, use BMPs, and restore degraded streams. New urban developments, however, are slightly more likely to permit impervious uses in open spaces, and provide more impervious sidewalk covers to accommodate pedestrian and bike movement. Second, in "infill" sites, new urban developments are more likely to incorporate impervious surface reduction techniques and restore degraded streams, but they are less likely to protect sensitive areas, use BMPs, and not have open spaces paved. These findings suggest that new urbansim at the suburban fringe could be criticized as just another variant of sprawl. In contrast, they could be viewed as a greener and more compact alternative to sprawl on the fringe. They also reveal that in "infill" sites, new urbanism is not offering more watershed protection benefits than conventional development. During the second year the findings reported here will be used to create scenarios that reflect low and high impact design alternatives to determine the relative importance of different urban land use designs and sensitive area features. When this study is completed, findings will be used identify how land use planning and urban design techniques can be used to implement more environmentally sustainable development designs in ways that mitigate stormwater runoff impacts.

The Use of the Natural Abundance of ^{15}N to Evaluate the Effect of Anthropogenic N on the Components of a Headwater Urban Stream

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Nitrogen processing is an important ecological function of low order streams, which is greatly impacted due to disturbances associated with urbanization. North Buffalo Creek, a typical urban stream located in the headwaters of the Cape Fear River Basin in Greensboro, NC, is impacted by N input from both point and nonpoint sources. These sources include lawn fertilizer runoff, leaky sewage pipes, confined sewer overflow, pet waste, as well as industrial and municipal sewage treatment effluent. Components of the North Buffalo Creek food web were collected for analysis of ^{15}N in order to detect the influence of anthropogenic N. The use of stable isotopes to detect N sources is possible due to the unique ^{15}N signature of the N pools. Sources with unique ^{15}N signatures include wastewater and animal waste, which is enriched in ^{15}N (10 to 20‰) and N fertilizer, which is depleted in ^{15}N (-3 to 3‰). The food web components studied include seston, algae, leaves, and macroinvertebrates. Leaves vary little in ^{15}N at all sampling sites with signatures near 0‰. Algae also varies little with ^{15}N signatures ranging from 6 to 8‰ at most sites. However, these values are more enriched compared to published ^{15}N values of algae at pristine sites, indicating influence from nonpoint sources such as leaky sewage pipes and pet waste. Algae also appears to be influenced by textile plant discharge (1‰), and the municipal sewage treatment plant (13‰). The seston ^{15}N fluctuates between 2.5‰ and 7.0‰ as the stream moves through the city. At most sites along North Buffalo Creek, the seston appears to be derived from a combination of algae and leaf ^{15}N, except for the sampling site located directly downstream from where textile effluent is discharged, where the ^{15}N signature is enriched compared to both sources. Hydropsychids are enriched 3‰ compared to seston at most sites, the expected trophic enrichment from a seston diet. Downstream from the municipal sewage treatment plant, the caddisfly ^{15}N signature is slightly enriched compared to those upstream. The diet appears to be derived from both seston and algae. These data suggest that anthropogenic N influences algae, which then influences other components such as seston and hydropsychids. The use of stable isotopes to better understand N processing in this headwater urban stream may give insight into future management decisions regarding the reduction of N input.

Can Geochemical Fingerprinting Be Used to Determine the Relative Contributions of Sediment through Time from Different Source Areas?—A Pilot Study in the Southern Appalachians, North Carolina

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Few studies have attempted to quantify the sedimentation-related impacts of land-use alterations resulting from upland erosion in the southern Appalachians: though it is a significant environmental problem. This study used a sediment mixing model based upon multivariate geochemical fingerprinting to determine the relative contributions of sediment through time to Fairfield Lake; source-area types evaluated were two geologic units and four delineated land-covers (e.g., forests, roads, lawns, and stream-side alluvium.).

The sediment-mixing model requires comparison of upland samples with lake-bed samples. Upland soil samples (n=108) were collected over the Whiteside Granite Gneiss and the Tallulah Falls Formation in forested and developed areas. Lake-bed sediments were collected in 19 cores; 3 were analyzed in detail. All samples were analyzed for a suite of 16 elements. Lead-210 dating on the lake sediments, combined with air photo information obtained in 1963, 1975, 1988, and 2000, indicate that sedimentation rates have increased several fold during the past two decades in response to local development. Linear discriminant analyses of upland soil geochemical data show that soils from different bedrock and land use areas can be statistically classified with 93% accuracy for bedrock and 79% accuracy for land class. Elements Cu, Sn, U, and Zn best distinguished bedrock source type whereas Ag, Mo, Ni, Sb, Sn, and Zn best distinguished land cover source type.

Using the statistically selected parameters, the sediment mixing models show a change in rock and land cover source that corresponds to the increase in sedimentation rates. Also, the model indicates that anthropogenic source areas (i.e. roads and lawns) increase with periods of development. The mixing model, though promising as a tool, does provide some unreasonable results (e.g. a 'false' association between lawns & Tallulah Falls). Also, there is an apparent loss of elemental mass between the upland and the lake basin sediments (which violates a premise of the mixing model). The loss is most likely due to intense weathering and the transport of material out of the watershed in solution thereby muting geochemical signals during transport/deposition. The use of a broader array of elements chosen to reflect local geology, based upon a solid understanding of watershed lithotypes, and use of non-mobile elements and/or elemental ratios should improve the accuracy of the mixing model and make this approach a viable tool for sedimentation studies in the southern Appalachians.

Groundwater/Surface Water Interactions and Nitrogen Flux Rates on a Watershed Scale

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Agricultural and urban land use has increased the fluxes of nutrients, sediments and different organic/inorganic chemicals into surface water and ground waters. To promote the long-term sustainability of natural and managed watersheds, fundamental processes that control water quality on a watershed scale need to be investigated. Watersheds with a greater fraction of agricultural land have been found to discharge proportionately greater amounts of N. This relationship has led to the development of nutrient export coefficients for different land-use types, but uniformly applied these export coefficients may be poor predictors of nutrient flux out of the watershed because export rates can vary widely for a given land types. Smaller watersheds may have no correlation between the percentage of agricultural land and discharges of N, whereas in larger watersheds discharges of N are correlated to a wide variety of anthropogenic inputs of N including atmospheric deposition, fertilizer application, cultivation of N_2 fixing crops and number of CAFO's (concentrated animal feed operations). What is the reason for this disconnect between land use and watershed nutrient flux?

Previous work has shown that ^{15}N in ground waters is directly related to land use. We have studied several watersheds in the Neuse and Cape Fear River basins with different numbers of swine and poultry CAFO's and different percentage of cultivated land, wetlands and forest land cover. The ^{15}N of nitrate in these watersheds is related to the land use in the groundwater discharge zones (GWDZ) and not to land use of the basin as a whole. Nitrogen concentration in these watersheds is highest in the upper portions of the basins near swine farms and decreases down stream. Poultry operations do not appear to export significant amounts of nitrogen to surface waters. In stream consumption or groundwater dilution could result in this concentration decrease down basin. The ^{15}N and ^{18}O relationship of nitrate in these watersheds indicates that in stream consumption is related to stream depth, and is not important once nitrate moves into larger streams and main channels. This conclusion is also supported by RiverNet DO measurements which shows that DO is only above saturation during low flow drought conditions. If we look at the HD / ^{18}O relationship of rainwaters, ground waters and surface waters in the Neuse River basin, we can asses the importance of groundwater dilution. Rain waters form a consistent HD/^{18}O relationship with a slope of ~5.5, slightly different from the GMWL as a result of relative humidity. Ground waters in the middle portion of the basin fall along this rainwater HD/^{18}O line, but ground waters in the lower portion of the basin are above this rainwater line. Surface waters in the upper and middle portion of the basin fall along the rainfall HD/^{18}O line, but surface waters in the lower portion of the basin fall in between the rainfall HD/^{18}O line and the deep groundwater line. This data supports the conclusions that groundwater hydrology and land use in the GWDZ's as mapped by Heath (1994) control nitrogen flux out of watersheds on a basin scale. To control nutrient fluxes and improve water quality in estuarine and coastal regions, land use in groundwater discharge areas must be controlled in addition to position and width of forest buffers. Agricultural operations such as CAFO's that rely on nitrogen consumption processes in groundwater are poor choices to located in GWDZ's. This data also indicates that once nitrogen is exported into larger streams or main channels, it is transported directly to the estuaries and coastal areas.

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Application of Transition Zone Research to Hydrogeologic Site Assessments

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The Groundwater Section of the North Carolina Department of Environment and Natural Resources, Division of Water Quality, in cooperation with the United States Geological Survey's Water Resource Division, is conducting a regional groundwater quality research project designated the Piedmont and Mountains Resource Evaluation Program (PMREP). Initially, four hydrogeologic research stations are being constructed in the North Carolina piedmont and mountains to intensively study groundwater quality, transport and availability. Twenty-three continuous soil and rock core borings have been advanced at these sites so far, and intact samples of the saprolite, bedrock and transition zone between saprolite and bedrock have been recovered for characterization studies. Extensive monitoring well networks have been installed and aquifer tests have been performed at some sites. Preliminary information from PMREP research stations shows great variability in the depth, thickness and weathering of the transition zone, and shows that the nature of the parent bedrock material determines the physical characteristics of the transition zone. For example, our observations indicate that the transition zone above fine-grained granodiorite is much thinner than above coarse-grained granodiorite, suggesting that weathering rates are a significant component to transition zone development. These characteristics would not have been evident without examining core samples. The physical characteristics (e.g., grain size, clay content, degree of sorting, thickness, etc.) of the transition zone, in turn, determine the hydraulic properties and relative importance of the transition zone for the migration of dissolved phase contaminants. The transition zone has long been recognized as a potential preferred pathway for the migration of dissolved phase groundwater contaminants, but the majority of hydrogeologic site assessments performed for the purpose of satisfying regulatory requirements overlook or mis-identify this important hydrogeologic unit. One of the goals of the PMREP is to transfer knowledge gained from the careful study of hydrogeological data obtained from the research station sites to the general public and the regulatory community. This study shows that site characterization, and ultimately remediation, at contaminated sites may be incomplete if the character of the transition zone has not been thoroughly defined and that this is best accomplished by coring.

Advanced Knowledge of Hydrogeologic Conditions in the Piedmont and Mountain Region

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A technique, referred to as Prior Conceptual Model Explanation (PCME), has been developed to get optimal value from past ground-water studies in the fractured rock system of the Piedmont and Mountain Region. Rather than relying on a costly, sheer data-based evaluation approach, the technique focuses on a concise knowledge network of key generalizations and interrelated factors.

The generalizations and interrelated factors are processed in a systematic way to get early perspective of local ground-water settings and of existing and future fluid behavior. By applying this form of background knowledge, the technique does not use precision-oriented quantitative data and is applicable anywhere without collection of new site specific data. Expressed in narrative language, the PCME assessment and report can be completed within a few days at little costs. Refined research and some training are needed.

Key generalizations, interrelated factors, and the technique are included in three related publications. These publications capitalize on concentrating value from non-universal generalizations and imprecise information

Among subjects to be assessed and approximated at a specific site are: relation of the two-media system (soil-saprolite and fractured rock), depth to water table, synthetic water-table map, depth to fresh rock, flow boundaries, character of discharge by natural and human causes, well yields at different spots, concern for contamination and plume development at different positions, wellhead protection, probabilistic approach to questions, and other subjects of concern.

The PCME approach, considered capable of useful application everywhere, has a wide range of beneficial uses, including the following: (1) helping stakeholders and the public to better understand ground-water conditions and specific issues relating to well supplies, contamination, and interrelated environmental issues at an early stage, (2) reducing costs of site studies, (3) providing helpful information regardless of existing rules and regulations, (4) helping in early stage planning, (5) providing early plateau of knowledge before starting each intensive study, (6) helping to screen sites for priority ranking, (7) providing judges and lawyers an early perspective and framework type of brief, and (8) providing early orientation and judgment on possible remedial actions at contaminated sites.

The PCME technique should be examined by State and Federal regulatory agencies to determine the extent to which it can help to fulfill their responsibilities in providing optimal public knowledge and benefits at minimal costs.

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Mixed Finite Element Methods and Higher-Order Temporal Approximations for Variably-Saturated Groundwater Flow

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Richards' equation is commonly used to model flow in variably-saturated porous media. However, its solution continues to be difficult for many conditions of practical interest. For example, infiltration after a heavy rainfall into a system initially at static equilibrium with the water table can easily lead to sharp fronts in the saturation profile which are difficult to resolve.

Much work has been devoted to numerical methods for both Richards equation and full two-phase models of air-water systems. In particular, significant effort has been focused on developing appropriate formulations and time discretizations. Among the various approaches that have been investigated, the method of lines has been used successfully to introduce robust, accurate, and efficient temporal approximations.

At the same time, mixed finite element methods have been shown to provide accurate approximations to groundwater velocity fields even over irregular, heterogeneous domains. A mixed-hybrid finite element method combined with an adaptive higher-order time discretization has been shown to have several benefits over traditional, lower-order temporal approximations for modeling single-phase groundwater flow in heterogeneous porous media. Here, we extend the earlier work for single-phase flow and apply a mixed finite element spatial discretization within a method of lines context to model variably-saturated flow. The resulting simulator has a number of advantages over traditional approaches. We examine its benefits for several challenging problems modeling flow in hillslope geometries.

Closure of Thermodynamically Constrained Models of Multiphase Flow

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The thermodynamically constrained averaging theory approach (TCATA) is a methodology for deriving a new set of models for multiphase flow in porous media. These models require determining various closure relations, one of which specifies the average curvature of the fluid-fluid interfaces. In this work, we use pore-network modeling to investigate the average curvature of the fluid-fluid interfaces during two-phase flow. We interpret our results in the light of the TCATA. The average curvature relates changes in saturations to changes in interfacial areas. It is also strongly correlated to the average capillary pressure.

Lattice-Boltzmann Simulation of Multiphase Flow in Water-wet Porous Media

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Multiphase flow in porous media is involved in a wide variety of engineering applications, such as groundwater remediation and oil recovery. In this work, we investigate the concurrent flow dynamics of water and a non-aqueous phase liquid (NAPL) in a porous medium by employing the lattice-Boltzmann (LB) modeling approach, a powerful pore-scale scheme for investigating multiphase flow in complex geometries.

In our previous work, we proved that the LB model faithfully describes single-phase flow processes. For multiphase flow, however, interactions of different phases must be incorporated into the numerical model. Microscopically, the segregation of a fluid system into different phases is due to the interpartical forces, which can be accounted for in a LB model by simulating the motion of fluid particles.

We implemented water-NAPL, water-solid and NAPL-solid interactions in a LB model. We chose the interaction coefficients such that the fluids separate because of immiscible flow and such that the contact angle vanishes because of presumably water wet medium. We develop an approach to be able to simulate drainage and imbibition processes of any given porous medium geometry. Primary drainage simulations in media with simple geometries show good agreement with results from a previously developed pore-morphology-based simulator as well as analytical solutions. Scanning curves obtained from two-phase LB flow simulations on random packings of spheres also show encouraging agreement compared to experimental data and pore-morphology-based simulations.

Discontinuous Galerkin Methods and Higher Order Temporal Approximations for Modeling Saturated Groundwater Flow

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Challenges persist in the accurate and efficient solution of groundwater flow equations for heterogeneous aquifers. Low-order approximations in both space and time have dominated traditional approaches for modeling saturated flow. Comparisons of either a higher order spatial or temporal approximation with its low-order counterpart have shown significantly improved accuracy and efficiency for higher order methods. Recently, discontinuous Galerkin methods have been investigated since they readily produce higher order spatial approximations while still conserving mass locally. Furthermore, they achieve this without requiring the approximation of additional unknowns, such as hydraulic head gradients, as is done with mixed finite element methods. In this work, we apply the discontinuous Galerkin finite element method with an adaptive higher order time discretization to single-phase groundwater flow in heterogeneous porous media. We then compare the results to traditional lower order methods for accuracy and efficiency.

Integration of Time Domain Electromagnetic Surveys, Borehole Geophysical Logs, Water Level and Chloride Concentration Data in the North Carolina Coastal Plain: Some Case Study Examples

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The continued growth of cones of depression in confined aquifers of the North Carolina Coastal Plain has led to concerns about saltwater encroachment in response to pumping and its effect on ground water supplies. The integrated use of time domain electromagnetic (tdem) surveys, borehole geophysical logs, water level, and chloride concentration data has been demonstrated to be a valuable approach to mapping the positions of fresh-water-saltwater interfaces in the ground water system in the coastal plain, both for regional mapping purposes, and for identifying localized salt-water intrusion problems. TDEM sounding is a surface geophysical technique that measures the earth's response to an induced electromagnetic field. Resistivity versus depth profiles are produced for each sounding location which can be compared to nearby borehole geophysical logs, water level and chloride concentration information. In areas where well data is sparse, TDEM resistivity logs can be used to distinguish between thick sequences of permeable and nonpermeable strata, and fresh versus salty aquifers. Cross-sectional profiles have been prepared for various ground water investigations in the North Carolina Coastal Plain using color contour plots of TDEM resistivity, upon which are superimposed borehole logs, water level and chloride data. The following case studies illustrate how this approach has been applied:

North Albemarle Area (Northeastern North Carolina)
Pitt County, NC
Craven County, NC , New Berne Well Field area
Southern Duplin and Onslow County, NC

Method of Lines Solution of Richards' Equation with Spatially and Temporally Adaptive Discretization Techniques

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Quick and efficient simulation of fluid flow in the unsaturated zone is critical to modeling subsurface flow. The solution of unsaturated subsurface flow equations are marked by the presence of sharp fronts in the fluid pressure that vary in space and time. Employing uniform space and time steps for the numerical solution of such equations results in inefficient and expensive simulations. In this work, we solve Richards' equation using a method of lines with variable-size steps in both space and time. Temporal adaptation uses a formal error indicator and adapts both the order of the method and the step size in order to satisfy user-specified error limits. We chose an *h*-refinement method for adapting the step size in space. We use a prediction of frontal position in time to determine when and where to refine in space. This method results in the robust and efficient simulation of unsaturated flow.

Conflicts and Future Long-Term Management of a Channelized Watershed: Ahoskie Creek, NC

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The Wiccacon River drainage basin covers 275 mi^2 of uplands and flows east into the Chowan River estuary. The Ahoskie Creek watershed drains 73 mi^2 in the uppermost reaches of the Wiccacon basin. Ahoskie Creek watershed was channelized between 1960-1965 under the Watershed Protection and Flood Prevention Act. Sixty-six miles of main stem and lateral ditches were dug and associated spoil banks constructed to provide drainage within 24 hours for 2- to 5-year frequency storms. Channelization increased the stream flashiness associated with major rainfall events by moving larger volumes of water downstream faster and for shorter time increments.
The town of Ahoskie, located near the downstream end of the channelization project, is situated on a narrow ridge of high land that forms a major geomorphic constriction in the stream valley immediately downstream of the town. This stream valley choke point is also the location of highway 13 built on a major road dam constructed across the narrow floodplain with two small bridge openings. A second geomorphic constriction occurs upstream and along the western portion of town. The highway 42 bridge and road dam crosses Ahoskie Creek at this constriction. In addition, the 61 mi^2 Stoney Creek drainage sub-basin discharges large volumes of water into Ahoskie Creek directly above the highway 13 constriction. Ahoskie experienced significant urban growth and development since the channelization project was completed. Urban sprawl increased storm-water runoff and led to significant encroachment of housing developments and industrial areas into the primary floodplain and locally to the channelized creek bank, all are within the 100-year floodplain.
Because of the above factors, the areas upstream of the constrictions were severely impacted by recent flash floods associated with hurricane Floyd (9, 1999) and tropical storm Allison (6, 2001). Flooding results from the cumulative impacts of modification and development by user groups working independently and ignoring basic functions of the total drainage system. Today, Ahoskie Creek watershed is seriously impaired resulting in conflicting and nonsupportive uses of the land and water resources. Society must develop management schemes for entire drainage basins and sub basins based upon the integration of the geomorphic framework, hydrologic dynamics, natural functions, as well as the needs of multiple user groups.

A Site Assessment Model for New Development

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Many jurisdictions specify combinations of zoning requirements and management practices to protect receiving water quality. These may include items such as limits on density, requirements for stormwater management, and engineering specifications for stormwater management practices. Detailed requirements are often seen as necessary to ensure protection, yet this very detail may stifle the use of innovative techniques that could achieve the same or better water quality results in a more cost effective manner. For instance, development guidelines might require use of stormwater wet ponds where use of low impact design techniques for onsite stormwater management could achieve better water quality with lower costs and a greater building yield. In general, proposals for designs other than those specified in regulation require a variance. How can local jurisdictions evaluate the water quality merits of a development design that differs from the default specified in regulation? To address this issue, we have created a development site assessment tool that is designed to compare the water quality impact of a proposed development design (with and without BMPs) to existing conditions and to the development of the site under allowed regulations. If the "allowed regulations" are tuned to represent a desired performance goal, the model yields an analysis of the ability of the proposed design to meet water quality targets. The model is contained in a user-friendly spreadsheet, and is built on relatively simple analyses that combine Center for Watershed Protection techniques, SCS curve number and unit hydrograph analyses, and event mean concentration data. The model addresses removal efficiency of multiple types of structural and non-structural BMPs, including BMPs in sequence, using simulated effects of BMPs on hydrology and literature-reported BMP pollutant removal efficiencies. Current prediction capabilities include total phosphorus, total nitrogen, metals, fecal coliform bacteria, and risk of channel degradation from alterations to the flood hydrograph. The model is currently proposed for use in the development review process in several North Carolina and Georgia counties. The tool will also be used by developers, and provides a useful framework for initial site BMP design. Perhaps most importantly, it provides a common framework for the evaluation of alternative designs and enhances communication between developers and regulators.

Bankfull Regional Curves for the Coastal Plain Physiographic Province of North Carolina

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Bankfull regional curves relate stream-channel geometrics to watershed basin areas for specific physiographic regions. This paper presents bankfull-curve information and recurrence intervals for the Southeastern Plains and Middle Atlantic Coastal Plain Ecoregions of North Carolina's Coastal Plain physiographic province. Cross sectional and longitudinal survey data from gage-stations and un-gaged stable reference reaches were used to compute channel dimension and profile information. Power-function regressional analysis generated watershed size-dependent relationships for bankfull discharge, cross-sectional area, width and mean depth. Partial-duration methods, which utilized average daily discharge values at the gaged sites, determined that return intervals for bankfull events ranged from 0.11 to 0.59 year, with an average 0.23-year period. However, near-level water gradients associated with muck-soil topographic flats found within the Outer Coastal Plain create site-specific hydraulic bankfull geometrics that are unique from the rest of the Coastal Plain province.

Sediment Resuspension in the Pamlico and Neuse River Estuaries: A Potential Source of Nutrients

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The Neuse and Pamlico river estuaries are shallow, dynamic systems that have been plagued with symptoms of eutrophication over the past two decades. Extensive research has been conducted over the last 5-10 years to better understand the complex nutrient dynamics of these systems. However, most of these studies have concentrated on nutrient cycling in the water column. Only recently have studies focused on the benthic environment, and most sediment studies have neglected the dynamic nature of the benthos, focusing instead on diffusion as the dominant transport process delivering nutrients to the water column. Although diffusion of nutrients across the sediment/water interface may be important during quiescent periods of sediment deposition and short-term storage, wind events associated with storms throughout the year will resuspend newly deposited sediments resulting in the advective transport of sediment porewater, rich with nitrogen, phosphorus and carbon, into the water column. Sediment resuspension may increase water column nutrient concentrations, and therefore present estimates of nutrient and carbon inputs from the sediments may be too low.

An on-going project is attempting to estimate short-term sediment dynamics and flux of nutrients released to the water column from natural resuspension events in these two estuaries. Sediment cores at 9 sites in the estuaries have been collected at least bi-monthly since May 2001. The short-term rate of sediment deposition is being evaluated using Cs-137 and the naturally occurring radionuclides Be-7and Th-234. Porewater nutrient inventories at all sites have also been determined. This technique will allow evaluation of the depth to which sediments have been disturbed and the advective flux of nutrients to the water column. Evaluating this advective flux of nutrients to the water column is crucial to understand estuarine nutrient cycling. The temporal and spatial relationships of sediment deposition and porewater concentration in both estuaries will be discussed, as will preliminary results for Be-7 and Cs-137 activities. The results of a laboratory study to evaluate nutrient (N and P) contributions to the water column from resuspension will also be discussed.

The results of this study will provide a more informed conceptual model of these estuaries upon which to base future policy decisions such as the setting of total maximum daily loads (TMDLs).

Patterns in Sedimentation Rates in the Neuse River Estuary

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Sedimentary organic matter in the Neuse River estuary functions as an important "time-release" source of nutrients and oxygen demand. The magnitude of this source ultimately depends on the rate at which detrital material is deposited in the sediments. The purpose of this study is to discern spatial patterns in sediment deposition rates throughout the Neuse estuary. We have measured vertical distributions of excess ^{210}Pb and bomb fallout isotopes (^{137}Cs and/or ^{239,240}Pu) in cores collected at 13 sites from New Bern to Pamlico Sound. Sedimentation rates are evaluated by applying numerical models to both excess ^{210}Pb and fallout isotope data; these models allow for episodic deposition or erosion in cases where the isotope data are inconsistent with steady accumulation. The use of two distinct tracers allows us to deconvolve the effects of particle deposition and benthic mixing, and provides a more reliable constraint on sediment accumulation rates. As expected, sedimentation rates in the Neuse follow a complex pattern that appears to be related to geomorphology. Deposition rates in the narrow, upriver portion of estuary near New Bern are less than 0.5 mm y^{-1}, but increase dramatically (4 to >8 mm y^{-1}) when the river widens below Broad Creek. This region of high sediment accumulation corresponds to the area where sediments are richest in organic matter (8% organic carbon) and bottom water hypoxia is prominent during the summer. Sedimentation rates decrease when the estuary narrows at the bend near Cherry point (1 mm y^{-1}), and then generally increase toward Pamlico Sound with values approaching 10 mm y^{-1} offshore of Oriental. Sedimentation rates increase linearly with inventories of excess ^{210}Pb ($r^2 = 0.93$), suggesting a relatively uniform ^{210}Pb content in settling detritus. However, the intercept is positive implying that particle-reactive materials are scavenged from the water column when sediments are resuspended.

Improving Endogenous Denitrification Rates in Secondary Anoxic Zones by RAS Addition

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Total Nitrogen (TN) removal in an activated sludge system is a two step process involving the conversion of ammonia to nitrate (nitrification) and nitrate to nitrogen gas (denitrification). The degree of denitrification is typically the limiting factor in determining the achievable target effluent TN concentration from any given system. For municipal plants with low effluent TN NPDES permit limits (<5 mg/L), secondary anoxic zones are commonly utilized for nitrate-N polishing. Since there is a lack of available carbon source after the aeration zone, denitrification is limited to that obtained by endogenous respiration. The endogenous rates associated with these zones are typically very low (10 to 20% of that of exogenous denitrification rates observed in primary anoxic zones), therefore basin volumes must be large. In addition, an external carbon source such as methanol is often necessary. A Return Activated Sludge (RAS) bleed-off enhancement can be used to increase the biomass concentration and the denitrification enzyme activity in the secondary anoxic zone, thereby improving the overall denitrification capability. This modification involves introducing a fraction of the RAS directly to the first stage of the secondary anoxic zone and does not affect the aerobic food to mass ratio.

A full scale evaluation was conducted at the North Cary WRF to quantify denitrification rate, nitrite reductase activity (NiR) and nitrate reductase activity (NaR) in the secondary anoxic zone with and without the RAS bleed-off. The facility employs two identical BNR treatment trains consisting of a phased oxidation ditch process and consistently achieves effluent TN concentrations of less than 3 mg/L without the benefit of external carbon addition. The facility is able to isolate each train and its associated secondary clarifier and RAS pump station. The RAS bleed-off enhancement was implemented in one of the trains, while the second train was used as the control. The results of this study indicate that this modification can increase the secondary anoxic zone denitrification rate and the facility's overall nitrogen removal capacity.

Heavy Metal Removal from Leachates at Two Industrial Disposal Sites by Adsorption/Co-Precipitation onto Metal Oxides in a Fluidized Reactor

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The MetClean™ process, developed by Kruger A/S for removing a range of dissolved metals, is an oxidation and adsorption process in a fluidized reactor. The adsorption media used in the fluidized reactor are iron oxides-coated or manganese oxides-coated quartz sands. During operation, raw water is introduced at the bottom of the column to generate fluidization of the media. At the same time, an appropriate amount of Fe(II)/Mn(II) and as well as oxidizing agent (e.g., O_2, $KMnO_4$, or H_2O_2) are injected through the feed stream. The Fe(II)/Mn(II) ion is adsorbed on the media surface followed by oxidation of Fe(II)/Mn(IV) on the surface into Fe(III)/Mn(IV) oxides. Metal ions are adsorbed on to the newly formed iron or manganese oxides simultaneously. Pilot studies of the MetClean™ process were conducted for metals removal from leachates at two industrial disposal sites – Robdrup and AV Miljø in Denmark. Robdrup site is a closed-down gravel pit that has been used to dispose coal fly ash. Major concern for this leachate is Cr(VI) (3.5 mg/L). MetClean™ process with iron oxides-coated sands as media was used in the testing.AV Miljø site is a disposal site for non-combustible residues from a solids waste incineration plant. The most concerned pollutants in the leachate from this site are Pb(II) (172 ppb) and Cd (II) (75 ppb). MetClean™ process with MnO_2 coated sands as media was used in the testing. The results from the above two studies demonstrate that the MetClean process is capable of removing dissolved heavy metals, both anions and cations, from the leachates generated from the two industrial disposal sites. The effluent concentrations obtained by MetClean™ process are at least comparable to those from traditional precipitation processes. The MetClean™ process performance was governed first by chemical dosage and second by process configuration and degree of fluidization. Competition for adsorption among different metal ions was observed during the tests. The removed residual granules from the process are very dense and compact like sands. These granules can be easily drained and dried completely at ambient air temperatures without the need of thickening and dewatering. The residual production from the MetClean™ process is about 10-20% of the aqueous chemical sludge produced in traditional precipitation processes. The residue generated from the MetClean™ process is very stable and can easily pass the USEPA's TCLP Test; therefore, it can be landfilled.

Watershed Delineation and Comprehensive Stormwater Network Inventory Methods Using GIS/GPS Technology

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Watershed-based management planning is a strategy for effectively protecting and restoring aquatic ecosystems and protecting human health. Geographical Information System coupled with Global Positioning System (GIS/GPS) technology is a valuable tool for constructing geocoded comprehensive stormwater drainage networks and delineating watersheds. GIS/GPS technology was recently applied at the Cherry Point Marine Corps Air Station, an 11,000-acre peninsula that drains into the Neuse River estuarine system on the Coastal Plain of North Carolina. The initial delineation of natural watersheds was accomplished with ArcView Spatial Analyst using Digital Elevation Model (DEM) and Digital Line Graph (DLG) data available from the US Geological Survey. Using high-resolution photographs, topographic overlays, existing data sets, and field delineation of streams and open ditches, a comprehensive stormwater drainage network was constructed. The contiguous sequence of stormwater network entities within each watershed was cataloged and geocoded. Five stormwater network entities (SWNE) were identified: subsurface stormwater network (piped); open stormwater network (ditches); ephemeral channels; streams; and surface water bodies. The upland SWNEs (pipes, ditches, and ephemeral channels) were delineated as linear features (lines) and the hydrographic areas (streams and open water) were delineated as areal features (polygons). Artificial paths (lines) completed the transport reach network through the hydrographic areas. Innovative data-collection methods included real-time GPS tracking and data capture on ArcPad (a handheld GIS platform) using Pocket PCs. The NC Division of Water Quality provided technical guidance on stream identification. Over 350 stream identification worksheets were completed at intermittent headwaters (i.e., the ephemeral/intermittent boundary). Twenty-one miles of modified and natural streams and 91 miles of open ditches were delineated and geocoded. Finally, watershed delineations were refined through field verification and interpretation of site-specific topographic data. This work facilitates rapid emergency spill response and has enabled the Air Station to develop a watershed-based management plan for addressing a wide array of water quality issues including state and federal compliance requirements for wetlands, stream buffers, and Phase I&II Stormwater NPDES Permitting.

Predicting Surface Water Movement using USEPA SWMM and GIS for a Watershed at Cherry Point Marine Corps Air Station

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The Marine Corps Air Station (MCAS) at Cherry Point near Havelock, North Carolina, is a military installation that contains a large urbanized area with lands ranging from residential areas to runways. Previous studies have documented the potential for runoff of oils plus other wastewater and their impacts on surface and subsurface ground water quality. The effects of surface storm water runoff on the transport of pollutants from various points within the MCAS to surface waters have not yet been documented. The purpose of this study is to apply the US EPA Storm Water Management Model (SWMM) to estimate flow rates and velocities, at distinct points on the flow paths within a basin of the MCAS at Cherry Point. The need to document and understand the flow paths has prompted the creation of a Geographic Information Systems (GIS) database of the drainage basin and stormwater network for the industrialized section of the basin.

Pollutants accumulated on the surface may be transported by storm flow into the drainage network. The storm flow travel path and its distance in the drainage network are generally measurable, but flow rates/velocities can vary. Thus, the model must be capable of tracking surface water routes and flow rates. In order to apply the model, it was first parameterized, calibrated and verified with data collected from the basin. The data includes a GIS spatial database of the basin characteristics, plus precipitation and storm flow rates at the basin outlet that has been continuously monitored since September 2000. Design rainfall events of varying return periods will be used to estimate the shortest travel times based upon predicted peak flow rates and velocities within a basin. The results will be used to document flow rates, their distribution at specific points and to estimate travel times (within the basin) for storms of various sizes and durations. This information will be useful in managing the storm water/pollutant movement on the MCAS.

Microsand Ballasted Flocculation and Clarification for Treatment of Storm Water Overflow into Wastewater Treatment Facilities

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Inflows of excess storm water into domestic sewer systems often poses a dilemma to conventional wastewater treatment facilities. When flows exceed the wastewater plant's hydraulic capacity, the choices are to attempt to treat the excess flow and risk a "washout" resulting in a temporary loss of treatment capability altogether; or, to bypass the excess flow around the treatment process resulting in discharge of untreated wastewater. Either recourse results in detrimental impacts to surface water resources not to mention possible legal ramifications for the facility due to NPDES permit violations. During October of 2000, the city of Greenville, NC conducted a pilot study to evaluate microsand-ballasted flocculation for treatment of excess wastewater flow created by contributions from storm events.

Microsand ballasted flocculation employs fine sand, which enhances floc formation and acts as a ballast agent to reduce hydraulic detention time and increase the nominal overflow rate up to 60 GPM/ft^2. The low retention time and high overflow rate reduces system footprint by more than 80% compared to conventional coagulation/ flocculation/clarification processes and allows the process to achieve steady state effluent conditions within 15-30 minutes of start-up. Both of these attributes make the process attractive for treatment of high volume intermittent flows.

Objectives of the study were to:
1) Demonstrate the process as technically viable for storm water overflow treatment; and
2) Establish process design parameters should design of a full-scale facility be pursued.

The pilot study was conducted with raw wastewater influent under dry weather conditions as well as simulated combined storm water/wastewater flow by diluting the raw influent with treated effluent. Chemical dosages for coagulant and polymer were optimized and overflow rates ranging from 30 GPM/ft^2 to 90 GPM/ft^2 were evaluated.

The process demonstrated insensitivity to varying influent conditions achieving stable and comparable results for nearly all flow conditions tested. TSS removal of 80% - 95%, COD removal of 40% - 60%, Ortho-Phosphate removal of 85% - 97%, and reductions in Fecal Coliform counts of 90% - 99% were achieved throughout the study. This presentation will further detail the methodology and results of the pilot study and briefly describe several full-scale facilities currently being designed to employ microsand ballasted flocculation for storm water overflow treatment.

Most Pollutants Delivered to Receiving Waters in a Few Events Annually - Implications for Measuring and Managing Non-point Source Pollutants

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Eighty percent of all sediment and nutrients from agricultural fields was delivered to grassed and forested filter zones by roughly 20 to 25 percent of all rainfall events over a ten year study period in Granville County, NC. On the same two watersheds, one storm event in December, 2000, delivered as much sediment as all the prior events combined in the two-year study period. Similar results were obtained in Wake and Wayne Counties, respectively in the lower Piedmont and upper Coastal Plain. These major rainfall events were usually very intense events that often occurred when antecedent moisture was high, thus infiltration capacity was low, and when agricultural fields were without much vegetation. Level spreaders (closed-end trenches on contour, designed to release water in sheet flow) into grassed and forested filter zones have been very effective even during these major storm events. In contrast, grassed filter zones repeatedly failed to remove sediments and nutrients during many of those same events. In fact, in the latter part of the growing season, grassed zones were often net contributors of sediment to the forested zones. We recommend use of grassed zones in conjunction with forested zones, but grassed zones alone will usually be insufficient, by themselves, to deal with major storm events. This conclusion is diametrically opposed to suggestions by some that major events be allowed to bypass treatment facilities such as level spreaders, for example. These results also have implications related to effective measurement and monitoring of pollution from non-point sources. For example, the 10% exceedance allowance used with many TMDL rules could be routinely exceeded as major storm events impacted small headwater streams, lakes and ponds unless very effective measured are used to decrease accelerated sedimentation and nutrient movement. In summary, any system that does not effectively handle the big storm events is an almost totally ineffective system because those few major events deliver the vast majority of all sediment and nutrients to receiving waters.

Jordan Lake Nutrient Response Model Calibration

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The B. Everett Jordan Reservoir ("Jordan Lake") is considered by the NC Division of Water Quality to be one of the most eutrophic lakes in the State, and legislation enacted in 1997 requires wastewater treatment facilities in the lake's watershed to meet a total nitrogen limit of 5.5 mg/l by January 1, 2003. This is a generic limit applicable to all designated Nutrient Sensitive Waters, and is not based on an analysis of nutrient response in Jordan Lake. NC General Statute 143-215.1 provides for, as an alternative approach, the determination of site-specific wasteload allocations through use of a calibrated in-lake nutrient response model. The nutrient response model must be capable of predicting the impact of nitrogen and phosphorus loading to lake water quality, and will be used to evaluate the potential for alternative nutrient limits for the wastewater treatment facilities. To achieve these goals, the model must be able to evaluate the impacts of changes in nutrient limits for each wastewater treatment facility, some of which are located upstream in the Haw River drainage and others of which discharge only short distances from the New Hope arm of the lake. Complex flow patterns in the lake, including intermittent stratification and reversing flow between the Haw River and New Hope arms, result in a complex interaction between loads discharged to different portions of the lake and requires a sophisticated approach to lake hydraulics. Evaluation of response to nutrient loads must address co-limitation on algal growth by light availability, phosphorus, and nitrogen. The response model developed for the lake combines the EFDC hydrodynamic model, the WASP water quality model, and an analysis of delivery from upstream watershed sources. The WASP water quality model is imposed on top of the EFDC hydrodynamic and thermal simulation, using an aggregation to larger spatial scale and longer time steps. Calibration of the water quality simulation relies in part on use of iterative, parameter optimization methods implemented through a generic software package called OPTSHELL. We present the results of calibration of the water quality model for nutrients, dissolved oxygen, and algae and will discuss the implications for potential management alternatives.

Development and Application of a Linked Watershed-Water Quality Model for Lake Lanier, Georgia

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Lake Sidney Lanier, Georgia, is the most heavily used U.S. Army Corps of Engineers (USACE) recreational reservoir in the United States. It is used for boating, fishing, drinking water supply and effluent discharge. While the lake presently has good water quality, it is threatened by rapid expansion of the Atlanta metropolitan area into the watershed that is expected to bring additional water supply demand, wastewater flow and nonpoint source runoff. The principal water quality concerns are excessive algal growth, water clarity and low dissolved oxygen in deeper waters, driven primarily by external phosphorus loadings. This project consisted of the development and application of a linked watershed-water quality model for Lake Lanier to help evaluate the potential impacts of alternative watershed and lake management strategies on water quality in the reservoir.

The watershed model was a version of the Generalized Watershed Loading Function (GWLF) model, modified to provide automated linkages to a GIS database for 35 subwatersheds and to provide continuous daily simulation results. The water quality model was a version of the CE-QUAL-W2 model developed by the USACE, modified to include manganese and branching around several mid-lake islands. The two models were calibrated to data collected during 1996-1997 as part of this study and validated to an independent set of data collected as part of a 1991 Clean Lakes study. Approximately 33,000 field measurements were collected during this study to support model application.

The calibrated models were used to evaluate a range of future development and water resource management scenarios. Model forecasts were conducted using five-year continuous simulations with historical environmental conditions from the period 1984-1988. This period contained extreme observed values for both temperature and rainfall. Forecast results from all scenarios indicated significant deterioration in Lake Lanier water quality compared to present conditions, primarily due to runoff from expected heavy development in the watershed. Nutrient loadings from wastewater treatment plants and septic systems were much less important. This study demonstrated the feasibility and utility of a linked watershed-water quality management tool, and it indicated that without changes in land use policies, deteriorated water quality is an inevitable consequence of future development in the watershed.

Annual Salinity Patterns and Seasonal Pycnocline Structure in the Neuse River Mesohaline Estuary

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The mesohaline Neuse Estuary is impacted by surface inputs from upriver and tributary freshwater sources and by bottom inputs from downriver high salinity sound water sources resulting in varying degrees of stratification. To gain a more complete initial assessment of the depth-dependent estuary-wide changes in salinity, a multiple time series was created using data from four discrete depths (surface and 1, 2 ,3 m). These data were obtained from a nine-year physical-chemical data (1993-2001) with weekly and biweekly frequency. The overall goal was to strengthen understanding of depth dependent variability, seasonal variability and variability related to extreme events, such as high precipitation events and hurricanes. The first two years of the record exhibit an expected seasonal signal and included events that impacted the surface layer from freshwater inputs. Thereafter, the data were more variable with higher maxima and minima over seasons and at all depths. Freshening events affected all depths and caused rapid decreases in salinity (e.g. salinity decrease from ~ 10 to ~ 1 ppt). The time series data for all stations revealed an increase in variability in the remaining years compared to the first two years. The impacts of wind field, hurricanes and small time scale high precipitation events represented a significant forcing. We also use this extensive nine-year database to compare pycnocline depth at specific geographical locations, to estimate the depth of the dissimilar water masses that occur depending on location and seasonal variation in precipitation and circulation patterns. This analysis produced a “snapshot” view of the relative depth of these water masses within the estuary by season (statistcally designated as spring, summer and winter). The pycnocline depth for these paired stations was then statistically analyzed for transect position, north/south shore position and seasonal effects using a SAS mixed model. The presence of low dissolved oxygen (<4.0 mg/l) in all hydrocast data were also examined to determine relative occurrence on the basis of geographical location and season. We have augmented physical-chemical data with flow pattern data acquired by a boat-mounted acoustic doppler profiler (ADCP). Composite visualizations constructed with single-transect data have shown classical estuarine circulation pattern of outflow at the surface/southern shore and inflow at the bottom/northern shore. Although this pattern deviates under extreme climatological events and is sometimes variable, the areas generally have exhibited a high probability of direction of flow.

High Resolution Monitoring of Physical and Chemical Conditions at Two Sites in the Mesohaline Neuse Estuary

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The Neuse Estuary has been highly impacted by agricultural and urban development. Bottom-water hypoxia/anoxia, toxic *Pfiesteria* outbreaks, and major fish kills have occurred frequently, and nitrogen loading has significantly increased within the past decade. Automated instrument platforms (spring 2000) allowed the remote monitoring of various phenomena on long and short time scales. These were installed in off-channel sites that were selected based on data showing high ambient nutrient concentrations, recurring fish kills, phytoplankton bloom and unique hydrologic steering patterns. Among many parameters measured at these stations, parameters measured on an hourly basis include wind speed and direction, air temperature, relative humidity, incident solar radiation, water level, dissolved oxygen (DO), salinity, water temperature, pH, redox and precipitation. Computer controlled profilers are present on specific platforms to take physico-chemical casts of the entire water column upon demand. High resolution data acquired from these profiler equipped platforms have revealed wind dependent water level variability, cross estuary upwelling and the rapid movement of low dissolved oxygen/high salinity water masses parallel to the shoreline. Approximately 2400 discrete Hydrolab casts taken at three-hour intervals illustrate site-specific differences in dissolved oxygen, salinity, temperature and pH on a seasonal and event basis. The rapid upwelling of a high salinity and low dissolved oxygen water mass which resulted in fish mortality was documented at 3-hrresolution over an entire 8-day period. These data were posted to a public domain website for use by water resources stakeholders and the general citizenry. The volume and area of the water column affected by high-salinity/low DO water is easily quantifiable using these high resolution methods. Cross estuary variability in salinity structure is evident and has been related to freshwater inputs from upriver in combination with circulation patterns. Phytoplankton blooms are readily detected by using high pH readings (> 8.0) as an indicator for high rates of photosynthesis.

Characterization of a Widespread and Persistent Seasonal Dinoflagellate Bloom in the Upper Neuse Estuary

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In recent years, seasonally persistent dinoflagellate blooms have been documented in portions of the mesohaline Neuse Estuary. The blooms often encompass a large areal extent and typically have been comprised mainly of two dinoflagellate species: *Heterocapsa triquetra* and *Prorocentrum minimum.* The goal of this study was to examine the spatial distribution of a recent, more unusual dinoflagellate bloom in the upper estuary as related to a number of environmental variables toward determining possible causes of the bloom formation. During the past decade, our Center has collected a wealth of physical, chemical, and biological data from the Neuse Estuary as part of an intensive monitoring and research project. Phytoplankton sampling has allowed us to identify and enumerate many key taxa, and has enabled considerable insights about the ecology of this nutrient sensitive ecosystem. Samples collected from the upper estuary in fall 2001 indicated that a major bloom dominated by *Prorocentrum minimum* was in progress. Cell densities were especially high at the confluence of the Neuse with the Trent River, with P. *minimum* concentrations approaching 200,000 cells/mL. Such densities are among the highest ever reported for a dinoflagellate bloom. While the lower Neuse and Trent Rivers are not usually brackish, eastern North Carolina had sustained a prolonged drought for the previous two months and saline waters (salinity up to 10) had extended up-river. The brackish conditions, in combination with hydro-meteorological forcing and high nutrient supplies, likely predisposed the upper estuary to develop this bloom of estuarine dinoflagellates that historically has been centered in the mesohaline estuary near Carolina Pines. Research is ongoing at our Center to further examine the physiology of this and other bloom-forming dinoflagellate species in the Neuse, with the ultimate goal of developing predictive models for bloom development and dissipation.

Molecular Characterization of the Harmful Nitrogen-fixing, Cyanobacterial Bloom-former *Lyngbya wollei* in Freshwater Environments

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Lyngbya is a cosmopolitan, non-heterocystous benthic cyanobacterial genus found in both freshwater and marine environments. *Lyngbya* is often found in nutrient-deprived waters, but can undergo explosive growth in response to eutrophication. Fishermen and swimmers have experienced respiratory irritation, eye inflammation, and contact dermatitis from exposure to *Lyngbya* blooms. In High Point, North Carolina, *L. wollei* has recently bloomed in a water treatment facility lake (City Lake), posing a serious drinking water problem. These blooms have reached unprecedented densities according to a 16-year record. Currently, we are growing *L. wollei* from City Lake on agar plates with and without combined nitrogen. Results from a diel study of *L. wollei* in City Lake in September 2001 show that the *L. wollei* bloom was fixing nitrogen in the early morning hours. Many bloom-forming cyanobacteria utilize N_2 fixation for obtaining biologically available nitrogen (NH_3) under N-limited conditions. The *nif*H gene, which encodes for the Fe protein subunit of the N_2 fixing enzyme nitrogenase, is highly conserved and therefore useful for identifying and characterizing N_2 fixing microorganisms. Using a protocol that removes potentially inhibitory (for the PCR reaction) extracellular polymeric substances (EPS) without damaging the DNA, we extracted and amplified the *nif*H gene from diverse *Lyngbya* species in Guam, Australia, Florida, and North Carolina, including *L. wollei*. We are using *nif*H sequence data to identify and characterize closely related, but potentially harmful, *L. wollei* strains capable of rapid expansion and toxic bloom formation.

Molecular Approaches for Identifying and Characterizing Harmful Nitrogen-fixing Blue-green algae (Cyanobacteria) in Eutrophying North Carolina Estuaries

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The detection and accurate identification of potentially-toxic blue green algal (cyanobacterial) species is essential for monitoring the distribution and expansion of this group of harmful algal bloom (HAB) organisms. The detection of cyanobacterial species before they reach bloom proportions is essential in lakes, estuaries, and water reservoirs, especially those used for drinking water and recreation. Molecular genetic approaches are particularly useful because of their ability to differentiate between strains and detect HAB species at low densities. The spatial and temporal distribution of N_2 fixing cyanobacterial populations in the Neuse River Estuary, which has a history of cyanobacterial blooms, was investigated based upon the *nifH* gene. This gene is highly conserved and encodes one of the enzymes involved in N_2 fixation. The *nifH* gene was present in the Neuse River Estuary, NC during most of the year, with *Anabaena* sp. and *Anabaenopsis* sp. the most common species identified. Another problematic cyanobacterial HAB species is *Cylindrospermopsis raciborskii*, recently becoming prevalent throughout Florida, particularly in the St. Johns River System. Based upon genetic sequences of the *nifH* gene in *C. raciborskii* found in Florida, a PCR-based method was developed for specifically detecting this species in environmental samples. This method was used to look for *C. raciborskii* in the Neuse River Estuary, as well as local water supplies. *C. raciborskii* was identified in some water reservoirs, though not in the Neuse River Estuary at the times sampled. Analysis of the *C. raciborskii* populations based upon *nifH* revealed a population with relatively high similarity to the Florida strains. Thus, these molecular tools have proven very useful in the detection of toxic cyanobacterial species in eutrophying estuaries, including those in the Albemarle-Pamlico system.

Strontium Isotopes and Major/minor Elements in Shallow Groundwater and Coastal Surface Water from Eastern North Carolina

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Following sampling in July, 2000 and April/November, 2001, water samples from aquifers, tidal creeks, the Intracoastal Waterway, and springs in southeastern NC were added to a growing database needed to develop geochemical methods for: 1) characterizing water from various groundwater and surface water reservoirs, 2) quantifying groundwater discharge into estuaries and the coastal ocean, and 3) investigating saltwater intrusion into coastal aquifers. In the northern coastal plain (NCP) the downgradient evolution of $^{87}Sr/^{86}Sr$ ratios and strontium concentrations [Sr] in Castle Hayne (CH) groundwater indicates two-component mixing combining increasing proportions of Sr from CH Limestone ($^{87}Sr/^{86}Sr = 0.70775$) with a single Surficial Aquifer (SA) groundwater having the highest $^{87}Sr/^{86}Sr$ ratio (0.711332) and low [Sr]. Such a model does not provide a good match for the southern coastal plain (SCP) where values plot between the NCP mixing line and a similar mixing line calculated for the SCP. Explanation of the Sr evolution of SCP groundwater apparently requires several mixing lines generated from a range of SA endmembers or mixing with groundwater from the SA or surface waters. The geographic complexity of the CH isotopic (and chemical) data in the SCP, may be due to the shallow, frequently unconfined nature of the aquifer, permitting more leakage from other aquifers or surface water. In the NCP the CH is deeper and more tightly confined. With one exception, water from the Cape Fear and Northeast Cape Fear Rivers plots on a mixing line calculated by combining river water from far upstream with various proportions of seawater. Samples from farthest up a tidal creek and local springs plot between the NCP and SCP SA/limestone mixing lines and at lower $^{87}Sr/^{86}Sr$ ratios than local river water, indicating the influence of groundwater input from limestone aquifers. Principal Components Analysis (PCA) of groundwater chemistry consistently reveals that three factors account for 70-95% of the variance. The two dominant factors are related to saltwater intrusion and dissolution of carbonate aquifer materials. Factors 3 and 4, correlate highly with pH and SiO_2 but are as yet uninterpretable in terms of the responsible geochemical process. On bivariate plots of PCA regression factor scores for factors 1 and 2: 1) CH samples in the NCP show more well-defined geographic clustering than in the SCP, 2) CH samples in the SCP are inseparable from those of the Peedee Aquifer, and 3) samples from the SA are usually distinguishable from those of other aquifers.

Hydrology and Water Quality of Lower Coastal Plain Watersheds in North Carolina

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A 10,000 ha lower coastal plain watershed near Plymouth in eastern NC has been intensively monitored since 1996 to measure hydro-meteorological parameters including outflows and quality of water drained from fields and subwatersheds with varying land management practices. This study summarized the data for a five-year period (1996-2000) for a 2950 ha forested, a 710 ha agricultural subwatershed and a 8140 ha watershed comprised of agricultural, forested, and riparian lands. The period covered a wide range of weather conditions from a dry year with annual rainfall of 993 mm in 1997 to a wet year with 1460 mm of rain in 1996. While 1998 (1253 mm of rain) experienced a wet winter and a prolonged dry summer-fall, the conditions were opposite in 1999 (1302 mm of rain) with three major hurricanes. A near normal rainfall (1219 mm of rain) was observed in the year 2000. The average annual potential evapotranspiration varied from 942 mm in 1996 to 1029 mm in 1999. Measured water table depths in the experimental fields were consistent with the weather pattern.

The runoff/rainfall (R/R) ratio varied from 0.15 in 1997 to 0.32 in 1996 for managed forest (S4) with mostly organic soils and from 0.32 in 1997 to 0.44 in 1998 for agricultural subwatershed T4 with mineral soils. The 8140 ha mixed land use watershed (C7) yielded an average R/R of 0.38 for the 1998-2000 period. Both the magnitude and frequency of occurrence of peak flow rates in subwatershed T4 were much higher than in the forested subwatershed S4, as expected.

Nitrogen concentrations varied greatly with time within each subwatershed. The TN concentrations observed at the C7 outlet were 25 to 60% lower than those observed at the S4 outlet located 11 km upstream of C7. The variation in N concentrations was also dampened as the drainage water moved though the reaches of the channels. Due to variation in both the outflows and concentrations, the range of TN loads delivered at the outlets were 6 to 9 kg ha^{-1} for dry years and 20 to 27 kg ha^{-1} for wet years. Most of the TN loads were in organic form. Concentrations and loading rates of other constituents were also analyzed and reported. While data from this study was used to develop and test watershed scale hydrology and water quality models, these data can be used to quantify water and nutrient balances of the coastal watersheds with varying land management practices.

Non-lethal Permanent Beaver Management: Use of a Trapezoidal Shaped Fence System to Prevent Dam Construction

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Hydrology is being monitored in a Carolina Bay in Robeson County, North Carolina as part of a wetland restoration program. Surface outflow from the bay is being measured to create a water budget. Due to damming activities of beavers, *Castor canadensis,* the weir has been periodically blocked, causing inaccurate outflow measurements. The objective of this work was to develop and test a non-lethal method for controlling beavers. Beavers are endemic to the area, but since they were causing no real damage, a non-lethal, permanent method to keep them away was devised. A wildlife biologist (S. Lisle) in Maine developed a non-lethal beaver management method, which has received little attention. The Lisle method uses wire mess to create a trapezoidal shape fence in order to keep beavers away from road culverts. Beavers will dam against the fence near the culvert and will eventually stop damming as they move away from the culvert. For this reason the fence needs to be at least 6 m long. Following Lisle's design a trapezoidal shaped fence system was installed and tested to determine if this is an effective beaver control method. The fence system consisted of three 6 m sections of 6 inch by 6 inch 10 gauge mess fence attached to metal fence posts. The floor of the fence system was not enclosed at first, which allowed the beavers to dig under the fence and continue their damming activity. A floor made out of the same wire mess was added to the enclosure to provide complete protection from beaver intrusion. After three months of testing and some adjustments, the fence has been able to control the beavers. The trapezoidal shaped fence system appears to be an effective method of beaver control when non-lethal beaver management is practical. This system can be installed around weirs, culverts, ditches and other water flow structures allowing the trapezoidal fence system to become a widely used means of beaver control.

Evolution of Oxygen Isotope and Major Element Geochemistry of Groundwater from the Shallow Aquifers of Eastern North Carolina

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Samples of groundwater and surface waters in southeastern North Carolina were collected in July 2000 and April 2001 and added to a growing database as part of an effort to determine the reactions controlling groundwater chemistry and evolution along chosen flowpaths. Urban development along the coastline relies heavily on groundwater from shallow limestone and calcareous sandstone aquifers including the Tertiary Castle Hayne (CH) and Cretaceous Peedee (PD), which dip and thicken eastward. In the Northern Coastal Plain (NCP), these aquifers are confined, deeper, and distal flow paths are farther from the recharge area, whereas these aquifers are often unconfined and shallower in the Southern Coastal Plain (SCP). Based on chemical data, water in the coastal plain tends to be Ca- or alkali-rich and HCO_3- or Cl-rich. d18O values for water from the Surficial Aquifer, CH, and PD in the SCP range from -5.37 to -4.01, -5.22 to -3.52, and -3.95 to -2.68, respectively. These CH values show enrichment relative to modern recharge and fall nearer the average d18O of modern precipitation than NCP values – reflecting shorter groundwater flowpaths in the SCP. Groundwater d18O for the eastern-most CH in the NCP is more positive (up to -3.12). As for the Floridan Aquifer in South Carolina and Georgia (Plummer, 1993), more positive values downdip are consistent with the idea that CH groundwater from the NCP preserves a record of d18O of meteoric water recharging the aquifer in the past. This inference depends on there having been no significant leakage from surface waters or other groundwater. Consistent with data from the NCP, the SCP d18O values are most negative in aquifers at the top of the stratigraphic section. However, patterns of geographic change in d18O of the SCP show less regularity than those in the NCP. Contour maps of the area fail to delineate a clear pattern of change in d18O values along flowpaths in the SCP. Artesian spring d18O values from the SCP (-4.75 to -2.96) are consistent with a CH groundwater source. However they are also similar to other surface waters in the region, including the Northeast Cape Fear River and tidal creeks (-3.64 to -2.5, -4.36 to 0.94, respectively). Use of multiple geochemical tracers will be necessary to sort out groundwater – surface water interactions, and exchange between aquifers.

Optimizing Water Acquisition in the Edwards Aquifer Region: A Decision-making Framework for Municipalities

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The steadily increasing demand for water has lead to a depletion of available ground and surface water sources in the United States. Recently, the Edwards Aquifer (EA) region in Texas has been faced with the problem of water scarcity. Environmental concerns over declining aquifer levels and springflows have resulted in the first ever issuance of groundwater pumping permits in Texas. Pumping discharge from the aquifer, which reached 530,000 AF during dry years, will be limited to 400,000 AF in the near future. Municipalities in the region, especially San Antonio, once completely dependent on the aquifer to meet demand, must now find alternative sources to prevent a shortfall. As a substitute to seeking water elsewhere, which would be expensive, deplete other water supplies, and not be available in the short-term; a more efficient solution is to trade the existing water rights to the highest valued use. EA water rights are currently sold and leased, typically involving transfers from agricultural users to municipalities. However, municipalities that are using the market are also planning capital-intensive water supply projects due to the perceived additional reliability in meeting demand that these projects can provide. By introducing contingent transfers (options) into the market, this project develops an instrument that will enable municipalities to meet demand through a market at the same level of reliability and at a lower cost than the capital-intensive projects. Because municipal permits in the region are tied to the aquifer level, there is a high level of uncertainty in estimating the short-term need for additional water supplies. The use of options as an added alternative enables a municipality to make a small down payment at the beginning of the year to guarantee that they can buy water later in the year at an agreed upon price, if a shortfall occurs. To improve the municipality's knowledge regarding potential shortfalls, the model predicts monthly aquifer levels, monthly municipal demand for additional water, and the agricultural water rights available for trading. Using a simulation approach, the model finds the optimum market portfolio of purchases, leases, and options that minimize water acquisition costs while providing a desired reliability of meeting a municipality's demand. The decision-making framework embedded in the model should prevent or delay the need for capital expansion projects, significantly reducing the municipality and taxpayers' expenditures.

Modeling Sorption of Diuron and Lindane by an Aquifer Sand

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Sorption of hydrophobic organic chemicals by natural sorbents (e.g., soils and aquifer sands) is assumed to be a diffusion-limited process. Experimental evidence has demonstrated that the time required for a solute-sorbent system to reach equilibrium is related to the magnitude of the equilibrium distribution relationship, and, to some extent, particle size; both observations are consistent with a diffusion-limited process. Given the variations in equilibrium distribution relationships and particle size possible within a bulk sample, it is not surprising that homogeneous sorption rate model have met with only limited success in simulating the results of laboratory experiments. Over the past decade, sorption rate models that attempt to account for heterogeneities within natural sorbents have become popular. The most commonly used modeling approach treats sorption rates as a log normally distributed first order mass transfer process. An alternative modeling approach explicitly accounts for diffusion into a set of particles with a log normally distributed equilibrium distribution relationship. We have developed a set of models that are based on these approaches for modeling the results of sorption experiments conducted in batch and column reactors. In addition, we conducted experiments that investigated the sorption and desorption behavior of the pesticides diuron and lindane by an aquifer sand. We used the models to estimate rate model parameters from the results of the sorption experiments conducted in batch reactors and achieved excellent agreement between the data and model fits. The estimated sorption rate model parameters were used to predict the experimental results from the desorption experiments conducted in batch reactors and from the sorption-desorption experiments conducted in column reactors. In general, both modeling approaches predicted the general sorption-desorption behavior observed in the experimental systems. However, the models were unable to predict long-term behavior accurately. The modeling results suggest that the underlying statistical distributions used in the models may be inappropriate choices and that other distributional forms should be investigated.

Extent of Hydraulic Connectivity between Lake Norman and Wells Located on the Langtree Peninsula, Iredell County, North Carolina, A Preliminary Study

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In 2000 the Groundwater Section, in cooperation with the U.S. Geological Survey (USGS), Water Resources Division, began the installation of a monitoring well network on Langtree Peninsula adjacent to Lake Norman in Iredell County, NC. The monitoring well network consists of 12 piezometers and 6 monitoring well clusters, each consisting of a well in the regolith screened across the water table, a well screened across the transition zone, and an open-hole bedrock well. Prior to advancing the borehole for the deep wells, rock cores were extracted and logged. Immediately following completion of the borehole, the USGS logged each deep well using state-of-the-science downhole geophysical tools. The bedrock underlying the study site can be generally characterized as a quartz diorite with interfingered gneiss and granite. The transition between the saprolite and bedrock portions of the aquifer is defined by a zone of variable thickness that grades downward from sandy silt (ML) to partially weathered rock to fractured bedrock. Collection of groundwater elevation data on a weekly to monthly basis has been conducted since October 2000. One well cluster, outfitted with telemetry, has provided real time hourly water level data via the Internet, since March 2001. Water surface elevations are correlative between monthly measurements of groundwater in four of the deep monitoring wells and the lake. In addition, daily water level elevations were also compared between the most up-gradient well (~1,300 feet from the shore) and the lake. The daily water level data showed that water elevation fluctuations appear to be correlative between the two. However, heavy pumping from nearby public water supply (PWS) wells is expected to be a significant component of groundwater fluctuations in the up-gradient deep well. To assess the influence of PWS well discharges on the local groundwater table elevation, PWS records of daily discharge (gallons per day) were analyzed and compared to daily groundwater elevations in the up-gradient deep well. The preliminary analysis suggests that increases in groundwater withdrawal from nearby PWS wells over a two month period do not correlate with decreasing groundwater elevations in the deep wells. Mixing of lake water with groundwater is a concern especially within the capture zone of PWS wells that pump between 2 and 3 million gallons of groundwater per month. Analytical results from planned groundwater and surface water sampling events should indicate the extent of lake water/ groundwater mixing. In addition, results of planned aquifer tests should provide the necessary data to access the extent of influence that pumping has on the aquifer.

Spatial Distribution of Phytoplankton in the Neuse River Estuary: Challenges for the Development of Effective Sampling Strategies

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Sampling strategies designed to investigate the abundance of phytoplankton in aquatic systems must be developed with a strong consideration for the spatial and temporal variability of phytoplankton. In addition, data on physical and chemical attributes of the water body are essential in understanding patterns in phytoplankton abundance. While acknowledging the importance of small-scale variability, sampling regimes should be designed to pick up important larger scale trends in both time and space. In the Neuse River Estuary, much attention has been devoted to determining spatial variability in phytoplankton along the main axis of the estuary and temporal variability on the scale of weeks to years. Less attention has been paid to cross-river and vertical spatial distributions in phytoplankton and variability on shorter time scales from hours to days. This work examined the spatial distributions of phytoplankton in the cross-river and vertical dimensions and assessed the importance of each in determining large-scale patterns of phytoplankton distribution. The data indicate that no significant cross-river patterns exist over the time scale of several months. However, patterns in the vertical distribution of phytoplankton may strongly affect the ability to accurately measure water column chlorophyll *a* concentrations, the metric for phytoplankton biomass. A persistent, subsurface chlorophyll maximum at the depth of the pycnocline may be missed by discrete sampling at the surface and bottom of the water column. So, water column concentrations of chlorophyll *a* produced by averaging the two discrete water samples may produce significant underestimates. However, integrated sampling, an alternative sampling method, makes determination of important biological and chemical gradients in the water column impossible. A combination of discrete depth sampling and *in vivo* fluorescence profiles provides the data to construct an average water column chlorophyll *a* concentration without losing valuable information on the biological and chemical gradients in these shallow, highly stratified, systems.

Utilization of FITC-labeled Lectins to Analyze Cell Surface Glycoconjugate Components of Estuarine Dinoflagellates

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Previous research has indicated that analysis of lectin binding patterns can be an effective method to distinguish between dinoflagellate species, both from within the same genus and nontoxic and toxic strains within the same species. Carbohydrates, especially polysaccharides, can comprise between 80-90% of the extracellular compounds released from phytoplankton cells. Such compounds may vary according to physiological state, cell age, growth phase, and nutrient uptake. In this study, Carbohydrate binding probes were used to examine the distribution of their respective epitopes on the cell surface of selected dinoflagellates collected from the Neuse Estuary and Pamlico Sound. Ligand binding profiles of 21 FITC-labeled lectins were determined for *Heterocapsa triquetra*, *Karlodinum micrum , Pfiesteria piscicida*, *Pfiesteria* shumwayae and *Prorocentrum minimum. These organisms were cloned using flow cytometry, and the lectin binding* characteristics of accessible cell surface glycoconjugates were determined during maximum growth phase. The cells were preserved with 5%v/v formalin, and labeled with 50 *u*g/ml of FITC-labeled lectin. An epifluorescent microscope equipped with a triple band filter set (FITC-DAPI-Texas Red) allowed for the visualization of fluorescently bound ligand. For all assays, the first 100 cells observed (n=3) were profiled according to the quality of the staining and lectin localization. We found unique differences in lectin binding signatures among species and, in particular, between the two members of the toxic *Pfiesteria* complex. In *Pfiesteria* spp., differences in lectin binding characteristics may prove to be a useful diagnostic tool for differentiating among morphological stages and, more importantly, toxic and nontoxic strains.

Distribution Survey of Toxic *Pfiesteria* Complex Species in the Neuse Estuary: Correlation between PCR Analysis and Standardized Fish Bioassays

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Species of the toxic *Pfiesteria* Complex Species (TPC, at present consisting of two known toxic species as *P. piscicida* and *P. shumwayae*) form several types of temporary and resting cysts that can be found in estuarine sediments. Since TPC species generally are so ephemeral in the water column (usually lasting for hours to days), we hypothesized that evaluation of sediments would assist in determining their distribution based on detection of the cysts. During several surveys in spring/summer 2001, water and sediment samples were collected from 213 stations throughout the Neuse and Pamlico Estuaries. Species-specific molecular (PCR) probes have been developed for both *P. piscicida* and *P. shumwayae*, the PCR results can be confounded when used with sediment samples because of high interference from sediment debris. PCR analysis indicated that ~13% of the survey samples contained TPC species. For further confirmation of *Pfiesteria* presence and importantly, to asses whether isolates are of the toxic or non-inducible strains, all PCR-positive survey sites are being evaluated using standardized fish bioassays for toxic *Pfiesteria* detection. The data are being compared to data for control fish exposed to cloned, known toxic *Pfiesteria* strains (positive controls), and for control fish that are not exposed to estuarine water/sediment samples or cultured toxic Pfiesteria (negative controls). The positive controls have consistently been associated with fish death, while no fish have died in the negative controls. Thus far, 13 of 15 PCR-positive samples collected in the lower estuary during the spring survey have been positive for fish killing activity. Samples that tested negative for *Pfiesteria* using PCR were also analyzed to check the accuracy of PCR in detecting *Pfiesteria* from sediment samples. Among fish bioassays evaluating 9 samples that had tested as negative for *Pfiesteria* spp. using PCR, to date, 8 were positive for fish killing activity. For all survey samples evaluated thus far as positive for toxic *Pfiesteria*, time to fish death has ranged from 18 to 51 days. The high incidence of toxic *Pfiesteria* in samples that tested as negative for *Pfiesteria* presence using PCR probes (8 of 9 thus far), suggests that either there is extreme fine scale variability among sediment sub-samples, or current PCR assays are not as sensitive as fish bioassays in detecting low levels of *Pfiesteria* strains. Two other survey data sets are under analysis and those results will also be presented.