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ANALYSIS

# Using GIS-based ecological–economic modeling to evaluate policies affecting agricultural watersheds

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## Abstract

This paper has three purposes. The first is to conceptualize agricultural watersheds as complex adaptive human ecosystems that co-produce agricultural goods and ecosystem services. The second is to demonstrate a generalizable framework for the spatial modeling of ecosystem service production in watersheds based on this conceptualization. The third 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) cause average farm income to decline by only 4%, a reduction that is nearly eliminated if the Conservation Reserve Program (CRP) is available to farmers as an income-generating alternative. The spatially variable response of farmers to soil loss restrictions and the CRP creates a complex pattern of winners and losers and a markedly different land use pattern and crop mix than occurs without these programs. The land use pattern associated with T restrictions and the CRP yields about 64% lower erosion rates and 43% lower sediment yields than the pattern without T restrictions or CRP. These and other results from the SDSS analysis point out that ecosystem service-based subsidies, such as CRP, improve the joint production of farm income, soil conservation and water quality in agricultural watersheds. These subsidies could perhaps receive greater funding by shifting agricultural subsidies from income supports tied to yield and price as well as other crop-based programs. 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 many agricultural watersheds. Further methodological developments now underway using evolutionary algorithms can find near-optimal solutions for farms over time and for landscape patterns over whole watersheds.


*Keywords:* Spatial decision support systems; Conservation Reserve Program; Agricultural conservation policy; Watershed management; Evolutionary algorithms

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## 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; UNDP et al., 2000). With the considerable successes that have been achieved in controlling industrial pollution, especially point-source water pollution, the scale of management for pollution control and improving ecosystem services is increasingly at the landscape and watershed scale. 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 emitted, managing landscapes to foster carbon sequestration is also a significant part of the potential response to increased greenhouse gases and consequent 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. While agricultural landscapes harbor natural capital and, thus, produce ecosystem services, forest, prairie, wetland, riparian and other ecosystems are often capable of producing far greater flows of ecosystem services per hectare than the agriculture fields that replaced them (Costanza et al., 1997). Tilman et al. (2002) outline the steep challenges that must be met if global food production is to fulfill the demands of a growing and increasingly affluent 21st Century population sustainably. Increasing demand for meat and use of fertilizers and water for irrigation pose substantial threats to ecosystem services flows from agricultural lands. Conversely, 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 sequester atmospheric carbon (Lal et al., 1998).

In Costanza's (2001) expanded model of the ecological–economic system, natural capital, in association with human, social, and manufactured capital, is responsible for maintaining the productive base upon which future economic productivity, as well as individual and community well-being, are absolutely dependent. If this positive model of the manner in which society, nature, and the economy interact is adopted, with the normative goal of sustainability, the conclusion is that society should make greater investments in natural capital to ensure greater delivery of ecosystem services in the present and the future. This greater investment might come at the expense of agricultural commodities produced in the present; however, it is possible such investments would result in greater future delivery of agricultural commodities. Unfortunately, as Zimmerman (1951), Ciriacy-Wantrup (1952), Firey (1960), Hardin (1968), Randall (1983), Lee (1992), Gottfried et al. (1996) and other social scientists have articulated over the past half-century, there is only a narrow range of social circumstances under which resource managers such as farmers are willing to make substantial personal investments in the present to achieve even more substantial public benefits in the future. One critical implication is that in private sector markets, ecosystem services and the natural capital generating them will be under-produced relative to agricultural commodities. This is a consequence of their non-excludable or public good nature and the resulting lack of markets for either the services or the natural capital itself (Randall, 1983). Empirical studies of modern agricultural systems bear out the conclusions of these social scientists. For example, 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/year (Pretty et al., 2000).

In the U.S., agricultural conservation policy influences considerably the land use choices farmers make and therefore the ecosystem services produced on farms (Lant et al., 2001). 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 (Wiebe et al., 1996). Farm Bills since 1985 have utilized (1) cross compliance in the