Adaptive Watershed Modeling
and Economic Analysis for Agricultural Watersheds

An Approach to Integrate Local Stakeholder Knowledge
with the Best Science

Amir P. Nejadhashemi, Assistant Professor, Departments of Biosystems and Agricultural Engineering and Crop and Soil Sciences, Michigan State University
Craig M. Smith, Doctoral Graduate Student, Agricultural Economics, Kansas State University
William L. Hargrove, Director, Kansas Center for Agricultural Resources and the Environment (KCARE)/Kansas Water Resources Institute (KWRI)

Introduction
In recent decades, nonpoint sources of pollution have received increased attention. In particular, runoff from agricultural lands has been cited as a primary contributor of sediments, nutrients, and pesticides into the nation’s waterbodies (KDHE 2006). Challenges still remain despite many years of effort and hundreds of millions of dollars spent on best management practices (BMPs) aimed at reducing these nonpoint sources of pollution. In Kansas, for example, nearly 39 percent of stream miles and 76 percent of lake acres were deemed impaired for one or more of their designated uses (KDHE 2006). The question is, how can conservationists and extension professionals use tools from science, combined with the knowledge and participation of local stakeholders, to address water resource issues at the watershed scale? This publication describes an adaptive approach used for watershed modeling and economic analysis activities in agricultural watersheds.

One primary objective of a nonpoint source (NPS) pollution control watershed project is to restore and/or protect the designated uses of waterbodies by reducing pollutant loads from the landscape and stream banks to the tributaries. Nonpoint source pollution usually originates from broadly scattered source areas, so mitigation of water quality problems can be challenging. In addition, given the potentially large cost for significant improvements in water quality, it is important to develop tools that can support cost-effective design of conservation policy and/or implementation of watershed plans focused on water quality.

Cost-effective implementation of agricultural best management practices requires knowledge of how they function in different landscapes within agricultural ecosystems and economic settings. In this regard, watershed models and economic analyses play a vital role in evaluating the effects of agricultural BMPs at field and watershed scales. The goal is to quantify the environmental and economic effects of structural and management BMPs on water quality in the presence of current and alternative agricultural practices. It is necessary to develop comprehensive models that account for both environmental and economic factors, to support better public policy, and to develop watershed-based solutions to environmental problems.

Watershed Model
Models use data and inferences to present something real as a mathematical description. In watershed terms, models represent a scientific understanding of how land characteristics, management practices, and other factors relate to pollutant loading into waterbodies. Models play a central role in the water quality assessment and improvement program. With results from watershed modeling, groups are able to identify critical areas that cause water quality degradation within a watershed. In addition, watershed modeling can be used to predict where BMPs should be located within a watershed to maximize their impact on water quality and to evaluate the performance of BMPs on a watershed scale. Specifically, watershed modeling can aid decision-makers by:

- Establishing a data-based spatial water resources information system to improve accessibility of water quantity and quality data critical
for sustainable water resources planning and management.

- Identifying the effects of location and distances from water bodies and the timing of agricultural practices on preserving the integrity of the environmental system.

- Identifying sustainable practices, which can help ensure protection of soil and water quality, biodiversity, and responsiveness to concerns of environmental, agricultural, and other stakeholder groups.

- Evaluating BMP implementation plans in order to examine pollution load reductions under alternative scenarios including different scales of time and space.

Economic Analysis

Cost-effectiveness is based on the relationship between tangible benefits and the money spent to achieve those benefits. Because available funding, time, and effort for the implementation of BMPs is limited, resources should be directed toward those investments that deliver the most environmental benefits produced per dollar spent. While watershed protection and/or restoration may be a fine goal, it is important to consider both the costs and benefits to watershed stakeholders in order to develop an economically feasible watershed management plan.

A watershed economic analysis can provide valuable information to stakeholders and other decision-makers as they make management decisions that ultimately affect the quality of life within and around the watershed. Specifically, watershed economic analyses can aid decision-makers by:

- Analyzing the impact that water and natural resources have on various economic segments of the watershed to show the value of protecting these resources. An example might include estimating the regional economic contributions of reservoir recreation and assessing how eutrophication and sedimentation of a reservoir affect the current levels of benefits.

- Estimating the benefits and/or returns of different agricultural BMPs at the producer/landowner level. Examples might include increased yields, topsoil savings, and reduced labor costs.

- Estimating the costs of different agricultural BMPs at the producer/landowner level. Examples might include competing land opportunity costs, additional time and labor requirements, increased risk, and reduced field efficiencies.

- Identifying incentives available and/or the funding levels needed for BMP adoption.

- Developing cost-effective watershed management.

An Integrated Watershed Modeling and Economic Analysis Framework for Watershed Assessment

Through watershed modeling, the environmental effects of BMP adoption can be estimated. Similarly, through economic analysis, the economic effects of BMP adoption can also be estimated. Combining these two assessment activities helps determine the comprehensive effects of BMP adoption. If soil erosion is the issue at hand, watershed plans can be evaluated in terms of the cost per ton of soil erosion reduction. Likewise, if phosphorus reduction is a goal of the stakeholders, watershed management plans can be evaluated in terms of cost per pound of phosphorus reduction. Comparing all plans by the same unit of measurement allows the stakeholder to make equitable comparisons.

Stakeholder Involvement

If the goal of a watershed assessment project is to provide valuable information to stakeholders as they make management decisions within the watershed, it is essential that the stakeholders “buy into” the assessment output. Experience has shown that output from watershed assessment tools (models) can have greater levels of acceptance among stakeholders if they feel that they played an important part in the development and execution of the assessment activities. Further, they need to feel that their voices were heard and acknowledged and that their input was used in the process.

It is essential that stakeholders are involved at each stage of the watershed assessment process. Their knowledge of local social, economic, political, and environmental conditions also provides the yardstick for measuring proposed solutions. Real change in a watershed will occur most effectively with ample stakeholder motivation, input, and support.

Challenges of Stakeholder Involvement

Stakeholder involvement in watershed issues has gained momentum in recent years. However, a complex array of factors relating to stakeholder involvement in the assessment process needs to be consid-
ered. For example, the stakeholders have no way of knowing how their input can affect the watershed management decision, nor do they have any insight into how seriously their comments are taken.

Furthermore, stakeholders do not see how their ideas and local knowledge compare with the “expert” knowledge of the watershed modeler and economist. As a result, many stakeholder groups are resistant to the concept of watershed management plans driven by results from new assessment tools such as watershed/water quality models. Democratic principles call for a new set of approaches to stakeholder participation that emphasizes learning and interaction between modelers (both watershed modeler and economic analyst) and stakeholders.

**Adaptive Modeling Strategy**

Stakeholders desire the best science to guide watershed management decisions, but not to the exclusion of their input. In order to address this concern there is a need to actively involve and use stakeholder participation within watershed and economic modeling decision-making approaches. In this regard, Nejadhashemi et al. (2007-a) introduced adaptive modeling for watershed restoration and protection. This approach fosters mutual learning among modelers and stakeholders and relies on a basic degree of communication competence. In the adaptive modeling strategy, watershed assessment is an iterative process driven by continuous evaluation and adaptation. The key to this strategy’s success is constructive contribution by all parties in decision-making. In the adaptive modeling strategy, power is shared and all parties take collective responsibility for their actions and subsequent outcomes from those actions.

The adaptive strategy for watershed modeling is summarized in Figure 1. The task starts with a learning process in which all parties are committed to learning from each other. These venues can lead to more substantive working relationships between stakeholders and modelers. In the next step, watershed issues and stakeholder concerns and questions are defined. Based on these issues and questions, information required to answer these questions is identified, including the data needed for modeling. Next, preliminary data are collected through the help of watershed specialists, facilitators, and/or stakeholder groups. These data will be used to complement and refine national databases.

The adaptive strategy should begin with simple modeling. Although some accuracy may be sacrificed by using simpler models, the data and results tend to be understandable for people with little or no modeling background, which allows the stakeholder group to be engaged in assessing, prioritizing, and analyzing key concerns within their watershed.

As results are analyzed jointly by the modelers and stakeholders, new questions are formulated and new simulations or models are identified; the stakeholder group continues to be involved in the modeling process. It is likely that refined stakeholder questions will require increasingly detailed models with increasingly refined data needs. This early stakeholder involvement can help in the acceptance and appropriate application of model results, because stakeholders understand the utility and limitations of these results.

Based on stakeholder and modeler interactions, successive refinements are made as needed until the results of the modeling section are accepted, stakeholder questions are answered, and implementation strategies are developed. At this stage, when the
Table 1. Review of commonly used watershed models.

<table>
<thead>
<tr>
<th>Model Type</th>
<th>Advantages</th>
<th>Limitation</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>Minimal data preparation (land use, soil, slope, etc.)</td>
<td>Limited to waterbodies where loadings can be aggregated over longer averaging periods</td>
<td>Loading Rate Simple Method USLE / MUSLE USGS regression PLOAD STEPL</td>
</tr>
<tr>
<td></td>
<td>Good for long averaging periods (annual or seasonal budgets)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No calibration</td>
<td>Limited to gross loadings</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Some testing/validation is preferable (comparison of relative magnitude)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mid-range</td>
<td>More detailed data preparation in comparison to simple models (meteorological data)</td>
<td>Limited pollutants simulated</td>
<td>AGNPS GWLF P8 L-THIA</td>
</tr>
<tr>
<td></td>
<td>Good for seasonal/event issues</td>
<td>Daily/monthly load summaries</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Minimal or no calibration</td>
<td>Limited in-stream simulation and comparison with standards</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Testing and validation preferable based on application objectives or storm events loads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detailed</td>
<td>Accommodate more detailed data input</td>
<td>More training and experience needed</td>
<td>HSPF LPC SWMM SWAT</td>
</tr>
<tr>
<td></td>
<td>Short-time steps and finer configuration (Ability to evaluate various averaging periods and frequencies)</td>
<td>Time-consuming (need GIS help, output analysis tools, etc.)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calibration is required</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Addresses a wide range of water and water-quality problems</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Include both landscape and receiving water simulation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Model and assessment results are being successively refined, it is important to strike a proper balance between analysis and action. An important benefit of the close collaboration among the modeler and stakeholders is a better understanding of when the information and model results are adequate to allow implementation of the watershed restoration and protection strategy.

**Model Selection Considerations**

A watershed model, like any predictive model, should be recognized as including both mathematical expressions and expert scientific judgment. As a rule, a predictive model should have the following characteristics:

1. **Data.** The model is consistent with the amount and quality of data available. Quality of results relate to quality of inputs. Models requiring large amounts of monitoring data should not be used in situations where such data are unavailable.

2. **Flexibility.** The model is flexible enough to represent the system being modeled and allow updates and improvements as understanding of that system changes.

3. **Cost.** The costs associated with model parameterization and long-term support must be acceptable over the long term. Given growth and change, water quality management will not end with the initial stakeholder plan.

4. **Complexity.** The model is appropriate to the complexity of the situation. Simple water quality problems can be addressed with simple models. Complex water quality problems may or may not require the use of complex models.
Review of Commonly Used Watershed Models

Watershed models can be classified into three major categories: simple, mid-range and detailed models. Table 1 (on facing page) outlines a number of these models and highlights the advantages and limitations of each type.

Application of the Adaptive Approach

The adaptive approach for watershed modeling and economic analysis was applied to the Pomona Lake Watershed, in east-central Kansas (Figure 2). Pomona Lake is about 30 miles south of Topeka, Kansas. The 519 square-mile watershed includes portions of Lyon, Osage, and Wabaunsee counties. Pomona Lake was impounded in 1963 and reached full pool in 1965. The authorized purposes of the project include flood damage reduction, recreation, water quality improvement, and fish and wildlife management. The main water quality threats to Pomona Lake are sedimentation and nutrient and bacterial contamination. The lake is listed on the state’s 2004 303(d) list for water quality impairment due to eutrophication and silt (USACE, 2007).

The Pomona Lake Watershed study plan included the following eight steps (Figure 3):

Step 1: Modelers introduce the stakeholder leadership team (SLT) to the concept and contributions of watershed modeling and economic analysis. The SLT should consist of those who know the watershed, and this core leadership group should have definite goals for the watershed. In many watersheds, individuals who likely fit this description would include representatives from county extension offices and councils, county conservation districts, and the NRCS, just to name a few. Regardless of the makeup of the SLT, it should be recognized that this is a learning process in which all parties are committed to learning from each other.

Step 2: Modelers provide the SLT with a preliminary understanding of the watershed and the situation from an outsider’s perspective. Modelers provide a comprehensive preliminary assessment report based on information collected from national databases (Nejadhashemi et al., 2009).

Step 3: Intensive teams (modelers and SLT) interact in both collection and analysis of data. In this step, the SLT has the opportunity to review and revise the data provided by modelers (Step 2) because the quality of the modeling results are highly dependent upon quality input data.

Step 4: Provide SLT with the watershed modeling and economic analysis results (tables and graphs) based on the revised databases.

Step 5: Provide SLT with targeting for potential pollutant loading areas based on the geospatial databases.

Step 6: Verify and validate the targeted potential pollutant loading areas by SLT and ground-truthing methods.

Step 7: Modelers and SLT present the watershed modeling and economic analysis assessment to the local public and consult with them regarding different scenarios for BMPs implementation.

Step 8: Present analysis of water quality and economic costs-benefits for various BMP scenarios given by local stakeholder groups, SLT, and the modelers.
**Step 4:** Modelers provide the SLT with the watershed modeling and economic analysis results (tables and graphs) based on the revised databases (Step 3). This task provides comparisons of the differences in national data versus revised (SLT derived) data. During the simple modeling process, modelers gain experience with local conditions, data sources, and practices while stakeholders gain experience with model interpretation. This experience leads to better selection of more complex models, more accurate watershed input data, and better use of their results in the decision making process.

**Step 5:** Modelers provide the SLT with targeting for potential pollutant loading areas based on geospatial databases. Watershed characteristics such as topography, land use, and soil type often combine to make some nonpoint sources have a higher potential for water quality degradation than others (Nejadhashemi and Mankin, 2007-b). Targeting strategies identify these high priority areas (Figure 4).

**Step 6:** Modelers with the SLT verify and validate the targeted potential pollutant loading using ground-truthing methods. Figure 5 shows the geographical area that the SLT visited during the ground-truthing verification activity. The data from this step can help modelers and the SLT recognize the amounts and types of BMPs currently in place in the high-priority areas. This assists in the development of future BMP implementation scenarios.

**Step 7:** Modelers and the SLT present the watershed modeling and economic analysis assessment to the local public and consult with them regarding different scenarios for BMPs implementation.

**Step 8:** Modelers present analysis of water quality and economic costs/benefits for various BMP scenarios given by local stakeholder groups, the SLT, and the modelers. Scenario one may simulate a random BMP implementation process – in other words, BMPs are implemented wherever there is a willing landowner – not taking into account the relative severity of the problem. The cost-effectiveness of the first scenario can be compared to more targeted approaches determined by either the stakeholders or technical team.

Through this process, the stakeholders can establish criteria for determining the BMPs to focus their money, time, and effort on for implementation. For example, this may be a focus on funding BMPs in high-priority areas determined from a watershed model or on fields that are within 500 meters of water bodies.

The Pomona Lake SLT used another option for cost-effective implementation through the use of a BMP auction. In a BMP auction, agricultural producers compete by submitting bids to supply the buyer (e.g., watershed group, state agency, etc.) with water quality improvements through the implementation of BMPs. The bids are ranked by the amount of water quality improvements generated per dollar. Winning bids will come from producers that can provide the most water quality improvement for the least cost. The ranking process is repeated until a predetermined point is reached (e.g., funds are exhausted, bids no longer meet a certain water quality improvement/price ratio target, etc.). The auction allows the buyer to identify and purchase the most cost-effective water quality improvements for a specified budget. The buyer could be a government entity or a private firm that needs to achieve a particular reduction in emissions.

In the Pomona auction, there were 24 bids for practices. The practices funded through the BMP auction resulted in 938 tons/year of soil loss reduction at Pomona Lake Watershed.
the edge of fields with an overall erosion reduction efficiency of 75.4 percent. In the final analysis, all bids were funded because the total did not exceed the amount of available funding. Figure 6 depicts the variation in cost-effectiveness across bids.

There are several benefits to coupling an auction approach with flexible BMP implementation funding. In the marketplace, where numerous producers are providing bid information, project sponsors can select among competing bids to purchase the most cost-effective bundle of pollution-reduction investments. Furthermore, the information provides valuable insights into the incentive levels required to induce producers to adopt various desirable practices.

**Conclusion**

No model is able to produce the one “right” answer to management questions and decisions. As with all modeling analyses, it must be acknowledged that model output is only as accurate as the data going into the system. Also, simulation models cannot predict absolute responses in the environment and a level of uncertainty exists in all model output. Therefore, models are only one tool to assist watershed stakeholders in the development of watershed management plans. Evidence in scientific literature, local knowledge of the watershed, and other information and data must be used to help develop a watershed management plan.

It is tempting to jump immediately into using more complex watershed models and economic analyses, with the assumption that the results will be more accurate. More complexity may not always be better or more desirable for a number of reasons. First, the stakeholder’s questions may be answered reasonably well by a relatively simple model. Second, the project budget might not accommodate the time and resources needed to develop and apply a complex model. Third, available data might not be adequate to meet all model input parameters, define all model coefficients, or take advantage of the increased model complexity. Even if data are available, they might be controversial or overly general, and thus raise concerns about their impact on model results. Lastly, complex models have more parameters to fine tune, making them more challenging to interpret.

If the complexity of the analytical problem requires that more complex models are used and the above-mentioned concerns are addressed, then careful consideration should be given to the pros and cons of alternative models. Model selection should ultimately come down to choosing the simplest model that will effectively answer the question(s) at hand.

The adaptive approach incorporates stakeholder knowledge and input and allows for stakeholder verification and validation. Through this approach, trusting relationships are built between the scientists and stakeholders. When done appropriately, watershed modeling and economic analysis assessment activities can provide watershed stakeholders with valuable information as they make management decisions that ultimately affect the quality of life within and around the watershed.
Acknowledgments
The authors would like to acknowledge Dr. Kyle Douglas-Mankin, Dr. John Leatherman, Dr. Jeff Williams and Mr. Reid Christianson for their help and comments.

Funding for this project was provided in part by the Kansas Water Plan; U.S. Environmental Protection Agency (Section 319 funds) through the Kansas Department of Health and Environment, Watershed Management Section; and U.S. Geological Survey through the Kansas Water Resources Institute.

References


Brand names appearing in this publication are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned.

Publications from Kansas State University are available on the World Wide Web at: www.ksre.ksu.edu

Contents of this publication may be freely reproduced for educational purposes. All other rights reserved. In each case, credit A.P. Nejadhashemi, Craig M. Smith and William L. Hargrove, Adaptive Watershed Modeling and Economic Analysis for Agricultural Watersheds, Kansas State University, June 2009.