A Framework for Trading Phosphorus Credits in the Lake Allatoona Watershed

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A. INTRODUCTION

Using the Lake Allatoona watershed in north Georgia as a case study, we plan to develop and analyze a framework for trading phosphorus (P) credits between point and agricultural non-point sources (Fig. 1). A well-designed trading program can meet water quality objectives at lower compliance costs and provide economic incentives to reduce emissions. By assessing the effectiveness of agricultural best management practices, we can help the farming community target control activities most effectively. Our long term goal is to prevent the degradation of water quality in Lake Allatoona by meeting the P load restrictions that have been imposed by the Georgia Environmental Protection Division and further reductions that are likely to be imposed in a TMDL to be developed by the end of 2003.

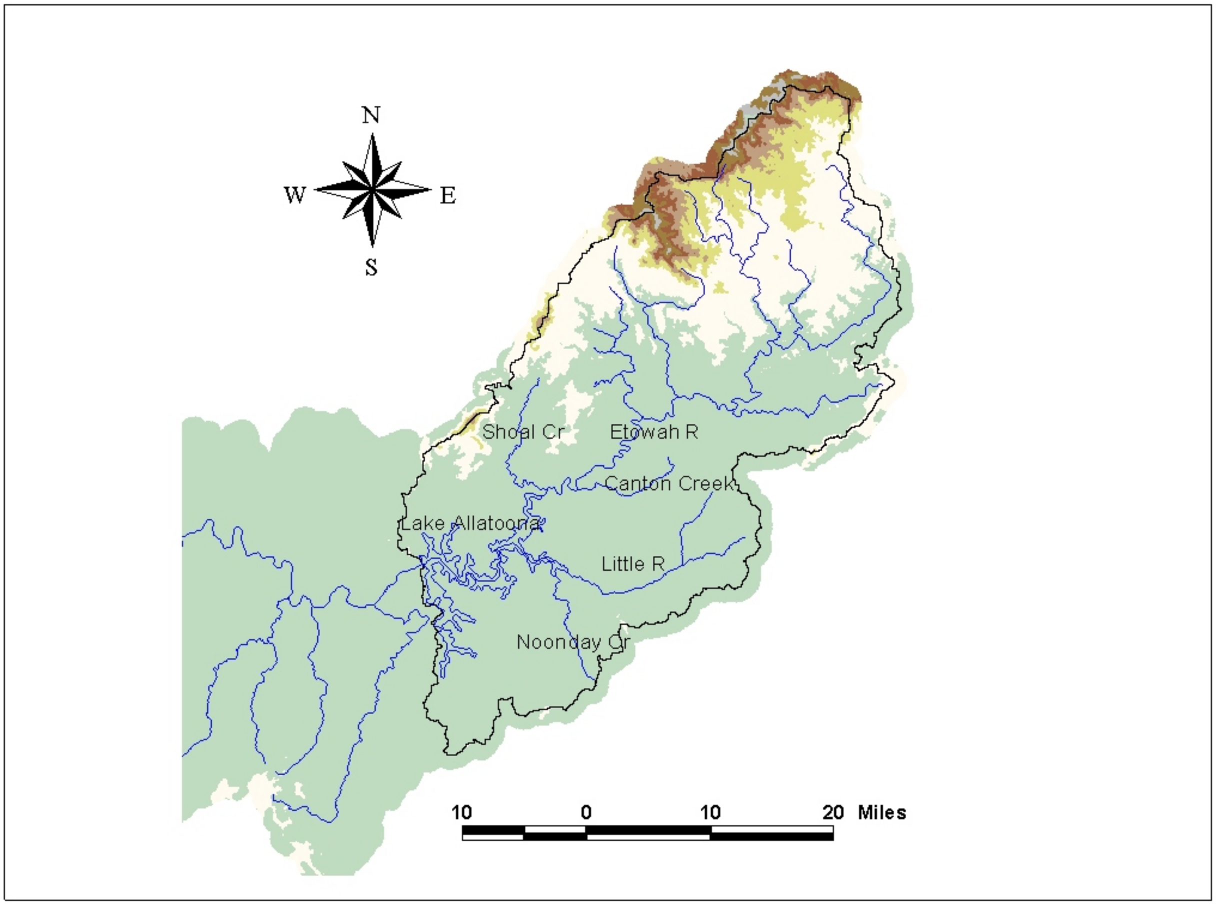

Figure 1. Lake Allatoona Watershed

Nutrient Trading

Our focus is on P as this is the primary non-point source pollutant in the Lake Allatoona watershed. Controlling non-point source pollutants requires a change in the tools we use to control pollutants. The permit process, which works well for point source pollutants, is difficult to apply to diffuse, dispersed non-point source pollutants. Instead, a mix of pollution prevention techniques, best management practices (BMPs), land use controls, and incentives for land preservation are necessary for the control of non-point source water pollution.

Emissions trading has become a widely accepted tool of cost-effective environmental protection over the past two decades. The best known examples are the Acid Rain Trading Program created by Title IV of the 1990 Clean Air Act Amendments and the architecture for international burden sharing under the Kyoto Protocol. Emissions trading programs designed to meet water quality standards bring additional complexities compared to these better-knows programs that regulate atmospheric emissions. US EPA's recently-finalized policy on water quality trading (US EPA, 2003b) sets forth the Agency's current framework for trading to meet water quality objectives.

A primary objective of water quality trading is to meet or exceed environmental objectives at lower cost than alternative regulatory structures. Those entities that face high costs of nutrient emission reductions can transfer their obligation to those that have lower costs, and do so in a way that makes both parties better off from the exchange. This central advantage of emissions trading has been thoroughly demonstrated in practice and in theory, and is vitally important in strategies to achieve the best possible combination of environmental and economic objectives.

In the case of water quality trading, an additional advantage is the ability to engage non-point sources of nutrients in solving watershed problems. If point sources (such as waste water treatment facilities, WWTFs) are willing to pay non-point sources (for example, farmers instituting BMPs) to engage in pollution-reducing activities, it would be an important step forward in engaging non-point sources as part of a strategy to meet watershed objectives. Equally important, this engagement would take place through voluntary actions by non-point sources.

Effluent trading programs were first developed in the early 1980s. A review of effluent trading and offset programs completed in 1999 found 37 programs in various stages of operation (Sessions and Leifman, 1999). The scale of the trading programs range from an individual facility, a localized group of facilities affecting the same water body, a watershed, or an entire state. The following programs have conducted a few point/non-point trades: Cherry Creek Basin Trading Program (CO), Lake Dillon Trading Program (CO), and Rahr Malting (MN). Credits generated in the Tar-Pamlico Nutrient Reduction Trading Program (NC) have not been needed by the dischargers and have been banked for future use. Although there are a number of trading programs in existence, a program has not been developed to date that has resulted in a significant number of trades between point and non-point sources.

Our goal is to develop a scientifically-based framework for water quality trading between point and non-point sources. We will use watershed-scale modeling to develop loading estimates for different agricultural practices that have been identified as contributing to non-point source pollution in the watershed. These loading estimates along with load estimates from other land use categories will be used to scale and route loads through the stream system. Load estimates for other land use types will be taken from previous studies in the region and the literature. Results from the model will be used to develop the appropriate trading ratios between non-point and point sources.

Watershed Models

Watershed models can be categorized as *lumped* or *distributed* models (Beven, 2001). Lumped models treat a watershed as a single unit and model water and chemical movement to the the watershed outlet using *effective* parameters. Fully distributed models divide the watershed into grid or pixel cells and model water and chemical movement from cell to cell, including along the stream channel, and eventually to the watershed outlet. There are few fully distributed models due to the complexity of these models and the need for parameters for each cell. Many models lie somewhere between lumped and distributed and are called *semi-distributed* models (Corwin et al., 1999). Semi-distributed models are appropriate for simulating the effect of BMPs because they have high spatial resolution, but do not have an excessive number of parameters for calibration.

Currently there are two semi-distributed models that are widely used for predominately rural watersheds. These are the Hydrological Simulation Program – Fortran (HSPF) (Bicknell et al., 2001) and the Soil Water Assessment Tool (SWAT) (Neitsch et al., 2001). Both models are part of the U.S. EPA Better Assessment Science Integrating Point and Non-point Sources (BASINS) software package designed for developing Total Maximum Daily Loads (TMDLs) (US EPA, 2003a). HSPF has a long history of usage by hydrologists and there is a large database of parameter values used by modelers in calibrated simulations in various regions of the U.S., including the Piedmont (Donigian et al., 1999). However, most of the HSPF parameters relating to soil processes are unique to the model and must be obtained by calibration.

We propose to use SWAT to model P transport in our project. Since P is tightly adsorbed to sediment, we must also model the movement of sediment. SWAT was developed in the 1990's and is derived from earlier models including the Simulator for Water Resources in Rural Basins (SWRRB; Williams et al., 1985; Arnold et al., 1990), the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS; Knisel, 1980), the Groundwater Loading Effects on Agricultural Management Systems (GLEAMS; Leonard et al., 1987) and the Erosion-Productivity Impact Calculator (EPIC; Williams et al., 1984).

For our purposes, the watershed model we use must be able to predict the reductions in P loading to the lake that occur as a result of the implementation of various best management practices (BMP). SWAT is able to simulate a very extensive set of agricultural BMP's ranging from changes in tillage practices (over 100 practices), manure/fertilizer management (over 50 sources), and conservation practices. SWAT also models in-stream processes affecting P and sediment transport including sorption and desorption to bed sediment and scouring and deposition of sediment.

Characteristics of the Lake Allatoona Watershed

The Lake Allatoona watershed drains an area of 1,050 square miles. The Etowah River is the major tributary and Canton Creek, Shoal Creek, Little River, and Noonday Creek are minor tributaries (Fig. 1). The average volume of Lake Allatoona is 367,000 acre-ft, although it has varied historically between 120,000 and 694,000. Mean annual flow is 1,939 cfs, so the average residence time is 95 days. Most of the watershed is in forest, with significant areas in pasture/hay, and residential land use (Table 1).

Table 1. Land use in the Lake Allatoona watershed based on Multi-Resolution Landuse Consortium data from 1991-1993 (US EPA, 2003a).

Land Use	Area (mi^2)	Area (%)
Deciduous Forest	440.8	42.0
Mixed Forest	302.8	28.2
Evergreen Forest	180.7	17.2
Pasture/Hay	81.2	7.7
Residential	29.0	2.7
Water	19.5	1.8
Row Crops	11.8	1.1
Commercial	10.4	1.0
Wetlands	2.8	0.5

There are significant areas of agricultural land use in the more rural northern part of the watershed. The number of animals in the counties with significant area in the Lake Allatoona watershed is shown in Table 2 for the year 2000. Broiler production is the main agricultural activity and a typical farm combines this with beef cattle production on pastures.

Table 2. Number of animals estimated by NRCS in 2000 for each county with significant area within the Lake Allatoona watershed.

County	Beef	Broilers	Dairy	Swine	Layers
Cherokee	9,000	3,513,000	125	-	-
Cobb	-	-	-	-	-
Dawson	3,500	5,177,600	-	-	-
Forsyth	7,500	4,664,000	-	-	9,000
Lumpkin	3,610	3,808,000	200	175	730,000
Pickens	4,200	4,396,000	-	300	-

There are eight point sources in the watershed with NPDES permits for P loads (Table 3). Lake Allatoona is on the northwestern outskirts of the Atlanta metropolitan area and rapid development is occurring along the southern shore of the lake. A 1999 study projected that population in these counties would double by 2010 (Rose, 1999).

Table 3. Point sources with NPDES permits for P loads in the Lake Allatoona Watershed (Rose, 1999).

Point Source	Permitted P Load (lbs/yr)
Cobb County Noonday Creek WWTF	36,420
Cherokee County Water and Sewerage	12,625
Cobb County Northwest WWTF	12,140
Big Canoe Sewage Treatment Plant	3,035
Woodstock WWTF	1,517
Fulton County Little River WWTF	1,289
Total	67,026

A comprehensive study water quality in Lake Allatoona (the Lake Allatoona Phase I Clean Lakes Diagnostic Feasibility Study, referred to hereafter as the Clean Lakes Study) was conducted under two Clean Lakes Section 319 projects during the 1990's (Rose, 1999). From May 1992 to April 1993 bimonthly samples of P concentrations and stream flow were measured at the 12 main tributaries where they enter Lake Allatoona (limited sampling was also done on secondary tributaries). Annual loads were calculated by summing the products of the measured P concentration, measured flow, and interval between sampling dates. The estimated mean annual flow, P concentration, and load for the various tributaries are shown in Table 4. Most of the P load came from the Etowah River which drains the agricultural production area. However, two of the streams that drained the developed areas (Little River and Noonday Creek) had substantial percentages of the load.

The Lakes Study classified the Lake Allatoona as being in transition between mesotrophic and eutrophic, with P being the primary limiting nutrient for algal growth (Rose, 1999). The authors concluded that unless measures were taken to control P inputs to the lake, it would be unfit for drinking or recreational purposes within ten years. As a result, the Georgia EPD has imposed a P load restriction of not more than 1.3 lb/acre-ft of lake volume per year (GAEPD, 2002). This was developed using the estimated total load for the year (May 1992 to April 1993) in which the Clean Lakes study was conducted. In Table 5, we show a P budget for loading to Lake Allatoona for 1992-1993. We compare the load restriction (converted to a total load using an average annual lake volume of 367,000 acre-ft) to the point source permitted loads (Table 3), non-point source loads (Table 4 corrected for any point source loads that were upstream of the sampling sites), and input from rainfall (from the Clean Lakes study). The Lake Allatoona Watershed is an ideal area for trading between point and non-point sources since most of the current P load to the lake appears to come from non-point sources.

Table 4. Estimated annual flow, P concentration, and P load for tributaries to Lake Allatoona for the period May 1992 to April 1993 from the Clean Lakes Study report for 1992-1997 (Rose, 1999).

Tributary	Annual Flow (m^3/yr)	Annual P Concentration (mg/L)	Annual P Load (lbs/yr)	Percent of P Load (%)
Allatoona Creek	23,106,630	0.064	3,242	0.73
Lake Acworth Discharge	7,611,215	0.032	543	0.12
Tanyard Creek	9,236,417	0.101	2,043	0.46
Kellogg Creek	2,037,494	0.071	319	0.07
Owl Creek	857,634	0.234	442	0.10
Noonday Creek	93,620,444	0.128	26,308	5.95
Little River	317,463,678	0.060	41,666	9.43
Etowah River	1,683,198,973	0.094	349,257	79.05
Shoal Creek	107,558,814	0.039	9,137	2.07
Stamp Creek	24,870,572	0.034	1,835	0.42
Roland Spring	1,338,078	0.032	95	0.02
Secondary Tributaries	8,121,213	0.387	6,919	1.57
Total	2,279,021,162	0.090	441,806	100.00

Table 5. Estimated P budget in 1992-1993 for loading to Lake Allatoona comparing P point and non-point source total loads with the load restriction for Lake Allatoona.

Source	Annual P Load (lbs/yr)	Percentage of Load Restriction (%)
Permitted Point Sources	67,026	14.0
Estimated Non-point Sources[1]	403,869	84.6
Rainfall input[1]	7,447	1.5
Total Load[1]	478,342	100.3
Current Load Restriction (1.3 lb/acre-ft-yr)	477,100	100.0

[1] For the year May 1992 to April 1993 from the Clean Lakes Study (Rose, 1999)

Since the completion of the Clean Lakes Study, there have been other indications that Lake Allatoona is becoming eutrophic . When municipal water supply systems use water from lakes that is high in organic C (due to algal growth) and treat it with chlorine before distributing the water to consumers, carcinogenic *disinfection byproducts* are produced (US EPA, 1991). EPA has set limits on the annual average concentration in drinking water systems for two groups of byproducts: total trihalomethanes (TTHMs) and total haloacetic acids (THAAs). These limits are 80 ppb for TTMMs and 60 ppb for THAAs. The Cobb County Water System draws most of it's water from Lake Allatoona and the annual average of THAAs for 2000 and 2001 were 56.4 and 55.9, respectively. An Atlanta Journal Constitution article in late 2002 described the situation as follows:

> At least two water systems that use chlorine – Cobb County's and Rome's – expect to exceed the federal limit for a group of cancer-causing chemicals called haloacetic acids. Correcting the problem will cost millions of dollars.... "If we stay as we are, we'll be in violation by the first of January," said R. Wayne Jackson, director of laboratories... (Unger, 2002).

EPD intends to develop a nutrient TMDL for Lake Allatoona in 2003 when Georgia's rotating-basin schedule for TMDLs focuses on the Coosa River watershed. Since the watershed includes counties with some of the fastest growth rates in the state, existing wastewater treatment capacity is likely to be expanded. It's also likely that the P load restriction will need to be lowered to keep Lake Allatoona from becoming eutrophic. These measures will likely make P trading a more attractive and cost-effective alternative to plant upgrades for point sources.

Outreach

There is a strong partnership between the University of Georgia and the governmental bodies and major stakeholders within the Lake Allatoona watershed. The partnership was initiated in 1996 in response to requests from local governments, regional planning bodies, water and sewer authorities and conservation organizations for information on preserving water quality, biodiversity and agricultural land in the region. This partnership has already proven productive. In 1998, UGA helped stakeholders establish the Upper Etowah River Alliance, a forum for addressing issues on a watershed basis with a diverse membership appointed by the elected officials of the five counties, the soil and water conservation districts, and the watershed's two resource conservation districts. Working with individual local governments within the watershed, a team of interdisciplinary University of Georgia faculty and students drafted a water management regime which allows increased withdrawal to meet water supply demands while providing flow necessary to protect endangered darters, state legislation allowing the use of transferable development rights in the Etowah and other regions to protect water quality and biodiversity, and an innovative conservation subdivision ordinance which provides significant incentives for preserving buffers along the river and its tributaries. The team helped develop a proposal for an Etowah River Greenway and a prioritization system for wetlands protection in the watershed. Faculty at the University of Georgia also serve on the Scientific Advisory Committee of the Lake Allatoona Preservation Authority, which was created by the Georgia Legislature in 1999 to preserve Lake Allatoona for the public good.

More recently, the U.S. Fish and Wildlife Service awarded a grant to a team of scientists, policy analysts and educators from the University of Georgia, Kennesaw State University and the

Georgia Conservancy in 2001 for the development of a regional Habitat Conservation Plan that minimizes the impacts of development on the imperiled aquatic species of the Etowah River. The watershed has been identified as a key "hot spot" of threatened biodiversity where it is still technically, socially, and economically feasible to preserve and rehabilitate the riverine ecosystem and thereby conserve endangered species (Dobson et al., 1997; Pulliam and Babbitt, 1997). The planning process is overseen by a steering committee composed of representatives from each of the counties and municipalities within the watershed.

This proposal would build on these past efforts and facilitate the development of a collaborative and comprehensive point and non-point source management program for the Lake Allatoona watershed that could be used as a model for other watersheds. It would specifically allow us to respond to stakeholders who have expressed an interest in creating a trading program and prominent members of the agricultural community who have pledged their commitment to implementing BMPs.

The University of Georgia is in a unique position to spearhead such a project because it is the entity the major stakeholders have already approached for solutions to water quality problems and it has an outstanding record of successful collaboration in the watershed. This is shown in the letters of support we have obtained for this project (Appendix). The University also has a nationally-recognized research and outreach program in animal waste management, especially in regard to P and broiler operations. The hydrology and ecology programs are also very strong with expertise in both stream and lake processes. Natural resource economics is another area where the university has expertise. The hallmark of integration of these programs is the recently formed River Basin Science and Policy Center at the University of Georgia, which has over 90 faculty members from 28 departments working together on science and policy issues related to water (www.rivercenter.uga.edu). All of the investigators are members of the center and one of the investigators (Laurie Fowler) is co-director for outreach.

B. OBJECTIVES

The overall objective is to establish a framework for trading P credits between point sources and agricultural non-point sources in the Lake Allatoona watershed. Specific objectives are to:

- use stream monitoring to determine the P and sediment loading from typical agricultural operations with a range of BMP implementation
- use this monitoring data plus historical data to calibrate a watershed-scale model for the basin, including the effects of implementing agricultural BMPs
- use uncertainty analysis of the model to develop scientifically-based P trading ratios for point and agricultural non-point sources
- analyze various frameworks for P trading in the watershed
- create an advisory council of stakeholders to assist in identifying potential trading opportunities, evaluating trading frameworks, and determining the best method for communicating to a larger, more diverse audience.

We view this project as the first step in a larger effort to develop a P and sediment trading program between point sources and all potential non-point sources, including urban and suburban areas. To include these other non-point sources in the proposed project would require additional monitoring beyond the resources available in the current program. We will seek funding through other programs for this work to expand the trading program to other trading partners.

C. METHODS

Stream Monitoring

Flow, sediment, and P data from small streams draining agricultural operations are needed to estimate loadings from agricultural lands, the load reductions that result when BMPs are implemented, and to calibrate the SWAT model. We will focus on poultry and beef cattle operations because these are the predominate agricultural land use in the watershed (and in the Piedmont region of Georgia). We plan to monitor flow, sediment, and P at nine first- or second-order streams draining small basins dominated by cattle and broiler operations partitioned into three levels of BMP implementation:

- Farms that have not participated in any conservation programs, have no stack houses for storing broiler litter, have a low level of nutrient management planning (NMP), use high levels of litter application, and have little use of riparian buffer or fencing of cattle from streams.
- Farms that have participated in conservation programs, have and use proper NMP, use of riparian buffers or fencing from streams, have intermediate levels of litter application.
- Farms that export all litter or apply less than 2 tons/acre-yr.

There will be sampling sites for each type of basin. In addition, we will monitor three streams draining mature forest land to act as controls and provide reference data for small streams in the Lake Allatoona watershed.

To monitor flows, we will install a V-notch weir or H-flume (depending on the stream substrate and the amount of flow) instrumented with a pressure transducer connected to a datalogger. Flows will be monitored at a 15 minute time interval. Stream water will be sampled with ISCO automated samplers. Water samples will be collected bi-weekly and during storm events. Robertson and Roerish (1999) found this to be an optimal sampling strategy for determining average annual loads. Samples will be analyzed for suspended sediment concentration (SSC), dissolved reactive P, and total P. Dissolved reactive P will be quantified using colorimetric techniques and total Kjeldhal P will be analyzed using a micro-Kjeldhal, automated ascorbic acid reduction method. Both techniques are adapted from EPA approved methods (Greenberg et al. 1992). SSC will be analyzed using the evaporation method (Guy, 1969).

To determine the effect of stream processes such as adsorption/desorption and immobilization/mineralization on P transport, we will conduct synoptic sampling along reaches on several dates using grab samples during baseflow conditions. After SWAT is calibrated for flow and loading of P from uplands, we will use this data to calibrate the in-stream process parameters.

Model Calibration

SWAT calculates daily additions of groundwater, interflow, and overland flow from different land use and soil combinations (called hyrdrologic response units, HRUs) to stream reaches within a watershed and routes these through the reaches to a designated pour point. SWAT uses a curve number approach to calculate overland flow. This is a strength in that the curve number approach is derived from watershed studies and has been shown to be compatible with a variable source area approach (Steenhuis et al., 1995). The primary parameter for runoff is the curve number and tables for relating curve number to soil, land use, and management are well established (McCuen, 1982). The parameters that control groundwater and interflow are usually obtained by calibration.

SWAT uses a common method for modeling P losses from a given HRU based on equations that predict the dissolved P and particulate P concentrations in runoff. Dissolved P is the product of the soil test P concentration in the surface soil, an extraction coefficient, and the runoff volume. Particulate P is the product of the total P in the surface soil, the sediment concentration, an enrichment ratio, and the runoff volume. Sediment concentration is calculated using the erosion losses and runoff volume. Erosion by storm event is modeled using the modified universal soil loss equation (MUSLE). The enrichment ratio is estimated from the erosion loss. As such, the most important parameters for modeling P loss from each HRU are the soil test and total P concentration in the topsoil and the extraction coefficient for dissolved P. Extraction coefficients can be estimated by the slope of a plot of dissolved P in runoff vs. soil test P in the topsoil measured using a rainfall simulator (Sharpley et al., 2002). These coefficients vary with management (especially incorporated vs. surface applied manures) and to a lesser degree with soils, but many experiments of this type have been conducted (for example, Edwards, and Daniel, 1994; Pote et al., 1999), including some of our own work on a benchmark soil that is common in the Lake Allatoona watershed (Schroeder, 2002). We will use this data to determine extraction coefficients for HRUs in our watershed with agricultural land use. To determine the soil test P (Mehlich-1) and total P in the topsoil, we will sample farm fields in the nine agricultural basins where we have stream monitoring sites. We will also sample soils in the forested watersheds where we have stream monitoring sites to determine background levels of soil P.

Like all watershed models, SWAT has a number of parameters that can only be determined through calibration, i.e., by comparing the model predictions of stream flow and pollutant concentration to observed values and adjusting the parameters to get the best fit. Several years of daily stream flow and periodic measures of pollutant concentration are considered the minimum data required for calibration (Mulla and Addiscott, 1999). Computer programs for performing calibration have been developed, one of which is the Model-independent Parameter Estimation (PEST) program of Doherty (2002). PEST uses an iterative process wherein an initial parameter set is assumed and the model is linearized using a Taylor expansion. Then a Levenberg-Marquardt approach is used to find an upgrade in the parameter set that minimizes the sum of squared error between observed and predicted values. The upgraded parameter set is then used as the starting point and the process is repeated until the error sum of squares reaches an acceptable minimum.

We will use calibration for two purposes. The first purpose is to find the value of parameters that characterize the general hydrology of the watershed. This will be done using the historical data collected in the Clean Lakes Study (Rose, 1999). In that study, they measured bimonthly P and sediment concentrations and stream flow at the 12 main tributaries that enter Lake from May 1992 to April 1993. Although, one year of data is considered less than ideal for watershed model calibration, the availability of data from 12 different mainstem sites is extraordinary.

The second purpose of calibration is to find the value of parameters that describe P and sediment losses from agricultural sources and the effect of BMPs. Once the model is calibrated using the historical large-tributary data set, we will use the monitoring data collected as part of this project (described above) on first- and second-order streams draining forest basins and agricultural basins with a range of BMPs to further calibrate the model for the second purpose.

We will need to know the current state of agricultural and forest BMP usage within the Lake Allatoona watershed. Much of this information will be gathered from forestry and agriculture extension personnel. To assess the use and distribution of forested buffers, we will overlay the 1:24,000 scale stream coverage on color infrared aerial photography and visually estimate the width and quality of the buffer along each side of each stream segment. Since buffers cannot be simulated directly in SWAT, we will develop effective parameters that model the combined effect of fields of different land use with buffers of different widths and quality.

Existing land cover GIS data sets for this area include maps for 1991 and 1998. We will use the 1991 land use cover for calibrating the model using the historical data from the large tributaries (collected in 1992 and 1993). For calibrations with the small-order stream data collected as part of this project, we will use the 1998 land cover. We will also use the 1998 land cover to develop the trading ratios and perform the uncertainty analysis.

Trading Ratios and Uncertainty Analysis

We propose a framework in which a regulatory agency will set ratios for trades between point and non-point sources. We can define the trading ratio *t* as the number of units of P reduction a non-point source must "produce" to allow the point source buyer to use one unit in meeting it's regulatory obligations.

$$t = \frac{Z_{nonpoint}}{Z_{point}}$$

Trading ratios can serve a variety of functions. One function is to reflect differing levels of uncertainty in the effect of non-point vs. point source reductions (US EPA, 2001; Malik, et al., 1993). There is more uncertainty in non-point source reductions because P loads are not easily measured from non-point sources such as farms that institute BMPs to reduce runoff and/or the concentration of P in runoff. Also, there is additional uncertainty due to the spatial and temporal distribution of non-point source reductions. If a number of farms in the upper reaches of the watershed of a lake institute BMPs to reduce P loads, what will be the reduction in P loads reaching the lake and when will they occur? This uncertainty is due to in-stream processes that affect the timing and efficiency of P transport from the upper reaches to the lake. For the sake of simplicity, if the expected non-point source P load reduction to the lake due to implementation of a best management practice was 50 lb/year and the uncertainty was normally distributed with a standard deviation of 20 lb/year, the non-point source load reduction is a distribution that would appear as in Fig. 2.

By comparison, there is less uncertainty in point source reductions because the flow and P concentration can be measured in the outfall of the point sources and (in the case of Lake Allatoona) the point sources are located very close to the lake. The distribution of the point source P load reduction to the lake could be represented as an infinite spike with a standard deviation of zero, as shown in Fig. 3.

A trade will be approved if the non-point source reduction achieves the same reduction as a point source, with an acceptable level of certainty (for example, 98 %). If the uncertainty is normally distributed, 98% of the time the actual load reduction achieved by a given non-point source practice will be more than the mean minus two standard deviations. Therefore, a satisfactory trade will require that mean of the non-point source load reduction be shifted to the right of the point source load reduction as shown in Fig. 4.

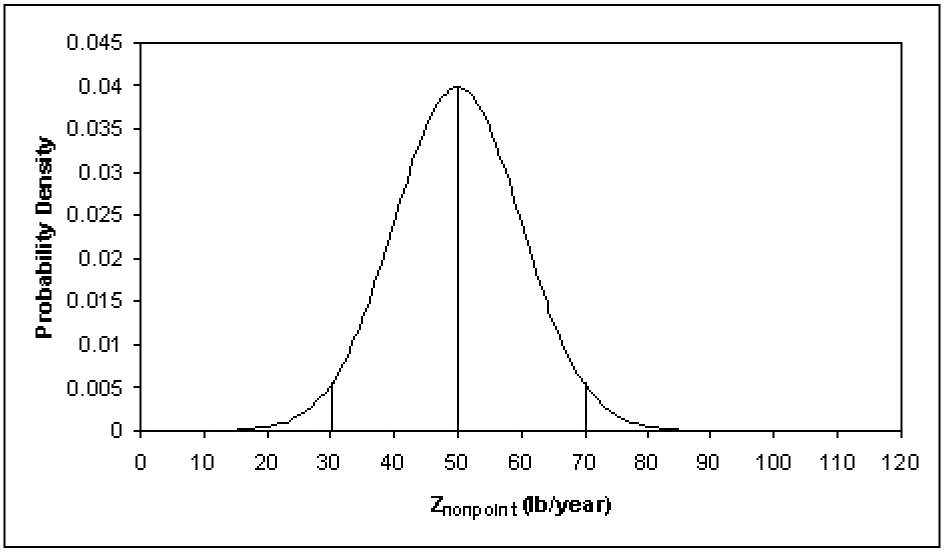

Figure 2. Hypothetical normal distribution of a non-point source P load reduction with a mean of 50 lb/year and a standard deviation of 10 lb/year. 95% of the distribution lies between the mean ± two standard deviations.

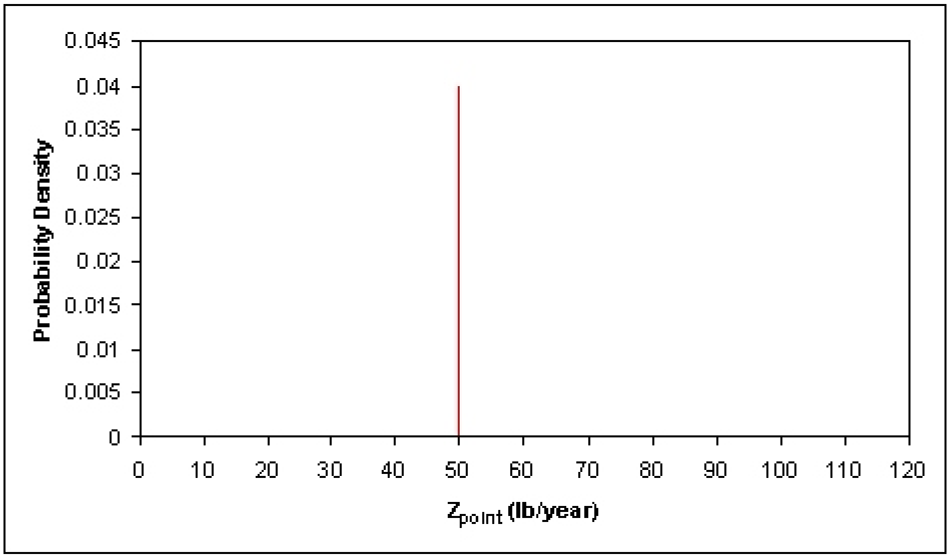

Figure 3. Hypothetical point source P load reduction of 50 lb/year with a standard deviation of zero.

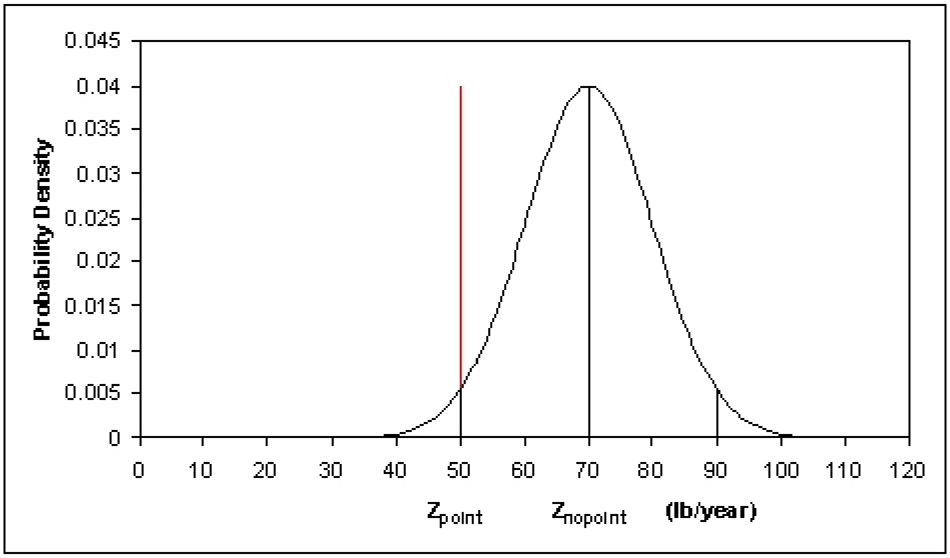

Figure 4. Hypothetical point and non-point source P load reductions. To achieve 98% certainty of an equivalent reduction, the non-point source distribution must be shifted to the right by two standard deviations.

In this hypothetical case, the mean of the non-point source P load reduction must be two standard deviations (σ) above the point source load reduction , so the required trading ratio is

$$t = \frac{Z_{nonpoint}}{Z_{point}} = \frac{Z_{point} + 2\sigma}{Z_{point}} = 1 + \frac{2\sigma}{Z_{point}}$$

It is clear that as the uncertainty in the response (represented by the standard deviation) of the error increases, so does the trading ratio. To calculate *t*, the probability distribution of non-point source reductions must be known.

We will assume that the watershed model can be used to estimate the distribution of non-point source P load reductions. PEST can be used to perform an uncertainty analysis of the model predictions. Since the parameters that drive the model are not known with absolute certainty (deterministic), there is uncertainty in the model predictions of P loading to the lake. In the uncertainty analysis procedure, the user specifies possible ranges of values for the parameters and any correlations between parameters. PEST then calculates the distribution of model predictions, from which the standard deviation of the predicted P load can be estimated.

We will use this procedure to develop trading ratios for the most effective BMPs that are likely to be used by agricultural non-point sources of phosphorus, sediment, and FC. These will vary spatially in that non-point source practices implemented in the upper reaches of the watershed are likely to require a higher trading ratio than practices implemented near the lake.

Trading Framework

The project will investigate trading frameworks that improve the likelihood of mutually beneficial trades in the Lake Allatoona Watershed. Our approach will be based on the observation that successful trading frameworks must perform three essential functions:

- They must bring together, and then transfer resources from, buyers to sellers.
- They must provide adequate information and contractual certainty for buyers and sellers in terms of how the transaction affects their regulatory obligations.
- They must successfully set trading ratios to protect environmental integrity, and determine which transactions are allowable, and which are not, in a timely and cost-effective manner.

There are three kinds of structures that could be used:

- A traditional bilateral structure where buyers and sellers make agreements on their own, with a public authority participating to approve the trade and set an appropriate trading ratio. This is similar to the structure used in textbook emissions trading programs such as the Acid Rain Trading Program, and is most similar to a pure market structure. This model requires that buyers and sellers have some low-cost way of locating each other and documenting the environmental consequences of a trade, as well as providing for monitoring of resulting actions by both parties.
- A "market-maker" model where an association of stakeholders, regulators, and other interested parties seeks out and brokers deals between buyers and sellers. This is similar to the model followed by the Tar - Pamlico Nutrient Trading Program (Sessions and Leifman, 1999).
- A less traditional and more innovative approach is a "fund" model where buyers pay money into a fund in return for credits, and the managers of the fund spend the money to achieve effluent reductions in the most cost-effective and environmentally effective manner. This approach is one of the options set out for local air quality trading programs in EPA's recent guidance for these programs (US EPA, 2001) This model carries some risks, but could also increase the effectiveness of any trading program. It works by having buyers purchase credits by paying a pre-determined price into a fund. The funds managers then use these resources to purchase emissions reductions, either by existing nontraditional sources or from other kinds of investments and programs. This has the advantage of reducing transactions costs, and also of making innovative large-scale projects to reduce emissions possible. Disadvantages include the difficulty of setting a correct price for reduction credits before projects are actually funded -- this requires a significant amount of information and carries risks that environmental integrity will be compromised if the fund managers are unable to purchase enough reductions with the money they collect for credits.

There is no reason why these models cannot be used in combination, but the second and third options entail significant public investment and careful attention must be paid to the likelihood of success before such approaches are recommended. Our approach to determining feasibility will be to gather and analyze data on:

- The number of potential buyers and sellers.
- The relative magnitude of transactions costs among the alternatives.
- Estimates of the cost that a point source would incur compared to the cost of buying credits from a non-point source.
- The uncertainty in actual loading reductions associated with different kinds of nutrient management practices
- The presence or absence of the expertise to manage a fund or watershed association, and the

degree of trust that stakeholders have in such managers to make good decisions that affect costs and environmental integrity

- The presence or absence of large-scale projects that could be facilitated through a fund structure better than through the other options.

Outreach and Education

To assist us in reaching our objective of developing a water quality trading program for the Lake Lanier watershed we will assemble an advisory council consisting of local agricultural producers, local water and sewer authorities, members of the Upper Etowah River Alliance and the Lake Allatoona Preservation Authority, and other potential trading partners in the watershed. The advisory council will assist us in identifying potential trading opportunities and limitations, evaluate trading frameworks, and most importantly, determine how to effectively communicate the concept of trading to the variety of audiences in the community.

One challenge that Michigan highlighted in securing non-point source partners to participate in trading activity in the Kalamazoo River Water Quality Trading Demonstration Project was the ability to communicate the scope, objectives and details of the project to a lay audience (Kieser and Batchelor, 1998). With this in mind, we will focus our outreach efforts on clearly communicating the complexities of water quality issues surrounding the process of trading to the advisory council. The council will assist us in creating a plan for effectively communicating to stakeholders in the watershed our findings regarding the water quality status of the lake, probable sources of the pollutants, and how a trading program could work to improve water quality. Based on previous work in the watershed this plan may include making presentations and soliciting input at a number of the routine (and well-attended) meetings of particular stakeholder groups, such as Farm Bureau meetings, the homebuilders associations, the homeowners associations, and work sessions of the local elected officials as well as more formal public meetings which often don't generate as much participation.

Using the results of our field and modeling efforts the advisory council will help us identify potential trading opportunities and limitations. Technical and regulatory advisory groups will be assembled to work closely with the steering committee providing assistance and oversight on critical elements of the project related to agricultural and forestry stream sampling site selection and control recommendations, as well as technical issues surrounding quantification protocols for non-point source reductions.

Focusing our data collection on P loading from agricultural practices provides the advisory council the opportunity to identify and discuss fundamental policy issues specific to the agricultural community. Two critical issues identified in Michigan were equity and accountability (Kieser and Batchelor, 1998). Fairness is an issue given that some farmers have already implemented environmentally-sound practices while others have not. The council will help us establish the agricultural baseline from which a trading credit may be generated. Accountability is necessary for ensuring that reductions are indeed real and surplus. The advisory council will work on identifying a mechanism that will work for the agricultural community and the other stakeholders in the basin. The advisory council will also review our analysis of trading frameworks described in the previous section and help determine the most effective framework for the Lake Lanier watershed.

King and Corwin (1999) point out that modern watershed-scale models can be particularly effective in policy discussions with stakeholders due to their ability to display results using GIS technology. A more complicated policy/science interaction has evolved in recent years where "science is an occupation of some of the personalities in the debate... but it is not a yardstick by which truth is measured, simply because the routine workings of science seldom provide precise answers to highly complex questions in the time required to reach policy decisions". Scientists can use watershed models and GIS to focus the debate and be more persuasive. We will use GIS layers and our model in meetings with the advisory council and other stakeholder meetings to show current land use and trends, stream and lake water quality data, point and non-point sources of P and sediment loads, and potential trading scenarios.

Part of our outreach effort will be devoted to discussing nutrient trading with the agricultural community, aside from the activity of the advisory council. We will make at least one presentation on project findings at the National 406 Water Quality Coordinators Conference. At the 2005 Southern Region Water Quality Workshop, we will conduct a nutrient trading workshop. Also, we will sponsor a nutrient trading track or workshop at the 2005 Georgia Water Resources Conference. We will also have training sessions for county extension agents presenting an overview of nutrient trading including case studies using our project results. We will also present findings of the on-farm monitoring portion at the Georgia Poultry Federation Annual Meeting and the US Poultry and Egg Environmental Conference. Significant outreach and extension will occur throughout the whole recruitment process for farmers as potential trading partners. We will also meet with farmers in the basins where we have our monitoring sites to compare and review results.

We will present our preliminary results in national conferences in the second and third year of the project. As the project is completed, we will prepare refereed articles for journals in hydrology, economics, soil science, and ecology. In addition, we will develop a white paper where we will provide the background on nutrient trading programs and present all aspects of the Lake Allatoona project. We will place the white paper on the River Basin Science and Policy web site (www.rivercenter.uga.edu) and the Georgia Conservancy (www.gaconservancy.org) web site.

Table 6. Investigators and the courses they teach in which the project will serve as a case study.

Instructor	Course
David Radcliffe, Crop and Soil Science Department	CRSS 8610 Spatial Modeling
Andy Keeler, Agricultural and Applied Economics Department	AAEC 4650 Environmental Economics AAEC 7600 Environmental Economics and Policy Analysis ECOL/FORS/ANTH 6140 Economics of Sustainability
Rhett Jackson, D.B. Warnell School of Forestry	FORS 4110/6110 Forest Hydrology
Laurie Fowler, Institute of Ecology and School of Law	ECOL 8720 Environmental Law for Scientists and Environmental Design Professionals

There will be a classroom component to our project in that we will use this project as a case study in soil, hydrology, economics, and ecology graduate courses that we teach. The courses and instructors are shown in Table 6.

Results Expected

We expect to show that there is good potential for a P trading program in the Lake Allatoona watershed. Waste water treatment plants in the watershed are bound to face the need for P load reductions in the near future due to an expanding population and new restrictions that are likely to be imposed with the development of a lake TMDL in 2003. The costs for achieving these reductions directly through plant improvements are likely to be much greater than the cost of trading for non-point source reductions. The Georgia EPD is interested in P trading as a means of achieving non-point source reductions and our framework might be used for the Lake Allatoona watershed, as well as for the much larger Lake Lanier watershed which is experiencing many of the same development and eutrophication problems.

Our hope is that this project will lead to the establishment of a P trading program in the Lake Allatoona watershed and perhaps the Lake Lanier watershed. Our results will provide scientifically-based trading ratios for point and non-point source trades and this should help alleviate some of the reservations environmental stakeholders have in regard to nutrient trading. The watershed-scale model that we develop should be useful for exploring different trading scenarios in which stakeholders are interested. We see this as a valuable aid for adaptive management of a trading program, once it is initiated.

We believe that a successful framework will initially have strong elements of a "market-maker" model, where an organization made up of stakeholders is central in identifying and helping to structure trades. As experience is gained, it is very possible that individual trading could develop. The potential for the "fund" model depends very much on the ability of the project to identity cost-effective P-reduction opportunities, and also on the level of stakeholder trust in Lake Allatoona's watershed institutions. We think that there is good reason to be optimistic about both of these factors, and intend to spend significant effort exploring the feasibility of this latter approach.

Pitfalls and Limitations

The main limitation of our study is that we are focusing on potential trading between point sources and only agricultural non-point sources. Our goal is to expand the project to suburban non-point sources such as septic systems and storm-water management. This effort will require stream monitoring sites on small-order streams with predominant suburban land use and the funding is beyond what is available in the integrated research program.

Another limitation is the ability of the watershed model to accurately predict the expected agricultural non-point source P load reductions and the uncertainties in these reductions. Watershed models represent the state of our scientific knowledge in an integrated, multi-disciplinary, spatial context. As long as they are used in an adaptive management approach, there is no more accurate alternative, short of very intensive and long-term monitoring of stream loads, an approach that is not going to be affordable in most basins.

D. COOPERATION AND INSTITUTIONAL UNITS INVOLVED

Our project represents a multi-disciplinary, integrated approach. All of the investigators are faculty at the University of Georgia, but we span a very wide range of departments and disciplines (Table 7). All of the investigators are members of the River Basin Science and Policy Center.

Table 7. Departments, disciplines and activities of investigators.

Investigator	Department	Discipline	Activities
Laurie Fowler	Institute of Ecology and School of Law	Environmental policy	Outreach and education
Rhett Jackson	D.B. Warnell School of Forestry	Hydrology	Research and education
Andy Keeler	Institute of Government and Applied and Environmental Economics	Natural resource economics	Outreach and education
David Radcliffe	Crop and Soil Sciences	Soil physics	Research and education
Mark Risse	Biological and Agricultural Engineering	Animal waste management	Outreach and research

E. FACILITIES AND EQUIPMENT

The Department of Biological and Agricultural Engineering's Environmental Water Quality Lab conducts nutrient and chemical analysis in support of water quality work within and external to the department. The lab tests for routine nutrients and solids, including PO_4, total-P, and SSC. The lab is equipped with a Bran+Luebbe TRAACS 2000 Continuous-Flow Analyzer, a Bran+Luebbe XYZ Sampler, a drying furnace, incubators, and other routine lab analysis equipment. The lab has two full-time support staff and two part-time support staff.

The D.B. Warnell School of Forestry and the Crop and Soil Science Department have a number of ongoing projects where we are doing in-stream sampling with automated ISCO samplers and pressure transducers so we are familiar with the installation and operation of this type of equipment. All of the departments involved in this study have excellent computer and GIS capabilities. The Institute of Ecology houses the Natural Resource Spatial Analysis Laboratory (NARSAL), established in 1995 to conduct research, training and public service and outreach in the area of natural resource management and planning.

F. PROJECT TIMETABLE

The project time table is presented in Table 8.

Table 8. Project timetable

Activity	Year 1		Year 2		Year 3	
Selection of 9 agricultural and 3 forestry first- or second-order stream sites	X					
Installation of ISCO samplers, transducers, and flumes at 12 low order stream sites		X				
Biweekly and storm sample collection from 12 stream sites and analysis of samples			X	X	X	X
Sample soils for P on farm and forestry sites			X	X		
Synoptic sampling along stream reaches to determine in-stream P processes				X	X	
Assess BMP usage and buffer coverage for watershed			X	X		
Post-doc attend BASINS and PEST workshops			X			
Set up input files for SWAT			X			
Calibrate SWAT using historical large-tributary data using PEST			X			
Uncertainty analysis of SWAT using PEST			X	X	X	X
Calibration of SWAT using data from 12 low order streams					X	X
Calculation of trading ratios for various BMPs					X	X
Identify all potential trading partners: point sources and number and location of agricultural operations		X	X			
Estimate and compare costs for P reductions by point sources directly and by agricultural sources implementing various BMPs			X	X		
Identify expertise to manage fund and degree of trust stakeholders have in such managers			X	X		
Identify large-scale projects that could be facilitated through a fund				X	X	
Develop analysis of options for economic framework					X	X

Table 8 continued.

Activity	Year 1		Year 2		Year 3	
Establish a watershed advisory council consisting of stakeholders	X					
Discuss evidence of water quality impairment, probable sources of P, and potential for trading program with advisory council		X	X			
Get feedback from advisory council on potential trading partners and limitations			X	X		
Get feedback from advisory council on our evaluation of best options for trading framework and proposed trading ratios					X	
Use advisory council to develop a plan to communicate to stakeholders our proposed trading program					X	X
Attend regular meetings of various stakeholder groups to get input on trading program and later to present recommendations		X	X	X	X	X
Use preliminary results from project as case study in hydrology, economics, and ecology courses			X	X	X	X
Present preliminary results at national conferences			X	X	X	X
Conduct trading workshop at Southern Region Water Quality Workshop				X		
Sponsor trading track at Georgia Water Resources Conference			X			
Develop white paper and journal articles					X	X

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APPENDIX

We have letters of support from the following stakeholders:

- David Howerin, Planning Director, Coosa Valley Regional Development Center
- Larry Vanden Bosch, Director, Community and Economic Development Services, North Georgia Regional Development Center
- Tiffanie Chee Hill, Water Resources Planning, Georgia Mountains Regional Development Center
- Roy Fowler, General Manager, Cobb County-Marietta Water Authority

KEY PERSONNEL

Table 9. Roles and responsibilities of investigators.

Investigator	Responsibilities
David Radcliffe	Principle investigator responsible for paper work and budgets; supervision of post-doc in model development, calibration, uncertainty analysis, and development of trading ratios; collection and analysis of soil samples; assessment of buffer coverage; presenting model results to stakeholders; presenting model and monitoring results at national conferences.
Laurie Fowler	Supervision of outreach associate in establishing and guiding advisory council activities and outreach with other stakeholder groups including workshops; presenting outreach results at national conferences.
Rhett Jackson	Selection of stream monitoring sites and installation of equipment; supervision of 3 forestry sites for operation and collection of samples; analysis of stream samples; model development for in-stream and forestry practices; presenting monitoring and model results at national conferences.
Andy Keeler	Supervision of outreach associate in gathering information on potential trading partners and analyzing frameworks for trading; development of trading ratios; presenting economic results at national conferences.
Mark Risse	Supervision of post-doc in model development, calibration, and uncertainty analysis; selection of stream monitoring sites and installation of equipment; supervision of 9 agricultural sites for operation and collection of samples; analysis of stream samples; assessment of BMP implementation in watershed; outreach with agricultural stakeholders; organizing workshops; presenting monitoring, model, and outreach results at national conferences.

BUDGET NARRATIVE

Salaries and Wages. Salary is included for a post-doc who will work under the supervision of David Radcliffe, Mark Risse, and Rhett Jackson on developing the SWAT model, calibrating and performing the uncertainty analysis using PEST, and using this to calculate the trading ratios. Funding for a Ph.D. graduate student is included. The student will be under the supervision of Rhett Jackson and Mark Risse for installing and operating the stream monitoring equipment, collecting the stream samples, and getting them analyzed. Part-time salary (50% in the first year and 75% in the second and third years) is included for an outreach associate who will be the project coordinator and under the supervision of Laurie Fowler for outreach activities with the watershed advisory council and under the supervision of Andy Keeler for development of the economic framework. A student worker to assist in the lab with monitoring sample analysis of SSC and preparing samples to send to the Environmental Water Quality Lab is included in the second (1/2 time) and third (full-time) year.

Position	Year 1	Year 2	Year 3	Total
Post-doc[1]	42,000	44,100	46,305	132,405
Graduate Student[1]	15,100	15,855	16,648	47,603
Outreach Associate	17,530[2]	23,904[3]	23,904[3]	65,338
Student Worker ($6.50/hr)		6,760	13,520	20,280
Staff benefits[4]	17,231	20,071	20,645	57,947
Total	91,860	110,690	121,021	325,572

[1] 5% annual raise.
[2] Part time at 55%.
[3] Part time at 75%.
[4] Staff benefits are 26% for post-doc and 36% for outreach associate.

Materials and Supplies. Most of the funding in this category is for 12 in-stream sampling sites (9 agricultural and 3 forestry sites). Other costs are for analysis of stream samples for dissolved P and total P on a fee basis by the Environmental Water Quality Lab ($12/sample) . Samples are collected in the second and third year of the project. We assume that we will collect 2 samples per month for baseflow conditions and 10 storms/year with 10 samples/storm for a total of 124 samples/year-site. With 12 sites, this produces an annual total of 1,488 samples per year for two years. We have also budgeted for 200 soil samples from the agricultural and forestry sites analyzed for soil test P and total P at a cost of $12/sample. We will also take 75 stream samples in the synoptic studies of stream P processes and analyze these samples for dissolved and total P. We have included $3,000 for a work station computer for the post-doc, $1,500 for a desktop computer for the graduate student, and $2,000 for two copies of Visual PEST software. Lastly, we have included funds for miscellaneous operating costs of $5,000 in the first year and $6,000 in the second and third years.

Item	Unit Price	Quantity	Total
ISCO sampler	2,300	12	27,600
Campbell datalogger	1,300	12	15,600
Druck transducer	725	12	8,700
Solar panels	210	12	2,520
Housing unit	400	12	4,800
Installation supplies	150	12	1,800
Soil sample analysis	12	200	2,400
Analysis of stream grab samples for synoptic studies	12	75	900
Analysis of stream ISCO samples	12	2,976	35,712
Workstation computer	3,000	1	3,000
Desktop computer	1,500	1	1,500
Visual PEST software	1,000	2	2,000
Miscellaneous operating			17,000
Total			123,532

Travel Costs. We have included funding for the postdoc to attend a 3-day PEST workshop ($1500 registration and $1500 travel) and a 3-day SWAT workshop ($1175 registration and $1500 travel). We have budgeted $2,000 in the first year and $3,000 in the second and third year for travel back-and-forth to the watershed by the graduate student and other members of the project (round-trip mileage to Canton, GA near the center of the watershed is 190 miles). We have also included funding for the graduate student and each investigator to attend national conferences in each of the last two years ($1500/conference).

Item	Total
Travel to 2 conferences for 5 investigators, outreach associate, post-doc, and graduate student ($1,500/conference)	24,000
Post-doc travel and registration for BASINS workshop and PEST workshop	5,175
Local travel to watershed	8,000
Total	37,175