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2007 WRRI Annual Conference

Meghan Rothenberger, NC State University, discusses her research with Dr. Craig Allan, UNC Charlotte, on "Long-term Impacts of Changing Land-use Practices on Water Quality and Phytoplankton Assemblages in the Neuse Estuary, North Carolina.

The Conference

The 10th WRRI Annual Conference, held March 27-28, 2007, at the McKimmon Center in Raleigh, brought together over 200 people from universities, state and federal agencies, local governments, non-profit organizations and consulting firms. The theme of the conference was "Managing Public Water Supplies." On March 27, Dr. David Moreau, director of WRRI, opened the plenary session stating the role WRRI plays to facilitate research and promote protection of North Carolina's water resources. Dr. Philip Singer, director of the UNC Drinking Water Research Center and professor, UNC Chapel Hill Department of Environmental Sciences and Engineering, gave the keynote address on "Disinfection By-products in Drinking Water: A Challenge in Managing Public Water Supplies."

On March 28, Mr. Terry Rolan, 2006 president, American Water Works Association, and director, City of Durham Department of Water Management, gave the keynote address during the plenary session on "Only Tap Water Delivers." At the luncheon, the North Carolina Water Resources Association (NCWRA) announced the student poster contest award winners. Then Mr. Bill Holman, visiting scholar, Duke University Nicholas Institute for Environmental Policy Solutions, gave a post-conference report on the March 1, 2007 conference on "The Future of Water in North Carolina: Strategies for Sustaining Abundant and Clean Water."

Overall, there were 46 oral presentations given in twelve concurrent sessions with topics ranging from streamflow modeling and management to water law. In addition, there were 33 poster presentations, 22 of which were student posters. Exhibitors of state and non-profit groups were also present.

Oral presentation and abstracts of the conference are available for viewing the WRRI web site at http://www.ncsu.edu/wrri/conference/2007ac/

NCWRA Student Poster Winners

Mr. Ken Carper, NCWRA President, presented the winners of the NCWRA undergraduate and graduate student poster contest with a certificate, a check and an NCWRA mug. Each poster was judged on criteria that includes organization, content, and visual presentation. Following are pictures of the student poster winners:

Ken Carper, NCWRA president, presents 1st place award ($300) to Melanie Markusic, NC State University graduate student. She presented a poster on "Effects of Design Changes on Sediment Retention Basin Efficiency."

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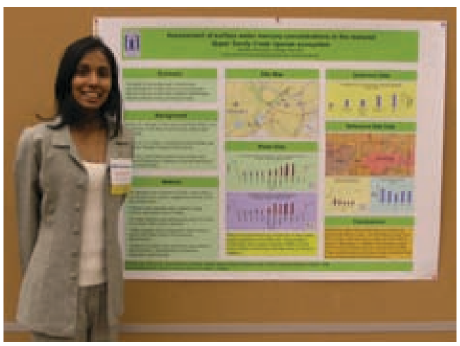
Ken Carper, NCWRA president, presents the 2nd place award ($200) to Peter Cada, Duke University graduate student. He presented a poster on "Test the 'Field of Dreams' Hypothesis: Stream Restoration Effects on Physical Structure."



Amrika Deonarine, Duke University graduate student, received one of the 3rd place awards ($100) for her poster titled "Assessment of Surface Water Mecury Concentrations in the Restored Upper Sandy Creek Riparian Ecosystem."

Ken Carper, NCWRA president, presents one of the 3rd place awards ($100) to Stephanie Salisbury, UNC Wilmington undergraduate student. She presented a poster on "In Situ Inorganic Nitrogen Reactivity in the Headwaters of an Urbanized Tidal Creek in Southeastern North Carolina."

Ken Carper, NCWRA president, presents one of the honorable mentions awards ($50) to Robert Tucker, NC State University graduate student. He presented a poster on "Analysis of the First-flush Phenomenon and Pollutant Relationships within Stormwater Runoff from Two Small Urban Drainage Areas."

Ken Carper, NCWRA president, presents one of the honorable mentions awards ($50) to Kim Duernberger, UNC Wilmington graduate student. She presented a poster on "Isotopic Enrichment of a Southeastern Urbanized Tidal Creek."

Ken Carper, NCWRA president, presents one of the honorable mentions awards ($50) to Gwendolyn Turner, Elon University undergraduate student. She presented a poster on "A Comparison of Plant Water Relations in Justicia americana and Saururus cernuus during Water Stressed Conditions."

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Educating Politicians and Public About Water Service Will Ease Infrastructure Growing Pains

by Carla Burgess, freelance writer

The people who operate public water systems recognize what it's going to take to keep the drinking water pipeline open for business. The general public and elected officials, however, are still behind the learning curve. As water rates begin to swell, customers must understand that they're not only paying for disinfection, they're also picking up the tab for repairing and replacing an aging underground delivery system not built with their dollars, says Terry Rolan, president of the American Water Works Association.

To meet the challenge, the AWWA has launched a comprehensive educational campaign to tout the true value of water service and the need to reinvest in water infrastructure. "It's designed to inspire people to think about the critical, irreplaceable nature of tap water service in their lives," he said. A keynote speaker at WRRI's 2007 annual conference, Rolan told attendees about AWWA's campaign "Only Tap Water Delivers," which includes a package of advertisements, public service announcements, slide presentations, templates for speeches that utility managers can customize for local audiences, and talking points for addressing community leaders and politicians. "This campaign provides a common vocabulary and materials to communicate with public officials and consumers and leverage media interest in water quality issues," he said. The City of Durham, for which Rolan serves as the director of the Department of Water Management, was one of the first cities in the country to use the campaign, starting with a series of print advertisements last summer.

Rolan has learned firsthand how the right message can convince leaders they need to "correct the neglect" toward infrastructure that in many communities throughout the nation was installed more than a century ago. "We still have 162 miles of unlined cast-iron pipes, some of which date back to 1887," he said of Durham's system." When he needed to sell the most recent rate increase to the City Council, Rolan developed a formula to illustrate how poorly the utility was keeping up with maintenance and replacement needs. He calculated the estimated cost of replacing the entire distribution system—1,200 miles of pipe—in today's dollars, then divided that by the actual average spending on replacement over the past 20 years ($226,000 per year). The result: At the current rate, the city was maintaining its underground water infrastructure on a 1,400-year replacement cycle. All of this information was put on a slide shown to the city leaders. "After that, the budget discussion stopped, and they approved the rate increase," he said.

Helping leaders and ratepayers understand the comprehensive benefits of water service is another part of the AWWA campaign. One of the print ads features a fire hydrant and the slogan "I want to be here for you." Its goal is to remind people that the same water they drink is also used to put out fires.

"All of our water systems were originally developed as fire protection systems primarily," said Rolan. "A very small percentage of the water we use is for potable purposes." To maintain the volume and pressure of flow necessary for fighting fires, pipes are large and thus expensive to replace. Eventually, he said, rates may need to be adjusted for customers with higher stakes. "Out in Research Triangle Park, there are big warehouses that use very little water, some not more than an average residence. But they have thousands of square feet and a great big pipe going out there so that if they need us, we're there. We've got to come up with a better system of cost recovery as it relates to that issue."

At present, water utilities are experiencing a turning point, not a crisis, Rolan says. But to keep pace with replacement needs, an immediate change in business as usual is essential. "We need funding on an annual basis on a level we've never funded before," he says, to the tune of several million, not several thousand. "We need rate structures and financing plans that reflect the cost." Relying on capital improvement programs and bond issues "will not cut it."

The "Only Tap Water Delivers" campaign is funded by AWWA member utilities and their dues. Materials are available free to members. For more information, visit www.awwa.org/advocacy/OnlyTapWater/. Resources for consumers, including a pressroom and kids page, are available at www.drinktap.org.

The Chlorine Dilemma and Other Challenges in Managing Public Water Supplies

by Carla Burgess, freelance writer

Chlorination of drinking water is largely credited for wiping out major waterborne diseases in America in the early 20th century. For people who draw their water from the tap, the chlorine widely used in the water treatment process provides the last line of defense against cholera, typhoid fever, hepatitis A, dysentery and a host of other historically devastating maladies. But in the 1970s, scientists discovered something insidious lurking in that chlorinated water—not a pathogen the chlorine failed to immobilize, but harmful byproducts created by the chlorine itself. These disinfection byproducts (DBPs) have been linked to cancers of the digestive and urinary tracts as well as miscarriages and developmental disorders. Such discoveries exposed what one of Philip Singer's students dubbed "the dark side of chlorine."

Singer, who is Dan Okun Distinguished Professor of Environmental Engineering and the director of the Drinking Water Research Center at UNC-Chapel Hill, spoke about this public health issue and the challenges of addressing it during his keynote address at WRRI's Annual Conference March 27-28 in Raleigh. The theme of the 2007 conference was "Managing Public Water Supplies."

In 1974, scientists discovered that chlorine disinfection of drinking water drawn from lakes and rivers creates four compounds known as trihalomethanes (THMs), including chloroform, which have been linked to both acute and chronic health effects. In the treatment process, chlorine reacts with bromide and natural organic material in the water to produce harmful DBPs that include THMs and another worrisome class of chemicals known as haloacetic acids (HAAs). In 1979, the U.S. Environmental Protection Agency placed conservative limits on the allowable maximum concentration of DBPs in finished drinking water in water systems serving more than 10,000 people. In 1998, the requirements were expanded to all community water systems, the maximum contaminant levels of THMs were further reduced, and new contaminants were added to the list of regulated chemicals, including bromate, chlorite and five HAAs.

Tackling the problem of DBPs has created myriad dilemmas for regulatory agencies, utility operations and the public at large, said Singer. "How do you balance disinfection with the fact that the agent you use to control waterborne disease also produces disinfection byproducts that may be carcinogenic," he said. "How do you develop a strategy for controlling the formation of these byproducts?"

To comply with the new regulations, many utilities abandoned chlorine-only disinfection and began using instead a combination of free chlorine and combined chlorine (also known as "chloramination"), the latter being used as a terminal disinfectant to protect the distribution system against recontamination. About half of the systems in North Carolina that serve more than 10,000 customers now use this disinfection method. Treatment using combined chlorine prevents the formation of THMs and HAAs. However, chloramination comes with its own baggage—its use has been linked to production of the contaminant NDMA (N-nitrosodimethylamine), a probable human carcinogen, and to elevated levels of lead in tap water.

No alternative treatment technologies, it seems, are without consequences: Ozonation forms bromate, a known animal carcinogen, in bromide-containing waters; chlorine dioxide forms chlorite, which is associated with liver toxicity; and treatments that remove organic material prior to chlorination (granular activated carbon adsorption, membrane (nano) filtration and anion exchange), while effective stopgaps, are expensive.

Meanwhile, as new threats emerge, more regulations may be headed down the pipe, as the government attempts to address public safety. Besides the problem of DBPs, health officials are starting to see increased occurrences of Giardia and Cryptosporidium—intestinal parasites that cause diarrhea—running past the water treatment gauntlet.

"So now there's a growing concern about more and more waterborne diseases that maybe our conventional disinfection practices are not addressing," he said. "At the same time, we are being squeezed to lower our trihalomethanes and potentially compromise disinfection."

The City of Durham, in particular, was progressive in tackling THMs early on, said Singer. In 1976, Durham's water system moved the point of chlorination to the stage following coagulation and sedimentation. Like most other utilities at the time, Durham had traditionally added chlorine to the raw water. By keeping chlorine out of that steeping organic brew, the city was able to achieve about a one-third reduction in THMs in finished drinking water. "This led the way ultimately to many other utilities in North Carolina and across the country to move their point of chlorination as a good strategy for controlling the formation of trihalomethanes," he said. Since 2002, water systems have been required by EPA regulations to use enhanced coagulation prior to chlorine application.

By 2013, all systems must comply with the EPA's Stage 2 Disinfectants/Disinfection Byproducts Rule, which will change the way compliance is measured. Because DBPs continue to form as the water flows through the distribution system, regulators want to be sure that the health of all customers—regardless of their position on the grid—is equally protected. Under the new rule, compliance must be based on a locational running annual average rather than a systemwide average. In addition, monitoring must take place at known and anticipated "hot spots" throughout the system.

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As utilities continue to tweak their operations to meet all the objectives of drinking water treatment, Singer predicts that water systems will have to bite the bullet and begin investing in more expensive technologies to remove organic material from the water. "That will allow us to have lower levels of disinfection byproducts and still be able to disinfect with chlorine or ultraviolet irradiation, which is relatively inexpensive, and then use free chlorine again [as a terminal disinfectant] in our distribution system," he said. "I think that's where we're headed in the future—I just don't know when that future is."

May 2007 Action of the Environmental Management Commission

At its regularly scheduled meeting on May 10, 2007, the Environmental Management Committee (EMC) took the following action:

- ❑ Approved the hearing officer's report on contingency Reasonably Available Control Technology (RACT) requirements for the Charlotte ozone nonattainment area. The US Environmental Protection Agency requires a preadopted contigency plan to be part of teh State Implementation Plan (SIP) before it will approve an ozone nonattainment area plan. The purpose of the contingency plan is to apply additional controls quickly, without rulemaking, on sources if the nonattainment area plan fails to acheive compliance with the amibient air quality standard.
- ❑ Approved the hearing officer's report on miscellaneous air quality rules which included the control of nitrogen dioxide and nitogen oxide rules; new source performance standard rule, fugitive dust rule; certification of leak tighness tester rule, open burning rules; banking applicability rule, permitting rules; proposed adoption of the other solid waste incineratior rule and a new open burning rule; and proposed repeal of automobile tailpipe emission standards rule and inital Title V permit application submittal rule.
- ❑ Approved to proceed to public notice and comment with the proposed amendments to the state coastal stormwater rules, 15A NCAC 2H .1005.
- ❑ Remitted to the Water Quality Committee the request to proceed to public notice and comment with the proposed site-specific management plan in the Goose Creek Watershed.
- ❑ Approved to proceed to public hearing with the proposed reclassifications for the following: Horsepasture River in Jackson and Transylvania Counties (Savannah River Drainage Area) to Class ORW and "+"; Big Laurel Creek and Spring Creek in Madison County (French Broad River Basin) to Class HQW; Boylston Creek in Transylvania and Henderson Counties and Fines Creek in Haywood County (French Broad River Basin) to Class Tr.
- ❑ Remitted to the Water Allocation Committee the request for proposed reclassification of Lake Wright in Rowan County (Yadkin River Basin) to Class WS-V "+."
- ❑ Approved the final draft of the White Oak River Basinwide Water Quality Plan.
- ❑ Approved the following designations as Phase 2 municipalities: Kings Mountain and Mooresville in the Catawba River Basin; Atlantic Beach and Morehead City in the White Oak River Basin.
- ❑ Deferred to the Water Quality Committee the following designations as Phase 2 municipalities: Henderson, Tarboro, and Washington in the Tar-Pamlico River Basin; Emerald Isle in the White Oak River Basin. The Attorney General was asked for an interpretation of law concerning Section 5 of Session Law 2006-246 on whether the EMC has the discretion to designate new areas as Phase 2 municipalities. The question was asked if the municipality has an alternative stormwater management plan can they be exempt and if a management plan is equivalent.
- ❑ Adopted to uphold the decision of the Administrative Law Judge (ALJ) in the case, Walter G. Mitchell v. DENR, DAQ, 06-155, Stanley County. The ALJ recommendation was to uphold the civil penalty and costs of $1,152 for conducting the open burning of a barn. Tires and rims were burned in the fire.
- ❑ Approved to uphold the decision of the ALJ in the case, John Darlington v. DENR, CV 06-0009, Onslow County. The ALJ granted summary judgment and recommended to uphold the civil penalty of $4,000. The penalty was assessed for failing to obtain a stormwater permit prior to construction of an eight acre expansion of a salvage yard. Darlington did not secure a sedimentation and erosion control permit before beginning land disturbing activity. A stormwater permit is required in conjunction with an erosion control permit in coastal counties. The expansion involved construction of compacted roads and other impervious surfaces.

WRRI-sponsored Research Reports

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Nitrate Flux from Ground to Surface Waters Adjacent to the Neuse River Waste Water Treatment Plant

Report 351-A April 2006

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Land application of biosolids produced from waste water treatment provides a cost effective reuse of nitrogen and an effective disposal method for sludge and sediment from the treatment process. Sustainable programs require attention to nitrogen management, because of soil nitrogen accumulation and leaching through groundwater, which have significant environmental impacts. Studies show that groundwater storage time and geochemical reactions, such as denitrification during ground water migration, affects nitrate concentrations in receiving streams. The purpose of this study was to investigate the processes that control nitrate concentrations in ground waters under Waste Application Fields (WAFs), and those that transport this groundwater nitrate into the adjacent Neuse River. The study was performed near Clayton, NC, at the Neuse River Waste Water Treatment Plant (NRWWTP), where biosolids have been land applied since 1980.

Groundwater nitrate concentrations under the WAFs were monitored via ground water chemistry and amounts of Plant Available Nitrogen (PAN). The PAN results were highly variable, ranging from 0.1 mg/l to 180 mg/l. Accumulation of biosolid N in groundwater was traced with heavy nitrogen isotope ratios in nitrate (^{15}N), while denitrification in ground and surface waters was detected by nitrogen and oxygen (^{18}O) isotopic ratios. Concentrations of these isotopes suggested that biosolid N impacted 57% of the monitoring wells and most surface waters that drain the site. Fertilizer N impacted 18% of the monitoring wells, while nitrate was significantly attenuated by denitrification in 23% of the wells. Hydric soils, which are associated with denitrification, were discontinuous throughout the WAFs and may explain the heterogeneous distribution of nitrate under biosolid application fields and offsite migration patterns.

The flux of water and nitrate from the WAFs into the adjacent reach of the Neuse River was measured using two RiverNet monitoring stations located above and below the plant, and the results were compared to daily plant discharge for two years. Nitrate contributed to the reach from non-point sources such as groundwater and streams (NPS flux) was about 43% of the nitrated discharged in plant effluent. NPS nitrate gained in the reach and nitrate discharged from the treatment facility together make up about 38% of the nitrate exported from the reach. Preliminary data from river nitrate mapping suggest that a major portion of the NPS nitrate flux enters the river along the northern edge of the plant, where concentrations in surface drainages are the highest.

The results of this study demonstrate that 1) the spatially heterogeneity of nitrate concentrations in groundwater under the biosolid WAFs are related to the distribution of hydric soils, 2) riparian buffers at the plant attenuate groundwater nitrate before it is transported into the river, 3) groundwater nitrate is transported into the Neuse River via surface drainages, and 4) over a two year period approximately 128,000 kg of nitrate has entered the river via this pathway, which represents 38% of the total nitrate discharge from the treatment plant over the same period. The nitrate flux from the WAFs via surface drainages is related to the amount of annual precipitation, and is controlled by a complex interaction between level of the ground water table, the amount of PAN applied and the distribution of hydric soils and riparian buffers within a drainage basin. Preliminary data from the riparian buffers indicate that nitrate does not migrate across the riparian areas in shallow groundwater flow paths. This suggests that ground water nitrate fluxes to the Neuse River can be successfully mitigated by wetland reconstruction in these surface drainages, and that biosolid application can be sustained at this site with little future impact on river water quality.

The relative importance of NPS nitrate in deep groundwater flow paths, and in surface drainages and groundwater inputs through riparian buffers that drain into the Neuse River could not be determined from these data, and should be the focus of future research. Understanding the predominate NPS nitrate flow path to the Neuse River at the site is critical for designing remediation strategies. Enhancing denitrification and water retention in the surface drainages, widening the narrow buffers adjacent to the stream drainages in the fields, and reducing the surface drainage nitrate flux to the Neuse River by creating artificial wetlands at the base of these drainages would be cost efficient approaches to formulate sustainable biosolid land application practices at the Neuse River Waste Water Treatment facility.

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A Systematic Evaluation of Polyacrylamide for Sediment and Turbidity Control
Report 352 December 2004

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The U.S. Environmental Protection agency has documented that sediment is the major pollutant of streams and rivers in the United States. Sediment impairs 13% of the assessed streams and contributes to 38% of the water quality problems. Much of this sediment is due to agriculture, but an increasing amount of sediment, particularly in urbanizing areas, is due to construction practices. One of the problems associated with increased sedimentation is increased turbidity levels, that can, in turn, increase water temperatures and decrease dissolved oxygen levels, causing fish kills. The use of polyacrylamides (PAM) to reduce turbidity has been shown to be effective and has great potential as a safe chemical treatment but there is little information on how to obtain the maximum benefits from it on a construction field site. One of the methods of introducing PAM into stormwater is by installing a solid block or log of PAM in the ditch or pipe, allowing the moving water to dissolve the PAM. The objective of this project was to determine the optimum method of use of PAM on construction sites for sediment and turbidity control.

Field and laboratory tests were conducted under controlled, replicated conditions at the Sediment and Erosion Control Research and Education Facility at the Lake Wheeler Field Laboratory in Raleigh, NC. The results provide some guidance on specific issues obtaining the maximum benefits for using PAM at construction sites.

- ❑ PAM logs are much more effective when they are not allowed to dry out between storm events. Dry logs have a lag time between when runoff first immerses them and when they begin to release sufficient PAM for effective turbidity treatment. Specific methods for maintaining logs in a moist condition on construction sites were beyond the scope of this study.
- ❑ Turbidity is always higher in colder water regardless of treatment, a result which can be explained by the increased viscosity of cold water. This phenomenon may impact the potential to achieve turbidity goals during the winter or other times and places where the water temperature is low (<15°C in the tests). No treatment combination was significantly better under cold conditions and flow-weighted turbidity was never dropped below 200 Nephelometric Turbidity Units (NTU).
- ❑ The inclusion of porous baffles in the basin enhanced the settling process and should be included as a standard feature. Flow-weighted turbidity was reduced to <100 NTU with baffles made of jute and coir, but other materials with similar porosity (5-10%) should work just as well.
- ❑ Although the rock dam and skimmer outlets did not have significant differences in turbidity, a surface outlet such as the skimmer would still be recommended as a standard feature in basins. Previous work has shown the skimmer/emergency spillway outlet to have superior sediment retention to the typical rock dam outlet.
- ❑ The addition of gypsum as a cation source to bridge the PAM-clay interface can have a positive, neutral, or even negative effect depending on the soil, indicating that the gypsum was competing with suspended sediment for binding sites on the PAM molecules. It was very effective in improving flocculation with PAM, but this effect will have to be determined for each individual site.
- ❑ The addition of PAM in solution to simulated runoff water prior to a sediment bag reduced turbidity in the water exiting the bag by an order of magnitude (from 500-4,000 to 50-100 NTU). The water from the typical commercial bag had the lowest turbidity with PAM added, but tended to clog more quickly compared to more porous bags. However, the use of PAM with sediment bags is still recommended, especially when the discharge flows directly into waters of the state.

Effect of Management Practices on Denitrification in Soils Fertilized with Liquid Swine Waste
Report 353 July 2004

Stephen C. Whalen and Julia A. Nelson
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Chapel Hill, NC

North Carolina has experienced explosive growth in the number of large-scale swine production facilities that utilize anaerobic lagoons and spray fields for waste storage and disposal, respectively. Liquid lagoon effluent is applied as an organic fertilizer to spray fields to meet the agronomic nitrogen (N) requirement of host crops. Denitrification is a soil microbial process that converts nitrate largely to inert N_2 gas, thus reducing undesirable offsite transport of biologically available N unassimilated by the cover crop. This one-year study evaluated the effects of fertilization frequency on denitrifying enzyme activity (DEA) and related microbial processes (nitrifying enzyme activity (NA) and N-mineralization). The overall objective was to identify the most beneficial fertilization scheme in terms of maximizing the potential for denitrification, thereby providing information that

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would be useful for modifying and developing best management practices (BMPs). The rationale was that if DEA and NA were maximized, the percentage of applied N denitrified in situ would generally increase, and that N available for environmentally harmful fates would be reduced.

Two agricultural fields were used that had been previously fertilized with liquid swine waste for one and ten years, respectively. Three fertilization frequencies (weekly, biweekly, monthly) delivering the same amount of N on an annual basis were evaluated to determine their influences on DEA, NA, net nitrification, and net N-mineralization.

Fertilization frequency was not found to have an effect on any of the four measured soil microbial processes. The prescribed fertilization scheme was deviated from too often, and effluent loads delivered to the study plots were too uneven to assign any meaning to the significant differences found among treatments. Better control of fertilization frequency in the field would be most desirable; however, factors such as adverse weather conditions and equipment malfunction are unavoidable.

Other factors, however, did have significant effects. For example, season had a significant effect on DEA and NA, and appeared to have an effect on net nitrification and net N-mineralization at the older site. DEA was highest in summer when soil temperatures were high, substrate (NO_3^--N) availability was highest, and water-filled pore space was low. These results suggest that denitrifying enzymes were preserved in soil under desiccated conditions. While NA was highest in winter, rates of net nitrification and net N-mineralization at the older site were qualitatively highest in summer.

Strong correlation of net N-mineralization and net nitrification at both sites, plus high summer DEA at both sites, suggests that denitrification in anaerobic soil microzones is a potentially significant pathway of for removal of effluent N in a brief post-spray period when saturation of soil microzones is likely to occur. High spatial variability in DEA and NA suggest that even if spray schedules were strictly observed, a prohibitively large number of samples would be necessary to statistically demonstrate a significant treatment effect. Further, mechanical malfunction and unpredictable weather render it impossible to adhere to a planned spray schedule. Accordingly, repetition of this study is not recommended.

Fertilization history also had a significant effect on all measured soil microbial processes, which were higher at the site fertilized for ten years as opposed to the younger site. This trend was most apparent with DEA, which was significantly higher at the older site for every month during the study. These results indicate that it takes several years to develop a large population of soil bacteria, which increase as soil organic matter, total-C and total-N increase. This could have significant ramifications for offsite transport of applied waste from the perspective that an aged field with an established N cycling microbial consortium may be more efficient at denitrification, thereby minimizing N loss from the application site via leaching to ground water or runoff to surface waters. Consequently, a survey study of the potential for denitrification along a continuum of spray fields of known age would be recommended to determine if age is positively correlated with the denitrification potential. An investigation of this nature would indicate whether the age of the spray field should be a factor when determining permissible loading rates.

Nitrogen Cycling Dynamics in Agricultural Fields Fertilized with Liquid Swine Waste – Microbial Nitrification and Denitrification
Report 354 July 2004

Stephen C. Whalen, Eric N. Fischer, and Daniel J. Brown
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Chapel Hill, NC

North Carolina has experienced an explosive growth in the number of swine produced and a decrease in the number of production facilities. This presents a formidable challenge with regard to disposal of swine waste, as uninformed or improper waste management may encourage offsite transport, leading to enhanced N loading in adjoining ecosystems, particularly rivers, estuaries and coastal waterways. The objective of this research was to assess in situ rates of nitrification and denitrification in representative spray field soils and to determine the influence of application volume and environmental factors (soil moisture and temperature) on these rates. To this end, the effects of temperature, moisture and effluent dose on rates of microbial nitrification and denitrification were assessed under controlled laboratory conditions in time course experiments involving intact soil cores and homogenized soil samples collected from agricultural fields regularly fertilized with liquid swine waste. The influences of fertilization history and substrate concentration (NO_3^--N and organic-C) on rates of nitrification and denitrification, respectively, were determined using similar methodology.

On average, about 90% of total-N in the effluent was found as NH_4^+-N, which remained largely in the top 5 cm of soil. Temperature, effluent dose, and fertilization history significantly affected net nitrification rates, while moisture levels used in these experiments had no statistically significant impact. Nitrate increased and reached a steady state within several days of waste application at all loading rates; roughly 80% of the total-N in applied waste was accounted for as NO_3^--N within 10 days of application, with the remainder presumably lost to volatilization and denitrification. Short-term immobilization of effluent NH_4^+-N and subsequent remineralization may be important in determining the long-term accumulation of NO_3^--N.

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Waste application immediately stimulated denitrification rates due to increases in anaerobic soil volume, labile-C, and nitrification which supplied NO_3^--N for denitrifiers. However, elevated rates only lasted 3 to 5 days, until soil moisture content and the availability of labile-C became limiting. Strong relationships were observed between rates of denitrification and environmental factors (soil moisture, organic-C, NO_3^--N, and temperature), pointing to the importance of these controls on denitrification in these soils.

As nitrification of added NH_4^+-N continued, soil concentrations of NO_3^--N increased dramatically and became the largest component of the soil N pool. By comparison, gaseous losses of N via N_2O and N_2 by denitrification were much less significant—fractional loss of applied N via denitrification was 1.6 to 4.5 %.

This study also demonstrated that vigorous populations of nitrifying and denitrifying bacteria become established in spray fields repeatedly fertilized with liquid swine waste and that these microbes respond rapidly to fertilization with liquid effluent at rates representative of the industry practices. Moreover, comparison of results of nitrification experiments between aged and fallow fields suggests that populations of nitrifiers develop with time in response to years of fertilization. Further study is recommended to determine whether a regional pattern is represented by these observations that aged fields process swine effluent more rapidly and actively, as this determination has clear implications for setting permissible loading rates.

A relatively small fraction of the land-applied waste was lost to denitrification. This microbial process represents a source of N-loss from receiving fields that does not impact adjoining terrestrial and aquatic ecosystems, although a minor endproduct (N_2O) is radioactively and chemically active. Rates of denitrification are strongly linked to soil type, as clays are more susceptible to the formation and persistence of anaerobic microzones than sands when soils are amended with liquid effluent. Accordingly, we recommend that studies of denitrification be expanded to include the entire spectrum of common regional soil textures to firmly establish the expected rate of loss of fertilizer N to this microbial process.

This study of denitrification was of short duration (less than two weeks) and measured the immediate loss of N_2 and N_2O to coupled nitrification-denitrification following a spray event. Because denitrification diminishes or ceases once oxic conditions are restored to soils following fertilization, considerable NO_3^--N can accumulate and is available as a substrate for further denitrification if soils become anaerobic following rainfall. Thus, this study clearly underestimates total fertilizer loss to denitrification. Field experiments of seasonal duration or laboratory experiments that incorporate simulated post-fertilization rainfall are recommended to estimate total fertilizer loss to denitrification.

Pilot Project on Groundwater Dating in Confined Aquifers of the North Carolina Coastal Plain
Report 355 August 2005

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Confined Cretaceous aquifers are a major water source for the North Carolina Coastal Plain but have been heavily overused. Studies have shown that the current demands for water in the central Coastal Plain of North Carolina exceed the sustainable production capabilities of the Black Creek and Upper Cape Fear aquifers. While basic hydrogeologic parameters of these two aquifers are fairly well known, quantitative data are lacking on groundwater flow, including measurements of travel times, groundwater ages, and vertical exchanges between aquifers. This pilot study used data on ^{14}C, ^{4}He, and ^{3}H from seven monitoring wells that lie along a trend roughly parallel to predevelopment groundwater flow. The objectives of this project were to identify groundwater ages for the aquifers at the wells of interest using ^{14}C dating techniques, establish relationships between ^{4}He and ^{14}C groundwater ages so that ^{4}He can be used as a quantitative age-dating tracer in future studies, and determine if ^{3}H concentrations provide evidence for the presence of very young groundwater (< 40 years).

^{14}C groundwater ages increased with distance from recharge area, and ranged from about 600 to greater than 35,300 years old at the seven wells dated in this study. The ^{14}C groundwater ages are evidence that groundwater from both aquifers is likely only quasi-renewable over very long time scales. Groundwater ages, together with falling heads, suggest that groundwater withdrawals in these aquifers represent a sort of "mining." Accordingly, withdrawals from these aquifers should to be regulated. Rules established for the Central Coastal Plain Capacity Use Area (CCPCUA) to lessen groundwater withdrawals should be stringently enforced, and a large-scale monitoring effort should be put in place to assess the strengths and weaknesses of the CCPCUA.

The difference in groundwater ages at two wells in particular implied groundwater flow in both the horizontal and vertical directions. This two-dimensional flow could be the result of aquifer heterogeneity, which is implicit in the large variability in hydraulic conductivity of the aquifers. Future work may include ^{14}C dating of groundwater in both the horizontal and vertical directions to evaluate 3-dimensional groundwater flow in the aquifers and to place constraints on aquifer heterogeneity.

The increase in ^{4}He concentration with ^{14}C groundwater age indicates that ^{4}He concentration can be used with groundwater

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age to determine the rate of ^4He accumulation in groundwater. For a first approximation of age, the rate of ^4He accumulation can be determined based on the results from this data set; however, a more statistically sound estimate could be obtained with a larger sample size. Future work may involve the quantification of the rate of ^4He accumulation using two independent methods: ^4He concentrations with independently determined groundwater ages, and the concentration of U and Th series radionuclides in the porous medium. Once quantified, the ^4He rate of accumulation could be used with ^4He concentrations to date groundwater. The availability of both ^{14}C and ^4He aging methods would appreciably increase precision in estimating groundwater ages.

Groundwater from six of the wells had ^3H concentrations that are consistent with the presence of young water, but it is uncertain whether the ^3H in these wells is from relict drilling fluid, downward leakage along the well casings, or a more broadly distributed downward leakage. Rapid vertical movement of water could represent a potentially serious problem, as it could represent a transfer of contaminants into these aquifers which are used as a water supply source. Future work may involve determining the source of the ^3H by calculating the amount of ^3H from *in situ* production and by dating the young fraction of groundwater with $^3H/^3He$. Dating the young fraction of groundwater will constrain when mixing could have occurred as relict drilling fluid should have an age equal to or older than the age of the well.

Rocky Mount Uses Quarry to Augment Public Water Supply

Mr. Paul Blount, director of the City of Rocky Mount Water Resources Department, contributed the following information in response to the article titled "Off-stream Storage: An Option for Augmenting Public Water Supplies" in the March-April 2007 issue of *WRRI NEWS*:

After Hurricane Fran, the City of Rocky Mount was able to purchase an abandoned quarry off Old Mill Road, just west of US 301 in Rocky Mount. The City's quarry holds about 400 million gallons. Currently, the City of Rocky Mount uses the quarry water to supplement river flow during times of drought. Since they operate a run of river reservoir (about 4,000 million gallons), the City is required to release at least 80 cfs to maintain flow. By replacing river flow from the reservoir with flow from the quarry, they are able to retain more water in the reservoir longer and have it available for treatment.

The City hopes to acquire a privately-held quarry off NC-97 once it is no longer active. This quarry contains about 1,400 million gallons of water that would be used for additional water storage to supplement the City's reservoir capacity.

Upcoming Events

August 1-3, 2007
Annual Southeast Watershed Roundtable: Sustaining Our Water Infrastructure through Watershed-based Approaches
Braselton, GA
More information: http://www.southeastwaterforum.org/roundtables/

September 10, 2007
NCWRA Forum and Luncheon
McKimmon Center, NC State University
"Using the Best Climate Information Technology for Managing Water Resources"
Dr. Ryan Boyles, State Climatologist, State Climate Office of North Carolina, NC State University
Web: http://www.ncsu.edu/wrri/ncwra/

Dr. Jean Spooner Honored

Ken Carper, NC Water Resources Association president, presents a Service Award to Dr. Jean Spooner during the WRRI Annual Conference luncheon. She was recognized for 15 years of outstanding and dedicated service to NCWRA. Dr. Spooner currently serves as NCWRA treasurer. Dr. Spooner is also professor in the Biological and Agricultural Engineering Department and director of the Water Quality Group at NC State University.