Report for 2001IL4241B: Multi-Objective Decision Support Tools for Protection of Streams in Urbanizing Watersheds

- Conference Proceedings:
  - Nicklow, J.W., M.K. Muleta, 2002, Integrative decision making for watershed management using evolutionary algorithms, in Proceedings of the 2002 Conference of the Environmental and Water Resources Institute, ASCE, Reston, VA.

Report Follows:

Illinois Water Resources Center
Annual Report

1. **Project Number:** 01-1

2. **Project Title and PIs:** Multi-Objective Decision Support Tools for Protection of Streams in Urbanizing Watersheds; Dr. John W. Nicklow, Assistant Professor of Civil Engineering, Southern Illinois University at Carbondale, and Dr. Leslie A. Duram, Associate Professor of Geography, Southern Illinois University at Carbondale

3. **Research Category:** Land Management, Urbanization, Decision Support System

4. **Problem and Research Objectives:** The 20th century has witnessed the conversion of a large number of natural and agriculturally dominated watersheds to urban developments. The Lower Kaskaskia watershed, located in the Metro East area of southwestern Illinois, is an example of a basin that is undergoing extensive land use changes through urbanization. It is clear that such drastic landscape changes in this and other watersheds stimulate a corresponding cascade of dynamic adjustments in both water quantity and quality at locations further downstream. Sophisticated hydrologic simulation models and Geographic Information Systems (GIS) have become the standard means for assessing the impacts of urban sprawl on water resources systems. Simulation and GIS models alone, however, are incapable of directly revealing optimal land development patterns that meet specified objectives. More comprehensive watershed-scale modeling techniques are needed to overcome this limitation and assist decision makers in the planning of new developments. Therefore, the objectives of this study are (1) to develop an adaptive, basin-wide decision support model that could be used by land use managers and watershed management institutions to identify optimal land use changes in the Lower Kaskaskia and other similar watersheds, and; (2) investigate stakeholder concerns and reactions regarding formulation and application of the model in order to ensure continuous local support. Outcomes of this two-year project will include the decision support software package; a historical survey and conceptual model of the relationship between urbanization and the hydrologic and water quality variability in the Lower Kaskaskia basin; results of the decision support model when applied to the Lower Kaskaskia basin; and a summary and set of conclusions concerning the social science investigation.

5. **Methodology:** The decision support model has been created by integrating the U.S. Department of Agriculture's Soil and Water Assessment Tool (SWAT) for comprehensive hydrologic simulation, a GIS for generating input and visualizing output, and an evolutionary optimization algorithm for identifying weighted, optimal land use patterns. The combination of these modules results in a single, multi-objective decision framework capable of yielding land use changes that solve the following problem:

Minimize → (i) The adverse effects on water quality and quantity caused by urbanization, and (ii) $-1 \times$ economic growth and profit to be earned through urbanization;

Subject To → (i) Physical, chemical and biological laws governing watershed hydrology; and (ii) realistic bound constraints on the feasible land development.

Within this problem formulation, scaled weighting factors are assigned to each of the two objectives so that the user can convey his or her personal hierarchy of objectives to the decision model. The independent decision matrix is comprised of alternative landscapes, which incorporate specific land use changes on a spatial and temporal scale. Dependent variables are those that describe water quantity and quality variability and economic growth. By using SWAT to solve constraints that govern watershed hydrology and ecology, the complex interactions between land use changes and water quality and quantity are fully captured. The remaining constraint that allows only feasible land use changes is handled directly by the optimization algorithm. Two types of evolutionary algorithms, a genetic algorithm and an artificial life algorithm, are being investigated for solution to this problem. At least initially, the optimal landscape is defined as that which minimizes sediment yield in subsequent streams, while simultaneously maximizing anticipated profit from urban development. Profit due to urbanization has been defined through a simple distance relationship; lands closer to the Metro East region or in the vicinity of major interstates will be more likely to incur larger profits from urbanization. Additional water quality objectives and a more comprehensive economic relationship will be sought once the initial model has been tested and feedback from stakeholders has been obtained. Following an extensive review of watershed planning activities in the Lower Kaskaskia basin, key stakeholders have been identified. Meetings with these stakeholders have been scheduled to aid in the determination of other locally valued parameters that should be included in the model and allow the effective dissemination of results to key individuals.

6. **Principal Findings and Significance:** Tasks completed to date include:
   - Mathematical formulation of the watershed management problem that involves minimizing sediment yield while maximizing economic benefit of urbanization;
   - Collection of SWAT data and thematic GIS data and construction of a basemap and digital elevation model for the Lower Kaskaskia basin;
   - Development of a real-valued genetic algorithm software module;
   - Modification of SWAT source code in preparation for an optimization linkage;
   - Construction of the interface between SWAT and the genetic algorithm;
   - Initial testing and application of the decision model to the Lower Kaskaskia basin;
   - Completion of a historical population survey from census tracts within the Lower Kaskaskia watershed (1970-2000);
   - Initiated a historical survey of water quality parameters and evaluation of parameters to be generated by SWAT for development of the conceptual model;
   - Identification of key stakeholders in the Lower Kaskaskia watershed, and;
   - Scheduled two stakeholder meetings (July and September, 2002).

Principal findings thus far can be categorized into the modeling component and social science aspect of the research. First, results of preliminary testing indicate that the integrative modeling approach is likely to be an efficient method for watershed planning in urbanizing basins. The initial model is capable of directly identifying optimal landscapes that meet both sediment reduction and economic objectives. Second, an extensive investigation of stakeholder involvement has identified two primary environmental planning and management activities in the Lower Kaskaskia basin. The first is the Kaskaskia River Corridor Stewardship Plan (1995), which brought stakeholders together to form the Kaskaskia River Private Lands Initiative Committee. Stakeholders include the Southwest Illinois Resource Conservation and Development Council (SWILRC&D), National Resource Conservation Service, Okaw River Basin Commission, Illinois Dept. of Agriculture, U.S. Fish and Wildlife Service, Farm Bureau, Soil and Water Conservation Districts, County Board members, Sierra Club, The Nature Conservancy, U.S. Army Corps of Engineers, and others. The second is the Metro East Sustainable Growth Resource Group (MESGRG), which has been recently active as part of the Illinois Growth Task Force. The MESGRG is comprised of numerous stakeholders including the SWILRC&D, Homebuilders Association, American Bottomland Conservancy, Sierra Club, County Planners, Illinois Dept. of Natural Resources, and others.

7. Graduate Students Supported with Funding

Name	Department	College	Institution	Degree Sought	Date Degree was or will be awarded
Kyle Allred	Civil Engrg.	Engineering	SIUC	MSCE	May 10, 2003

8. Publications and Presentations

Nicklow, J.W., M.K. Muleta, 2002, Integrative decision making for watershed management using evolutionary algorithms, in Proceedings of the 2002 Conference of the Environmental and Water Resources Institute, ASCE, Reston, VA.

9. Notable Achievements: The strategic interface between an optimization algorithm and a comprehensive watershed simulation model represents a new methodology to guide cost effective and environmentally sound watershed planning decisions. Consequently, the resulting model provides land use managers and watershed management institutions with a useful visualization tool for planning and communicating urbanization activities that will affect watershed health.

10. Related and Seed Projects

Beaulieu J., J. Nicklow, S. Kraft, C. Lant, 2001, Decision support for water quality planning in multiple ownership watersheds: The case of the Cache River and applications in other Illinois watersheds, Illinois Council for Food and Agricultural Research: Water Quality Strategic Research Initiative. Period Covered: 7/01-6/02, Funds Received: $65,000.