USING GIS-BASED ECOLOGICAL-ECONOMIC MODELING TO EVALUATE POLICIES AFFECTING AGRICULTURAL WATERSHEDS

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Abstract.

This paper has two purposes. The first is to demonstrate a generalizable framework for the spatial modeling of ecosystem service production in watersheds. The second is to examine the policy implications of the analysis conducted using this spatial decision support system (SDSS).

Analyses using the SDSS show that restrictions on soil loss to the tolerance level (T) do not cause overall farm income to decline so long as the Conservation Reserve Program (CRP) is available to farmers as an income-generating alternative. However, the spatially variable response of farmers creates a complex pattern of winners and losers and a markedly different land use pattern and crop mix between the CRP with T restrictions and the no CRP, no soil loss regulation scenarios. These results point out that by shifting agricultural subsidies from price supports and other crop-based programs to the CRP and other ecosystem service-based subsidies, the decision environment of land and water managers in agricultural watersheds would be changed in a manner that would lead them to choose land use patterns that produce similar farm income, but fewer crops, more soil conservation, and less water pollution. In this way, public expenditures on agriculture would produce a valuable public benefit in the form of load reductions in a TMDL context, and an augmentation of ecosystem services now in decline in agricultural watersheds.

Keywords:

spatial decision support systems, Conservation Reserve Program, agricultural conservation policy, watershed management.

1 INTRODUCTION

Ecosystem services such as nutrient cycling, regulation of atmospheric gases, soil formation and binding, sediment trapping, energy fixation, and expansion of wildlife habitat are increasingly recognized as essential to society and of great economic value (Costanza et al, 1997; Daily 1997). With the considerable successes that have been achieved in controlling industrial pollution, especially point-source water pollution, the target for improving ecosystem services in the U.S. and elsewhere is increasingly focused on landscapes. Improvement in biodiversity and control of polluted runoff, for example, are issues that must be addressed by managing landscapes. While fossil fuel combustion is the primary source of greenhouse gases

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emitted, managing landscapes to foster carbon sequestration is also a significant part of the potential response to global warming (Caspersen et al. 2000, Schulze et al. 2000).

Agricultural landscapes, which constitute about 50% of the land in the contiguous U.S. and similar proportions in other inhabited regions of the world (Vitousek et al., 1997), are distinct from other rural landscapes by their focus upon production of food and fiber commodities. However, agricultural landscapes also harbor natural capital and therefore produce ecosystem services, even if the forest, prairie, wetland, riparian and other ecosystems that were lost on conversion to agriculture were generally capable of producing far greater ecosystem services per hectare (Costanza et al. 1997). The flow of ecosystem services from agricultural landscapes in Sweden is declining (Bjorklund et al., 1999). Negative environmental externalities (i.e. damage to ecosystem services) in UK agriculture are large – over $300/ha/yr (Pretty et al., 2000). However, because of these trends, the potential to restore the production of ecosystem services lies greatly in private agricultural lands, especially grazing lands and croplands that are marginal due to wetness, dryness, steepness, or erodibility. For example, the vast majority of U.S. sites suitable for wetland restoration are now farmland (McCorvie and Lant, 1993) and working farmland has a considerable capacity to absorb atmospheric carbon (Lal et al., 1998).

In the U.S., the focus of this study, agricultural conservation policy influences considerably the land use choices farmers make and therefore the ecosystem services produced on farms (Lant et al., 2001). Farm Bills since 1985 have utilized (1) cross compliance in the form of Conservation Compliance, Sodbuster and Swampbuster and and (2) economic incentives in the form of the Conservation Reserve Program (CRP), Wetland Reserve Program (WRP), and Environmental Quality Incentives Program (EQIP) as policy tools to influence land use behavior with considerable effect in reducing soil erosion and wetland drainage (Esseks and Kraft 1991, 1993). For example, the rate at which wetlands have been drained for agricultural production dropped 87% from 237,000 acres/year in the decade 1974-1983 to 30,900 acres/year in the decade 1982-1992 (Weibe et al., 1996).

2 A SPATIAL DECISION SUPPORT SYSTEM FOR MANAGING WATERSHED DYNAMICS

Spatial decision support systems (SDSS) were created to facilitate the analysis of complex spatial problems where it is not possible to completely define a problem or fully articulate the objectives of the solution in mathematical terms (Armstrong and Densham, 1990). In recent years, several SDSS developments have been reported in the GIS literature that integrate GIS and modeling software to provide support to decision-makers for natural resources management (Leavesley et al., 1996; Watson and Wadsworth, 1996). Here we demonstrate the relevance to policy-making of a SDSS using the Cache River basin of southernmost Illinois, USA as a case study (Figure 1).

The SDSS uses the Arcview GIS software package to link two models -- GEOLP and AGNPS – on a common spatial and temporal modeling framework. GEOLP is a linear programming model of gross margin-maximizing farm decisions developed by Kraft and Toohill (1984), enhanced with a GIS interface. GEOLP determines land use choices for each farm unit that maximize gross margin as constrained by farm characteristics, land characteristics, crop prices and regulatory rules. Thus GEOLP can predict how a farmer's profit-maximizing choices will change, for example, when crop prices rise or fall or when the eligibility of lands for the CRP changes. These land use choices can then be registered to specific parcels of land, thus creating an interface for spatial and environmental analysis. In this study, land use choices are used as the basis for estimating parameters for the AGNPS (Young et al., 1989) watershed hydrology and water quality model. For a more in-depth discussion of the structure of the SDSS see Beaulieu et al (2000), Bennett et al. (2000), Sengupta et al. (2000) and Sengupta and Bennett (in press).

To demonstrate the usefulness of the SDSS, we chose three scenarios that are relevant in the context of the Big Creek watershed of the Cache River basin. A TMDL for sediment load is now required for Big Creek to reduce sedimentation in Buttonland Swamp – a RAMSAR site, a Nature Conservancy Bioreserve and the core of the Cypress Creek National Wildlife Refuge. These scenarios are:

> (1) a base scenario where land uses are chosen to maximize gross margin unconstrained by soil loss limits, but farmers are not able to enroll land in the CRP;
>
> (2) the base scenario with the inclusion of an option to enroll in CRP for eligible lands;
>
> (3) a CRP option, but with a "T by 2000" constraint on soil loss of T (maximum amount of soil that can be lost per acre year without damaging the long-term productivity of the soil)

Figure 2 demonstrates how the SDSS functions with respect to these scenarios, the outputs it produces and its verification. The upper left hand map shows the actual land uses in the Big Creek watershed as determined by Landsat imagery in 2000. The lower-left map shows the land uses on farmlands (forest lands are omitted) predicted by GEOLP under economic and policy circumstances obtaining in 2000. The correspondence is very close thus verifying the model's predictive ability. The map at upper right shows the results when scenario (1) above is compared to scenario (3). While mean farm income is similar under the two scenarios (see below), a complex pattern of winners and lowers occurs on the landscape showing the spatial dynamics of how farmers adapt to changing economic and policy regimes related to soil conservation and water quality control. The lower right map shows the flux of sediments as modeled by AGNPS for a 1.5 inch rain with the land uses chosen by farmers under scenario (3) above. This sediment flux is only 57% of what would occur with land uses chosen under scenario (1).

Table 1 provides the overall results for each of the scenarios studied. Under scenario (1), crop sales are highest and over 90% of farmland is allocated to conservation tillage corn and soybeans. Soil loss averages over twice T, with nearly 20% of farms losing soil at over 3T; sediment fluxes are correspondingly large. When the CRP enrollment option is introduced (scenario 2), gross margin increases by about 5% as 16% of hectares are switched from conservation tillage corn and soybeans to the CRP where this maximized gross margin. Average soil loss decreases to 1.63T and the percentage of farms losing soil at over 3T decreases to only 5.2% of all farms. Nevertheless, 75% of farms still lose soil at a rate of T of greater. Sediment flux decreases correspondingly, especially for smaller storms. When a soil loss constraint of T is introduced, while maintaining the CRP option (scenario 3), gross margin falls, but remains slightly (<1%) above the base scenario. However, while farm income is roughly equivalent between scenarios 1 and 3, it is derived from quite different land use mixes. Crop sales in scenario 3 are 22% lower than in scenario (1), income that is replaced with CRP payments, as half of the acres in conservation tillage corn and soybeans are converted to the CRP, no-till corn and soybeans and alfalfa hay. By definition, all farms lose soil at T or lower, and sediment fluxes are reduced by 71% for a 0.75 inch rain, 47% for a 1.5 inch rain, and 33% for a 3.0 inch rain as compared to the scenario (1).

The spatial distribution of these results is also of considerable importance and demonstrates the capabilities of the SDSS. For example, while scenarios (1) and (3) produce very similar average farm incomes, some farms gain over 10% due to the CRP opportunity, while others lose more than 5% of income due to required cropping changes to meet the T constraint (Figure 2-upper right).

3 CONCLUSIONS AND POLICY IMPLICATIONS

3.1 Implications for Farm Policy

The analysis shows that, for the study watershed, farm income need not be sacrificed to achieve soil losses no greater than T, provided CRP or other ecosystem service payments are available to farmers changing land uses. The reduction in crop sales that results, while considerable, may also be beneficial to the farm economy. Markets for agricultural commodities in the U.S. and in many other countries suffer from surplus supply causing low prices that undermine profitability. Public subsidization of U.S. farmers is at an historic high. Since 1996, federal subsidies have averaged $14.8 billion per year and will be increased to over $100 billion over six years under the 2002 Farm Bill. Subsidization of European farmers is also at very high levels. The reduction in output of agricultural commodities that may occur with a reallocation of farmland from commodity production to ecosystem service production should shift commodity supply curves left, thereby reducing surpluses and raising market prices. In this way the need for crop-based price supports would be reduced by ecosystem service payments such as CRP. Such payments are also legitimate under the Uruguay Round of GATT/WTO negotiations whereas direct crop subsidies receive much closer scrutiny and have resulted in foreign policy difficulties (Becker, 2002).

Conversely, such a policy would increase production of ecosystem services. Taxpayers would then be obtaining greater benefits from the subsidies paid to farmers if those subsidies were tied to the production of public benefits in the form of ecosystem services, especially if those subsidies are well targeted -- along the lines of CREP and the Continuous CRP as opposed to the regular CRP (United States General Accounting Office, 2002). This is a task the SDSS is designed to assist.

3.2 Implications for Watershed Planning and TMDLs

The analyses conducted using the SDSS also have important implications for controlling polluted runoff in the regulatory context of TMDLs. GEOLP estimates how farmers will adjust to new regulatory constraints by changing land uses. Whether or not these land uses will meet the TMDL is then estimated using AGNPS.

Integrating Agricultural and Environmental Policy

The analyses conducted also point to the benefits to be achieved by integrating agricultural policy and environmental policy, especially water quality control. Conservation subsidies, such as the CRP, make it possible for farmers to greatly reduce erosion and sedimentation, and likely also fertilization, without incurring deficits in farm income. By shifting agricultural subsidies from price supports and other crop-based programs to the CRP and other ecosystem service-based subsidies such as carbon credits, the decision environment of land and water owners in agricultural watersheds would be changed in a manner that would lead to changed land use patterns. These land use patterns would produce similar farm income, but fewer crops, more soil conservation, less water pollution, less flooding, and probably more carbon sequestration and wildlife habitat. In this way, public expenditures on agriculture would produce a valuable public benefit in the form of load reductions in a TMDL context, and an augmentation of ecosystem services now in decline in agricultural watersheds.

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Table 1. Income, Crop Acreage Distribution, and Soil Loss Associated with Four Policy Scenarios.

	Uncon-strained without CRP	Uncon-strained with CRP	Constrain-ed to T with CRP
Income			
Gross Margin			
Total ($)	2,118,151	2,223,364	2,125,587
Average ($)	22,064	23,160	22,142
Crop Sales ($)	3893,102	3483,244	3022,263
Per Agr. Hectare ($)	278.48	292.32	279.46
Hectares			
Corn/Soybean	6,972	5,988	5,182
Conservation	6,891	5,988	3,436
No-till	81	0	1,758
Alfalfa/hay	631	672	1,051
CRP	0	1,405	1,839
USLE Sediment Loss			
% T	224%	163%	65%
% of farms			
<100% of T	11.5%	25.0%	100%
101%T to 200%T	37.5%	46.9%	0%
201%T to 300%T	22.9%	22.9%	0%
>301% of T	19.8%	5.2%	0%
Sediment Yield (tons)			
0.75 inch rain	125.1	64.6	35.9
1.50 inch rain	849.8	605.6	447.8
3.00 inch rain	4758.1	4658.7	3180.9

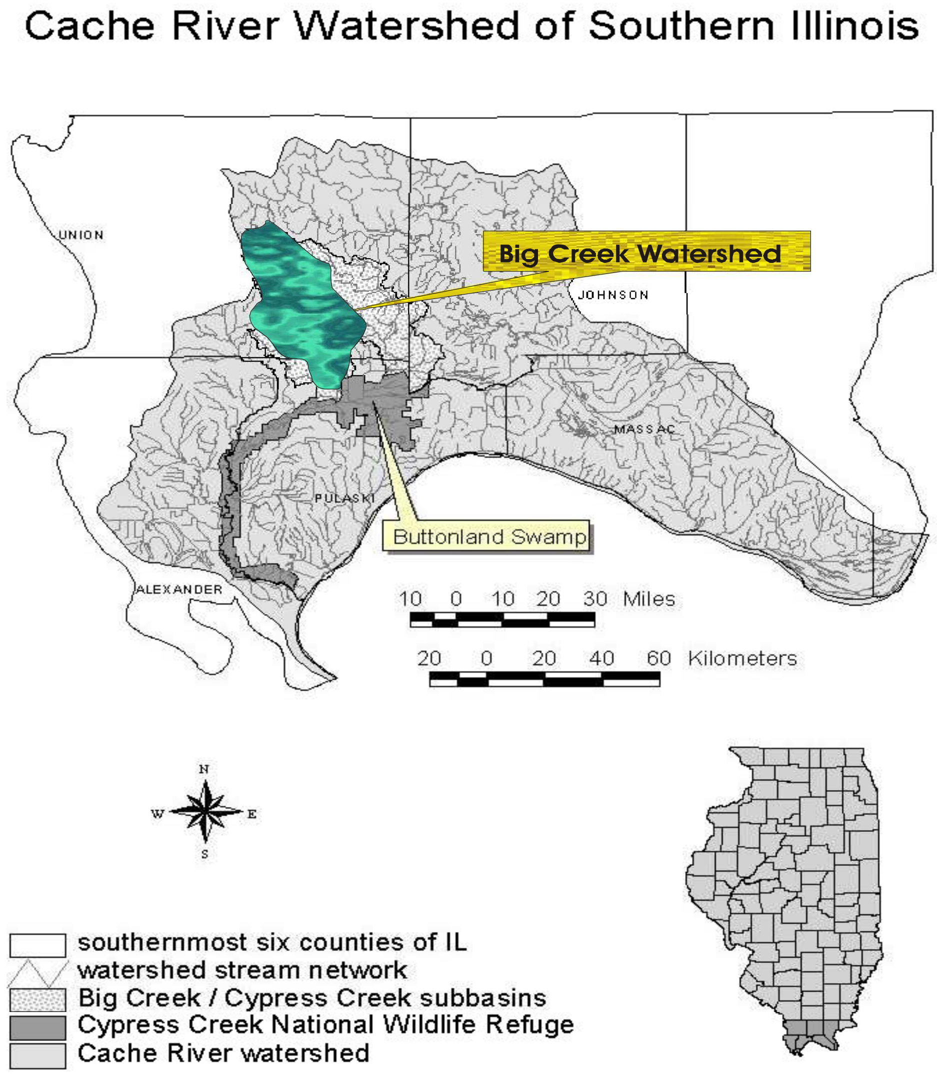

Figure 1. Location of the Big Creek watershed within the Cache River basin of southernmost Illinois, USA.

Figure 2: Farm management - Sediment delivery linkage: Big Creek Watershed