Penn State Institutes of the Environment
Annual Technical Report
FY 2005

Introduction

The FY 2005 Annual Report for the Pennsylvania Water Resources Research Center at Penn State University includes annual update information about six research and technology transfer projects supported by the 104B base funding program and one supplemental project. Base funded projects are competitively awarded, one-year, exploratory or seed grants related to some critical water resource needs. This year's base funded projects include three recently completed projects for FY 2005 that directly involve pollution source tracking using phenotypic or genotypic characteristics of micro-organisms in water that can cause human health effects. A fourth project deals with design of cost effective water quality and quantity monitoring programs using a coupled multi-objective optimization, uncertainty modeling, and geostatistical visualization. The fifth project in the FY 2005 program supported water resources educational efforts that were part of an awarding-winning Master Well Owners volunteer program. Progress on a project from FY 2004 that deals with design and implementation of a split-flow test facility for stormwater management from paved surfaces is also given. Finally, an annual report on a special supplementary project funded through the PA WRRC that dealt with soil carbon sequestration in dry regions of Africa is included.

Research Program

Nitrate Source Tracking: Combining Isotopic, Microbial, and Chemical Tracers in a Mixed Land-Use Watershed

Basic Information

Title:	Nitrate Source Tracking: Combining Isotopic, Microbial, and Chemical Tracers in a Mixed Land-Use Watershed
Project Number:	2005PA40B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	5th
Research Category:	Water Quality
Focus Category:	Nitrate Contamination, Surface Water, Water Quality
Descriptors:	
Principal Investigators:	David Russell DeWalle, Michael A. Arthur, Anthony Robert Buda, Chitrita DebRoy

Publication

1. Buda, A.R. and D.R. DeWalle. 2005. Tracing Nitrate Sources in a Mixed Land-Use Watershed During Baseflow and Peakflow Conditions. Eos Transactions AGU. 86(52). Fall Meeting Supplement. Abstract H21F-06. Oral Presentation

PRINCIPAL FINDINGS AND SIGNIFICANCE

Six storm events were sampled during 2005 in Spring Creek, a predominately karst geology watershed in central Pennsylvania. For each storm event, five nested subwatersheds representing a downstream progression of forested, agricultural, urban, and mixed land-uses in Spring Creek were sampled for chemical, isotopic (^{15}N and ^{18}O in nitrate), and microbial (*E. coli*) tracers to assess potential sources of nitrate during baseflow and peakflow conditions. The distribution of storms throughout the year also allowed for comparisons of tracers and nitrate sources during the growing and dormant seasons. Preliminary results and conclusions from this sampling effort are presented below.

- During baseflow conditions, ^{15}N in nitrate was a better discriminator of nitrate sources than ^{18}O in nitrate. In general, ^{15}N in nitrate was lowest for Galbraith Gap Run, a predominately forested watershed underlain by sandstone. The low ^{15}N values for Galbraith Gap Run showed that nitrate derived from microbial nitrification in soils was the most likely source of nitrate during baseflow conditions. In comparison to the forested watershed, ^{15}N in nitrate was slightly greater in baseflow for Cedar Run (agricultural), Thompson Run (urban), and Spring Creek Houserville (mixed land-use site upstream of UAJA sewage treatment plant), all of which are underlain by karst geology and had fairly similar ^{15}N signatures. This suggested a mixture of soil-derived nitrate and manure or sewage nitrate sources for these sites during baseflow. Moreover, samples taken from Thompson Spring and Bathgate Spring, two local karst springs, had similar values of ^{15}N in nitrate to Cedar Run, Thompson Run, and Spring Creek at Houserville, which implied that nitrate in these streams may be primarily derived from the same groundwater sources. Spring Creek at Rock Road (mixed land-use) had the highest baseflow ^{15}N in nitrate of all sites, which was primarily due to high ^{15}N inputs of sewage nitrate from the UAJA treatment plant about 2.2 kilometers upstream. A significant positive relationship between ^{15}N and chloride also verified the importance of sewage nitrate at this site.

- ^{15}N and ^{18}O in nitrate were useful for showing the importance of overland flow delivery of nitrate, especially in the Thompson Run watershed (urban). At baseflow, ^{15}N and ^{18}O in nitrate showed that nitrate sources were primarily derived from organic sources (manure / sewage). During a storm event, ^{15}N and ^{18}O shifted toward precipitation nitrate signatures, which demonstrated that nitrate from urban stormwater runoff predominated during the storm. As a result, ^{15}N and ^{18}O in nitrate appear to be excellent tracers of urban stormwater and would be very useful for evaluating the effectiveness of urban best management practices (BMPs) for stormwater mitigation.

- ^{15}N and ^{18}O in nitrate were also useful to illustrate the differences in behavior during storms for rural watersheds in karst versus sandstone geology. In general, ^{15}N and ^{18}O in nitrate showed little changes from baseflow to peakflow for rural karst subwatersheds (Cedar Run and Spring Creek at Houserville), suggesting that sources of nitrate may be predominately from the same groundwater throughout storm events in these basins. On the other hand, nitrate stable isotopes in Galbraith Gap Run, a forested watershed with sandstone geology and shallow soils, shifted more toward precipitation nitrate signatures during storms. This implied that shallow subsurface soil flow paths in the sandstone watershed delivered more precipitation nitrate than in watersheds with karst geology and deeper soils.

- ^{15}N in nitrate varied seasonally during baseflow conditions for all sites, although the variations were not substantial. In general, ^{15}N showed slight declines from spring through fall for Cedar Run, Thompson Run, and Spring Creek at Houserville. Galbraith Gap Run showed a slight increase in ^{15}N, although it was minor. Spring Creek Rock Road and the sewage effluent from UAJA showed more substantial and well correlated increases in ^{15}N during 2005, which suggested that these sites may need to be sampled at different times of the year to adequately characterize sources of nitrate. ^{18}O in nitrate increased slightly during 2005 at all sites, but the increases were minimal. In general it appears, except for UAJA sewage effluent, that temporal variability of nitrate stable isotopes is minimal throughout the year and that potential nitrate sources can be assessed with relatively few samples at a given site. Sampling efforts should focus more on spatial variability of nitrate stable isotopes that exist between watersheds with different land-uses and geology.

- Nitrate stable isotopes (^{15}N and ^{18}O) in precipitation varied seasonally and within individual storm events. These variations may provide information on pollutant sources and atmospheric processes that are affecting precipitation nitrate for this site in central Pennsylvania.

- Denitrification was not considered a major control on stream nitrate isotopes during this study. Nitrate stable isotope results from a downstream (Lagrangian) sampling program for four distinct reaches (3 – 5 km long) in the mainstem of Spring Creek during a typical summer low-flow period (June 2005) suggested that decreases in nitrate loads were not primarily due to denitrification. Ultimately, we can conclude that nitrate stable isotopes are likely to be conservative during in-stream transport and should represent nitrate sources and not in-channel transformation processes during warm season baseflow periods.

- The overall objective of the project is to combine information from chemical, isotopic, and microbial tracers to identify important sources of nitrate in streams within the Spring Creek watershed. We are in the process of evaluating the potential sources of *E. coli* bacteria in streams using Eubacterial Repetitive Intergenic Consensus (ERIC) polymerase chain reaction (PCR). Once this analysis is complete, all tracer information will be analyzed using multivariate statistics (e.g. classification and regression trees, discriminant analysis) to help develop models to identify nitrate sources for all stream sites during baseflow and peakflow conditions.

STUDENTS SUPPORTED

Anthony Buda, Forest Resources, Ph.D.

PRESENTATIONS AND OTHER INFORMATION TRANSFER ACTIVITIES

Buda, A.R. and D.R. DeWalle. 2006. Tracing Nitrate Sources in a Mixed Land-Use Watershed During Baseflow and Peakflow Conditions. Environmental Chemistry Student Symposium – Center for Environmental Chemistry and Geochemistry (CECG). Penn State University.

First Place Oral Presentation: http://www.essc.psu.edu/CECG_symposium/

Buda, A.R. and D.R. DeWalle. 2005. Tracing Nitrate Sources in a Mixed Land-Use Watershed During Baseflow and Peakflow Conditions. Eos Transactions AGU. 86(52). Fall Meeting Supplement. Abstract H21F-06. Oral Presentation

AWARDS

First Place Oral Presentation, Environmental Chemistry Symposium, Penn State University, 2006

Fatty acid methyl ester (FAME) profiles of Escherichia coli and enterococci for predicting sources of microbial pollution

Basic Information

Title:	Fatty acid methyl ester (FAME) profiles of Escherichia coli and enterococci for predicting sources of microbial pollution
Project Number:	2005PA41B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	7th
Research Category:	Water Quality
Focus Category:	Water Quality, Surface Water, Non Point Pollution
Descriptors:	
Principal Investigators:	Metin Duran

Publication

1. Duran, M.; B.Z. Haznedaroðlu; D.H. Zitomer, 2006, Microbial Source Tracking Using Host Specific FAME Profiles of Fecal Coliforms, Water Research, 40(1), 6774.
2. Haznedaroðlu, B.Z.; D.H. Zitomer; G.B. Hughes-Strange; M. Duran, 2005, Whole-cell Fatty Acid Composition of Total Coliforms to Predict Sources of Fecal Contamination, Journal of Environmental Engineering, ASCE, 131(10), 1426-1432.
3. Haznedaroðlu, B.Z., 2005, Fatty Acid Methyl Ester Profiling of Indicator Organisms for Microbial Source Tracking, MS Thesis Civil and Environmental Engineering Department, College of Engineering, Villanova University, Villanova, Pennsylvania, 93.
4. Duran, M., 2006, Fatty Acid Methyl Ester (FAME) Profiles of Escherichia coli and enterococci for Predicting Sources of Microbial Pollution, Pennsylvania Water Resources Research Center, University Park, PA, 5.
5. Haznedaroðlu, B.Z. and M. Duran, 2005, Fatty Acid Methyl Ester (FAME) Profiles of Total Coliforms as a New Tool for Predicting Sources of Fecal Pollution, in Proceedings of the WEFTEC 05: The Water Quality Event, pp. 7142-7149.
6. Haznedaroðlu, B.Z. and M. Duran, 2005, Predicting Sources of Fecal Pollution Using Fatty Acid Methyl Ester (FAME) Profiling, in Proceedings of WEF TMDL 2005 Conference, pp. 634-644.
7. Duran, M. and B.Z. Haznedaroðlu, 2005, Host Specific Differences in Fatty Acid Methyl Ester

Profiles of Indicator Organisms as a New Tool for Microbial Source Tracking, in Proceedings of the World Water and Environmental Resources Congress, ASCE Conference Proceedings, Vol. 173, Paper 316.

INTRODUCTION

The Year 2000 National Water Quality Inventory lists microbial contamination as the leading cause of water quality impairment in rivers and streams in the US (EPA, 2000). The EPA report states that 93,000 miles of river and streams and 4,764 square miles of estuarine were contaminated with pathogens as of year 2000. According to the National Section 303(d) List, pathogens are the primary cause of water quality impairment nationwide, with 3,630 Total Maximum Daily Load (TMDL) being implemented due to presence of pathogens between 1996 and 2006 (EPA, 2006). Nine of these TMDL programs are in the state of Pennsylvania that is one of the significantly affected states.

Effective methods for predicting the sources of microbial pollution are needed to ensure timely and precise response to protect human and environmental health and to develop more accurate TMDL programs to maintain long-term water quality.

ABSTRACT

The overall objective of this study was to investigate the host-specific differences in fatty acid methyl ester (FAME) profiles of *Escherichia coli* and *enterococci* for the purpose of predicting sources of microbial pollution in water environments. In addition, commonly used indicator organisms total coliform (TC) and fecal coliform (FC) were included for the sake of completeness of the study. During the study period (January 1, 2005 through February 28, 2006), the FAME profiles of 303 TC, 314 FC, 605 *E. coli*, and 246 *enterococci* isolates were developed and the host specific differences in the FAME profiles were investigated using multivariate statistical tools. Due to a three month delay in project start, complete investigation of *enterococci* was not possible and thus the results from 246 *enterococci* isolates are not included in this report. The results indicate that the FAME profiles of TC, FC, and *E. coli* show statistically significant host-specific differences due to presence of signature FAMEs and different relative abundance of common FAMEs. The FAME profiles of FC isolates resulted in the most accurate source prediction, in comparison to those of TC and *E. coli*, with 95% precision in discriminating isolates of human origin from those of livestock and wildlife. The field testing showed that the signature FAMEs are conserved in the aquatic environments and that known-source FC library predicted the dominant source of microbial pollution at 81% accuracy.

PRINCIPAL FINDINGS AND SIGNIFICANCE

1. The results of this study, funded by the PA Water Resources Center, strongly suggest the validity of the original hypothesis that FAME profiles of indicator organism show statistically significant host-specific differences.

   - The presence of three signature fatty acids in the isolates of human origin; 12:0 2OH, 12:0 3OH and 14:0 2OH, and other three in the isolates from the livestock samples; 15:0, 18:0 and 19:0 ISO, are the primary factors that allow accurate discrimination of the human isolates against the non-human sources when TC and FC are used as indicators.

   - In the case of *E. coli* isolates, the presence of fatty acids 10:0, 16:1 ω5c, and 19:0 ISO suggest livestock sources fecal pollution. Furthermore, the absence of saturated fatty acid 18:0 implies that the likely source of the fecal pollution is non-human.

- In addition to presence of signature fatty acids, the differences in the average relative masses of some of the FAMEs common in all host categories are statistically significant contributing to accurate classification of isolates when TC, FC, and *E. coli* are used as indicators.

2. While the FAME profiles of all of the indicator organisms resulted in comparable or higher accuracy when compared to other commonly used phenotypic methods, the results of this study suggest that using the FAME profiles of FC will result in more accurate source prediction than those of TC and E. *coli.* A linear discriminant function based on host specific differences in the FAME profiles of FC isolates classified the known-source isolates into three pooled host categories, human, livestock, and wildlife, with 95% accuracy.

3. In the later stages of the study, the FAME profiles of FC isolated from environmental samples were also evaluated. The goal was to determine if the FAME profiles of the isolates from environmental samples can be discriminated using the known-source library constructed. The FAME profiles of the environmental isolates would provide insight regarding the conservation of known-source library FAMEs in the environment and whether FAME profiling can be useful in microbial source tracking. A total of 5 water samples were also collected from a natural pond to culture environmental isolates. The pond provided a unique opportunity to field test the effectives of FAME profiling, since it was well-protected with the only apparent source of fecal pollution being waterfowl, particularly Canada geese (*Branta canadensis*), and perhaps to a smaller extent, other wildlife such as deer. The discriminant function developed from known-source FC library predicted that 81% of the total 37 FC isolates cultured from the pond were coming from wildlife sources.

4. In conclusion, the results indicate that the FAME profiles of TC, FC, and *E. coli* isolates show host-specific differences and those differences can be used to differentiate the primary sources of the coliform isolates, which in turn can be used to predict the sources of fecal pollution in water environments.

5. It is important to emphasize that since the FAME profiling relies on the presence of signature FAMEs and differences in FAME profiles to identify primary host of the indicator organism, developing a large known-source libraries may not be necessary to predict sources of fecal pollution, as it is the case for the other phenotypic MST methods.

6. Besides its accuracy, FAME profiling as an MST tool offers advantages such as being relatively rapid and highly economical ($2.00-$2.50 per isolate).

STUDENTS SUPPORTED
1. Berat Z. Haznedaroglu '05, Water Resources and Environmental Engineering, MS
2. Deniz Yurtsever '07, Water Resources and Environmental Engineering, MS
3. Kimberly L. Daileader '06, Civil and Environmental Engineering, BS
4. George B. Hughes-Strange, '06, Chemistry, BS
5. Jamie R. Lefkowitz '06, Civil and Environmental Engineering, BS

PRESENTATIONS AND OTHER INFORMATION TRANSFER ACTIVITIES

1. Duran, M. (Invited speaker), 2005. "Host Specific Differences in FAME Profiles of Fecal Coliforms as a New Tool to Predict Sources of Microbial Pollution", Presented at Center for Urban Environmental Research and Education, University of Maryland, Baltimore County, Baltimore, MD, April 1, 2005.
2. Results posted on Villanova Urban Stormwater Partnership (VUSP) website at: http://www3.villanova.edu/VUSP

AWARDS
None yet

REFERENCE
1. **U.S. Environmental Protection Agency (EPA)**. 2000. National water quality inventory: 1998 Report to Congress. EPA-841-R-00-001. 413 pp.
2. **U. S. EPA National section 303(d) List**. 23 February 2006. [Online.] http://oaspub.epa.gov/waters/national_rept.control#TPOL

Source Water Protection from Infectious Cryptosporidium spp. Oocysts

Basic Information

Title:	Source Water Protection from Infectious Cryptosporidium spp. Oocysts
Project Number:	2005PA42B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	15th
Research Category:	Water Quality
Focus Category:	Water Quality, Water Supply, Surface Water
Descriptors:	
Principal Investigators:	Kristen L. Jellison

Publication

1. None.

Methods Modifications

1. The original proposal indicated that one surface water sample would be filtered and processed in the Jellison lab for both genotyping and infectivity status.

   Modification: Each surface water sample was filtered by the Philadelphia Water Department into two separate Gelman Envirochek sampling capsules. One sampling capsule was sent to the Jellison lab for genotyping and phylogenetic analysis, and the other sampling capsule was sent to Jennifer Clancy's lab (Clancy Environmental Consultants, Inc., Saint Albans, VT) for infectivity analysis.

2. The original proposal indicated that 5 surface water sites would each be sampled once per month, and that watershed fecal samples would be collected once per month.

   Modification: Two (2) surface water sites were each sampled twice per month during baseflow (dry weather) conditions. These 2 sites were each sampled a third time per month during wet weather conditions (weather permitting). Several months into the project, one wastewater treatment plant effluent sample was also collected and analyzed once per month. Watershed fecal samples were collected seasonally rather than once per month.

Project Scope/Timeline Modifications

The scope of this project has extended beyond the initial year of watershed sampling funded by the PA WRRC grant. Two additional grants from the Pennsylvania Department of Community and Economic Development have been obtained for this work:

> Pennsylvania Department of Community and Economic Development.
> "Source Tracking of Infectious *Cryptosporidium* spp. Oocysts in
> Wissahickon Creek." December 2005-March 2007. $46,083.

> Pennsylvania Department of Community and Economic Development.
> "Source Water Protection from Infectious *Cryptosporidium* spp. Oocysts."
> April 2005-March 2006. $30,400.

Source water and watershed fecal sampling will continue in the Wissahickon Creek watershed until March 2007 at the earliest. Additional funding for sampling beyond March 2007 will be sought. Given the extended nature of this project, the submission of a peer-reviewed journal paper reporting findings from this study will be delayed until Spring 2007.

Principal Findings and Significance
- Multiple *Cryptosporidium* genotypes were frequently found in a single surface water sample (Table 1), indicating that (i) multiple oocyst sources are impacting a single surface water location, and/or (ii) a single host may be shedding multiple genotypes of *Cryptosporidium* into the watershed.

- The genotypes detected suggest that human, agricultural, and wildlife inputs are all present in the Wissahickon Creek watershed (Table 1). Thus, a variety of watershed management strategies targeting each of these sources will likely be important to protect the Wissahickon Creek from *Cryptosporidium* oocyst contamination.

- Novel genotypes were identified on each sample date that *Cryptosporidium* oocysts were detected, and likely oocyst sources were determined based upon the known *Cryptosporidium* genotypes to which the novel genotypes were most closely related phylogenetically (Table 1). The inclusion of a second genetic locus for genotyping and phylogenetic analysis would enable more conclusive determinations of the likely oocyst sources in the watershed.

- Watershed fecal samples were collected on 7/20/05 (3 sheep, 5 geese, 3 deer, 4 cows, 1 racoon, and 3 horses) and 12/5/05 (1 cat, 4 dogs, 5 deer, and 5 ducks). No *Cryptosporidium* oocysts were detected in any of the watershed fecal samples collected, so the phylogenetic analysis was performed using *Cryptosporidium* genotypes in the GenBank database.

- No seasonal trend associated with human, agricultural, or wildlife sources of *Cryptosporidium* was observed. More extensive sampling (currently being performed) and stronger genotype resolution (e.g., by using a second genetic locus) may help to elucidate seasonal trends.

- No particular hydrologic condition (baseflow vs. wet weather events) was associated with human, agricultural, or wildlife impacts on Wissahickon Creek water quality. More extensive sampling during wet weather events will help determine if a correlation exists between hydrologic condition and watershed source of oocysts.

- Water quality data from the Philadelphia Water Department and infectivity data from the Clancy lab need to be compiled and analyzed to identify (i) correlations between water quality data and *Cryptosporidium* presence in Wissahickon Creek and (ii) the public health risk associated with the oocysts detected in this study. These data will be compiled in the near future and again upon completion of the study.

Table 1. Summary of surface water sampling results in the Wissahickon Creek watershed.

Date	Location*	Wet/ Dry	*Cryptosporidium* sp. Detected?	Genotype(s)**	Likely Source(s)
5/23/05	Wiss 140 Wiss 410	Dry	No No		
6/6/05	Wiss 140 Wiss 410	Dry	No No		
6/27/05	Wiss 410	Dry	No		
7/8/05	Wiss 140 Wiss 410	Wet	No No		
8/3/05	Wiss 140 Wiss 410	Dry	No **Yes**	Novel (*C. hominis*)	Human
8/22/05	Wiss 140 Wiss 410	Dry	No No		
9/6/05	Wiss 140 Wiss 410	Dry	No **Yes**	Novel (*C. parvum* bovine)	Human, Agriculture
9/26/05	Wiss 140 Wiss 410	Dry	No No		
10/3/05	Wiss 140 Wiss 410	Dry	**Yes** No	Novel (Goose genotype, *C. andersoni*)	Agriculture
10/8/05	Wiss 140 Wiss 410	Wet	No No		
10/24/05	Wiss 140 Wiss 410	Dry	**Yes** **Yes**	2 Novel (1-*C. hominis*; 1-Goose genotype, *C. andersoni*) 2 Novel (1-*C. hominis*; 1-*C. parvum* animal genotype [deer, pig])	Human, Agriculture Human, Wildlife
11/1/05	Wiss 140 Wiss 410	Dry	No No		
11/28/05	Wiss 140 Wiss 410	Dry	No No		
12/6/05	Wiss 140	Dry	**Yes**	2 Novel (1-*C. hominis*; 1-*C. meleagridis*)	Human, Wildlife
1/3/06	Wiss 140 Wiss 410	Wet	No **Yes**	3 Novel (1-*C. parvum* bovine;1- *C. wrairi;* 1-*C*. parvum animal genotype [deer, pig])	Human, Agriculture, Wildlife
1/23/06	Wiss 140 Wiss 410 Abbington WWTP	Wet	No No No		
2/6/06	Wiss 140 Wiss 410	Dry	**Yes** **Yes**	3 Novel (1-*C. wrairi*; 1-*C. parvum* animal genotype [deer, pig]; 1-*C. meleagridis*) 2 Novel (1-*C. wrairi;* 1-*C. meleagridis*)	Wildlife Wildlife

*See Appended Figure 1 for sampling locations within the Wissahickon Creek watershed.
**If novel genotype detected, the most closely related genotype(s) according to phylogenetic analysis is indicated in parentheses.

Figure 1. Sampling locations in the Wissahickon Creek watershed.

Students Supported
Joseph Ziemann
M.S. Civil and Environmental Engineering (expected August 2006)

Presentations/Information Transfer Activities
Jellison KL. "Cryptosporidium spp. Oocyst Source Tracking in the Wissahickon Creek Watershed, May 2005-June 2006." Report to the Philadelphia Water Department, *to be submitted July 2006*.

Jellison KL. "*Cryptosporidium* spp. Oocyst Source Tracking in Drinking Water Source Watersheds Serving Boston, MA and Philadelphia, PA." American Water Works Association International Symposium on Waterborne Pathogens, Atlanta, GA, March 17, 2006.

Jellison KL. "Source Tracking of *Cryptosporidium* spp. Oocysts in Drinking Water Source Watersheds." Invited Speaker, The W. Harry Feinstone Department of Molecular Microbiology and Immunology Seminar Series, Bloomberg School of Public Health, Johns Hopkins University, March 9, 2006.

Jellison KL. "Genetic source tracking of *Cryptosporidium* spp. oocysts in Boston and Philadelphia drinking water supplies." Invited Speaker, Water Quality in Urban Environmental Systems (WaterQUESt) Workshop, Carnegie Mellon University, December 8, 2005.

Jellison KL. "*Cryptosporidium* spp. Source Tracking Using PCR, Sequencing, and Phylogenetic Analysis of the 18S rRNA Gene." Invited Speaker, Pathogens Workshop for the Interstate Commission on the Potomac River Basin, June 28, 2005.

Awards
The following two research grants were awarded to PI Jellison to support further work on the current project:

1. Pennsylvania Department of Community and Economic Development. "Source Tracking of Infectious *Cryptosporidium* spp. Oocysts in Wissahickon Creek." December 2005-March 2007. $46,083.

2. Pennsylvania Department of Community and Economic Development. "Source Water Protection from Infectious *Cryptosporidium* spp. Oocysts." April 2005-March 2006. $30,400.

A Bayesian Framework for Cost Effective Groundwater Monitoring Design

Basic Information

Title:	A Bayesian Framework for Cost Effective Groundwater Monitoring Design
Project Number:	2005PA43B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	5th
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Models, Solute Transport
Descriptors:	
Principal Investigators:	Patrick M. Reed

Publication

1. Kollat, J. B., and P., Reed, 2006, Comparison of Multi-Objective Evolutionary Algorithms for Long-Term Monitoring Design, Advances in Water Resources, 29(6), 792-807.
2. Reed, P. J. B., Kollat, and V. Devireddy, In-Press, Using Interactive Archives in Evolutionary Multiobjective Optimization: A Case Study for Long-Term Groundwater Monitoring Design, Environmental Modeling & Software.
3. Kollat, J. B., and P. M., Reed, In-Review, A Computational Scaling Analysis of Multiobjective Evolutionary Algorithms in Long-Term Groundwater Monitoring Applications, Advances in Water Resources.
4. Tang, Yong, P. M., Reed, and J. B. Kollat, In-Review, Parallelization Strategies for Rapid and Robust Evolutionary Multiobjective Optimization in Water Resources Applications, Advances in Water Resources.
5. Kollat, J. B., 2005, The Epsilon Non-Dominated Sorted Genetic Algorithm II: A Highly Effective Multi-Objective Evolutionary Algorithm for Water Resources Applications, MS Dissertation, Department of Civil and Environmental Engineering, College of Engineering, The Pennsylvania State University, University Park, PA, 71 pages.
6. Kollat, J. B. and P. M., Reed, 2005, The Value of Online Adaptive Search: A comparison of NSGA-II, å-NSGAII, and åMOEA, Third International Conference on Evolutionary Multi-Criterion Optimization (EMO 2005), Guanajuato, Mexico, March 2005, Editors Coello Coello, C. A., Hernandez, A., Zitzler, E., Lecture Notes in Computer Science, Springer-Verlag, 386-398.

ABSTRACT.

The goal of this proposed research is to develop a decision support framework for designing cost-effective monitoring (LTM) networks. The monitoring framework allows hydrologic scientists' to balance multiple design objectives while characterizing complex hydrologic systems and adapt their objectives and system design to account for advances in real-time sensing. The objectives of this research are to:

1. Initiate the Real-Time Hydrologic Monitoring Network in the Shale Hills experimental watershed.
2. Develop, assess, and extend decision support tools for long-term monitoring network design.

The monitoring framework couples multiobjective optimization with the geostatistical visualization and uncertainty modeling to inform cost-benefit analysis for sensor investments. This research has yielded robust monitoring design tools that have been shown to be superior to existing tools. Additionally, computational scaling studies have shown that the framework can be used to reduce growth of computational demands from being quadratic with increasing network design problem sizes to linear, making it feasible to solve large-scale spatiotemporal monitoring problems.

Ongoing extensions of this work will utilize the multiobjective design framework to adaptively design a real-time groundwater monitoring campaign within the Shale Hills experimental watershed. The Shale Hills 19.8 acre experimental watershed was established in the 1970's by the Forest Hydrology group at Penn State to experimentally determine the physical mechanisms of streamflow generation for an upland forested catchment and to evaluate the effects of antecedent soil moisture on storm flow volume and timing. Historical and current research at the site will provide the opportunity to demonstrate our methodology for the two scenarios discussed below:

> Scenario 1: An extensive monitoring network exists and the framework will be used to analyze the value of existing and proposed monitoring stations in reducing site uncertainties.
> Scenario 2: Given fixed funds and a new experimental site, the monitoring framework will be used to identify the locations, sampling rates, and observation technologies for new monitoring stations. Note this will be part of a long-term research effort that extends beyond the time frame of this proposal.

The multiobjective decision support tools will provide stakeholders and policy makers with a better understanding of the value of adding monitoring points into existing networks and allow them to exploit a broader array of information sources.

STATEMENT OF CRITICAL NEED.

Groundwater is a vital resource for the Commonwealth of Pennsylvania (PA), supplying nearly 50-percent of the residential drinking water demand (PADEP 1997). Long-term monitoring of

the quantity, quality, and susceptibility of groundwater has been and continues to be an issue of paramount importance within the state. Figure (1) illustrates this point showing Pennsylvania's state-wide effort to develop long term, real-time groundwater monitoring stations.
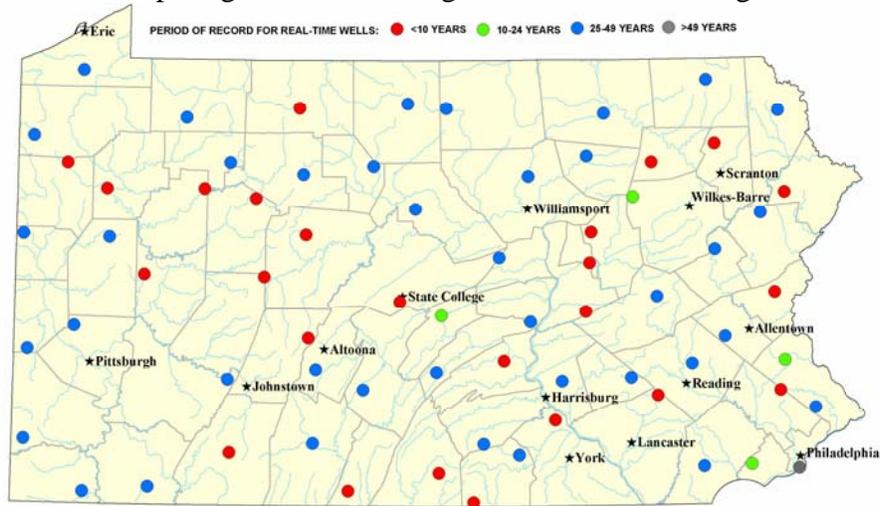

Figure 1: PA long-term, real-time groundwater monitoring stations (Courtesy of Patricia Lietman, PA District Chief USGS).

Broad initiatives such as Act 220 the Water Resources Planning Act and the Pennsylvania Wellhead Protection Program (WHPP) mandated by the Federal Safe Drinking Water Act will continue to increase the need for long-term groundwater monitoring records at both regional and local scales. Signed in 2002, Act 220 will require the Department of Environmental Protection to develop a state water plan by 2007, which will establish water budgets within critical planning areas throughout Pennsylvania. Given that groundwater is the largest store of fresh water within the state, increased investment in long-term groundwater monitoring will be required to better understand recharge and baseflow contributions to streams in critical watersheds. In the context of the WHPP, management of the wellhead protection areas will require rigorous, long-term groundwater quality assessments. The success of Act 220 and the WHPP as well as future groundwater resources management initiatives will require new tools for optimally balancing monitoring costs and data uncertainty.   This is particularly important when monitoring groundwater for pollutants such as volatile organic chemicals, pesticides, and other expensive analytes over very long time periods. Nationally, ASCE (Task Committee on Long-Term Groundwater Monitoring Design 2003) highlights that projected federal expenditures on long-term groundwater monitoring for the decade beginning in the year 2000 will be more than $5 billion (Task Committee on Long-Term Groundwater Monitoring Design 2003).

Notice in Figure (1) that there has been a phased or "adaptive" addition of monitoring stations over the past fifty years as societal and scientific needs placed a greater emphasis on monitoring PA's groundwater resources. The figure also illustrates a shifting emphasis toward spatially distributed, real-time monitoring technologies. Two fundamental questions had to be considered with the addition of each new monitoring station in the network shown in Figure (1):

1. Is the cost of the proposed station justified by value of information it will contribute?
2. Where should the proposed monitoring station be located and at what frequency should sampling occur to maximize the information gained?

The goal of this proposed research is to aid monitoring stakeholders in answering these questions by developing a decision support framework for designing cost-effective long-term groundwater monitoring (LTM) networks. The long-term goal of this research is to provide the first *adaptive observation system* design paradigm that will enhance hydrologic scientists' abilities to (1) balance multiple design objectives while characterizing complex groundwater systems across space-and-time, (2) merge physical model predictions with a broad range of data sources (e.g., indicator contaminant samples, expert knowledge, real-time data series), (3) consider a much broader range of model and data uncertainties, and (4) adapt their objectives and system design to account for advances in real-time sensing.

STATEMENT OF RESULTS OR BENEFITS.

The expected outcome of this proposed research will be a new monitoring design framework that will enhance our ability to cost-effectively characterize the quantity, quality, and susceptibility of groundwater resources within Pennsylvania and throughout the United States. The multiobjective decision support tools will provide stakeholders and policy makers with a better understanding of the value of adding monitoring points into existing networks and allow them to exploit a broader array of information sources. This project is expected to generate the following deliverables: (1) Monitoring Design Software Library, (2) Journal Publications, and (3) Conference Publications. The software tools have a general applicability across scientific disciplines, ensuring that they can be used to optimize large-scale investments into a broad array of environmental observation systems (e.g., the CLEANER, CUAHSI, or NEON initiatives).

NATURE, SCOPE, AND OBJECTIVES.

The goal of this proposed research is to develop a decision support framework for designing cost-effective long-term groundwater monitoring (LTM) networks. The monitoring framework allows hydrologic scientists' to balance multiple design objectives while characterizing complex groundwater systems and adapt their objectives and system design to account for advances in real-time sensing. The objectives of this research are to:

- Initiate the Real-Time Hydrologic Monitoring Network in the Shale Hills experimental watershed.
- Develop, assess, and extend decision support tools for long-term groundwater monitoring network design.

The monitoring framework couples multiobjective optimization with the geostatistical visualization and uncertainty modeling to inform cost-benefit analysis for sensor investments. This research has yielded robust monitoring design tools that have been shown to be superior to existing tools. Additionally, computational scaling studies have shown that the framework can be used to reduce growth of computational demands from being quadratic with increasing network design problem sizes to linear, making it feasible to solve large-scale spatiotemporal monitoring problems.

Ongoing extensions of this work will utilize the multiobjective design framework to adaptively

design a real-time groundwater monitoring campaign within the Shale Hills experimental watershed. The Shale Hills 19.8 acre experimental watershed was established in the 1970's by the Forest Hydrology group at Penn State to experimentally determine the physical mechanisms of streamflow generation for an upland forested catchment and to evaluate the effects of antecedent soil moisture on storm flow volume and timing. Historical and current research at the site will provide the opportunity to demonstrate our methodology for the two scenarios discussed below:

> Scenario 1: An extensive monitoring network exists and the framework will be used to analyze the value of existing and proposed monitoring stations in reducing site uncertainties.

> Scenario 2: Given fixed funds and a new experimental site, the framework will be used to identify the locations, sampling rates, and observation technologies for new monitoring stations. Note this will be part of a long-term research effort that extends beyond the time frame of this proposal.

METHODS, PROCEDURES, AND FACILITIES.

The objectives of this proposed research will be addressed using the two research tasks:

> Task 1: Develop the monitoring framework.
> Task 2: Demonstrate the monitoring framework at the Shale Hills experimental watershed located in north central PA within the Valley and Ridge Province of the Susquehanna River Basin (task ongoing beyond the time allocated for this project)

Detailed descriptions of these tasks and the methods that will be employed in this research are provided below.

Task 1: Develop the monitoring framework.

The purpose of this task is to couple the optimization capabilities of the NSGA-II with the advanced geostatistical mapping and uncertainty modeling. The NSGA-II and the mapping library, in combination, will help hydrologic scientists to (1) balance multiple design objectives while characterizing complex groundwater systems across space-and-time, (2) merge physical model predictions with a broad range of data sources (e.g., indicator contaminant samples, expert knowledge, real-time data series), (3) consider a much broader range of model and data uncertainties, and (4) adapt their objectives and system design to account for advances in real-time sensing. A brief background for evolutionary multiobjective optimization methods are given below to justify our proposed methodology. The NSGA-II will potentially evaluate thousands of sampling strategies using the enhanced geostatistical estimation routines to determine the optimal tradeoffs for an application; therefore this as part of this task we will ensure that our software estimation routines are highly robust.

Background on Evolutionary Multiobjective Optimization

Within the monitoring framework, multiobjective genetic algorithms will be used to search for optimal LTM tradeoffs similar to the tradeoff in Figure (2). Genetic algorithms' population-based search enables them to efficiently evolve entire design tradeoffs for nonlinear, discrete problems with huge decision spaces (Back et al. 2000; Goldberg 1989; Salomon 1998). This is particularly relevant for LTM design since the problem is discrete and the total number of possible monitoring designs (i.e., the decision space) grows according to the function 2^n where n is the number of potential samples in space-and-time. For a simple spatial monitoring network design, choosing one new sampling point from 30 potential monitoring sites will yield more than 1,000,000,000 (or 2^{30}) possible designs. Reed and Minsker (Reed and Minsker 2004) have specifically shown these solution methods have significant promise for LTM design. Schaffer (Schaffer 1984) developed one of the first evolutionary multiobjective optimization (EMO) algorithms termed the vector evaluated genetic algorithm (VEGA), which was designed to search decision spaces for the optimal tradeoffs among a vector of objectives. Subsequent innovations in EMO have resulted in a rapidly growing field with a variety of solution methods that have been used successfully in a wide range of applications (as reviewed by (Coello Coello et al. 2002; Deb 2001; Fonseca and Fleming 1995; Van Veldhuizen 1999)). These solution methods have garnered increased attention over the past decade and have been applied successfully in a variety of water resources and environmental applications (Cieniawski et al. 1995; Erickson et al. 2002; Halhal et al. 1997; Horn and Nafpliotis 1993; Loughlin et al. 2000; Reed and Minsker 2004; Reed et al. 2001; Ritzel et al. 1994).

Task 2: Demonstrate the monitoring framework at the Shale Hills experimental watershed located in north central PA within the Valley and Ridge Province of the Susquehanna River Basin.

The monitoring framework's design capabilities will be tested at the Shale Hills experimental watershed. The test case will be used to carefully validate the monitoring framework's effectiveness relative to current design methods and justify broad dissemination of its software tools. The Shale Hills 19.8 acre experimental watershed was established in the 1970's by the Forest Hydrology group at Penn State to experimentally determine the physical mechanisms of streamflow generation for an upland forested catchment and to evaluate the effects of antecedent soil moisture on storm flow volume and timing. The experiment consisted of a comprehensive network of piezometers, neutron access tubes, and 4 weirs. A spray irrigation network was installed to apply a controllable amount of rainfall over all or part of the entire watershed. The data collected have been used for many years for teaching and research.

Shale Hills will provide an excellent test bed for the monitoring framework because of the historical research infrastructure illustrated in Figure (2) and current instrumentation initiatives. Historical and current research at the site will provide the opportunity to demonstrate our methodology for the two scenarios discussed below:

> Scenario 1: An extensive monitoring network exists and the framework will be used to analyze the value of existing and proposed monitoring stations in reducing site uncertainties.

Scenario 2: Given fixed funds and a new experimental site, the framework will be used to identify the locations, sampling rates, and observation technologies for new monitoring stations. Note this will be part of a long-term research effort that extends beyond the time frame of this proposal.
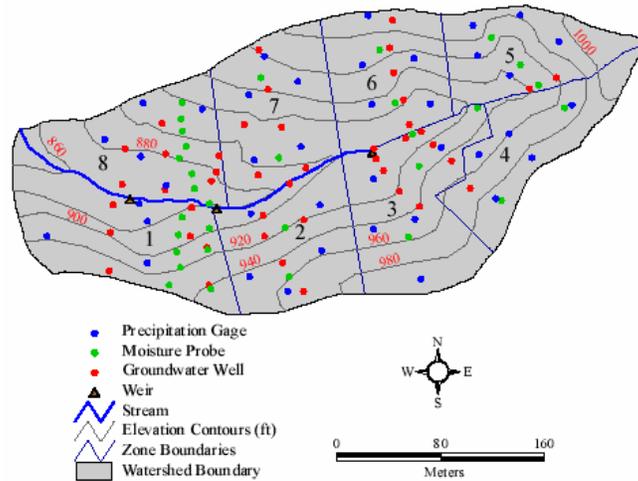

Figure 2: Illustration of the historical research infrastructure used to monitor the Shale Hills Experimental Watershed (Courtesy of Chris Duffy, Penn State University).

The scenarios discussed above are representative of the types of problems practitioners will face when seeking to improve PA's long-term groundwater monitoring systems. For Scenario 1, we will evolve Cost—Uncertainty tradeoffs using historical data from the 40 groundwater monitoring wells [see Figure (2)] used to initially characterize the Shale Hills site. As part of this research, we will analyze the impact of data uncertainty, the value of physical models, and the value of alternative sampling technologies (e.g., real-time versus synoptic sampling). For Scenario 2, the framework will synergistically support current efforts (i.e., Reed, Duffy, and Helly NSF/EAR-0418798, 2005-2007) to develop long-term monitoring infrastructure in several sites within the Shavers Creek watershed, which includes Shale Hills. This research will test the framework's ability to find solutions that maximize the value of fixed annual investments in new groundwater monitoring stations. In Scenario 2, Cost—Uncertainty tradeoffs will arise when selecting a subset of proposed observation sites while considering cost constraints and alternative monitoring technologies (i.e., manual sampling, pressure transducers connected to data loggers, or wireless sampling with internet-based data access). This research task will exploit the NSF-supported research of Duffy and Reed (Duffy and Reed 2004), in which a Monte Carlo physics-based groundwater simulation is currently being developed for the Shale Hills site. This task is part of a long-term monitoring effort that will continue well beyond the scope of this funded project.

PRINCIPAL FINDINGS AND SIGNIFICANCE.

The goal of this proposed research is to develop a decision support framework for designing cost-effective long-term monitoring (LTM) networks. The monitoring framework allows

hydrologic scientists' to balance multiple design objectives while characterizing complex water resources systems and adapt their objectives and system design to account for advances in real-time sensing. The objectives of this research are to:

1. Initiate the Real-Time Hydrologic Monitoring Network (RTH_Net) in the Shale Hills experimental watershed.
2. Develop, assess, and extend decision support tools for long-term monitoring network design.

The monitoring framework couples multiobjective optimization with the geostatistical visualization and uncertainty modeling to inform cost-benefit analysis for sensor investments. This research has yielded robust multiobjective monitoring design tools that have been shown to be superior to existing tools. Computational scaling studies have shown that the framework can be used to reduce growth of computational demands from being quadratic with increasing network design problem sizes to linear. Additionally, the multiobjective network design tools can be used effectively on parallel computing platforms. Advances in this project have substantially enhanced the computational tractability of solving large-scale spatiotemporal monitoring problems. The multiobjective decision support tools developed in this research have also been used to calibrate an integrated hydrologic model of the Shale Hills experimental watershed.

The hydrologic modeling tools developed for the Shale Hills have been used to initiate long-term adaptive monitoring within the RTH_Net experiment (http://www.engr.psu.edu/rth_net/). The goal of the RTH_NET adaptive monitoring experiment is to promote multidisciplinary environmental research into the optimal design of real-time sensor systems that are capable of characterizing coupled processes (e.g. atmosphere, soil, groundwater, and streams) and improving predictions of hydrologic response. Support from the Pennsylvania Water Resources Center has aided in garnering additional support from the National Science Foundation to extend the experimental and theoretical scope of the RTH_Net experiment.

The monitoring design concepts developed in this project and extended in the long-term RTH_Net experiment will be used to develop river-basin scale observatory network design tools, with a specific emphasis on the Susquehanna River Basin and Chesapeake Bay (http://www.srbhos.psu.edu/default.asp). Ongoing work will develop statistical simulation-optimization network design frameworks formulated for multiples scales and processes that will be capable of conditioning model-based predictions on real-time observations.

STUDENTS SUPPORTED.

Joshua Kollat, Civil and Environmental Engineering, Master Degree.

PRESENTATIONS AND OTHER INFORMATION TRANSFER ACTIVITIES.

Reed, P. M. and Kollat, J. B., "Comparison of State-of-the-Art Multi-Objective Evolutionary Algorithms for Long-Term Monitoring Design." Fall 2005 Meeting of the American Geophysical Union, San Francisco, California, December 2005.

Kollat, J. B., Tang, Yong, and Reed, P. M., "Tools for Comparing Evolutionary Multiobjective Optimization Algorithms." In Proceedings of the ASCE World Water and Environmental Resources Congress, Anchorage, Alaska, May 2005.

Kollat, J. B., and Reed, P. M., "Comparison of Multi-Objective Evolutionary Algorithms for Long-Term Monitoring Design." In Proceedings of the ASCE World Water and Environmental Resources Congress, Anchorage, Alaska, May 2005.

Award No. 05HQAG0076 Soil Carbon Sequestration in Drylands

Basic Information

Title:	Award No. 05HQAG0076 Soil Carbon Sequestration in Drylands
Project Number:	2005PA67S
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	5th
Research Category:	Not Applicable
Focus Category:	Management and Planning, Law, Institutions, and Policy, Agriculture
Descriptors:	arid-zone farming, land-use change
Principal Investigators:	Petra Stchakert

Publication

1. Manuscripts for publication will be developed after the synthesis workshop in Accra, Ghana, in August 2006.

TITLE: Soil Carbon Sequestration in Drylands

ABSTRACT:
Community-based resource management and land rehabilitation programs through carbon offset activities have been promoted to restore degraded drylands and improve the livelihoods of the rural poor. However, smallholders often face considerable constraints that reduce adoption rates. There exists very little systematic research on carbon stocks and trends in relation to land use and land cover changes as well as livelihood needs in Africa. A holistic assessment is needed to simultaneously evaluate the biophysical, socio-economic, institutional and policy context for long-term carbon sequestration programs in drylands. This project provides detailed and experienced scientific input and capacity building in collaboration with researchers from Mali, Niger, Burkina Faso, and Ghana with respect to 5 key areas: 1) assessment of land use and land cover change based on a series of remotely sensed images and estimation of biomass for different land use/land cover classes; 2) soil and biomass carbon estimates and measurements in selected focus areas; 3) socio-economic and institutional assessment of management practices, technical knowledge, and adaptive capacity at the household and community level in selected focus areas; 4) biogeochemical modeling and evaluation of "best" management practices for water-constrained environments; and 5) capacity building, technical training, networking, and information exchange among all participants.

STATEMENT OF CRITICAL NEED:
Drylands cover nearly 40% of the world's land area and are home to over two million people (FAO, 2000). Dryland environments are characterized by a unique set of features that influence the biogeochemical potential for carbon sequestration. By definition, drylands are limited in their water supply, low and highly variable precipitation, and recurrent droughts. In addition, these water constraints are often accompanied by the occurrence of high temperatures at some points throughout the year. Thus, this generic deficiency of water severely constraints plant productivity that is the major driver for carbon sequestration. Most drylands contain very low quantities of soil carbon, usually ranging from 0.2% to less than 1% (Lal, 2002). Nevertheless, drylands have been supporting human populations for thousands of years. Today, an estimated one billion people depend on rural drylands for their livelihood, relying on rainfed and irrigated agriculture, livestock production, and forest/woodland products. People have adopted a diverse set of coping mechanisms to adapt to their risk-prone environment and, thus, spread and reduce risks.

However, due to increased human pressure on marginal lands and fragile resources in combination with persistent poverty among many dryland countries, particularly in the Sahel, traditional coping mechanisms are no longer sufficient to adapt to new and more severe risks and shocks, including climate change. Unsustainable land use and management practices together with ill conceived policies and weak structures of environmental governance, dryland degradation has reached alarming dimensions. To date, 70% of the world's drylands are affected by desertification. As a result, soil carbon has decreased significantly from an initially low base. In Senegal, for instance, estimated C losses over the last 35 years amounted to roughly 300 million tons (Woomer et al., 2004) or 71% since the beginning of agricultural activities in 1800 (Tschakert et al., 2004). On the other hand, due to longer residence times of C in dryland soils (Gifford et al., 1992) and the fact that many soils have been degraded, drylands may well have a significant potential to sequester carbon (Rosenberg et al., 1999).

Community-based resource management and land rehabilitation programs through carbon offset activities have been promoted to restore degraded drylands and improve the livelihoods of the rural poor. Afforestation and prolonged fallow periods in drylands, encouraged through increased water use during photosynthesis under elevated CO_2 concentrations as well as no- or reduced tillage which also prevents water losses have been put forward as most efficient land use and management practices. However, smallholders often face considerable constraints that reduce adoption rates. A holistic assessment is needed to simultaneously evaluate the biophysical, socio-economic, institutional and policy context for long-term carbon sequestration programs in drylands.

STATEMENT OF RESULTS OF BENEFITS:
The aim of this project is to provide detailed and experienced scientific input into a new initiative on carbon sequestration (Spatially Explicit Modeling of Soil Organic Carbon, "SEMSOC") in four West-

African countries (Mali, Niger, Burkina Faso, and Ghana). SEMSOC, funded by USAID, is the expansion of a pilot study conducted in Senegal from 2000 to 2003. The project assists the partner institutions in carrying out the various identified project activities, organize training workshops, support field work, facilitate the publication of research results, and assist the overall operation of national carbon teams. The results of this project will benefit the collaborating institutions to contribute to mitigation and adaptation research and gain relevant understanding for the mainstreaming of climate change into national development priorities

NATURE, SCOPE AND OBJECTIVES:
Based on initial planning workshops, held with national experts in all four countries in January 2005, national work plans have been developed that encompass 5 key areas: 1) assessment of land use and land cover change based on a series of remotely sensed images and estimation of biomass for different land use/land cover classes; 2) soil and biomass carbon estimates and measurements in selected focus areas; 3) socio-economic and institutional assessment of management practices, technical knowledge, and adaptive capacity at the household and community level in selected focus areas; 4) biogeochemical modeling and evaluation of "best" management practices for water-constrained environments; and 5) capacity building, technical training, networking, and information exchange among all participants. The overall objective of SEMSOC is to explore conceptual and empirical approaches to link climate change mitigation research and activities related to terrestrial carbon management with observed adaptation trajectories of rural populations which can serve as a base line for evaluating potential adaptive capacity under more stressful climatic, demographic, and economic conditions. The results from the study are envisioned to help the four countries to position themselves more efficiently in the international climate change debate and in the emerging market of environmental service provision through improved land use and management.

METHODS, PROCEDURES AND FACILITIES:

1) Selection of study sites:
All four countries have selected two or three study sites for detailed work with respect to tasks 1-4. The main criteria for selection were "hotspots" of either vegetation improvement or degradation, different agro-ecological zones, different farming systems, and possibly different ethnic groups. The sites are as follows:
   - Ghana: Ejura-Sekyedumase District (severely degraded) and Assin District (fairly well managed)
   - Mali: three pairs of sites in a N-S transect (Alasso, Tiende, Kaniko, Trie, Missira, N'Dokan)
   - Niger: Koure with 3 specific sites: Dallol (ancient river bed, high population pressure, poor soil), Zigui (the area of the giraffes, open savanna), and Niger river area (with rain-fed agriculture and irrigated agriculture)
   - Burkina Faso: Koumbia/Houndé in the Sudanian zone; Nouaho/Boulgou in the Sahel-Sudanian zone; and Kaya/Binogo in the Sahelian zone
2) Literature review on the study sites (climate, soils, hydrology, vegetation, land use;
3) Land use/land cover analysis using a series of remotely sensed imagery from the 1970s to 2002, including LandSat and SPOT; this part is executed in close collaboration with the SOCSAB project (EDC/USGS) and includes training workshops through AGRHYMET in Niamey, Niger;
4) Soil and biomass measurements: soil and biomass samples at study sites to complete existing national or regional data; the methods to be followed involve tree measurements (DBH), understory and litter sampling, and soil and bulk density samples at 2 soil depths; C analysis is performed following Walkley&Black;
5) Socio-economic and adaptation assessments:
   Reconnaissance visits and in-depth visits to selected communities within the identified study areas are undertaken; assessments involve a combination of community discussions, mapping activities, and household-level questionnaires; particular emphasis is put on land use and management strategies, livelihoods activities and major risks perceived and experienced in relation to climate change and other stressors;
6) C modeling:

The goal for 2005 is to get familiar with the model and practice with preliminary data. A collective modeling workshop is scheduled for early summer 2006;

7) <u>Information sharing and networking:</u>
   Set up of national project web sites and communications channels (listserv), depending on the technical infrastructure.

<u>Facilities and country partners:</u>
- Ghana: EPA Ghana in Accra and University of Ghana in Legon
- Mali: Institut d'Economie Rurale (IER) in Bamako
- Niger: Institut National de Recherches Agronomiques du Niger (INRAN) in Niamey
- Burkina Faso : Institut National de l'Environnement et de Recherches Agricoles (INERA) in Ouagadougou

PRINCIPAL FINDINGS AND SIGNIFICANCE

All four countries have started to compile data and carry out their data collection in the individual study sites. Between July 2005 (when the first funds were transferred from EDC/USGS to the partner countries) to February 2006, all activities were ongoing. Preliminary results on the C stocks and socio-economic drivers of land use/land cover change are presented for Ghana only since Ghana was the first country to receive funding and, therefore, is ahead of the other teams.

Soil organic carbon content
Soil carbon in the Awura forest reserve was consistently lower than those in the Kakum forest. This may be due to the occurrence of annual bush fires that sweep the Awura forest. In all soils, organic carbon content of the surface soils (0-20 cm) was higher than those in the 20-40 cm depths. In the Awura forest reserve, total C ranged from 2.292 to 4.778 t/ha with more soil C in Compartment 7 than in that of 72. This may be due to *Chromolaena odorata* undergrowth common in Compartment 7. This plant species is known to produce large biomass wherever it is found. On the degraded soils adjacent to the Awura forest. Carbon stock ranged from 4.834 to 6.510 t/ha. The higher soil C in the degraded soils may be attributed to belowground biomass contributed by roots. Grasses tend to have greater root turnover than forest trees in the soils. The Kakum forest site had soil C stock ranging from 7.101 to 13.753 t/ha compared to the degraded soils in the area. The total C stock in the degraded soil was between 5.986 to 6.618 t/ha.

Biomass carbon content
The preliminary results indicated that in the Awura forest reserve the total C stock in biomass was 191.31kg C/ha whereas in the Kakum forest reserve it was 270.87 kgC/ha. Most of the C was obtained from the woody species. The difference in C stock in the two forest reserves may be attributed to annual bush fires which do not occur in the Kakum forest and therefore there was carbon build up in that reserve compared to the Awura forest which experiences annual bush fires. In the degraded areas the total C stock amounted to only 8.20 kgC/ha in the Awura degraded sites and 14.98 kg/ha in the Kakum site. It is clear from the results that clearing and cultivation reduced the C stock significantly over the years in the degraded soils.

Socio-economic Assesment (Ejura-Sekyedumase District, 3 sites)

Ejura-Sekyedumase District
The district is located within the transitional zone of the semi-deciduous forest and the Guinea Savanna zones. It therefore experiences both the forest and savannah climatic conditions and vegetation cover. The district has a wide diversity of ethnicity and its economy is largely agrarian with about 60% of the population engaged in farming. The district is endowed with a number of natural resources including three forest reserves which occupies a total area of 92.7km^2. Land use in the district for the past 3 years has been mainly for food and tree crop production, charcoal production and afforestation mostly Teak. Current programs exist in the district that encourages afforestation. These programs support private developers and companies in the form of credit and technical

support. About 62% of the households within the Ejura-Sekyedumase district live below the poverty line with 21% within the hard core zone.

Based on these divisions, the different soil associations and land use, Awura forest reserve and areas where production has declined for the past decade the following communities were selected for detailed surveys; *Nyamebekyere* (North West) *Babaso* (middle) and *Anyinasu* (south).

Activities that cause degradation
- Annual bush fires
- Charcoal production
- Group hunting
- Opening of new lands for farming activities and firewood
- Illegal logging
- Slash and burn method of land preparation
- Mechanized farming (tractor plough)
- Farming practice (shifting cultivation, and short fallow periods)
- Over grazing by cattle

Activities that minimize land degradation
- Land management practice which reduces land degradation is minimum tillage and this is being demonstrated as a sustainable practice for farmers.
- Improvement of tractor operations.
- Alternate livelihood for game group hunters who hunt with fire and normally set the forest on fire – domestication of grass cutters.
- Sustainable forest management practices –Taungya system

Drivers of land use / land management
- Marketability /marketing policy
- Income or prices of commodities / fast source of income
- Cultural and social acceptability / perception /attitudes
- Poverty levels of household / community
- Population increases / migration
- Household size and labor
- Capital –grants support from NGOs; linking farmers to credit source.
- Indigenous technical knowledge
- Land tenure system
- Size of land / number of farms per household
- Soil types and agricultural productivity
- Increase demand for agricultural, land and forest resources
- Fluctuations in annual rainfall and temperature / climate change

STUDENTS SUPPORTED (name, major, degree)

- Amadou Moctar Dieye, Geography and GIScience, South Dakota State University, PhD (Major collaborator on the project, supported for travel and training workshops in West Africa)
- Ryan Updike, History, Pennsylvania State University, BA (undergraduate research assistant for P. Tschakert)

PRESENTATIONS AND OTHER INFORMATION TRANSFER ACTIVITIES

- Petra Tschakert and Larry Tieszen (EDC/USGS) participated in UNCCD CRIC-3 meeting in Bonn, Germany (May, 2005) and organized the side event "Integrated 'Pro-Poor' Ecosystem Service Provision in Dryland Africa: National Capacity Building and Project Implementation in Land Cover Assessment, Carbon Sequestration, and Adaptation to Climate Change";
- Petra Tschakert and Amadou Moctar Dieye, "Detection, Drivers, and Dynamics of LULCC in the Sahel: Linking Scientist with Local Decision-Makers", International Human Dimensions Programme Open Conference, Bonn, Germany, October 9-14, 2005;

- Petra Tschakert, "CDM and Equity: A Southern Perspective", Science Debate, University of Antwerp, Belgium, November 28, 2005;
- Workshops on participatory methods for climate change vulnerability and adaptation assessments, held by P. Tschakert in Bamako (Mali) and Accra (Ghana) in August 2005. Participants were the representatives from the socio-economic teams from each country;
- Workshop on land use/land cover analysis and spatially explicit C modeling with CENTURY/GEMS held by A.M. Dieye in Bamako (Mali) and P. Tschakert in Accra (Ghana) in August 2005. Participants were the members of the land/use land cover and the C modeling teams;
- In collaboration with Amadou Moctar Dieye (CSE), Tim Mendele (EDC) and Michelle Anthony (EDC), and myself, a SEMSOC web portal was designed, one in English (http://edcintl.cr.usgs.gov/SEMSOC/) and one in French (http://www.cse.sn/semsoc/); it has been regularly updated and contains important articles (pdf files) on C sequestration and climate change mitigation for drylands and the sub-humid tropics. The Ghana team has set up it's own site to make results available to the general public (http://www.epa.gov.gh/SEMSOC/index.html)
- Amadou Moctar Dieye and Petra Tschakert produced documented training materials (CENTURY/GEMS modeling, land cover change analysis, participatory methods for vulnerability/adaptation assessments) for follow-up and in-depth training workshops.

AWARDS
None.

Split-Flow Stormwater Demonstration and Feasibility Study

Basic Information

Title:	Split-Flow Stormwater Demonstration and Feasibility Study
Project Number:	2005PA69B
Start Date:	3/1/2004
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	5th of PA
Research Category:	Not Applicable
Focus Category:	Hydrology, Water Quantity, Water Quality
Descriptors:	None
Principal Investigators:	Stuart Patton Echols

Publication

1. None

PRINCIPAL FINDINGS AND SIGNIFICANCE - The first Split-Flow feasibility test facility was constructed in Port Matilda, PA and is being used to test the system's ability to replicate natural discharge from two 10,000sf undeveloped areas with two adjacent 10,000sf impervious areas equipped with Split-Flow systems. Control weirs combined with pressure transducers and flow depth meters are connected to the discharge points from the two Split-Flow systems and the two undeveloped areas. These instruments are collecting discharge flow rates, volumes, frequency and duration from both systems. Additional pressure transducers are measuring water storage volume in the infiltration chambers and the bio-retention systems. Data from this feasibility test will be used to refine the Split-Flow system for use in future applications where it can be used to recreate preexisting evapotranspiration, infiltration and discharge levels and demonstrate how Split-Flow systems can be distributed throughout a typical development site to manage groundwater recharge; runoff levels and control first flush contaminates from parking lots and other impervious surfaces.

STUDENTS SUPPORTED (name, major, degree) - None at this time.

PRESENTATIONS AND OTHER INFORMATION (please note these are not from this year)

Echols, S. 2005 , "Split Flow Drainage Systems," Invited presentation at the New Jersey American Society of Landscape Architects Annual Conference, February 7, 2005.

TRANSFER ACTIVITIES - None at this time

AWARDS - None at this time

Information Transfer Program

Private Water System Education and Outreach

Basic Information

Title:	Private Water System Education and Outreach
Project Number:	2005PA45B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	5th
Research Category:	Water Quality
Focus Category:	Water Quality, Groundwater, Treatment
Descriptors:	private water system, private well, spring, cistern, water quality, conservation, water treatment, wellhead protection, drinking water standards
Principal Investigators:	William E. Sharpe, Stephanie S. Clemens, Bryan Reed Swistock

Publication

1. Clemens, Stephanie, Bryan Swistock and William Sharpe. 2006 (submitted). The Master Well Owner Network: Volunteers Educating Pennsylvania Well Owners, Journal of Extension.

PRINCIPAL FINDINGS AND SIGNIFICANCE

Satellite Program
A 1.5 hour Safe Drinking Water satellite program was delivered on May 3, 2005 to 25 downlink sites around the state. The program was presented by Penn State water quality experts including Dr. William Sharpe, Bryan Swistock and Stephanie Clemens. This program included approximately 15 minutes of pre-recorded information at a well and spring site.

Forty-four Master Well Owner Network (MWON) volunteers helped to publicize and sponsor the program at the 25 downlink sites around the state. These volunteers attended the program and answered questions from homeowner attendees at each site. A total of 142 well owners attended the program at the 25 sites.

Evaluation from the satellite program indicated that 100% of attendees found the program good, very good or excellent. Nearly all (96%) indicated that they would take an action to better protect their drinking water as a result of attending the program.

130 videotape copies of the satellite program were distributed throughout the state to each county extension office, interested MWON volunteers and various water resources professionals. Volunteers and extension educators used the tape in programs for private well owners and the tapes were loaned to various interested homeowners. Overall, MWON volunteers educated 6,483 homeowners with private wells in fiscal year 2005 and the videotape was an important tool in this education. Another 29,252 homeowners were educated through newsletters, news articles, and TV interviews. A follow-up survey of homeowners that interacted with volunteers during fiscal year 2005 determined that 97% felt the interaction was beneficial, 92% learned at least one new idea for private water system management and 82% had taken an action to better protect their drinking water supply.

Master Well Owner Statewide Conference
A statewide conference of Master Well Owner volunteers was held on Saturday, September 24, 2005 at the Ramada Inn in State College, PA. This conference was intended to increase the capacity of trained volunteers by creating increased knowledge about recommended topics. The all-day conference included one hour presentations from various experts on the following topics:
- Effective Public Outreach
- Well Grouting
- Groundwater and Public Health
- Septic System Management

A Resource Session was also held to allow volunteers to observe equipment and displays and interact with experts related to water treatment, well drilling, groundwater flow models and general water quality questions.

A total of 68 MWON volunteers from 33 counties attended the conference. Seventy-one percent rated the conference as excellent and 29% rated it very good. All presentations at the conference were rated as very helpful by 63 to 95% of attendees. All attendees indicated that they would like the conference repeated annually.

STUDENTS SUPPORTED (name, major, degree)
Leonard McNeal, Environmental Pollution Control, M.S., Summer 2005

PRESENTATIONS AND OTHER INFORMATION TRANSFER ACTIVITIES
- Master Well Owner Network volunteer training workshop, Northwest Region, March 5, 2005, Franklin, PA.
- Master Well Owner Network volunteer training workshop, Susquehanna Region, April 2, 2005, Williamsport, PA.
- Safe Drinking Water Clinic, Statewide Satellite Program, May 3, 2005, 25 downlink sites at extension locations.
- Update on Master Well Owner Network, Pennsylvania Groundwater Association, Summer Field Conference, June 10, 2005, Rock Springs, PA.
- Master Well Owner Network Statewide Conference, September 24, 2005, Ramada Inn, State College, PA.
- Private Water System Management and Master Well Owner Network. December 7, 2005, PA Geologists Meeting, Indiana, PA.
- Master Well Owner Expansion into the Delmarva Peninsula, Mid-Atlantic Regional Water Program, December 9, 2005, University of Maryland Eastern Shore.
- Educating Rural Homeowners in Pennsylvania, One Well at a Time (Poster Presentation), National Ground Water Association, 2005 Annual Conference, December 13-14, 2006, Cobb County, Georgia
- The Master Well Owner Network: Working with PGWA to Educate Rural Homeowners, Pennsylvania Ground Water Association, 2006 Winter Conference, January 26, 2006, Grantsville, PA.
- The Master Well Owner Network: Educating Rural Homeowners One Well at a Time, USDA 2006 National Water Quality Conference, February 5 9, 2006, San Antonio, TX.
- Master Well Owner Network Regional Coordinators training, February 17, 2006, State College, PA.

AWARDS
- National Ground Water Association, 2005 Ground Water Protection Award (outstanding science, engineering, or innovation in the area of protecting ground water). Presented at National Ground Water Expo, Cobb County, Georgia, December 2005.
- Pennsylvania Ground Water Association, 2005 award in appreciation of support to PGWA.

Student Support

Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	4	0	0	0	4
Masters	5	0	0	0	5
Ph.D.	2	0	0	0	2
Post-Doc.	0	0	0	0	0
Total	11	0	0	0	11

Notable Awards and Achievements

Several awards were received during 2005 that were related to research supported by the PA Water Resources Research Center.

Project 2005PA45B-Bryan Swistock, Stephanie Clemens, and Bill Sharpe at Penn State won an award for the OUTSTANDING SCIENCE, ENGINEERING OR INNOVATION FOR GROUNDWATER PROTECTION from the National Ground Water Association as well as a certificate of appreciation from the Pennsylvania Ground Water Association for their work with the Master Well Owner Network.

Project 2005PA42B-Kristen Jellison at Lehigh University received two grants from the PA Department of Community and Economic Development in support of her research on source water protection from infectious Cyrptosporia.

Project 2005PA40B-Anthony Buda a PhD candidate won first place in the 2006 Environmental Chemistry Student Symposium at Penn State for his oral presentation about tracing sources of stream nitrate using isotopic, microbial and inorganic chemical tracers.

Publications from Prior Projects

1. 2004PA30B ("Nitrogen dynamics in the Spring Creek watershed (Pennsylvania, USA): Evaluating stream retention of point and non-point source loadings") - Articles in Refereed Scientific Journals - Carrick, H.J. 2005. Under-appreciated aspects of biodiversity in planktonic communities: The role o protozoa in Lake Michigan (A case study). Hydrobiologia 551: 1-16. Invited.
2. 2004PA30B ("Nitrogen dynamics in the Spring Creek watershed (Pennsylvania, USA): Evaluating stream retention of point and non-point source loadings") - Articles in Refereed Scientific Journals - Carrick, H.J., J.B. Moon, and B.F. Gaylord. 2005. Phytoplankton dynamics and hypoxia in Lake Erie: Evidence for benthic-pelagic coupling in the central basin. Peer-revised and Accepted for Publication. J. Great Lakes Res. 31: 111-124, Invited.
3. 2004PA30B ("Nitrogen dynamics in the Spring Creek watershed (Pennsylvania, USA): Evaluating

stream retention of point and non-point source loadings") - Articles in Refereed Scientific Journals - Marchi, A.M., and, H.J. Carrick. 2005. Limnological variation in an urbanized lake system (California, USA): Developing trophic indices to predict algal blooming, Lake & Reservoir Management. 22: 33-43.

4. 2004PA30B ("Nitrogen dynamics in the Spring Creek watershed (Pennsylvania, USA): Evaluating stream retention of point and non-point source loadings") - Articles in Refereed Scientific Journals - Ostrom, N.E., H.J. Carrick, M. Twiss, and L. Piwinski. 2005. Evaluation of primary production in Lake Erie by multiple proxies. Oecologia. 144: 115-124.

5. 2004PA30B ("Nitrogen dynamics in the Spring Creek watershed (Pennsylvania, USA): Evaluating stream retention of point and non-point source loadings") - Articles in Refereed Scientific Journals - Ostrom, N.E., M.E. Russ, A. Field, L. Piwinski, M.R. Twiss , and H.J. Carrick. 2005. Ratios of community respiration to photosynthesis and rates of primary production in Lake Erie via oxygen isotopes techniques. Peer-revised and Accepted for Publication. J. Great Lakes Res. 31: 138-153, Invited.

6. 2004PA30B ("Nitrogen dynamics in the Spring Creek watershed (Pennsylvania, USA): Evaluating stream retention of point and non-point source loadings") - Other Publications - Moon, J.B., and H.J. Carrick. Seasonal succession of phytoplankton nutrient limitation in the central basin of Lake Erie. In review Canadian Journal if Fisheries and Aquatic Sciences.

7. 2000PA-03 ("The Use of Seasonal Oxygen-18 Variations in Modeling Shallow Groundwater Recharge") - Other Publications - Adams, M. B., D. R. DeWalle, and J. L. Hom (Eds.). 2006. The Fernow Watershed Acidification Study. Environmental Pollution, Vol. 11, Springer, 279 p.

8. 2000PA-03 ("The Use of Seasonal Oxygen-18 Variations in Modeling Shallow Groundwater Recharge") - Articles in Refereed Scientific Journals - O'Driscoll, M. A., D. R. DeWalle, K. J. McGuire, and W. J. Gburek. 2005. Seasonal ^{18}O variations and groundwater recharge for three landscape types in central Pennsylvania, USA. J. Hydrol. 303(1-4):108-124.

9. 2000PA-03 ("The Use of Seasonal Oxygen-18 Variations in Modeling Shallow Groundwater Recharge") - Book Chapters - Adams, M. B., D. R. DeWalle, and J. L. Hom (Eds.) 2006. The Fernow Watershed Acidification Study. Environmental Pollution, Vol. 11, Springer, 279 p.