Water Resources Research Institute of the University of North Carolina
Annual Technical Report
FY 2001

Introduction

The Water Resources Research Institute of The University of North Carolina program for 2001-2002 (FY 2001) continued to foster research, training, and information dissemination responsive to the water issues of the State and region. Support from the USGS was supplemented by State Appropriations, Urban Water Consortium, and other external funding. Funded projects addressed such issues as groundwater, nutrients, microbial source tracking, animal waste, septic systems, stream and wetland restoration, and sediment transport in watersheds.

To develop its programs, the Institute maintains an aggressive effort to interact and communicate with federal, state, and local water managers. The close contact with water managers is a basis for determining the ever-changing water research priorities. Priority water research needs were developed in close consultation with the Institutes Advisory Committee. The highest priorities focused on sediment control, aquifer storage, watershed hydrologic changes, restoration of streams and wetlands, animal waste treatment, intermittent and perennial streams, and water reuse. Much of the focus remains on the coastal areas of North Carolina. Many of the river basins that drain into the estuaries are experiencing signs of advanced eutrophication, contamination by pollutants, and habitat modifications.

The technology transfer program continued to focus on disseminating research-based information on emerging water issues, regulations, and problems. The bi-monthly newsletter summarized research results, regulations, and upcoming conferences and workshops. In addition, the WRRI sponsored eight workshops, eight seminars, six workshops, and one annual conference on key water issues. The WRRI also published six final reports as part of the WRRI report series. The WRRI is continuing to identify and address emerging water issues. Priority is being directed to such issues as water supply, drought management, urban stormwater, low impact development, river basin management, and environmental restoration/mitigation.

Research Program

Reuse of Wastewater from Septic Systems

Basic Information

Title:	Reuse of Wastewater from Septic Systems
Project Number:	2001NC801B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	
Congressional District:	4th
Research Category:	
Focus Category:	Waste Water, Irrigation, None
Descriptors:	Septic Tanks, Hydraulic Conductivity, Wastewater Irrigation
Principal Investigators:	aziz.amoozegar.1, Stuart L. Warren, Wayne P. Robarge

Publication

Problem and Research Objectives: Approximately 50% of the people living in North Carolina, and 25% of the United States population, use septic systems for on-site management of their sewage. Based on the estimated number of people living in a residential dwelling (2.9 people), and the average amount of wastewater produced by each individual (170 L/d), the volume of wastewater dispersed into North Carolina soils through septic systems could exceed 1 billion L/d (275 million gal/d). Approximately an equal volume of wastewater is treated and disposed of through public sewer facilities in North Carolina. Wastewater treated by large sewage facilities is being used for irrigating agricultural and non-agricultural crops (e.g., golf courses, home lawns). However, little has been done for the on-site reuse of the partially treated wastewater from septic systems as irrigation water for ornamental plants and lawns. According to the EPA, the average volume of sewage generated within a residential dwelling arises from toilet facilities (35%), laundry (22%), shower/bath and lavatory sinks (20%), and the kitchen (10%). The remaining 13% comes from other sources (e.g., a water softener) within the dwelling. It is possible that some of the wastewater generated in residential dwellings, referred to as graywater, could be used for irrigation on-site following minimal treatment. The overall goal of this study is to determine the potential reuse of graywater from laundry and wastewater from kitchen dishwashing machines for irrigating at a residential landscape. The specific objectives of the study are: (1) to assess the effect of wastewater from laundry and kitchen facilities of residential dwellings on soil hydraulic conductivity, and to determine the impact of surfactants and sodium hypochlorite present in laundry products on soil hydraulic conductivity and water retention, and 2) to evaluate the effects of untreated household wastewater generated by kitchen and laundry facilities plus a calcium amendment on growth and appearance of selected ornamental plants.

Methodology: This is a laboratory-greenhouse study to assess the impact of graywater on selected soils and selected ornamental plants. To evaluate the characteristics of graywater a sampling device was designed and constructed to collect wastewater samples from a laundry machine outlet and the sink receiving effluent from a dishwashing machine. Wastewater samples were collected from the homes of a number of volunteers and analyzed for selected chemicals. Additional samples will be collected from the homes of volunteers. Sixty intact core samples, 6.5 cm in diameter and over 10 cm long, were collected from the Bt horizon of a clayey soil, a sandy soil, and a saprolite. Each intact core was covered with paraffin, trimmed to an 8-cm length, and a 2.5-inch polyvinyl chloride (PVC) fitting was attached to one end of it. Saturated hydraulic conductivity (K_{sat}) of five samples from each of three soils (15 cores) was measured with water over a 5-day period. Another five cores from each of the soils were used to measure their K_{sat} using wastewater from washing machines over a 9-day period. At the termination of the K_{sat} measurements, each core was trimmed to 7 cm length and analyzed for soil water retention under 0, 25, 50, 75, 100, 150, 200, 300, and 400 cm of tension. Saturated hydraulic conductivity for laundry wastewater and the laundry-dishwashing combination wastewater, as well as the soil water retention of the remaining core samples will be measured during the remainder of the project period. In addition, the aggregate stability of the core samples following wastewater application to the cores will be assessed. Additional intact core samples will be collected to assess the impact of sodium and surfactants on soil hydraulic properties. To conduct the greenhouse study,

two different top soils were obtained and preparations were made to grow ornamental plants to be irrigated with water, laundry wastewater, dishwashing wastewater, and laundry wastewater plus a calcium amendment.

Principal Findings and Significance: This study will be continued through the end of November 2002. The preliminary results show that the K_{sat} of the Bt horizon core samples was increased during the 2nd day of measurement, but decreased to an average value ranging between 2.4 and 3.4 cm/day after the third day. The average saturated hydraulic conductivity of the sandy soil remained between 6 and 7 cm/d for five days. Saturated hydraulic conductivity of the Bt and the sandy soils decreased substantially after applying laundry wastewater to them. The K_{sat} of both soils reached the low value of 0.5 cm/d and remained below 1 cm/d after 5 days of laundry wastewater application. The measured K_{sat} values for the saprolite cores for both water and laundry wastewater were unusually low. After inspecting these cores, we determined that the cores did not represent the saprolite found at the site. Another set of saprolite samples will be collected to replace these samples. Based on the water retention under various soil water pressure heads, the sandy soil contains 30% water by volume at saturation with approximately 40% of the pores draining under 100 cm of tension. The total porosity of saprolite was approximately 55% while the porosity of the Bt horizon was approximately 47%. The average water content of the saprolite under 400 cm of tension was the same as the average water content of the Bt horizon.

Awards, Honors, promotions: None

Publications: None

Effect of Riparian Buffers on Removal of Nutrients and Sediment in Urban Streams

Basic Information

Title:	Effect of Riparian Buffers on Removal of Nutrients and Sediment in Urban Streams
Project Number:	2001NC1441B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	6th
Research Category:	Water Quality
Focus Category:	Water Quality, Non Point Pollution, None
Descriptors:	urban water systems, water quality,riparian vegetation
Principal Investigators:	Anne Hershey, Paul P Mou

Publication

Problem and Research Objectives:

Riparian buffer zones in urban streams are important in the protection and restoration of water quality, especially nutrient and sediment removal. The specific benefits of buffers vary with local conditions, such as vegetation type and structure, and soil physical and chemical properties. Management of vegetation within riparian buffer zones in urban areas is constrained by many conflicting needs, and management concern for improving urban water quality is recent. However, there is no scientific consensus or set of guidelines on the benefits of buffers of different types, thus, managers are further constrained in their efforts to resolve conflicting needs.

Urban streams in the Piedmont of North Carolina are characterized by poor water quality, high sedimentation, and impaired biotic habitat. Most are on the 303d list. To improve water quality the City of Greensboro is instituting a large-scale effort to develop vegetated riparian buffers. However, the site-specific parameters for maximum buffering capacity for nutrient and sediment removal are unknown

This project was designed to isolate the effect of vegetation type on the quality of water passing through riparian buffers in an urban stream. Of the many aspects of riparian zones that can affect water quality, we chose to focus our initial efforts on the impact of vegetation types on stream water quality. The specific objectives of this research were:

a. To determine the effect of vegetation type within riparian buffer zones on surface runoff water quality.
b. To determine the effect of riparian vegetation type on sub-surface water quality.
c. To experimentally evaluate loss of nutrient tracers moving across riparian zones of different composition.
d. To incorporate field experimental and comparative data into a GIS database for future development of a predictive model of the effects of riparian buffer development on quality of water discharging into the Upper Cape Fear River Basin.

This research will contribute to our ultimate long-term goal, not expected to be completed during this initial project, which is to develop a comprehensive GIS-based predictive model for buffer effectiveness across land-use types, soil characteristics, topographical features and site-specific hydrological conditions for the Upper Cape Fear Watershed.

Methodology:

Sites, Treatment, and Sampling: The Buffalo Creek riparian zones within the City of Greensboro NC (Guilford County) was the study site. Two vegetation types were represented which had sufficient width to conduct the experiment: forested and grassy. We selected several possible sites based on slope and width of the riparian buffer zones using GIS generated broad-scale 2-ft contour maps overlaid on the aerial photos. Then, we examined these sites in the field and selected 6 experimental sites (3 in forested and 3 in grassy). At each site, 5 sampling locations were determined at 50-m, 30-m, 20-m, 10-m and 1-m distance from the stream. The sampling locations follow the general flow path of water runoff. To collect sub-surface water, two lysimeters, 20-cm deep and 50-cm deep, were installed at each sampling location. Two wells of 1.5 meter deep were also

installed at the upslope edge and near the stream at each of the study site for collecting deeper soil water samples. Soils were examined, and slopes, aspects were measured.

We applied one treatment for each site each season. For each site, we applied 6,500 gallons of nutrient solution (NO3-14ppm, NH4-8ppm, P2O5-6.5ppm) from a 3-meter long spreader at an application rate of 55-65 gallons (210-250 liters)/minute. The N content of the solution was 3X the concentration of the highest storm water N concentration measured in the city. The duration of the treatment (starting and ending of the nutrient solution application) and the ending surface runoff were recorded. Soil samples were collected for examining soil water content before each treatment.

One day (24 hr) prior to the treatment, the lysimeters were pumped. Water samples were collected from the lysimeters immediately before treatment. During treatment, surface runoff samples were collected at each sampling location as soon as the runoff reached that point. 24-hr after each treatment, lysimeters were sampled and pumped dry. An additional set of samples was collected from the lysimeters 12-18 hours later. Well and stream water samples were collected the same time as lysimeter samples.

Each season, we also collected lysimeter and well samples after one medium-heavy precipitation event (> 20 mm). The lysimeters and wells were pumped 12-hr after the rain event, sampled, re-pumped, then re-sampled 12-18 hours later.

For all sampling, water samples were immediately placed in a cooler, brought to the lab, and stored in the freezer until they were analyzed. Nutrient concentrations were analyzed with a Bran-Luebbe TRAACS 2000 auto-analyzer. Soil water contents were examined following standard methods.

Data Analyses: ANOVA is being used to evaluate the impact of two types of vegetated riparian on water quality mediation.

Table 1: Variable Summary of the Data Collected in this Study (reps=3)

Variable:	**samples**
Distance to stream:	1m, 10m, 20m, 30m, 50m,
Depth of water samples:	0 cm (surface runoff), 20cm, 50cm, 1.5m (well)
Seasons:	2001-winter, 2002-spring, 2002-summer, 2002-fall
Sample time:	pre-treatment, 1-day, and 2-day pos-treatment,
Riparian Vegetation Type:	forest, grass
Watering Events:	treatment (nutrient solution application), natural rain

Principle Findings and Significance (progress report):

Due to start-up delays, the first treatment occurred in the 2001-2002 winter season. We have completed winter, spring, and summer treatments and associated sampling, and three sets of sampling of natural rain events (winter, spring, and summer). The field sampling will be completed in 2002 fall season. The following are the work elements we have accomplished:

May 9, 2001 – June 1, 2001

- Ordering supplies
- Construction of lysimeters.

June 2, 2001 – Sep 1, 2001

- Construction of lysimeters and surface water collectors continued.
- Continued purchase of supplies.

- Refinement of field site selection.
- Begin field installation of lysimeters and surface water collectors at field sites.

Sep 2, 2001 – Dec 1, 2001

- Train students in use of the auto-analyzer. Considerable effort was expended in getting it calibrated and running for local water chemistry.
- Conduct preliminary experiment. This preliminary experiment provided essential information for making modifications to the experimental design (see methodology)

Dec. 2, 2001 – June 30, 2002

- Conducting winter, spring, and summer treatments and sampling (~500 samples collected each time).
- Sampling after natural rain events (once each season, ~300 samples collected each time).
- Sample analyses (40% of collected samples have analyzed)
- Design statistical model for data analyses (5% of the task has been finished)

The preliminary data indicate that the overall approach and design have been successful. At this moment, we may conclude that:1) forested riparian zone has stronger hydrological buffering capacity than grassy riparian; 2) topographical relief affects surface runoff; 3) riparian soils effectively buffer NH4, but have little impact on NO3; 4) riparian width greatly affects water quality of sub-surface runoff, but has little impact on that of surface runoff; 5) impact of riparian width on surface runoff is through soil infiltration that reduces amount of surface runoff and its flux.

Role of Sediment Processes in Regulating Water Quality in the Cape Fear River

Basic Information

Title:	Role of Sediment Processes in Regulating Water Quality in the Cape Fear River
Project Number:	2001NC1461B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	4th
Research Category:	Water Quality
Focus Category:	Sediments, Nutrients, Water Quality
Descriptors:	Nutrients, phosphorus binding capacity, sediment characteristics, phosphorus speciation, 31P Nuclear Magnetic Resonance Spectrometry, land use, water quality
Principal Investigators:	Curtis J. Richardson, P. V. Sundareshwar

Publication

Problem and Research Objectives:

We selected the Cape Fear River system, the largest river system in North Carolina, since during the recent decades it has experienced a proliferation of agriculturally related industries including large-scale agricultural operations, agrochemical manufacturing, and intensive livestock operations. This has resulted in dramatic increases in anthropogenic imports of nitrogen and phosphorus into the river basin. Between 1985 and 1995 hog production in North Carolina increased by 248% and turkey production increased by 92%. North Carolina is now the second largest producer of hogs in the nation. The majority of these intensive livestock operations are located within the Cape Fear and Neuse River watersheds. Given the magnitude of increased phosphorus and nitrogen import into the watershed, even relatively effective water quality management practices will still allow considerable nitrogen and phosphorus loading to the river, thus increasing the potential for eutrophication. While the Neuse River basin has been the focus of numerous water quality related investigations, the Cape Fear River basin has been accorded relatively little attention. However, there is a clear trend in water quality degradation on the Cape Fear River.

Although, surface waters in North Carolina rivers have been the focus of intense monitoring and research, the role of the sediment chemical environment (SCE) in regulating surface water quality has been essentially ignored. The reciprocal interaction between surface water quality and the processes occurring within the SCE underscores the need to better understand this (SCE) important but least understood class of conditions that dictate the nutrient status and quality of adjoining water bodies.

Our primary objectives for this study were:

1) *To identify the chemical forms in which nutrients are input into the Cape Fear River basin, and*
2) *To address the previously overlooked role of sediments in buffering water quality in order to facilitate its incorporation in future water quality management programs.*

These objectives were achieved with a focus on Phosphorus (P) fractions.

Methodology:

Site Selection: Water quality data were collected from three Lock and Dam locations within the middle Cape Fear River basin. Lock and Dam #1 (which is located furthest downstream) was completed 1915, Lock and Dam #2 was complete in 1917, and Lock and Dam #3 (the furthest upstream) was completed in 1935. Additionally, sediment samples were also collected from the Barra Farms site for NMR analyses. The Barra Farms Cape Fear River Mitigation Bank is located at the headwaters of Harrison Creek, a tributary of the Cape Fear River that drains just downstream of Lock and Dam # 3 and upstream of Lock and Dam # 2. The Barra Farms site was originally part of a Carolina Bay wetland, large areas of which were ditched and converted to agricultural production. In 1997 about 600 acres of this converted agricultural land was restored to wetland, while adjacent agricultural areas remained in production.

Surface water monitoring: The surface water quality at the selected sites were monitored monthly. Surface water at these sites were monitored for nutrient parameters such as ammonium, nitrate+nitrite, total Kjeldahl nitrogen, soluble reactive phosphorus, total phosphorus, dissolved organic carbon, and major cations and anions. Three replicate samples were collected at each site during each sampling event to ensure sufficient statistical replication.

Sediment Characterization: Bulk densities of riverbank sediments were determined after drying intact sediment cores to a constant weight. The organic matter content of the sediments was calculated as weight loss upon ignition at 550 ^{0} C overnight. Total Carbon and nitrogen were measured on a CHN analyzer, while total P and elemental composition of the sediments was determined using an Atomic Absorption Spectrometer after acid digestion of the sediment samples.

Nutrient buffering capacity of sediments: Surface sediments (0 – 10 cm depth) from the selected sites were used to estimate their nutrient buffering capacity. Sediment samples were incubated with solutions of increasing phosphorus concentration. The sorption coefficients were estimated by fitting the data to sorption models such as Freundlich adsorption model. The zero equilibrium phosphate-P concentration (ZEPC) (a concentration at which no net adsorption or desorption occurs) was also estimated from the above data set. Phosphorus binding capacities of sub-surface sediments (10-20 cm depth) from our sites were also estimated

^{31}P NMR Studies: To identify various phosphorus species in the riverbank (from the three lock and dam structures) and Barra Farms sediments (from agricultural lands, restored wetlands and a natural wetland), triplicate surface sediment cores (0-10 cm depth) from each site were pooled and extracted overnight at room temperature (using a soil:solution ratio of approximately 10 g dry sediment : 100 ml 0.5 M NaOH + 0.1 M EDTA). Extraction efficiencies were calculated as the difference in total phosphorus concentrations between un-extracted sediment samples and the total phosphorus in the NaOH+EDTA extract. Extracts were centrifuged at 3200 rpm after adjusting the pH to12.5, and 3ml of the supernatant was used for NMR analyses after adding 0.3 ml of D_2O. All spectra were collected over 24 hrs with a 100 ppm window centered at 0 ppm on a Varian 500 spectrometer. Chemical shifts (relative to 85 % phosphoric acid) were assigned based on external standards and literature. ^{31}P NMR analysis was also run on surface water from lock and Dam # 3 that was concentrated approximately 140 fold using a rotary evaporator.

Pyrophosphate analysis in water samples: We used a new technique to specifically measure pyrophosphate (Ppi) in water samples. This technique relies on a cascade of enzymatic reactions, of which the first enzyme is Ppi dependent. Thus the reaction will only occur in the presence of Ppi (e.g. in water sample from our sites).

Principle Findings and Significance:

Our results indicate that there are differences in water quality parameters among the three Lock and Dam (LD) structures. In comparison to the upstream site, LD 3, downstream sites LD 2 and LD1 generally had higher concentration of nutrient parameters such as dissolved reactive phosphorus (DRP) and total phosphorus (TP) in surface waters. However, the relative contributions of organic and particulate fractions of phosphorus were generally higher at LD 3 site than those measured at downstream sites LD 2 and LD 1. While trends in DRP concentrations may partly be due to the difference in number of permitted discharge locations just upstream of these sites, accumulation of phosphorus in the riverbank sediments is most certainly controlled by sediment loading from the sub-watersheds and in situ sediment processes. Results from our previous study indicate 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 1, respectively. The sedimentation rates correspond well to the total sediment phosphorus concentrations, which indicate that sediment deposition during the recent decades (≈ 40 years) has caused an increase in nutrient loading to the CFR. The present study reveals that the total phosphorus in sediments at these sites, in general, was positively correlated with the sum of total Fe, Al, Ca and Mg. This positive relationship was observed for surface and sub-surface sediments at all sites except in surface sediments at LD 2. At this site, while sub-surface sediments exhibited a positive relationship, the surface sediments site did not. This suggests that recent input of phosphorus and mineral elements from external sources may have altered this relationship. Among the three lock and dam sites, the floodplain sediments at LD 2 had the greatest phosphorus binding capacity, while the most downstream site LD 1 had the lowest. This trend in P-sorption capacity of the riverbank sediments persisted for the sub-surface sediments, although the P-binding capacity of the sub-surface sediments was lower than the binding capacity of corresponding surface sediments. Importantly, the intra-site variability in P-sorption capacity and mineral element composition increases downstream, most likely due to differential sorting of the riverine sediment load. Despite the higher sorption capacity of LD 2 sediments, the surface water concentrations of dissolved phosphorus were

highest at this site. ^{31}P Nuclear Magnetic Resonance (NMR) analyses of concentrated river water and floodplain sediments reveal that phosphorus loading in this river occurs in diverse chemical forms. NMR analyses of riverbank sediments reveal the presence of P-forms such as Glyphosate (a commonly used weedkiller), Aminomethylphosphonic Acid (a degradation product of Glyphosate) and pyrophosphate (the smallest chemical form of polyphosphate with wide industrial applications), in addition to more commonly observed P-forms. The concentration of pyrophosphate in surface waters was below detection, however, 31P NMR analysis of surface water that was concentrated 140 fold showed a peak that corresponded to pyrophosphate. Although the surface water concentration of these forms of phosphorus may be very low, overtime, the phosphorus binding properties of the deposited sediments may concentrate these forms of phosphorus in the floodplain of the CFR. Our NMR analyses of sediment samples from the areas under varying landuse within the Barra Farms site, demonstrates that converting natural wetlands to agricultural land results in the loss of natural 'diversity' in the chemical forms of phosphorus – analogous to the loss of 'biodiversity' in impacted ecosystems. Results from the restored site indicate that restoration of impacted sites may result in re-establishment of the lost diversity in chemical speciation of nutrients. This also provides a valuable tool to track the progress of a restored site relative to a corresponding undisturbed and natural wetland. Together, these finding suggest that sediments play a key role in regulating the water quality of the Cape Fear River. The diversity in the chemical forms of phosphorus in the riverbank sediments helps identify the types and sources of nutrient loading in the CFR. It is conceivable that, after few years of sustained nutrient loading (e.g. phosphorus), floodplain sediments of the Cape Fear River system will eventually become saturated with nutrients and thus will be unable to ameliorate nutrient driven surface water quality degradation. Importantly, increasing variability downstream in the mineral element composition and the P-binding capacity of riverbank sediments suggests that moving seaward, sediment sorting will lead to creation of 'hot spots' for efficient P-sorption and release along the riverbank of the CFR, and this could pose a considerable challenge with regard to water quality management. This implies that sources for sediment load to the CFR need to be identified and effective BMPs implemented to restrict the sediment loading in the upper reaches of the watershed. These findings have important implications for water quality management in this largest river system in North Carolina.

An Assessment of the North Carolina Water Reuse Regulations

Basic Information

Title:	An Assessment of the North Carolina Water Reuse Regulations
Project Number:	2001NC33B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	NC 12
Research Category:	Water Quality
Focus Category:	Waste Water, Irrigation, None
Descriptors:	Reclaimed Wastewater, Water Reuse, Land-Water Interactions, Regulatory Requiements
Principal Investigators:	Helene A Hilger, Mark David Sobsey

Publication

Problem and Research Objectives: North Carolina water reuse regulations were promulgated in 1996 in response to growing municipal interest in water reuse. They were drafted by an expert committee, however they were written without benefit of any North Carolina pilot or demonstration data, since none were available. The original research objective of this project was to document the quality of reclaimed water that was produced at the first two full-scale municipal wastewater reclamation facilities in North Carolina and use the data to assess the state water reuse regulations with respect to their ability to (1) stipulate water quality standards that safeguard public health; and (2) permit sensible facility design and operation plans that stimulate confidence in municipal water reuse options.
Because one of the plants was never permitted and the other operated only a few months out of the period for which we were funded, an additional objective was added: to evaluate the North Carolina reuse regulations relative the guidelines and laws about reuse in other states.

Methodology: The tasks performed to accomplish these objectives included (i) a review of monitoring data from the Mallard Creek Wastewater Reclamation Facility (MCWRF) in Charlotte, NC; (ii) collection and laboratory testing of reclaimed wastewater samples from MCWRF and the irrigation site [Tradition Golf Course] to measure pollutant concentrations and to assay for indicators of bacterial, viral, and protozoan pathogens; (iii) preparation of a written review of recent and pertinent literature on microbiological contaminants associated with reclaimed wastewater; (iv) development of a water balance model to assess the efficacy of set-back distances designed to prevent any fecal contaminants delivered to the turf in the irrigation water from flushing into a nearby stream with storm runoff; and (v) preparation of a database containing summaries of the reuse guidelines and regulations in other states regarding applications to public access sites.

Progress Report: Monitoring data from the treatment plant have been collated and summarized, and field samples have been analyzed for the several months during which the plant produced reclaimed wastewater. The review of pertinent water microbiology literature has been completed, as has the water balance model. The summary of state water reuse regulations for reclaimed water applied to areas of public access is expected to be complete in the next two months.

The monitoring data indicate that the nutrient and organic content of the irrigation water was within acceptable limits, but the fecal coliform data showed some spikes that caused frequent shut-downs of the system. When measurement indicated that chlorine residual in the reclaimed water samples was negligible, substantial indicator virus counts were evident while fecal coliforms were not. These results support the notion that the absence of fecal indicators does not necessarily mean that the water is free of possible pathogens. When chlorine residual concentrations were in a more typical range, there was good correlation between the bacterial and viral indicator counts.

The review of very recent literature about waterborne pathogens and human health risks associated with reclaimed wastewater revealed that current concerns center around (a) the nature of the microbial indicators used for water testing and (b) the possible use of risk assessment models to set acceptable water quality limits. With new detection methods and the availability of viral pathogen surrogates, the use of such surrogates is being considered

because several pathogenic viruses are hardier than fecal coliforms. The use of risk assessment analyses would allow consideration of factors such as likely exposure, likely dose needed for infection, and likely outcome if infected, so that a set of allowable limits could be generated that was based on scientific data rather than expert opinion. This is an appealing direction in which to go, however, in many cases, the scientific data to support such decisions are incomplete or absent.

The water balance model showed that even under the most extreme storm water loading conditions, the impact of fecal coliforms from the site on a nearby receiving stream would not differ significantly with or without the buffer distance stipulated in the North Carolina regulations. The model requires input about the viability and die-off rate of fecal coliforms applied to the irrigation site. Since these variables are not well-characterized for any irrigation or storm water runoff system, we used the most conservative estimates for them in the model. Although subsequent field tests can be used to confirm most of the model parameters, further general study of fecal coliform fate and transport is needed to improve modeling predictions.

The review of the 50 states' reuse regulations was added to the task list for the project when it became evident that little data collection would be possible at the single study site available to us. Data collection for this task has been completed, and the summaries are currently being drafted. It is clear from the review that numerous states have begun to look to wastewater reclamation as a viable method of supplementing existing water resources. Only a handful of states have no guidelines or regulations to guide permit irrigation with reclaimed wastewater on public access sites, and even those will sometimes allow it by special permitting processes. Despite fairly uniform recognition of the benefits of wastewater reclamation, there is wide variability in areas of emphasis and level of detail in the rules and recommendations offered from state-to-state.

Based on our survey, North Carolina regulations are clearly among the most progressive and far-sighted regulations nationwide; they allow diverse uses other than golf course and park irrigation and contain numerous features to insure public health safety and treatment reliability. Some of the most notable distinctions in our regulations are the inclusion of a buffer zone in areas of unrestricted public access and the allowable fecal coliform limits. Fecal coliform limits in other state guidelines and laws are typically much lower than the 14 cfu/100 mL monthly geometric mean and the 25 cfu/100 mL maximum allowed in North Carolina.

Throughout the project, we have maintained contact with the treatment plant operator, who provided valuable insights and comments about how the state regulations guided his plant operations. He pointed out that as a plant manager, the ways that he and his staff were trained was appropriate for sewage, but not for reclaimed wastewater. In his opinion, a whole new mindset was required of every plant employee when they began producing a product of much higher quality, with narrower margins for error, and aimed for uses where human contact was possible. Another interesting issue he raised was the maintenance of the distribution lines. They could not be handled as if the pipes held sewage, nor were they as safe to handle as pipes that held potable water. Identifying the responsible municipal agencies, developing

new policies, and retraining the work crews were all new tasks required to maintain the integrity of the reclaimed water lines.

Assessment of Changing Land-Use Practices on Basin Sediment Yields and Provenance in Western North Carolina Using Multivariate Fingerprinting Techniques

Basic Information

Title:	Assessment of Changing Land-Use Practices on Basin Sediment Yields and Provenance in Western North Carolina Using Multivariate Fingerprinting Techniques
Project Number:	2001NC34B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	11th
Research Category:	Water Quality
Focus Category:	Sediments, Geomorphological Processes, Surface Water
Descriptors:	Sedimentation, Geomorphology, Water Quality, Reservoir Siltation, Fingerprinting
Principal Investigators:	Jerry R. Miller

Publication

1. Lord, Mark L., Miller, Jerry R., Yurkovich, Steve P., Kolenbrander, Larry G., Mackin, Gail, 2001. Assessment of changing land-use practices on basin sediment yields and provenance in western North Carolina using multivariate fingerprinting techniques. Geological Society of America Abstracts with Programs, v. 33. Miller, Jerry R., Lord, Mark L., Yurkovich, Steve P., Kolenbrander, Larry G., and Mackin, Gail, 2002. 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. Proceedings, WRRI 2002 Annual Conference, Setting the Agenda for Water Resources Research, Raleigh, NC.

Problem and Research Objective:

The ecological and financial impacts of sediment on streams and rivers has become a significant issue in the southern Appalachians during the past decade. It is generally assumed that most of this sediment is the result of land-use alterations, particularly those associated with development activities. However, there have been few attempts to actually quantify the impacts of land-use alterations on upland erosion in the southern Appalachians. This investigation examines the use of physical and geochemical fingerprinting techniques and sediment mixing models within the Fairfield Lake basin to determine if they can be effectively utilized in the steep terrain of western North Carolina. More specifically, the study attempts to determine the relative contributions of sediment, at any given time, to Fairfield Lake from specific geologic units and delineated land-cover types (e.g., forests, roads, lawns, etc.). To our knowledge, this is the first attempt to apply these procedures in the southern Appalachians.

The analysis was primarily carried out between March 1, 2000 and February 28, 2001 and a draft of our final report was submitted to the Water Resources Research Institute in February, 2001. Financial support for the project during this reporting period (March 1, 2001 to February 28, 2002) was limited to internal funds from Western Carolina University. Thus, work during the past year has been restricted to the refinement of the fingerprinting/mixing model techniques that were previously developed and presentation of the study results.

Methodology:

As described below, a principal finding of our initial studies was that the geochemical signal of distinct bedrock or land-use types was muted by chemical processes as the sediments were transported through upland streams to depositional sites within Fairfield Lake. Thus, the original approach required modification before it could be effectively used in western North Carolina. At the present time, we are attempting to improve the technique by (1) using elemental ratios as geochemical fingerprints, and (2) using weighted factors based on the ratios of more soluble to less soluble constituents (e.g., Ti) to reduce the effects of elemental loss on the mixing model results. Both of these procedures require additional analyses of the sediment samples collected from Fairfield Lake and the upland areas surrounding the lake. Thus, the samples were sent to the Nevada Bureau of Mines and Geology for analysis by an ICP-MS under the direction of Dr. Paul Lechler. We are currently waiting on the analytical results.

Principal Findings and Significance:

Sedimentation within Fairfield Lake has been limited since dam closure in 1890. Most of the sediment that enters the lake is deposited near the mouth of tributaries creating deposits on the order of 50 to 100 cm in thickness. Deep-water areas located along the axis of the reservoir, and which are removed from the direct influx of tributary sediment, have received only a limited amount of debris (generally <30 cm).

^{210}Pb data clearly indicate that sedimentation rates have significantly increased during the past few decades. The most significant increases occur in the mid-1980s and the late 1990s, both of which correspond to periods of development documented by the comparison of aerial photographs obtained in 1963, 1975, 1988, and 2000. The more recent sedimentation rates are several fold greater than the rates observed during the first half of the 1900s.

The statistical treatment of geochemical data from sediments overlying the Whiteside Granite and the Tallulah Falls Formation suggest that the soils associated with these lithologies can be delineated on the bases of Cu, Mn, Sn, U, and Zn. That is, the bedrock units exhibit a unique geochemical fingerprint defined by these five parameters. Similarly, materials from differing sediment sources within the Whiteside Granite, including forests, roads, lawns, and alluvial deposits along upland streams can be defined on the basis of Ag, Bi, Cr, Mn, Mo, Ni, Sb, Sn, and Zn. Thus, the results from the linear discriminant analysis suggest that it is possible to use sediment mixing models to determine the quantity of material derived from differing lithologies or land-cover types.

In light of the above, a separate sediment mixing model was developed using the parameters defined in the discriminant analysis to (1) assess the relative contributions of sediment derived from the different bedrock units that underlie the watershed, and (2) define the contributions of materials to the lake from the four different upland sediment sources. With respect to differentiating between bedrock sources, the model worked reasonably well. However, it appears to have been unable to distinguish between sediment derived from the Tallulah Falls Formation and sediment from a micaeous, more mafic-rich unit of the Whiteside Granite. These two units apparently have a similar geochemical fingerprint. This problem may be addressed by using one of two different approaches. First, the micaeous unit of the Whiteside Granite can be treated as a separate sediment source. Thus, in this study, the mixing models would examine the contributions of material from three lithologic units. For small watersheds, such as the Fairfield Lake basin, this approach may work well. However, for larger watersheds, the approach may lead to an unmanageable number of different sediment sources. An alternative approach, which is currently being examined, is to define sediment sources according to the gross mineralogical composition of the rocks. In this case, sediments from the Tallulah Falls Formation and the micaeous unit of the Whiteside Granite are being treated as a single source type. There is some merit to this approach in that previous studies have shown that rock units of similar composition also function similarly in terms of their erodibility. Model output may then lead to a conclusion that sediment from a particular lithologic (mineralogic) group tends to produce most of the sediment in an area and, therefore, these rock units should be treated differently (perhaps more stringently) in terms of management practices.

The modeling of the relative contributions of sediment from forests, lawns, roads, and upland alluvium also shows promise in that the model was able to define systematic changes in core geochemistry that are related to changing sediment sources documented on aerial photography. However, it appears that the geochemical signal of lawns, roads,

and forests is muted by chemical processes as the sediments are transported through upland streams to depositional sites within the lake. Thus, the approach is being modified for use in western North Carolina. Specific modifications are focusing on (1) the use of elemental ratios as geochemical fingerprints, and (2) the use of weighting factors based on the ratios of more soluble to less soluble constituents (e.g., Ti) to reduce the effects of elemental loss on the mixing model results.

In addition to the studies conducted in North Carolina, it should also be noted that the developed mixing model has been used in geochemical fingerprinting studies that utilize lead isotopes in southern Bolivia. The results of the Bolivian study, funded by the National Science Foundation, is currently in press in Miller et al. (2002.

Technical and Economic Evaluation of Alternatives for Animal Waste Management

Basic Information

Title:	Technical and Economic Evaluation of Alternatives for Animal Waste Management
Project Number:	2001NC35B
Start Date:	3/1/2001
End Date:	10/1/2002
Funding Source:	104B
Congressional District:	4th
Research Category:	Water Quality
Focus Category:	Agriculture, Nutrients, None
Descriptors:	Animal Waste, Nutrients, Treatment
Principal Investigators:	Michael Overcash

Publication

1. Overcash, M., K. Zering, M. Renkow, 2001, Technical and Economic Evaluation of Alternatives for Animal Waste Management, Water Resources Research Institute of the University of North Carolina, Raleigh, NC, 20p.

Problem and Research Objectives:

The overall goal of this proposal is to provide more complete information on the full environmental impact and the broad economic consequences of changing the waste management technologies for livestock production industry. We seek to accomplish this through tools that provide an "apples-to-apples" comparison of current and developing waste management technologies. The comparisons will be for

a) all environmental emissions and

b) the broader economic costs.

Specific goals are,

1) to tailor a life cycle framework and an economic framework to the unique challenges of evaluating technologies for waste management in the livestock industry of North Carolina. The specific rules, assumptions, and ultimate data will assure that a reasonable apples-to-apples comparison can be made of each current and new technology. Developing these frameworks will streamline future work and direct research to areas of inadequate understanding.

2) to conduct life cycle comparison of technologies currently being evaluated in direct economic terms by DEHNR as potential candidates for change .

3) to utilize analogous literature information to expand the economic analyses currently undertaken at DEHNR in order to begin to move from direct costs (on-site) to the significant total systems economics that will be influenced by proposed waste management technology changes at livestock facilities. This will improve the cost/benefit analyses (on-going at DEHNR), but will not be able (during this one year project) to represent the complete economic analysis. Thus only certain economic modules will be developed.

4) to provide environmental and economic information to decision-makers as a means of better understanding the complex system of livestock waste management. These individuals include agribusiness, government, and communities. The results of this project will lead to help in making more informed decisions about future waste management alternatives and hence better decisions.

Methodology:

Life cycle and economic frameworks were developed to meet the needs of this research project. For this study, the research method focuses on both the direct comparisons of new alternative livestock waste management technologies to the conventional anaerobic/land application systems, but also on understanding the general magnitude of the indirect or off-site components versus the on-site environmental emissions. This allows one to begin generalizing the results to future alternative technologies or to locations elsewhere in North Carolina or the U.S.

Principal findings and significance:

The following synopsis represents the outcomes of this project.

Three animal waste management technologies were completed in this study, the conventional anaerobic lagoon with irrigation of effluent, the biological filter process and the covered lagoon.

The covered lagoon has the highest nitrogen contents in both the lagoon effluent the lagoon sludge among other technologies. The biological filtered process is followed by the covered lagoon in the preservation of nitrogen. The anaerobic lagoon has the highest loss ratio of nitrogen due to the vaporization of ammonia in the lagoon.

For the total energy use, the covered lagoon has the highest avoided energy because of the utilization of biogas, methane, from the lagoon. The biological lagoon requires the electricity for the aeration. The total energy in the biological filtered process ranges from -9.66×10^3 to 3.79×10^3 because of the data sources: from municipal wastewater data or from aerated lagoon data.

The resources like coal, crude oil and natural gas, follow the profile of the total energy. It shows that the energy is a major factor influencing the use of resources, not feedstock.

Except the biological filtered process, where carbon dioxide is released from the lagoon, the anaerobic lagoon and the covered lagoon release methane, but the covered lagoon utilizes methane gas to generate electricity and to heat water. Therefore, the anaerobic lagoon has the highest methane emission. The avoided methane emission due to saving the inorganic fertilizer is relatively small.

All the three technologies release carbon dioxide from the lagoon. The biological filtered process has the highest carbon dioxide emission. The covered lagoon has the lowest carbon dioxide emission. Though there are avoided energies due to the utilization of methane, the amount of carbon dioxide emission excluding the avoided emission from the inorganic fertilizer is still positive because carbon dioxide is included in the biogas.

Nitrogen oxide is released from the land application: the largest nitrogen applied in the land casues the highest nitrogen oxide emission. Therefore, the covered lagoon has the highest nitrogen oxide emission. Ammonia is also released during the land application. However, the ammonia emission shows different profile from nitrogen oxide because the anaerobic lagoon loses nitrogen throught the vaporization of ammonia in the lagoon. The anerobic lagoon has the highest ammonia emission among other technologies.

For NOx emission, the biological filtered process has the highest NOx emission because nitrogen is oxidized and converted into NOx during the aeration. Other emissions shows the same emission profile as the total energy.

The comparison between three technologies shows that the covered lagoon is superior to other two technologies in most of the environmental loadings except N_2O and NH_3 emission. In the covered lagoon the biogas from anaerobic digestion is utilized to generate electricity and to heat water, and there is no nitrogen loss so that the avoided inorganic nitrogen fertilizer is maximized.

Information Transfer Program

Watershed to Estuaries: Basin Management in the 21st Century

Basic Information

Title:	Watershed to Estuaries: Basin Management in the 21st Century
Project Number:	2001NC23O
Start Date:	4/9/2001
End Date:	4/9/2001
Funding Source:	Other
Congressional District:	4th
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	Kenneth H. Reckhow

Publication

Convened the Annual WRRI Conference, “Watershed to Estuaries: Basin Management in the 21st Century,” in March 2001. Investigators from universities, agencies, industry, and consulting firms presented results of work on topics ranging from agricultural erosion to water demand. Some 300 people participated in the conference. Participants had 48 technical presentations in 3 concurrent sessions from which to choose, as well as 23 technical posters to view. A booklet of abstracts was produced and distributed to participants. Abstracts were also made available on the WRRI website.

An Introducation to Erosion and Sediment Control for Construction Sites

Basic Information

Title:	An Introducation to Erosion and Sediment Control for Construction Sites
Project Number:	2001NC24O
Start Date:	9/25/2002
End Date:	9/26/2002
Funding Source:	Other
Congressional District:	4th
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	Kenneth H. Reckhow

Publication

Organized and co-sponsored with the N.C. Division of Land Resources “An Introduction to Erosion and Sediment Control for Construction Sites” in September 2001 in Hickory, NC, and October in New Bern, NC.

Erosion and Sediment Control for Construction Sites: Intermediate/Advanced Level

Basic Information

Title:	Erosion and Sediment Control for Construction Sites: Intermediate/Advanced Level
Project Number:	2001NC25O
Start Date:	2/19/2002
End Date:	2/20/2002
Funding Source:	Other
Congressional District:	
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	Kenneth H. Reckhow

Publication

Organized and co-sponsored with the N.C. Division of Land Resources “Erosion and Sedimentation Control for Construction Sites: Intermediate/Advanced Level” February 2002 in Raleigh, NC

International Symposium Addressing Animal Production and Environmental Law

Basic Information

Title:	International Symposium Addressing Animal Production and Environmental Law
Project Number:	2001NC26B
Start Date:	10/3/2001
End Date:	10/5/2001
Funding Source:	104B
Congressional District:	4th
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	Kenneth H. Reckhow

Publication

Co-sponsored with NC State University and others the “International Symposium Addressing Animal Production and Environmental Issues” held in October, 2001, in Research Triangle Park, NC.

N.C. Water Resources Association Forums

Basic Information

Title:	N.C. Water Resources Association Forums
Project Number:	2001NC27B
Start Date:	4/1/2001
End Date:	2/1/2002
Funding Source:	104B
Congressional District:	4th
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	Kenneth H. Reckhow

Publication

Organized and coordinated the following luncheon-forums for the N.C. Water Resources Associations:

April 2001 - Dam Removals in North Carolina
September 2001 - On-Site Wastewater Issues
December 2001 – Floodplain Management
February 2002 – Interbasin Transfer

The Institute NEWS

Basic Information

Title:	The Institute NEWS
Project Number:	2001NC28O
Start Date:	3/1/2001
End Date:	2/1/2002
Funding Source:	Other
Congressional District:	4th
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	, Amy (Jeri) B Gray

Publication

Published the *WRRI News* six times during the reporting period. The WRRI News is a 16-page newsletter that covers a wide range of water-related topics from current federal and state legislation and regulatory activities to new research findings, water-related workshops and conferences, and reviews of water-related publications. The WRRI News is sent to nearly 4,100 federal and state agencies, university personnel, multi-county planning regions, city and local officials, environmental groups, consultants, businesses and individuals.

The Sediments News

Basic Information

Title:	The Sediments News
Project Number:	2001NC29B
Start Date:	3/1/2001
End Date:	2/1/2002
Funding Source:	104B
Congressional District:	4th
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	, Amy (Jeri) B Gray

Publication

Published four issues of the *Sediments* newsletter. WRRI publishes this newsletter for the N.C. Sedimentation Control Commission to provide information and assistance to the regulated community and to facilitate communication among personnel of state and local erosion and sediment control programs. Current circulation is about 5,600.

Water Resources Research Seminar Series

Basic Information

Title:	Water Resources Research Seminar Series
Project Number:	2001NC30O
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	Other
Congressional District:	4th
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	Kenneth H. Reckhow

Publication

Organized and sponsored the following seminars by investigators working under WRRI grants:

March 2001 – Assessment of Changing Land-use Practices on Basin Sediment Yields, Dr. Jerry Miller, Western Carolina University.

April 2001 – A Comparative Analysis of compact and Low-Density Development, Dr. Philip Berke, UNC-Chapel Hill.

May 2001 – Technical and Economic Evaluation of Alternative Animal Waste Management, Dr. Michael Overcash, NC State University.

September 2001 – Recommendations for the Total Maximum Daily Load Program, Dr. Kenneth H. Reckhow, WRRI and Duke University.

October 2001 – Examination of the Wetland Hydrologic Criterion and Its Application in the Determination of Wetland Hydrologic Status, Dr. Wayne Skaggs, NC State University.

November 2001 – Southern Village: A Case Study in the Water Quality Benefits of Compact Development, Research Assistant Joseph MacDonald, UNC-Chapel Hill and Research Assistant Michael Holmes, NC State University.

January 2002 – Development of stream Identification Methodology, Dr. James Gregory, NC State University.

February 2002 – Performance Evaluation of Regional Wet Detention Ponds and a Wetland for urban Nonpoint Source Control, Dr. Robert Borden, NC State University.

Erosion and Sediment Control Workshop for Local Programs

Basic Information

Title:	Erosion and Sediment Control Workshop for Local Programs
Project Number:	2001NC31O
Start Date:	1/23/2002
End Date:	1/24/2002
Funding Source:	Other
Congressional District:	4th
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	Kenneth H. Reckhow

Publication

New Research Reports

Basic Information

Title:	New Research Reports
Project Number:	2001NC32O
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	Other
Congressional District:	4th
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	Kenneth H. Reckhow

Publication

New WRRI Research Reports- A strong demand for Institute reports continues. During the year, the Institute published the following reports for distribution to users throughout the state and nation:

WRRI-333- Examination of the Wetland Hydrological Criterion and Its Application in the Determination of Wetland Hydrologic Status.

WRRI-334- Evaluation of Performance and Operational Costs for Three Biological Nutrient Removal Schemes At a Full-Scale Wastewater Treatment Plant.

WRRI-335-Performance Evaluation of Regional Wet Detention Ponds and Wetland for Urban Nonpoint Source Control.

WRRI-336-Soil Processes Impacting Groundwater Quality in the North Carolina Piedmont: Contamination by Organic Agrochemicals.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	2	20	24
Masters	2	0	3	31	36
Ph.D.	1	0	1	13	15
Post-Doc.	2	0	2	4	8
Total	7	0	8	68	83

Notable Awards and Achievements

R. Wayne Skaggs (Project #70137, 70162) William Neal Reynolds Professor of Biological and Agricultural Engineering at NC State University was installed as the President of the American Society of Agricultural Engineers.

Viney Pal Aneja, Reseach Professor in the Department of Marine, Earth, and Atmospheric Sciences at NC State University has received the Air & Waste Management Association's 2001 Lyman A Ripperton Award to recognize his ability to inspire students to excellence in professional and social endeavors.

Viney Pal Aneja of the Department of Marine, Earth, and Atmospheric Sciences at NC State University has been selected to serve on the USDA/Natural Resources Conservation Service Task Force on Agricultural Air Quality. The task force provides advice and counsel to the Secretary of Agriculture on issues related to air quality and agriculture.

Publications from Prior Projects

1. Lord, Mark L., Jerry R. Miller, Steve P. Yurkovich, Larry G Kolenbrander, and Gail Mackin, 2001, Assessemnt of Changing Land-Use Practices on Basin Sediment Yields and Provenance in Western North Carolina Using Multivariate Fingerprinting Techniques. Geological Society of America Abstracts with Programs, v. 33.
2. Miller, Jerry R., Mark L. Lord, Steve P. Yurkovich, Larry G Kolenbrander, and Gail Mackin. Can geochemical fingerprinting be used to determine the relative contributions of sediment through time from different source areas? A pilot study in the southern Appalachian, North Carolina. Proceedings, WRRI 2002 Annual Conference, Setting the Agenda for Water Resources Research, Raleigh, NC.
3. Vasudevan, D., E.M. Cooper, and O.L. Van Exem. 2002. Sorption-Desorption of ionogenic compounds at the mineral-water interface: A comparison of metal oxide rich soils and pure phase minerals. Environmental Science and Technology, 36, 501-511.
4. Amoozegar A., 2001. Use of the Gover Soluation for Determining the Saturated Hydraulic Conductivity of the Vadose Zone. Agronomy Abstract [CD-ROM computer file]. TSNo

s01-amoozegar143310-0. ASA, CSSA, SSSA, Madison, WI. Niewoehner, C.P. and A. Amoozegar, 2001. Water Movement from a Cylindrical Auger Hole in The Vadose Zone. Agronomy Abstract [CD-ROM computer file]. TSNo s01-amoozegar150143-P. ASA, CSSA, SSSA, Madison, WI.