ASSISTING DECISION-MAKERS MANAGE COMPENSATORY PAYMENTS TO PRESERVE WATER QUALITY IN AGRICULTURAL WATERSHEDS THROUGH MODELING AND SIMULATION

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ABSTRACT

It is well established that intensive agricultural activities have the propensity to degrade water quality within a watershed, and pose a threat to food security in developing countries. It is, therefore, important to strike a balance between intensive agricultural activities (and resultant non-point source pollution) and economic profits in order to maintain overall fertility of soils and improve downstream water quality. Spatial Decision Support Systems (SDSS) provide decision-makers with a computerized environment within which to model these trade-offs in order to identify compensation strategies for affected individuals that would also ensure the acceptance of specific conservation policies. For example, there has been a concerted effort to manage amount of soil erosion from agricultural fields and improve water quality through the use of a compensatory payment structure called the "Conservation Reserve Program (CRP)" designed to reduce soil erosion in the southern region of the state of Illinois, USA. While technically not a "developing country", southern Illinois is an economically disadvantaged area in comparison to the rest of the US. However, compliance with CRP has been problematic because of perceived negative impacts on a farmer's profitability. This paper describes an SDSS that can be used by farmers and policy-makers alike to identify the level of compensatory payments that is sufficient to bring reticent farmers into compliance by offsetting their economic losses. Further, this paper also describes how the existing SDSS can be adopted to identify the appropriate levels of Biocarbon Fund (www.biocarbonfund.org) payments for farmers in developing countries, and model the level of ecosystem services achieved by implementing certain strategies.

1 INTRODUCTION

The need for managing the impact of intensive agricultural activities on streams and rivers has increased during the last two decades as societies worldwide have recognized the value of freshwater resources to support growing populations and economic development. In fact, protection and availability of freshwater resources have been noted as being essential to the "food security" of a nation. However, intensive agricultural practices have a negative impact on both water and land quality, which creates a vicious cycle of negative feedback loops that lessen, not improve, the food security of that country. Therefore, there is intense debate on development of compensation strategies that preserve and protect land from being degraded by excessive agriculture. In addition to land and water quality protection, such compensatory payments can also provide a suite of ecosystem services to society in general, such as Carbon sequestration and maintenance of wildlife habitat.

In the United States, emphasis on the protection and sustainable use of existing water resources has forced water planners to seek out methods of minimizing impacts on these resources, and finding a balance between both human and ecological needs for water. With the considerable successes that have been achieved in controlling industrial pollution, especially point-source water pollution, environmental issues in the U.S. are increasingly focused on watersheds. Because 70% of the land in the U.S. is held privately, with at least 90% of this total outside metropolitan areas [1], non-point source pollution (in the form of sediments and agricultural chemicals) from privately owned rural land is an issue of large and increasing importance. Often, these issues can only be addressed by managing landscapes at watershed scales.

In order to reduce the sediment and nutrient loads of agricultural streams, legislation (such as the Conservation Reserve Program or CRP) was created in the U.S. to take croplands out of production by providing cash incentives. CRP payments are provided by the U.S. Department of Agriculture to farmers in order to retire highly erodible parcels of land from active farming for a period of ten years. However, since the rental rate provided to the farmers is usually below market value of what a farmer could derive from farming that parcel, the acceptance of this payment structure is not always 100% and the success of this program is dependent upon the attitude of local farming communities. Further, given that there is only a finite amount of funds available for these programs, tax dollars are wasted if croplands that enroll under CRP do not maximize benefits (i.e., reductions in sediment and nutrient load) in comparisons to the costs involved. Therefore, a better alternative would be to create higher levels of payments specifically targeted towards those that have the greatest potential to degrade water quality.

Computer modeling and simulation have been used to assist decision makers maximize the distribution of funds available under CRP. In this respect, computer simulation has been used to identify, and hence target conservation payments, to specific farms in the watershed that optimize profitable crop distributions, while subject to limitations of allowable sediment and nutrient runoffs from farm fields for the watershed. It can be used to determine an optimal payment structure that could potentially induce farmers whose land-holdings are targeted for reduced sediment erosion and nutrient runoff to enroll in CRP.

The use of computer simulation for the two above-stated uses can be demonstrated through a Spatial Decision Support System (SDSS) developed for the Cache River, a rural watershed in the economically disadvantaged region of Southern Illinois. The goal of this SDSS was to use a linear program (GEOLP) to determine crop distributions within the Cache river watershed that maximized profits for farmers in the watershed, when subject to constraints of a fixed amount of soil loss from specific soil types per year. Other variables in the model included current crop prices and constraints of available labor and machinery for individual farmers. The difference in profits between optimized crop distributions with and without soil loss constraints formed the basis for suggested compensation for individual farms.

Further, the Biocarbon Fund (www.biocarbonfund.org) can form the basis for similar compensatory payments for farmers in developing countries. For example, the money from this fund can be targeted as compensatory payments towards those tracts of land in developing countries that provide significant and conjunctive ecosystem services in the form of Carbon sequestration, water and land quality protection, and wildlife habitat improvement. The current SDSS can be modified to determine the level of compensatory payments that must be provided in order to convince individuals impacted by any protection plan to adopt the necessary measures.

2 OVERVIEW OF SPATIAL DECISION SUPPORT SYSTEMS (SDSS)

Spatial Decision Support Systems (SDSS) were created to support the analysis of semi- and un-structured spatial problems (*i.e.,* complex spatial problems where it is not possible to completely define a problem or fully articulate the objectives of the solution in mathematical terms). Spatial decision support systems extend the spatial analytical capabilities available in existing

GIS. SDSS owe their origin to Decision Support Systems (DSS) developed by researchers in management science. According to Sprague [2], DSS:

a. tend to be aimed at solving semi- and un-structured problems that upper level managers typically face;

b. attempt to combine analytical modeling with traditional data storage and retrieval functions to solve semi-structured problems;

c. are designed to be user-friendly and accessible to decision makers with minimal computer experience; and

d. emphasize flexibility and adaptability to accommodate changes in decision-making approaches.

Extending the definition of a DSS presented above, Densham [3] suggested that a GIS software package can be considered a decision support technology (*i.e.*, SDSS) if the system has a user-friendly front-end and seamlessly incorporates spatial analytical modeling software.

In recent years, several SDSS developments have been reported in the GIS literature that integrate GIS and modeling software and provide support to decision-makers for water resources management. The NELUP DSS [4] was developed to study the impact of policy changes (at a global, continental, national, regional, county or local level) on the rural landscape, agriculture and environment, and its impact on river water quality in the U.K. NELUP DSS integrates three categories of models within its framework: agricultural economic models, ecological models and hydrological models, and uses them to estimate the impact of specific agricultural policy. The Modular Modeling System (MMS) [5] was developed to help decision-makers manage watersheds and multipurpose reservoirs. It utilizes a variety of compatible model components that can be integrated together to simulate water, energy, and biogeochemical processes.

3 TARGETING CONSERVATION PAYMENTS TO SPECIFIC FARMS: CACHE RIVER SDSS

The Cache River SDSS, created for the Cache River watershed of southern Illinois (Figure 1), integrates a Linear Program (LP) based farm model (GEOLP) and the AGNPS hydrologic model within ArcView GIS to model the ecological and economic impacts of implementing the Illinois Erosion and Sediment Control law of 1980. According to this law, often referred to as the “T by 2000” program, sediment loss from all crop fields in Illinois were to be reduced to a “tolerable” level T by the year 2000 [6]. Tolerable soil loss (T), measured individually in tons/acre for each soil type, is defined as the maximum amount of topsoil that can be eroded without reduction in long-term soil fertility

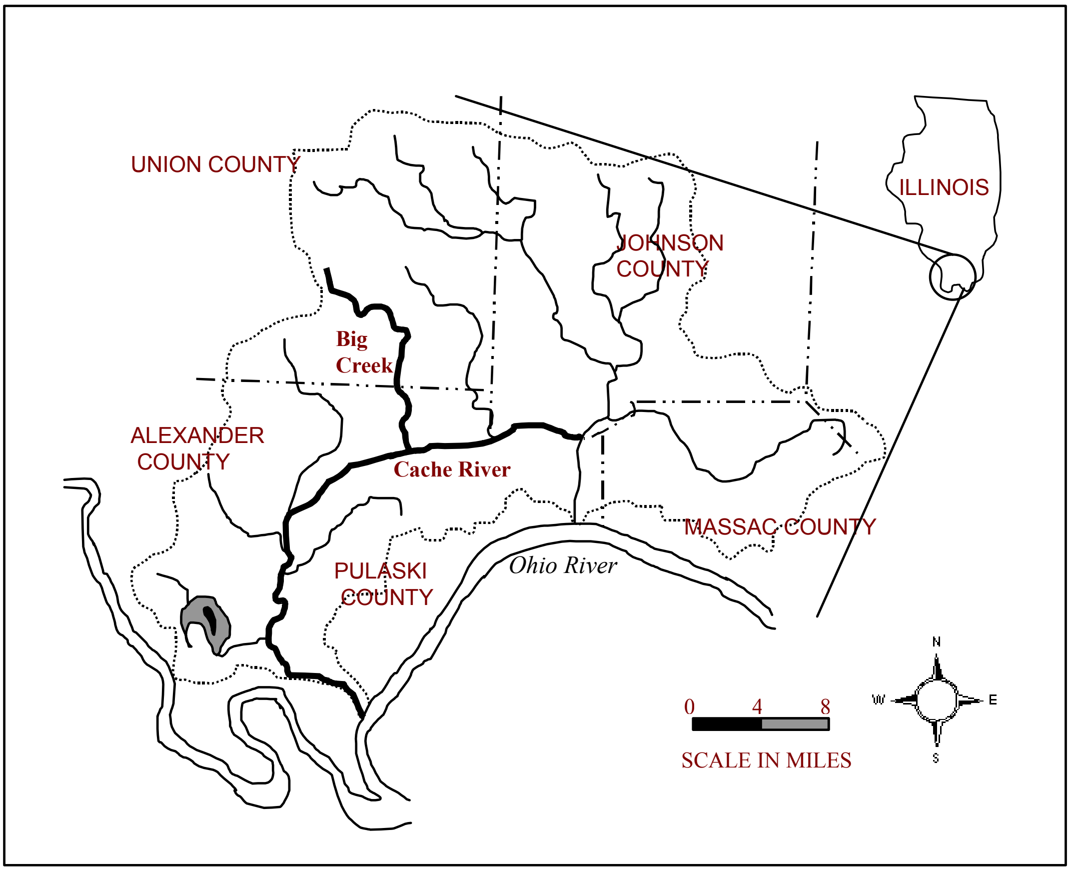

Figure 1: Location Map of southern Illinois showing the Cache River watershed

One of the issues hindering adoption of "T by 2000" program by farmers, however, is the loss in farm income that it entails. Most often, shifting from conventional to no-till or other forms of conservation tillage means lower crop yields, and therefore lower profits. In the face of already low farm incomes in the southern Illinois region (compared to the rest of the U.S.), compliance with the "T by 2000" mandate faced stiff resistance from the farming community.

Therefore, the goal of the SDSS described here was to help decision-makers (*i.e.,* U.S. Department of Agriculture district soil conservation officers) determine the nature and spatial distribution of economic losses suffered by farmers in the Cache River watershed if they adhered to the "T by 2000" program, and to develop a compensation strategy. Further, the SDSS was also designed to determine the impact of an altered landscape on sediment erosion and transport within the watershed. To achieve these goals, two models, a spatially enhanced Linear Program (LP) called GEOLP, and a watershed-based hydrological and sediment-transport model called AGNPS, were integrated with a desktop GIS (ArcView© 3.2) software (Figure 2).

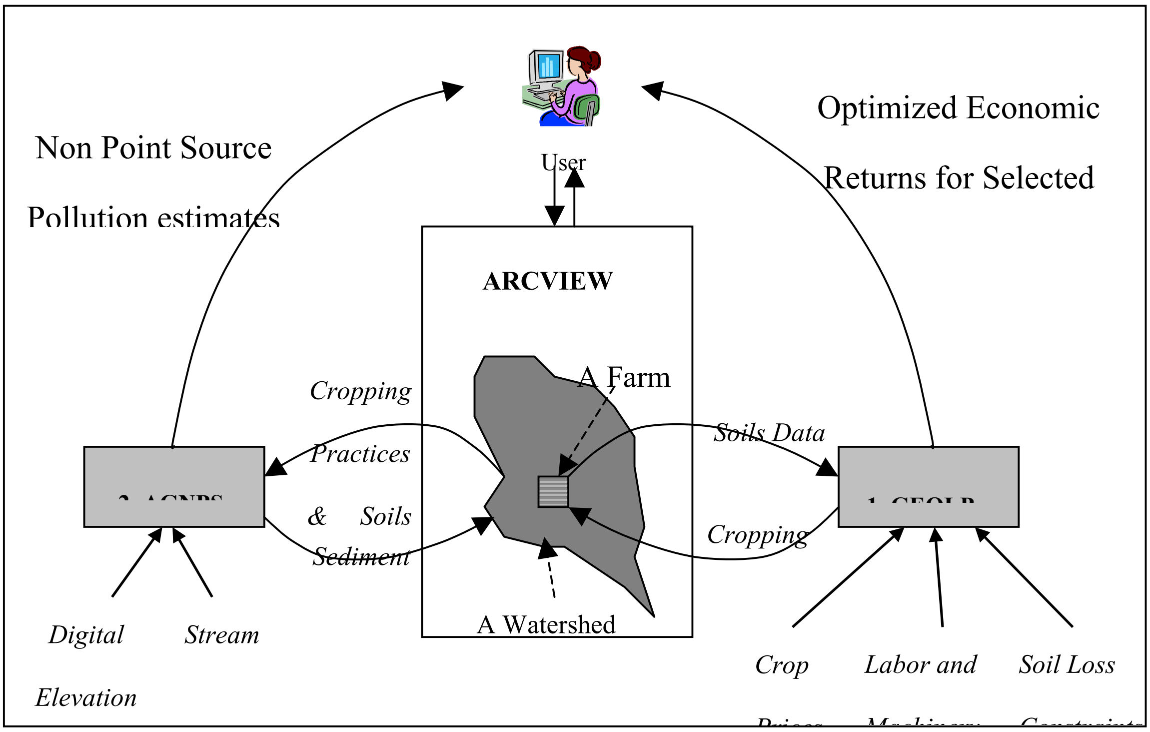

Figure 2: Architecture of the Cache River SDSS

GEOLP spatially extends the farm model developed by Kraft and Toohill [7], and maximizes economic profits for a parcel of land, subject to the constraints:

a. crop yields on available soil-types,

b. current market prices,

c. long-term sustainability of the soil based on tolerable soil loss 'T', and

d. available labor and machinery.

Therefore, GEOLP can be used to determine the most profitable crop-types that can be grown on a parcel of land at different levels of allowable soil loss. For example, GEOLP can predict the most profitable options for a farmer when s/he is allowed 12 tons/ha of soil loss as compared to 24 tons/ha. Certainly, crops grown under more stringent soil loss constraints (i.e., 12 tons/ha) are likely to be less profitable. Further, GEOLP is designed to determine the location and extent of economic losses suffered by farmers in the watershed as a result of implementing the soil loss constraints. For example, Figure 3 shows optimal crop distributions for the Big Creek watershed (a sub-watershed of the Cache River) with and without adherence to "T by 2000". Figure 4 indicates the

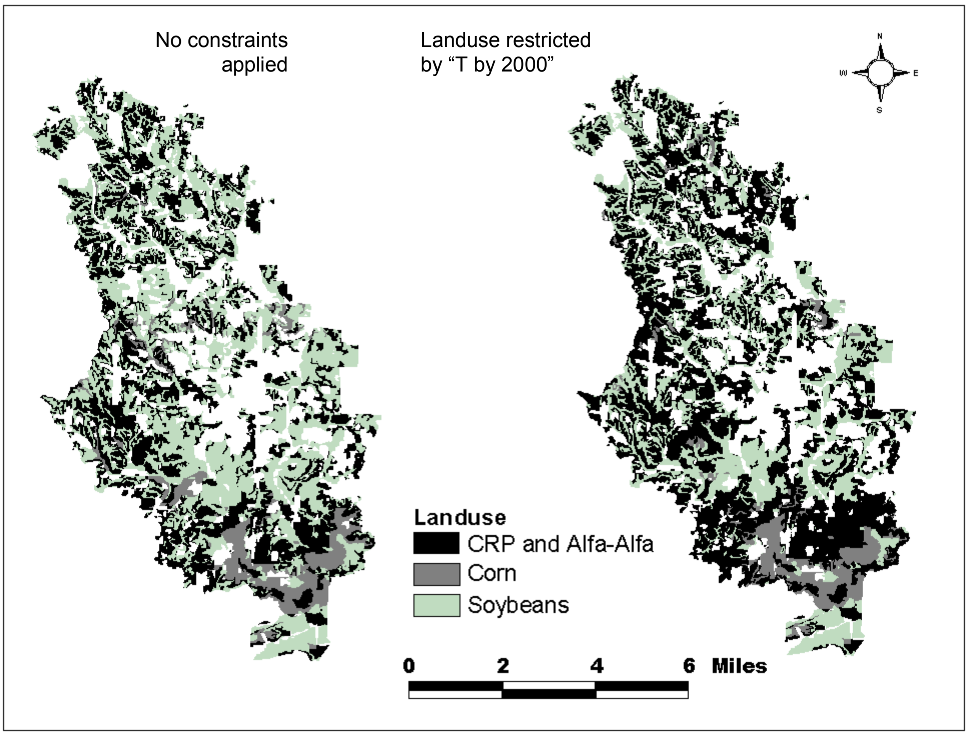

Figure 3: Crop distribution for Big Creek sub-watershed impacted by “T by 2000”

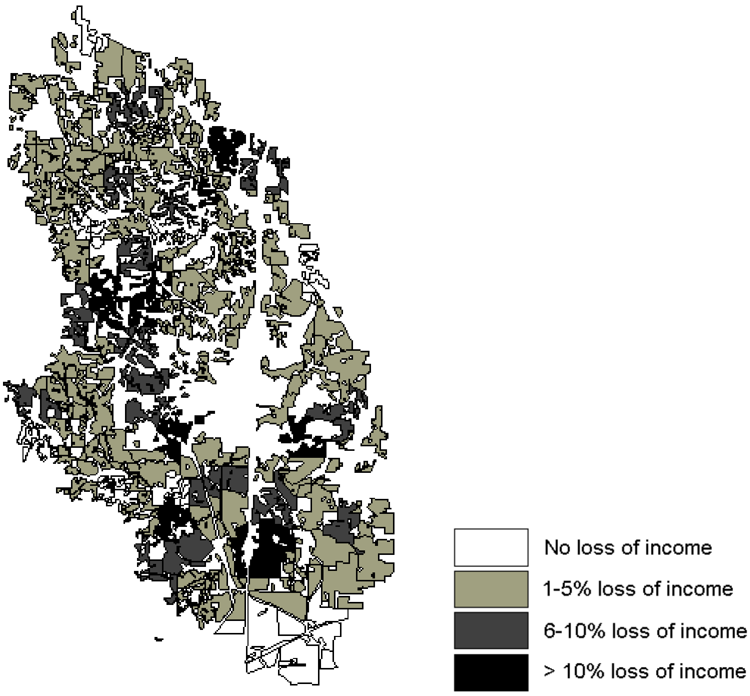

Figure 4: Percentage loss in income resulting from implementation of the “T by 2000” program

percentage losses suffered by farms located in different parts of the Big Creek watershed as a result of adherence to the "T by 2000" program.

AGNPS (or Agricultural Non-Point Source Model) is an event-based, distributed-parameter model designed to simulate hydrology, erosion, and the transport of sediment and chemicals through a watershed [8]. The spatial pattern of model parameters is captured using a grid-based data structure (i.e., raster format). As input, AGNPS requires data relevant to landform, soil and land cover for each cell. Erosion is calculated using a modified form of the universal soil loss equation expressed in terms of rainfall energy intensity, soil erodability, slope length, slope, cover factor, support practice factor, and slope shape. As output, AGNPS provides an estimate of the runoff volume and sediment yield for each cell in the watershed, and estimates of basin-level sediment and nutrient yields. The altered landscape resulting from implementation of the "T by 2000" law (as generated by GEOLP) is used as the landuse/landcover input into AGNPS. A sample AGNPS output file, depicting the sediment yield (in tons) for the Big Creek watershed following a simulated 1.5 inch, 6 hour rainfall, is shown in Figure 5.

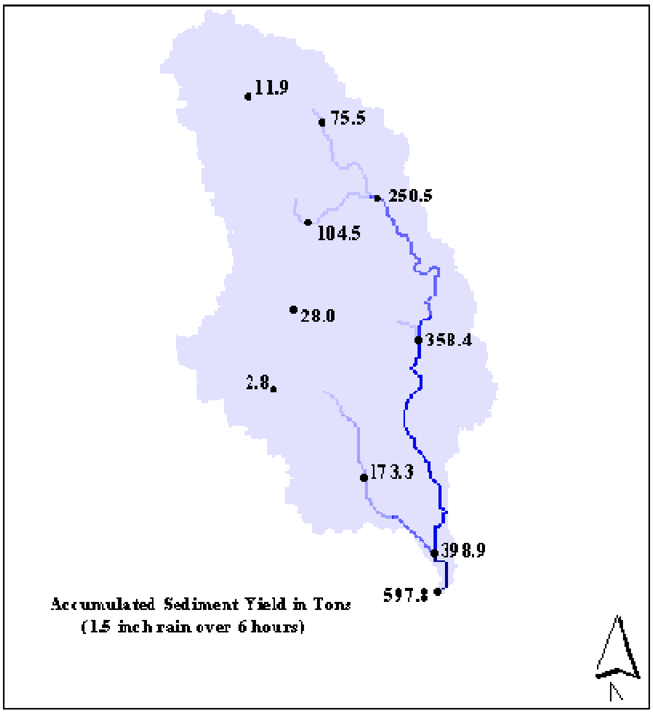

Figure 5: Sediment Yield for Big Creek Watershed (Simulated rainfall of 1.5 inches over 6 hours)

Using the SDSS described above, decision-makers can determine the amount of economic losses suffered by the various farms in the Big Creek watershed as they adopt soil conservation measures. For example, when soil loss constraints are tightened, the amount and location of economic losses within the watershed changes, and can be estimated by GEOLP (refer to Figure 4). This knowledge is then used to target a compensation strategy, such as CRP, towards the affected farmers. Further, the crop distribution map (effectively, a landuse/landcover map) produced by GEOLP during the simulation can be used by AGNPS to generate estimates of non-point source (sediment, nutrient and pesticide) pollution entering Big Creek. Improvements in non-point source pollution obtained by introducing soil loss constraints can also be compared and evaluated against an unconstrained scenario.

4 IMPLICATIONS OF THE SDSS FOR AGRARIAN ECONOMIES IN DEVELOPING COUNTRIES

We propose that the modeling techniques presented above also hold significant value for developing countries with largely agrarian economies. While taking cropland out of production is a difficult (and politically untenable proposition) in a developing country context, it is possible that subsidies to help farmers with technology to practice conservation measures can be targeted at farmlands that have a high rate of erosion but significant potential for carbon sequestration.

One such fund that specifically promotes sustainable agriculture in developing countries by promoting Carbon sequestration, soil conservation and biodiversity is the Biocarbon Fund (www.biocarbonfund.org) developed by the World Bank. As stated in their mandate, the BioCarbon Fund represents "an opportunity to attract private capital to biodiversity protection, soil conservation and sustainable community development".

An SDSS similar to the one described above can be used to identify the level of compensatory payments required to obtain the optimum amount of Carbon sequestration, water quality, and soil conservation measures from specific parcels of land. As with the U.S. scenario, the amount of payments required under this reimbursement program and the corresponding ecosystem services generated could be modeled using a series of connected spatial models. For example, Figure 6 shows the hypothetical structure of the SDSS, where GEOLP is used as an optimizing spatial model that embodies the two major objectives of the Biocarbon Fund mandate (e.g., restricting soil loss and maximizing Carbon sequestration). The resulting landuse is then fed into various other models that determine the actual ecosystem services generated in terms of Carbon-sequestration (i.e., RothC: Rothamsted C-sequestration model), water quality (i.e., AGNPS) and habitat suitability (i.e., FRAGSTATS) improvements.

5 CONCLUSIONS

Using a Spatial Decision Support System (SDSS), it is possible to identify a compensation strategy that can be used in agrarian watersheds to offset economic losses sustained by farmers as they attempt to reduce sediment erosion from farm fields

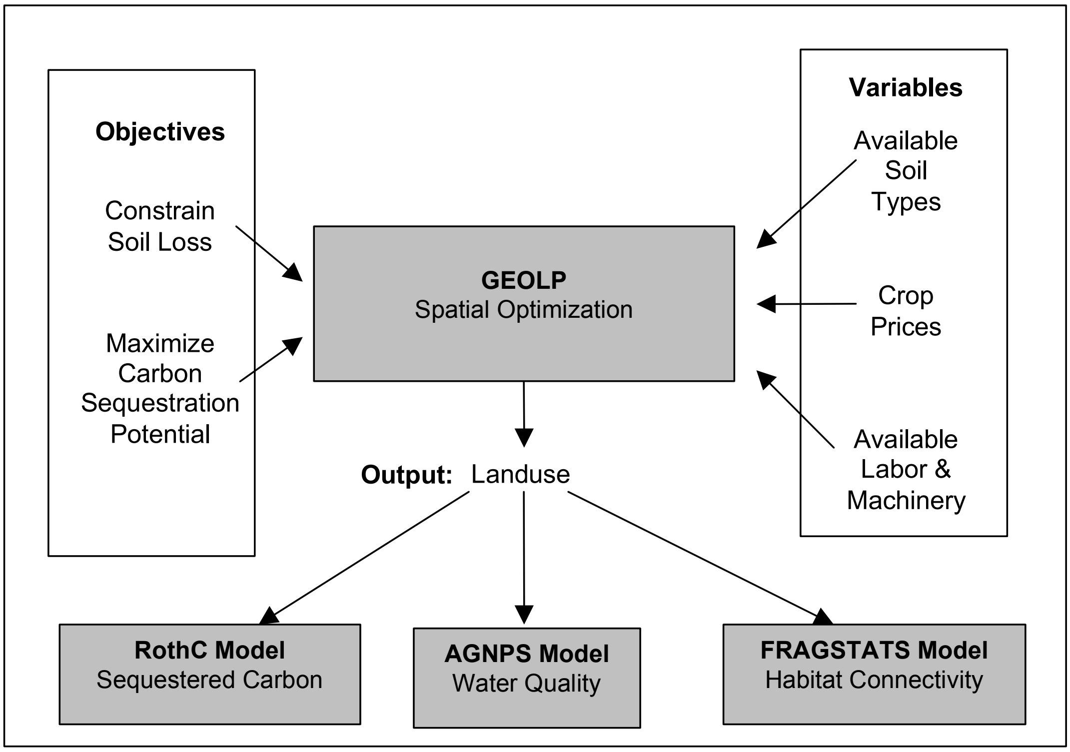

Figure 6: Structure of the proposed SDSS for Biocarbon Fund

This is indicated by Figure 6, where an SDSS is proposed that determines the optimal level of compensatory payments required to meet the mandate of the BioCarbon fund in developing countries. Using the SDSS, decision-makers can estimate the economic costs (including monetary amounts and spatial distribution of the costs) associated with implementing a specific compensation program in a watershed, and the ecosystem service benefits (such as Carbon sequestration) derived by implementing the program. This is particularly useful for agrarian economies in developing countries, where in addition to Carbon sequestration, it may be necessary to reduce intensive farming practices in certain watersheds to prevent excessive degradation of land and protect downstream water quality, thereby preserving the "food security" of a region.

6 ACKNOWLEDGMENTS

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