Selection and Placement of Best Management Practices Used to Reduce Total Phosphorous Runoff in the Lincoln Lake Watershed in Northwest Arkansas

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BACKGROUND

An increased loss of agricultural nutrients is a growing concern for water quality in Arkansas especially in nutrient surplus areas. Methodologies that help to find solutions that are accepted and understood by all the stakeholders involved in water quality issues are needed. Several studies have shown that best management practices (BMPs) are effective in controlling total phosphorous (TP) pollution. However, selection, placement and affordability of those practices need to be taken into consideration when making water management decisions.

OBJECTIVE

To develop a BMP optimization technique that searches for near optimal solutions to achieve minimum TP pollution runoff and minimum total net cost increase for BMP placement within a watershed in Arkansas.

RESEARCH METHODS

To accomplish this objective, this study used a methodology that is able to determine the specific combinations of BMPs to reduce TP runoff in a cost-effective way. This approach linked pollutant reduction loads from SWAT and total net cost increases from a baseline with a multi-objective genetic algorithm.

Genetic algorithm (GA) is a technique based on evolutionary principles of reproduction, recombination and mutation that seeks for optimal solutions to solve a search problem (Goldberg, 1989). In this study a non-dominated sorting genetic algorithm, NSGA-II (Deb et al., 2002) was employed. The NSGA-II finds multiple near optimal solutions in a single model execution and provides trade-off curves (Pareto-optimal front) between two different objective functions. This optimization technique helped to minimize both TP loads and total net cost increase.

Table 1. Best Management Practice Factors

Grazing and Pasture Management	Buffer Width (meters)	Poultry Litter Management		
		Amount (tons/ha)	Application Time	Alum Application
NONE, OPTIMAL	0, 15 , 30	0	N/A	NO
		2.5, 3.7, 4.9	SPRING	YES / NO
			SUMMER	
		4.9, 6.2, 7.4	FALL	

Ninety-five scenarios were created using combinations of BMPs. Practices were grouped into pasture management (no grazing and optimum), buffer zones (0, 15 and 30 meters) and poultry litter application practices. Poultry litter contained three factors: poultry litter application rates (0, 2.5, 3.7, 4.9, 6.2 and 7.4 tons/ha), litter characteristics (non-amended litter and alum amended litter) and application timing (spring, summer or fall).

Each BMP combination had a TP load (from SWAT) and cost associated. All scenarios were compared against a baseline, scenario 36 (optimal grazing and 4.9 tons of litter per ha spread during the fall semester). Scenarios with TP loads greater than the baseline were excluded from the optimization analysis. Table 1 displays the factors used to create 95 scenarios.

RESEARCH METHODS

The usefulness of the optimization framework proposed was evaluated in the Lincoln Lake watershed, a sub-watershed within the Illinois River basin located in Northwest Arkansas. The watershed was divided into 72 sub-basins (figure 1). These sub-basins were also divided into 461 pasture hydrological responses units (HRUs). The NSGA-II optimally selected and placed BMPs, from the 95 BMPs available, according to their TP load and cost for each of the 461 pasture HRUs after comparing them against the baseline. The study was conducted for year 2008.

Figure 1. Lincoln Lake Watershed Sub-basins

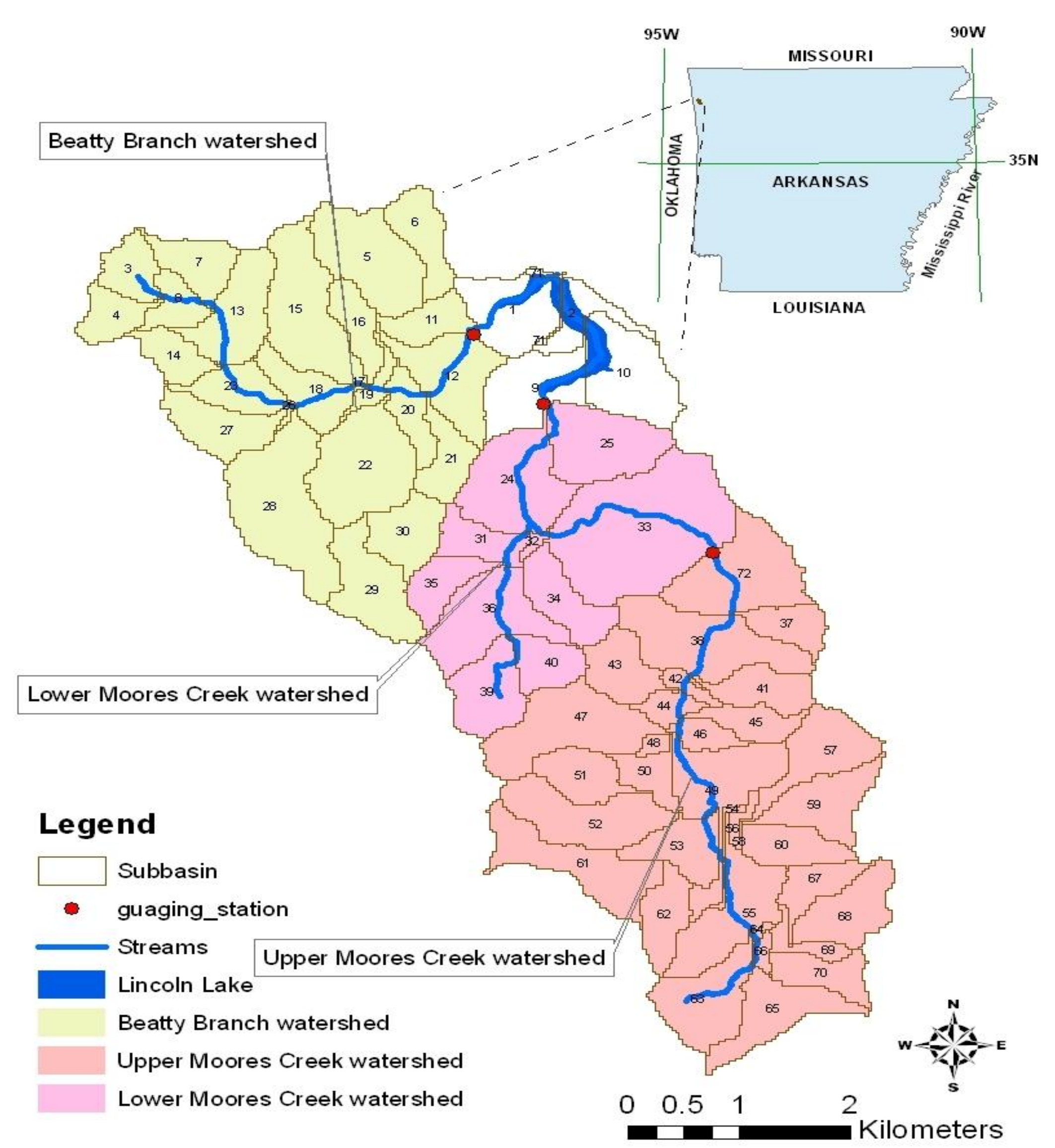


Figure 2. Progress of the Pareto-optimal Front for Total Phosphorous and Net Cost, 2008

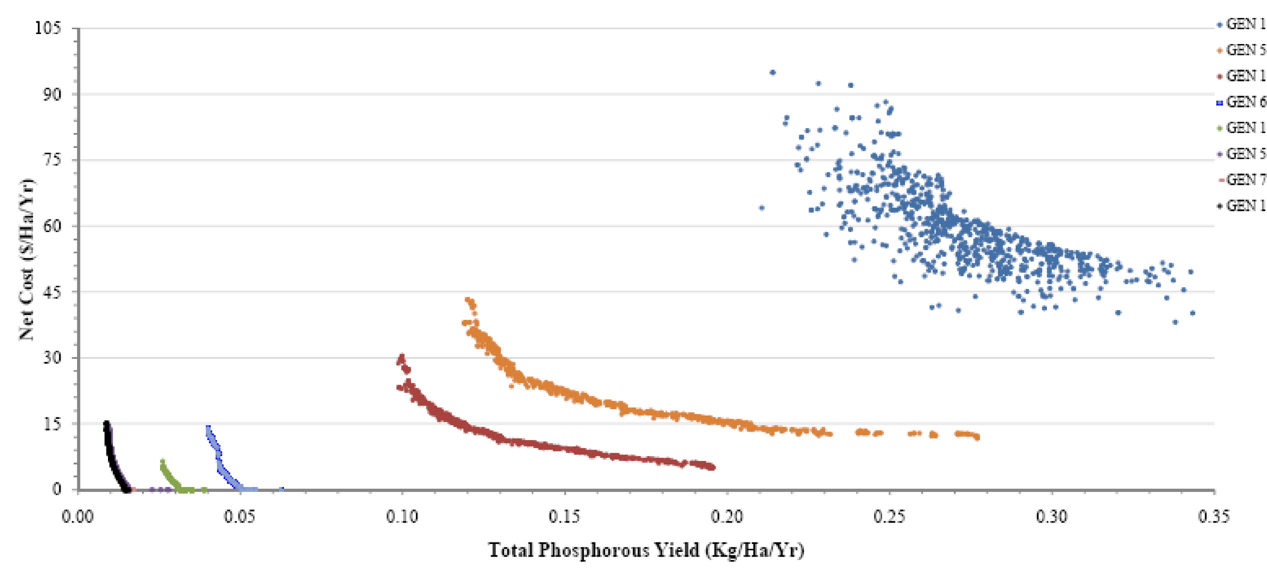
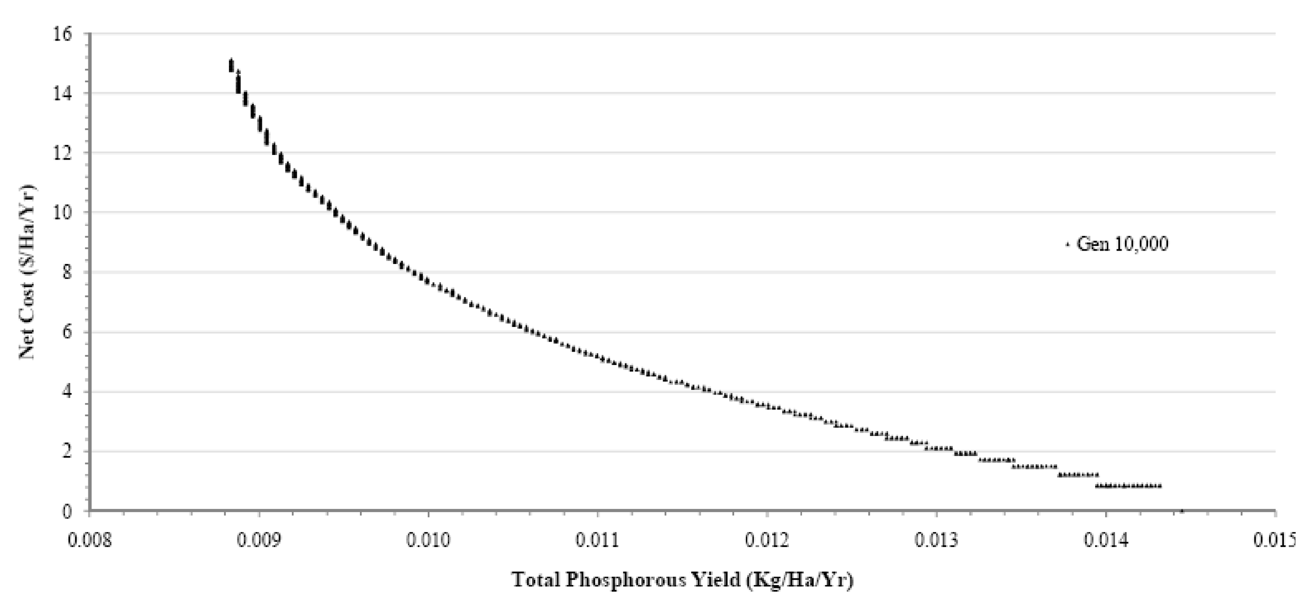


Figure 3. Optimal Front for Total Phosphorous and Net Cost – Generation 10,000

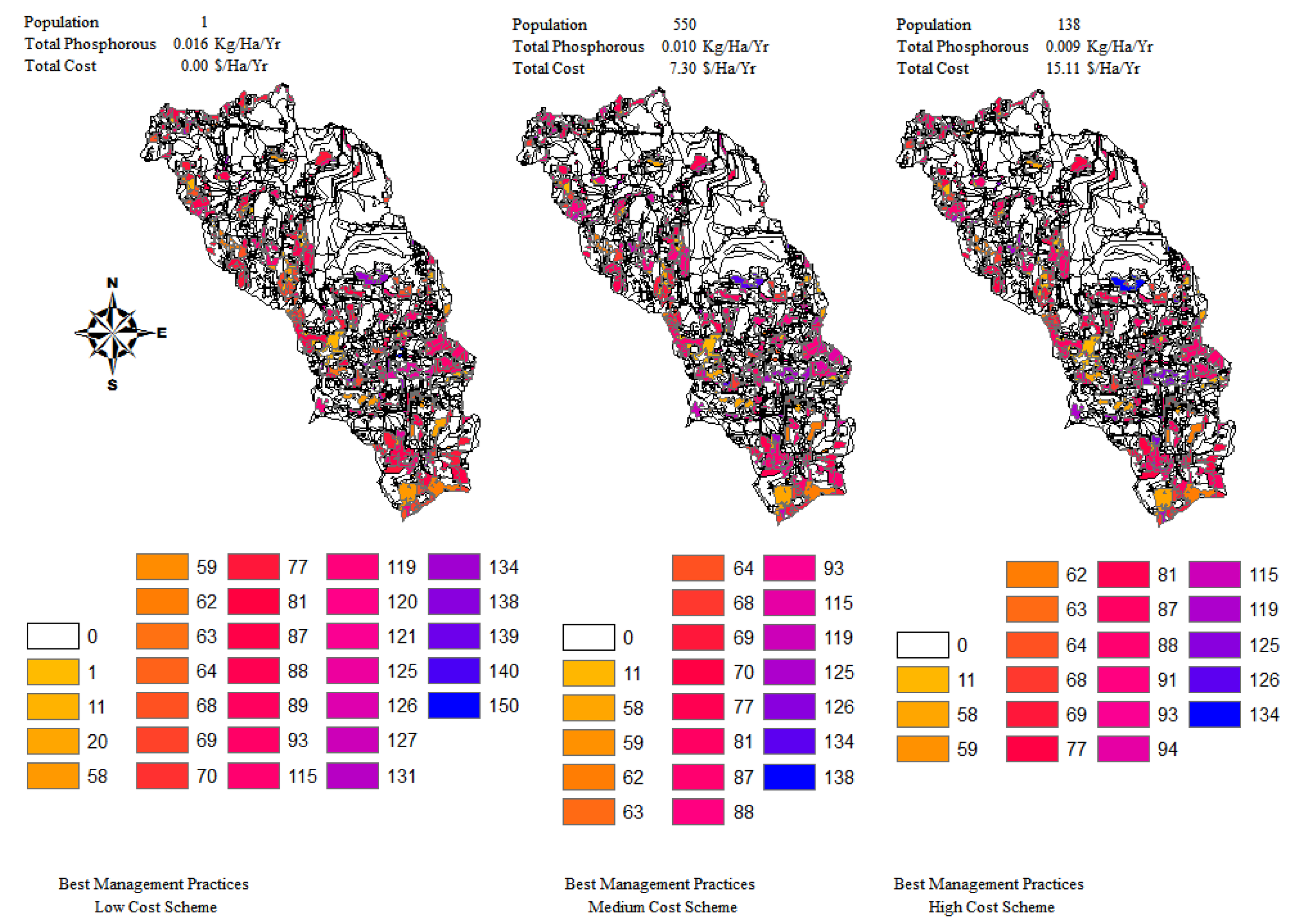


RESULTS AND DISCUSSION

The operating parameters needed to run the GA were determined by conducting sensitivity analyses. The final optimization model used 800 populations and ran for 10,000 generations with recombination and mutation probabilities of 0.7 and 0.005 respectively. The final generation (generation 10,000) produced a number of near-optimal solutions by selecting and placing BMPs that minimize TP runoff and minimize total net costs for hay producers in year 2008.

The annual average HRU area weighted baseline TP loadings from the watershed was 0.505 kilogram per hectare per year. The spread of the solution was improved significantly from the initial generation as optimization progressed to future generations (figure 2). The final solution, obtained after generation number 10,000, displays a range of populations that reduce TP up to 98% and increase net cost by no more than 4.63% per hectare when compared to the baseline (figure 3). In addition, the Pareto-optimal front was wide spread without solutions being concentrated either in the lower or in the higher net cost solutions.

Figure 4. Locations of BMP Placements in the Watershed for Varying Costs of Implementation



The selection and placement of BMPs under three different cost levels are shown in figure 4. Under all cost implementation schemes, TP loads were reduced significantly. In this example (figure 4), the NSGA-II assigned mainly BMPs with buffer zones and low litter application rates for all three levels of costs. Based on the NSGA-II allocations, low cost scenarios applied more non-grazing BMPs than did mid and high level costs schemes. The presence of alternative solutions allows decision makers to weigh tradeoffs between TP load reduction and costs.

Results from this study provide agricultural decision makers with a wide range of optimal solutions when tradeoffs between environmental and economic conditions must be analyzed simultaneously. Although the results are watershed specific, the methodology can be easily extendible for application in other watersheds to obtain cost-effective solutions for non-point sources pollution control.

REFERENCES

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