Evaluating Alternatives for Watershed-Scale Design of BMPs

Basic Information

Title:	Evaluating Alternatives for Watershed-Scale Design of BMPs
Project Number:	2006IL134G
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Congressional District:	12th District, IL
Research Category:	Engineering
Focus Category:	Management and Planning, Hydrology, Models
Descriptors:	
Principal Investigators:	John William Nicklow

Publication

1. Kaini, P., K. Artita, J. Nicklow, 2007, Evaluating optimal detention pond locations at a watershed scale, in Proceedings of the 2007 World Environmental and Water Resources Congress, American Society of Civil Engineers, Reston, VA, CD-ROM.
2. Artita, K.S., P. Kaini, and J.W. Nicklow, 2008, Generating alternative watershed-scale BMP designs with evolutionary algorithms, in Proceedings of the 2008 World Environmental and Water Resources Congress, American Society of Civil Engineers, Reston, VA, CD-ROM (in press).
3. Kaini, P., K.S. Artita, and J.W. Nicklow, 2008, Designing BMPs at a watershed-scale using SWAT and a genetic algorithm, in Proceedings of the 2008 World Environmental and Water Resources Congress, American Society of Civil Engineers, Reston, VA, CD-ROM (in press).
4. Artita, K.S., M.W. Sears, P. Kaini, and J.W. Nicklow, (in preparation), An information theoretic approach to sensitivity analysis of distributed watershed models, Journal of Hydrology.
5. Artita, K.S., P. Kaini, and J.W. Nicklow, (in preparation), Examining the possibilities: Generating alternative watershed-scale BMP designs with evolutionary algorithms, Journal of Water Resources Planning and Management.

National Institutes of Water Resources/
Illinois Water Resources Center
Annual Report

1. **Project Number:** 2006IL134G

2. **Project Title and PIs:** Evaluating Alternatives for Watershed-Scale Design of BMPs; Dr. John W. Nicklow, P.E., P.H., D.WRE, Professor, Department of Civil and Environmental Engineering, Southern Illinois University at Carbondale (SIUC)

3. **Research Category:** Best Management Practices, Decision Support Modeling

4. **Problem and Research Objectives:** Best management practices (BMPs) are widely-used structural or non-structural methods intended to manage and/or improve the quantity and quality of stormwater runoff. BMPs are commonly individually designed and site-specific. Studies (e.g., Ferguson, 1991), however, suggest that such fragmented layouts may actually worsen stormwater impacts at the scale of a watershed, thus negating the intended purpose of runoff controls. Detention systems and other structural BMPs are instead most cost-effective when designed and implemented in regionally-strategic combinations to meet related stormwater treatment goals. Implementation of a watershed-scale BMP design is often challenged by conflicting objectives (e.g., environmental, ecological, economic criteria) as well as unquantifiable (and therefore, unmodeled) objectives. Identifying a least cost BMP design and several alternative, near-optimal combinations allows decision-makers to assess tradeoffs between designs and will likely result in a more effective reduction of stormwater impacts at lower stakeholder cost.

   The objective of this research was the development of a new, publicly-available decision-support framework and software model that bridges the gap between individual BMP design and the implementation of watershed-scale runoff controls. The corresponding computational model is capable of determining the least-cost combination of BMP design (including types, sizes, and locations of BMPs), along with a set of near-optimal alternatives for the control of stormwater impacts. This decision-making framework was developed and tested on Silver Creek watershed, a portion of the Lower Kaskaskia watershed in southern Illinois. To promote the realization of benefits of watershed-scale design in professional practice, the methodology and application results have been disseminated to federal and state agency personnel, concerned local stakeholders, and the wider water resources community through regional meetings and workshops, an outreach bulletin, nationally-organized conferences, and peer-reviewed journal articles.

5. **Methodology:** A decision support model has been created by linking evolutionary optimization algorithms (EAs) with the U.S. Department of Agriculture's Soil and Water Assessment Tool (SWAT). The initial model underwent testing, evaluation, and refinement to improve predictive capacity and computational performance. The resulting modeling framework is capable of determining watershed-scale BMP designs that:

Minimize → total cost of BMPs

Subject to →
i. governing physical laws of watershed hydrology and water quality,
ii. BMP size constraints (e.g., maximum detention pond area)
iii. maximum peak flow and sediment load rates (i.e., water quantity and quality constraints),
iv. BMP placement constraints (i.e., no BMPs can be placed in subbasins with wetlands or forests as its dominant land use type).

Within the new model, SWAT is used to solve constraints that govern watershed hydrology such that the complex interactions between water quantity and quality are fully captured. SWAT also simulates several standard structural BMPs, including detention ponds, infiltration ponds, parallel terraces, grade stabilization structures, grassed waterways, and filter strips. Meanwhile, the EA identifies optimal BMP designs and solves the overall optimization problem. Two types of EAs, a genetic algorithm (GA) and a species conserving genetic algorithm (SCGA), are used for solution to this problem. The GA solves the problem by finding a single near-optimal solution; the SCGA produces multiple alternative designs that vary minimally in cost from that of the optimum, but are maximally different with respect to design parameters (i.e., BMP type, size, and/or location) and unmodeled objectives (e.g., stakeholder preferences).

To meet outreach objectives, PIs have discussed work with stakeholders in and near the test watershed, and they held a formal a workshop on July 31, 2008. Attendees included federal and state employees, city planners, and others. The workshop included presentation and demonstration of the new model and solicitation of feedback. A subsequent roundtable discussion revealed several possible future improvements, and a number of attendees were interested in applying the model to their respective local watersheds. Future collaboration with these individuals is highly likely.

6. Principal Findings to Date and Significance:

- Collection and review of pertinent scientific literature demonstrates increasing emphasis on the use of EAs in watershed-scale design of BMPs and on the need for watershed-scale designs;
- In addition to detention ponds, other structural BMPs, including infiltration ponds, grassed waterways, parallel terraces, and filter strips, have been included into the model, thus incorporating more realistic options for BMP designs;
- The integrated model (SWAT – GA – SCGA) is capable of yielding one least-cost BMP design for a watershed, followed by a number of near-optimal alternatives that can be evaluated with respect to unquantified objectives;
- Presentation of preliminary results at recent meetings, including a University-wide research meeting, local community outreach meeting, and the World Environmental and Water Resources Congress, has facilitated practical utility and cross-fertilization of concepts and interdisciplinary collaborations;
- Distribution of an educational outreach brochure that included general information about watershed-scale design of BMPs and application-specific results (i.e., proof of concept) raised interested in the topic;

7. Graduate Students Supported with Funding

Name	*Department*	*College*	*Institution*	*Degree Sought*	*Date Degree was or will be awarded*
Kim Artita	Civil Engr.	Engineering	SIUC	Ph.D.	Dec 2009
Prakash Kaini	Civil Engr.	Engineering	SIUC	Ph.D	Dec 2009
Eric Zgonina	Civil Engr.	Engineering	SIUC	M.S.	May 2009
David Macak	Elect. Engr	Engineering	SIUC	M.S.	Dec 2009
Dennis Owen	Civil Engr.	Engineering	SIUC	M.S.	Dec 2008

8. Publications and Presentations

Artita, K.S., P. Kaini, and J.W. Nicklow, 2008, Generating alternative watershed-scale BMP designs with evolutionary algorithms, in *Proceedings of the 2008 World Environmental and Water Resources Congress*, American Society of Civil Engineers, Reston, VA, CD-ROM.

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9. Notable Achievements:

The strategic interface between an optimization algorithm and a comprehensive watershed simulation model represents a new methodology to guide cost-effective, watershed-scale BMP design. This project demonstrates that the method and associated model are viable and, based on outreach efforts, are appealing to those involved in watershed planning. The resulting model provides watershed management institutions a useful tool for watershed planning and development by providing an optimal design, as well as multiple, near-optimal design alternatives to accommodate unmodeled objectives.

10. Related and Seed Projects:

Lant, C., Nicklow, J., Schoof, J., and Bekele, E. (2008). "Modeling interactions among 21st century climate, land use, and water quantity and quality to representative watersheds." USEPA. (in review).

Project Proposal: Kraft, S., Lant, C., Nicklow, J., and Beaulieu, J. (2007). "Multifunctionality of agricultural landscapes using modeling and surveying." USDA (proposal revision requested).