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Introduction

Statewide Mission: The Arkansas Water Resources Center (AWRC) has a statewide mission to plan and conduct water resource research. AWRC cooperates closely with colleges, universities and other organizations in Arkansas to address the state's water and land-related problems, promote the dissemination and application of research results and provide for the training of scientists in water resources. Through the years, projects have included irrigation, ground water modeling, non-point source pollution, quality of ground water and surface water, efficient septic tank design and ecosystem assessment. These projects have been funded by a variety of federal, state, local and tribal sources.

Support Provided: The Center Acts as a liaison between funding groups and the scientists and then coordinates and administers grants once they are funded. Accounting, reporting and water analyses are major areas of support offered to principal investigators.

Technology Transfer: AWRC sponsors an annual water conference held in Fayetteville, Arkansas each spring, drawing an average 100 researchers, students, agency personnel and interested citizens to hear about results of current research and hot topics in water resources throughout the state. AWRC also co-sponsors short courses and other water-related conferences in the state and region. In addition, AWRC maintains a technical library containing over 900 titles, many of which are on-line. This valuable resources is utilized by a variety of user groups including researchers, regulators, planners, lawyers and citizens.

AWRC Water Quality Laboratory: The Center maintains a modern water quality laboratory that provides water analyses for researchers and for farmers and others who submit samples through the Cooperative Extension Service and the Department of Housing and Urban Development.

Research Program

AWRC has contributed substantially to Arkansas water resources via research and training of students. In 2005, 48 projects passed through the Center which included funding from a variety of organizations including 1) USGS 104B program, 2) U.S.G.S., 3) Arkansas Natural Resources Commission, 4) Arkansas Department of Environmental Quality, 5) Rogers Water Utilities, 6) Upper White River Basin Foundation, 7) Walton Family Foundation, Inc. 8) Beaver Water District, 9) Lake Fayetteville Watershed Partnership, 10) Environmental Protection Agency, 11) U.S.D.A., 12) Washington County, 13) Santee Sioux Nation. These projects involved training of 34 students made up of 15 undergraduates, 11 master's and 8 Ph.D. candidates, and 2 post doctoral associates.

Flow and hydrochemical evolution of arsenic in ground water: tracking sources and sinks in the alluvial aquifer of southeastern Arkansas, USA

Basic Information

Title:	Flow and hydrochemical evolution of arsenic in ground water: tracking sources and sinks in the alluvial aquifer of southeastern Arkansas, USA
Project Number:	2005AR77B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	3
Research Category:	Water Quality
Focus Category:	Hydrogeochemistry, Groundwater, Geochemical Processes
Descriptors:	ground water, geochemical evolution, arsenic, sediment/water interaction, alluvial aquifer, geochemical modeling Arkansas
Principal Investigators:	Kenneth F. Steele

Publication

Problem and Research Objectives

Following the accumulation of evidence for the chronic toxicological health effects, including cancer, of arsenic (As) in drinking water, the United States Environmental Protection Agency (USEPA) recently reduced the maximum concentration level (MCL) for As from 50 $\mu\text{g/L}$ to 10 $\mu\text{g/L}$ (USEPA, 2001). Widespread high concentrations of arsenic in ground water (>10 $\mu\text{g/L}$) have been documented in drinking-water aquifers in the West, the Great Lakes region, and New England. Moderate to high concentrations of As have been found in parts of the central and southern United States (Welch, 2003). The health impact of As to municipal water supply systems in Arkansas is low, based on analyses collected by the Arkansas Department of Health. However, recent publications documenting water quality in the Bayou Bartholomew watershed (Kresse and Fazio, 2002, 2003) revealed that 21 out of 118 irrigation water wells completed in shallow Quaternary alluvial deposits (alluvial aquifer) with a depth of 80-100 feet had As concentrations exceeding 10 $\mu\text{g/L}$. Most municipal water supply wells in eastern Arkansas are advanced predominantly into deeper Tertiary Formations because of the problems associated with the high concentrations of Fe and Mn in the shallow alluvial aquifers. However, domestic wells completed in alluvial deposits may present risks to private well owners not protected by the Safe Drinking Water Act (SDWA).

This proposed study of the hydrogeology and hydrogeochemistry along the flow paths in both areal and vertical dimensions within the alluvial aquifer in southeastern Arkansas has implications for:

- 1) Understanding the geochemistry of soils, sediments, and ground water, and characterization of the spatial and vertical distribution and mobilization mechanism of As in different geochemical environments (soils, sediments, and ground water).
- 2) Identifying the temporary and permanent sources and sinks (mineral phases) for as in the aquifer.
- 3) Identifying the speciation of As in its total, dissolved, adsorbed, and organic forms.
- 4) Assessing the solubility or saturation indexes of important mineral phases in the aquifer and their relations to As partitioning and solubilities in the environment.
- 5) Understanding the flow pattern and hydrochemical evolution and fate of As in the ground water.
- 6) Application of geochemical modeling tools as an aid in predicting source, behavior, distribution, and fate of As in the alluvial aquifer.

- 7) Evaluation of model capability and sensitivity to model parameters in portraying the true field conditions.
- 8) Discussion of model limitations as an aid to predict geochemical processes occurring in the aquifer.

There is now considerable evidence that high-As ground water can be associated with reducing conditions, particularly in alluvial and deltaic environments (Smedley et. al., 2002).

The Bengal Basin in Bangladesh and India is the most notable example. While the precise mechanisms responsible for this remain uncertain, it is possible that both reductive desorption and reductive dissolution of As from oxides and clays play a vital role.

Statistical and graphical analysis of ground-water quality data provides strong corollary evidence of reductive dissolution of As bearing Fe oxyhydroxides as the releasing mechanism of elevated ($>10\mu\text{g/L}$) concentrations of As in the alluvial aquifer (Kresse and Fazio, 2002, 2003) in Arkansas. This conclusion was based solely on the occurrence and geochemical trends of some reduction sensitive parameters (as $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, Fe, Mn, etc) in the aquifer. The present study is evaluating the following conceptual models of As mobilization and release mechanisms by interpreting chemical analyses of sediment and ground water, and results of model simulations:

- 1) As release mechanisms: we will test the three established conceptual models of As release mechanisms.
 - a) The oxidation model (Acharyya, 1997; Pearse, 1995; Sinha Roy, 1997) would support the source of As in the aquifer as As-bearing sulfide minerals e.g. arsenopyrite, and that the mechanism of release is by oxidative dissolution. The trigger to oxidative dissolution is the anthropogenic factor of extensive groundwater development, which via lowering of the piezometric surface/water table has drawn atmospheric oxygen into a previously anoxic aquifer environment. As a result, an "oxidation front" is created where oxygen meets reduced sediments containing As-bearing pyrite (FeS_2), thus releasing As to the fluid phase.
 - b) An alternate model, known as the Fe oxyhydroxide reduction model (Matisoff, 1982; Korte, 1991; BGS, 1999; Nickson et al. 1997, 1998, 2000), is now widely accepted as the principal mechanism of As mobilization in the ground water of the alluvial aquifers in many parts of the world. This model proposes that the As in the ground water derives from reductive dissolution of As-rich Fe oxyhydroxide that exists as a dispersed phase (e.g. as a coating) on sedimentary grains. The reductive dissolution process dissolves Fe oxyhydroxide and releases to ground

water both Fe²⁺ and the sorbed load of the Fe oxyhydroxide, which includes As.

- c) The competitive ion exchange model (Acharyya et al., 2000) proposes that the high levels of As in ground water and its enhanced mobility are due to the competitive anion exchange between As-oxyanion and phosphate. Phosphate, which has a very similar adsorptive capacity as arsenate, will compete for the same adsorption sites on metal oxides, clay surfaces, organic matter, etc. This model assumes that the excessive use of fertilizers (artificial phosphate source) to augment agricultural output has affected As sorption, effectively displacing or “knocking” it off adsorption sites. This results in higher concentrations of As in ground water.
- 2) If the As releasing mechanism supports the reducing model, then we must justify whether the reductive dissolution (Guo et al., 1997; Nickson et al., 1997; Ahmed et al., 2004) or the reductive desorption (Zobrist et al., 2000;) is the prime geochemical process.
- 3) If the As releasing mechanism supports the reducing model, then we must justify the redox driver for iron oxyhydroxide reduction, as organic matter, such as peat, in the aquifer (Ravencroft et al., 2001).
- 4) Organic carbon or its degradation products may quickly mobilize arsenic. Young carbon brought to depth by irrigation pumping plays a role in arsenic mobilization (Harvey et al., 2002).
- 5) High concentrations of As are localized mostly along the paleochannels (Nickson et al., 1998; Pal et al., 2002; Ghosh and Mukharjee, 2002) and are associated with the presence of sub-aerial peat layers along the paleochannels (Nickson et al., 1998, 2000; Ravencroft, 2001).

Methodology

The direction of groundwater flow in the Bayou Bartholomew aquifer is dominantly southward with the slope of the land within the watershed (Kresse and Fazio, 2002). So, the transect of drilling locations is oriented in an in a triangular pattern to the flow path. Three locations for monitoring wells were selected on the basis of arsenic screening data of Arkansas Department of Environmental Quality (ADEQ), geologic cross sections prepared from well log data of Arkansas Geologic Commission, ground water flow maps of United States Geological Survey (USGS), distribution of upper clay to silty clay aquitard. Three pairs of monitoring wells (each pair within a distance of 5 feet consists of one deep well of about 120 feet and one shallow well of about 30 to 40 feet) were drilled in three locations forming a triangle

Grain size analysis was done by using a micro pipette method (Miller et al., 1987). A five step sequential extraction (Modified from Tessier et al., 1979 and Chao and Zhou, 1983) was done to differentiate the exchangeable, carbonate, amorphous iron and manganese oxide, organic, and acid leachable fractions of arsenic and other chemical compounds. A separate water soluble extraction (Quevauviller, 2002) and a rigorous HNO_3 - H_2SO_4 acid leachable (Adeloju et al., 1994) extraction were also done. A total of 60 sediments were extracted. Five duplicates, one gravel pack, one bentonite, eight wet sediments, and two coarse ($>1\text{mm}$) sediments were also extracted. The extracted solutions were shipped to ADEQ laboratory in Little Rock, Arkansas for analysis by ion coupled plasma – mass spectrophotometer (CP-MS).

- 1) Literature review of the present status of arsenic research in USA and in other arsenic affected areas in the world.
- 2) Sediment samples were collected continuously up to about 35 feet by 5 feet tube (CME spoon) sampler and after 35 feet 18 inches split spoon sampler was used at 5 feet interval. About 150 sediment samples were collected from the six wells. Sub samples of 300g of wet sediment cores were collected in 3 line zip bags to provide fresh sediment for preservation in freezer, and the rest of the collected sediment samples (cores) were archived in aluminum foil. All the sediment samples were transported to the geochemistry laboratory in the Department of Geosciences for further processing. About 100g of archived sediment cores were separated and dried below 40°C in an oven. The sediments were crushed using a conventional porcelain pestle and mortar and passed through a 1mm screen. These sediments were used for several single and sequential extraction procedures for major and trace elements including As.

Proper sampling collection, handling, and preservation procedures of USGS's National Water-Quality Assessment (NAWQA) Program will be followed (Shelton et al., 1994).

- 3) After completion of the boring operation, monitoring wells were installed for groundwater quality monitoring and sampling. Standard sample collection and preservation procedures will be followed. A set of 4 samples will be collected in 60 ml high density polyethylene (HDPE) bottles:
 - a) filtered and acidified (to 1% HNO_3), (2) filtered but not acidified, (3) not filtered and acidified, and (4) non filtered and non acidified. Another set of non filtered and non acidified samples will be collected in amber glass bottles for dissolved organic carbon. Dissolved ions including Ca^{2+} , Mg^{2+} , Na^+ , K^+ , SiO_2 , As, Fe, Mn, PO_4^{3-} , SO_4^{2-} will be measured on the acidified samples. Dissolved NO_3^- and Cl^- will be measured on non acidified samples. Both filtered and non filtered samples will be run to find differences in concentrations, if any methods, sampling, and analytical protocols of

USGS's National Water-Quality Assessment (NAWQA) programs will be followed <http://water.usgs.gov/nawqa/>.

Parameters to be studied

- 1) Ground water chemistry: major ions, metals/metalloids including different forms of As (total, water soluble, adsorbed, and organic), Dissolved Oxygen (DO), Redox Potential (Eh), Total Organic Carbon (TOC), Organic Carbon (OC), Inorganic Carbon (IC), alkalinity, other possible redox indicators (e.g. Fe^{2+} , Fe^{3+} , Mn^{2+} , S^{2-}) pH, temperature (T), etc.
- 2) Sedimentology of soil and aquifer sediments: mineralogy, grain size, etc. Thin section petrography using binocular microscope, polarizing microscope, and scanning electron microscope) will be done to determine the characteristic detrital modes and to infer their provenance. If resources permit, mineral species in the sediments will be identified using X-ray diffraction (XRD), scanning electron microscopy – energy dispersive spectrometer (SEM-EDS) and electron probe micro analysis (EPMA) technology.
- 3) Chemistry of aquifer sediments: major ions, metals/metalloids including different forms of As (total, water soluble, adsorbed, and organic), DO, Eh, pH, EC, TOC, other possible redox indicators (e.g. Fe^{2+} , Fe^{3+} , Mn^{2+} , S^{2-}), pH, T, etc.
- 4) Soil pretreatment for a series of selective partial extractions will be carried out to separate the different As species. Separate extraction procedures will be run for other chemical parameters in sediment samples. Procedures of extraction will be those described by Ito (2001). The extractions for chemical forms and leaching agents will be as follows: (i) acid soluble form (As mainly fixed in carbonates), which will be leached using 0.1 M acetic acid; (ii) reducible form (As fixed in Fe- and /or Mn-oxides), which will be leached using 0.1 M hydroxylamine hydrochloride solution, adjusting pH to 2 using HNO_3 acid; (iii) organic form, which will be first decomposed by 0.1 M sodium pyrophosphate solution heated on a hot plate and dissolved into 1 M ammonium acetate solution; and (iv) insoluble form (As fixed mainly in sulfide and rarely in silicate minerals), which will be dissolved by a mixture of concentrated HNO_3 and HClO_4 acid if appropriate ventilation equipment is available to work with the HClO_4 .
- 5) Hydraulic properties: hydraulic conductivity and/or transmissivity, porosity, saturated thickness, water table elevations, etc.

Geochemical Modeling

Expertise with two geochemical modeling tools of PHREEQCI (Parkhurst 1995) and MINTEQA2 (Allison et al., 1991) was developed. These two geochemical modeling tools will be used to predict the solid phase partitioning of arsenic having a ratio of unity for modeled (solid phase arsenic derived from model simulation) to calculated (solid phase

arsenic derived by different extraction techniques) arsenic found in sediments. These modeling tools will also be used to predict the speciation of liquid phases and solubilities of mineral phases and their relation to As mobility in the aquifer. A 1 D-reactive transport geochemical model along the flow path for a considerable time interval will be simulated to predict future scale of arsenic contamination in the alluvial aquifer.

Forward modeling is used to predict water chemistry after completion of predetermined set of equilibrium reactions. Whereas, inverse modeling is used to suggest which geochemical processes take place along the flow path. Prediction of As behavior needs a combination of forward models with speciation and surface complexation capabilities. The program PHREEQC (Parkhurst, 1995), a forward model, has been extensively used to model evolution of ground water chemistry along a flow path. MINTEQA2 can be operated in forward and inverse modes. This model requires accurate ground water flow direction and the mineralogy of the sediments. If the necessary data are available, then MINTEQA2 model will be run in inverse mode.

Speciation Modeling

Speciation modeling provides a “snapshot” of the assumed equilibrium state of a dynamic system. That is, the chemical composition of a ground-water sample is provided, and assuming that the chemical species in the solution are at mutual equilibrium, the concentrations and activities of the various ionic species present are calculated. Speciation calculation can be used to indicate if some As bearing minerals can precipitate. Another application includes determination of saturation indices for minerals, which could be a sink for dissolved Fe (the highly suspected sink for As). Chemical analyses results of water and sediment collected from the 3 monitoring wells will be used as input into the speciation module of the PHREEQC program to achieve speciation and solubilities of mineral phases and their relation to As mobility in the aquifer.

Surface Complexation Modeling

Surface Complexation Models (SCM's) provide a rational interpretation of the physical and chemical processes of adsorption and are able to simulate adsorption in complex geochemical systems (Stollenwerk, 2003). The importance of oxides in controlling the concentration of As in natural water is well established (Matisoff et al., 1982). Iron oxyhydroxides are probably the most important adsorbents in sandy aquifers because of their greater abundance and the strong binding affinity (Smedley et al., 2001). The SCM module of PHREEQC considers hydrous ferrous oxide to be the single most important adsorbents of As in aquifers. A perfect simulation of the partitioning of arsenic would reveal all samples having a ratio of unity for modeled to calculated arsenic found on sediments. The first stage of the surface complexation modeling is to determine the model parameters:

- 1) Determination of the quantity of solid phase (iron oxides present in the aquifer sediments) concentration can be derived from petrographic analysis of sediment samples. Bulk sediment extraction data for total iron will be used as surface concentrations of iron.

- 2) Determination of surface site density of the solid phase (iron oxides) present in the aquifer. Literature values (Dzombak and Morel, 1990) will be used as a first approximation.
- 3) Determination of surface area of the solid phase (iron oxides). The best approach is to use literature values (Dzombak and Morel, 1990) of surface area as an initial estimate.
- 4) Determination of equilibrium constants for the mass action equations describing all relevant adsorption reactions. Dzombak and Morel (1990) database are used for PHREEQC.

Reasonable estimates of surface site density are important for accurate modeling of solute adsorption (Davis and Kent, 1990). Natural systems contain complex mixtures of minerals and it is difficult to quantify the concentration of surface sites for individual minerals. For consistency in applying the surface complexation modeling approach to natural systems, Davis and Kent (1990) recommended that equilibrium constants for strongly binding solutes be derived using the site density from Dzombak and Morel (1990) of $3.84 \mu\text{moles}/\text{m}^2$.

Inverse Mass Balance Modeling

Inverse mass balance modeling shows that if the chemistry of the start and end solutions along a flow path are known, possible mass transfer reactions that have produced the compositional difference may be determined. The extent to which these reactions have taken place, can be deduced from mass balance principles. So, this modeling approach will indicate which processes take place along the flow path. Inverse modeling is generally used to verify hypotheses on the origin of As (Sracek et al., 2004). The basic prerequisites of inverse modeling are the knowledge of flow pattern and information about mineralogy, including As mineral phases together with a full suite of chemical composition of ground water along the flow path. Results from mineralogical analysis and chemical analysis of ground water of the three wells, and aquifer properties (e.g. flow pattern) from existing flow models of southeastern Arkansas (Czarnecki et al., 2003) and data together with water-level data of the proposed three wells, will be used as an input into the Inverse Mass Balance module of PHREEQC to infer the geochemical processes occurring along the flow path.

Research To Be Completed

The following steps will be done to complete the research:

- 1) Mineral species in the sediments will be identified by using XRD. Surface properties of specific minerals (host minerals for arsenic as iron oxides, pyrites, etc.) will be identified by scanning electron microscopy – energy dispersive spectrometer (SEM-EDS).

- 2) More precise ground-water level measurement by survey grade GPS (Fast Static GPS Survey) will be conducted for investigating ground-water flow direction, particle movement, and physical ground water modeling.
- 3) Water samples will be collected from the six monitoring wells for total analysis of major, trace, and dissolved organic matter.
- 4) Arsenic speciation will be done on the six monitoring wells using an ion-exchange chromatography method modified after Grabinski (1981).
- 5) Three more extraction procedures to determine the FeII/FeIII ratio (the ratio of amorphous iron oxides to crystalline iron oxides), sediment sulfide contents, and total digestion for chemical elements in the sediments.
- 6) Geochemical model run (forward modeling) and sensitivity analysis. Compilation, analysis, and interpretation of chemical data from geochemical model run.
- 7) Finally, assessment of geochemical model findings, identification of source and sinks (permanent and temporary) for arsenic, releasing mechanism of As to ground water, prediction of future nature of As contamination problem, dissertation writing, writing papers for publication, etc.

Principal Findings and Significance

According to the grain size analysis results, available As screening data, and spatial distribution of upper clay to silty clay layer, the high As site is more sandy to a depth of approximately 25 feet from surface than the other two low As sites. Average level of the water table in the 3 sites varies from 18.5 to 24 feet. This observation suggests that high As sites are getting more recharge than the other two low As sites. One possible explanation for this observation is that vertical recharge has a relationship to As mobilization in the aquifer system. Our speculation is that As is being released from the sediments in a specific zone of the aquifer where seasonal water table fluctuation brings successive oxidation and reduction conditions. As is being released due to the complex interplay between redox reactions and microbial activities. The releasing As is going down due to recharge water and spatially distributed due to local flow dynamics. More detailed investigation will be followed for the conclusion.

The Ground Water Flow System in the Alluvial Aquifer of the Arkansas River at Dardanelle, Arkansas

Basic Information

Title:	The Ground Water Flow System in the Alluvial Aquifer of the Arkansas River at Dardanelle, Arkansas
Project Number:	2005AR79B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	3
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Models, Hydrogeochemistry
Descriptors:	Ground Water, Alluvial Aquifer, Numerical Flow Model, Hydrogeochemistry, Unconfined Aquifer
Principal Investigators:	Stephen W. Kline, Tim Kresse

Publication

1. Kline, Stephen W., Timothy M. Kresse, John A. Fazio, William L. Prior, William D. Hanson, Roger A. Miller, Tyler M. Treece, Jody B. Adams, and David W. Hebard, 2005, Groundwater Flow and Chemistry in Alluvium of the Arkansas River in Central Arkansas: A Progress Report: Abstracts with Programs--Geological Society of America, v. 37, no. 7, p. 214.
2. Kline, Stephen W., Timothy M. Kresse, John A. Fazio, William L. Prior, William D. Hanson, Rober A. Miller, Tyler M. Treece, Jody B. Adams, and David W. Hebard, 2005, Groundwater Flow and Chemistry in Alluvium of the Arkansas River in Central Arkansas: A Progress Report: Abstracts with Programs--Geological Society of America, v. 37, no. 7, p 214.

Problem and Research Objectives

The alluvial aquifer of the Arkansas River in central Arkansas is the richest supply of groundwater in the entire Arkansas River Valley area, supplying municipalities such as Dardanelle, agriculture, industry, and individual households. There are also many areas of wetlands on the flood plain that caps the alluvium with possible hydraulic connection to the aquifer. The present research has the goal of fully characterizing the hydrologic properties of the aquifer in the vicinity of Dardanelle and to produce a calibrated and verified numerical flow model with a view to expanding the characterization and modeling to the rest of the same segment of the aquifer system in the future. A calibrated and verified flow model can be used to predict potential impacts from further development of various supply systems from the aquifer.

Methodology

We have approached this problem by installing a series of monitoring wells that are being used for a number of purposes related to the goal of the project. By careful sampling and analysis of sediment penetrated during drilling of the wells we are deriving a clearer understanding of the distribution of sediment of the aquifer. Above the water table a continuous sampler in the hollow-stem auger drilling rig was used to obtain **in situ** sediment samples that were examined in the field. Below the water table the continuous sampler could not hold the saturated sediment, so samples were obtained by taking what was “spun up” and/or sampling what was retained on auger flights. Samples obtained by either method have been taken to the lab for grain size analysis.

At ten sites, pairs of monitoring wells were installed, one to intersect the lower part of the aquifer and the other to intersect the water table. There are also five “test wells” that the City of Dardanelle has drilled for determining new locations for expansion of their municipal well field, and they have given us access to these wells. Two drive-point piezometers have also been installed. These wells are being used to monitor water level changes in the aquifer over time, both short term variations related to the pumping schedule of the municipal well field, and longer term variations related to seasonal weather patterns and to variation in stage of the Arkansas River. The wells are also being used to conduct aquifer tests to determine the distribution of properties such as hydraulic conductivity and storativity in the aquifer. The aquifer tests include both pumping aquifer tests and slug tests. Pneumatic slug tests have been particularly useful in these highly conductive sediments. Finally, the wells are being used for taking water samples for chemical analysis. A suite of inorganic parameters are being measured to evaluate chemical evolution of the aquifer water and to determine the degree of infiltration of Arkansas River water into the aquifer. Also the water is being analyzed for a host of potential organic contaminants.

All the information that is being gathered will be used to construct a numerical flow model using Visual MODFLOW (software by Waterloo Hydrogeologic, Inc.). At the time of this writing, construction of the flow model has only barely begun and some of the parameters mentioned above are still being obtained. The water levels and the mixing

characteristics of aquifer and river sources expressed in the geochemistry will be used in model calibration and verification.

Principal Findings and Significance

Although the flow model has not yet been completed, a number of important components have been determined in regard to the physical hydrology of the aquifer and its geochemistry. For example, there is a much better understanding of the sediment distribution in the aquifer with implications regarding its hydrology. The alluvial sediment varies from about 16 to 22 m thick above Atoka shale and sandstone, thinning away from the river. The upper 8 to 12 m consists of very fine silty sands with numerous, discontinuous clay-rich layers, which appear to be more continuous in farther reaches from the river. These sediments represent natural levee and crevasse splay deposits near the river, and flood basin deposits toward the outer margin of the alluvium. The lower section contains medium to very coarse sands and gravelly sand formed from channel bars, point bars, and channel lag deposits. The saturated zone is in the lower section in most of the area but extends up a short distance into the upper, fine-grained section in the area farther from the river; although in every location we sampled, saturation was below the lowest clay-rich layer, indicating unconfined hydraulic conditions. The heterogeneity of the sediment in the saturated zone means that permeability will be very heterogeneous producing complex flow patterns in the aquifer. The apparently more continuous clays in upper section of the alluvium in the outer reaches of the flood plain and the more discontinuous clays nearer the river indicate that an uneven recharge value from infiltration of meteoric water will need to be assigned in the flow model, with more aerial recharge in the portion of the aquifer nearer to the river.

Ground-water level measurements show that outside the immediate area of Dardanelle's municipal well field, the natural hydraulic gradient is towards the Arkansas River, with the aquifer discharging into the river. This pattern is interrupted by composite cones of depression in the municipal well field. However, a small groundwater ridge remains between the well field and the river most of the year. Nevertheless, during periods of sustained high river stage the gradient is reversed in the area bordering the river, and the river infiltrates the aquifer and feeds into the well field. One high-river-stage event of three weeks duration induced a reversal of gradient 600 m wide in the area outside the city's well system, and the gradient reversal penetrated even farther where the effect of the river stage was complimented by drawdown of the water table within the well field. Seasonal water level fluctuations observed thus far in the aquifer appear to corroborate the implications of aerial recharge distribution indicated by the distribution of clay layers in the upper section of the alluvium discussed above. After periods of substantial rainfall began in mid to late winter, water levels in monitoring wells began to rise in areas nearer to the river, but continued to fall farther out from the river. One other observation with regard to water level measurements implies reduced aerial recharge in the outer portion of the flood plain. An earlier ground water flow model of the area (Kline and others, 2003), based on published regional information, applied a homogeneous value for aerial recharge, except that it was reduced a little in the area of the city to account for paved areas there. That model predicted that the water level in the aquifer would extend up to

near the land surface in areas farthest from the Arkansas River, but the water level in a drive-point piezometer installed in that area consistently rests nearly 6 m below the surface. The fact that water levels in the aquifer throughout the area are consistently 6 to 15 m below the land surface suggests that at least many of the wetlands in other portions of the Arkansas River flood plain may not have hydraulic connection with the groundwater system. Of course, that will have to be determined on a case by case basis in the future.

The variation in aquifer permeability suggested by the variation in sediment encountered in drilling is borne out by slug tests conducted thus far. Problems with pumping aquifer tests and with slug tests carried out by conventional methods raised concerns whether hydraulic conductivity in the aquifer could be determined with any degree of accuracy. However, we obtained a “pneumatic slug”, which when combined with a relatively new slug test analysis model (Butler and Garnett, 2000) obtains excellent results in these highly conductive sediments. The range of hydraulic conductivity values that we have obtained thus far, with a few more wells to be tested, is from 18 to 96 m/d. These values represent the average hydraulic conductivity over the 10 ft screens in the monitoring wells. It is very likely that thin channel lag gravels that have been encountered in drilling would have much higher hydraulic conductivity, but without being able to isolate them we cannot say just how high.

There are a number of definite matters with regard to issues of water chemistry of the aquifer that are of significance. These have to do with oxidation/reduction processes, chemical evolution of water in the aquifer, mixing of water from the Arkansas River, and flow paths of water in the aquifer.

The sampling of water from both shallow and deep portions of the aquifer reveal redox processes at work in the aquifer. Water from near the water table, where relatively oxygen-rich meteoric recharge water first arrives and where water is in contact with gaseous phases in the vadose zone, shows higher Eh (oxidation potential) than water deeper in the aquifer. The mean nitrate-N concentration for samples from the shallow wells was 3.5 mg/L, as compared to the mean concentration of 1.8 mg/L for deep well samples. In four samples from deep wells with iron concentrations >10 mg/L, nitrate-N concentrations were non-detect, revealing nitrate reduction at depth with complete reduction of nitrate where iron exceeds 10 mg/L. The highest concentration of nitrate (17.9 mg/L) was in a shallow well in an area outside of town where corn fields surround the well site, the elevated nitrate coming from over-fertilization.

Iron, manganese, and arsenic all show definite trends of increasing concentration with decreasing Eh, especially Fe and As. All the samples with Eh greater than 200 mV have low (<1 mg/L) to non-detect Fe concentrations and low (<5 µg/L) As concentrations. At Eh values <200 mV, Fe concentrations exceed 10 mg/L and As concentrations generally are above 5 µg/L. The Fe and the As appear to be from reductive dissolution of Fe-oxides and oxyhydroxides in the alluvial sediment. There are detrital grains of magnetite, ilmenite, and hematite in the sediment and also there is reddish staining on grains of sands above the water table. Likely this staining is from Fe-oxyhydroxides that were

precipitated onto the grains while they were in an oxidizing condition during the transportation or deposition phase. Arsenic would have been co-precipitated with the Fe. Then in the reducing conditions in the lower part of the aquifer Fe and the co-precipitated As are dissolved together. One sample had an As concentration of 19 $\mu\text{g/L}$, exceeding the EPA MCL of 10 $\mu\text{g/L}$. Causes of the reducing chemistry in the lower part of the aquifer are likely the oxidation of *in situ* detrital grains of organic matter and/or interaction with organic-rich shales of the underlying Atoka Formation. The interface between shale bedrock and the alluvial sediments is a zone of gummy black clay, the upper weathered surface of the bedrock. The highest Fe and As concentrations are from wells outside the area of the municipal well field. Samples taken from within the well field have lower values probably because of infiltration and mixing of oxygen-rich river water, and also perhaps from the vertical component to flow in the aquifer induced by the pumping wells pulling oxygenated water downward in the vicinity of the wells.

Besides the redox processes, one of the best indicators of chemical evolution of waters in the aquifer is seen with comparing Na/Cl molar ratios to molar ratios of $(\text{Ca}+\text{Mg})/\text{HCO}_3$ and the involvement of sulfate. If Ca is progressively exchanging for Na on exchangeable cation sites on minerals of the aquifer (primarily clays) a trend of increasing Na/Cl ratios of equivalent concentrations should be seen along with a decreasing $(\text{Ca}+\text{Mg})/\text{HCO}_3$ trend. If the original water of the aquifer derived its Na, Cl, Ca, Mg, and HCO_3 from dissolution of halite and carbonate minerals, then the “origin” of that trend would intersect at x and y values of 1.0 on a graph of these ratios. Such a trend is evident in the molar ratio plot for the Dardanelle samples, but the “origin” of the trend starts at a much higher $(\text{Ca}+\text{Mg})/\text{HCO}_3$ ratio, that is, close to 1.6 instead of 1.0. The high $(\text{Ca}+\text{Mg})/\text{HCO}_3$ ratio for this “origin” is explained by an excess amount of Ca in the water being contributed by dissolution of gypsum. If Na/Ca is plotted against $(\text{Ca}+\text{Mg})/(\text{HCO}_3 + \text{SO}_4)$, the same trend is seen, but the origin is now at approximate x and y values of 1.0, where it would be expected to be if the Ca in the water was from both carbonates and from gypsum.

A number of chemical parameters indicate the infiltration of Arkansas River water into the aquifer in the area of the city well field. The best indicator is that of chloride in the deep wells (including the city pumping wells which are screened in the lower 10 ft of the aquifer). Analysis of water samples taken in both August 2005 and in February 2006 show the highest chloride values to be in the Arkansas River with progressively lower values in wells progressively farther from the river and farther into the city well field. A good example is an inspection a transect of wells from the river to the southernmost municipal well field. From a concentration of 9 mg/L in the farthest inland city pumping well, chloride concentrations increase to 24, 31, 42, 62, and 71 mg/L in five approximately equal-spaced wells moving eastward toward the river, which has a concentration of 185 mg/L; clearly reflecting the strong influence of river water infiltration in the aquifer.

A matter that complicates the interpretation that elevated chloride concentrations are the result of river water infiltration is that wells located farthest up-gradient from the city well field also have elevated chloride values (>40 mg/L), though not as elevated as

chloride in the river water. The complication is resolved by examining a plot of Br vs Cl in the samples. This plot has two definite trends, and the same trends are seen in the two sets of samples taken 6 months apart. One trend starts from a cluster of points with low values of both Br and Cl and trends towards progressively higher values of Cl with very little Br enrichment; the Arkansas River sample is the maximum-Cl end of this trend. All the points along this trend are from samples taken from wells along the river-to-well-field transect. The second trend starts at the same cluster of points with low Cl and Br values and has increasing values of Br along with Cl-enrichment. All the points along this trend are from samples taken from the up-gradient wells. So the Br-enrichment trend along with Cl-enrichment indicates water derived from within the aquifer without mixing in of river water.

Mean and median chloride concentrations were significantly lower in shallow well samples (12 and 11 mg/L, respectively) than in deep well samples (45 and 35 mg/L, respectively), even in wells closest to the river, suggesting that infiltration of river water is dominantly through the coarser-grained sediment at the base of the aquifer.

It is striking to note that, with regard to the analyses from the two sampling dates, the results are very consistent for each sampling site. The Cl decrease from the river into the well field, the trends in Br vs Cl plots, and Piper diagram plots of the major cations and anions are very similar for each shallow and each deep well sample and for the city pumping wells and the city test wells and the river. Evidently the water moving past the monitoring wells and the water moving into the city supply wells maintains a very constant flow path and chemical evolution. It may be significant that there were no major sustained Arkansas River high stage events between the two sampling dates, for such events may disrupt the normal flow pattern.

A particularly striking example of consistency of chemical analyses is with a pair of shallow/deep wells placed only about 2 meters apart at an up-gradient site designated well D-5S and D-5D. Due to the unexpected shallowness of the base of the aquifer at that point and problems encountered during drilling, the “shallow” well has the bottom and top of its screened interval only 0.84 m (2.76 ft) higher than the bottom and top of the “deep” well. In spite of such a small difference, during both sampling times the D-5S (shallow) well’s screen straddled the water table and the D-5D’s screen was completely below the water table. In spite of the nearness horizontally and the only slight depth difference, there is a great difference in the Piper diagram plot of the major ion concentrations between the two wells, yet the February sample for the shallow well plots very close to the August sample for the shallow well, and the same goes for the deep well. The two wells are consistently drawing water along significantly different flow paths. This indicates that water flow in the aquifer is greatly influenced by preferential flow paths. It is likely that the deeper of the two wells has hydraulic connectivity more directly with a highly permeable gravel layer than the upper well, and that the gravel zone brings in some significantly different water, chemically speaking, than what is encountered in the shallower zone.

Another implication has to do with infiltration from the Arkansas River. As discussed above, there were a couple of times since our water-level monitoring began when the Arkansas River held a high stage for a significant time period such that the gradient reversed and clearly there was infiltration from the river into the well field. The second event was the smaller of the two, sustaining a reversed gradient for about one week. It began only a few days after the water samples were taken in the August sampling time. It is possible that these two events are responsible for the apparent mixing of infiltrated river water with aquifer water seen in the chemical analyses discussed above. However, the remarkable similarity of analyses for each well at the second sampling time in February, so long after the August sampling time, leads us to think that there may be a more constant infiltration of Arkansas River water into the supply-well field than what is produced by relatively short-lived gradient reversals during exceptionally high river stage events.

Contrary to this thought, though, are the observations with regard to water-level distribution discussed above. There are monitoring wells between the river and the well field in which the measured water level stands consistently slightly higher than the daily average water level in the Arkansas River (which fluctuates daily due to power generation needs at the hydroelectric dam just upstream from Dardanelle). The solution to the discrepancy may be in the fact that the head in the deeper part of the aquifer that is indicated by the water level in the deep monitoring wells is the average head over the 10-foot interval of the well screen. It is likely that gravel layers within the lower part of the stratigraphy, although probably fairly thin, are significantly more conductive than the average hydraulic conductivity of the 10-foot interval. Water drawing to the pumping wells in the cone of depression will transmit easier through the gravel layers. The result would be that reduction in hydraulic head induced by the pumping wells would propagate farther within the conductive gravel layers than in the rest of the sediment. In other words, the cone of head depression from the pumping wells would extend out farther within the gravel layers than within the rest of the sediment, perhaps even reaching the Arkansas River. The result would be that head distribution through much of the thickness of the aquifer would register a ground water ridge between the well field and the river, and water in that part would be transmitting down the head gradient from the ridge to the river and from the ridge to the well field. At the same time, water within highly conductive intervals would register a downward head gradient all the way from the river into the well field with flow from the river to the well field causing a degree of river infiltration to show up in the monitoring wells and city supply wells. More work is needed to determine just what is happening. Perhaps some nested piezometers tapping small elevation intervals through the saturated zone and/or numerical modeling could resolve the issue.

The distribution of roxarsone and its byproducts in soils, soil pore-water, groundwater, and stream water

Basic Information

Title:	The distribution of roxarsone and its byproducts in soils, soil pore-water, groundwater, and stream water
Project Number:	2005AR82B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	1
Research Category:	Biological Sciences
Focus Category:	Agriculture, Geochemical Processes, Ecology
Descriptors:	Poultry litter, Trace metals, Arsenic
Principal Investigators:	Carolyn Dowling

Publication

1. McKay, T. and C.B. Dowling, 2006, The effects of metal-rich poultry litter on the metal body burden of ground-dwelling arthropods: with notes on abundance (oral), The Society of Environmental Toxicology and Chemistry (SETAC), MidSouth Regional Chapter Annual Meeting, Jonesboro, AR.
2. McKay, T. and C.B. Dowling, 2006, The effects of metal-rich poultry litter on ground beetles, 80th Annual Meeting of the Southeastern Branch Entomological Society of America (oral), Wilmington, NC.
3. McKay, T., C.B. Dowling, B. Gougeau, K.M. Williams, J.W. Klasky, J.S. Wright and K. Vanderpuye, 2005, Impact of poultry litter application on ground-dwelling arthropod populations (poster), Annual Meeting of the Entomological Society of America, Fort Lauderdale, FL.

Problem and Research Objectives

Problem

Most poultry litter from commercial poultry operations contains arsenic from the use of roxarsone, an organoarsenic feed additive. Because of the high nutrient content, poultry litter is reused as fertilizer for neighboring agricultural fields. The roxarsone in the poultry-litter fertilizer will degrade into both inorganic arsenic species [arsenite (As(III)) and arsenate (As(V))], and organic arsenic species [monomethylarsenic acid (MMA) and dimethylarsenic acid (DMA)]. The organoarsenicals (MMA and DMA) are produced by biomethylation via bacteria, fungi, and algae and are more toxic than their inorganic counterparts. Previous research indicates that the composting of poultry litter may release roxarsone and its by-products into the environment, which may impact soil and water resources from the accumulation of arsenic, other heavy metals, and nutrients over time.

Research Objectives

This investigation will characterize the mobility and concentration of roxarsone and its byproducts (inorganic and organic arsenic species) in poultry litter, soils, soil pore-water, groundwater, and streams in a small area on the Farm Complex at Arkansas State University. The transport pathway for roxarsone, As(III), As(V), MMA, and DMA in the environment will be determined.

Modifications to Research Objectives

Because a drought affected northeast Arkansas during the summer of 2005, no soil water or stream water samples were collected. Unfortunately, the contractors for the groundwater well, which was necessary for the proposed research, did not drill as agreed. The well was to be installed in late May/early June but the date was constantly pushed back. Ultimately, the well could not be drilled in a timely manner for last year's field experiments. Due to these setbacks, an additional experiment concerning the impacts of poultry litter on the plants and insect population was implemented. Soil, plant, and insect samples were collected on a weekly basis throughout the summer.

The arsenic speciation methods have not been reproduced yet in the laboratory. Because the arsenic species are not separating using the published methods on IC-ICP-MS, the samples were only analyzed for whole trace metal chemistry.

Methodology

Study Area

A 100 m x 100 m field located at Arkansas State University Farm Complex was divided into nine 20 m x 20 m plots. There were three control plots where litter was not applied (Plot A) and six treatment plots where poultry litter was applied (Plots B and C). Approximately 181kg of poultry litter obtained from a poultry house in Strawberry, AR was applied to each treatment plot.

Soil, plant, and insect samples were collected prior to poultry litter application. In addition, samples of the commercial poultry litter were collected. After poultry litter application, poultry litter, soils, plants, and insects were collected on a weekly basis and properly stored until analysis. Poultry litter from an organic farm in Bono, AR was collected in Fall 2005.

Insect Identification

All the insects that were collected were identified down to family; some were identified down to genus; and only a few were identified down to species. After identification, the insects were stored in 70% ethanol until analysis.

Digestion Experiments

Total arsenic concentrations of the samples were determined by digesting a subset of the samples. The samples were rinsed with 18 MΩ water and air-dried. The organic samples (e.g. poultry litter, insects) were digested using the procedure outlined in Garbarino et al. (2003). First, 30% hydrogen peroxide was added to the samples in a closed Teflon® beaker. Afterwards, the clear solution was evaporated and re-dissolved in concentrated nitric acid and hydrochloric acid, followed by heating to dryness. In the final step, the sample was dissolved in concentrated nitric acid, diluted with 18 MΩ water, and stored within their closed Teflon® beakers.

The inorganic soil samples were dissolved using concentrated hydrochloric acid, nitric acid, and hydrofluoric acid in closed Teflon® beakers. The digested samples were evaporated to dryness, re-acidified using ultrapure nitric acid, and stored within their closed Teflon® beakers.

Trace Metal Chemistry

To prepare the samples for ICP-MS trace metal analysis, the samples were further diluted with 18 MΩ water and again acidified with ultrapure nitric acid. The analyses were done on the Perkin Elmer DRC II ICP-MS with auto sampler at Arkansas State University according to US EPA Method 200.8 (Long and Martin 1991). A five-point calibration curve was created using standards traceable to NIST.

Principal Findings and Significance

Poultry litter does affect the geochemistry and ecology of the agricultural environment. Based on the ICP-MS data, the concentrations of trace metals such as arsenic, cadmium, and aluminum in insects, plants, and soils were elevated overall after the field application of poultry litter.

Certain insect communities changed after the poultry litter application. There was a population shift in ground-dwelling insect species (e.g., family: Carabidae) in response to poultry litter application. It is hypothesized that different Carabidae species were attracted to the odor of the poultry litter and overwhelmed the resident Carabidae population.

Further work needs to be done on the effects of poultry litter on the hydrology of an agricultural area (hopefully, when there is no drought!), and it is essential for the progress to be made on the IC-ICP-MS method for arsenic speciation.

Effect of Reduced Effluent Phosphorus Concentrations at the Illinois River, Northwest Arkansas

Basic Information

Title:	Effect of Reduced Effluent Phosphorus Concentrations at the Illinois River, Northwest Arkansas
Project Number:	2005AR90B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	3
Research Category:	Water Quality
Focus Category:	Water Quality, Sediments, Surface Water
Descriptors:	
Principal Investigators:	Mark J. Cochran, Brian E. Haggard

Publication

1. Haggard, Brian E., 2006, Effect of Reduced Effluent Phosphorus Concentrations at the Illinois River, Northwest Arkansas, Journal of Environmental Quality, in preparation.

Problem and Research Objectives

Recently, the main municipal effluent discharges into the headwaters of the Illinois River Basin in northwest Arkansas reduced effluent phosphorus concentrations to less than 1 mg per liter on a voluntary basis, except for the City of Fayetteville which is regulated at that level. The research objective of this project was (1) to evaluate the spatial distribution of phosphorus concentrations at the Illinois River drainage area from the effluent discharges downstream to the Arkansas and Oklahoma border near the Illinois River at Arkansas HWY 59, and (2) to evaluate if phosphorus concentrations have changed over the one year study period and also compared to data collected in previous years.

Methodology

The project selected 29 water quality monitoring sites from the Illinois River near the Arkansas and Oklahoma border upstream into Osage, Spring, Clear and Mud Creeks to each municipal effluent discharge from the Cities of Rogers, Springdale and Fayetteville, Arkansas. Water samples were collected approximately monthly from each site, and then analyzed for dissolved phosphorus and total phosphorus using the automated ascorbic acid reduction method on filtered (0.45 μm membrane) and unfiltered-digested (persulfate autoclave method) aliquots.

Principal Findings and Significance

The results clearly showed the marked longitudinal gradient in dissolved and total phosphorus concentrations from the Illinois River near the Arkansas and Oklahoma border upstream to the municipal effluent discharges, particularly from the City of Springdale. Elevated phosphorus concentrations could be traced from the state-line upstream over 47 river km to one effluent discharge. However, it was also apparent that phosphorus concentrations have been changing with time, and the effect of the reduced effluent phosphorus concentrations has been observed downstream near the state-line. With time, the phosphorus concentrations should become even further reduced compared to historical concentrations.

Hydrodynamics of a Karst Soil Catena in the Ozark Plateau, USA

Basic Information

Title:	Hydrodynamics of a Karst Soil Catena in the Ozark Plateau, USA
Project Number:	2005AR156B
Start Date:	3/1/2004
End Date:	8/31/2005
Funding Source:	104B
Congressional District:	Third
Research Category:	Water Quality
Focus Category:	Agriculture, Hydrogeochemistry, Non Point Pollution
Descriptors:	Denitrification potential; ground water; hydraulic conductivity; infiltration, karst hydrogeology, nitrate-N; soil water; vadose zone
Principal Investigators:	John Van Brahana, Stephen K. Boss

Publication

1. DeFauw, S.L., T.J. Sauer, K.R. Brye, M.C. Savin, P.D. Hays and J.V. Brahana. 2005. Nitrate-N distributions and denitrification potential estimates for an agroforestry site in the Ozark Highlands, USA. In: Brooks, K.N., and P.F. Ffolliott. 2005. (Eds.) Moving agroforestry into the mainstream. The 9th North American Agroforestry Conference Proceedings, June 12-15, 2005, St. Paul, Minnesota, pp. 1-13. Dept. of Forest Resources, University of Minnesota, St. Paul, MN. [distributed on CD-ROM]
2. DeFauw, S.L., T.J. Sauer, K.R. Brye, M.C. Savin, P.D. Hays and J.V. Brahana, 2005. Nitrate-N distributions and denitrification potential estimates for an agroforestry site in the Ozark Highlands, USA. Poster Abstract for the 9th North American Agroforestry Conference, 12-15 June 2005, Rochester, MN, pp.25-26. [Invited abstract]
3. DeFauw, S.L., T.J. Sauer, P.D. Hays, K.R. Brye, and J.V. Brahana, 2004. Hydrodynamics of an Experimental Silvopastoral Field in the Ozark Plateau of Northwestern Arkansas, USA. In: Book of Abstracts, First World Congress of Agroforestry, 27 June-2 July 2004, Orlando, FL, USA, p.176.
4. Thomas, A.L., S.L. DeFauw*, T.J. Sauer, and D. Brauer, 2004. Hydrologic Influences on the Growth of Young Grafted Black Walnut Trees in Arkansas, USA. In: Book of Abstracts, First World Congress of Agroforestry, 27 June-2 July 2004, Orlando, FL, USA, p.213. [*presenter]

5. Sauer, T.J., S.L. DeFauw, K.R. Brye, J.V. Brahana, J.V. Skinner, W.K. Coblenz, A.L. Thomas, P.D. Hays, D.C. Moffitt, J.L. Robinson, T.A. James, D.K. Brauer, and K.A. Hickie, 2004. N and P Assimilation in a Silvopastoral System Receiving Poultry Litter or Inorganic Fertilizer. In: Book of Abstracts, First World Congress of Agroforestry, 27 June-2 July 2004, Orlando, FL, USA, p.207.

Problem and Research Objectives

The dynamics of nutrient infiltration and subsurface transport and transformation in karst terrains characterized by high soil heterogeneity, multi-level permeability contrasts within the vadose zone (e.g., plowpans, fragipans, and relict chert layers), rapidly fluctuating unconfined aquifers, and preferential flow paths is very poorly understood. Despite these gaps in our knowledge of basic soil-water relations and biogeochemical processing, land application of animal manures has intensified, in this region, over the past five decades. The main objectives of this research are fivefold: (1) determine saturated and unsaturated hydraulic conductivities at the soil surface for the three soil series (Nixa, Captina, and Johnsburg) that dominate an experimental alley cropping agroforestry field (4.3 ha) on the University of Arkansas Farm; (2) estimate saturated hydraulic conductivities for various subsoil horizons penetrated by select shallow wells; (3) track fluctuations in the unconfined aquifer, throughout the year, and produce a probability map for the water table surface; (4) evaluate nutrient ($\text{NO}_3\text{-N}$) sources, transformations and transport, within a karst catena, using stable isotopes; and (5) examine current management practices (i.e., the timing and rate of poultry litter and commercial fertilizer applied per hectare) in light of the hydrodynamic patterns that develop in this field throughout the year (and suggest modifications that should be implemented to enhance fertilizer use efficiency).

Methodologies

Soil Water and Ground Water Monitoring and Analysis: Concentrations of nitrate-N and total P in the soil and ground waters have been regularly monitored over the past four growing seasons (March 2002 – September 2005), and include several storm events. Water samples from porous cups and shallow wells were colorimetrically analyzed for nitrate-N using a Lachat continuous-flow ion analyzer. In addition, ground water DOC (collected over three growing seasons, from May 2003 – September 2005) was determined using a Shimadzu TOC- V_{CSH} Analyzer.

Stable Isotope Analyses: Recent sharp increases in per sample costs quoted from USGS stable isotope lab facilities (i.e., Menlo Park, CA and Reston, VA – March 2005) precluded the analysis of a meaningful number of ground water samples using the denitrifier method (as originally proposed). Sample collection continued throughout the 2005 growing season; frozen samples of ground water and fertilizers collected by Dr. DeFauw have been stored in Dr. Brye's laboratory (Dr. Phillip D. Hays, Visiting Hydrologist at the University of Arkansas, has been apprised of archival of these samples). The focus of the stable isotope study was amended (and approved by Dr. Ralph Davis in May 2005) to examine isotopic signatures ($\delta^2\text{H}$ and ^{18}O) from precipitation and ground water samples collected from the agroforestry experimental field (AEF), in order to determine transit times through the soil profile to the unconfined aquifer. Assurances were received from the University of Arkansas Stable Isotope Laboratory (UASIL) lab manager that the facility could accommodate processing the aforementioned samples for stable isotopes of water (samples were submitted in September 2005). As of

this date (28 February 2006), stable isotope analyses are still "in process" (using a Finnigan TC/EA ThermoQuest with Conflo II interface) due to unforeseen complications in resolving methodological problems.

Saturated and Unsaturated Infiltration Rates at the Soil Surface: In early October of 2004, 12 topographic patch sites (2.0 m^2) were established, with 6 sites residing in the AEF and 6 sites located, at comparable elevations and aspects, in adjacent cattle pastures (within the same hillslope soil assemblage). Three measurement loci were identified within each soil map unit (i.e., Captina, Nixa, and Johnsburg series soils) at two elevations, high and low; resulting in a total of 36 locations distributed between these two land-use settings. A differential global positioning system (DGPS) was used to acquire coordinates and elevations for the southeast corner of each topographic patch. Sites on the AEF were selected based on a map of surface hydrology (ArcView 3.3, not shown); similar settings were then chosen, in the appropriate soil series, from the pastures. All infiltration measurements were completed between 14 November and 16 December 2004. Antecedent soil water content was determined using a Field Scout TDR-300 outfitted with 0.12-m probes (Spectrum Technologies, Inc., Plainfield, IL); the average of five readings per site was reported. Ponded infiltration rate (i_s) was measured under 0.05 m of head using a double-ring infiltrometer (15 cm inner ring diameter and 30 cm outer ring diameter). Water influx was manually recorded (at 1 min intervals) until steady-state conditions were apparent (typically 20-30 minutes). A tension infiltrometer (0.08-m diameter model, Soil Measurements Systems, Tucson, AZ) was set up on the same site to measure the unsaturated infiltration rate at pressure heads (h) of -0.03, -0.06, and -0.12 m. The descending head sequence used corresponds to equivalent pore diameters of 1×10^{-3} , 5×10^{-4} , and 2.5×10^{-4} m (using capillary theory to estimate pore sizes excluded from transmitting water infiltrating at the different tension settings). Data were manually recorded every 30 seconds for the first 5 minutes, then at 1 minute intervals until a steady-state rate was established.

Subsoil Hydraulic Conductivities: Saturated hydraulic conductivities for select wells were derived from bail-down data (acquired February-March 2005). Well recoveries were plotted in Excel. The Bouwer and Rice method (incorporating modifications from Bouwer, 1989) was used to estimate subsoil saturated hydraulic conductivities. This methodology was designed to account for the geometry of partially penetrating or fully penetrating wells in unconfined aquifers.

GIS Database: A DGPS unit was used to produce a high-resolution topographic map of the AEF (March 2003). The GIS database (ArcView 3.3) incorporates topography, soils, unconfined aquifer fluctuations (including basic water quality parameters), electromagnetic induction (EMI) geophysical surveys, tree growth patterns, nitrate-N profiles, and the spatiotemporal delineation of N pools developed at the soil-karst interface of this agroecosystem. The ArcView Hydro extension was used to produce a simple model of the AEF's surface hydrology. Field-scale nitrate-N distributions for porous cup and well datasets were mapped using grid interpolation techniques (i.e., Spline method with a 1 meter cell size, weight varied 100-700 for the purpose of

optimization, number of points varied from 2-4, type Tension). Change detection operations were performed on optimized grid maps using Map Calculator.

Principal Findings and Significance

Transport and biogeochemical processing of nitrate-N in upland watersheds is very poorly understood. Denitrification potential estimates for the thin soil veneers of a headwater catchment in the Ozark Highlands (HUC 11110103) have just recently been documented (DeFauw et al., 2005). Nitrate-N distributions have been monitored (since March 2001), from an array of 53 shallow wells emplaced in a 4.3 ha experimental agroforestry tract (receiving split-field treatment of poultry litter to the eastern half in Spring, and a comparable annual N-load from commercial fertilizer applied on the western half in Spring and Fall). These shallow wells were designed to sample throughout the vadose zone to the karst interface (with depths varying from 0.5 to 5.6 m). The field integrates subsurface flows from a small catchment (approximately 18 ha) and, in March 2001, contained several “hot spots” with ground water nitrate-N varying from 25.0-64.5 mg/L (DeFauw et al., 2005). Late winter peaks in nitrate-N from this 6 year-old alley cropping system have steadied over the last 3 years (13.2 mg/L for mid-March 2003; 12.0 mg/L for late-February 2004; 11.7 mg/L for mid-March 2005).

Saturated hydraulic conductivity means for 3 down-gradient wells (2.0-3.6 m) in Johnsbury series soils ranged from 0.83 ± 0.17 ($\pm 1SD$) to 1.12 ± 0.20 m/day during baseflow conditions. High aquifer-stand hydraulic conductivity estimates were significantly lower for two out of three wells, thus expanding the range from 0.41 ± 0.05 to 1.39 ± 0.02 m/day, with the well in the lowest landscape position stemming the flow through part of this hillslope soil assemblage. Mean denitrification potentials, based solely on declines in nitrate-N throughout the growing season for this key ground water integration area, were 8.15 ± 6.20 kg/ha (2002), 20.80 ± 10.23 kg/ha (2003), 7.11 ± 3.65 kg/ha (2004), and 14.91 ± 11.64 kg/ha (2005). Cross-validation of these estimates, using dissolved organic carbon (DOC) concentrations, resulted in mean denitrification potentials of 22.45 ± 4.41 kg/ha, 16.78 ± 3.63 kg/ha, and 159.97 ± 34.71 kg/ha for the 2003, 2004 and 2005 growing seasons, respectively (DeFauw et al., 2005; DeFauw, 2006). Hydraulic conductivity distributions suggest enhanced opportunities for deep soil denitrification may occur as subsurface flows diminish during the transition from baseflow to aquifer high-stand conditions.

Field-scale GPS mapping and GIS modeling of surface hydrology combined with quantification of topographically-directed infiltration rates by soil series, spatiotemporal monitoring unconfined aquifer fluctuations, as well as the resolution of near-surface hydrogeologic features using apparent electrical conductivity (EC_a) surveys provide key insights for the site-specific management of this young agroforestry system. Some of the topographic sinks recognized in the surface hydrology model coincided with “hot spots” of nitrate-N recorded during the first ground water collection event (March 2001). These patches most likely represented residual accumulations of nitrate-N shed in response to changes in subsoil pH (the delayed result of liming the field in 1999) which, in turn,

gradually altered the anion exchange capacity (AEC) proximate to the deep soil–karst interface, thus releasing nitrate-N stored in these formerly highly acidic subsoil “pockets” (DeFauw et al., 2005). Surface infiltrability was parameterized for topographic patches (high and low) of the three prevalent soil series (all Fragiudults). Variability of mean ponded infiltration rates from 18 sites was quite high, with the overall range from 4.0 ± 1.7 cm/h for Captina soils at high topographic positions to 18.0 ± 6.0 cm/h for Nixa soils at high topographic positions. Johnsbury soils, at the lowest landscape positions, exhibited infiltration rates of 12.0 ± 6.0 cm/h (DeFauw, 2006). A time-series assemblage of 66 water table maps (constructed from over 3200 depth to water records for the shallow well array over a 17-month interval – late May 2003 - late October 2004, including 6 maps from 2002) was used to create a simple, field-scale model of hydrodynamics. Based on the percentage coefficient of variation (%CV), five hydrologic zones were resolved. The spatial extent of hydrologically sensitive areas (HSAs) was delineated; these HSAs were typically present from early February through March (DeFauw et al., 2005). In addition, several small patches ($<25\text{m}^2$) prone to saturation excess runoff were detected in three electromagnetic induction (EMI) surveys of this field (DeFauw et al., 2005; DeFauw, 2006). A series of storm events in April 2004, prolonged the persistence of HSAs until mid-May. The quantification of HSAs in watersheds where variable source area hydrology is a dominant process provides a starting point for water quality risk assessment and the development of management practices for non-point source (NPS) pollution.

Traditional hydrologic monitoring efforts reveal an exceedingly small fraction of a field’s (or small catchment’s) hydrodynamic character. This GIS-based investigation provides benchmark data on process-response relationships that have developed in a young agroforestry alley cropping ecosystem (converted from pastureland in 1999), which will facilitate the discernment of longer-term trends in the biogeochemical processing of subsequent N inputs from poultry litter, commercial fertilizer, and cattle on this site, as well as be of use in the refinement of nutrient management strategies for the Ozark Highlands region.

The Vadose-Zone Losses of Soluble Heavy Metals from Pasture Soil Amended with Varying Rates of Poultry Litter

Basic Information

Title:	The Vadose-Zone Losses of Soluble Heavy Metals from Pasture Soil Amended with Varying Rates of Poultry Litter
Project Number:	2005AR158B
Start Date:	3/1/2004
End Date:	8/31/2005
Funding Source:	104B
Congressional District:	Third
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Solute Transport, Water Quality
Descriptors:	equilibrium-tension lysimeters, leaching, heavy metals, arsenic, chromium, cadmium, pasture and poultry litter
Principal Investigators:	Kristofor R. Brye

Publication

1. Brye, K.R., and A.L. Pirani, 2006, Metal uptake by tall fescue (*Festuca arundinacea*) as affected by poultry litter application, *Grass For. Sci.*, 61: 192-199.
2. Pirani, A.L., K.R. Brye, T.C. Daniel, B.E. Haggard, E.E. Gbur, and J.D. Mattice, Soluble metal leaching from a poultry-litter-amended Udult under pasture vegetation, *Vadose Zone J*, In Press.
3. Priani, A.L., K.R. Brye, T.C. Daniel, B.E. Haggard, E.E. Gbur, and J.D. Mattice, Plant nutrient leaching from poultry-litter-amended pasture soil. *Vadose Zone J*. (Submitted/In Review).
4. Pirani, A. 2005, Leaching of plant nutrients and heavy metals from poultry-litter-amended tall fescue pasture. MS Thesis, Department of Crop, Soil and Environmental Sciences, College of Agricultural, Food & Life Sciences, University of Arkansas, Fayetteville, Arkansas, 177 pages.

Problem and Research Objectives

Problem: Agriculture and the economies of the Ozark Highlands, (i.e., northwest Arkansas and northeast Oklahoma), and other regions throughout the southern United States, are largely influenced by the poultry industry. Consequently, animal waste disposal and, ultimately, surface and groundwater quality become major issues in areas with a large concentration of confined-animal-feeding operations. Since poultry litter contains notable amounts of heavy metals and despite the cost-effective use of poultry litter as an organic N and P fertilizer, the potential impairment of groundwater drinking supplies from heavy metals contained in poultry litter is an important concern to those requiring clean drinking water supplies. Relatively little information exists on the nature and concentration of these compounds in the soil solution as a result of the addition of poultry litter. The likelihood of heavy metals leaching from pasture soils with a history of repeated poultry litter applications is too great to ignore.

Research Objective: To continuously monitor water movement and heavy metal leaching from the root zone of tall fescue (*Festuca arundinacea* Schreb.) vegetation amended with varying rates of poultry litter using equilibrium-tension lysimeters.

Methodology

Equilibrium-tension lysimeters were employed to provide continuous, year-round drainage, solute concentration, and solute leaching loss data from the root zone of tall fescue as a function of poultry-litter application rate (0, 2.5 and 5 tons/acre). Equilibrium-tension lysimeters (0.19 m²), with a 0.2- μ m porous-stainless-steel plate, were installed below undisturbed root zones of the tall fescue vegetation, at approximately a 0.9-m depth, in each of six plots with high soil-test P in the top 5 cm. Filtered leachate samples collected from the lysimeters were acidified and analyzed for soluble heavy metals by ICAP. Drainage fluxes were multiplied by solute concentrations to obtain leaching losses (i.e., loads) from the root zone of pasture soil.

Principal Findings and Significance

Leachate was collected continuously throughout the year for two consecutive years (2003 and 2004), with flow-weighted mean concentrations and mass losses calculated by 3-month season and year. Total annual leachate collected did not differ among treatments. In 2003, there were no significant differences in flow-weighted mean concentrations or mass losses of heavy metals (Fe, Cu, Zn, Mn, As, Se, Cd, and Cr) among treatments. In 2004, several significant differences among treatments were observed in flow-weighted mean concentrations, however they were inconsistent among element, treatment, and season. Treatment differences in mass loss were also inconsistent among elements and seasons in 2004. The data suggest that the addition of poultry litter to pasture soil will influence concentrations and mass losses of heavy metals in areas of concentrated poultry production. Further monitoring is necessary to evaluate the longer-term effects of repeated annual poultry litter applications on soil solution water quality.

The type of data generated in this study will provide credible scientific evidence for soil leachate solution concentrations and loads that may aid regulators in defining new and/or adjusting existing solute concentration and load limits to realistic and achievable thresholds to maintain high quality groundwater resources in the Ozark Highlands region of the mid-South.

Nutrient losses in runoff and leaching from poultry litter applications to loblolly pine stands and pastures

Basic Information

Title:	Nutrient losses in runoff and leaching from poultry litter applications to loblolly pine stands and pastures
Project Number:	2005AR161B
Start Date:	3/1/2004
End Date:	8/31/2005
Funding Source:	104B
Congressional District:	Third
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Nutrients, Water Quality
Descriptors:	Runoff, poultry litter, leaching, nitrogen, phosphorus, arsenic, loblolly pine, best management practices
Principal Investigators:	Hal O. Liechty

Publication

1. Liechty, H.O., J. Richardson, S. Wilson, and R. Colvin, 2006, Surface and soil water chemistry during the first year following poultry litter application to pastures and a pine plantation. Arkansas Water Resources Conference April 18 & 19, 2006, University of Arkansas Center for Continuing Education, Fayetteville, AR.

Problem and Research Objectives

The poultry industry in the United States and Arkansas produces large amounts of poultry litter that needs to be disposed of in an environmentally sound manner. This litter is commonly applied to pastures to increase forage production. Repeated application of poultry litter in pastures has led to reductions in water quality and increases in the amount of nutrients that drain from watersheds that contain high densities of poultry production. Current policies and regulation may limit the amounts of poultry litter that can be applied to pastures in these watersheds and suitable, alternative applications sites are needed to maintain a viable poultry industry in many locations in Arkansas. Loblolly pine forests could be suitable application sites for poultry litter since pine tree growth responds well to nutrient additions and forest soils have attributes that limit surface runoff and mitigates off site transport of contaminants. The objective of this study is to evaluate the ability of loblolly pine plantations to environmentally mitigate nutrients from poultry litter applications. Specific objectives include to: 1) quantify and compare the impacts of poultry litter application to forests and pastures on nutrient and other environmentally important elements in surface water runoff 2) quantify and compare the impacts of poultry litter application to forests and pastures on nutrients and other environmentally important elements in soil water.

Methodology

A field study was implemented on pastures and a loblolly pine plantation growing on similar soils in southwestern Arkansas. The trees were 26 years old at the time of study establishment and the pastures, which are used for hay production, contain a mixture of Bermuda grass, Bahia grass, tall fescue and clovers. Treatment application and water monitoring occurs on six 0.4-ha plots within the pine plantation and another six plots in the pastures. Three of the plots in the pine plantation and three of the plots in the pastures received a nine Mg/ha application of poultry litter in April of 2004. Surface water was collected in a 102 m² runoff plot and soil water was collected using four tension lysimeters within each 0.4 ha plot in the pastures and loblolly pine plantation. Total flux of surface water was determined for each runoff plot. Nutrient concentrations (N, P, K, Ca, Mg, Total As, As(V), As(III) and other selected micronutrients) were determined for all or a subset of water samples collected by the runoff plots and lysimeters.

Principal Findings and Significance

Application of poultry litter to the pastures and pine plantation significantly increased total phosphorus and nitrogen concentrations in the surface runoff. Concentrations of total phosphorus were 8-15 times higher in areas receiving poultry litter compared to areas that had no litter application. Concentrations of nitrogen were approximately 3 times greater. Increases were similar in pastures and the pine plantation. However, total surface runoff loads of N and P in the pine forest were much lower than in the pastures because the amount of runoff was much greater in the pastures than the pine

forests. Total surface runoff averaged 6.25 and 22.5 cm in the pine plantation and the pastures respectively. Thus loads of N and P in surface runoff were approximately 4 times greater in the pastures than the pine forests.

Concentrations of P in soil water were low in both the pine forest and pasture. Application of litter increased these concentrations from approximately 0.05 to 0.10 mg/l in both the pastures and forests. Application of litter increased the concentrations of N most dramatically in the forest compared to the pastures. Concentrations of total N increased from 0.23 to 1.96 mg/l in the pine forest and 1.97 to 4.85 mg/l in the pastures. Nitrogen in soil water of the forest without poultry litter application was dominated by organic forms of N but with the application of litter, $\text{NO}_3\text{-N}$ was the dominate form of N. The forms of N within the pastures that received the litter were similar to the portion of the pastures not receiving poultry litter.

Application of poultry litter to forests may be a suitable alternative to the application of poultry litter to pastures. Loads of N and P in surface runoff from the pine forest were much lower than that from pastures because of reductions in the amount of surface runoff from the forests compared to the pastures. High infiltration rates, large amount of canopy interception, and the ability of the pine forests to transpire over much of the year most likely contributed to the reductions in surface runoff. Although the level of N in soil water dramatically increased with litter application to the pine forest, concentrations were still lower than that in the pastures. Thus application of litter to pine forests could minimize off site movement of nutrients in subsurface flow as well as nutrients in surface runoff compared to pastures.

Information Transfer Program

AWRC sponsors an annual water conference held in Fayetteville each spring, drawing in about 100 researchers, students, agency personnel, and interested citizens to hear about results of current research and hot topics in water resources throughout the state. AWRC also co-sponsors short courses and other water-related conferences in the state and region. The 2005 Arkansas Water Resources Conference featured twenty oral presentations and eleven posters during the one and one-half day conference.

In addition, AWRC maintains a technical library containing over 900 titles, many of which are on-line. This valuable resource is utilized by a variety of user groups including researchers, regulators, planners, lawyers and citizens. Many AWRC publications have been converted to electronic pdf format which can be accessed via our web site at <http://www.uark.edu/depts/awrc>. Click the "Publications" link on the left-hand side of the page to view these publications.

2005 Arkansas Water Resources Center Conference

Basic Information

Title:	2005 Arkansas Water Resources Center Conference
Project Number:	2005AR159B
Start Date:	4/19/2005
End Date:	4/20/2005
Funding Source:	104B
Congressional District:	Third
Research Category:	Water Quality
Focus Category:	Water Quality, Water Supply, Non Point Pollution
Descriptors:	
Principal Investigators:	Ralph K. Davis

Publication

1. Davis, R., 2005, Annual Arkansas Water Resources Center Conference. April 19 and 20, 2005, University of Arkansas Center For Continuing Education, Fayetteville, AR. Conference Agenda and Abstracts On-Line at <http://www.uark.edu/depts/awrc/Publications/2005AWRCCConference/Trifold2005>.

Characterization and Biomonitored Responses to Turbidity Using Single Point Storm Event and Multipoint Longitudinal Sampling in a NE Arkansas River. *Brent L. Walker, Graduate Research Assistant, Biological Sciences, ASU; Jerry L. Farris, Professor, Biological Sciences, ASU; Elizabeth A. Ashcraft, Graduate Research Assistant, Biological Sciences, ASU; and Marc A. Nelson, Research Assistant Professor, Arkansas Water Resources Center, UA **11:30 am**

Alternatives to Conventional On-Site Wastewater Disposal Systems. *Floyd Gilzow, Executive Director, Upper White River Basin Foundation, Branson, Missouri **4:00 pm**

Hydrogeology, Flow and Water Quality of the Prairie Grove Area, Arkansas. With Implications for Public Health. Matt J. Edmonds, Graduate Research Assistant, Geosciences, UA; and *J. Van Brahana, professor, Geosciences, UA **4:30 pm**

2005 Arkansas Water Resources Center Conference
TUESDAY, April 19
8:00am to 7:00pm

Registration and Continental Breakfast..... **8:00 am**

Ralph K. Davis, Director , Arkansas Water Resources Center Welcome and Introductions **8:25 am**

PRESENTATIONS
 * Denotes Speaker

Session Moderator: Bob Morgan, Manager of Environmental Quality, Beaver Lake Water District

Designing and Restoring Urban Ecological Services Using Greenways and Urban Streams. *Marty Matlock, Associate Professor, Biological and Agricultural Engineering, UA; Robert Morgan, Manager of Environmental Quality, Beaver Water District; Andrea Ludwig, Brian Schafer, Eric Cummings, and Derrick Schluterman, all Graduate Research Assistants, Biological and Agricultural Engineering, UA **8:40 am**

Influence of Fine Sediments on Meiofauna Colonization in Artificial Stream Channels. *Andrea J. Radwell, Graduate Research Assistant; and Arthur V. Brown, Associate Professor, Biological Sciences, UA **9:00 am**

West Fork – White River Impairments, Current Restoration Projects and Proposed Conservation Priorities.
 *Melissa Terry, Conservation Director for Audubon Arkansas' NW Field Office in Fayetteville **9:30 am**

Break **10:00-10:30 am**

Water Quality In The Lower Little Red River Watershed.
 Phillip Fields, Coordinator, Lower Little Red River Watershed **10:30 am**

Alluvial Aquifer Water Chemistry: Function of Sample Filtration and Spatial Variability. * Burnshik Kim, Graduate Research Assistant, Environmental Dynamics Program, UA; Ken Steele, Professor, Geosciences, UA; and Todd Fugitt, Geology Supervisor, Arkansas Soil and Water Conservation Commission **11:00 am**

***RECEPTION AND POSTER SESSION,
 Tuesday, April 19.....5:00-7:00 pm
 *See back page for information**

WEDNESDAY, April 20
8:00am to 12:05pm

Registration and Continental Breakfast..... **8:00 am**

Session Moderator: Phil Hays, Hydrologist, U.S. Geological Survey and Adjunct Professor, Department of Geosciences, UA

Heavy Metal Leaching From Poultry Litter Amended Pasture Soil. *Kris R. Brye, Assistant Professor, Crops, Soils and Environmental Sciences, UA; and A.P. Pirani, Graduate Research Assistant, Crops, Soils and Environmental Sciences, UA **8:30 am**

Long-term Effects of Poultry Litter, Alum-treated Poultry Litter and Ammonium Nitrate on Soil Chemistry, Water Quality, and Pasture Productivity . *Philip A. Moore, Jr., Adjunct Professor, USDA Agricultural Research Service; and Dwayne Edwards Professor Biological and Agricultural Engineering, University of Kentucky **9:00 am**

Occurrence of Organic Wastewater Compounds and Antibiotic Residuals in Selected Streams in Northern Arkansas *Joel M. Galloway, Hydrologist, U.S. Geological Survey, Little Rock, AR; and Brian E. Haggard, Hydrologist, USDA Agricultural Research Service **9:30 am**

Break **10:00-10:30 am**

The Sparta Aquifer in Southcentral Arkansas-Monitoring the Recovery of a Valuable Water Resource. *Tony P. Schrader, Hydrologist, U.S. Geological Survey, Little Rock, AR **10:30 am**

Additional Presentations on Back Page

Lunch (Lunch on you own: list of restaurants in conference packet) **12:00-1:30 pm**

Session Moderator: John Czarniecki, Hydrologist, U.S. Geological Survey, Little Rock

Ground-Water Flow Model of Tar Creek and Vicinity. *John B. Czarniecki, Hydrologist, U.S. Geological Survey, Little Rock, AR; and Thomas Reed, Hydrologist, U.S. Geological Survey, Little Rock, AR **1:30 pm**

A Coupled Biogeochemical/Hydrological Approach For Elucidating Transport And Cycling of Nitrogen Within Manted Karst Watersheds. *Jozef Lincez, Graduate Research Assistant, Environmental Dynamics Program, UA; Byron Winston, Graduate Research Assistant, Biological Sciences, UA; Tim Kresse, Geologist, Arkansas Dept. of Environmental Quality; Susan Ziegler, Associate Professor, Biological Sciences, UA; John Fazio, Geologist, Arkansas Dept. of Environmental Quality; Phillip Hays, Hydrologist, U.S. Geologist Survey and Adjunct Professor, Geosciences, UA **2:00 pm**

The Extent and Variability in Biogeochemical Processing Within A Karst Watershed. *Susan Ziegler, Associate Professor, Biological Sciences, UA; Byron Winston, Graduate Research Assistant, Biological Sciences, UA; Phillip Hays, Hydrologist, U.S. Geological Survey and Adjunct Professor, Geosciences, UA; and Jozef Lincez, Graduate Research Assistant, Environmental Dynamics Program, UA **2:30 pm**

Break **3:00-3:30 pm**

Onsite Soil Treatment of Household Wastewaters. *E. Moye Rutledge, Professor, Department of Crop, Soil, and Environmental Sciences, UA; C. Roland Mote, Assistant Dean, Tennessee Agricultural Experiment Station, University of Tennessee-Knoxville **3:30 pm**

Bacterial and Sediment Fate and Transport in Mantled karst Aquifers, Savoy Experimental Watershed, Northwest Arkansas. *Tiong-Ee Ting, Graduate Research Assistant, Chemical Engineering, UA; Ralph K. Davis, Associate Professor Geosciences, UA; Greg Thoma, Associate Professor, Chemical Engineering UA; J.V. Brahana, Professor, Geosciences, UA; Tim Unger, Graduate Research Assistant, UA; and Dixie Androes, Graduate Research Assistant, UA11:00 am

Sediment Phosphorus Release at Lake Francis on the Illinois River, Arkansas and Oklahoma, 2003. *Brian E. Haggard and Thomas S. Soerens11:30 am

Parting Comments12:00 pm

**RECEPTION AND POSTER SESSION
TUESDAY, APRIL 195:00-7:00 pm**

Historical Bathymetry, Sediment Thickness, and Sediment Accumulation In Lake Fayetteville, Fayetteville, Arkansas, S.K. Boss, Department of Geosciences, UA, and T.M.Garcia, Department of Geology, University of Florida, Gainesville, FL

Ballard Creek, Illinois River, Washington County, Arkansas, Section 319, Best Management Practice Implementation Project, C.D. Duminigan Resource Conservationist, Washington County Conservation District

Relocation of Native Arkansas Plants Due to Water Supply Construction, R.E. Easley, Environmental Manager, Environmental Services Department, City of Fort Smith

Developing Resource Management Systems for Golf Courses in Washington County, Arkansas, Sarah Franklin, Water Quality Technician, Washington County Conservation District

In-Situ Evaluation of Best Management Practices for Animal waste Storage in Mantled Karst – A Case Study From The Savoy Experimental Watershed, Christopher M. Hobza, Department of Geosciences, UA; David C. Moffitt, Nat. Resource Conservation Service (NRCS), National Water Mgmt Ctr. Little Rock, Danny P. Goodwin, NRCS National Water Mgmt Ctr, Little Rock, J. Van Brahana and Phillip D. Hays, Department of Geosciences, UA

Hydrogeologic Assessment of a Shallow Mantled Karst Aquifer, North-Central Washington and South-Central Benton Counties, Arkansas, Aaron C. Laubhan, Graduate Research Assistant, Geosciences, UA, Ralph K. Davis, Associate Professor, Geosciences, UA and J. Van Brahana, Professor, Geosciences, UA

Quantification of Critical Runoff Contributing Areas in a Pasture Watershed, M. Leh, Graduate Research Assistant, I. Chaubey, Assistant Professor and J. Murdoch, Instr. Tech.

Ecological Assessment of Black Bear Watershed, Pawnee, Oklahoma, A. Ludwig, Graduate Assistant, M. Matlock, PhD, PE, CSE, Ecological Engineering Group, Department of Biological and Agricultural Engineering, UA

Using Neural Net Model to Predict Eucha Watershed Total Phosphorus Concentration From Watershed Features, E. Mutlu, Biological and Agricultural Engineering, UA, I. Chaubey, Biological and Agricultural Engineering, UA and H. Hexmoor, Computer Sciences and Computer Engineering, UA

Surface Water Quality of the Little Red River Tributaries, G. M. Ogendi, L. Cox, J.L. Farris, and R.E. Hannigan, Program of Environmental Sciences, Arkansas State University, State University, AR

Overview of Soil Treatment of Septic Tank Effluent in Arkansas, E. M. Rutledge, Professor, Department of Crop, Soil, and Environmental Sciences, UA, M. Savin, Assistant Professor, Department of Crop, Soil, and Environmental Sciences, M. Gross, Professor, Department of Civil Engineering, C. Hawkins, Graduate Assistant, Department of Crop, Soil, and Environmental Sciences, UA

Development of an Integrated Water Quality – Water Management Program in the Arkansas Delta, B.K. Schaffer, I. Chaubey, and Phil Tacker, Department of Biological and Agricultural Engineering, UA, Division of Agriculture, and E. Vories, USDA – Agricultural Research Service

Production of Europium-Labeled Escherichia coli Using High Cell Density Fermentation for Bacteria Tracking in Mantled Karst of Northwest Arkansas, T. Ting, Graduate Research Assistant, Chemical Engineering, UA, G.J. Thoma, Associate Professor, Chemical Engineering, UA, R.B. Beitle, Jr., R.K. Davis, Associate Professor, Geosciences, UA, J.V. Brahana, Professor, Geosciences, H. Liu, Graduate Assistant, Chemical Engineering, UA, and R. Perkins, Graduate Assistant, Chemical Engineering, UA

WELCOME TO THE



April 19 & 20, 2005
at the

**2005 ARKANSAS WATER
RESOURCES CONFERENCE**

Center for Continuing Education
and the
Fayetteville Radisson
70 North East Avenue
Fayetteville, Arkansas



Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	14	0	0	0	14
Masters	3	0	0	0	3
Ph.D.	3	0	0	0	3
Post-Doc.	0	0	0	0	0
Total	20	0	0	0	20

Notable Awards and Achievements

The Arkansas Water Resource Center in conjunction with a multidisciplinary team have leveraged funding provided by the USGS 104 b program over several years to supplement infrastructure and provide basic and applied research at the Savoy Experimental Watershed, Northwest Arkansas. The Savoy Experimental Watershed (SEW) is an approximately 1,250 hectare University of Arkansas property located about 24 km west of the University of Arkansas campus in northwest Arkansas. It was selected because it is representative of mantled-karst aquifers throughout northwest Arkansas, the Ozarks and much of the remaining 20% of the United States dominated by karst topography. Ongoing research at the site has facilitated development of a fully instrumented site that allows investigation of the integrated transport of surface applied nutrients and bacteria through primary pathways to their ultimate discharge into major streams.

USGS 104 b funds have been provided to several researchers utilizing SEW over the last several years with a goal of providing seed data creating the basis for preparation of proposals to other entities. This includes investigation of transport and storage of E. coli bacteria in streams and aquifers of Northwest Arkansas. Results of this project were recently published in the Journal of the American Water Resources Association (Davis et al. 2005). The initial state and Federal funds provided via the Arkansas Science and Technology Authority and the USGS 104 B program provided initial data sets which were then used as the basis for a proposal to the National Science Foundation which was awarded for continued research in this area

Dr. Phil Hays who holds a joint appointment with the USGS and the University of Arkansas, and Dr. Susan Ziegler, UA Department of Biological Sciences are conducting an interdisciplinary study with USGS, USDA, and the UA Departments of Geosciences and Biological Sciences to define biogeochemical processes occurring in karst, and how N transport and utilization is controlled by the interplay of biological and hydrological inputs to the complex systems. Additional funds provided by the USGS 104 B program have augmented this project providing resources to investigate nitrogen processing in a Karst Soil Catena. Results of their work was recently published by Defaw et al. (2005)

Dr. Indrajeet Chaubey, Biological and Agricultural Engineering at UA, and Dr. J. Van Brahana, Geosciences at UA, utilized seed funds provided under the USGS 104 B program in conjunction with funding from US EPA, USDA, Arkansas Department of Environmental Quality, and others to establish a fully instrumented facility at SEW with a main goal of understanding nutrient (nitrogen and phosphorus) fate in strongly linked surface-subsurface karst agricultural watersheds, which is critical to development of effective management strategies to protect human health and minimize adverse effects of phosphorus on river and lake systems. Their team has published several papers related to the site including several papers in the proceedings of the USGS Karst Interest Group (Brahana et al, 2005; and Laincz et al, 2005).

The Arkansas Water Resource Center continues to be a leader in non-point source water-quality monitoring related to nutrient loading of surface waters in the Ozark Plateaus Province. Dr. Marc Nelson, who heads up the AWRC Water Quality Laboratory, leads the monitoring program for six sites throughout the area. High quality nutrient loading data collected by Dr. Nelson and his team are regarded as the best available data for calculation of Total Maximum Daily Loads. These data are also routinely used by other researchers involved with development of non-point source pollution decision support systems. The decision support systems which are being developed for the ten high priority watersheds in the state will be used to prioritize resource allocation to minimize non-point source nutrient and sediment loading to the surface waters of the state

Dr. Indrajeet Chaubey is leading a team that models and assesses impacts of Best Management Practices on nonpoint source loading at the watershed scale using the Soil Water Assessment Tool (SWAT) model. The base data sets provided by Nelson et al are used as calibration data for the modeling effort. Chaubey has published numerous recent articles including one dealing with DEM resolution affects on SWAT model results which was recently published in the Journal of Hydrologic Processes (Chaubey et al 2005).

Dr. Brian Haggard, UA Biological and Agricultural Engineering (2006) published an article on the Effect of Reduced Effluent Phosphorus Concentrations at the Illinois River, Northwest Arkansas in the Journal of Environmental Quality as a direct result of funding provided through the USGS 104 B program. The research conducted by Dr. Haggard supports and extends ongoing efforts by Nelson and Chaubey by looking more closely at the impacts of point sources of contamination at the watershed scale.

Researchers continue to investigate impacts of Best Management Practices on watershed scale contaminant loading including Dr. Hal Leichty, University of Arkansas at Monticello, who is interested in the uptake of nutrients in a forested environment where external nutrients are applied. Their research shows that application of poultry litter to the pastures and pine plantation significantly increased total phosphorus and nitrogen concentrations in the surface runoff. Concentrations of total phosphorus were 8-15 times higher in areas receiving poultry litter compared to areas that had no litter application. Concentrations of nitrogen were approximately 3 times greater. Increases were similar in pastures and the pine plantation. However, total surface runoff loads of N and P in the pine forest were much lower than in the pastures because the amount of runoff was much greater in the pastures than the pin forests. Thus application of litter to pine forests could minimize off site movement of nutrients in subsurface flow as well as nutrients in surface runoff compared to pastures.

Research by Dr. Stephen Kline, Department of Geology, Arkansas Tech Univeristy, on the alluvial aquifer of the Arkansas River is helping assess the degree of stream-aquifer interaction and hydrochemical variations between the river water and the aquifer. His work will help municipal providers better manage their wellfield to maximize production while minimizing water quality variations. This effort was

coordinated with the groundwater section of the Arkansas Department of Environmental Quality and points to an excellent University and State Agency partnership.

The Arkansas Department of Environmental Quality also partnered with Dr. Ken Steele, UA Geosciences, on assessment of arsenic contamination in the alluvial aquifer south of Pine Bluff, Arkansas in the eastern Delta area of Arkansas. Funds provided under the USGS 104 B program provided drilling and coring of three sites. Multi-stage acid leaching of sediments from the cores were analyzed by the State Agency laboratory. These data will help refine conceptual models about the spatial distribution of arsenic in the Delta Region of Arkansas which pose a potential health problem for municipal and domestic water supplies throughout the region.

Through the efforts of the Arkansas Water Resources Center, the Center for Advanced Spatial Technologies, the Arkansas Soil and Water Conservation Commission, and the Natural Resources Conservation Service, digital county soils maps, SURGO level, are available for all but one of Arkansas 75 counties. The linkage between the AWRC, CAST, ASWCC, NRCS, and the state legislative delegation make projects like this a reality. The base support provided to the AWRC through the USGS 104 B funding truly facilitates these linkages between various local, state, and federal entities.

Publications from Prior Projects

1. 2002AR11B ("Chemical Variation of Water From The Alluvial Aquifer") - Conference Proceedings - Kim, Burmshik and Kenneth F. Steele, 2005, Application of geologic information for ground-water quality management, Proceedings of the XXXI International Hydrologic Resources Congress, Seoul, Korea, p.5577-5585.
2. 2002AR11B ("Chemical Variation of Water From The Alluvial Aquifer") - Other Publications - Kim, B., and F. K. Steele, 2005, Alluvial Aquifer Water Chemistry: Function of Sample Filtration and Spatial Variability, 2005 Arkansas Water Resources Center Conference. [CD]
3. 2002AR11B ("Chemical Variation of Water From The Alluvial Aquifer") - Other Publications - Steele, K F., T. Kresse, R. K. Davis and S. Boss and J. Johnston, 2005, How uniform is the ground water chemistry of the alluvial aquifer?, Arkansas Water Resources Center Annual Conference: Quality Water to Meet Our Competing Needs, University of Arkansas, Fayetteville. [CD]
4. 2002AR11B ("Chemical Variation of Water From The Alluvial Aquifer") - Articles in Refereed Scientific Journals - Kim, Burmshik, Kenneth F. Steele, and Todd Fugitt, submitted and invited, Comparison of dissolved and acid-extractable metal concentrations of ground water, eastern Arkansas, U.S.A., Journal of Environmental Informatics.
5. 2002AR11B ("Chemical Variation of Water From The Alluvial Aquifer") - Other Publications - Steele, K., B. Kim and Todd Fugitt, 2005, Aerial variation of water quality in the alluvial and Sparta aquifers of Arkansas, EOS Trans. AGU, 86(52), Fall Meet. Suppl., Abstract H23F-1490
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