Building a Foundation for Water Quality Trading in Georgia

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FINAL REPORT

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by

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Abstract

This report describes the outputs of a multi-disciplinary project designed to provide research and outreach needed to support the consideration of the use of water quality trading in Georgia watersheds. The project was funded by the Environmental Protection Agency. In summary, the project's most important areas of impact were threefold:

(1) the evaluation of Georgia watersheds and policy as to the feasibility of implementing water quality trading (WQT);

(2) the development of cost estimates for wastewater treatment of phosphorus, a commonly traded pollutant, and the subsequent evaluation of the economic driver for WQT in Georgia and across the U.S.; and,

(3) the initiation and facilitation of the discussion of WQT as a policy option among a wide audience of Georgia policymakers and stakeholders.

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Building a Foundation for Water Quality Trading in Georgia

Introduction

This report describes the outputs of a multi-disciplinary project designed to provide research and outreach needed to support the consideration of the use of water quality trading in Georgia watersheds. This project produced a number of important outputs, but the most important areas of impact were threefold:

(1) the evaluation of Georgia watersheds and policy as to the feasibility of implementing water quality trading (WQT);

(2) the development of cost estimates for wastewater treatment of phosphorus, a commonly traded pollutant, and the subsequent evaluation of the economic driver for WQT in Georgia and across the U.S.; and,

(3) the initiation and facilitation of the discussion of WQT as a policy option among a wide audience of Georgia policymakers and stakeholders.

From a research perspective, the project joined together experts in economics, policy, law, water quality, engineering, and environmental modeling to advance the understanding needed to implement water quality trading in Georgia. Eight working papers have resulted from the research related to this grant project. Presentations of results have been made at two national conferences, including the Second National Water Quality Trading Conference hosted by the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Agriculture (USDA) in May 2006, as well as numerous in-state meetings, including the 2005 Georgia Water Resources Conference and the 2005 Georgia Farm Bureau Commodity Conference. The findings from our research are directly relevant to the current considerations of Georgia water policymakers. Furthermore, our economic findings are relevant to WQT programs nationally.

The project was designed to emphasize outreach as well as research. As discussed above, results have been presented at a variety of water-related meetings. Additionally, numerous small meetings (approximately 25-30) to discuss water quality trading were held with stakeholders, including environmentalists, wastewater service providers, government officials, environmental planners, utilities directors, farmers, and entrepreneurs interested in water quality trading markets. Also, water quality trading was discussed by phone and in person with numerous contacts involved in trading from across the U.S. Project personnel developed a broad network of stakeholder contacts on this topic. We distributed two articles on water quality trading to audiences of local leaders and water managers across the state. These were published in *Water Talk*, a newsletter with a circulation of 350 local government leaders in Georgia, and *Water Steward*, a magazine with a circulation of 6500 water managers in the state of Georgia. Finally, at the close of the project, we organized and presented a workshop on water quality trading for Georgia policymakers and stakeholders.

Given the size of the project budget, the outcomes of this project have been substantial and far-reaching. For a relatively small investment, the EPA was able to leverage federal funding to expand research, understanding, and readiness for water quality trading in Georgia. The report that follows details our accomplishments in each area of the project.

Task 1: Evaluate Georgia watersheds for water quality trading

Three working papers report the findings from this area of our research:

- ***{** HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/2005-020.pdf" \t "_blank" **}*** A Feasibility Analysis of Applying Water Quality Trading in Georgia Watersheds, K. Rowles, June 2005.

- ***{** HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/2005-003.pdf" \t "_blank" **}*** An Evaluation of Water Quality Trading for Georgia Watersheds, K. Rowles, January 2005.

- ***{** HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/2004-015.pdf" \t "_blank" **}*** Nutrient Trading in the Upper Chattahoochee Watershed: A Feasibility Analysis, K. Rowles, June 2004.

In summary, based on criteria of environmental suitability, regulatory incentive, economic incentive, availability of participants, and stakeholder response, we evaluated each of Georgia's 14 major river basins for the feasibility of implementing water quality trading. The evaluation concludes that the Georgia watersheds where WQT appears to be most feasible include the *Chattahoochee, Coosa, Savannah, and Ocmulgee* basins. Feasibility is also likely to be high in the *Flint and Oconee* basins. Although WQT is most likely in these Georgia watersheds, it is not precluded in other watersheds, though the extent of trading would likely be more limited. The evaluation also notes that the opportunity for WQT in Georgia is currently limited, mostly by a lack of regulatory drivers. However, current regulatory trends are likely to alter those conditions more favorably for WQT in the next several years.

The results of this analysis were also presented at the biennial Georgia Water Resource Conference in April 2005, with a summary paper of the presentation published in the conference proceedings.[1] Results from this analysis have also been incorporated into other presentations conducted by project personnel.

[1] Rowles, K. 2005. An Evaluation of Water Quality Trading for Georgia Watersheds. *Proceedings of the 2005 Georgia Water Resources Conference,* held April 25-27, 2005, at the University of Georgia. Kathryn J. Hatcher, Editor, Institute of Ecology, University of Georgia, Athens, Georgia.

Task 2: ***Analyze the legal framework for water quality trading in Georgia***

Understanding the legal issues raised by water quality trading is a prerequisite to the development and implementation of WQT programs. Therefore, we conducted legal research on potential legal issues, barriers, and needs for water quality trading in Georgia. Two working papers report the findings from this area of our research.

- ***{ HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/WP2006-010.pdf" \t "_blank" }{ HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/WP2006-011.pdf" \t "_blank" }*** Water Quality Trading in the Context of the Antidegradation Requirements of Federal and State Clean Water Policies, K. Rowles and B. Thompson, June 2006.

- ***{** *HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/2005-021.pdf" \t "_blank"* **}** Water Quality Trading: Legal Analysis for Georgia Watersheds, K. Rowles and B. Thompson, June 2005.

In summary, the legal analysis found no policy barriers to water quality trading in Georgia. Legal challenges to water quality trading might be a concern, but at this time, there have been no legal challenges in WQT programs in other states. Many states have proceeded with the development of state policies on water quality trading to support its implementation, but we recommend that pilot trades be a precursor to the development of a state policy.

As a result of our legal research, project personnel commented on proposed policy language changes in the state code which might have precluded the opportunity for water quality trading in the future. Following from this issue, our legal researchers explored in greater detail the issue of uncertainty surrounding the application of the antidegradation clause of the Clean Water Act in watersheds where water quality trading is implemented and issued a working paper specifically focused on this topic.

Task 3: ***Develop a simulation model for water quality trading in a Georgia watershed***

The attached report in Appendix A summarizes the work completed in this area of the project in detail. In summary, this area of our research was focused on developing a model that could be used to evaluate WQT scenarios in a Georgia watershed. This work was completed by our partners, led by Dr. M. Bruce Beck, from the Warnell School of Forest Resources at the University of Georgia.

Modeling was based on the STAND model (Sediment-Transport-Associated Nutrient Dynamics), developed previously at UGA. Building upon the simulation studies from our work on generating cost estimates for phosphorus removal by wastewater treatment facilities (see Task 4), we assembled a rather complete model for a watershed, wherein the *dynamic* behavior of point sources, together with that of the nonpoint sources, can be properly accounted for. The model was set up to mimic closely the context of metropolitan Atlanta within the Upper Chattahoochee watershed. It can generate all manner of patterns of stream water quality as a function of the various candidate alternatives for pollutant trading schemes and assess these in the presence of the substantial sources of uncertainty surrounding watershed behavior, facility performance, and cost estimation. On this basis we have begun developing a systematic framework for screening out preferred trading mechanisms for much more detailed feasibility analyses (a subject of our future program of work).

Task 4: Conduct technical and policy analyses to support development of trading program

The primary focus in this area of the project was our effort to evaluate the economic driver for water quality trading from the point source perspective. A primary step in predicting the feasibility of water quality trading is to estimate point source treatment costs. The financial attractiveness of trading will depend upon the relative costs of treatment and pollution costs for point sources. We issued three working papers that analyze the costs for wastewater plant for increasing levels of phosphorus treatment:

- ***{** HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/WP2005-023.pdf" \t "_blank" **}*** Watershed Pollutant Trading: Estimating Costs of Phosphorus Removal in Wastewater Treatment Facilities, F. Jiang, M.B. Beck, R.G. Cummings, and K. Rowles, December 2005.

- ***{** HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/W2005011.pdf" **}*** Estimation of Costs of Phosphorus Removal in Wastewater Treatment Facilities: Adaptation of Existing Facilities, F. Jiang, M.B. Beck, R.G. Cummings, K. Rowles, and D. Russell, February 2005.

- ***{** HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/2004-010.pdf" \t "_blank" **}*** Estimation of Costs of Phosphorus Removal in Wastewater Treatment Facilities: Construction De Novo, F. Jiang, M.B. Beck, R.G. Cummings, K. Rowles, and D. Russell, June 2004.

This effort demonstrated the complexity of accurately estimating the demand for water quality trading credits *ex ante*. The results indicate a sharp increase in abatement costs at the level of a 1mg/l TP effluent standard. At or above 1mg/l, the costs of compliance may not be greater than the costs of equivalent nonpoint source reductions, especially under the requirement for a trading ratio greater than 1:1. Our cost estimates suggest that the economic incentive for trading in phosphorus reduction credits will be weak when effluent standards are above 1mg/l TP, a common condition in most watersheds. These results might help to explain, in part, the dearth of trading activity in many existing WQT programs. We are continuing to explore the implications of the results of our cost estimates, including how water quality trading might alter the incentives for compliance with water quality regulations.

The results of this research have national application, and we have received numerous inquiries about our findings. We presented this research at the 2006 USDA CSREES National Water Conference and the Second National Water Quality Trading Conference, co-sponsored by the EPA and USDA.

In addition, this project has also been a stimulus for the development of related projects. For example, through our initial watershed evaluation work, we identified chicken manure transfer as a practice that had great potential to be a water quality offset in a trading program. Chicken operations in North Georgia are located in watersheds where rivers and soils have high levels of phosphorus. The removal of chicken litter from these watersheds is a practice that could help to improve water quality, but the costs of transporting manure have generally limited the use of this practice. Water quality trading could provide the necessary financing to support this practice. Pollutant credits would be exchanged between chicken producers and growing North Georgia communities that need additional nutrient allocations for their wastewater plants. To advance this idea, we wrote a successful grant application to the USDA Conservation Partnership Initiative on behalf of the Georgia Soil and Water Conservation Commission to support the development of a partnership to create such a program.

Task 5: Engage stakeholders in discussion about the development of water quality trading in Georgia

A new water quality trading program would affect stakeholders across the state. Successful adoption of water quality trading in Georgia will require that stakeholders are involved in the discussion of how trading should be implemented in the state. Therefore, the involvement of stakeholders in discussions about water quality trading is important at any stage of policy consideration, program development, or implementation. To address this important factor, we made stakeholder outreach an important component of this project.

As discussed above, the results of project research were presented to WQT stakeholders at meetings around Georgia and the U.S., including:

- Georgia Conservation District Supervisors Annual Meeting (Savannah, January 2005)
- Georgia Water Resources Conference (Athens, GA, April 2005)
- Farm Bureau Commodity Conference (Jekyll Island, GA, December 2005)
- USDA CSREES National Water Conference (San Antonio, TX, February 2006)
- Second National Water Quality Trading Conference (Pittsburgh, PA, May 2006)
- Joint briefing for USDA CSREES national program staff and U.S. Congressional staff (Washington, DC, April 2006)
- Briefing for U.S. Congressional field staff (Albany, GA, February 2006)
- Briefing for EPA Region IV and Georgia Soil and Water Conservation Commission officials (Gainesville, GA, June 2004)

Additionally, to introduce and facilitate the discussion of water quality trading in Georgia, numerous small meetings (approximately 25-30) to discuss water quality trading were held with stakeholders, including environmentalists, wastewater service providers, government officials, environmental planners, utilities directors, farmers, and entrepreneurs interested in water quality trading markets. Project personnel used these meetings to discuss trading and to collect information on stakeholder concerns and information needs. Water quality trading was also discussed by phone and in person with numerous contacts involved in trading from across the U.S. Project personnel developed a broad network of stakeholder contacts on this topic.

We distributed two articles on water quality trading to audiences of local leaders and water managers across the state. These were published in *Water Talk*, a newsletter with a circulation of 350 local government leaders in Georgia, and *Water Steward*, a magazine with a circulation of 6500 water managers in the state of Georgia. Another *Water Talk* article is currently in press.

Finally, at the close of the project, we organized and presented a workshop on water quality trading for Georgia policymakers and stakeholders. This workshop was the culmination of the project. It brought together the research and outreach components in a meeting with leading water resource stakeholders from across the state. The state of Georgia is currently developing a statewide plan for water resource management, and the workshop, therefore, provided a timely discussion of a policy tool that could be important in the planning process. Approximately 50 policymakers and stakeholders attended the workshop. To increase policymaker involvement, the workshop was presented at a joint meeting of the Georgia State Senate Committee on Natural Resources and the Environment and the Committee on Agriculture and Consumer Affairs.

The meeting provided attendees with an introduction to water quality trading, including a demonstration, and presentations from EPA and USDA officials on their agencies' perspectives on and support for WQT. Then, we presented the results of our WQT research and recommended that policymakers and stakeholders accelerate consideration of this important policy tool. We reported that while our research indicates that the conditions to support water quality trading are not widespread in Georgia at this time, regulatory trends are likely to change these conditions in the near future. Given the complexity of designing a successful WQT program, planning efforts should begin now to prepare for the future. The workshop was well-received, and it was an important event to help facilitate the discussion of water quality trading in Georgia. The workshop was covered by print and television media.

Following on the success of our workshop, we decided to pursue a grant to support a Southeastern U.S. regional conference on water quality trading. To support this project, we made an application to the EPA Assessment and Watershed Protection Program Grants (AWPPG) in mid-August. Through this proposed conference, we hope to continue our efforts to expand the knowledge base about water quality trading among regional policymakers and stakeholders. The Southeastern U.S. was a pioneer in water quality trading in the Tar-Pamlico (North Carolina), but generally appears to be lagging behind other regions of the U.S. in developing new WQT programs. We believe that bringing together researchers and practitioners in the region could help to accelerate the knowledge transfer needed to support consideration and development of WQT in the Southeast.

Deliverables Summary

The project proposal listed the following deliverables: (a) stakeholder workshop (held August 8, 2006), (b) legal issues review (see working papers listed in Task 2), (c) simulation model (report on model attached as Appendix A), and (d) a project report (this report).[2] The actual deliverables comprise a much longer list, including:

{ HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/WP2006-010.pdf" \t "_blank" }{ HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/WP2006-011.pdf" \t "_blank" } Water Quality Trading in the Context of the Antidegradation Requirements of Federal and State Clean Water Policies, K. Rowles and B. Thompson, June 2006.

{ *HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/WP2005-023.pdf" \t "_blank"* ***}*** Watershed Pollutant Trading: Estimating Costs of Phosphorus Removal in Wastewater Treatment Facilities, F. Jiang, M.B. Beck, R.G. Cummings, and K. Rowles, December 2005.

{ *HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/2005-021.pdf" \t "_blank"* ***}*** Water Quality Trading: Legal Analysis for Georgia Watersheds, K. Rowles and B. Thompson, June 2005.

{ *HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/2005-020.pdf" \t "_blank"* ***}*** A Feasibility Analysis of Applying Water Quality Trading in Georgia Watersheds, K. Rowles, June 2005.

[2] The proposal deliverables also included a monitoring report, but subsequent changes to the project scope, approved by the project officer, eliminated the monitoring component and expanded other areas of the project.

{ HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/W2005011.pdf" } Estimation of Costs of Phosphorus Removal in Wastewater Treatment Facilities: Adaptation of Existing Facilities, F. Jiang, M.B. Beck, R.G. Cummings, K. Rowles, and D. Russell, February 2005.

{ HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/2005-003.pdf" \t "_blank" } An Evaluation of Water Quality Trading for Georgia Watersheds, K. Rowles, January 2005.

{ HYPERLINK "http://www.h2opolicycenter.org/pdf_documents/water_workingpapers/2004-015.pdf" \t "_blank" } Nutrient Trading in the Upper Chattahoochee Watershed: A Feasibility Analysis, K. Rowles, June 2004.

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Rowles, K. 2005. An Evaluation of Water Quality Trading for Georgia Watersheds. *Proceedings of the 2005 Georgia Water Resources Conference*, held April 25-27, 2005, at the University of Georgia. Kathryn J. Hatcher, Editor, Institute of Ecology, University of Georgia, Athens, Georgia.

Rowles, K. 2006. **{** HYPERLINK "http://www.extension.iastate.edu/WaterConf2006/ShowAbstract.aspx?TypeID=1&PresID=125" **}**. *Proceedings of the USDA – CSREES 2006 National Water Conference*, held February 5-9, 2006, San Antonio, TX. (See: **{** HYPERLINK "http://www.extension.iastate.edu/waterconf2006/" **}**)

NOTE: All working papers are available on the Internet: { HYPERLINK "http://www.h2opolicycenter.org/research.shtml" }

Conclusion

The results of this research and outreach project will be useful to a number of stakeholders with an interest in water quality trading in Georgia and across the U.S. The impact of the project is observable in the wide range of stakeholder contacts, the presentations of our work at national and regional meetings, requests for our research reports from researchers and practitioners from across the U.S., and the success of our August 2006 workshop.

Georgia is currently developing a statewide plan to direct how water resources will be managed in this state. Water quality trading is a policy tool that could be incorporated into state's water resources management plan. Our project developed analyses and initiated discussions that will be critical to Georgia's consideration of water quality trading. Through this project, we have created a research base that will support consideration of water quality trading in Georgia. We have also begun the process of stakeholder involvement that will be necessary to create acceptance of this novel policy tool. Water quality trading can bring financial and environmental benefits to Georgia, but only with careful planning, design, and implementation. This project has provided research and outreach outcomes that can help Georgia to attain these benefits.

Appendix A: Report from Task 3: Develop a simulation model for water quality trading in a Georgia watershed

Developing Models for Investigating Watershed Pollutant Trading Schemes

M B Beck, F Shi, and R Villarroel (University of Georgia)

Introduction

The primary goal of this program of work was to assemble a set of simulation models for a watershed so that the dynamic behavior of *both* point and nonpoint discharges of pollutants to a river system could be simulated in a compatible manner. Hitherto, the behavior of point discharges, i.e., the sub-system of urban surface runoff, sewer network, and wastewater treatment plant, has generally been considered static, i.e., invariant with time (when clearly this is never the case in practice). Following achievement of this goal, the watershed model was to be formulated so as to mimic closely a significant part of the Upper Chattahoochee watershed, thus to begin exploring alternative schemes for nutrient trading, under uncertainty. Accounting for such uncertainty has been an important feature of our research. A further goal was to utilize data collected from the nearby Soque watershed in order to improve the characterization and understanding of the behavior of nonpoint discharges of nutrients from agricultural land.

Assembly of Watershed Model

Simulation of watershed behavior is achieved herein through three component models (Figure 1). BASINS-HSPF (Hydrologic Simulation Program–FORTRAN) (EPA, 2001) estimates pollutant loads from nonpoint sources (mainly generated in runoff following storm events) from each sub-basin. The WEST-based realization of Activated Sludge Model No.2d (ASM 2d) (Henze *et al*, 1999) simulates the dynamic behavior of the point source, treated sewage discharges from urban wastewater treatment plants. The consequences of these nonpoint and point discharges for the quality of the receiving river are then simulated by the Sediment-Transport-Associated Nutrient Dynamics (STAND) model (Zeng and Beck, 2001, 2003). The entire model is embedded in a framework for the analysis of uncertainty, broadly based upon a Monte Carlo simulation scheme, but allowing what is called a "regionalized" analysis of sensitivity.

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Figure 1: Components of the Integrated Watershed Water Quality Simulation System

A significant portion of the Upper Chattahoochee River has been chosen for our hypothetical case study. This covers the segment of the river from Buford Dam at the outflow of Lake Lanier, southwards past the city of Atlanta, as far as the inlet to Lake West Point (Figure 2). In essence, the principal outputs of interest from the model are the concentrations of suspended sediment and phosphorus at various points along the river system, provided as daily time-series for a variety of hydrological years.

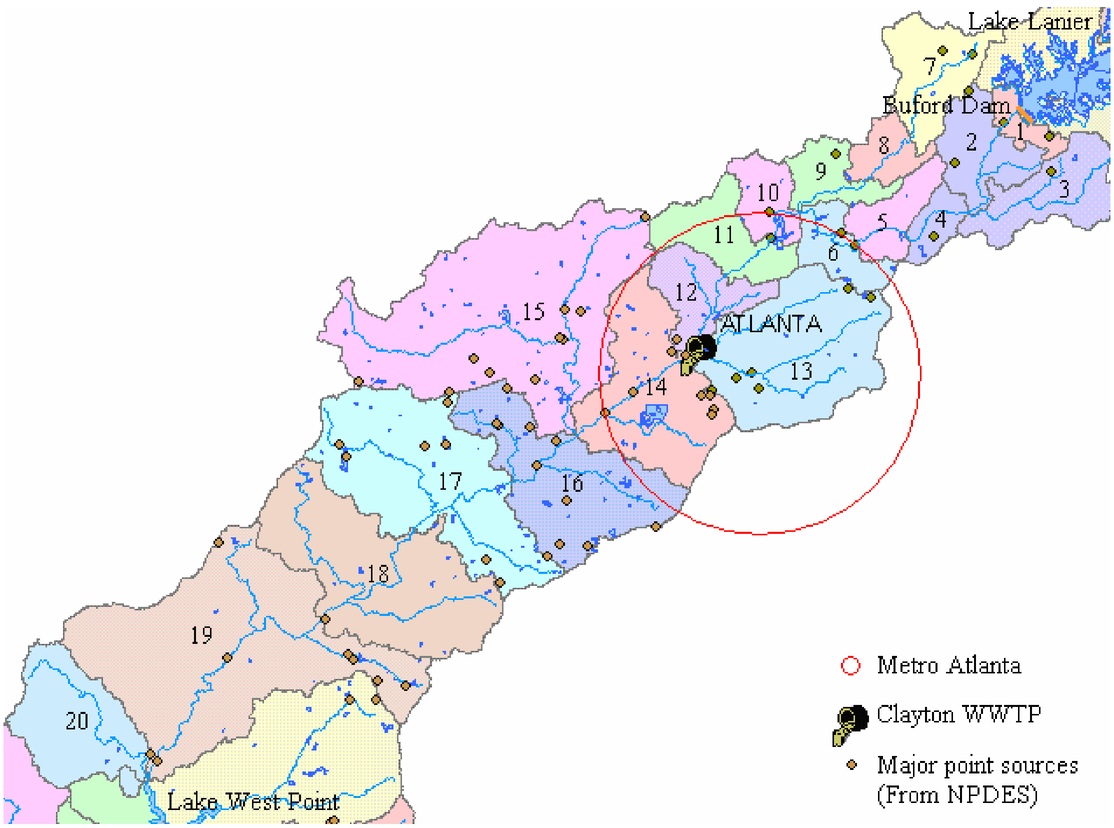

Figure 2: Pollutant Sources in Chattahoochee Watershed around Metro-Atlanta Area

Nonpoint-source pollution load assessment

Processes of rainfall-runoff generation in the watershed, i.e., rainfall, interception, surface storage and detention, infiltration, generation of surface runoff, mobilization and runoff of sediment and associated phosphorus release, are modeled by BASINS-HSPF. For this purpose the watershed is separated into sub-basins (Figure 2), drawing upon the relevant spatial data of properties such as land use and soil type. Using 36 years of historical daily precipitation sequences as inputs to this model, corresponding spatial and temporal distributions of runoff and nonpoint-source pollutant loadings can then be generated for the river system. For example, for the year of 1995 and the 13th sub-basin, Peachtree Creek (in downtown Atlanta), the resulting nonpoint source loads are illustrated in Figure 3. Further comments on improving simulation of these types of loads – a critical issue – are given below under the discussion of developing and using models for interpretation of the data from the Soque watershed.

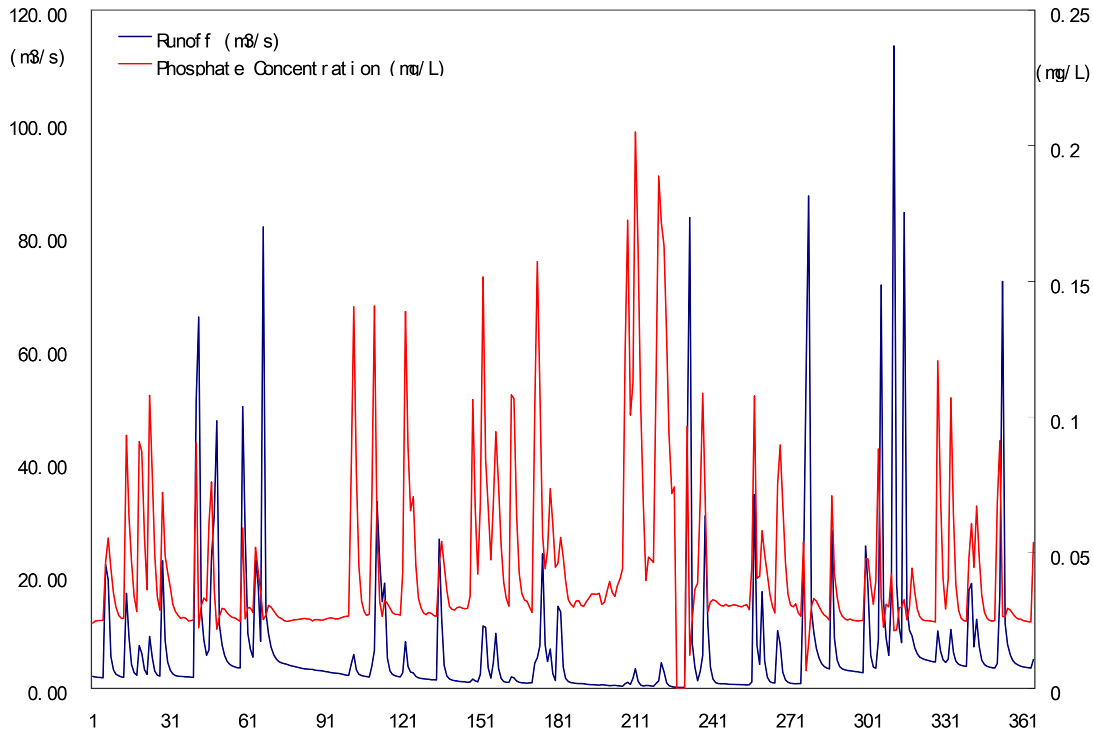

Figure 3: Peachtree Creek Watershed (Sub-basin 13) Nonpoint Source Load in 1995

Point-source pollution load assessment

According to the NPDES, there are over twenty main point-source discharges located in the segment of the Upper Chattahoochee shown in Figure 2. In the present study, however, simulation of just the single discharge from Atlanta's largest wastewater treatment plant, the R.M Clayton facility (with a capacity of 100 million gallons per day) is included. The WEST package is an advanced software platform for simulating *inter alia* the behavior of a wastewater treatment plant. From its "library" of options, Activated Sludge Model No.2d (ASM 2d) has been selected for our present purposes; ASM 2d provides simulation of removal of phosphorus (the focal pollutant/nutrient here) by biological and chemical (precipitation) means. Given previous detailed and comprehensive studies of (simulated) wastewater treatment plant behavior (in association with our studies on generating marginal cost estimates for phosphorus removal; Jiang *et al*, 2005), patterns of treated sewage discharges to the Upper Chattahoochee, which are typical for Georgia, can be obtained. In practice, current operation of the R.M Clayton WWTP lacks unit treatment processes designed specifically to remove phosphorus, such that the total phosphorus discharge concentration is bounded only at 2 mg/L. Under three representative hydrological conditions (wet, dry and moderate), signaling thus the important fact that our simulation can take into account the impacts of these and other *dynamic* perturbations, sequences of simulated discharge rates and effluent total phosphorus (TP) are produced. For 1995 (a moderate hydrological year) they are as shown in Figure 4.

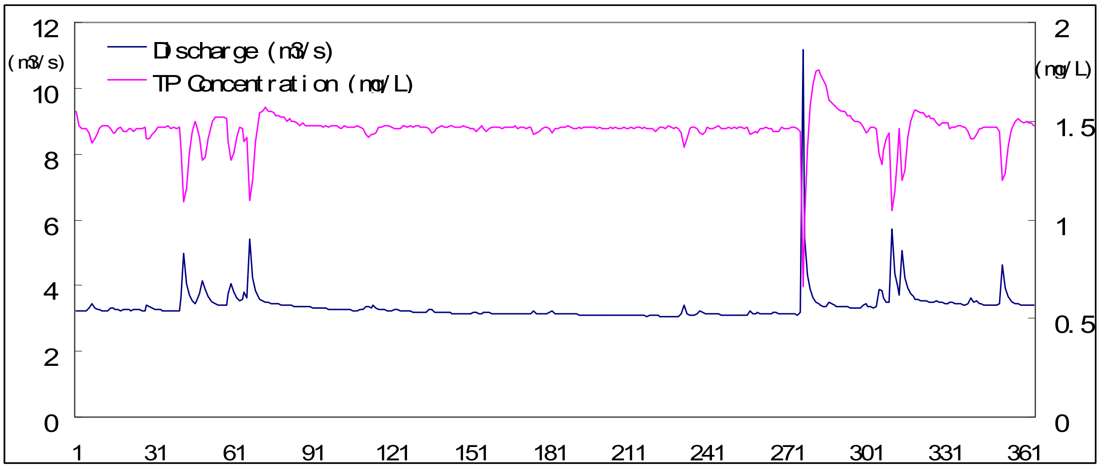

Figure 4: Discharge and TP Concentrations from R.M. Clayton WWTP in 1995

In-stream pollutant transformation

Our third component in the assembly of models for the Upper Chattahoochee watershed is the STAND model, developed originally to address the water quality issues associated with sediment behavior in streams and rivers under transient hydraulic conditions (and tailored to conditions typical of the Piedmont region). Stream hydraulic processes (flow routing), suspended sediment transport, exchanges of suspended sediment with bed sediment, and the behavior of (soluble) phosphate are all therefore simulated by STAND (Zeng and Beck, 2003). Relative to the (in-stream) channel component in BASINS-HSPF, STAND is better suited to simulating flow and sediment concentrations under transient, highly unsteady conditions.

Taken together, the nonpoint-source and point-source pollutant loads from their respective sub-models (as described above), together with variations in the upstream discharge from Buford Dam (the stream boundary condition), collectively provide the external forcing functions for the STAND sub-model. The in-stream processes are characterized in STAND by a set of parameters (coefficients) associated with the fluvial attributes of the channel segments. Annual sequences of day-to-day variations in stream water quality under different climate and watershed conditions are, as we have said, the outputs of primary interest from the entire simulation model. Again taking the year 1995 as an example, typical patterns of these outputs are shown in Figure 5 for stream discharge, while the accompanying sequences of suspended sediment concentration and orthophosphate concentration are given in Figure 6 (all for the inlet to Lake West Point; USGS station 03328550).

With the simulation model thus set up to mimic closely the context of metropolitan Atlanta in the Upper Chattahoochee watershed, we have the basis for exploring the merits and disadvantages of the various alternative schemes for nutrient/pollutant trading – and all under the presumption of significant uncertainty attaching to the problem specification.

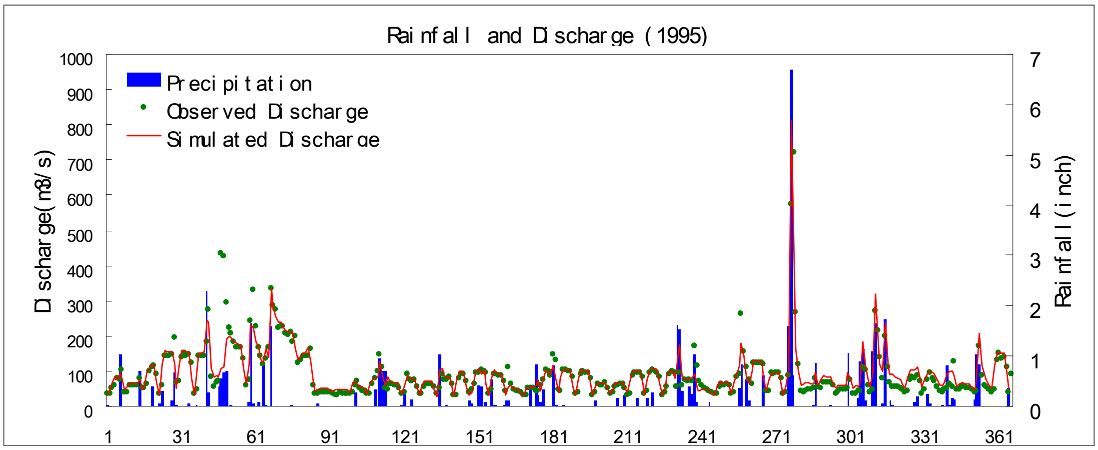

Figure 5: Observed and STAND-Simulated Stream Discharge (1995)

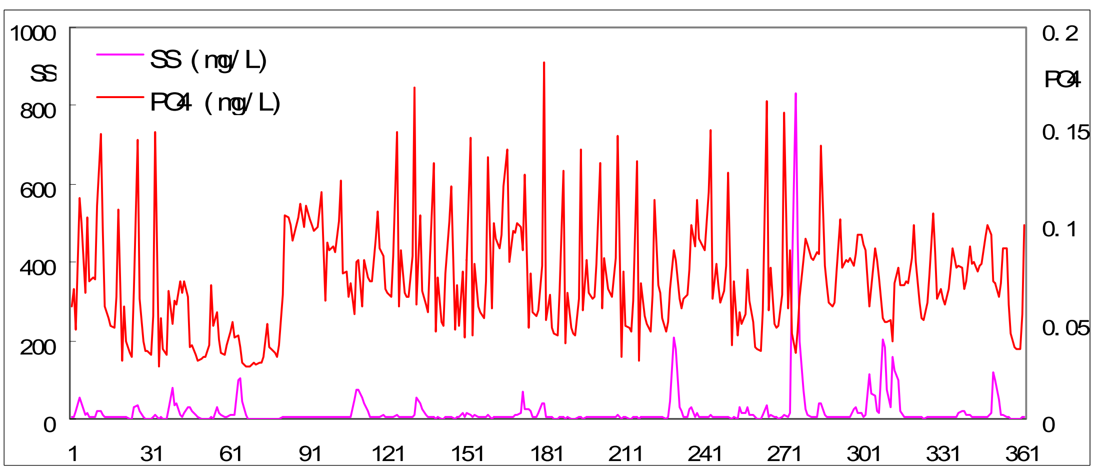

Figure 6: STAND-Simulated SS and PO4 concentration (1995)

Analysis of Uncertainty

Our understanding, and therefore our models, of watershed hydrological processes and their associated fluxes and transformations of variables characterizing water quality are subject to significant uncertainties, in particular, in respect of water quality and its transient behavior in response to precipitation variations, not only in association with nonpoint-source discharges, but also point-source systems (Osidele *et al*, 2003). From the recognition of these uncertainties springs our accompanying interest in improving these particular features of the model, as discussed below in respect of interpreting the data from the Soque watershed.

Herein, methods based essentially on Monte Carlo simulation are employed for analyzing the consequences of these uncertainties, in respect of (eventually) identifying trading schemes likely to be maximally robust against these affects of uncertainty.

Preliminary studies indicate that four uncertain factors affect sediment and nutrient behavior in the Chattahoochee River as it passes through the Atlanta area (Osidele et al., 2003): (i) reservoir operations at the upstream Buford Dam, which determine the release pattern from Lake Lanier and consequently the stream flow at Atlanta; (ii) watershed loading resulting from precipitation-induced soil erosion and overland transportation; (iii) urban wastewater discharge and effects of wastewater treatment plant operations; and (iv) in-stream processes of entrainment, deposition, phosphate adsorption and desorption. A key task for watershed pollutant trading research is to account for these uncertainties quantitatively and to manipulate them, in order to satisfy designated environmental objectives.

For the nonpoint-source watershed loadings and their attaching uncertainties, 36 annual sequences of daily rainfall patterns (generated from 1970-1995 historic data) and three land-use scenarios (derived from the current trends of urban development in the Atlanta region;ARC, 2003), are parameterized as indexes for the Monte Carlo simulation. For the point-source loadings and their uncertainties, given that construction of phosphorus removal facilities are under consideration at the R. M. Clayton WWTP, the imposed, i.e., regulated, effluent TP concentration limit is also parameterized so as to account for a variety of scenario uncertainties. Uncertainty in the release from Buford Dam – category (i) of the above four sources of uncertainty -- is parameterized through an index of 35 different annual patterns of daily mean reservoir discharges. Finally, model parameters reflecting in-channel fluvial processes are considered to be uncertain.

Once more, taking the inlet to Lake West Point as our reference spatial (output) location from the overall model, the cumulative probability density functions for the annual sets of daily maximum and daily mean phosphate concentrations at this point – resulting from the propagation of uncertainties from all four of the above sources (in concert) – are shown in Figure 7.

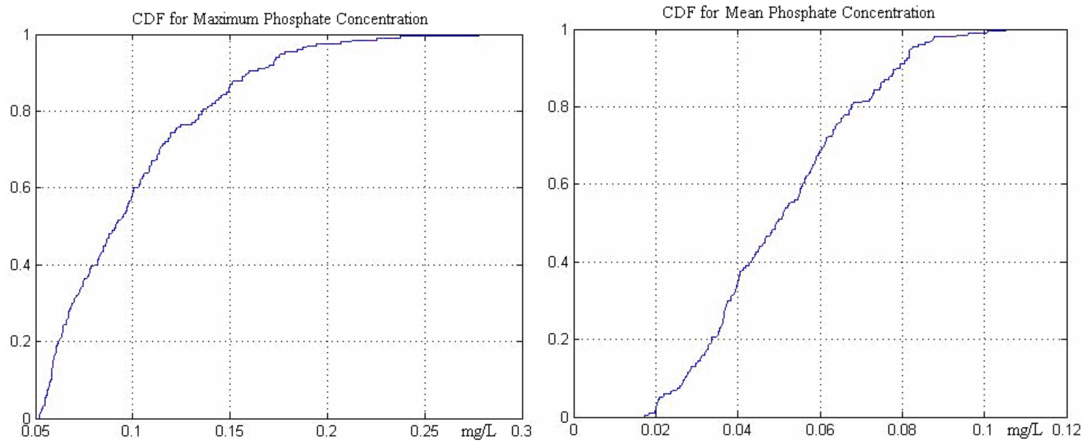

Figure 7: Distributions of simulated daily maximum and daily mean phosphate concentrations

Towards evaluating candidate pollutant trading schemes

The procedures of simulation and the attaching capacity for analysis of uncertainty that underpin the summary results of Figure 7 provide the platform on which we have been constructing our evaluation of candidate pollutant trading schemes for managing water quality in a watershed, as follows.

The first criterion we are proposing to use in our evaluation is that the post-trading water quality conditions are not worse than those obtaining in the pre-trading period. Target values for water quality must accordingly be identified for the criteria determining attainment of water quality standards, specifically those linked to the designated uses for the water body of interest (EPA, 1999). For instance, if we choose 0.1 and 0.05 mg/L as the standards for phosphate concentration, then the current water quality target (Figure 6) can be expressed as an attainment probability for those water quality standards as:

{ EMBED Equation.3 **}**

The performance of a candidate pollutant trading scheme can then be simulated using the models and procedures set out above, such that if the simulated post-trading water quality conditions can meet the pre-trading water quality target, we will say this scheme is valid, or tradable in principle (otherwise, it is eliminated from any subsequent consideration and analysis). Hence, at the next stage, when economic costs are evaluated, the credits available from trading under the given “valid” scheme can be calculated using the marginal cost curves of pollutant abatement (through point-source plant upgrades or the installation of Best Management Practices for curbing nonpoint sources of phosphorus; for example, Jiang *et al*, 2005). All such candidate “valid” schemes would then be comparable on the basis of their attaching tradable credits, amongst other factors, creating a framework such as that of Figure 8 for then indeed selecting a scheme that performs well and is robust against all the sources of uncertainty in watershed behavior and economic cost estimation.

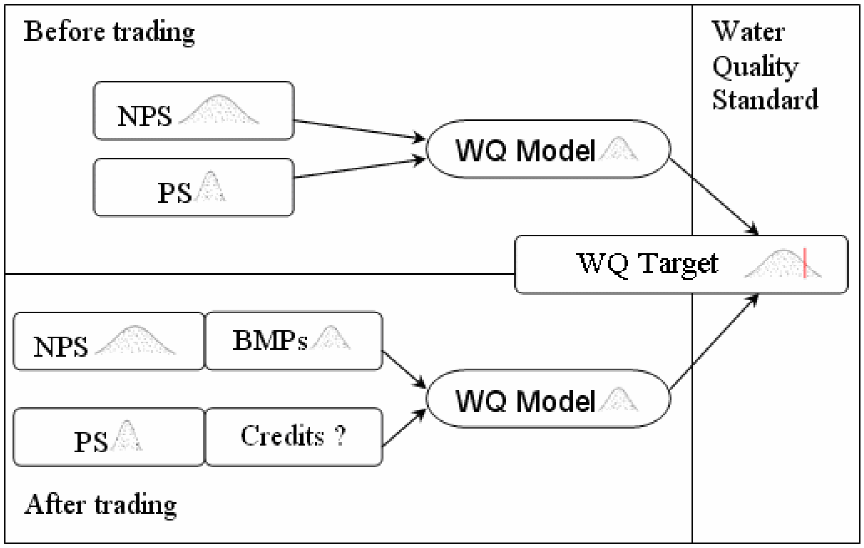

Figure 8: Suggested paradigm for pollutant trading scheme evaluation

Towards improving simulation of nonpoint-source behavior

Development of a simulation model for nonpoint-source pollution load assessment, in respect of both rural and urban land uses, is widely recognized as an outstanding challenge, as already noted.

The Soque watershed is located upstream of Lake Lanier within the Upper Chattahoochee watershed, with predominantly rural/agricultural land uses, such as poultry and turf production. We have accordingly begun work on improving our simulation of nonpoint sources of pollutants based on a comprehensive set of time-series data from this watershed, where these data have an especially high frequency of sampling (of the order of hours and minutes over an extended period of weeks). The field work was designed, in particular, to identify how phosphorus-bearing materials enter the main stem of the river from the application of chicken manure on pasture land. Analysis of this data base to date has proceeded in three preliminary steps: (a) statistical assessment of the correlation between hydrological variables, such as precipitation or stream discharge, and observed in-stream phosphorus concentration; (b) application of advanced methods of time-series analysis for, for example, extracting trend components, smoothing, the interpolation of missing data, and identifying outliers; and (c) application of the STAND model (Zeng and Beck 2001, 2003), in particular, to try to reconstruct the sequence of lateral inflow fluxes of phosphorus to the river from the surrounding land, i.e., to reconstruct the dynamics of the nonpoint-source loads of phosphorus.

In short, the results from the correlation analyses of the first step of this preliminary study show that in-stream (soluble) phosphorus variations are essentially not correlated with precipitation variations. Proceeding therefore to the second step of our analysis, of more advanced time-series analysis, Figure 9 shows the extraction of a longer-term trend from the observed in-stream phosphorus concentration at the upstream boundary of the studied stretch of river. Technically, the trend has been extracted using the Dynamic Harmonic Regression (DHR) model, as discussed in detail elsewhere (Young 1998; Young, Pedregal, and Tych 1999). The trends extracted in this manner from the raw data are compared in Figure 10 for the two observed (upstream and downstream) phosphorus time series. The two follow the same pattern – up to a point – suggesting that on a broad scale the phosphorus response at the outlet of this segment of the river is strongly driven by the perturbations entering the segment upstream.

However, most significantly, the two trends do not follow identical patterns, since there are smaller-amplitude discrepancies of a more transient nature occurring over a number of shorter periods, notably at about 100, 250, 300, and 420 hours in the observed record. Some of these "anomalies" suggest net removal of phosphorus across the stretch of river, while others are indicative of net additions (which might arguably be associated with nonpoint-source fluxes of phosphorus). In the third stage of our preliminary analysis, involving application of the STAND model, estimation of the downstream concentration of phosphorus from the model and the upstream boundary conditions reveals the same anomalies (Figure 11). These results, viewed from another perspective, enable us to reconstruct an estimate of the dynamic variations in the lateral influx of phosphorus to the studied stretch of river, which after about hour 250 in the record bears some apparent, but weak, correlation with the observed precipitation sequence (Figure 12).

All in all, answering the question of how phosphorus enters this segment of the Soque River from activities on the surrounding land remains a significant challenge, towards which the results reported above are nevertheless a promising start.

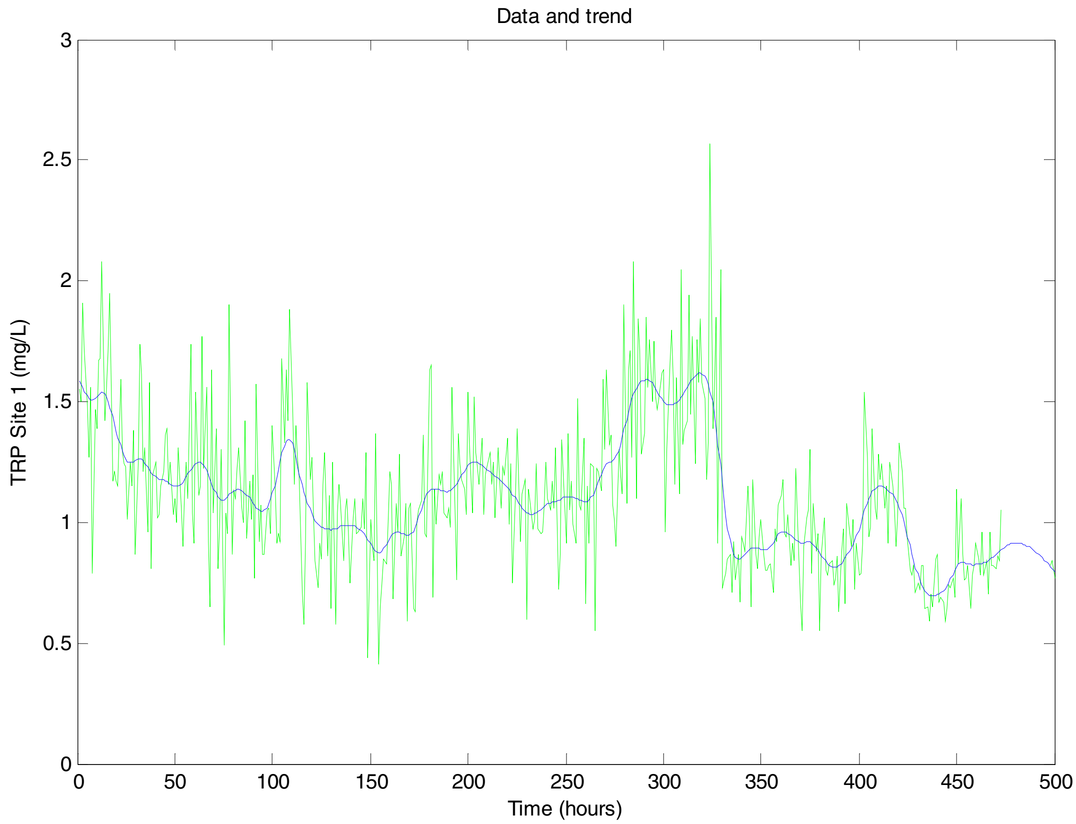

Figure 9. Trend extracted for upstream site by using the DHR model

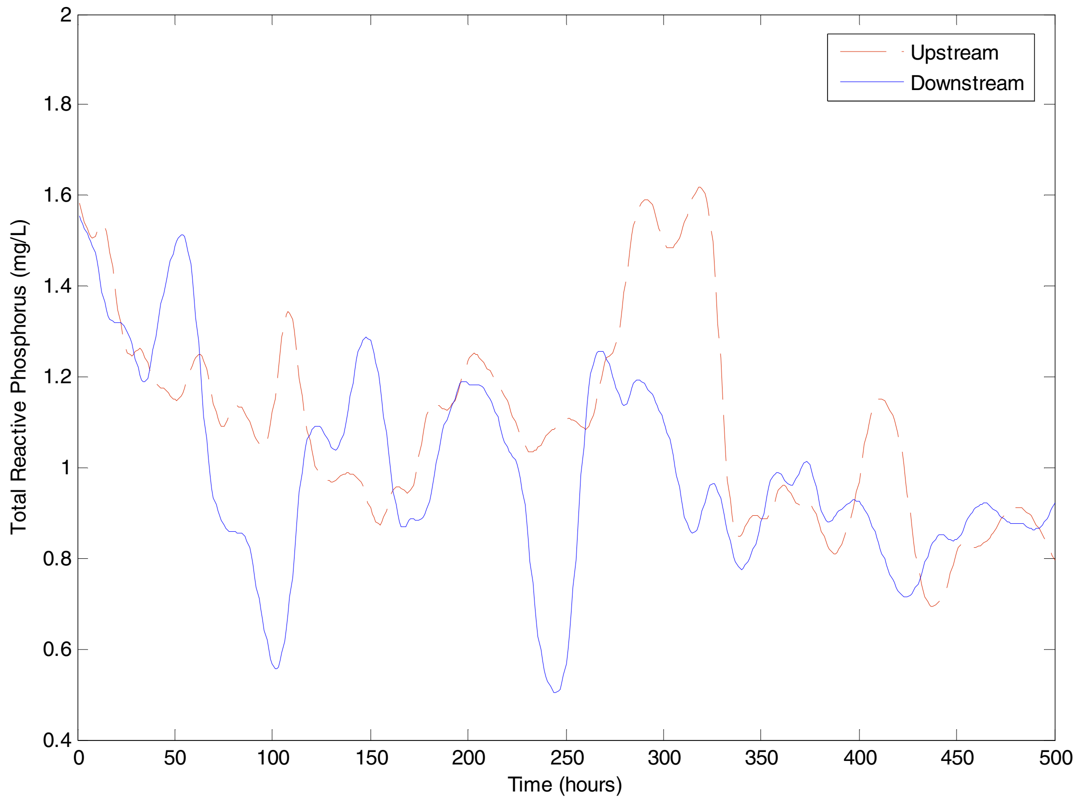

Figure 10. Comparison of trend curves obtained for both sites

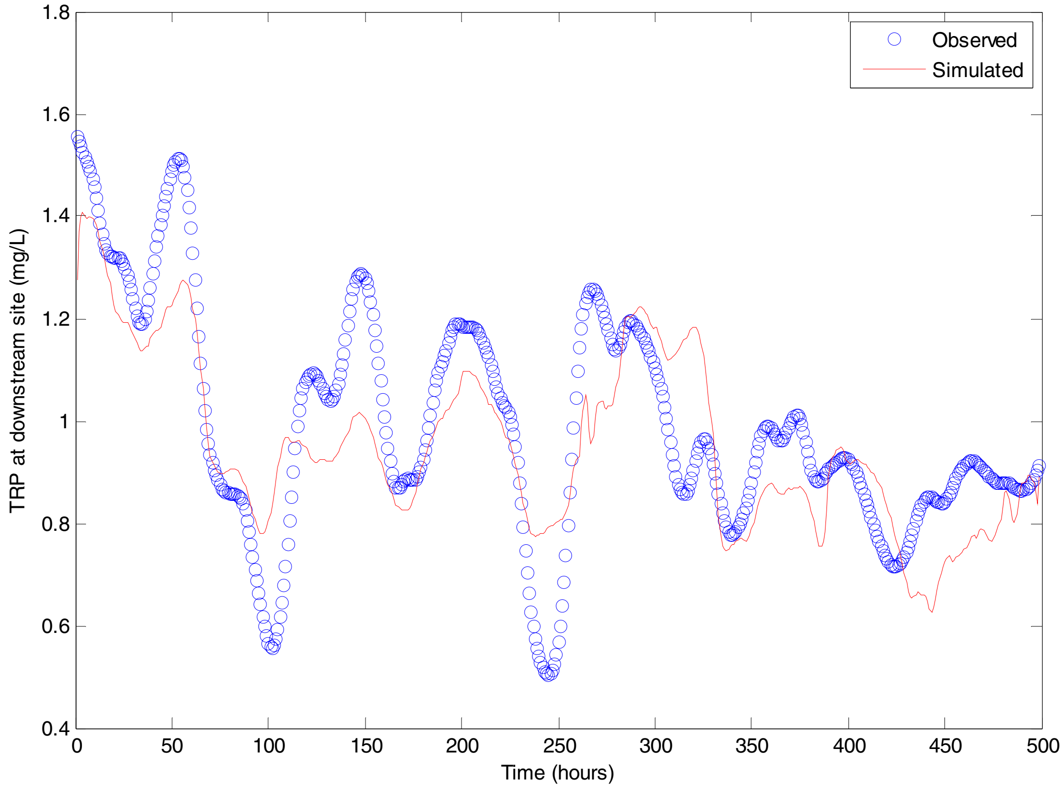

Figure 11. Output from STAND (simulated TRP) versus trend of observed values

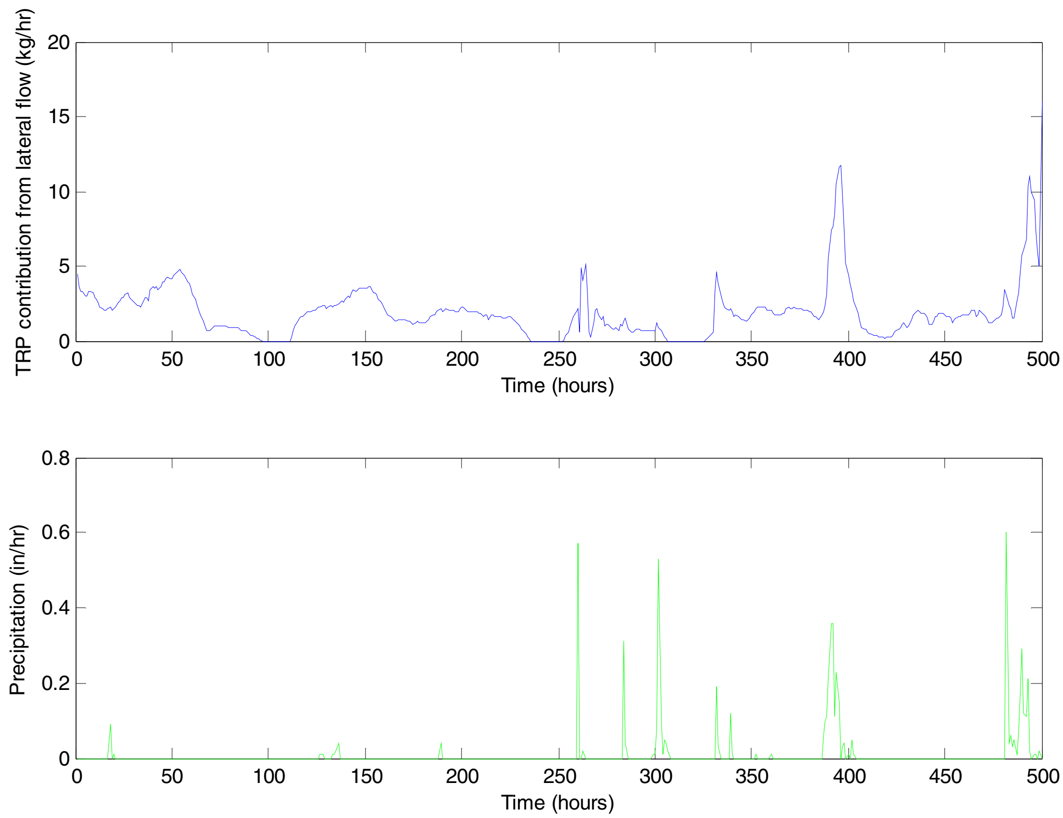

Figure 12. Relationship between estimated lateral phosphorus load and precipitation

Conclusions

Building upon the simulation studies underpinning our work on generating marginal cost estimates for phosphorus removal in the upgrading of point-source wastewater treatment facilities (Jiang *et al*, 2005), we have assembled a rather complete model for a watershed, wherein the *dynamic* behavior of these point sources, together with that of the nonpoint sources, can be properly accounted for. This is a significant outcome of this program of work.

Equally significant, the model has been set up to mimic closely the context of metropolitan Atlanta within the Upper Chattahoochee watershed, such that we can generate all manner of patterns of stream water quality as a function of the various candidate alternatives for pollutant trading schemes and assess these in the presence of the substantial sources of uncertainty surrounding watershed behavior, facility performance, and cost estimation. On this basis we have begun developing a systematic framework for screening out preferred trading mechanisms for much more detailed feasibility analyses (the subject of our future program of work).

Future research will also be addressing the very significant current uncertainties in describing the behavior of nonpoint sources of pollutant loads, encouraged by our first, preliminary results from the interpretation of observations from a small agricultural watershed elsewhere in the Upper Chattahoochee.

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