

Penn State Institutes of the Environment

Annual Technical Report

FY 2004

Introduction

This report summarizes the water research and information transfer activities sponsored through the Pennsylvania Water Resources Research Center during FY 2004. The PA WRRC is located at Penn State University and receives funding from an annual base grant program and occasional grants awarded through a national competitive grants program. Priority in funding through the base grant program is given to projects that involve new and innovative research ideas, participation by undergraduate and graduate students with interests in water resources, new faculty in water resources programs, and to the extent possible, participation by faculty representing a wide range of educational institutions across the state. In addition, the Director of the PA WRRC is active in representing water resources interests in Pennsylvania at a variety of local, regional, and national meetings and events.

The research program report for FY 2004 summarizes work on four different research projects and one primarily technology transfer project which continue an emphasis on water quality problems in Pennsylvania from both point-source and non-point source pollutants. The projects are :

1. Controls on Nutrient Levels for Spruce Creek and a Major Tributary-Drs. Ryan Mathur, David Lehman, and Dennis Johnson, Juniata College, Huntingdon, PA;
2. Split-Flow Stormwater Demonstration and Feasibility Study-Dr. Stuart Echols, Landscape Architecture Department, Penn State University, University Park, PA;
3. Nutrient Removal of a Sequencing Batch Reactor (SBR) Treating Wastewater with Potential for Water Reclamation-Dr. Baikun Li, Department of Civil and Environmental Engineering, Penn State University-Harrisburg, Harrisburg, PA;
4. Nitrogen Dynamics in the Spring Creek Watershed (Pennsylvania, USA): Evaluating Stream Retention of Point and Non-Point Source Loadings-Dr. Hunter Carrick, School of Forest Resources, Penn State University, University Park, PA;
5. Spruce Creek Watershed Keystone Project-Professor Lysle Sherwin and Dr. C.A. Cole, Center for Watershed Stewardship and School of Forest Resources and Department of Landscape Architecture, Penn State University, University Park, PA.

Progress on each of these projects is described in detail later. Most are exploratory in nature and have been only underway for one year. Many investigators secure additional funding to continue the research and information transfer initiated with these PA WRRC grants.

Research Program

Controls on Nutrient Levels for Spruce Creek and a Major Tributary

Basic Information

Title:	Controls on Nutrient Levels for Spruce Creek and a Major Tributary
Project Number:	2004PA26B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	9th of PA
Research Category:	Water Quality
Focus Category:	Water Quality, Nutrients, None
Descriptors:	Spruce Creek, nutrient analysis, water quality
Principal Investigators:	David Lehmann, Dennis Johnson, Ryan Mathur

Publication

Abstract:

Spruce Creek, one of the premier trout fisheries in the state, economically bolsters an otherwise agricultural economy. Although both the tourism and agriculture industries are essential to the Spruce Creek watershed region's economy; agricultural land use, if not properly managed, does present potential environmental risks to the stream. In order to monitor the health of the stream, we conducted a baseline study focusing on nitrates and phosphates, total dissolved solids, pH, temperature, and discharge. The baseline water quality dataset for Spruce Creek will be used to understand the physical and chemical aspects of the stream so as to highlight conditions that lead to stream impairment. In this study, we utilize high frequency sampling and analysis (HFSA) techniques, as our previous work and recently published work of others indicates that HFSA leads to more accurate predictive models.

Two students will measure the nutrients (phosphorus and nitrogen), pH, total dissolved solids, turbidity, and temperature of the water and the discharge of the stream at ten sampling sites for ten consecutive weeks in the summer of 2004 and continue monitoring the stream at least twice a week throughout the 2004-2005 academic year. This study builds upon two consecutive years of HFSA we have completed in the watershed. Previous years included abnormally dry (2002) and abnormally wet (2003) springs and summers. Because there is very little overlap of conditions between these two years of data, a third year of data is needed to complete predictive models which we are designing. Few studies have examined stream chemistry with as much frequency over such a long duration of three years. This large dataset will clearly identify what 'normal' physical and chemical conditions versus abnormal conditions would be on the stream.

The objectives of the study are threefold:

1. Illustrate the influence of agricultural inputs to the stream: The dataset may quantify the effect of agricultural practices in the Spruce Creek watershed. The data will allow us to complete the development of a predictive model that will help avoid impairment of the stream's health. Additionally, the data will allow us to help engineer solutions to minimize agricultural influence upon the stream.
2. Provide research experience for undergraduates: The students involved in the experience will gain invaluable practical training in water quality assessment and collection of information.
3. Involve and spark interest in the local community: The dataset will be assessable to the community and presented at local meetings. The study will provide valuable information to a community that relies so heavily on the health of the stream.

Statement of Critical Need:

Spruce Creek is a well-known trout stream in south-central Pennsylvania. Outfitters, guide services, and eateries augment the economy in the Spruce Creek watershed. As such, the economic health of the village of Spruce Creek, which relies heavily upon tourist/recreation business, is intimately tied to the stream's health. This tourist business has seen declines a number of times over the past 20 years as fish kills affecting local waterways have occurred.

Nutrient loading has been the primary suspected cause of some of these fish kills. Furthermore, Spruce Creek is a major tributary to the Little Juniata River and part of the Juniata River drainage basin. This basin supplies water for residential and industrial use to a multi-county area, including three municipalities (Alexandria, Petersburg, and Huntingdon) less than 20 miles downstream of Spruce Creek. Increased understanding about influences upon water quality of Spruce Creek has significant economical, environmental, and societal value.

During the winter and spring of 2001, concerned citizens from Spruce Creek, PA approached a representative of the Geology Department from Juniata College (Huntingdon, PA) and asked for assistance in assessing water quality for Spruce Creek and collecting baseline water quality data for future assessments. Based upon this request, Geology faculty at Juniata College (Dr. Ryan Mathur and Dr. David Lehmann) investigated previous work and existing data for the stream. They talked with a wide variety of regulatory personnel and researchers including representatives from the PA DEP, PA Geologic Survey, and academic institutions. Although there was some data relating to macroinvertebrates for the stream, at that time there was no recent data on background levels of nutrients or seasonal variation of nutrients for Spruce Creek. All parties with whom the Geology Department checked indicated that they did not intend to examine nutrient levels on a regular basis. However, there was general agreement that this type of examination could prove valuable for recognizing and quantifying many forms of stream degradation and stream health. This background research was performed as a community service by Juniata College.

Because of their interest in and concern for local stream water quality, in May, 2001, faculty and students from Juniata College began rigorously studying the water quality of Spruce Creek, paying particular attention to phosphate and nitrate levels in conjunction with recording discharge, conductivity (an indirect measurement of total dissolved solids or TDS), temperature, turbidity, and pH. Funding for this initial work has come primarily from Juniata College, the Geologic Society of America (student grant), and local citizens from Spruce Creek. This has clearly been an example of academic/professional organization/municipal combined efforts.

Baseline data collected by the Geology Department is beginning to elucidate a better understanding of variable nutrient level patterns, localized areas of nutrient loading, and the interactions between stream flow dynamics and nutrient levels. Teeters and others (2002) presented these initial findings at the national Geological Society of America Conference at Denver, CO in October, 2002 and at a local meeting of the Colerain Rod and Gun Club. Because of the quality of initial results and positive feedback, the Geology Department supported two students for an expanded study of Spruce Creek during the summer and fall of 2003. In addition to collecting more data to understand baseline conditions of the stream, this continued investigation is leading to a better understanding of surface water and groundwater influences upon nutrient loading. Furthermore, a comparison of the summers of 2002 and 2003 is leading to a better understanding of how unusually dry (2002) and unusually wet (2003) seasons may influence water quality of Spruce Creek. An analysis of relationships between land use and nutrient loading, as well as a comparison/contrast of

nutrient loading during wet and dry seasons will be the topics of two professional papers that will be presented at conferences within the next six months.

Based upon the data that Juniata College has collected during the past year and a half, it is apparent that a more complete understanding of the stream's health would develop if we also had data from a major tributary of Spruce Creek. Ideally, sampling and measurements of Spruce Creek and the tributary should occur nearly synchronously. With two nearly synchronous datasets, we can begin to establish regional and seasonal patterns so as to be able to identify any events that deviate from the 'normal' conditions of the stream. By examining two streams, we can also collect better data to investigate how bedrock geology and land use may affect water quality. With this in mind, we propose to compare land use, bedrock geology, and water quality of the upper portion of Spruce Creek (above Warriors Mark Run) and Warriors Mark Run. These are ideal drainages to compare because they have similar hydrogeologic characteristics, flow through similar geologic units and combine to form the lower portion of Spruce Creek. The obvious difference between the two drainages is the surrounding land use patterns.

Statement of Results of Benefits:

In order to understand the general health of Spruce Creek, we will obtain baseline physical and chemical information for the upper portion of Spruce Creek and for Warriors Mark Run. These baseline data sets will highlight nutrient loading into the streams via surface or groundwater sources, seasonal discharge patterns, and turbidity fluctuations. Over the proposed study period (one year), we will collect a minimum of 120 data sets. Each data set will address water chemistry and stream hydrology for 10 sample locations (five per stream). Using these data sets, we will compare different measurements of water quality and stream characteristics by both date and sample location. We will use multivariate analysis to investigate relationships between nutrient levels, physical characteristics of stream water, and stream discharge. Additionally, we will investigate if local changes in nutrient levels or physical characteristics of stream water may be related to land use or bedrock geology.

In this project, we will utilize high frequency sampling and analysis (HFSA), collecting and analyzing data (including water chemistry data) between two and five times per week. Most previous studies of nutrients in streams have utilized more temporally spaced out data sets or have concentrated on specific events that researchers believe may be related to nutrient loading. Temporally-spaced data sets do not offer the resolution to identify stream response to nutrient loading, and based upon our preliminary data, may bypass significant loading events. Following some loading events, nutrient levels returned to pre-event levels within two to three days. To address our concerns regarding poor resolution of stream assessment based upon infrequent sampling, we developed HFSA. HFSA offers the benefit of identifying specific loading events without making assumptions about when and where those loading events will occur. Additionally, HFSA facilitates a more precise and complete picture of stream response to and recovery from loading events. Independent of our work, Harris and Hollabaugh (2003) found that an HFSA-like approach helped elucidate an

understanding of stream response to loading events that was not available through standard sampling techniques.

Preliminary data indicates that HFSA may allow differentiation of nutrient loading from springs and surface water. Immediately following some storm events, nutrient levels increase almost synchronously with discharge. This, we believe records nutrients delivered from runoff. In some cases, three to twelve days following the initial nutrient spikes, secondary—but equally significant—nutrient spikes occur. These may record spring influence. In light of karstic conditions and extremely complex hydrogeologic conditions for the area, HFSA offers a viable approach to start to differentiate potential roles of groundwater and runoff to nutrient loading.

We are presently seeking additional funds to use infrared technology to precisely locate springs in Spruce Creek and Warriors Mark Run to further investigate the role of groundwater in nutrient loading. This project proposed here would provide valuable background data to understand the timing of nutrient loading related to springs.

With a firm understanding of the patterns present in the chemical and physical datasets, we will be able to confidently identify anomalous or detrimental events to the ‘normal’ stream health. Integration of information from these datasets will lead to a clear evaluation of the overall stream health and to the development of an effective, efficient risk analysis model for Spruce Creek.

Nature, Scope and Objectives:

This proposal seeks funds to:

- Train students in HFSA field sampling, laboratory techniques, and water quality analysis. This is an ongoing process that has already begun. Training will be completed on or before June 1, 2004.
- Continue assessment of Spruce Creek drainage basin. This is an ongoing process that has already begun. We plan to continue this assessment through the grant period.
- Compare water quality dynamics between a major tributary of Spruce Creek and the upper portion of Spruce Creek. We have begun to collect data from both streams and plan to continue collecting data through the time-frame covered by this grant.
- Investigate the relationships between land use, bedrock geology and nutrient loading in these streams. We have begun analysis of nutrient loading and bedrock geology. We will begin investigation of land use immediately upon receiving notification of these funds.
- Develop a predictive risk analysis model for Spruce Creek that identifies conditions that create high risk for stream impairment and when and where those conditions occur. Model development is an ongoing process on which we are already working. However, a sophisticated model requires the data we would gather under this grant. We predict that we can begin to finalize our model by November 1st, 2004. Previous years’ data suggests that by October 1st, nutrient loading becomes much simpler and more predictable until the following spring. As a precaution, we would like to wait an additional month before starting to finalize our model.

- Provide background data to facilitate effective and efficient stream remediation in the event that Spruce Creek tributaries are negatively impacted at some time in the future. We have begun this process. At the request of citizens' group from Spruce Creek, we are presently preparing a response to a Chapter 71, PA DEP Public Comment request regarding development in the watershed. We plan to provide data as requested. Additionally, we are presently collaborating with the USGS to identify the best way to make data accessible to interested parties. We have also communicated with other groups examining portions of the Spruce Creek watershed and with State and regional interested groups. We will make data intranet or e-mail accessible within one month of receiving notification of this grant.
- Based upon our risk analysis and present land use, identify and propose best management practices to prevent impairment and improve stream quality. This is an ongoing process, but we will have a report prepared by November 1, 2004
- Provide communication about our findings to the Spruce Creek watershed community, regulatory agencies, and professionals working with similar watershed issues across the United States. This project will result in a minimum of two presentations at regional or national professional meetings, three public presentations to the community, and one journal publication during the grant period. We will prepare a final report that will define and interpret stream water quality and will present a water quality risk analysis model. This report will be provided to the granting agency and could also be available on-line.

Although not the primary goal of this specific project, Juniata College hopes to provide the technical expertise and labor to serve as an outreach to the south-central Pennsylvania community for protecting and enhancing local watersheds. This grant would support the development of our envisioned community—academic interactions.

Methods, Procedures and Facilities:

We propose that two appropriately trained Juniata College students (junior or senior standing with outstanding academic credentials and requisite upper level science courses) work ten forty-hour weeks as paid interns during the summer of 2004. These students along with four others will continue their research efforts throughout the semester as credit (unpaid) internships. Three professors will supervise students, assist in the field and lab to assure data quality, and oversee report preparation. The students will sample five locations along each of the streams. To ensure quality and reproducible results, careful and precise field and lab techniques are critical. Therefore, we intend to utilize only students who have demonstrated a high proficiency of requisite skills and an ability to excel at semi-independent work.

In order to accomplish the objectives stated above we will:

- 1) Measure pH, temperature, total dissolved solids, discharge, turbidity, nitrogen, and total phosphorous concentrations. To improve the efficiency of measuring discharge, we plan to install several stream gages that allow us to record depths of flow at specified intervals. A rating curve will be developed at these sites, thus allowing for determination of flows as well as depth. A hydrologic model (e.g. the U.S. Army Corps of Engineers HEC-HMS) will be calibrated for the flows and rainfall as obtained from a variety of sources such as the National Weather Service.

- 2) A GIS database will be developed that includes land use, topography, geology, and historical photographs (to name a few). The GIS will be used in conjunction with a GPS to verify land use and to locate site specific information such as springs and point source discharges.
- 3) Examine published topographic and geologic maps and confirm surface geology with outcrop exposure.
- 4) Present study updates and final outcomes at both public meetings to communities in and near the watershed and at professional conferences.

Juniata College has two fully stocked environmental geochemistry laboratories in Brumbaugh Science Center in which sample analysis will take place. Students working on this project will have an office, dedicated to their research project, with campus network accessibility in the Geology wing of Brumbaugh Science Center. To measure nutrient levels, we utilize HACH photospectrometry per state regulatory agency guidelines. To increase the precision of measuring extremely low levels of phosphates and to give us the capability of looking at other potential ions of concern, we are in the process of purchasing an ion chromatograph. Field equipment that will be available for this work includes a Global Water flow meter, HACH's highest quality pH, temperature, and conductivity meters (multiple sets to ensure no down time due to equipment failure), and ReelLogger equipment. Students will have access to a wide array of other modern scientific equipment, including TRIMBLE GPS units, a fluorimeter and GC and HPLC systems. By December, 2003 we will have an analytical SEM installed on campus, funded by a \$300,000 NSF grant to the Geology Department. The SEM may prove useful in imaging macroinvertebrates or other organisms that are included in bioassessments. This commitment to quality extends even to basic equipment. For example, if students working on this project require microscopes, they will have access to Leitz and Zeiss petrographic microscopes and Meiji's highest quality stereo-zoom microscopes.

The College maintains a fleet of vehicles that are available to use by students or faculty for research projects at modest charges. Extensive camping, sampling, and mapping equipment are available for this project if needed. Likewise, the College maintains a tool/machine shop in Brumbaugh Science Center so that we can build specialized equipment or customize stock equipment in-house. For data analysis, we have licenses for a wide variety of statistical and graphical software including Excel, MiniTab, SAS, Corel Draw, PowerPoint, and Adobe Illustrator. We have a color plotter on campus for preparing posters up to 42" wide.

Principal Findings and Significance:

Nutrient Transport: Typical sources of nitrates within stream water include septic tanks, leach pools, refuse dumps, animal feed lots, fertilizers, municipal and industrial wastewater, urban drainage, and decaying plant debris (NMENV). Within this particular watershed, the only possible sources are septic tanks, leach pools, animal feed lots, and fertilizers. Typical sources of phosphates within a stream system include animal wastes, fertilizers, sewage, detergents, and road salts used in winter (FOSC). For the Spruce Creek watershed, the possible sources include animal wastes, fertilizers, and sewage.

It is possible that the differences in nitrates and phosphates are due to different sources for the nutrients. The source of phosphates could be fertilizers, whereas the source of nitrates could be animal wastes. Another possible explanation is that nitrates and phosphates enter the stream system differently. Our data indicates that nitrates are present in the system regardless of discharge, but phosphates appear to enter most noticeably during increases in discharge. It is possible then that nitrates enter the system through groundwater inputs, whereas phosphates enter the system through overland flow.

Increases in nitrates and phosphates coinciding with increases in turbidity would suggest that the increased sediment load is likely responsible for the increases in nutrient concentrations. This sediment load likely contains many particles that have been recently washed from agricultural fields, like particles of fertilizer and animal waste. These particles, while not dissolved, will still add nitrates and phosphates to the stream system.

CAFO versus Traditional Agriculture: Even though nitrate concentrations are similar on Spruce Creek and Warrior's Mark Run, the total amount of nitrate in kilograms per day varies greatly between the two streams. The reason for this variation is that Spruce Creek, with its larger discharge, is able to dilute its total nitrate load to concentrations that are comparable to those on Warrior's Mark Run. This indicates that the agriculture along Spruce Creek is contributing a larger total nitrate load into the stream system than Warrior's Mark Run.

Seasonal Changes in Nitrate Concentration: Nitrate concentrations are higher during the spring and summer months than during the fall and winter months. Discharge rates do not dramatically increase or decrease during this transition which indicates that the drop in nitrate concentration is not associated with a change in discharge. This shift would signify that a major source of nitrate is removed from the stream system around the beginning of September. Farm owners typically stop/lessen the amount of fertilizer/manure that they spread on fields at the end of the growing season, which is typically around the start of September for this particular area. (NOTE: The growing season may end around the start of September, but fertilization continues well into October) This decrease in manure spreading coincides closely with the drop in nitrate concentrations in the Spruce Creek watershed indicating that the spreading of manure/fertilizer is the likely source of the nitrates.

Effects of Nutrient Input on Water Quality: Nitrate levels for ambient water should be 0.31 mg/L or less to ensure a healthy stream system (EPA, 2000). During the summers of 2002, 2003, and 2004, there was not a single nitrate concentration that was at or below this level.

Warrior's Mark Run: The headwaters of Warrior's Mark Run consistently contain a lower concentration of nitrate than its stream waters. This indicates that there is a significant source of nitrate directly downstream from the headwaters. Water interaction with bedrock in stream bottoms is very unlikely; the rock units that underlie the stream are typically limestone (Coburn, Loysburg, Axemann, Stonehenge, Warrior Run, and Pleasant Hill Formations) and dolomite (Bellfont, Nittany, and Gatesburg Formations), with an occasional shale (Reedsville and Juniata Formations) or sandstone unit (Bald Eagle and Juniata Formations). These rocks do not have the chemical makeup necessary to add such

significant concentrations of nitrate to the stream system. The likely source of this nitrate is from the surrounding agricultural land use.

Although there is no source of nitrates near the headwaters, there is a significant source of phosphates. This source could be the underlying bedrock, the Bald Eagle sandstone and conglomerate, which contains phosphatic minerals.

Undergraduate Students Supported:

Elizabeth A. Diesel, 2005, Bachelor of Science, Environmental Science and Studies/Geology
Evan Teeters, 2005, Bachelor of Science, Geology
Mathew Sauers, 2005, Bachelor of Science, Geology
Caitlan Zlatos, Current student, Environmental Science and Studies/Geology
Lori Hodel, Current student, Geology
Greg Pierotti, Current student, Geology
Dane Fischer, Current student, Geology
Allison Phillips, Current student, Geology
Melissa Wilson, Current student, Natural Sciences/Geology

Publications:

None, but Elizabeth A. Diesel is preparing an article for submission in fall 2005.

Presentations and Other Information Transfer Activities:

1. Presentation at the National Geological Society of America conference in Denver, Co on November 11 2004 by Elizabeth Diesel.
2. Presentation at the Geological Society of America conference in Reston, VA on April 14 2004 by Elizabeth Diesel.
3. Caitlan Zlatos presented project information at the Environmental Symposium at Penn State University in March 2004
4. Elizabeth Diesel also gave a presentation at Penn State in April 2005.
5. The information was also presented at the Juniata College research symposium in April 2004 and 2005 by Elizabeth Diesel and Melissa Wilson.
6. Results from the work were discussed with the community during meetings held in the town Warrior's Mark, PA during the spring of 2004 and winter of 2005.

Awards:

None

Split-Flow Stormwater Demonstration and Feasibility Study

Basic Information

Title:	Split-Flow Stormwater Demonstration and Feasibility Study
Project Number:	2004PA27B
Start Date:	3/1/2004
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	5th of PA
Research Category:	None
Focus Category:	Hydrology, Water Quantity, Water Quality
Descriptors:	None
Principal Investigators:	Stuart Patton Echols

Publication

1. Echols, S. 2004. Split-Flow LID Stormwater Strategy: How to Improve LID Design to Eliminate the Need for Detention Systems. Proceedings of the Putting the LID on Stormwater Management Conference, B.M. Rustia (ed.) Washington, DC: Metropolitan Washington Council of Governments. pp. 380-385.
2. Echols, S. 2004. Split-Flow Stormwater Strategy BMPs. Abstract in Proceedings, Southeast Regional Conference on Stormwater, Emerging Issues for Local Communities. April 19-22, 2004, Ashville, NC.
3. Echols, S. 2003. Introduction of a New Distributed Split-Flow Stormwater Design Strategy. Proceedings of the 2003 American Society of Landscape Architects Annual Meeting. J.M. Brown (ed.). Washington, DC: American Society of Landscape Architects. pp. 81-85, ISSN 10907432.
4. Echols, S. 2003. Implementing Stormwater Management through Split-Flow Drainage Design. Proceedings of the 2003 Pennsylvania Stormwater Management Symposium. R.G. Travel, Conference Chair, C. Emerson (ed.). Villanova University: Philadelphia, PA.
5. Echols, S. 2003 A New Split-Flow Sustainable Urban Drainage Strategy. Proceedings of the Second National Conference on Sustainable Drainage. C.J. Pratt, J.W. Davies, A.P. Newman and J.L. Perry (eds.). Coventry University: Coventry, UK. pp. 113-119, ISBN: 1903818273.
6. Echols, S. 2003. Developing Split-Flow Stormwater Systems. Proceedings of the US EPA National Conference on Urban Stormwater: Enhancing Programs at the Local Level. R.J. Kirschner (ed.). Cincinnati, OH: U.S. Environmental Protection. pp. 114-121, EPA/625/R-03/003.

Abstract:

Engineers, Planners, Water Resource Professionals, Local Government Officials and Land Development Professionals are expected to plan and regulate urban developments that protect and restore our natural ecosystems. However, every time we create a new impervious building, plaza, sidewalk or parking space, we increase runoff and degrade our aquatic environments. As a result of new federal regulations, thousands of municipal governments are now required to develop, adopt and implement stormwater management strategies to reduce non-point source pollution directly related to new development. Despite these regulations, current stormwater management strategies have shown only limited success in protecting aquatic environments that depend on the preservation of existing natural processes. To address this issue, we need a new stormwater management strategy that regards runoff as a valuable resource, emulates the natural hydrology system, fulfills our environmental goals, and satisfies local flood control regulations. The Split-Flow Stormwater Management Strategy is a newly developed method for managing stormwater on-site by replicating the natural processes of evapo-transpiration, soil infiltration and stream flow. This Split Flow strategy has been modeled and studied by comparing its design feasibility and construction cost to other methods with promising results. However, development of the strategy is at a standstill due to a lack of in-ground testing. The purpose of this proposal is to implement initial in-ground testing of the strategy. The knowledge gained from the proposed in-ground testing will offer practical evidence of the strategy's usefulness and reveal areas in need of further refinement.

The study will be the first in-ground test to assess the Split-Flow Stormwater Design Strategy's ability to replicate natural discharge flow rates, volumes, frequency and duration by comparing runoff discharges from parking lots equipped with Split-Flow systems to runoff discharges from undeveloped adjacent analogous land. The primary objective of this study is to test the Split-Flow Stormwater Management Strategy's efficacy in preserving the land's natural stormwater discharge rates, volume, frequency and duration. Another outcome of the study will be the creation of a sustainable stormwater management demonstration and education facility within the Spring Creek Watershed, located in Centre County, PA. The longer-range goal of this study is to continue development of the Split-Flow Stormwater Management Strategy in order to provide an ecologically responsible stormwater management alternative based on preserving the land's pre-development hydrological processes. Funding provided by the PA Water Resources Research Center will be used to procure monitoring equipment for the Split-Flow demonstration including: stormwater flow, rainfall, soil moisture, water & air temperature, water depth meters and on-site data recording equipment.

The Split-Flow needs to be tested before it can be applied to land development practice where it should help resolve many of the problems that current stormwater management methods need to address. As a result of Split-Flow strategy, the actual difference in volume created by development can be distributed throughout a site to restore groundwater recharge; natural runoff that existed before development can be cleaned and routed downstream; and the first flush containing the highest levels of pollution can be diverted and isolated in effective treatment facilities. Under such conditions, the reduction in downstream degradation should be quite substantial.

Statement of Critical Need:

The national significance of this project is widespread because all municipal regions with a population greater than 100,000 are legally required to address non-point source pollution problems created by excess urban runoff. At the international level, urban runoff problems have been and continue gaining increased attention with innovative solutions being sought. In-ground testing of the Split-Flow Strategy will establish the strategy's utility, reveal areas in need of further refinement, and will advance our understanding of how stormwater design can more effectively incorporate environmental stewardship into land development. By establishing the Split-Flow Strategy's utility, land developers and communities who are hesitant to use new stormwater designs will have tangible evidence of this strategy's application and usefulness.

Statement of Results of Benefits:

The outcome of this study will be five-fold. First, the study will assess the Split-Flow Stormwater Design Strategy's ability to preserve natural stormwater discharge flows, providing a better understanding of the strategy's potential application for protecting aquatic environments and enhancing its practical application in land development practice. Second, the test sites will serve as public demonstration facilities for both Penn State students and watershed conservation groups. Third, graduate students from the Center for Watershed Stewardship, the Department of Landscape Architecture, and other related disciplines will have opportunities to participate in the refinement and revision of the Split-Flow Stormwater Design Strategy by collecting and analyzing data from the test facilities, as well as participating in the Split-Flow facilities' design, construction, and maintenance. Fourth, interpretative signage will explain the facilities' functions and the importance of ecological stormwater design for the protection of aquatic systems in the Spring Creek Watershed. Lastly, locating the facilities within existing campus parking lots will create additional educational opportunities for local residents and visitors to Penn State's University Park campus.

Nature, Scope and Objectives:

Nature and scope - The basic premise of Split-Flow stormwater management strategy is that rainfall can be divided into three portions specific to any given design storm, that these portions should reflect predevelopment evapotranspiration, infiltration and natural runoff volumes based on existing conditions, and that these portions can then be filtered, distributed and redirected respectively into bioretention, recharge and downstream discharge. The Split-Flow strategy preserves a site's predevelopment hydrology by a combination of distributed bio-retention facilities that overflow into raised drop inlets and paired Vee-notch flow splitters connected to small infiltration facilities. Runoff is directed to bioretention facilities where the designated first flush volume of contaminated urban drainage is retained by mulch, soil and plant material. These bioretention facilities are designed as separate off-line facilities to assure that first flush pollutants are not re-suspended and released downstream. The facilities are sized based on the predevelopment initial abstraction runoff depth for each

impervious surface. This simple ratio of parking to bioretention area can be easily applied to small parking lots and still allow area for tree planting in the medians as shown in figure 1.

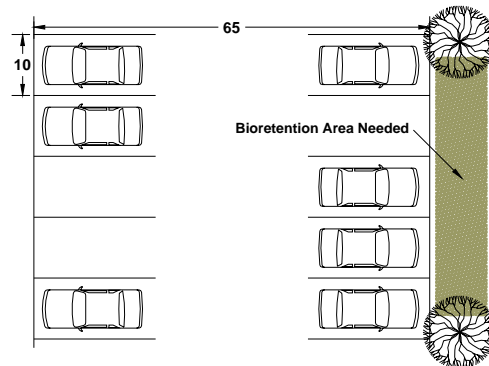


Fig. 1 - Bioretention area needed for small parking lot

By sizing the facility for 1.3 inches, any storm with less than 1.3 inches of rainfall would be held completely on site. Storms with more than 1.3 inches of rainfall would overflow into a raised drop inlet with a proportional flow-splitter. The basic design concept of a bioretention area with a raised drop inlet and flow-splitter is shown in figure 2.

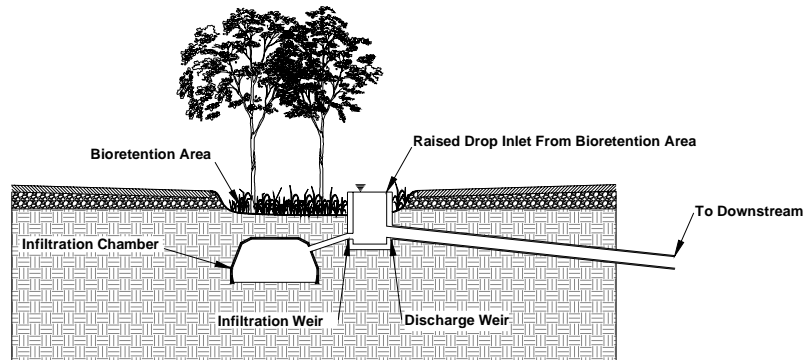


Fig. 2 – Basic Design Concept for Bioretention Facility with Flow-Splitter

After entering the raised drop inlet, runoff is separated by a proportional flow splitter into the infiltration and discharge hydrographs. The proportional flow splitter consists of paired weirs designed to split the runoff so that the portion of the post development hydrograph created by buildings and impervious surfaces is diverted into infiltration facilities and the natural runoff that existed before development is discharged downstream. The total difference in volume between any pre and post development design storms is calculated with the equation: $(\text{post } Q_p - \text{pre } Q_p) \times \text{ToC} \times 80.1$. This method closely recreates the pre-development hydrograph by infiltrating the additional runoff volume created by development as shown in figure 3.

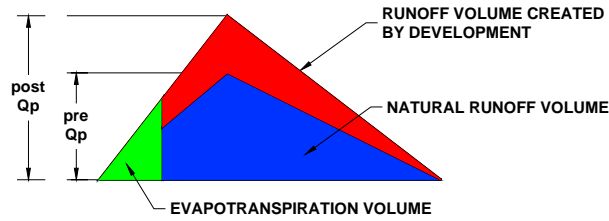


Fig. 3 - Development Volume Hydrograph

The discharge weir is designed to capture the pre-development runoff volume while the infiltration weir is designed to capture the increase runoff volume caused by development based on pre and post development conditions. These two weirs combine to act as a proportional flow splitter as shown in figure 4.

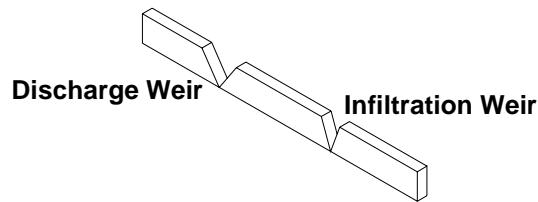


Fig. 4 – Proportional Flow Splitter

Each weir angle can be sized with identical heads and different flow rates based on the pre-development flow rate and the difference between the pre and post-development flow rate. For example, if the pre-development peak runoff rate is 5.6cfs and the post-development peak runoff rate is 8.5cfs, the bypass weir angle can be sized for 5.6cfs and the diversion weir angle can be sized for 2.9cfs. Using a Vee-notch weir nomograph, the bypass weir angle would be 120 degrees and the diversion weir angle would be 90 degrees. These weirs can be easily built into plastic drop inlets as shown in figure 5.

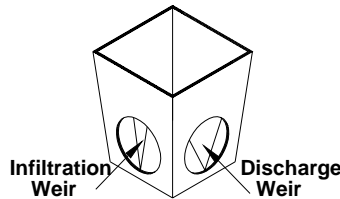


Fig. 5 - Plastic Inlet With Weirs

The importance of dividing the site into small drainage areas and distributing the system over the entire site in numerous small facilities cannot be over emphasized. An important aspect of this method is that the design for the paired Vee-notch weirs is based on proportions and not the overall capacity. Runoff is split into these proportions regardless of the Vee-notch height, storm intensity or duration. In other words, the system is not designed for a specific design storm but rather it is designed to split the flow into a specific ratio for all storms large and small. This fact provides an immense advantage over existing methods. The key for success with this management strategy is to install proportional flow splitters for each impervious surface and distribute the flow into individual facilities. This is achieved by

sizing the angles on each individual pair of Vee-notch weirs to discharge the predevelopment runoff volume and to infiltrate the increased runoff volume created by impervious surfaces. By customizing each proportional flow splitter's weir angles to match predevelopment hydrologic conditions, the Split Flow system adapts itself to the unique conditions of and within any site. The site specific design of each proportional flow splitter assures that peak flow rates are effectively controlled without the need to exceeds a site's predevelopment infiltration capacity. The system controls the overall peak flow rates by distributing and infiltrating the difference in volume proportional to time over the entire site and therefore eliminates the need for any stormwater detention system.

Objectives of the project - The primary objective of this study is to test the Split-Flow Stormwater Design Strategy's ability to preserve the land's natural stormwater discharge rates, volume, frequency and duration. The funding requested will assist in creating a sustainable in-ground stormwater design demonstration and education facility on Penn State's University Park campus. These test sites will serve as demonstration facilities for Penn State students and watershed conservation groups. The site will also become a public educational facility with on-site interpretive signage that explains not only the facility's function, but also the vital role ecological stormwater management plays in the protection of aquatic systems throughout the Spring Creek Watershed. Graduate students from the Center for Watershed Stewardship will participate in the Split-Flow facility design, construction, maintenance, collect and analyze data from the test facilities. By locating the facilities within existing campus parking lots, additional education opportunities will be created for local residents and visitors to Penn State's University Park Campus.

Timeline of activities

- Fall 2003 – preliminary test sites identified by Penn State
- Winter 2004 – conduct soil and percolation test on test sites
- Spring 2004 – construct Split-Flow demonstration facility
- Summer 2004 – install water flow and depth meters
- Fall 2004 – collect preliminary stormwater flow data
- Winter 2005 – recalibrate proportional flow splitters
- Spring 2005 – collect adjusted stormwater flow data
- Summer 2005 – analyze adjusted data and compare results

During the first year, preliminary reports about the research design and information gained during construction will be submitted for peer review and presentation at regional and national stormwater conferences. The project is expected to continue for two years after the funding period. During the second year, reports detailing the Split-Flow Stormwater Design Strategy's ability to replicate natural discharge rates, volumes, frequencies and durations will be submitted for review and publication to peer-reviewed journals, including: *Urban Water*, the *Journal of American Water Resources Association*, the *Journal of Water Resources Planning and Management* and *The International Journal of Water*. During the third year, project results will be presented at conferences, and submitted for peer-reviewed publication at both national and international levels. Educational brochures and web-based information will be made available throughout the research process as funding permits. The final

deliverable from this project will include an ongoing Split-Flow stormwater design demonstration/education facility on the Penn State University Park campus.

Principal Findings and Significance:

We are currently in the process of building the pilot Split-Flow feasibility test facility. We have spent most of the past two years working with Penn State to design a feasibility and demonstration study as part of the new School and Architecture and Landscape Architecture building. Unfortunately, after investing considerable time and effort by our department and outside consultants, Penn State OPP decided that they would not approve the feasibility and demonstration study at the new building site. We are, therefore, temporarily using an off campus site to build a pilot feasibility test facility until we can find a highly visible campus location that is suitable for the long-term feasibility and demonstration study and receive construction approval from OPP. This change actually works out fairly well because it gives us a better opportunity to work out all the details and make design revisions as needed before we construct the on campus feasibility facility.

The PA Water Resources Research Center grant funds have been used only to purchase equipment that can be easily and safely relocated to the future on campus feasibility and demonstration facility. I am personally funding the construction materials and labor for the pilot study thereby assuring that funding provided by the PA Water Resources Research Center will only be for equipment that can be reused for the long-term feasibility and demonstration facility. We are currently fabricating control weirs and calibrating flow interments. We hope to have the pilot Split-Flow feasibility test facility completed in the next few weeks and start gathering data over the summer.

Students Supported:

None at this time.

Presentations and Other Information Transfer Activities:

Echols, S. 2004, "New Technologies for Stormwater Restoration," Invited presentation at the University of Georgia, School of Environmental Design, April 19, 2004 Athens, GA.

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

Awards:

None at this time

Nutrient Removal of a Sequencing Batch Reactor (SBR) Treating Wastewater with Potential for Water Reclamation

Basic Information

Title:	Nutrient Removal of a Sequencing Batch Reactor (SBR) Treating Wastewater with Potential for Water Reclamation
Project Number:	2004PA29B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	17th of PA
Research Category:	Engineering
Focus Category:	Treatment, Nitrate Contamination, Waste Water
Descriptors:	nitrogen removal, sequencing batch reactor (SBR), water reclamation, nitrification, denitrification, nitrifiers, redox potential
Principal Investigators:	Baikun Li

Publication

1. Li, B. and S. Irvin. 2005. Optimizing nitrogen removal in the SBR system. Proceedings of International Water Association (IWA) Leading Environmental Technology (LET).
2. Li, B. and S. Irvin. 2005. ORP and alkalinity change in the SBR system for nitrogen removal. Proceedings of Water Environmental Federation (WEF) 2005 conference.
3. Li, B. and S. Irvin. 2005. Nitrogen removal in low/middle/high concentration wastewater using a SBR. Submitted to Environmental Engineering and Science.
4. Li, B. and S. Irvin. 2005. Alkalinity and ORP changes at nitrification and denitrification in a sequencing batch reactor (SBR). Water Environment Research (in preparation).
5. Li, B. and S. Irvin. 2005. The population of nitrifying bacteria in a SBR system at different nitrogen removal efficiency. Applied Environmental Microbiology (in preparation).

Abstract:

The overall vision for this research is to optimize a cost- and space-effective biological nutrient removal (BNR) system to remove nitrogen from wastewater for water reuse. The ultimate goal is to protect natural water resources and reduce energy consumption in wastewater treatment. Ammonia/nitrate pollution of surface water and groundwater has been a significant problem in Pennsylvania and the Chesapeake Bay watershed for many years. The deteriorated natural water resource is the main obstacle for water reuse necessary to save water consumption in Pennsylvania. Nitrification/denitrification in biological wastewater treatment is the approach commonly used to remove nitrogen from wastewater. However, this process needs large amounts of space, long treatment time, and has a high operational cost, and the performance is not stable.

It is critical to develop an innovative cost- and space-effective process in order to solve low nitrogen removal efficiency, and if possible, to provide high effluent quality for water reclamation. Current research conducted in the Environmental Engineering Laboratories at Penn State Harrisburg aims at enhancing nitrogen removal by the sequencing batch reactor (SBR). Compared with conventional biological wastewater treatment processes, the SBR has several distinct advantages: 1. the SBR process converts the conventional wastewater treatment processes from space-course to time-course, which substantially reduces the space occupation. This feature especially makes the SBR suitable for small community wastewater treatment. 2. the SBR operation sections (aeration, anoxic reaction, settling, etc.) are auto-controlled which offer the easiness and flexibility to adjust the SBR operation for different treatment requirements.

With the objective of enhancing nitrogen removal efficiency from wastewater, this research will be conducted in two phases. Phase 1 consists of laboratory studies to evaluate the SBR nitrogen removal efficiency when treating low concentration wastewater (municipal wastewater) and high concentration wastewater (agricultural wastewater). The optimization of nitrification/ denitrification by adjusting aeration intensity, aeration duration, and anoxic duration will be investigated. The study will establish the relationships between the SBR performance (including organic removal, nitrogen removal, and sludge settleability), and oxygen consumption and operation cycles. Phase 2 consists of laboratory studies to examine the nitrogen removal in the SBR system under influent shock. Two inhibitors for nitrification will be added into influent to test the SBR nitrification stability. The study will provide information for the adjustment of SBR operation cycles, and test the feasibility of SBR handling nitrogen removal under influent shock.

Use of the SBR for nitrogen removal is currently applicable for community and agricultural wastewater treatment, but optimization of operation and on-line control is far from completion. The outcome of this research will provide useful guidance for the optimization of the SBR operation and energy savings for contaminant removal from wastewater with potential for water reuse. This project is supported by Penn State Harrisburg, Cromaglass Inc. (the equipment manufacture) and Skelly & Loy (the consulting firm supporting the equipment).

Statement of Critical Need:

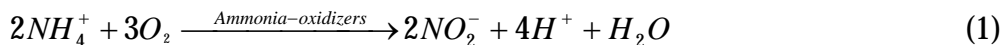
Nitrogen pollution in water resources is a long existing environmental and public health problem in Pennsylvania. Agriculture and farming are the main economy resources for Pennsylvania. However,

waste generated by agriculture and farming is the major source of nutrient (nitrogen and phosphorous) to water resources. USGS studies in agricultural areas in the Susquehanna River Basin, which drains to Chesapeake Bay, have documented high concentrations of ammonia (NH₃) and nitrate (NO₃⁻) that create conditions detrimental to aquatic life. This is the leading cause of environmental degradation in the Chesapeake Bay, primarily because it fuels the runaway growth of algae. When algae decompose, it consumes oxygen, a crucial element for survival of the Chesapeake's famed shellfish and fish stocks. Moreover, high concentration of nitrogen in groundwater has posed potential human and livestock health hazards (PADEP, 1996). EPA regulates drinking water nitrogen concentration should be lower than 10 mg/L, but nitrogen is higher than 30 mg/L in some Pennsylvania areas, and citizens are worried about nitrate pollution of drinking water supply, since high levels of nitrates have been associated with (blue-baby) syndrome in infants (Susquehanna River Basin Commission, 1991). Pennsylvania aimed at reducing the levels of nitrogen entering the Susquehanna River by 40 percent by the year 2000 (PADEP 1996). However, efforts to meet this goal have been impeded by the nutrient pollution from new factory farms locating in the watershed.

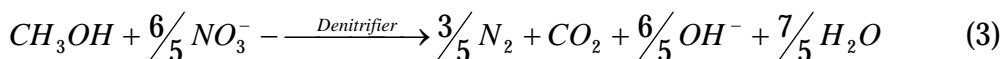
Beside public health issues related to contamination of water resources, nitrogen pollution also causes the obstacles for water reuse in Pennsylvania. Pennsylvania has been suffering water shortages for over one decade due to the increasing water demand and dry weather conditions. The water shortage has caused billions of dollars economic losses for agriculture in Pennsylvania. In 1999, crop losses state-wide were estimated at \$1.3 billion and milk production loss was \$1.5 trillion. In order to solve the water shortage problem, reclaimed wastewater is a beneficial application. However, wastewater reclamation is impeded by high nitrogen concentration as a result of ineffective nitrogen removal in the wastewater treatment processes. In most wastewater treatment plants in Pennsylvania, treated wastewater still has high amount of organic/inorganic nitrogen. This is the main reason that water reuse is not allowed in some places in Pennsylvania. In order to solve water shortage by water reclamation and reuse, effective nitrogen removal should be employed to enhance the treated wastewater quality.

The commonly used process for nitrogen removal in biological wastewater treatment is aerobic nitrification/anoxic denitrification by different microorganisms. Nitrification has two steps: ammonia (NH₃) is first oxidized to nitrite (NO₂⁻) by autotrophic ammonia oxidizers, then nitrite is oxidized to nitrate (NO₃⁻) by autotrophic nitrite-oxidizers. In anoxic denitrification, nitrite/nitrate is reduced to nitrogen gas (N₂) by heterotrophic denitrifiers with the presence of extra carbon source (methanol) as electron donor. The reactions are listed below:

Aerobic nitrification:



Anoxic denitrification:



Nitrification/denitrification of the biological nutrient removal process is generally recognized as the most vulnerable activated sludge process, depending on many factors (influent contaminant concentration, sludge retention time, oxygen concentration, microbial phase in activated sludge, etc.)

which are often interconnected (Metcalf & Eddy, 2003). Because the growth rate of autotrophic nitrifiers is far slower than normal heterotrophic bacteria, nitrification could not occur in wastewater treatment systems unless cell retention time is long enough for nitrifiers to reproduce and grow. This causes a large space requirement for wastewater treatment. Moreover, heterotrophic bacteria dominate over autotrophic nitrifiers at medium/high contaminant concentration, which leads to low nitrogen removal efficiency when treating municipal and agricultural waste. In order to achieve an efficient nitrogen removal to protect natural water resources and provide good effluent for water reuse, an innovative biological cost and space-effective is pursued in this research.

With the objective of enhancing biological nitrogen removal efficiency, the research team will investigate the optimization of nitrogen removal in the sequencing batch reactor (SBR)—a recently adopted process converting traditional wastewater treatment from space-course to time course. The research goal is to achieve good nitrogen removal from low/high concentration wastewater with short retention time and low/medium oxygen concentration in order to save energy cost. The research contributes to establishing multi-disciplinary Environmental Engineering research at Penn State. The education goal is to create opportunity for students to study the innovative wastewater treatment process and understand the importance of nutrient removal. Along with this, it will bring a professional view to sustainable water environmental development. The SBR system studied in the research project is a part of graduate-level course “wastewater treatment design” at Penn State Harrisburg.

Statement of Results of Benefits:

The proposed SBR project will optimize two important criteria for nitrification/denitrification:

1. oxygen concentration, and
2. aeration duration under different influent organic loadings.

The nitrogen removal efficiency at different influent qualities (municipal sewer, agricultural waste) and SBR operation conditions (oxygen, aeration duration, anoxic duration) will be studied. The optimal condition with respect to nitrogen removal, contaminant removal, and solid removal will be obtained to balance good treatment and energy consumption. Moreover, the performance of the SBR nitrogen removal will be tested under influent shocks to provide information for the stability of the SBR treating municipal and agricultural waste. This full-scale SBR study will provide valuable information for nitrogen removal from wastewater for protecting water environment and water reuse.

The optimization of the SBR will provide a far more efficient nitrogen removal technology for wastewater treatment and reuse, and is expected to achieve effluent nitrogen concentration lower than 5 mg/L. The small space requirement, flexible operational modes, and low energy cost of the SBR will significantly reduce the cost of nitrification/denitrification. After optimization of the SBR for nitrogen removal, it could be used in communities, agricultural areas, and farms to treat municipal sewage and high concentrated agricultural waste. This economic and highly efficient treatment technology can help to solve the nitrogen contamination in Pennsylvania.

Nature, Scope and Objectives:

A full scale SBR system (treatment capacity 500 gallon per day) is being studied in the

Environmental Engineering Laboratories at Penn State Harrisburg. The distinct feature of the SBR is its inherent flexibility of cycle phasing, providing different operational modes on time sequence, and not being as space dependent as the traditional activated sludge process. SBR is perfectly suited for small wastewater flows (<10 MGD, Irvine et al. 1987). In an SBR operation, the wastewater is fed for a period of time. It goes through a sequence of treatment processes in the same basin and is drawn periodically. A typical cycle involves five operational phases: fill, react, settle, decant and idle/waste sludge (Figure 1). Among the several advantages that the SBR offers compared to a CFR are flexibility in operation, quiescent or carefully controlled mixing during settling, no need for separate clarifier, and space saving (Norcross, 1992).

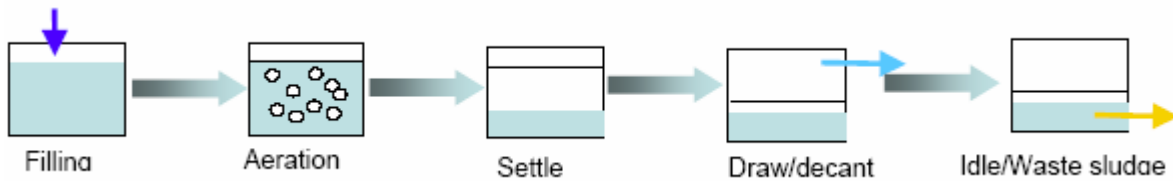


Figure 1. Operation timeline of the SBR system

Although the SBR has several advantages compared with traditional wastewater processes, several areas still need to be developed for the nitrogen removal of the SBR:

1. Real-time monitoring for the SBR operation beside dissolved oxygen (DO) and pH in order to get the on-line information of nitrification/denitrification;
2. Simultaneous nitrification/denitrification which might be achieved at low DO ($DO < 1\text{mg/L}$). How to keep good sludge settleability at a low DO condition is a challenge;
3. How to optimize SBR to get good effluent quality for water reuse to save water resources;
4. Very limited knowledge is available in terms of the change of microbial activity at different operational cycles of SBR and how it can be used to optimize operation.

In order to give answers to above questions, a comprehensive test is being conducted through the collaboration of Penn State Capital College, Skelly & Loy and Cromaglass, Inc.

The research will be conducted in two phases. Phase 1 consists of laboratory studies to optimize nitrogen removal by adjusting aeration intensity, aeration duration, anoxic duration. Phase 2 consists of laboratory studies to examine the nitrogen removal in the SBR system under influent shock. The anticipated schedule, along with major milestones, is presented in Table 1.

Table 1. Proposed project schedule (with starting state of March 1, 2004)

	Oct. 2003- Mar. 2004	Mar.2004- June.2004	July.2004- Sept. 2004	Oct. 2004 – Dec. 2004	Jan. 2005- Feb.2005
Phase 1A. Operation mode and influent quality on nitrogen removal *	*				
Phase 1B. oxygen concentration on nitrogen removal					
Phase 1C. ORP on-line monitor *	*				
Phase 2. Nitrogen removal under					

influent shock					
Write report					

*: The PSH research team has been working on nitrogen removal at laboratory since Sept. 2003 (shown in brown slots). The results from this phase will contribute to the SBR project proposed for 2004-2005.

Methods, Procedures and Facilities:

Phase 1: Optimize nitrogen removal in SBR operation

In this phase of the study, nitrogen removal in the SBR system will be studied in the laboratory by using synthetic wastewater (representing municipal wastewater: low organic and low ammonia concentration; and agricultural wastewater: high organic and high ammonia concentration). The preset SBR operation cycle is fill: 0.5 hr, aeration: 2.5 hr, anoxic mixing 1.5 hr, settling 1 hr, and decant 0.5 hr. The experimental set-up is shown in Figure 2. Based on the SBR operation from experience by Skelly & Loy field-work, nitrification/denitrification is not stable. Therefore, the phase I will be aimed at improving nitrogen removal in the SBR. In the first step, nitrogen removal will be evaluated through a series of tests of different operational cycles, hydraulic retention times, and influent organic loadings in order to find the optimal operation for nitrogen removal. In the second step, the oxygen concentration for nitrification/denitrification will be studied to find the optimal aeration condition for contaminant removal, and nitrogen removal. The redox potential (ORP) will also be tested as an on-line monitor for contaminant removal and nitrification/denitrification. The detailed plan for Phase I study is stated below:

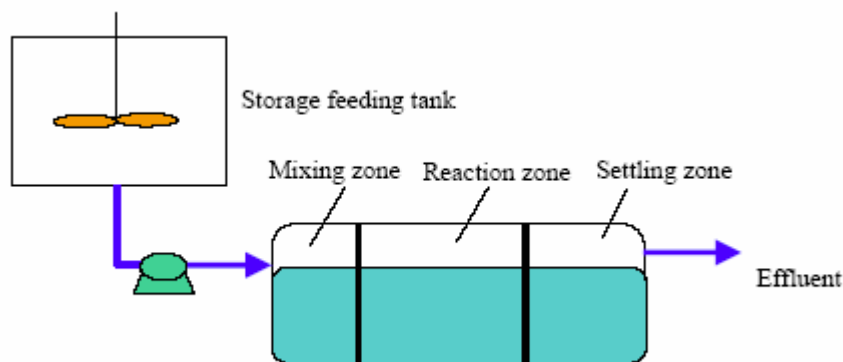


Figure 2. The SBR experimental set-up diagram

1A. Effects of operation mode and influent quality on nitrogen removal

The research currently being conducted is testing the adjustment of operational modes to get high nitrogen removal efficiency. The hypothesis of this research is: due to the flexibility of the SBR, the duration of aerobic and anoxic reactions can be adjusted to achieve good nitrification/denitrification performance. The SBR system is run at various aeration and anoxic durations. It is anticipated that long aeration is good for carbonaceous removal and nitrification, and long anoxic duration is good for denitrification, but nitrogen gas generated may interfere with the settleability of activated sludge. By adjusting aerobic/anoxic duration, we hope to find the optimal operation mode for achieving carbonaceous removal, nitrogen removal, and good effluent quality. The SBR influent and effluent will be tested for chemical oxygen demand (COD), ammonia, nitrite, nitrate, and suspended solid according

to Water Standard Method. Also, the ammonia, nitrite and nitrate will be measured at the end of aeration and anoxic mixing steps to test nitrification and denitrification efficiency. The tested operation modes to be tested are list in Table 2. The test period for each mode will last two weeks.

Table 2. SBR operation modes (influent COD: 300-400 mg/L simulating municipal wastewater)

	Fill	Aeration	Anoxic mixing	Settling	Decant
Preset	Aerobic, 0.5 hr	2.5 hr	1.5 hr	1 hr	0.5 hr
Mode 1	Aerobic 0.5 hr	3.5 hr	1hr	1 hr	0.5 hr
Mode 2	Aerobic 0.5 hr	4.5 hr	1.5hr	1 hr	0.5 hr
Mode 3	Anoxic 0.5 hr, Aerobic 0.5 hr	2 hr	1.5 hr	1 hr	0.5 hr
Mode 4	Aerobic 0.5 hr, Anoxic 0.5 hr	2 hr	1.5 hr	1 hr	0.5 hr

Besides the study of operational modes, hydraulic retention time (HRT) will also be tested for the SBR nitrogen removal. HRT will be adjusted by the influent flow rate, ranging from 80, 125, 250, and 500 gallon per day. It is anticipated that long HRT leading to low organic loading for biomass might be favorable for autotrophic nitrifier growth and nitrification. We will test whether the low flow rate can enhance the nitrogen removal efficiency in SBR.

Since the SBR process can be used for communities, agricultural areas and farms, the next study is to change the influent organic concentration from simulating municipal wastewater (low organic and low ammonia concentration) to agricultural wastewater (high organic and high ammonia concentration). The SBR system will be run at high organic concentration levels (COD: 1000 mg/L). It is known that in traditional activated sludge processes, nitrification can be severely inhibited at high COD concentration due to the domination of heterotrophic bacteria (Metcalf and Eddy Inc., 2003). We will test whether the SBR can achieve desirable nitrogen removal at high organic concentration. In the mean time, we will adjust the aeration/anoxic duration to find optimal operation mode for treating agricultural waste.

1B. Effects of oxygen concentration on nitrogen removal

Oxygen is a critical operational parameter for contaminant and nitrogen removal, and nitrification is especially sensitive to oxygen concentration. However, the aeration system accounts for more than half of total energy consumption in biological wastewater treatment systems. To balance good treatment efficiency and energy consumption is an important issue for sustainable wastewater treatment. In STEP 1B, the SBR system will be run at three oxygen levels in aeration sections (2, 3-4, and 5-6 mg/L) to evaluate the impact of oxygen concentration on nitrification. Moreover, the aeration duration will be adjusted for different oxygen levels to examine the possibility of shortening SBR operation cycle and still keeping good nitrogen removal.

Low oxygen concentration for simultaneous nitrification/denitrification (SNdN) will also be investigated for the possibility of skipping the denitrification step but still achieving good nitrogen removal. Currently, most conventional wastewater treatment processes separate nitrification and

denitrification into two zones: aerobic and anoxic, in order to create the proper environment for the different microorganisms responsible for nitrogen removal. However, this separation neglects the interaction between the aerobic nitrifier and anoxic denitrifier. In nitrification, extra alkalinity has to be added to keep a stable pH, and in denitrification, an external carbon source (methanol) might be needed for the reduction of nitrate if organic matters are not sufficient in water. This will cause difficulties for operation and maintenance. The occurrence of nitrification/denitrification in a single tank can resolve this problem, since alkalinity produced in denitrification can neutralize the hydrogen ion produced in nitrification, as such, save alkalinity dosage. The wastewater can serve as an internal carbon source for denitrification, thus saving the organic dosage. SNDN might be achieved at low oxygen concentration ($DO < 1-2$ mg/L) (Moriyama et al. 1993). However, this raises another issue: how to prevent sludge bulking at this low oxygen condition, since filamentous bacteria can cause loose and light activated sludge which is difficult to settle, and lead to the high solid concentration in effluent (Metcalf & Eddy, 2003). Therefore, our research will test SNDN at low oxygen concentration and compare the nitrogen removal efficiency with separate nitrification/denitrification in STEP 1A. The SBR influent and effluent will be tested for ammonia, nitrite, nitrate, and suspended solids. Sludge settleability will be tested by sludge volume index (SVI). The STEP 1B will provide information for achieving good nitrogen removal and good effluent quality, saving aeration energy at same time.

1C. On-line monitor for contaminant and nitrogen removal

Along with the SBR operational testing in STEP 1A and 1B, parameters for on-line monitoring SBR performance will be evaluated. Currently, the most commonly used parameters are pH and oxygen. However, when oxygen is lower than 0.5 mg/L, the concentration is too low for measurement to be reliable. In order to get the on-line information for aerobic nitrification/anoxic denitrification, it is critical to find a parameter which could reflect reaction status at both aerobic and anoxic conditions.

In this study, redox potential (ORP, $E = E_0 + \ln([\text{oxidized form}]/[\text{reduced form}]) * RT/nF$, where n is the electron transferred in a redox reaction) will be tested as an on-line monitoring parameter, since nitrification/denitrification are redox reactions involving electron donors and electron acceptors (reaction 1-3, page 6). The P.I. has done extensive work on ORP control for wastewater treatment and found a clear correlation of ORP with different biodegradation processes. For instance, nitrification needed higher ORP (360 mV) values than does carbonaceous compound oxidization (200-300 mV) (Li and Bishop 2002, 2003a). In addition, aeration tank effluent quality could be indicated by on-line ORP values much faster than COD measurement (Li and Bishop 2003b). The correlation of ORP and nitrification was also verified by the microelectrode and molecular biology studies (Fluorescent in situ hybridization, FISH) (Li and Bishop 2003c). The number of nitrifiers at higher redox condition is significantly greater than at lower ORP. Based on the success of using ORP to indicate wastewater quality, it is promising to evaluate ORP as an indicator of nitrification/denitrification.

ORP monitoring will be evaluated with pH and oxygen in experiments conducted in STEP 1A and 1B. It is expected to obtain the correlation between ORP and nitrogen removal, and find the setpoints of ORP values for the completion of nitrification and denitrification. If this correlation can be established, the extent of nitrogen removal could be monitored on line, and the aeration duration can be adjusted immediately to ensure the good nitrogen removal efficiency.

Upon the completion of the Phase 1 study, the optimal SBR operational mode for nitrogen removal can be obtained, and optimal oxygen concentration for nitrification or simultaneous

nitrification/denitrification can also be gotten for balancing good nitrogen removal and energy saving. The nitrogen removal of low/high concentrated wastewater can test the feasibility of SBR treating municipal and agricultural wastewater. The relationship of ORP and the extent of nitrification/denitrification will be established for the on-line monitoring of SBR performance, which is critical for improving SBR nitrification/denitrification.

Phase 2: Nitrogen removal efficiency under shock

While the Phase 1 study is conducted in steady operational status. Phase 2 will evaluate the stability of SBR performance under influent shock, since there are a variety of compounds in wastewater that could inhibit nitrifier activity and interfere with the nitrification/denitrification. Two chemicals NaClO₃ and allylthiourea (ATU) will be used to represent the inhibitors in wastewater. ATU inhibits ammonium oxidation (Reaction 1, page 6), while NaClO₃ inhibits nitrite oxidation (Reaction 2, page 6) (Gorska et al., 1996). ATU and NaClO₃ will be added separately to SBR influent at the dosage of 5 mg/L and 2.5 g/L respectively. The ORP values in SBR system and effluent ammonia, nitrite and nitrate will be tested for the response of microorganisms to inhibitors, and check the feasibility of ORP for on-line indicator of influent shock. Also, the oxygen uptake rate (OUR) of microorganism in aeration section will be measured for the impact of inhibitors in nitrifier activity. These results will be compared with the stable status in Phase 1 study. Moreover, the oxygen concentration, aeration duration, and anoxic duration will be adjusted for influent shock in order to find the operational mode to keep good nitrogen removal under shock conditions. The recovery of the SBR system after influent shocks will also be evaluated to check the time necessary for recovering to steady-state conditions. The recovery time is important for the development of robust systems capable of rapidly returning to steady-state condition after environmental shock.

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Principal Findings and Significance:

An extensive study of chemical oxygen demand (COD) and nitrogen removal in a sequencing batch reactor (SBR) system (treatment capacity: 450 gallon per day), funded by PA Water Resource Center, was conducted at Penn State Harrisburg wastewater treatment lab from Sept. 2003-May 2005.

The major goal of the project was to achieve nitrogen removal in the SBR system for wastewater reuse. During the study, nitrogen removal was tested at different operation conditions (influent COD, influent NH₃ concentration, oxygen concentration, and flow rate). The overall performance of SBR for nitrogen removal was good under most conditions, with effluent nitrogen concentration less than 5 mg/L. Several parameters (alkalinity, pH, and redox potential) were tested as on-line indicators for nitrogen removal. It was found that alkalinity was the best indicator of nitrogen removal efficiency. Moreover, nitrogen removal efficiency of the SBR system was tested under shock, which was

supposed to inhibit NH₃ oxidization. The comparison between batch test and the SBR for the toxic shock indicated that SBR system can tolerate toxic shock in terms of nitrification. In the mean time, the population of nitrifying bacteria in the SBR system under different operation conditions was observed by fluorescent in situ hybridization (FISH). The results indicated the different nitrifying bacterial groups were present in activated sludge.

This SBR project has a great significance for wastewater treatment and water reuse. Starting in September 2005, the Pennsylvania Department of Environmental Protection will require that wastewater treatment facilities in Pennsylvania need to meet effluent total nitrogen less than 10 mg/L. This regulation sets a higher standard for total nitrogen than the current requirement for wastewater treatment facilities. The results from this project indicate that SBR systems can be used to help meet this new requirement and provides guidance for manufacturers and customers for the SBR operation. Nitrogen removal is critical for wastewater reuse. This project has provided solid support for nitrogen removal from small wastewater treatment systems.

Besides this application significance, the graduate student in this project learned a lot in biochemistry, wastewater treatment. Moreover, the SBR system has been widely used for high school students, undergraduate, and graduate education in the past 2 years. It is also used for wastewater treatment plant operator's training. Molecular biology technology (FISH) applied in this project has laid a solid preparation for a graduate student course "Environmental Biotechnology", set to open in Spring 2006.

Overall, the successful completion of this SBR project has a great application and education significance. Because of the high quality work, the SBR manufacturer has showed a great interest in continuing the collaboration with the Principal Investigator for nitrogen and phosphorous removal research.

Students Supported:

Shannon Irvin, M. S. in Environmental Pollution Control, Penn State Harrisburg, May 2005.

Presentations and Other Information Transfer Activities:

Shannon Irvin, Baikun Li. Factors affecting nitrogen removal in a SBR system. *2004 PSU graduate student exhibition. University Park, PA. March 2004*

Shannon Irvin, Baikun Li. The optimization of nitrogen removal in a SBR system. *2005 PSU graduate student exhibition. University Park, PA. March 2004*

Shannon Irvin, Baikun Li. Nitrogen removal from wastewater in a SBR system. *2005 Innoventure, Hershey, PA April 2005*

Baikun Li. The overview of nitrogen removal in the Cromaglass CA-5 SBR system. *Presented for Cromaglass Inc. Skelly&Loy Inc., Middletown Wastewater treatment plant, and Harrisburg International Airport Wastewater treatment plant. April 2005.*

Shannon Irvin, Baikun Li. The optimization of nitrogen removal in a SBR system. *2005 Pennsylvania Environmental Association (PAEA) Annual Conference. Spring Valley, PA. June 2005.*

Shannon Irvin, Baikun Li. Nitrogen removal from wastewater in a SBR treating low/mid/high wastewater. *International Water Association (IWA) LET2005 Conference. Sapporo, Japan, June 2005.*

Shannon Irvin, Baikun Li. Nitrogen removal in a SBR system under ATU shock. *Water Environmental Federation (WEF TEC) Annual Conference 2005. Washing DC. Sept. 2005 (accepted).*

Awards:

Student Research Award (Pennsylvania Environmental Association (PAEA) 2005) for Shannon Irvin.
Advisor: Baikun Li

Nitrogen dynamics in the Spring Creek watershed (Pennsylvania, USA): Evaluating stream retention of point and non-point source loadings

Basic Information

Title:	Nitrogen dynamics in the Spring Creek watershed (Pennsylvania, USA): Evaluating stream retention of point and non-point source loadings
Project Number:	2004PA30B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	5th of PA
Research Category:	Not Applicable
Focus Category:	Nutrients, Non Point Pollution, Ecology
Descriptors:	nutrient loading, nutrient retention, trophic transfer
Principal Investigators:	Hunter Carrick

Publication

Abstract:

This project will assess the quantitative effect point and non-point watershed source loads (as estimated by stable isotope ratios and traditional wet chemistry) have on the retention of nutrients within the body of the Spring Creek ecosystem. Characterization of the sources of stream nitrate through analysis of stable isotopes and inorganic chemistry is expected to allow estimation of the relative magnitudes of various nitrogen sources at key locations with the streambed of the ecosystem. Finally, first order evaluation of the fate of N-loadings to Spring Creek will be accomplished by measuring the biomass, nutrient stoichiometry, and growth of resident biota. In this manner, I can evaluate the relative contribution of anthropogenic sources to the overall production of new (net) periphyton biomass within the streambed, and the transfer of this material to the next, step-wise trophic level in the food chain. The relative comparison of up and downstream sites can be used to, not only evaluate the addition of unique loads within the watershed, but the cumulative effect of loading on the stream ecosystems.

Statement of Critical Need:

The total maximum daily loads (TMDL's) to specific aquatic ecosystems are largely determined through modeling point and non-point land use practices of surrounding watersheds, as calibrated against limited water quality monitoring (e.g., Steinman et al. 2000). While this has proved to be an important and useful management construct, the actual influence of realized loads on the health (and therefore consequences of loads) is more difficult to ascertain. This project will assess the quantitative effect point and non-point watershed source loads (as estimated by stable isotope ratios and traditional wet chemistry) have on the retention of nutrients within the body of the Spring Creek ecosystem. The retention of material loads will be compared with variation in the biomass, production, and species composition of the resident biological community of periphyton.

Statement of Results of Benefits:

I expect to identify the retention of unique sources of nitrogen loading to spring Creek within the resident stream biota. The use of stable isotopes, in concert with traditional wet chemistry sampling is one of the only ways known to accomplish this task. While point sources are rather straight-forward to estimate, non-point sources can be very difficult to evaluate, and therefore require creative and new methods. I believe my approach will work, because, specific loads will likely have unique ^{15}N and ^{18}O signatures (fertilizers, animal manure, human wastes) that could not be distinguished by measuring gross quantities of nitrogen, as is the case with conventional wet chemistry techniques.

Finally, we can make a first order evaluation of the fate of N-loadings to Spring Creek by sampling biota among major trophic levels. Nitrogen signals in stream biota can be traced to specific watershed loads and variation in the trophic transfer of nitrogen can be tracked using ^{15}N (Adams and Sterner 2000). Our investigation of the resident periphyton assemblage and functional groups of macroinvertebrates from headwater and down-stream locations will allow us to determine if variations in nitrogen loading along the stream continuum causes

differences in the trophic increase in ^{15}N , as well as N retention in the stream-bed in key reaches of the Spring Creek ecosystem. A simple trophic transfer model will be used to calculate efficiency (see Wetzel 2001) in affected and unaffected areas in order to evaluate the relative cost of N-loading on the local fishery. The model applied here will estimate retention from the difference between nutrient uptake by the biota (nutrient stoichiometry versus growth) and total available delivery of nutrients in that portion of the streambed.

This research will support several forms of scientific progress. First, the results from this project will be used to formulate a larger research proposal to retain more substantial support for this work (National Science Foundation or PA State Agency). Second, preliminary results from this project will constitute a research report that can be published in a referred scientific journal. Third, aspects of this information will be used to augment instruction in several courses through the further development of lab-field based exercises.

Nature, Scope and Objectives:

Given their size and position within watersheds, prominent lake and river ecosystems integrate conditions from the surrounding landscape, often serving as barometers of local, regional, and global-scale change (Wetzel 2001). Cultural eutrophication is a problem of epidemic proportion in the United States, and this issue is particularly pronounced in lakes and rivers that are in close proximity to the demands of a growing human population (Karr 1993). Elevated material loading from changing land-use (urban and agricultural practices) has had a measurable effect on aquatic ecosystems throughout the state of Pennsylvania, where more than 2,500 miles of native stream receive some degree of impact (see Landis 1995).

Spring Creek (4th order stream) is an important tributary to the Susquehanna River, which in turn constitutes the major source of water (and nutrients) to the Chesapeake Bay. The stream serves as an important water resource for two urban centers in central Pennsylvania (St. College and Bellefonte, PA), and in the early part of the century it supported a productive native brook trout fishery that has been subsequently displaced through the stocking of brown trout (Wohl and Carline 1996). By the mid 1950's, water quality was impacted (weed growth, oxygen depletion) by the addition of sewage effluent (Landis 1995). Moreover, the introduction of toxic chemicals (e.g., Kepone, Mirex, and chlorine) into the stream was associated with major fish kills downstream (Landis 1995). By 1981, all stocking efforts ended and a no-kill policy was put into place, due to the high levels of Kepone and Mirex found in fish tissue, such that the stream again supports a premier brown trout fishery that is nationally recognized (Carline et al. 1991).

Having said this, water quality in Spring Creek has been an issue for over 30 years and recent declines are of particular concern. Point source nutrient loads can be attributed to three municipal wastewater treatment plants and two fish hatcheries within the watershed, all of which have been in violation of their pollution discharge permits (Bradley et al. 2002). Moreover, sediment loading from non-point sources appears to be responsible for compromised fish spawning habitat in stream reaches fed by portions of the watershed where agricultural activities (land drained by Slab Cabin and Cedar Runs) are widespread (Beard

and Carline 1991). Finally, a survey of 17 sites in Spring Creek and its major tributaries showed that 8 of the sites supported impaired water quality and benthic macroinvertebrate species composition; the poorest sites were in proximity to known point and non-point sources (Hughey 2002). While references have been made to the development and growth of nuisance plants within the streambed (see Spring Creek Watershed Community, <http://www.springcreekwatershed.org>), few if any studies have been done to evaluate the cause of excessive plant growth, its growth relative to material loads, or their influence on the function of the stream.

Identification of the source of nitrate in streams can be facilitated by using ^{15}N and ^{18}O stable isotope signatures along with inorganic water chemistry. Nitrate from point sources such as fish hatcheries and sewage treatment plants and non-point sources such as seepage, urban runoff, agricultural lands, and atmospheric deposition can be characterized using stable isotope signatures. I hypothesize that- *stable isotope signatures and inorganic water chemistry can be used to identify sources of nitrate in streams* (Williard et al.2001). As a first step in testing this hypothesis, I will characterize sources of nitrate at their origin and in streams within the Spring Creek basin. In addition, Spring Creek supports relatively simple food-web structure with few benthic macroinvertebrate taxa (see Hughey 2002) and an expansive coverage of attached algae (Carrick, unpublished data). This in turn allows for a clearly identification of a single trophic step in the food web. I plan to test the hypothesis- *variation in the nitrogen loading to a system affects the magnitude trophic transfer of resident biological community*. I will address this hypothesis by measuring the ^{15}N content within a single trophic step (algae to dominant invertebrate grazer) at up-stream and down-stream sites relative to known anthropogenic sources of nitrogenous inputs to Spring Creek. Spring Creek is an ideal *in situ* study site for this investigation, because it has several isolated point sources of anthropogenic nitrogenous inputs (three sewage plants and two fish hatcheries), which are known to contribute to downstream increases in ammonium and nitrate (Bradley et al. 2002; Hughey 2002). Last, the content of the stable isotope of nitrogen (^{15}N) in the tissue of living organisms increases in a stepwise fashion with increasing trophic position (from plants to herbivores to carnivores; Minawaga and Wada 1984). In this way, I plan to track unique source loads of N that are retained by stream biota, and thus predict the retention of loaded N in Spring Creek.

Methods, Procedures and Facilities:

Watershed Sampling Design:

We plan to estimate watershed-scale source loadings and stream retention of N in the Spring Creek ecosystem by sampling key in stream locations that reflect unique watershed loading scenarios (SPU- below Galbraith Gap, SPH-Spring Creek Park, Houserville; SPA- Fisherman's Paradise, Bellefonte). The first site will is located above the Cedar Creek inflow (denoted as SPU by SCWC), and is influenced by few point sources and several non-point sources loads (Galbraith Gap draining Tussey Mountain, municipal Golf course). The second site is located in Houserville (denoted SPH, at USGS gauging station) that integrates loads from Slab Cabin Run, Cedar Run, and two wastewater treatment plants. Lastly, the third site (denoted SPH, at USGS gauging station) receives loadings from one wastewater treatment plant and two fish hatcheries (Bellefonte and Benner Springs Fish Culture

stations). At all sites, stream samples will be retrieved at one mid-stream location and for water analysis, and at left, mid, and right bank locations for tissue nutrient content of major stream organism (periphyton and macroinvertebrates).

All samples will be retrieved at five intervals throughout 2004-05 (same day collections) to characterize major flow periods throughout the year based on the annual hydrograph data (mid winter low-flow, winter/spring high-flow, early summer moderate-flow, mid summer/late low-flow, fall high-flow). Sampling of sites for stable isotopes signatures of dissolved nitrate will be limited by budget. Preliminary samples of nitrate in precipitation, sewage effluent, septage, agricultural runoff, fish hatchery discharge, Big Spring spring flow and urban storm runoff will be characterized for isotopes and inorganic chemistry. Several storm samples of streamflow at the mouth of Spring Creek basin at Milesburg will be used to test decision-tree models of nitrate origin.

Sample Processing and Analysis:

Biomass and Nutrient Stoichiometry of Resident Biota- At the three in-stream sites, we will sample across the streambed to characterize the resident biological community. Algae will be collected from grab samples of natural substrata and placed in one zip-lock bag (see Steinman and Lamberti. 1996). Macroinvertebrates will be individually picked from the rocks sampled for periphyton (Hauer and Resh 1996). The nutrient content of algae and key macroinvertebrates (mainly *Lirceus* and *Gammarus*) will be evaluated by measuring concentrations of total phosphorus, nitrogen, and carbon using standard digestions and colorimetric reactions (Wetzel and Likens 2000). The $\delta^{15}\text{N}$ stable isotope content of key food web components will be measured using a mass spectrometer (Minawaga and Wada 1984). Both algal and invertebrate samples will be concentrated in sample vials, and suspended in alcohol for subsequent stable isotope analysis (5 dates x 3 sites x 3 habitats x 2 replicates = 90 samples for both periphyton and invertebrates).

Growth of Stream Periphyton- Artificial substrata will be used to estimate the accumulation of nutrients in the tissue of the developing periphyton assemblages at all sites in the stream (Carrick and Lowe 1988). Eight artificial substrata (unglazed clay tiles) will be placed at all three sites and secured to the streambed using bricks during each of the 5 temporal periods. Preliminary analyses show that the flora that develops on the tiles is indistinguishable from the resident periphyton growing on nearby rocks in the stream (Carrick and Adams, unpublished data). Duplicate tiles will be retrieved at one week intervals for a total of four weeks to determine accumulation rates. Once collected, samples will be analyzed from chlorophyll (to estimate biomass), and nutrient stoichiometry (see above).

Nutrient Loads- Analysis for ^{18}O and ^{15}N in nitrate will also be analyzed using a mass spectrometer. Inorganic water chemistry will be analyzed at the Water Lab, Penn State Institutes of the Environment. Characterization of the sources of stream nitrate through analysis of stable isotopes and inorganic chemistry is expected to allow estimation of the relative magnitudes of various nitrogen sources in Spring Creek basin. A simple decision tree model will be developed to determine source of nitrate in stream water from isotope and inorganic chemical analysis. If perfected, this technique would allow identification of watershed nitrate sources and imply potential solutions without detailed watershed inventories and extensive water quality sampling.

At each site, I will characterize the habitat quality of the streambed and channel (five sampling periods x 3 sites x 2 samples per site = 30 total). The width of the stream will be measured with a forester's tape and condition within the bed will be summarized using a habitat assessment survey (DEP survey form). At 2 locations at each site, water temperature, dissolved oxygen concentration, and conductivity will be measured using an YSI meter. Whole water samples will be collected in clean bottles in order to determine a series of physical-chemical measurements (pH, alkalinity, nitrogen and phosphorus species) using standard wet chemistry techniques (Wetzel and Likens 2000). The N and P data will be compared with those collected by the Clear Water Conservancy (monthly data plus flow measurements) in order to calculate loadings.

Nitrogen Retention in Spring Creek- The retention of material loads will be compared with variation in the biomass, production, and species composition of the resident biological community of periphyton. The difference between the inputs of estimated sources versus uptake/storage of nutrients within resident biota will provide first-order estimates of retention (see Wetzel 2001). In this manner, I can evaluate the relative contribution of anthropogenic sources to the overall production of new (net) periphyton biomass within the streambed, and the transfer of this material to the next, step-wise trophic level in the food chain (see Minawaga and Wada 1984; Adams and Sterner 2000). The relative comparison of up and downstream sites can be used to not only evaluate the addition of unique loads within the watershed, but the cumulative effect of loading on the stream ecosystem.

Principal Findings and Significance:

Periphyton biomass (as chlorophyll concentration) in Spring Creek was measured at three-week intervals at five sites during the March 2004-2005 period (see Figure 1). Values for the downstream sites were very high, with average values being above the 90th percentile for more than 300 temperate streams. Biomass at sites 1 and 2 were modest and appear to reflect the relatively undisturbed nature of the stream reach (Figure 2 and 3). The chlorophyll densities vary significantly over time and across the sites. Two-way ANOVAs evaluating variation in chlorophyll densities among sites and seasons, revealed a significant interaction ($p=0.0001$) between the seasons and sites factors (Figures 2 and 3).

Periphyton in Spring Creek exhibited limited (less than expected) temporal variation. When the effects of season were analyzed at each site using a one-way ANOVA, the fall periods were significantly different than the other seasons at the downstream sites, but no significant differences existed upstream (Figure 2 and 3). Although some of the seasons were not significantly different, it suggests that there may be varying degrees of seasonality among the sites. Interestingly, our sampling period brackets the occurrence of a hurricane that passed through the area in September of 2004 (see Figure 2). The scouring associated with this climatic influence appears to out-weigh the seasonal variation throughout the year, underscoring the relative importance of episodic disturbances.

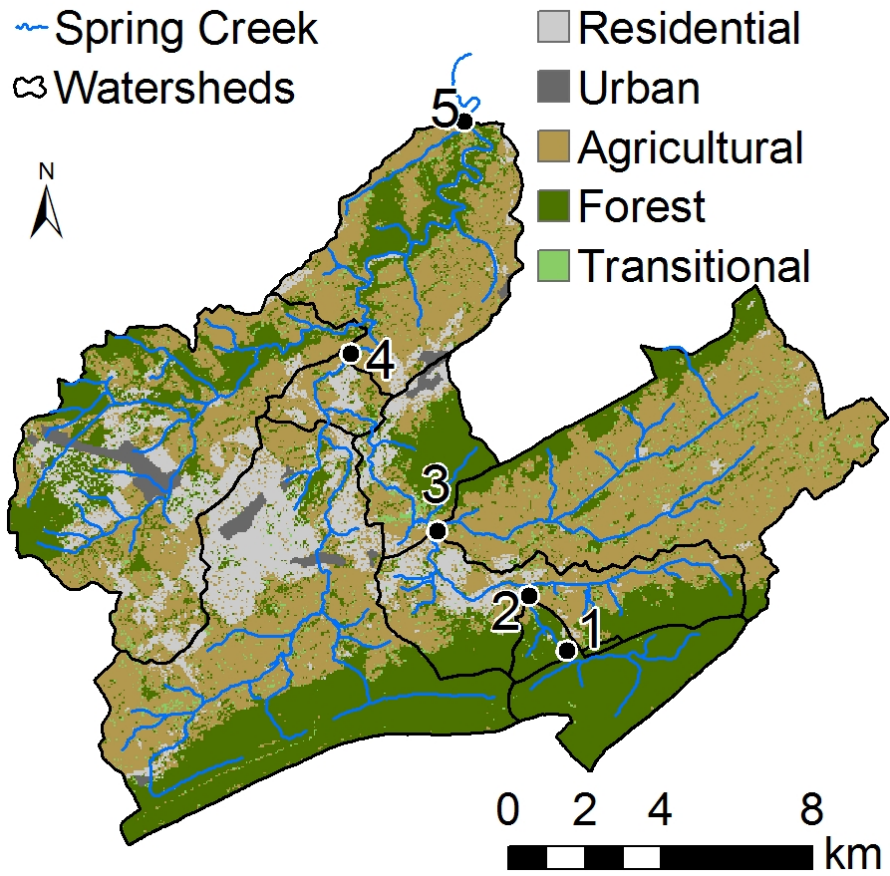
Average chlorophyll densities increase longitudinally downstream, although sites 4 and 5 supported the highest biomass and were not significantly different from one another (Figure 3). These data indicate that the downstream sites (sites 3, 4, and 5) are likely nutrient enriched from point and non-point sources influences in the watershed. This conclusion is supported further by the stable isotope

data measured on periphyton tissue (delta N-15 values), which shows a large increase downstream (range 1-3 upstream to 5-6 downstream), that was analogue to shift typically seen over 1-2 trophic levels in studied food webs. Because we see the shift at one trophic level (algae), we believe this is strong evidence for the incorporation of changing watershed sources N downstream. Interestingly, average chlorophyll at the five sites was highly correlated with increasing conductivity downstream as well ($r=0.94$, $p<0.01$, $n=5$). These results are consistent with predictions made from the River Continuum Concept, where growing watershed loadings impinge on downstream sites relative to upstream, headwater locations.

Nitrogen concentrations in stream water increase significantly from up to downstream locations (range 0.20 to 4.4 mg/liter). Concentrations were low at sites 1 and 2, increase at site 3, and were highest at sites 4 and 5. At the same time, total phosphorus concentrations were low at all sites (<0.200 mg/liter). Having said this, concentrations of N and P were measured in periphyton tissues during all sampling intervals ($n=17$ for all sites). While these data are still being analyzed, preliminary analysis indicates that internal nutrients stores in the periphyton were many times greater compared with those in the overlying water. Moreover, periphyton nutrients concentrations in the periphyton also increase downstream in accord with N concentration in the overlying water.

Two experiments were conducted to evaluate the degree of nutrient limitation exhibited by the periphyton in Spring Creek using nutrient releasing substrata (Control, N, P and N+P additions) that were deployed in the stream at selected sites (Spring and Summer seasons). In April of 2005, no significant difference was noted among enrichment treatments at sites 2 and 4. The result at site-2 was likely due to disturbance and high flow (observation), while we suspect the lack of response at site 4 may reflect the nutrient sufficiency of the periphyton community there. Another experiment was conducted in the summer of 2004 at sites 3 and 5, which also showed no differences among nutrient additions. These preliminary results suggest that periphyton in Spring Creek are nutrient sufficient (not limited), particularly at the downstream sites.

Figure 1. The Spring Creek watershed with five sampling locations and landuse identified.



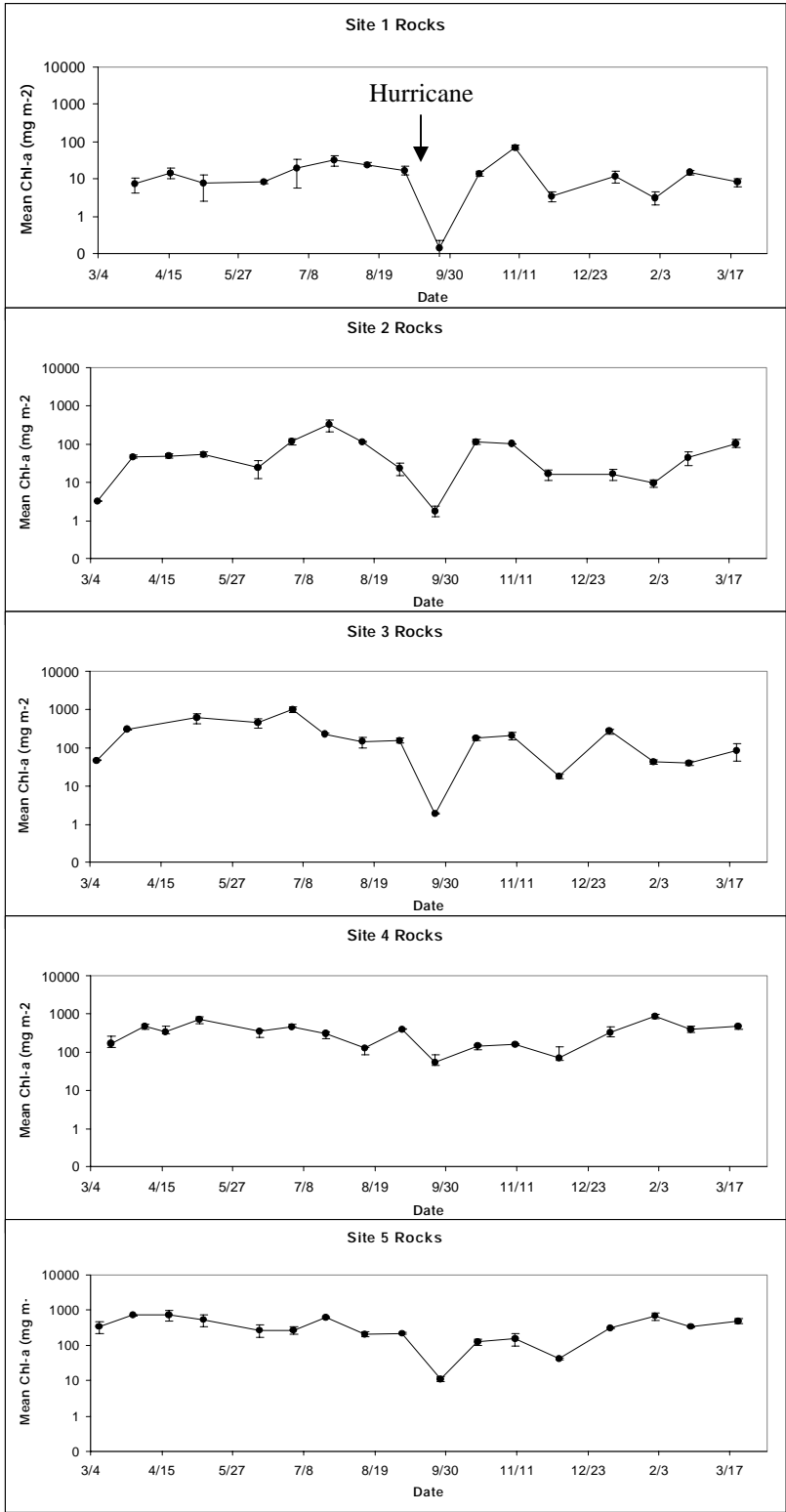


Figure 2. Log Chlorophyll-a concentrations (mg/m^2) for the five sampling sites (± 1 standard error). Peak flows from the Hurricane occurred on 9/18/04.

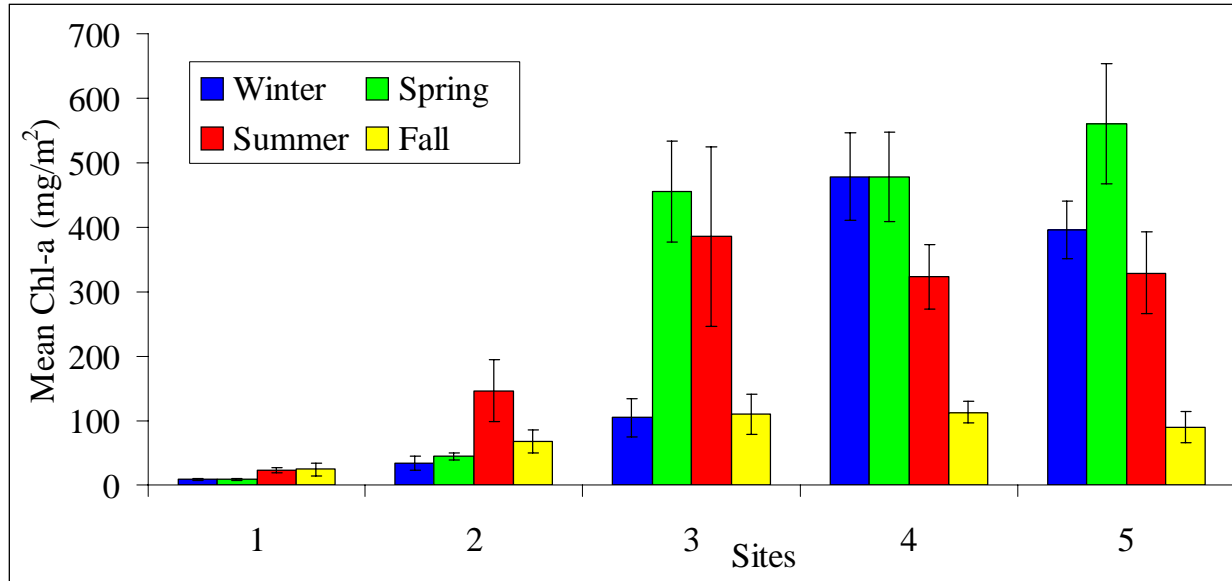


Figure 3. Mean chlorophyll densities (± 1 standard error) among four seasons at the five sites.

Publications: None published, but several in preparation including a student thesis.

Students Supported:

Student research has been supported on the Spring Creek project in the form of student financial support (wage employment), support of graduate research, and/or through undergraduate student involvement in independent research (completed credit hours 11).

- Casey Godwin (M.S. Student, Ecology, PSU, thesis in progress)
- Jessica B. Moon (Ph. D. Student, Ecology, PSU)
- Morgan Johnston (Undergrad, Environmental Resources Management, PSU)
- Joshua Jackson (Undergrad, Environmental Resources Management, PSU)
- Lindsay Olinde (Undergrad, Environmental Engineering, Louisiana State University)
- Corey L. Rilk (Undergrad, Environmental Resources Management, PSU)

Presentations and Other Information Transfer Activities:

- Godwin, C.M. (presenter), H.J. Carrick, and M.E. Johnston. 2005. Temporal and spatial variation in periphyton growth in a temperate, cold water stream. 3rd Annual Northeast Ecology and Evolution Conference, *Penn State University*, March 20.
- Carrick, H.J. 2005. Use of periphyton to evaluate stream environmental quality. PA Dept. of Environ. Protection Regional Workshop on Periphyton Sampling. State College, PA (26 April).
- Godwin, C.M. (presenter), H.J. Carrick, and M.J. Johnston-Greenwald. 2005. Temporal Patterns of Periphyton Accumulation in a Temperate, Cold-Water Stream. Joint Assembly of the American Geophysical Union and the North American Benthological Society, New Orleans, Louisiana (24 May)

Carrick co-hosted. Two-day workshop on periphyton sampling and identification (servicing 15 PA Dept. of Environ. Protect Agency employees). Pennsylvania State University and Fish and Boat Commission, University Park, PA (26-27 April).

Awards:

Support from this project supported the development (and eventual acquisition) of several research projects. These include the following:

- 2004 **PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION:** Water Quality Division. Entitled: Using periphyton to estimate TMDL endpoints and assess impairment in an urban-suburban stream (Skeppack Creek, Pennsylvania). PI: H. Carrick (\$40,242 over 1 year).
- 2004 **PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION:** Water Quality Division. Entitled: Assessing water quality conditions in an urban-suburban stream (Skeppack Creek, Pennsylvania) based on BOD measurements. PI: H. Carrick (\$28,700 over 1 year).
- 2005 **GROWING GREENER: Environmental Stewardship and Watershed Protection:** Use of periphyton to estimate TMDL end-points. PI: H. Carrick (\$ 158,749 over 2 year, PENDING).
- 2005 **GROWING GREENER: Environmental Stewardship and Watershed Protection-** Determining Variation in TMDL Reduction Criteria. PI: H. Carrick (\$ 144,333 over 2 year, PENDING).

Information Transfer Program

Spruce Creek Watershed Keystone Project

Basic Information

Title:	Spruce Creek Watershed Keystone Project
Project Number:	2004PA61B
Start Date:	3/1/2003
End Date:	4/30/2005
Funding Source:	104B
Congressional District:	5th of PA
Research Category:	Water Quality
Focus Category:	Management and Planning, Water Quality, Education
Descriptors:	education, management, nonpoint source pollution, planning, trout fishery, water quality, watershed stewardship
Principal Investigators:	Lysle Sherwin, Charles Andrew Cole

Publication

1. Torres, M.C. 2004. Using the AVGWLF Model and the Predict Tool for Quantitative Evaluation of Nutrient Loadings for the Spruce Creek Watershed. Masters Thesis in Environmental Pollution Control, Pennsylvania State University. University Park, PA.
2. Center for Watershed Stewardship, Pennsylvania State University. 2004. Spruce Creek Watershed Assessment and Stewardship Plan. University Park, PA.
3. Center for Watershed Stewardship, Pennsylvania State University (in press). Spruce Creek Watershed Assessment and Stewardship Plan, Phase II. University Park, PA.
4. Center for Watershed Stewardship, Pennsylvania State University (in press). Halfmoon Creek Restoration Plan. Growing Greener grant project report to the Pennsylvania Department of Environmental Protection.

Abstract:

This proposal seeks support for a graduate assistant working with two interdisciplinary teams of graduate students and faculty engaged in a two year watershed assessment and planning practicum (Keystone Project) in the Spruce Creek watershed of the Little Juniata River, Pennsylvania. One team of eight students will be assigned to the first phase (2003/2004) and a second team of nine students will be engaged in the second phase (2004/2005). Through participation in a watershed case problem, the students will develop competence in scientific data collection techniques and problem analysis tools directed at quantifying, analyzing, and ultimately mitigating widespread types of polluted runoff. The Keystone Project will also afford the graduate assistant an enhanced education in community-based, team-oriented watershed management and will provide outreach to the host watershed community. The project itself will address water quality issues in Spruce Creek, a high quality trout stream threatened by land development, agricultural enterprises, and in-stream flow reductions from groundwater withdrawals. The entire Spruce Creek watershed is designated as a High Quality-Cold Water Fishery by the PADEP Chapter 93 Water Quality Standards. However, two major tributaries and part of the mainstream were recently listed as impaired for suspended solids by the PADEP 303(d) list, attributable to agriculture and land development activities. Watershed stakeholders are concerned that other stream segments may be impaired, and there are emerging problems with inadequate treatment of sewage effluent from on-lot systems. Data on stream flow and water chemistry are insufficient to calculate pollutant loadings as the baseline to determine appropriate reductions needed to achieve water quality standards and protect designated uses. Modeling polluted runoff in the impaired reaches will serve to target critical contributions and serve as a basis for development of a watershed restoration plan.

Statement of Critical Need:

Spruce Creek is a nationally recognized trout fishery potentially threatened by residential and commercial land development pressure, a variety of agricultural enterprises, and in-stream flow reductions from groundwater withdrawals. The entire Spruce Creek watershed is designated as a High Quality-Cold Water Fishery by the PADEP Chapter 93 Water Quality Standards, which mandates special protection under the “non-degradation” criteria of the Federal Clean Water Act. However, a 1.4-mile reach of Halfmoon Creek, a major tributary, a 16 mile segment of Warriors Mark Run, and two miles of the main stem of Spruce Creek were recently listed as water quality impaired for suspended solids by the PADEP 303(d) list, attributable to poor livestock pasture management practices at several beef cattle, dairy, and horse stable operations and to residential land development activities. There are concerns among watershed stakeholders that other stream segments may be similarly impaired, or are becoming so, as well as emerging problems with excessive nutrient loadings and pathogens associated with inadequate treatment of domestic sewage effluent from on-lot systems. Quantitative data on stream flow and water chemistry are insufficient to calculate current pollutant loadings as the baseline to determine appropriate reductions required to achieve water quality standards and protect designated uses. Despite deep-seated concerns about future water resources trends and strong motivation among stakeholders to protect the water resource and fishery, there is a lack of a cohesive watershed initiative grounded in the

community or collaborative approaches and restoration strategies and programs in place to address the problem.

Statement of Results of Benefits:

We will produce a watershed stewardship plan and a watershed restoration plan in two phases which are responsive to watershed residents' goals and incorporates implementable recommendations and strategies for cooperative action. Deliverables at the conclusion of the Keystone Project in May 2005 will include: printed color copies of the final plan document; CD-ROM files of all related work products such as public meeting information and educational display posters and digital presentations, GIS data layers, field data, and relevant analyses used on specific assessment topics; documentation of community focus group sessions, planning meetings and workshops to develop management recommendations and; a model TMDL prescription for suspended solids impairment of Halfmoon Creek in the form of a restoration plan.

Nature, Scope and Objectives:

The nature and scope of the project essentially entails experiential training of graduate students in water resources disciplines through a scientific watershed assessment utilizing existing and original data and a team-based, case problem planning approach conducted in close collaboration with community stakeholders, governmental agencies, and academics. The project objectives are to: a) Collect original and existing data on water chemistry and flow, land cover and land use, aquatic biota, and other information relevant to the restoration of impaired water quality and the protection of water resources to meet designated uses in the study watershed; b) Analyze data to assess problems and engage a broad base of stakeholders in developing shared watershed restoration goals; c) Produce a watershed stewardship plan that is responsive to those goals and that incorporates recommendations and strategies for cooperative action. A model Total Maximum Daily Load (TMDL) prescription would be prepared for the impaired reach of Halfmoon Creek; d) Produce a Watershed Restoration Plan for Halfmoon Creek; and, e) Replicate the TMDL analysis for the second impaired tributary (Warriors Mark Creek) as a precursor for future restoration planning in that subwatershed.

a) Conduct an assessment of biophysical and cultural factors in the watershed related to protection and restoration of water quality to support designated uses and progressive land use.

b) Analyze assessment data to identify problems and opportunities and engage a broad base of stakeholders in developing shared watershed restoration and protection goals.

c) Produce a watershed stewardship plan responsive to those goals and that incorporates implementable recommendations and strategies for cooperative action. A model Total Maximum Daily Load (TMDL) would be prepared for the impaired reach of Halfmoon Creek.

d) Produce a Watershed Restoration Plan for Halfmoon Creek

e) Replicate the TMDL analysis for the second impaired tributary (Warriors Mark Creek) as a precursor for future restoration planning in that subwatershed.

Methods, Procedures and Facilities:

Water samples will be collected beginning August 2003 at five stations on Halfmoon Creek - three within the impaired reach, one upstream of the impaired reach, and one reference station in the upper watershed. A sampling location will also be established on an unnamed tributary, locally known as Loveville Creek. Analysis will be done for total suspended solids, total nitrogen, and total phosphorus. Runoff event samples will also be collected randomly through the project period. Measurement of stream flow will be done concurrently using portable current meters. Pennsylvania Spatial Data land cover and other data will be retrieved and clipped using Arc-View GIS. The Keystone team and the research assistant will be engaged in organizing a series of community stakeholder input meetings. A day-long watershed planning workshop of experts will be convened in Spring 2004 to review and critique the proposed pollution abatement recommendations developed by the student team and to develop strategies for implementation of management practices. These recommendations would be presented at a public forum at the completion of the first phase of the Keystone Project in April 2004. The graduate research assistant funded by this proposed grant would have lead responsibility of communicating the data findings and the analysis to layperson and technical audiences at the various forums and workshop and in direct meetings with private landowners and representatives of collaborating agencies involved in implementation of watershed restoration practices.

Over the summer, 2004, the graduate assistant will be involved in digitizing site maps and coordination with landowners and partner organizations relevant to a site specific restoration plan for Halfmoon Creek. Beginning in the fall 2004 semester, the full student team will commence work on a more extensive assessment and field data collection at a number of sites throughout the Spruce Creek. Methods will include an IBI, Rapid Bioassessments, electrofishing, Arc-View GWLF modeling and a variety of other data collection and analytical tools. The team will also work in collaboration with watershed stakeholders to define task areas that would be supportive of an emerging community-based watershed protection and restoration program in the Spruce Creek watershed. The 2004/2005 team will utilize a similar schedule of planning workshops and meeting and produce a report document and community presentation in April 2005.

Principal Findings and Significance:

Watershed data collection and assessment in the Spruce Creek watershed during the summer of 2004 and the 2004/2005 academic year by graduate students at the Center for Watershed Stewardship supported by the USGS Water Center grant focused on the following research areas:

- a). Nine digital temperature data loggers (Stow Away TidbiT -4 to 122F model) purchased with the USGS grant were installed in the summer of 2004 at locations throughout the Spruce Creek watershed. Hourly temperatures were recorded from July 2 to August 3, 2004 and compared with long term climate averages at the Rock Springs and State College weather stations. Despite a cooler and wetter than average summer in 2004, four of five stations on Halfmoon Creek tributary exceeded the 70 degree stress threshold for brown trout

for extended periods (from 12 to 19 days) during the 33 day monitoring period. A close correlation was observed between the lack of vegetative riparian cover at the four monitoring stations and elevated stream water temperatures. The thermal data are being applied to the prioritization of riparian buffer planting projects being planned and implemented in the Halfmoon Creek subwatershed.

b). Water quality data (N, TSS, and P) were obtained and analyzed at the PSIE Water Laboratory by two students for their thesis research and the Keystone Project watershed assessment to conduct AVGWLF (ArcView Generalized Watershed Loading Function) modeling of the Halfmoon Creek and Warriors Mark Run subwatersheds and the entire Spruce Creek basin. Analysis of Halfmoon Creek data by Maria C. Torres and the simulated nutrient data from the modeling showed good agreement. Measured concentrations at three flow rates (base, mean, and bank-full) showed P exceeded EPA recommended levels (.10 mg/l) during bank-full flow at all stations and at mean flow rates for half of the monitoring stations. Total nitrogen exceeded recommended levels (1.00 mg/l) at all stations for all flow levels by 2-6 times. Modeling and water sample analysis by Megan Walsh on Warriors Mark Run is underway. Preliminary data indicate similar findings for that subwatershed which will also underscore the need for improved agricultural land management to address water quality impairment issues.

c). Drinking water monitoring primarily involved two students (Leonard McNeal and Nesha Mizel) partly supported by the USGS grant. In collaboration with Bryan Swistock, PSU Cooperative Extension, fifty private drinking water wells in the Spruce Creek watershed were analyzed at no cost to homeowners for Nitrates, Arsenic, and pH at the PSIE Water Laboratory. Students were trained in and conducted laboratory tests for coliform and E. coli bacteria and Total Dissolved Solids. Approximately 60 percent of the wells tested had coliform bacteria. Ten percent of the wells tested exceed Safe Drinking Water Act standards for Nitrates, TDS and E.coli; none of the wells exceeded Arsenic drinking water standards. Primary outcomes of the research in Spruce Creek watershed has been the Keystone Project's impetus for the formation of Spruce Creek Watershed Association, the active engagement of a broader base of community stakeholders, and an expanding base of private/public partners involved in implementation of projects targeting restoration of watershed streams and educational and outreach programming at the community level.

Students Supported:

Cristina M. Torres, MS Environmental Pollution Control (AVGWLF model)
Brent Bakner, MS Environmental Pollution Control (thermal monitoring)
Megan Walsh, MS Environmental Pollution Control (AVGWLF model)
Leonard McNeal, MS Environmental Pollution Control (drinking water monitoring)
Nesha Mizel, MS Forest Resources (drinking water monitoring)

Presentations and Other Information Transfer Activities:

Students and faculty made presentations and three evening workshop and meetings open to the public to communicate research objectives and findings and to recruit participants in the Drinking Water Monitoring project. In addition, on April 23, 2005 a day-long “Spruce Creek Watershed Activity Day” was held at a church camp facility in the Spruce Creek watershed. An overview presentation of the Keystone Project was made by students, as well as individual distribution of confidential well monitoring reports with discussion of best management practices given by Bryan Swistock to address specific problems. Further, the Activity Day events included a riparian buffer planting project and program on watershed benefits of buffers, fish census electrofishing demonstration, macroinvertebrate collection techniques and bioassessment protocols, and a tour of dairy farm operations describing water and nutrient management practices.

Copies of the 2004 Keystone Project Stewardship Plan in print and CD ROM formats were distributed to six Townships, county planning agencies, county conservation districts, local fishing clubs and community leaders. Similar distribution will be made of the 2005 Phase II Spruce Creek report in press.

Awards:

None

Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 RCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	13	0	0	0	13
Masters	7	0	0	0	7
Ph.D.	1	0	0	0	1
Post-Doc.	0	0	0	0	0
Total	21	0	0	0	21

Notable Awards and Achievements

Research and public education programs on the Spruce Creek basin in south-central PA, supported through two separate projects during this past year to faculty at both Penn State-University Park (Prof. Lysle Sherwin and Dr. C. A. Cole) and Juniata College (Drs. D. Johnson, R. Mathur, and D. Lehman), led to a significant public education program and the formation of the Spruce Creek Watershed Association that has engaged a broader base of community stakeholders to begin restoration of water quality impaired by intensive dairy farm operations.

Laboratory research conducted by Dr. Baikun Li at Penn State-Harrisburg on sequenced batch reactor (SBR) systems for treatment of wastewater showed that SRB systems are capable, under the proper operating conditions, of meeting newer more stringent nitrogen removal being required by the PA Department of Environmental Protection. SRB systems require that flow rates, aeration times for nitrification and anoxic times for denitrification be controlled to match flow rates and carbon sources in the wastewater to achieve sufficient nitrogen removal. The research has led to a proposed field test of SBR technology at the Middletown, PA wastewater treatment plant in cooperation with the equipment manufacturer.

Publications from Prior Projects

1. 2001PA2881B ("In-line Coagulation for Microfiltration") - Articles in Refereed Scientific Journals - Choi, K.Y. and B.A. Dempsey. 2004. In-line coagulation with low-pressure membrane filtration. *Water Research* 38, 4271-4281.
2. 2001PA2881B ("In-line Coagulation for Microfiltration") - Articles in Refereed Scientific Journals - Choi, K.Y. and B.A. Dempsey. 2005. Fouling in Ultrafiltration: Effects of Aquatic and Terrestrial Natural Organic Materials. *Journal American Water Works Association* (in press-July).
3. 2001PA2881B ("In-line Coagulation for Microfiltration") - Articles in Refereed Scientific Journals - Choi, K.Y. and B.A. Dempsey. 2005. Bench-scale Evaluation of Critical Flux and Trans-membrane Pressure for Low-Pressure Membrane Filtration. (In Review).
4. 2002PA3B ("Water Reuse: Using Crumb Rubber for Wastewater Filtration") - Dissertations - Chen,

- Peng. 2004. Ballast Water Treatment by Crumb Rubber Filtration - A Preliminary Study, Master's Paper, Environmental Pollution Control Program, Penn State Harrisburg.
5. 1998PAC-03 ("Seasonal Oxygen-18 Variations and Groundwater Recharge for Three Landscape Types in Central Pennsylvania, USA") - Articles in Refereed Scientific Journals - O'Driscoll, M.A., D.R. DeWalle, K.J. McGuire, and W.J. Gburek. 2005. *J. Hydrol.* 303(1-4):108-124.
 6. 1998PAC-03 ("Influences of Bedrock Geology and Tree Species Composition on Stream Nitrate Concentrations from Mid-Appalachian Forested Watersheds") - Articles in Refereed Scientific Journals - Williard, K.W.J., D.R. DeWalle, P.J. Edwards. 2005. *Water, Air, and Soil Pollution.* 160(1-4):55-76.