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Cost Effective Targeting of Land Retirement to Improve Water Quality: A Multi-Watershed Analysis

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Abstract

An integrated watershed management framework that combines economic, hydrologic and GIS modeling is developed to study cost effective land retirement in multiple watersheds to achieve off-site sediment reduction goal. This integrated framework examines two alternative standards – a uniform standard under which each watershed is required to achieve the same sediment reduction goal and a non-uniform standard under which marginal cost of sediment abatement is equal across watersheds. Furthermore, for each standard, costs of abatement under two alternative rental instruments based on marginal cost of sediment abatement ($/ton) and uniform payments per acre ($/acre) are examined. Then the cost effectiveness of the four policy options (uniform standard with $/ton and $/acre instrument, non-uniform standard with $/ton and $/acre instrument) is discussed. The integrated framework is applied to 12 agricultural watersheds in Illinois Conservation Reserve Enhancement program (CREP) region. The watersheds varied in size between 29,995 and 70,849 acres. Cropland within 900 feet of streams – 129,955 acres (33.4% of all cropland in the 12 watersheds) – is considered eligible for enrollment into the CREP. Consistent with Illinois' program, a sediment reduction goal of 20% is selected for all of the simulations. Policy implications from the empirical results are quite interesting. With either a $/ton or a $/acre instrument, the non-uniform standard, which equalizes marginal cost of abatement across watersheds, outperforms the uniform standard policy. With either a uniform or non-uniform standard, a $/ton instrument outperforms a $/acre instrument. The least preferred policy option, the uniform standard with a $/acre instrument, is 2.5 times as costly as the most preferred policy option, the non-uniform standard with a $/ton instrument. These results suggest that program administrators may want to consider a program that includes a non-uniform standard and a rental payment instrument based on marginal cost of abatement in order to achieve their objectives at least cost.

Key words: Watershed management, integration framework, land retirement, cost effectiveness

I. Introduction

Growing concern about the adverse effects of agricultural activities on water quality has redirected the focus of land retirement programs from reducing on-site erosion and maintaining soil productivity of fields towards reducing damages to water bodies caused by sediment, nutrient, and chemical laden runoff water from fields and enhancing aquatic and wildlife habitat. This shift in program emphasis has led to several modifications of the Conservation Reserve Program (CRP) with the most recent one being the Conservation Reserve Enhancement Program (CREP). Authorized as part of the 1996 Federal Agriculture Improvement and Reform Act, the CREP is a state-federal land retirement program that targets geographic areas within states to achieve specific state and national environmental priorities. Within the targeted geographic area, landowners may enroll environmentally sensitive cropland into the CREP for 15 years or more.

The Illinois CREP was initiated in 1998. With a budget of $500 million, CREP administrators seek to retire 0.23 million acres environmental sensitive land out of 15.7 million acre Illinois River Basin to meet multiple environmental objectives, such as reducing total sediment loading by 20% and reducing phosphorus and nitrogen loading by 10%. The small amount of acreage to be enrolled coupled with the heterogeneity of land parcels throughout the multi-watershed river basin implies the need for considerable selectivity in the land parcels selected for enrollment in order to achieve cost effectiveness. Furthermore, policy instruments need to be designed for inducing cost-effective land retirement voluntarily by landowners in a decentralized decision making setting.

In order to achieve cost effectiveness of land retirement, it is necessary to determine the environmental benefits and costs of eligible land parcels and then target the land parcels with most favorable benefit to cost ratios based on budget constraint and environmental standards accordingly. But this targeting process is complicated by at least two issues. First, the environmental benefits due to retiring a land parcel from crop production are not independent. The estimation of off-site sediment abatement benefits, for example, requires the estimation of on-site erosion and a sediment transport coefficient that links on-site erosion with off-site sediment loading in a water body. The portion of eroded soil that is transported from a land parcel to a water body depends not only on that parcel's site-specific characteristics (like slope, soil characteristics and distance from a water body) and land use decision (such as, crops, pasture or grass) but also those of intervening parcels lying in the direction of the runoff flow. As a result of this interdependence, the sediment abatement benefits by retiring a parcel cannot be specified exogenously in a benefit-cost calculation simply based on its on-site erosion and on the fixed site-specific characteristics of intervening land. Instead, the benefits provided by each parcel in a flow path are also dependent on the optimal land use decisions of all parcels in that flow path and need to be determined jointly or endogenously with those land use decisions. Secondly, the distribution of benefit to cost ratios across watersheds is different. Land retirement targeted to achieve environmental objectives at least costs in individual watersheds may not be cost effective at multiple watershed level.

Several studies have sought to develop criteria to improve the efficiency of conservation programs in one watershed or multiple watersheds. Babcock et al. (1997; 1996) showed that conservation efficiency is achieved by targeting land that has the highest ratio of benefits to costs rather than minimizes costs or maximizes benefits only. Ribaudo (1986, 1989) discussed the differences in the efficiency of conservation programs by comparing targeting land based off-site criteria rather than on-site criteria across regions or watersheds. These studies illustrated the importance of targeting conservation by appropriate criteria. But how policy instruments could be designed to achieve these objectives are not discussed.

Previous studies focusing on a social planner's strategies for reducing off-site pollution damages, assume that the relationship between on-site pollution generation and damages is dependent on exogenously given site-specific factors (Carpentier et al., 1998) or that the portion of pollution trapped depends only on the site-specific characteristics and management practices of downstream parcels (Braden et al., 1989). The latter study does not incorporate the effect of the volume of pollution flowing into a land parcel from upstream on the trapping capacity of downstream land parcels and therefore ignores the impact of land use changes upstream on sediment transport coefficients. Lintner and Weersink (1999) incorporate the interdependence between sediment deposition coefficients and land-use decisions of all parcels in a flow path while analyzing the implications of alternative policies to control fertilizer pollution. However, They applied their framework in a watershed that all land parcels are identical in physical characteristics such as soil type and slope. They estimated sediment transport coefficients assuming same farming practice adopted over the entire watershed and then used the coefficients in an optimization model to identify landuse pattern in the watershed to achieve water quality objectives at least costs. This approach reduces the true complexity of the problem of simultaneously determining land-use and off-site sediment abatement for all parcels in a flow path.

Theoretically the cost-effective environmental policy instruments are those that equalize marginal cost of pollution abatement across heterogeneous pollution sources. Tradable Permit Program (TPP) as an effective policy instrument has been widely applied in point-source control to achieve equal marginal cost of pollution abatement. But the use of this policy instrument for controlling non-point source pollution has no been straightforward. In 1996 the US. EPA released draft guidelines to encourage the development of watershed-based effluent trading systems. Five pollution credit trading program exist in the United States but trades are not been made (Hoag and Hughes-Popp, 1997). So in non-point source pollution control, the tradable permit policy is still at an experimental stage. Instead, subsidy policies like land retirement programs are dominating approaches adopted by governments.

Many studies sought to study the minimum incentives needed to induce farmer's participation in conservation programs. Seita and Osborn (1989) discussed the minimum variable incentive payment rates needed to induce conservation compliance based on cost per unit of erosion reduction criteria. The minimum incentive rates were defined as the farmer's costs switching from base scenario to conservation practices. Parks et al. (1995a, 1995b) developed a farmer behavior model to predict farmer's participation into the Wetland Reserve program (WRP) with farmers' and land attributes as explanatory variables. With the predicted value as the minimum incentive to inducing farmers' participation into the WRP, they estimated the public funds required to achieve a million-acre target. Smith (1995) discussed how mechanism design theory could be used to design contracts to induce landowner's participation into the CRP under asymmetric information between government and landowners. Based on county-level cash rental value of farmland, his model simulated the required incentive payment to induce landowner's participation into the CRP and estimated the least cost for achieving the goal of a 34-million acre CRP. The common feature on these studies is that they emphasize the incentives required to induce landowners' participation into conservation program to achieve a fixed acreage goal, rather than design a policy instrument also based on environmental benefit contributions of land parcels.

Some other studies discussed how pollution taxes could be designed as second-best policy instruments to achieve cost effective non-point source pollution control. Huang et al. (1992) discussed 4 policy options include a fertilizer tax and a corn sale tax in reducing the use of nitrogen. They found that limiting nitrogen fertilizer has the lowest costs to farmers while a corn sale tax has the highest cost. Helfand et al. (1995) and Larson et al. (1996) compared the efficiency of uniform taxes, individual taxes and input restriction standard in reducing nitrate pollution on heterogeneous soils. They found that uniform tax instruments do not lead to large deadweight losses of quasi-rents relatively to an efficient base line based on individual tax instruments. These studies suggested that second-best instruments could be carefully designed to achieve environmental goal at costs comparable to first-best instruments. But they did not examine the second-best subsidy instrument like land rental payments in controlling non-point source pollution.

The first purpose of this paper is to develop an integrated watershed management framework that combines economic, hydrological and GIS modeling to identify cost effective land retirement pattern to achieve environmental objectives at least costs. With an innovative land retirement scheme based on flow paths, the hydrologic model recognizes the inter-relationships between land parcels in their sediment trapping efficiency and sediment transport coefficients of land parcels are endogenously determined with the land use decisions of those parcels and of parcels upstream and downstream from them. In the modeling framework, the conditions for cost effective land retirement targeting in multiple watersheds under two policy scenarios: uniform standard and non-uniform standard are examined. Under uniform standard, land retirement is targeted to achieve the same sediment abatement objective at least costs, regardless the differences in these watersheds. This scenario treats each watershed separately.

Under non-uniform standard, multiple watersheds are treated as one large watershed to target land retirement for achieving environmental objectives. Because of the heterogeneity in pollution abatement efficiency across watersheds, the land retirement pattern determined in this scenario will be different from the previous option. The watersheds with higher abatement to cost ratios have more land retirement while the watersheds with lower abatement to cost ratios have less land retirement compared to uniform standard case, in order to achieve equal marginal cost of pollution abatement across watersheds.

The second purpose of this paper is to empirically apply the conceptual framework to 12 sample watersheds in the Illinois River Basin to examine the cost effectiveness of land retirement in the CREP across multiple watersheds. At first, the land retirement patterns under a uniform standard and a non-uniform standard are identified. It then examine the kind of rental payment instrument needed to induce cost-effective land retirement voluntarily by landowners in a decentralized decision making setting. A rental payment instrument based on marginal cost that provides a dollar per ton of abatement ($/ton) is required to achieve this cost-effective allocation in a decentralized decision-making setting. Given the complexity of implementing a rental payment based on the marginal costs of sediment abatement ($/ton), we also examine the implications of payments per acre ($/acre) under uniform and non-uniform standards. The $/acre payment instrument resembles an “offer system” under which farmers are offered a single price (dollars per acre of land retired) that is typically based on the average cash-rental rates in each county, a second-best instrument which is widely practiced by governments. Under each environmental standard, the costs of abatement with $/ton and $/acre instruments are compared.

The third purpose of this paper is to compare the cost effectiveness of 4 policy options: uniform standard with a dollar per ton instrument, uniform standard with a dollar per acre instrument, non-uniform standard with a dollar per ton instrument and non-uniform standard with a dollar per acre instrument. Then the policy implications are discussed.

II. Conceptual Framework

The multiple watersheds are denoted by $n = 1, 2, ..., N$. Each watershed is divided into land parcels of equal size, each parcel being α acres. Each land parcel is assumed to be a homogeneous management unit. Individual land parcels are then grouped into independent flow channels, or runoff paths, based on surface hydrology. In terms of the pollution transport process, land parcels from different flow channels are not related, but land parcels assigned to the same flow channel are interdependent. For simplicity, the theoretical model analyzes two cost-effective decision choices for a parcel of land: continue with current cropping activities (base scenario) or retire the parcel, to support an environmental objective such as reducing the amount of sediment flowing into a water body or water bodies.

The quasi-rents and total sediment deposited to the water body in the nth watershed before land retirement are $\overline{\pi}_n$ and $\overline{S}_n$, respectively. The land allocated to the k^{th} activity of land parcel i in flow channel j is x_{nijk} with earned quasi-rents π_{nijk} and erosion generation s_{nijk}. The endogenous pollution deposition coefficient for sediment produced by the i^{th} parcel and deposited in each of the i-m downstream parcels in flow channel j is $d_{n,i,i-m,j}$, where $m=0,...,i-1$ (refer to Yang (2000) for the detailed discussion of endogenous pollution transport coefficients). The total sediment deposited to the water body in the nth watershed is

$$S_n = \sum_{j=1}^{J} \sum_{i=1}^{I_j} (1 - \sum_{m=0}^{i-1} d_{n,i,i-m,j}) \sum_{k=0}^{1} s_{nijk} x_{nijk} \ .$$

Cost Effective Land Retirement under a Uniform Standard

Under a uniform standard, each watershed is treated independently and a uniform sediment abatement standard is applied to each watershed. For example, each watershed may be required to reduce sediment loading by 20%. Under a uniform standard, the sediment abatement need to be achieved by the *n*th watershed is denoted by $\bar{A}_n$. Then the social planner's land retirement decision model in multiple watersheds is as follows:

$$(1)\quad \text{Min} \quad \sum_{n=1}^{N} \bar{\pi}_n - \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{i=1}^{I_j}\sum_{k=0}^{1} \pi_{nijk} x_{nijk}$$

Subject to

$$(2)\quad \sum_{k=0}^{1} x_{nijk} = \alpha,\ \forall n, i, j \text{ and}$$

$$(3)\quad \bar{S}_n - \sum_{j=1}^{J}\sum_{i=1}^{I_j}(1 - \sum_{m=0}^{i-1} d_{n,i,i-m,j}) \sum_{k=0}^{1} s_{nijk} x_{nijk} \geq \bar{A}_n\ .$$

The model described by (1) – (3) is an optimization model in block diagonal form. In the model, the cost minimization objective is set for multiple watersheds, but each watershed has a separate sediment abatement constraint, which is independent of other watersheds. So this model is equivalent to the single watershed model for each of the multiple watersheds developed in Yang (2000). The Lagrangian associated with the model is given as follows:

(4)

$$L = (\sum_{n=1}^{N} \bar{\pi}_n - \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{i=1}^{I_j}\sum_{k=0}^{1} \pi_{nijk} x_{nijk}) + \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{i=1}^{I_j} \mu_{nij} (\alpha - \sum_{k=0}^{1} x_{nijk}) + \lambda_n \{\bar{A}_n - [\bar{S}_n - \sum_{j=1}^{J}\sum_{i=1}^{I_j}(1 - \sum_{m=0}^{i-1} d_{n,i,i-m,j}) \sum_{k=0}^{1} s_{nijk} x_{nijk}]\}$$

The fist order optimality conditions are:

$$(5)\quad \frac{\partial L}{\partial x_{nijk}} = \{-\pi_{nijk} - \mu_{nij} + \lambda_n [(1 - \sum_{m=0}^{i-1} d_{n,i,i-m,j}) s_{nijk} - \sum_{m=0}^{i-1} \frac{\partial d_{n,i,i-m,j}}{\partial x_{nijk}} \sum_{k=0}^{1} s_{nijk} x_{nijk}]\} \geq 0 \text{ and}$$

(6) $\frac{\partial L}{\partial x_{nijk}} x_{nijk} = 0, \forall n, i, j$ and k.

And the optimal condition for land retirement can be represented as

(7) $\lambda_n[(1-\sum_{m=0}^{i-1} d_{n,i,i-m,j})(s_{nij1}-s_{nij0})+\sum_{m=0}^{i-1}\frac{\partial d_{n,i,i-m,j}}{\partial x_{nij0}} s_{nij0}]>\pi_{nij1}$.

The variable λ_n is the marginal social cost of sediment abatement and is the cost effective government payment to landowners for per unit sediment abatement in the *n*th watershed. The cost-effective condition is that the social cost of sediment abatement or cost-effective land rental payments for sediment abatement contribution per acre should be greater than the private benefit from crop production in respective watershed.

Cost Effective Land Retirement under a Non-Uniform Standard

Under a non-uniform standard, the multiple watersheds are treated as one decision unit and one sediment abatement objective is set for all the watersheds. Different from the uniform standard case described above, the individual watersheds are not independent anymore since they interact through the aggregated sediment abatement objective. It is reasonable to expect that the watersheds with higher abatement to cost ratios to have more land retirement and the watersheds with lower abatement to cost ratios to have less land retirement compared to uniform standard case. So this type of environmental objective refers to non-uniform standard. The social planner's land retirement decision model under the non-uniform standard with one aggregated sediment abatement goal is as follows:

(8) Min $\sum_{n=1}^{N}\overline{\pi}_n - \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{i=1}^{I_j}\sum_{k=0}^{1}\pi_{nijk}x_{nijk}$

Subject to

(9) $\sum_{k=0}^{1} x_{nijk} = \alpha$, $\forall n, i, j$ and

(10) $\sum_{n=1}^{N} \overline{S}_n - \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{i=1}^{I_j}(1 - \sum_{m=0}^{i-1} d_{n,i,i-m,j})\sum_{k=0}^{1} s_{nijk} x_{nijk} \geq \overline{TA}$.

The Langrangian for the above problem is

(11)

$$L = (\sum_{n=1}^{N} \overline{\pi}_n - \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{i=1}^{I_j}\sum_{k=0}^{1} \pi_{nijk} x_{nijk}) + \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{i=1}^{I_j} \eta_{nij}(\alpha - \sum_{k=0}^{1} x_{nijk}) + \theta\{\overline{TA} - [\sum_{n=1}^{N} \overline{S}_n - \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{i=1}^{I_j}(1 - \sum_{m=0}^{i-1} d_{n,i,i-m,j})\sum_{k=0}^{1} s_{nijk} x_{nijk}]\}$$

Similar to the arguments presented above, we can generate the first-order optimality conditions as follows:

(12) $\frac{\partial L}{\partial x_{nijk}} = \{-\pi_{nijk} - \eta_{nij} + \theta[(1 - \sum_{m=0}^{i-1} d_{n,i,i-m,j})s_{nijk} - \sum_{m=0}^{i-1} \frac{\partial d_{n,i,i-m,j}}{\partial x_{nijk}} \sum_{k=0}^{1} s_{nijk} x_{nijk}]\} \geq 0$ and

(13) $\frac{\partial L}{\partial x_{nijk}} x_{nijk} = 0, \forall n, i, j$ and k.

The optimality condition for land retirement is

(14) $\theta[(1 - \sum_{m=0}^{i-1} d_{n,i,i-m,j})(s_{nij1} - s_{nij0}) + \sum_{m=0}^{i-1} \frac{\partial d_{n,i,i-m,j}}{\partial x_{nij0}} s_{nij0}] > \pi_{nij1}$ for all n,i,j.

Suppose the optimal solutions obtained from (8) – (10) under the non-uniform standard are: η^*_{nij}, θ^* and x^*_{nijk}. Then the sediment abatement achieved for the *n*th watershed under the non-uniform standard is

(15) $\overline{A}^*_n = \overline{S}_n - \sum_{j=1}^{J}\sum_{i=1}^{I_j}(1 - \sum_{m=0}^{i-1} d_{n,i,i-m,j})\sum_{k=0}^{1} s_{nijk} x^*_{nijk}$

Suppose the optimal solutions from model (1) – (3) under the uniform standard is μ^*_{nij}, λ^*_{nijk} and x^{**}_{nijk}. If $\overline{A}^*_n$ is plugged into (1)-(3) and the model is solved again, we get solutions μ^{**}_{nij}, λ^{**}_n and x^{***}_{nijk}. Comparing the first-order conditions of the two models we can see that

(16) $\mu_{nij}^{**} = \eta_{nijk}^{*}$, $\lambda_{n}^{**} = \theta^{*}$ and $x_{nijk}^{***} = x_{nijk}^{*}$.

In particular, the following condition holds:

(17) $\lambda_1^{**} = \lambda_2^{**} = \cdots = \lambda_N^{**} = \theta^{*}$

This means that for multiple watersheds, the cost-effective condition for land retirement is that the marginal cost of sediment abatement is equal across the individual watersheds.

If a uniform sediment abatement standard (for example, 20% sediment abatement over the base sediment loading) is applied in each of the multiple watersheds, we can expect unequal λ_n^{*} because of the differences of physical and economic conditions across watersheds. If $\lambda_n^{*} < \theta^{*}$, that means the marginal cost of sediment abatement in the *n*th watershed under the uniform standard is less that under the non-uniform standard which equalizes marginal cost of sediment abatement across watersheds. This implies that the *n*th watershed has a higher sediment abatement to cost ratio and should abate more. If $\lambda_n^{*} > \theta^{*}$, that means the sediment abatement in the *n*th watershed is less cost-effective. Then it should have less sediment abatement and give some share of sediment abatement to other watersheds with a higher benefit-cost ratio. So in aggregated multiple watersheds, some watershed may abate more and some abate less sediment compared with the uniform sediment abatement standard.

III. Empirical Model

Consistent with the theoretical model developed above, each watershed is partitioned into parcels or small management units that are grouped into runoff channels for sediment flow from upland areas to the river. In this study, cropland parcels eligible for CREP enrollment are restricted to the first three land parcels adjacent to the water bodies in each flow path or runoff channel. The rationale for this is discussed in the next section. The flow of runoff in any three-parcel chain is independent of that in adjacent chains of parcels.

In the empirical model, the three-parcel flow chains, rather than individual land parcels, are treated as decision units. For each flow chain, we define 8 (=2^3) alternative land management plans that represent all possible combinations of discrete enrollment decisions (retire/continue cropping) for the three parcels that make up the chain. These combinations are *GGG*, *GGC*, *GCG*, *GCC*, *CGG*, *CCG*, *CGC*, and *CCC* where *C* denotes crop production and G denotes enrollment in a land retirement program that requires the planting of permanent grass cover. We denote these 8 alternative management plans by $p=1,\ldots,8$ where $p=1$ corresponds to the plan with all three parcels under crop production (*CCC*). The optimization problem is to identify flow chains with certain land-use plan to achieve sediment abatement objective at least costs. The flow channel approach overcomes the endogenous pollution deposition coefficient problem (Yang 2000).

Typically, this type of 'either/or' problem is formulated as a mixed integer (binary) programming problem. However, for one or multiple watersheds, the model involves a large number of land parcels and even more land-use plans (if the land parcels are to be sufficiently small and homogenous entities in terms of their economic profitability and individual contribution to environmental pollution). This would lead to a very large-scale nonlinear integer-programming model that would be computationally complex. To cope with this complexity we develop a linear programming (LP) approximation that transforms the theoretical models into computationally convenient empirical models.

For watershed $n = 1,\ldots, N$, quasi-rents assigned to each land management plan are the sum of the profits of the 3-parcel chain in channel $j=1,\ldots, J$ and are denoted by r_{npj}. Quasi-rents for cropland parcels outside the buffer are assumed to remain unchanged. We denote the total sediment generated by channel *j* under plan *p* by s_{npj} and denote the fraction of sediment loaded into the water body by *(1- d_{npj})*, where d_{npj} represents the deposition ratio under land management plan *p*. To choose among the 8 alternative land management plans for each chain we introduce an endogenous convex combination (weight) variable associated with the management plan *p* for channel *j*, denoted by Z_{npj} where $0 \le Z_{npj} \le 1$ with $\sum_{p=1}^{8} Z_{npj} = 1$ for all *j*. Suppose the maximum level of sediment that can be loaded into the water body by the watershed is restricted to $\overline{S}_n$.

Under a uniform standard, each watershed is independent. In the *n*th watershed, the empirical model that determines the cost-effective choice of land management plan for each of the chains in the *J* channels is:

(18) $$Maximize \sum_{j=1}^{J}\sum_{p=1}^{8} r_{npj}\ Z_{npj}$$

subject to:

(19) $$\sum_{j=1}^{J}\sum_{p=1}^{8}(1-d_{npj})s_{npj}\ Z_{npj} \le \overline{S}_n$$

(20) $$\sum_{p=1}^{8} Z_{npj} = 1 \text{ for all } j=1,..J$$

(21) $$Z_{npj} \ge 0 \text{ for all } p, j$$

Under non-uniform standard, the multiple watersheds are treated as one watershed. The empirical model to identify cost effective land-use plans for all flow chains subject to sediment loading constraint in multiple watersheds.

(22) Maximize $$\sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{p=1}^{8} r_{npj} Z_{npj}$$

Subject to

(23) $$\sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{p=1}^{8}(1-d_{npj})S_{npj} Z_{npj} \le \sum_{n=1}^{N}\overline{S}_n \ ,$$

(24) $$\sum_{p=1}^{8} Z_{npj} = 1 \text{ for all } j=1,..J \ ,$$

(25) $Z_{npj} \geq 0$ for all p, j.

Note that in the above formulations the endogenous weight variables, Z_{npj}, are defined as continuous variables. Therefore equations (18) – (21) or (22) – (25) define a linear program model. In the uniform standard model, equations (20) and (21) imply that each Z_{npj} can take any arbitrary value in the range of $[0,1]$. This means that for each flow chain the model solution can have a weighted sum of alternative management plans, with the endogenous weights adding up to 1. However, in any optimal solution, all Z_{npj} except one pair of variables defined for a single channel j in the nth watersheds or all watersheds, have to take binary values, namely either 0 or 1. The reason for this is as follows: There are 8 J variables and $J+1$ constraints in the above model. Therefore, any basic feasible solution can have at most $J+1$ positive variables. Equations (21) imply that there is at least one positive variable for each channel, otherwise the sum cannot be equal to 1. These nonzero variables determine J of the $J+1$ basic variables, one variable belonging to each channel, and leaves only one remaining basic variable. Thus, except for one pair of management plans for a single flow chain, all other chains must have $Z_{npj} =1$ for some option p and Z_{npj} =0 for all other options in the nth watersheds. Based on the same logic, the results also hold for non-uniform standard case.

Binary solutions for the enrollment choice variables for all flow chains imply that the model may select one of the p plans for channel j rather than a mixed (weighted) enrollment option. Therefore, after rounding the non-binary solution for that single channel to a binary solution, we obtain a pure binary optimal solution that very closely approximates the true binary solution of the enrollment problem that would be obtained from an integer programming formulation (where Z_{npj}'s would be defined as binary variables).

The error involved in this approach is negligibly small, but the convenience of this linear approximation procedure is enormous. First, linear programming allows us to solve the model even with a large number of flow chains and choices of management plans per chain. Second, a shadow price interpretation of the optimal solution, which is important for determining economic policy incentives as will be elaborated below, is now possible, unlike in the case of an integer programming formulation.

The solution of this model provides the optimal shadow price information to determine an appropriate price incentive. The optimal values of σ_n and σ represents the uniform price that the social planner would be willing to pay per unit of sediment abatement in the *n*th watershed under a uniform standard and in all watersheds under a non-uniform standard. To determine the payment per acre that the social planner could offer to each parcel, we first need to disaggregate, ex-post, the contribution of each parcel to the total abatement achieved by each 3-parcel chain that chooses management plan $p>1$. The procedure used to make the allocation is explained here by using a particular example to estimate the contribution of each land parcel to sediment abatement under a uniform standard. Suppose for instance that plan *GGC* is found to be optimal for a particular chain. This means that the first two parcels adjacent to the water body should be targeted for retirement and the third parcel (farthest from the water body) should not be targeted. Each parcel's contribution can be identified by examining sediment loading that would have been achieved under plans *CCC*, *CGC* and *GGC*. Let s_{n1j}, s_{n2j}, and s_{n3j} be the sediment loading under the three plans $p=1$ (*CCC*), $p=2$ (*CGC*) and $p=3$ (*GGC*), respectively. The total payment that should be made to the chain in channel *j* for plan GGC is $\sigma(s_{n1j}-s_{n3j})$. The difference between s_{n1j} and s_{n2j} can be interpreted as the sediment abatement achieved by the land retirement decision of the middle parcel alone. Then the payment for that parcel for sediment abatement must be $\sigma(s_{n1j}-s_{n2j})$. Similarly, $(s_{n2j}-s_{n3j})$ is the sediment abatement contribution of the first parcel (adjacent to the water body) alone, and therefore the payment for that cell must be $\sigma (s_{n2j}-s_{n3j})$. Note that the payments for individual parcels add up to the total payment for the 3-parcel chain, namely $\sigma(s_{n1j}-s_{n2j}) + (s_{n2j}-s_{n3j}) = \sigma(s_{n1j}-s_{n3j})$.

If instead of a rental payment per ton of sediment abatement under a uniform standard or a non-uniform standard, the social planner sought to pay a fixed price per acre of land retired, the relationships and parameters used to specify the model above can also be used to determine the fixed price offer that would achieve the targeted abatement, using a heuristic procedure. For any specified rental payment per acre of retired land, each 3-parcel chain chooses the land management plan that leads to higher quasi-rents (including land retirement payments) than obtained by other plans. These management plan choices in turn determine the aggregate abatement level. Here the policy question is to determine the critical rental payment per acre that meets the abatement goal. To do this, we start from a low value and systematically increase the rental payment offered per acre in small increments until the abatement goal is achieved in individual watershed or multiple watersheds. The lowest rental payment at which the abatement goal for the individual watershed or multiple watersheds is achieved is reported as the least cost rental payment per acre.

IV. Data

The integrated modeling framework developed above is applied to 12 adjacent agricultural watersheds in the south end of the Illinois CREP region (see Figure 1). These watersheds have sizes varying between 29,995 and 70,849 acres with a total of 618,639 acres. Cropland acres account for 44 percent to 70 percent of each watershed's land base. Total cropland in the 12 watersheds equals 389,627 acres, which is 63% of the watershed area. These watersheds are partitioned into 300-by-300 foot parcels. This parcel size was chosen because it led to parcels that are relatively homogenous in their soil characteristics and slope. In addition data could be easily obtained from GIS data sources and matched to this parcel size.

We consider cropland within a 900-foot buffer (the length of the first three parcels) along all streams and tributaries of the Illinois River to be eligible for land retirement. The rationale behind the definition of eligible land in this study is that all buffer area of the stream network should have equal importance for conservation, no matter the buffer is located in the main stream or tributaries. And the buffer will encompass most of the 100-year floodplains along the streams, which is eligible for CREP enrollment.

Three different types of data were needed for this analysis: spatial and topographical data, sediment runoff data and economic cost data. The satellite image of 12 watersheds was used to identify land use in every parcel (Illinois Department of Natural Resources). Publicly available GIS databases were used to obtain elevation data (U.S. Geological Survey), streams, watershed boundaries (Illinois Department of Natural Resources) and soils data (Illinois Natural Resource and Conservation Service). These data were used to assign slope, distance from the nearest water body and soil characteristics (soil type and erodibility properties) to every parcel.

Within the GIS, information on each parcel's slope and aspect were used to create flow paths or channels that directed the flow of runoff from upland areas in the watershed to the nearest water body. The flow channels with at least one cropland parcel within 900-foot buffer were identified as eligible. The identified flow channels in the 12 watersheds range from 1,477 to 4,106 with a total of 32,858. The eligible cropland within 900-foot buffer of the 12 watersheds varies from a minimum of 2,510 parcels to a maximum of 7,683 parcels. The eligible land captures 21.7% to 42.2% of the cropland in respective watersheds. In total, there are 62,780 eligible land parcels with 129,955 acres, which is 33.4% of all cropland in the 12 watersheds and 21.0% of the watershed area.

In each watershed, sediment runoff data for the 8 alternative land management plans were generated by using the Agricultural Non-Point Source Pollution (AGNPS) model, a hydrologic model that has been extensively used to simulate water, sediment and nutrient flows under different land management scenarios (Young et al. 1989, 1994). An interface was developed to input GIS data into the model and the model was parameterized to reflect hydrological conditions in specific watersheds. Many of the AGNPS parameters such as curve number, Manning's coefficient, surface condition coefficient, cropping factor, conservation factor, and chemical oxygen demand were obtained from USDA publications (USDA, 1972, 1986) and adjusted in consultations with state Natural Resource Conservation Service officials to fit conditions in the 12 watersheds. We obtained rainfall data from the Illinois State Water Survey (Huff and Angle, 1989). These data were used to construct a 5-year storm event (3.73 inches of rainfall for 12 hours) for the 12 watersheds (for detailed justifications, see Yang 2000). The AGNPS model was used to obtain estimates of the channel deposition ratio coefficients d_{npj} for each flow channel for every combination of land management plan in each watershed.

The opportunity cost of enrolling land in a land retirement program is the forgone quasi-rent from crop production, defined as total revenues minus total variable costs. Quasi-rents per acre were estimated for a 700-acre farm, the average-sized commercial operation in Central Illinois, growing corn and soybean using reduced-till and no-till systems[1], respectively (details are discussed in Yang, 2000). Quasi-rents varied across parcels because crop yields and inputs

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[1] . Reduced-till has less intensive operations on soil than conventional tillage such as smaller cultivation equipment. No-till does not allow operations that disturb the soil other than the planting or drilling operation.

changed according to each parcel's soil productivity rating. Soil productivity information in Olson et al. (1994) was used to determine maximum potential crop yields. These expected yield estimates were used together with recommended input-output ratios based on Illinois Agronomy Handbook (Cooperative Extension Service, 1999) to determine the quantities of seed, various fertilizers and pesticide inputs required per acre. The fixed and variable costs of machinery and labor required for a 700-acre corn and soybean farming operation were calculated by using a machinery program developed by Siemens (1998). We collected data on output and input prices for 1998 from various state sources. Using all of the above data, we calculated quasi-rents per acre for the 62,780 eligible cropland parcels in the 12 watersheds.

Summary statistics for the eligible cropland parcels are provided in Table 1. Land parcels differ considerably in their quasi-rents, distance to water bodies, slopes, upland sediment inflows and on-site erosion. The eligible land is highly productive in nature. The range of mean quasi-rents in individual watersheds is $197.6/parcel to $266.6/parcel. But the minimum quasi-rent is $31.11/parcel and the maximum is $319.6/parcel. The range of the mean distance from water bodies is 388.6 to 430.8 feet. This indicates that most of the eligible land parcels are first or second parcels from water body. The larger the mean distance means more land parcels are further away from the water body. The range of mean slope in the 12 watersheds is from 0.9% to 3.7%. The minimum slope is 0.5% and the maximum slope is 15.0%. This indicates that the cropping land parcels within the 900-foot buffer are relatively flat. The range of the mean upland sediment inflow in individual watersheds is from 1.4 to 3.3 tons. But there exists a large variation among the 12 watersheds with the minimum 0.0 tons and maximum 186.7 tons. The mean on-site erosions in individual watersheds are between 2.5 tons to 9.2 tons. There also exists a significant variation in on-site erosion generation among the 12 watersheds. The minimum is 0.1 tons and the maximum is as high as 55.4 tons.

V. Results

The empirical models described above were run for the 12 watersheds under two alternative environmental rules: uniform standard and non-uniform standard. Under a uniform standard, each watershed is treated individually and land retirements are targeted to achieve the same sediment abatement objective independently. Under a non-uniform standard, all 12 watersheds are combined into one larger watershed and sediment abatement objective is achieved in the extended area. Because of physical and economic differences among the watersheds, the cropland parcels selected for retirement are different between the two environmental standards. Furthermore, costs are lower for the non-uniform standard that equalizes marginal cost of sediment abatement across watersheds. For each environmental standard option, the cost effectiveness of a rental payment instrument based on marginal cost of sediment abatement ($/ton) and a rental payment per acre ($/acre) are estimated and compared. Then the cost effectiveness of the 4 policy options (uniform standard with a $/ton instrument, uniform standard with a $/acre instrument, non-uniform standard with a $/ton instrument and non-uniform standard with a $/acre instrument) is compared.

Cost Effective Land Retirement Targeting with a Uniform Standard

Cost effective land retirement targeting is identified for each of the 12 watersheds under a uniform 20% sediment abatement standard. In the 12 watersheds, 10,973 acres of land need to be retired to achieve 20 percent sediment abatement (31,915 tons), which is 8.4% of total eligible land (129,555 acres). The quasi-rent losses are $989,217. Also, the first land parcels adjacent to water bodies dominate among selected land parcels and account for between 62.4% to 87.2% of selected parcels in individual watersheds. The total selected first parcels comprise 74.9% of 5,301 parcels selected in the 12 watersheds (see Table 2). The position and slope of selected cropland parcels in the 12 individual watersheds under a uniform standard are shown in Table 3. Except for Watersheds SA8060 and SA8091 that have the highest marginal costs of abatement, very few selected parcels fall into slope class 0-2%. In the 12 watersheds, 527 selected parcels (493 first parcels, 28 second parcels, 6 third parcels) are in slope class 0-2%, which is only 10% of the total selected parcels. This indicates that the land parcels closer to water bodies and with higher slopes are more likely to be selected for enrollment.

The 12 watersheds have significant differences in sediment abatement, selected land retirement acres and quasi-rent losses under the policy with a uniform sediment abatement standard, as shown in Table 4. Under uniform 20% sediment abatement standard, watershed SA8091 only has 667.4 tons of sediment abatement but watershed MC1011 has 4,724.1 tons. To achieve the same 20% sediment abatement, watershed MC1012 only needs 488.5 acres with $39,529 quasi-rent losses but watershed SA8060 needs 1,819.5 acres with $222,187 quasi-rent losses. The unequal watershed sizes and base sediment loading as well as sediment abatement efficiency lead to these differences.

The 12 watersheds have significant differences in cost effectiveness of land retirement targeting. For a 20% sediment abatement goal, as shown in Figure 2 and Table 4, Watershed MC1011’s average cost of sediment abatement equals $18.0 per ton, which is the minimum for the 12 watersheds. Average cost is highest at $96.0 per ton in Watershed SA8060. Correspondingly, Watershed MC1011 also has the smallest marginal cost of sediment abatement among the 12 watersheds, which is $22.6 per ton. Again, Watershed SA8060 has the largest marginal cost of abatement, $180.3 per ton.

A comparison of the two extremes, Watershed MC1011 with lowest marginal cost of abatement and Watershed SA8060 with the highest marginal cost of abatement suggests that slope structure and productivity play important roles in determining sediment abatement efficiency (see Table 5). For Watershed MC1011, none of the selected parcels fall into slope class 0-2 percent, but Watershed SA8060 has 468 parcels (443 first parcels, 22 second parcels and 3 third parcels) out of 879 total selected parcels in slope class 0-2 percent. In terms of productivity index, the select land parcels in watershed MC1011 are in the range 106-114. But most of the selected parcels in Watershed SA8060 have productivity index around 130. In Watershed MC1011, 4,742.1 tons were abated by retiring of 486 parcels, (9.8 tons/parcel). In watershed SA8060, 2,313.6 tons were abated by retiring 879 parcels (2.6 tons/parcel). Sediment abatement efficiency in Watershed SA8060 is much lower than that in Watershed MC1011.

Uniform Standard: Comparison of $/ton and $/acre Rental Payment Instruments in Land Retirement Targeting

The rental payment $/acre to achieve a 20% of reduction in sediment within each watershed is also different, ranging from a minimum of $83.60 per acre for Watersheds MC1012, SM1012 and SM1013 to a maximum of $129.1 for Watershed SA8060. With a $/acre instrument, 25,618.3 acres of land are selected to achieve a 20% reduction in sediment for a 5-year storm event, which is a 133% increase over the selected land retirement acreage with a $/ton instrument. Total quasi-rent losses are $1,965,000, which is 99% more than the costs with a $/ton instrument (see Table 6). Given a uniform sediment abatement standard applied in each of the watersheds, the land retirement targeting based on a $/acre policy instrument is much more costly than that of a $/ton instrument.

Cost effective Land Retirement Targeting with a Non-Uniform Standard

The theoretical model developed earlier indicates that the condition to achieve cost effectiveness of land retirement targeting in multiple watersheds is to equalize marginal costs of sediment abatement across watersheds. From a social planner's position, it is necessary to rearrange land retirement targeting among these watersheds to achieve equal marginal costs across watersheds. After rearrangement, sediment abatement levels across watersheds will be different.

Based on the empirical model, all flow channel-based sediment abatement and quasi-rent data are pooled together to determine cost effective land retirement targeting among the 12 watersheds subject to one sediment abatement constraint over the aggregated base sediment loading. At 20% sediment abatement level, the marginal cost of sediment abatement is $46.1/ton across watersheds. In the 12 watersheds, the targeted land retirements are 9,255 acres, which is 7.1% of eligible land and 2.4% of total cropland in 12 watersheds. The quasi-rent losses are $787,945.

The non-uniform standard significantly alters the distribution of selected cropland parcels identified under a uniform standard. The maximum reduction in selected land retirement acreage is 1,691.2 acres in Watershed SA8060. Under a uniform standard, SA8060 had the highest marginal cost of sediment abatement $180.30 per ton. The maximum increase in selected land retirement is 1,252.4 acres in Watershed MC1011, which had least marginal cost of sediment abatement ($26.30/ton) under a uniform standard (see Table 7). After this rearrangement, sediment abatement levels in each watershed change. A non-uniform standard results in only a 3.6% sediment reduction in Watershed SA8060. In Watershed MC1011, the sediment abatement level is 33.4% (see Figure 3).

As before, the location of selected cropland parcels relative to the water body under non-uniform standard is important. First parcels dominate among all selected parcels, with the percentage in selected parcels ranging from 65.5% to 91.2% in individual watersheds (see Table 8). The position and slope of selected land parcels in the 12 watersheds under a non-uniform standard are shown in Table 9. Of the 4,471 selected parcels, only 27 parcels (26 first parcels, 1 second parcel) fall into slope class 0-2%. Especially for Watersheds SA8060, compared to 284 parcels in slope class 0-2% under a uniform standard, there are only 3 selected parcels that are in slope class 0-2% under a non-uniform standard. This is consistent with the land retirement targeting with a uniform standard that the land parcels closer to water bodies and with higher slopes are more likely to be selected for enrollment.

Non-Uniform Standard: Comparison of $/ton and $/acre Rental Payment Instruments

For comparison purpose, a $/acre rental payment instrument is applied to each of the 12 watersheds to achieve the sediment abatement equivalent to the non-uniform standard policy with a $/ton rental payment instrument. As shown in Table 10, average rental payments range $83.60 and $110.60 per acre. Given a non-uniform sediment standard and a $/acre instruments, 20,342 acres of cropland need to be retired, which is 120% increase over land retirement with a non-uniform standard and a $/ton instrument. Quasi-rent losses equal $1,344,000, which is 71% more than the costs of a non-uniform standard and $/ton instrument. This result is consistent with previous empirical findings that a $/ton policy instrument is more cost effective than a $/acre instrument under the uniform standard.

Comparison of Land Retirement Policy under Uniform vs. Non-Uniform Standard and Each Standard with $/ton vs. $/acre Rental Payment Instrument

In above sections, 4 types of land retirement policies were examined: 1. Uniform standard with a $/ton instrument. 2. Uniform standard with a $/acre instrument. 3. Non-uniform standard with a $/ton instrument. 4. Non-uniform standard with a $/acre instrument. Comparisons of the 4 types of policies in terms of cost effectiveness are shown in Table 11.

While a $/ton rental payment instrument is classified as a cost effective way to target land retirement, there exist differences in defining the instruments in individual watersheds or multiple watersheds, which refers to uniform standard or non-uniform standard approach discussed earlier. As shown, with 20% sediment abatement, the uniform standard policy with a $/ton rental payment instrument needs 10,973 acres of land retirement and generates $987,217 of quasi-rent losses, which are 18.6% and 25.3% more than the land retirement and quasi-rent losses in the non-uniform standard policy with a $/ton rental payment instrument (9,255 acres of land retirement and $787,976 of quasi-rent losses). The policy implication from this comparison is that the policy-maker needs to consider the differences among watersheds in pollution abatement efficiency to set non-uniform standards for land retirement policy.

The land retirement policy with a instrument based on marginal cost of sediment abatement ($/ton) is more cost effective than a policy with a $/acre rental payment instrument, regardless it is with uniform or non-uniform standard. From here we can also see an interesting comparison. The uniform standard policy with a $/acre instrument is more costly than the non-uniform policy with a $/acre instrument. This indicates that even more easily implemented $/acre instrument is adopted, a non-uniform standard policy with the consideration of watershed differences may achieve more cost effectiveness than a uniform standard policy.

In summary, with either a $/ton or a $/acre instrument, a non-uniform standard policy, which equalizes marginal cost of sediment abatement across watersheds outperformed a uniform standard policy. With either a uniform or non-uniform standard policy, a $/ton instrument outperformed a $/acre instrument. The least preferred policy option (uniform standard with $/acre instrument) is 2.5 times as costly as the most preferred policy (Non-uniform standard with $/ton instrument).

VI. Conclusions

This paper develops an integrated watershed management framework that combines detailed spatial biophysical attributes of land with a hydrologic model and an economic model to achieve CREP's environmental protection objectives across multiple watersheds at least cost. The hydrological model recognizes the inter-relationships between land parcels in determining their sediment trapping efficiency. An interface was developed to input GIS data into the Agricultural Non-point Source Pollution (AGNPS) model, a hydrologic model that has been extensively used to simulate water, sediment and nutrient flows under different land management scenarios. The hydrologic, spatial and economic characteristics of land are then incorporated into a linear programming model to identify cropland that would satisfy CREP's sediment goals at least cost.

This integrated framework is applied to the multiple watersheds to achieve an aggregate sediment abatement of 20% using two alternative rules – a uniform standard policy under which each watershed is required to achieve 20% abatement and a non-uniform standard policy under which marginal cost of sediment is equalized across watersheds to achieve 20% abatement over aggregated sediment base of multiple watersheds. Furthermore, under each type of standard, costs of abatement under two alternative rental policy instruments are examined, a rental payment based on marginal cost of pollution abatement ($/ton) and a rental payment that provides uniform payments per acre. The latter resembles an "offer system" under which farmers are offered a single price (dollars per acre of land retired) that is typically based on the average cash-rental rates in each county, a second-best instrument which is widely practiced by governments. Then the cost effectiveness of the four policy options (uniform standard with $/ton instrument, uniform standard with $/acre instrument, non-uniform standard with $/ton instrument and non-uniform standard with $/acre instrument) is discussed.

The integrated modeling framework is applied to 12 agricultural watersheds in Illinois CREP region. Empirical results reveal that under the uniform standard of 20% sediment abatement, there exist significant differences in marginal costs of sediment abatement across watersheds, ranging from $22.6/ton to $180.3/ton. This indicates that significant gain can be achieved if land retirement pattern can be identified to equalize marginal cost of sediment abatement across watersheds. The model shows that with uniform $46.1/ton marginal cost of sediment abatement across watersheds, land retirement can achieve 20% sediment abatement over aggregated sediment base. With $/ton instrument, the uniform standard is 18.6% and 25.3% more in land retirement acreage and quasi-rent losses than the non-uniform standard. The performance of $/acre policy instrument under the two standards are simulated to achieve the comparable environmental objective with the $/ton instrument. Under uniform standard, the land retirement and quasi-rent losses with $/acres instrument are 133% and 99% more than those with a $/ton instrument. Under non-uniform standard, a $/acre instrument needs 120% and 71% more in land retirement and quasi-rent losses than a $/ton policy instrument in order to achieve the same 20% sediment abatement objective in multiple watersheds.

The policy implications from the empirical results are quite appealing. With either a $/ton or a $/acre payment instrument, the non-uniform sediment standard, which equalizes the marginal cost of sediment abatement across watersheds, outperforms the uniform standard policy. With either a uniform or non-uniform sediment standard, the policies with a $/ton payment instrument outperforms policies using a $/acre instrument. The least preferred policy option, the uniform sediment abatement standard with a $/acre instrument, is 2.5 times as costly as the most preferred policy option, the non-uniform sediment standard with a $/ton payment instruments. Also, the majorities of targeted land parcels are close to water bodies and are with higher slopes.

Compared with previous studies, this paper advances knowledge in two aspects. First, it incorporates endogenous sediment deposition coefficients in estimating off-site sediment abatement benefits. Secondly, it examines policy instruments in multiple watersheds and the cost-effective condition for land retirement is achieved at parcel-level and watershed level simultaneously. The model results suggest that the decision-makers need to design non-uniform standards based on physical and economic differences of the watersheds in order to achieve cost effectiveness in a large policy region like multiple watersheds. Also, current Illinois CREP criteria focus primarily on floodplains, which are large expanses of flat land. Empirically results from this study indicate that the decision-makers may want to expand their current targeting criteria to include any cropland within a buffer zone on both side of streams and rivers, especially if their sediment goal ranks higher than other environmental goals.

Table 1. Summary Statistics for Eligible Cropland in 12 Watersheds

W[1]	Quasi-rent ($/parcel)			Distance from River (feet)			Slope (%)			Erodibility Index			Upland Sediment Inflow (tons)			Onsite Erosion (tons)		
	Min	Max	Mean (Std. dev)	Min	Max	Mean (Std. dev)	Min	Max	Mean (Std. dev)	Min	Max	Mean (Std. dev)	Min	Max	Mean (Std. dev)	Min	Max	Mean (Std. dev)
W1	40.7	319.6	232.1 (55.7)	150.0	750.0	393.0 (236.4)	0.5	15.0	2.1 (2.8)	0.09	0.37	0.30 (0.04)	0.0	83.7	2.1 (3.9)	0.7	53.6	5.7 (7.3)
W2	34.2	319.6	225.4 (92.6)	150.0	750.0	389.9 (237.4)	0.5	15.0	1.7 (2.2)	0.11	0.37	0.29 (0.06)	0.0	46.1	1.9 (3.3)	0.8	53.6	4.5 (5.5)
W3	34.2	319.6	244.4 (65.3)	150.0	750.0	393.8 (236.6)	0.5	15.0	3.0 (2.8)	0.15	0.37	0.29 (0.03)	0.0	48.2	2.9 (4.4)	0.8	53.6	8.2 (7.9)
W4	125.8	319.6	224.2 (64.4)	150.0	750.0	388.6 (237.3)	0.5	15.0	2.9 (2.8)	0.14	0.37	0.32 (0.03)	0.0	59.6	3.3 (4.9)	1.1	53.6	8.0 (7.6)
W5	125.8	278.7	224.2 (62.5)	150.0	750.0	412.0 (240.1)	0.5	15.0	1.7 (1.8)	0.16	0.37	0.31 (0.04)	0.0	39.0	2.2 (3.1)	1.3	53.6	4.8 (5.1)
W6	125.8	319.6	209.8 (47.1)	150.0	750.0	419.7 (235.0)	0.5	15.0	3.7 (3.4)	0.15	0.37	0.35 (0.04)	0.0	44.2	2.5 (4.0)	1.2	53.6	9.2 (8.0)
W7	125.8	319.6	231.0 (63.4)	150.0	750.0	430.8 (239.2)	0.5	15.0	3.2 (2.9)	0.15	0.37	0.33 (0.04)	0.0	33.2	2.2 (3.3)	1.2	53.6	7.9 (7.1)
W8	34.2	319.6	250.7 (47.7)	150.0	750.0	393.7 (238.0)	0.5	15.0	1.7 (2.2)	0.11	0.37	0.31 (0.03)	0.0	48.6	1.7 (2.6)	0.9	53.6	4.8 (5.6)
W9	31.1	275.9	197.6 (97.6)	150.0	750.0	392.6 (293.3)	0.5	15.0	0.9 (1.1)	0.01	0.31	0.26 (0.06)	0.0	41.5	1.4 (2.5)	0.1	36.3	2.5 (2.4)
W10	44.0	319.6	266.6 (65.3)	150.0	750.0	402.6 (238.3)	0.5	15.0	2.0 (2.4)	0.14	0.37	0.32 (0.04)	0.0	50.5	2.2 (3.4)	0.8	53.6	5.5 (6.1)
W11	40.7	300.3	263.1 (38.6)	150.0	750.0	398.7 (239.0)	0.5	15.0	1.2 (1.3)	0.16	0.37	0.29 (0.02)	0.0	186.7	2.8 (6.5)	0.9	55.4	3.4 (3.1)
W12	34.2	319.6	242.2 (75.3)	150.0	750.0	394.3 (235.5)	0.5	15.0	2.2 (2.2)	0.16	0.37	0.31 (0.05)	0.0	35.9	2.1 (3.2)	0.8	53.6	5.8 (6.1)

1. W – Watersheds, W1 – MC1020, W2 – MC1010, W3 – MC1011, W4 – MC1012, W5 – MC1013, W6 – SM1012, W7 – SM1013, W8 – SA8090, , W9 – SA8091, , W10 – SA8092, W11 – SA8060, W12 – SA8070.

Table 2. Uniform Standard: The Position[1] of Selected Cropland Parcels in 12 Watersheds

Watershed	Parcel 1		Parcel 2		Parcel 3		Total selected parcels	Total eligible parcels
	Count	%	count	%	count	%		
MC1020	350	62.4	163	29.1	48	8.6	561	7,683
MC1010	196	79.7	44	17.9	6	2.4	246	4,948
MC1011	424	87.2	56	11.5	6	1.2	486	7,683
MC1012	187	79.2	45	19.1	4	1.7	236	2,560
MC1013	237	74.5	71	22.3	10	3.1	318	4,400
SM1012	316	71.3	106	23.9	21	4.7	443	3,931
SM1013	191	64.5	92	31.1	13	4.4	296	2,510
SA8090	373	71.5	118	22.6	31	5.9	522	7,146
SA8091	313	86.0	37	10.2	14	3.8	364	3,253
SA8092	402	70.8	131	23.1	34	6.0	566	6,338
SA8060	681	77.5	142	16.2	56	6.4	879	6,280
SA8070	298	77.6	80	20.8	6	1.6	384	6,084
Total	3,968	74.9	1,085	20.5	248	4.6	5,301	62,816

1. Parcel 1 is adjacent to a water body while Parcel 3 is the third parcel from a water body

Table 3. Uniform Standard: Position[1] and Slope of Selected Cropland Parcels in 12 Individual Watersheds

	Slope (%)	Watersheds												Total
		SA8060	SA8091	SA8090	SA8092	MC1013	SM1013	MC1020	MC1010	SA8070	SM1012	MC1012	MC1011	
Marginal Cost ($/ton)		180.3	156.2	68.9	65.3	57.5	52.4	49.1	45.8	44.6	38.7	31.3	26.3	
Parcel 1	0-2	273	194	7	4	1	1	5	8	--	--	--	--	493
	2-5	333	88	106	88	74	26	21	18	28	9	7	1	799
	5-10	63	23	183	227	136	102	179	130	203	146	130	289	1,811
	10-15	12	8	77	82	26	62	145	40	67	161	50	134	864
Parcel 2	0-2	10	18	--	--	--	--	--	--	--	--	--	--	28
	2-5	63	7	3	2	1	2					1		79
	5-10	61	10	79	87	62	47	65	21	47	33	18	8	538
	10-15	8	2	36	42	8	43	98	23	33	73	26	48	440
Parcel 3	0-2	1	5	--	--	--	--	--	--	--	--	--	--	6
	2-5	20	1	--	--	--	--	--	--	--	--	--	--	21
	5-10	33	8	14	18	9	6	14	1	1				104
	10-15	2	0	17	16	1	7	34	5	5	21	4	6	118
Total		879	364	522	566	318	296	561	246	384	443	236	486	5301
Eligible Parcels (62,780 in total)		6,280	3,253	7,146	6,338	4,400	2,510	7,683	4,948	6,084	3,931	2,560	7,683	

1. Parcel 1 is adjacent to a water body while Parcel 3 is the third parcel from a water body.

Table 4. Uniform Standard : Selected Land, Sediment abatement, Quasi-rent Losses and Marginal Cost of Sediment Abatement

Watershed	Selected Land (Acres)	Sediment Abatement (tons)	Quasi-rent Losses ($)	Marginal Cost of Abatement ($/ton)
MC1020	1,161.3	4,010.8	100,880.1	49.1
MC1010	509.2	1,673.6	42,087.6	45.8
MC1011	1,006.0	4,742.1	85,207.0	26.3
MC1012	488.5	2,124.8	39,528.6	31.1
MC1013	658.3	1,954.7	55,328.7	57.5
SM1012	917.0	3,380.1	74,147.7	38.7
SM1013	612.7	1,873.5	50,721.3	52.4
SA8090	1,080.5	2,959.9	96,541.0	68.9
SA8091	753.5	667.4	45,424.6	156.2
SA8092	1,171.6	3,352.3	108,660.5	65.3
SA8060	1,819.5	2,313.6	222,187.0	180.3
SA8070	794.9	2,861.6	68,520.8	44.6

Table 5. Uniform Standard: Comparison of Land Retirement in Watersheds MC1011 and SA8060

Sediment abatement	Position[1]	Slope (%)	Number of parcels	Average erodibility	Average upland sediment (tons)	Average productivity index	Aggregated sediment abatement (tons)
MC1011 (486 parcels, sediment abatement 4,742.1 tons)	Parcel 1 (424 parcels)	0-2	--	--	--	--	--
		2-5	23	0.37	19.50	112.90	175.34
		5-10	315	0.37	6.84	113.50	2928.30
		10-15	86	0.37	5.92	109.35	1113.82
	Parcel 2 (56 parcels)	0-2	--	--	--	--	--
		2-5	--	--	--	--	--
		5-10	26	0.37	7.96	110.53	203.70
		10-15	30	0.37	5.45	108.30	282.47
	Parcel 3 (6 parcels)	0-2	--	--	--	--	--
		2-5	--	--	--	--	--
		5-10	--	--	--	--	--
		10-15	6	0.37	6.45	106.21	38.43
SA8060 (879 Parcels, sediment abatement 2,313.6 tons)	Parcel 1 (681 Parcels)	0-2	443	0.30	8.13	134.91	888.23
		2-5	192	0.31	5.81	132.67	594.68
		5-10	35	0.31	4.08	131.20	195.52
		10-15	11	0.36	9.98	113.37	99.04
	Parcel 2 (142 Parcels)	0-2	22	0.32	27.02	132.68	41.33
		2-5	83	0.32	6.83	133.67	216.85
		5-10	31	0.33	4.11	125.97	111.86
		10-15	6	0.37	3.93	110.34	35.58
	Parcel 3 (56 Parcels)	0-2	3	0.30	73.02	141.17	7.6
		2-5	30	0.31	7.67	130.59	61.01
		5-10	22	0.34	2.85	123.49	57.49
		10-15	1	0.37	12.72	110.34	4.41

1. Parcel 1 is adjacent to a water body while Parcel 3 is the third parcel from a water body.

Table 6. Uniform Standard: Comparison of Land Retirement Policy with $/ton vs. $/acre Rental Payment

Watershed	Sediment abatement		$/ton rental payment					$/acre rental payment				
			CREP land		Quasi-rent losses		Marg.P	CREP Land		Quasi-rent losses		Avg.P
	Tons	%[1]	Acres	%[1]	$1,000	%[1]	$/T	Acres	%[1]	$1,000	%[1]	$/acre
SA8060	2,313.6	7.2	1,819.5	16.6	**222.2**	22.5	180.3	5,336.5	20.8	**581.8**	29.6	129.1
SA8091	667.4	2.1	753.5	6.9	**45.4**	4.6	156.2	3,657.7	14.3	**235.8**	12.0	113.4
SA8090	2,959.9	9.3	1,080.5	9.8	**96.5**	9.8	68.9	1,647.7	6.4	**130.9**	6.7	95.3
SA8092	3,352.3	10.5	1,171.6	10.7	**108.7**	11.0	65.3	1,827.8	7.1	**158.9**	8.1	95.3
MC1013	1,954.7	6.1	658.3	6.0	**55.3**	5.4	57.5	890.1	3.5	**74.8**	3.8	88.1
SM1013	1,873.5	5.9	612.7	5.6	**50.7**	5.1	52.4	828.0	3.2	**65.9**	3.4	83.6
MC1020	4,010.9	12.6	1,161.3	10.6	**100.9**	10.2	49.1	2,579.2	10.1	**166.7**	8.5	90.6
MC1010	1,673.6	5.2	509.2	4.6	**42.1**	4.3	45.8	2,353.6	9.2	**84.9**	4.3	91.1
SA8070	2,861.6	9.0	794.9	7.2	**68.5**	6.9	44.6	2,484.0	9.7	**146.2**	7.4	90.6
SM1012	3,380.1	10.6	917.0	8.4	**74.2**	7.5	38.7	1,316.5	5.1	**104.5**	.3	83.6
MC1012	2,124.8	6.7	488.5	4.5	**39.5**	4.0	31.1	726.6	2.8	**58.7**	3.0	83.6
MC1011	4,742.1	14.9	1,006.0	9.2	**85.2**	8.6	26.3	1,970.6	7.7	**156.2**	7.9	88.1
Summary	31,908.7	100	10,973.0	100	**989.2**	100		25618.3	100	**1,965.3**	100	

1. Percentage refers to the total in 12 watersheds

Table 7. Comparison of Land Retirement under Uniform vs. Non-Uniform Standard

Watershed	Uniform Standard		Non-Uniform Standard		Land retirement change (acres)
	Marginal costs ($/ton)	Land retirement (acres)	Marginal costs ($/ton)	Land retirement (acres)	
SA8060	180.3	1,819.5	46.1	128.3	-1,691.2
SA8091	156.2	753.5	46.1	118.0	-635.5
SA8090	68.9	1,080.5	46.1	629.3	-451.2
SA8092	65.3	1,171.6	46.1	741.1	-430.5
MC1013	57.5	658.3	46.1	486.5	-171.8
SM1013	52.4	612.7	46.1	505.1	-107.6
MC1020	49.1	1,161.3	46.1	1,068.1	-93.2
MC1010	45.8	509.2	46.1	527.9	18.7
SA8070	44.6	794.9	46.1	832.1	37.2
SM1012	38.7	917.0	46.1	1,182.0	265.0
MC1012	31.3	488.5	46.1	778.3	289.8
MC1011	26.3	1,006.0	46.1	2258.4	1,252.4

Table 8. Non-Uniform Standard: Position of Selected Land Parcels in 12 Watersheds

Watershed	First parcel		Second parcel		Third parcel		Selected parcels	Elig. parcels
	count	%	Count	%	count	%		
MC1020	338	**65.5**	137	**26.6**	41	**7.9**	516	7,683
MC1010	204	**80.0**	44	**17.3**	7	**2.7**	255	4,948
MC1011	807	**74.0**	249	**22.8**	35	**3.2**	1,091	7,683
MC1012	274	**72.9**	88	**23.4**	14	**3.7**	376	2,560
MC1013	182	**77.4**	50	**21.3**	3	**1.3**	235	4,400
SM1012	399	**69.9**	142	**24.9**	30	**5.3**	571	3,931
SM1013	166	**68.0**	67	**27.5**	11	**4.5**	244	2,510
SA8090	240	**78.9**	52	**17.1**	12	**3.9**	304	7,146
SA8091	52	**91.2**	5	**8.8**	0	**0.0**	57	3,253
SA8092	271	**75.7**	74	**20.7**	13	**3.6**	358	6,338
SA8060	46	**74.2**	13	**21.0**	3	**4.8**	62	6,280
SA8070	315	**68.3**	81	**17.6**	6	**1.3**	402	6,084
Total	3,294	**73.7**	1,002	**22.4**	175	**3.9**	4,471	62,816

Table 9. Non-Uniform Standard: Position[1] and Slope of Selected Land Parcels in 12 Individual Watersheds

		Watersheds												Total
		SA8060	SA8091	SA8090	SA8092	MC1013	SM1013	MC1020	MC1010	SA8070	SM1012	MC1012	MC1011	
Marginal cost ($/ton)		46.1	46.1	46.1	46.1	46.1	46.1	46.1	46.1	46.1	46.1	46.1	46.1	
Parcel 1	0-2	3	4	4	1	--	--	4	8	--	--	2	--	26
	2-5	10	31	25	37	34	15	17	25	41	36	55	98	424
	5-10	22	9	134	155	122	91	172	131	207	198	167	553	1,961
	10-15	11	8	77	78	26	60	145	40	67	165	50	156	883
Parcel 2	0-2	--	1	--	--	--	--	--	--	--	--	--	--	1
	2-5	1	1	--	--	--	2	--	--	--	--	1	1	6
	5-10	7	1	26	37	42	25	48	21	48	50	53	159	517
	10-15	5	2	26	37	8	40	89	23	33	92	34	89	478
Parcel 3	0-2	--	--	--	--	--	--	--	--	--	--	--	--	--
	2-5	--	--	--	--	--	--	--	--	--	--	--	--	--
	5-10	2		2	5	2	5	10	1	1	3	7	8	46
	10-15	1		10	8	1	6	31	6	5	27	7	27	129
Total		62	57	304	358	235	244	516	255	402	571	376	1,091	4,471
Eligible Parcels (62,780 in total)		6,280	3,253	7,146	6,338	4,400	2,510	7,683	4,948	6,084	3,931	2,560	7,683	

1. Parcel 1 is adjacent to a water body while Parcel 3 is the third parcel from a water body.

Table 10. Non-Uniform Standard: Comparison of Land Retirement Policies with $/ton and $/acre Rental Payment Instruments

Watershed	Sediment abatement		$/ton rental payment					$/acre rental payment				
			CREP land		Quasi-rent losses		Marg.P	CREP land		Quasi-rent losses		Avg.P
	Tons	%[1]	Acres	%[1]	$1,000	%[1]	$/T	Acres	%[1]	$1,000	%[1]	$/acre
SA8060	420.6	1.3	128.3	1.4	**13.1**	1.7	46.1	503.0	2.5	**38.6**	2.9	106.3
SA8091	276.7	0.9	118.0	1.3	**6.4**	0.8	46.1	2,113.5	10.4	**64.9**	4.8	110.6
SA8090	2,199.6	6.9	629.3	6.8	**53.9**	6.8	46.1	1,088.8	5.4	**79.0**	5.9	90.6
SA8092	2,577.7	8.1	741.1	8.0	**66.1**	8.4	46.1	1,115.7	5.5	**92.2**	6.9	90.6
MC1013	1,672.2	5.2	486.5	5.3	**40.6**	5.2	46.1	579.6	2.8	**47.7**	3.5	83.7
SM1013	1,677.4	5.3	505.1	5.5	**41.0**	5.2	46.1	689.3	3.4	**54.3**	4.0	83.6
MC1020	3,832.6	12.0	1,068.1	11.5	**92.4**	11.7	46.1	2513.0	12.4	**160.7**	12.0	90.6
MC1010	1,711.3	5.4	27.9	5.7	**43.8**	5.6	46.1	2,366.0	11.6	**86.0**	6.4	91.1
SA8070	2,931.8	9.2	832.1	9.0	**71.8**	9.1	46.1	2,513.0	12.4	**148.8**	11.1	90.6
SM1012	3,920.3	12.3	1182.0	12.8	**97.0**	12.3	46.1	1,776.1	8.7	**144.1**	10.7	88.2
MC1012	2,781.8	8.7	778.3	8.4	**64.7**	8.2	46.1	950.1	4.7	**77.4**	5.8	83.7
MC1011	7,906.6	24.8	2,258.4	24.4	**197.3**	25.0	46.1	4,133.8	20.3	**350.6**	26.1	90.6
Summary	31,908.7	100	9,255.0	100	**788.0**	100		20,341.9	100	**1,344.4**	100	

1. Percentage refers to the total in 12 watersheds.

Table 11. Comparison of Policy with Uniform vs. Non-Uniform Standard and $/ton vs. $/acre Rental Payment Instrument

	Uniform Standard			Non-Uniform Standard		
	Land retirement (acres)	Total Quasi-rent losses ($)	Average Cost ($/ton)	Land retirement (acres)	Total Quasi-rent losses ($)	Average Cost ($/ton)
$/ton	10,973.0	987,216.8	30.9	9,255.0	787,946.5	24.7
$/acre	25,618.3	1,965,289.9	61.6	20,341.9	1,344,368.6	42.1

Figure 1 Location of Multiple Watershed Study Area in Illinois CREP Region

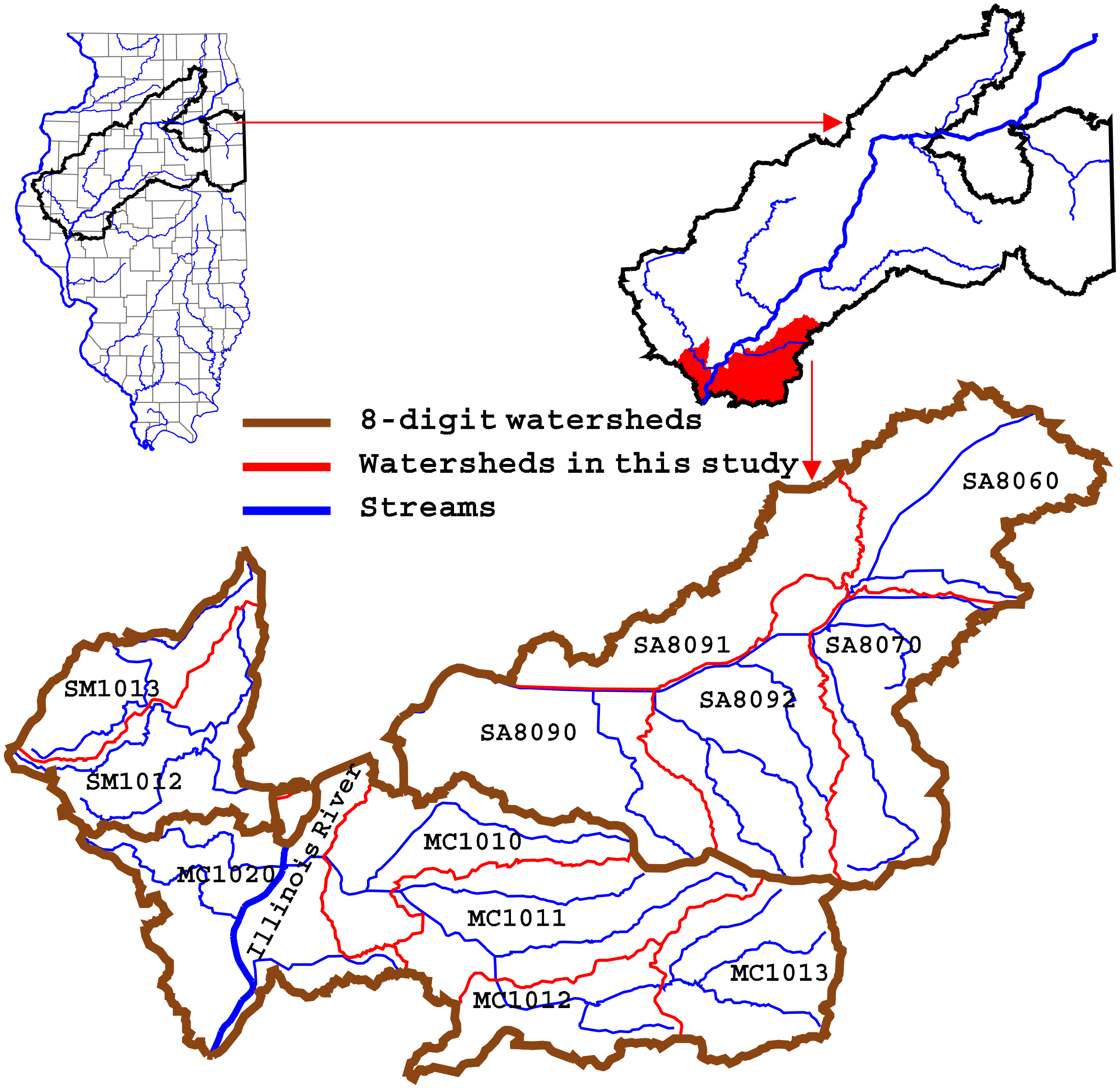
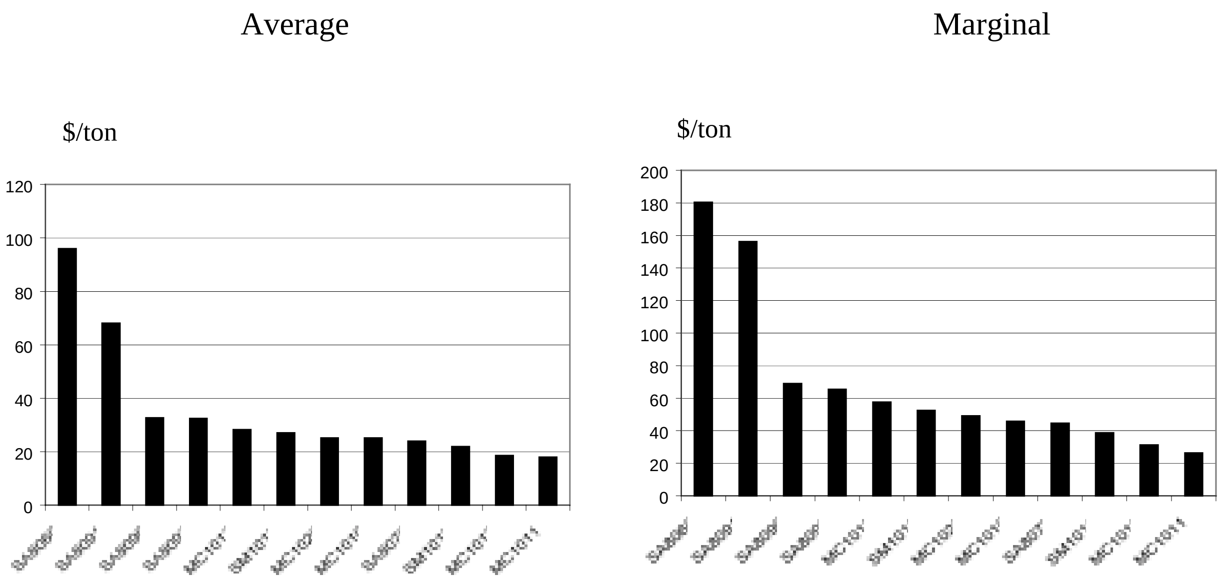
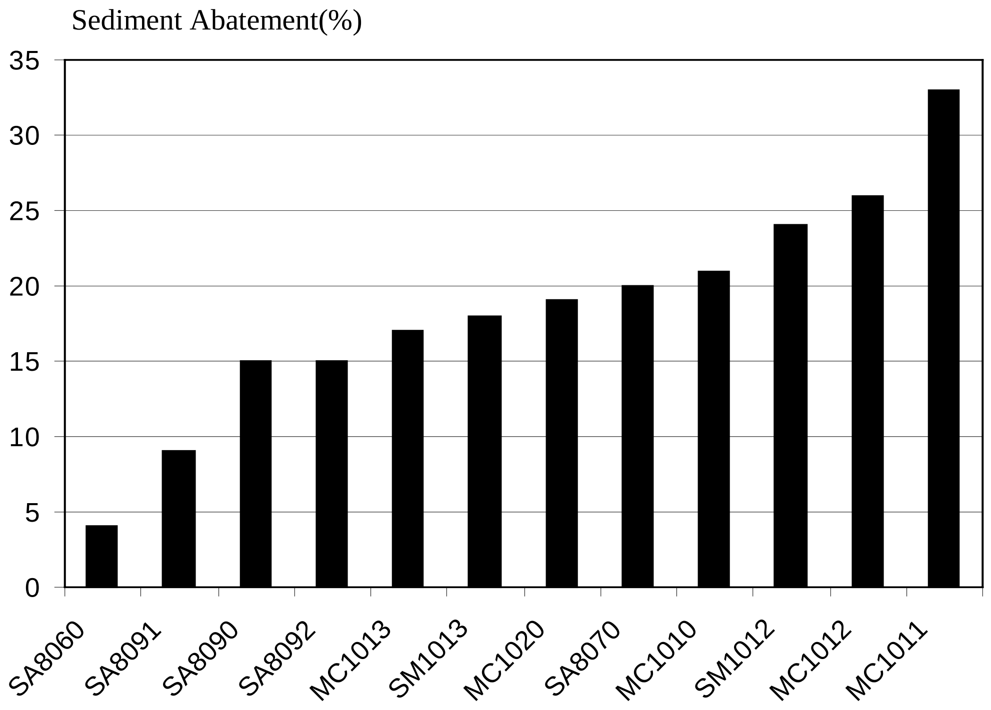


Figure 2. Uniform Standard: Average and Marginal Costs in 12 Watersheds


Average

Marginal

Figure 3. Non-Uniform Standard: Sediment Abatement Levels in 12 Watersheds



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