The Empirics of Environmental and Distributional Impacts of Conservation Targeting Strategies

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Introduction

Green payments and environmental stewardship programs have become a major vehicle for resource conservation and environmental protection. The 2002 Farm Bill not only re-authorized some of the most important conservation programs in U.S. history (e.g., Conservation Reserve Program), but also included provisions for new conservation programs (e.g., Conservation Security Program, Grassland Reserve Program). This trend is likely to continue in the new Farm Bill. Previous green payment programs have used various strategies to target resources for conservation, the choice of which may lead to striking differences in environmental performance and agricultural output (Babcock *et al.* 1997; Wu, Zilberman, and Babcock 2001; Newburn 2004). Wu, Zilberman, and Babcock (2001) compared the environmental and distributional effect of three different targeting strategies theoretically. They showed that when output prices are fixed,

- Benefit targeting strategy (purchases the resources with the highest environmental benefit) takes the smallest amount of resource out of production and results in highest output level.
- Cost targeting strategy (purchases the least expensive resources) takes the largest amount of resource out of production but results in the smallest environmental benefits.
- Benefit-cost ratio targeting strategy (purchases resources with the highest ratio of environmental benefit to economic cost) is efficient and provides more environmental benefits than cost or benefit targeting strategies.

This study provides an empirical application of Wu, Zilberman, and Babcock (2001). Specifically, we compare the environmental and economic effects of alternative targeting strategies (benefit, cost, and benefit-cost ratio targeting) for reducing nitrate-N water pollution. We apply the three targeting strategies to the Conservation Reserve Program (CRP) in the Des Moines Watershed in Iowa[1]. This watershed has been under increasing scrutiny as a significant source of nitrate-N (NO_3-N) loads to the Gulf of Mexico, causing one of the largest hypoxic zones in the world.

The objective is achieved by applying an integrated modeling system to nitrate-N runoff from the Des Moines Watershed. Our integrated modeling system consists of an econometric model and a physically-based hydrologic balance simulation model. The econometric model estimates farmers' decisions of participating in the CRP at 4,911 agricultural parcels in the Natural Resource Inventories (NRI). From the estimated results, the opportunity cost of CRP enrollment (defined in terms of output forgone) is calculated at each parcel. The Soil and Water Assessment Tool (SWAT) is then used to simulate the level of nitrate-N runoff at each NRI parcel in the watershed. As a result, our integrated modeling system provides all necessary information for this study at parcel-level: the cost and benefit of purchasing land and their ratio.

Our results show that the benefit-cost targeting achieves the highest nitrate-N runoff reduction for a given budget. The cost targeting results in the largest amount of land out of production. This strategy, however, results in the smallest environmental benefits. The benefit targeting takes the smallest amount of resource out of production and results in highest output level. The percent differences in the amount of land retired and total nitrate-N runoff reduction among alternative targeting strategies tend to be larger when the conservation budget is smaller. Finally, benefit targeting and benefit-cost ratio targeting tend to result in similar environmental and economic outcomes. Differences in nitrate-N runoff and acres of land retired between these two strategies are shown to be quite small.

Empirical Procedure

Study Area

We apply an integrated modeling system to the Des Moines Watershed, encompassing 8.8 million acres in Iowa and Minnesota (figure 1). This watershed accounts for 8 percent of the Upper Mississippi River Basin (MRB). The elevation of the watershed ranges between 146 and 595 meters. Topography is flat, with an average slope of 1.5 percent. This watershed consists of two major tributary channels, those of the Raccoon and Des Moines. The watershed has a typical subhumid, continental climate. Data from Iowa Environmental Mesonet reports that mean monthly temperatures range from -9.8 ºC in January to 24.9 ºC in July. Mean monthly precipitation ranges from 16 millimeters during February to 216 millimeters during July for the period of 1988 and 1999. Mean annual precipitation for those two years is 881 millimeters. In this watershed, much of the precipitation is produced by thunderstorms in spring and summer months. Precipitation is generally high in the midstream area, and low in the upper and lower areas of the watershed.

The level of NO_3-N water pollution in this watershed is higher than other watersheds in the Upper MRB. NO_3-N concentrations in the public water supply of the Des Moines often exceeds the Maximum Contamination Level (MCL) of 10 mg/L from April to July, the period after fertilizers are applied and when storm runoff is frequent (USGS 2003). About 7 million acres of land is used for agricultural production, accounting for 83 percent of the watershed. Much of land midstream and upstream is planted to row crops (corn and soybean) and heavily fertilized. In contrast, land downstream is mainly used for hay and pasture. The most common cropping practices for row crops is corn-soybean rotation under conventional tillage and under conservation tillage, accounting for 22 and 43 percent and in the watershed, respectively[2]. Other cropland is mostly used for producing hay and other crops (e.g. winter wheat). Major non-agricultural land uses in the watershed include urban, forest, and wetland.

Integrated Modeling System

We develop the integrated modeling system to compare the environmental and distributional effect of the three different targeting strategies in the Des Moines Watershed. To achieve our objective, we need to estimate the benefits and costs associated with conservation easements at each of agricultural parcels in the watershed. To this end, an integrated system consisting of the economic and SWAT models is developed. The structure of the integrated modeling system is presented in figure 2.

The economic model estimates the opportunity cost of participating in the CRP. To decide whether or not to participate, farmers take into account various costs incurred to them: those include the costs associated with retirement of agricultural production, unused agricultural labor and machinery, and possible restart of production in the future. We develop the empirical model to estimate the opportunity cost associated with CRP participation, at each agricultural parcel. The SWAT model predicts environmental benefits in spatially different agricultural parcels. Environmental benefits may be evaluated in terms of pollution avoided. Since Des Moines Watershed has been under increasing scrutiny as a significant source of agricultural NO_3-N pollution, the reduction in NO_3-N runoff is used as an indicator of environmental benefits each agricultural parcel provides.

The estimated opportunity costs and environmental benefits are then used for policy simulation. We simulate: (1) NO_3-N reduction; (2) acreage participated; and (3) budget required, under the three different targeting strategies (cost, benefit, and cost-benefit ratio) in the CRP.

This integrated system allows region-scale policy simulations while incorporating parcel-specific information. Below, we describe in detail both the economic and physical components of the system.

Economic Model: Estimating the Opportunity Cost

The economic model is developed to predict farmers' decisions as to whether or not to participate in the CRP at each agricultural parcel in the Des Moines Watershed. Farmer *i* participates in the CRP if and only if rental payment is greater than or equal to than the farmer's opportunity cost, i.e., $R \geq \mathrm{OC}_i$, where *R* is the rental rate offered by the CRP. Thus, the probability that farmer *i* participates in the CRP equals $\Pr\left(OC_i \leq R\right)$. In the empirical analysis, farmers' participation decisions are modeled using a logit model. Thus, the cumulative density function of the opportunity cost is specified as

$$\begin{aligned} F_i\left(R\right) &= \Pr\left(OC_i \leq R\right) \\ &= \frac{\exp\left(X_i'\beta + R\gamma\right)}{1+\exp\left(X_i'\beta + R\gamma\right)} \end{aligned} \tag{1}$$

where X_i' s are the economic and physical variables affecting farmer *i's* CRP participation decision, and β and γ are parameters to be estimated. Differentiating equation (1) with respect to the rental rate, we have the probability density function of the opportunity cost:

$$f_i\left(R\right) = \frac{\exp\left(X_i'\beta + R\gamma\right)}{\left[1+\exp\left(X_i'\beta + R\gamma\right)\right]^2} \cdot \gamma \tag{2}$$

By taking integration over R, we have the formula of the expected value of the opportunity cost:

$$
\begin{aligned}
E[OC] &= \int_0^\infty R \frac{\exp(X_i'\beta + R\gamma)}{\left[1+\exp(X_i'\beta + R\gamma)\right]^2} \cdot \gamma dR \\
&= \left. \frac{-R}{1+\exp(X_i'\beta + R\gamma)} \right|_0^\infty + \int_0^\infty \frac{1}{1+\exp(X_i'\beta + R\gamma)} dR \qquad (3) \\
&= \frac{1}{\gamma} \log\left(1+\frac{1}{\exp(X_i'\beta)}\right)
\end{aligned}
$$

The economic model in this study uses equation (3) to estimate the expected opportunity cost of participating in the CRP.

The economic model requires extensive amount of information, which needs to be collected and integrated from various sources. The primary data for the economic model is the Natural Resource Inventories (NRI). The NRI, conducted by the Natural Resource Conservation Service (NRCS), is a scientifically based, longitudinal panel survey of the Nation's soil, water, and related resources, designed to assess conditions and trends every five years (NRCS 2000). The NRI contains information on nearly 800,000 samples across the continental United States. At each parcel, information on nearly 200 attributes, including cropping history, soil properties, and agricultural land management practices, are collected. The NRIs also contain an expansion factor, which indicates the acreage each parcel represents. Thus, the total acreage in the basin can be calculated by summing up the expansion factors for all parcels in the basin. In the Des Moines Watershed, there are a total of 8,838 parcels in agricultural land and, among these parcels, 4,911 parcels are used for agriculture and Conservation Reserve Program (CRP) in 1997. Using the 1982, 1987, 1992, and 1997 NRIs and other parcel-specific information about production practices and physical characteristics, the economic models are estimated to predict agricultural land use before and after a policy change in the Des Moines Watershed.

The parameter values of β and γ are taken from Tanaka and Wu (2004), who estimated a logit model to examine farmers' CRP participation decisions under various payment levels in the Upper Mississippi River Basin, which include the Des Moines river basin as a subbasin.

SWAT Model: Simulating the NO_3-N runoff

This study uses Soil and Water Assessment Tool (SWAT) to estimate the reduction in NO_3-N runoff from a parcel when it is retired from agricultural production and use it as a measure of environmental benefit[3]. SWAT is developed by the USDA Agricultural Research Service (ARS) to simulate water balance in a large scale watershed for a long period of time (up to 100 years). SWAT can predict the impact of crop practices on water, sediment, and agricultural chemical movements in large, complex watersheds with varying soils, land use, and management conditions over a long period of time (Neitsch *et al*. 2002). Because SWAT is a physically based, no regression equation is necessary to predict the relationship between input and output variables. Instead, SWAT requires detailed information about topography, soil properties, land management scenarios, and weather in the watershed.

SWAT uses topographic information to determine watershed and subbasin (subwatershed) boundaries and to digitize the streams (line representation of accumulated perennial water flow over the soil surface) in the watershed. This study uses 1-degree Digital Elevation Model (DEM) data provided by the USGS[4]. To enhance the accuracy of this process, the National Hydrography Dataset (NHD), digitized stream network developed by the USGS and EPA, is used as a complement to the DEM. As a result, a total of 9 subbasins are delineated by the hydrologic component of SWAT.

SWAT requires a geographical representation of soil distribution, which is used to define the soil's chemical and physical properties to simulate the watershed. The soil coverage is prepared from the State Soil Geographic (STATSGO) digital soil association map, developed by the NRCS. SWAT GIS interface (called AVSWAT) automatically chooses the most dominant soil class from STATSGO map and extract necessary information from a relational database. Extracted information includes texture, bulk density, saturated conductivity, available water capacity, organic carbon, and others.

Primary land use information is derived from the National Land Cover Dataset (NLCD) provided by the USGS. The NLCD is a 30-meter resolution raster land cover for the entire United States. The NLCD presents detailed land use for agriculture (row-crop and hay), forest, wetland, water, urban, and other land uses (figure 1). Land planted to row crops (corn and soybean) is further classified by four major cropping systems (corn-soybean rotation and continuous corn under conventional and conservation tillage) in the watershed. This classification is derived from the baseline estimates of the economic model.

The land management schedules describe management practices for each land use in the watershed (e.g. timing and amount of fertilizer application). The scenario for each land use can be either different across subbasins or identical in the entire watershed. In this study, we use the same management scenario for each land use[5]. Although many types of tillage operations are defined as conservation tillage, this study uses no-till as a representative[6]. Non-agricultural land uses follow SWAT default land management scenarios.

The weather variables required for SWAT simulations are the daily values of maximum and minimum air temperature, precipitation, solar radiation, wind speed, and relative humidity. We obtained historical observations of the daily temperatures and precipitation from Iowa Environmental Mesonet. AVSWAT gathers weather data reported from 60 weather stations in and around the Des Moines Watershed and chooses the variables reported from the nearest station for each subbasin. The daily values of solar radiation, wind speed, and relative humidity are simulated using SWAT built-in random weather generator.

Empirical Results

The Opportunity Cost of Participating in the Conservation Easements

Using equation (3), we estimate the expected opportunity cost of participating in the CRP at each of 49,11 agricultural parcels in the Des Moines Watershed. The estimated values range from less than $1 to nearly $400, with the average of $217. Table 1 provides the averages across land uses and subbasins. As table indicates, there is significant variation in the expected opportunity cost among subbasins. Relatively high opportunity costs are predicted in middle and upper watershed. Subbasins in these areas includes subbasin 7 ($265/acre), 1 ($250/acre), 9 ($249/acre), and 6 ($244/acre). These subbasins locate in the middle of the watershed. In contrast, relatively low opportunity costs are predicted in subbasins in lower watershed, including subbasin 2 ($141/acre) and 3 ($179/acre).

Table 1 also shows significant variation in the opportunity cost among land uses. The estimated values are generally high for row cropping systems: those include corn-soybean rotation and continuous corn production. The highest value is predicted for corn-soybean rotation with conservation tillage ($267/acre). Lands used fro other row cropping systems are also predicted to have high opportunity costs. In contrast, the opportunity costs are much lower for land used for hay and pasture ($91/acre). Finally, the model predicts that land currently participating in the CRP have the lowest opportunity cost ($24/acre).

NO_3-N Runoff from Agricultural Land

Table 2 shows the average annual NO_3-N runoff from different land use. The level of runoff from land planted to row crops is generally high. Particularly high levels of runoff are predicted from land adopting conventional tillage, estimated to be 4.0 lb. per acre and 2.4 lb. per acre from continuous corn and corn-soybean rotation, respectively. NO_3-N runoff from the land adopting conservation tillage are generally lower, 1.9 lb. per acre and 0.9 lb. per acre from continuous corn and corn-soybean rotation, respectively. The model estimates that NO_3-N runoff from continuous corn is about 120 percent higher than corn-soybean rotation. This difference may be due to fertilizer management. Continuous corn production requires the application of nitrogen fertilizer every year, nitrogen fertilizer is usually applied every other year under corn-soybean rotation (i.e. fertilizer is applied only when corn is planted). NO_3-N runoff from hay and other crops is the lowest among alternative cropping systems. This is expected because hay and other crops do not require nitrogen application. Thus, the only source of NO_3-N runoff is nitrogen fixation. Overall, NO_3-N runoff from row crops is estimated to be 30 times higher than hay and other crop, which is consistent with the prior literature. NO_3-N runoff from row crops is generally 30 to 50 times higher than from the perennial crops (Randall 1997).

Table 2 also shows a considerable difference in NO_3-N runoff among 9 subbasins in the Des Moines Watershed. The predicted runoff ranges from 0.8 Lb per acre to 2.6 Lb per acre. The highest runoff is predicted in subbasin 1. As figure 1 indicates, row crops are intensively planted in this subbasin. In addition, annual precipitation in subbasin 1 is higher than any other subbasins in the watershed. In contrast, the lowest NO_3-N runoff is predicted in the subbasin 2, in which row crop production is less intensive. Furthermore, annual precipitation in this subbasin is lower than watershed average. Overall, high levels of NO_3-N runoff are predicted in the middle of the watershed, and low levels of runoff are estimated in the upper and lower areas of the watershed. This spatial variation can be mainly explained by cropping patterns and precipitation.

Policy Simulation

Using the economic and SWAT models, we identify the cost (expected opportunity cost) and benefit (NO_3-N runoff potential) at each of 49,11 agricultural parcels in the Des Moines Watershed. This parcel-level information is compiled for evaluating economic and environmental impacts under the three targeting strategies. The cost targeting purchases the parcels with the lowest expected opportunity costs. The benefit targeting takes the parcels with the highest NO_3-N runoff potential out of production. Under the benefit-cost ratio targeting, the parcels will be taken from highest expected ratio of NO_3-N runoff and opportunity cost. The expected benefit-cost ratio in parcel *i*, $E\left(BC_i\right)$ is calculated by: $E\left(BC_i\right) = B_i / E\left(OC_i\right)$, where B_i is the level of NO_3-N in parcel *i* under the current land use. $E\left(OC_i\right)$ is the expected opportunity cost estimated by equation 3. The estimated values are summarized in table 3.

Figure 3 illustrates the levels of estimated NO_3-N reduction (%) under different budget levels of the CRP. Figure 3 shows that the benefit-cost targeting achieves the highest nitrate-N runoff reduction for a given budget. In contrast, the cost targeting results in the lowest level of NO_3-N reduction. The difference is particularly significant when the budget is relatively small. When the budget is less than 50 million dollars, the cost targeting uses most budget to purchase low-polluting lands: those for hay and pasture. Environmental benefit from those lands is much lower than from row cropping systems (table 2). As a result, the cost targeting can reduce only a limited amount of NO_3-N runoff from the watershed.

Figure 4 depicts the acreage enrolled in the CRP under different budget levels of the CRP.

The cost targeting takes the largest amount of agricultural parcels out of production. However, as already mentioned, its environmental impact is quite limited. Although the benefit and benefit-cost targeting purchases smaller amount of agricultural parcels, their environmental contribution is much higher than the cost targeting strategy.

Overall, our results are consistent with results from Wu, Zilberman, and Babcock (2001). The main contribution of this study is to provide quantitative estimates of the magnitudes of the tradeoffs between environmental benefits and other performance measures (i.e., acres of land retired) when alternative targeting criteria are used. Our results show that the difference in environmental outcomes can be quite large, especially when the conservation budget is relatively small (less than 50 million dollars). Thus, the choice of targeting strategies is relatively more important as the program faces a limited budget. Finally, it should be noted that the benefit and benefit-cost targeting strategies tend to result in similar environmental outcomes. This is expected because environmental benefits and opportunity costs of land retirement tend to be negatively correlated across parcels.

Summary and Conclusions

This study provides an empirical application of Wu, Zilberman, and Babcock (2001). Specifically, we compare the environmental and economic effects of alternative targeting strategies (benefit, cost, and benefit-cost ratio targeting) for reducing nitrate-N water pollution. We apply the three targeting strategies to the Conservation Reserve Program (CRP) in the Des Moines Watershed in Iowa. This watershed has been under increasing scrutiny as a significant source of nitrate-N loads to the Gulf of Mexico, causing one of the largest hypoxic zones in the world.

The objective is achieved by applying an integrated modeling system to nitrate-N runoff from the Des Moines Watershed. Our integrated modeling system consists of an econometric model and a physically-based hydrologic balance simulation model. The econometric model estimates farmers' decisions of CRP participation. From the estimated results, the opportunity cost of CRP enrollment (defined in terms of output forgone) is calculated at each parcel. The Soil and Water Assessment Tool (SWAT) is then used to simulate the level of nitrate-N runoff at each NRI parcel in the watershed. Thus, the integrated modeling system provides all information necessary for this study: the cost and benefit of land retirement at each parcel.

Our results show that the benefit-cost targeting achieves the highest nitrate-N runoff reduction. The cost targeting results in the largest amount of land out of production. However, this strategy also results in the smallest environmental benefits. The benefit targeting takes the smallest amount of resource out of production. Those differences among alternative targeting strategies tend to be larger when budget of land purchasing fund is smaller. Finally, benefit targeting and benefit-cost ratio targeting strategies tend to result in similar environmental and economic outcomes in the watershed. Differences in nitrate-N runoff and acreage purchased between these two strategies are shown to be quite small.

This study can be extended in several ways. First, this study uses the NRI as a primary data source. Although the NRI is spatially referenced data, the exact geographical location of each parcel is unavailable due to confidentiality constraints. The accuracy of the simulation results (especially prediction of NO_3-N runoff) may be improved if such spatial information is available. The other issue concerns the output price effects of conservation easements. If the prices of agricultural outputs are not fixed, large-scale easement programs, such as CRP, may cause two types of "slippage": those include (1) activation of previously idle land and (2) increase in the value of production due to increase in the output prices. Ignoring such slippage effects may have severe consequences (Wu 2000; Wu, Zilberman, and Babcock 2001). The assumption of fixed output prices may be reasonable if study region is relatively small. However, if the methodology is applied to a large basin (e.g. entire Upper MRB), the price effects must be considered

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Notes

[1] The CRP, administrated by the Farm Service Agency (FSA), is a voluntary land retirement program for agricultural landowners. The CRP was originally enacted in 1985, and remains the largest agricultural land retirement program in the U.S. Through CRP, agricultural landowners receive annual rental payments and cost-share assistance to establish resource-conserving cover on eligible cropland (Farm Service Agency 2003).

[2] Any tillage operation is referred to as conservation tillage if at least 30 percent of crop residue is left after harvesting (e.g. no-till). Conventional tillage refers to any tillage operation leaving less than 15 percent of crop residue after harvesting (e-g. chisel-plowing).

[3] The official website of SWAT model: http://www.brc.tamus.edu/swat/

[4] The 1-degree DEM is also called as 30-meter DEM. Each cell of this 30 by 30 meter grid is given a single elevation value.

[5] Detailed description of each agricultural land use management scenario is available upon request.

[6] No-till is a method of farming where the soil is left undisturbed from the harvest of one crop to the beginning of next growing season. Soil disturbance therefore occurs only when fertilizer is applied before growing season and crop is harvested.

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Table 1. The estimated opportunity cost of participating in the CRP in the Des Moines Watershed ($/acre)*

Land Use	Subbasin 1	2	3	4	5	6	7	8	9	Subbasin average
Corn-soybean/CT	256	247	243	246	266	252	282	214	253	250
Corn-soybean/NT	275	266	271	-	257	260	266	265	270	267
Continuous corn/CT	241	225	232	233	226	230	237	186	-	231
Continuous corn/NT	247	236	236	-	228	236	251	243	246	240
Hay and pasture	100	83	90	93	61	96	174	113	94	91
CRP	32	24	18	19	33	43	15	25	38	24
Land use average	250	141	179	219	234	244	265	218	249	217

* CT and NT are referred to as conventional tillage and no-till, respectively

Table 2. The estimated NO_3-N runoff in the Des Moines Watershed (lb./acre)*

Land Use	Subbasin 1	2	3	4	5	6	7	8	9	Subbasin average
Corn-soybean/CT	3.5	1.1	2.1	3.1	2.6	2.0	2.7	2.3	2.1	2.4
Corn-soybean/NT	1.3	0.5	0.8	1.0	0.8	1.1	1.0	0.9	1.0	0.9
Continuous corn/CT	5.2	1.5	3.8	5.9	4.1	3.8	3.7	3.9	3.6	4.0
Continuous corn/NT	2.8	0.8	2.1	2.6	1.4	2.4	1.7	1.6	2.0	1.9
Hay and pasture	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1
CRP	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1
Land use average	2.6	0.8	1.8	2.5	1.8	1.9	1.8	1.8	1.8	1.9

* CT and NT are referred to as conventional tillage and no-till, respectively

Table 3. The estimated benefit-cost ratio in the Des Moines Watershed*

Land Use	Subbasin 1	2	3	4	5	6	7	8	9	Subbasin average
Corn-soybean/CT	0.009	0.004	0.007	0.011	0.008	0.007	0.007	0.005	0.006	0.009
Corn-soybean/NT	0.008	0.003	0.040	-	0.006	0.006	0.006	0.006	0.005	0.010
Continuous corn/CT	0.013	0.003	0.010	0.013	0.009	0.009	0.009	0.008	-	0.010
Continuous corn/NT	0.013	0.003	0.010	-	0.009	0.009	0.008	0.006	0.008	0.008
Hay and pasture	0.002	0.005	0.005	0.003	0.001	0.002	0.002	0.004	0.001	0.004
CRP	0.003	0.007	0.014	0.006	0.002	0.002	0.006	0.010	0.003	0.008
Land use average	0.008	0.004	0.017	0.009	0.006	0.006	0.006	0.005	0.005	0.008

* CT and NT are referred to as conventional tillage and no-till, respectively

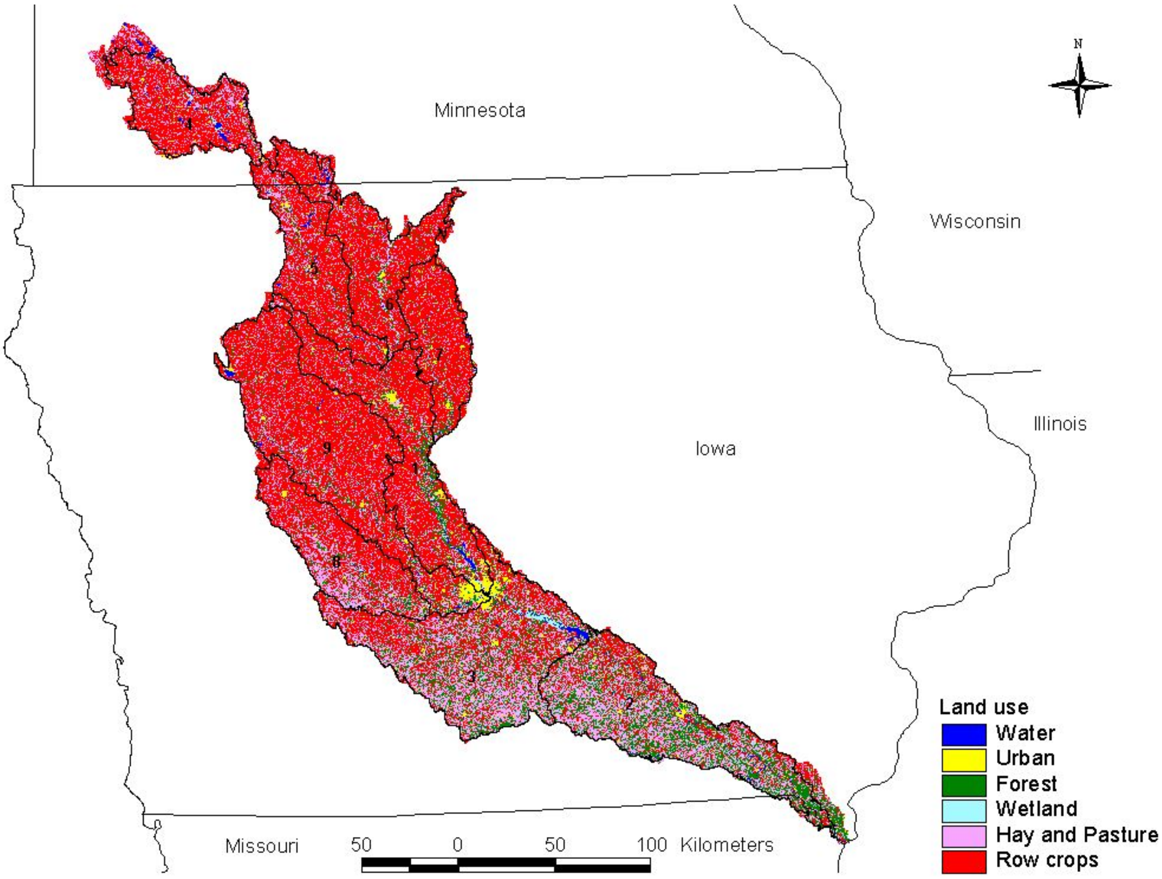

Figure 1. Major land use in the Des Moines Watershed

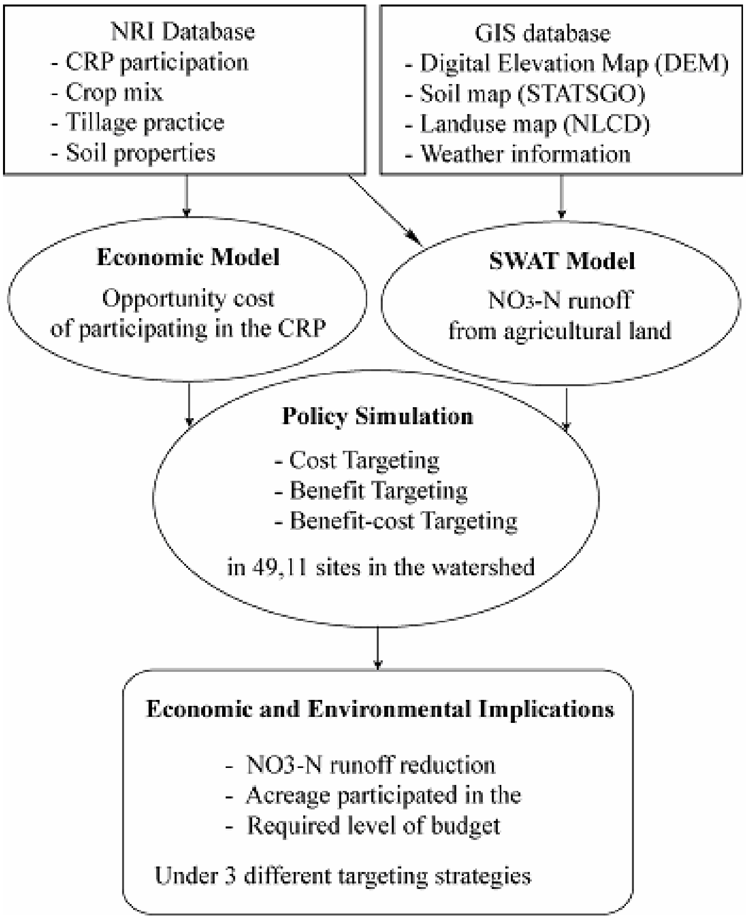

Figure 2. Integrated Modeling System

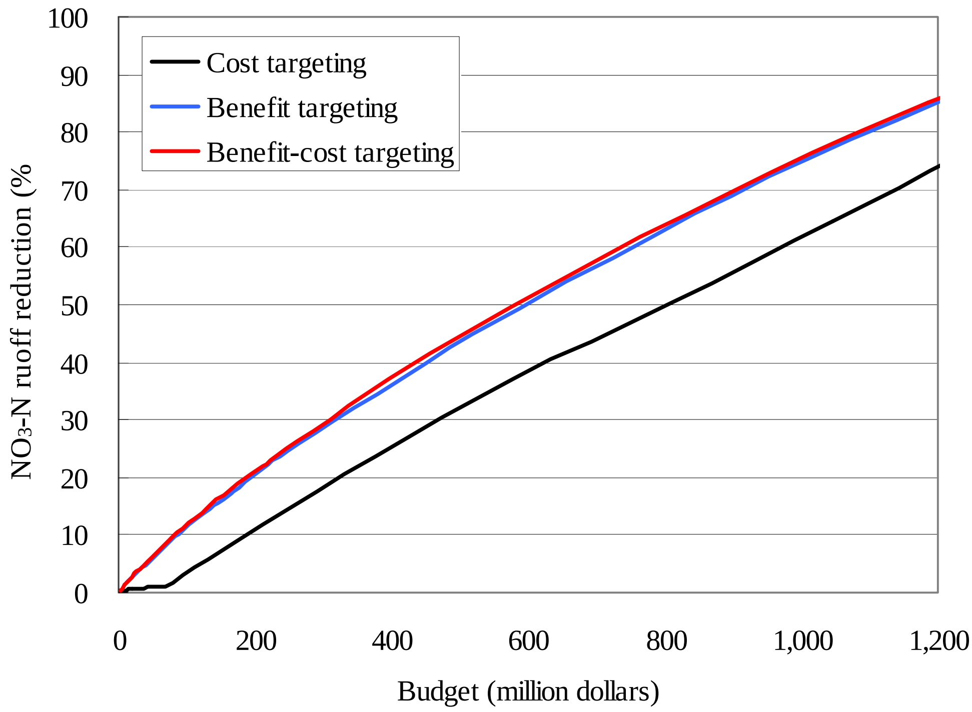

Figure 3. The estimated NO_3-N reduction (%) under different budge levels

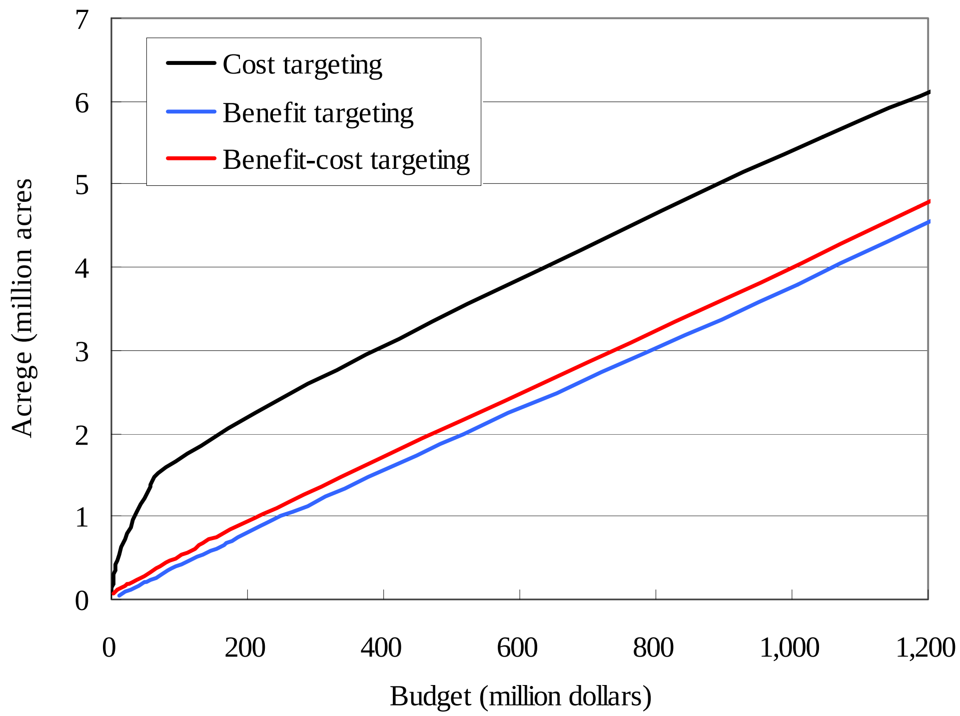

Figure 4. The estimated acreage participated in the CRP under different budge levels

Appendix: SWAT Model Validation

Using the land use information under the baseline scenario, the SWAT model is run for the period of 1988-1999. Simulated monthly average streamflow is compared to measured values reported from the USGS stream gage station on the Des Moines River in Ottumwa, Iowa (figure a). Overall performance of the SWAT prediction is quite reasonable ($R^2 = 0.88$). Although the model overpredict during post- and pre-harvesting seasons, the difference between the simulated and measured annual average streamflow is less than 4 percent. The model's prediction is particularly well for the period of 1999 ($R^2 = 0.95$). Thus, we use the values predicted for this period to estimate NO_3-N runoff from the watershed.

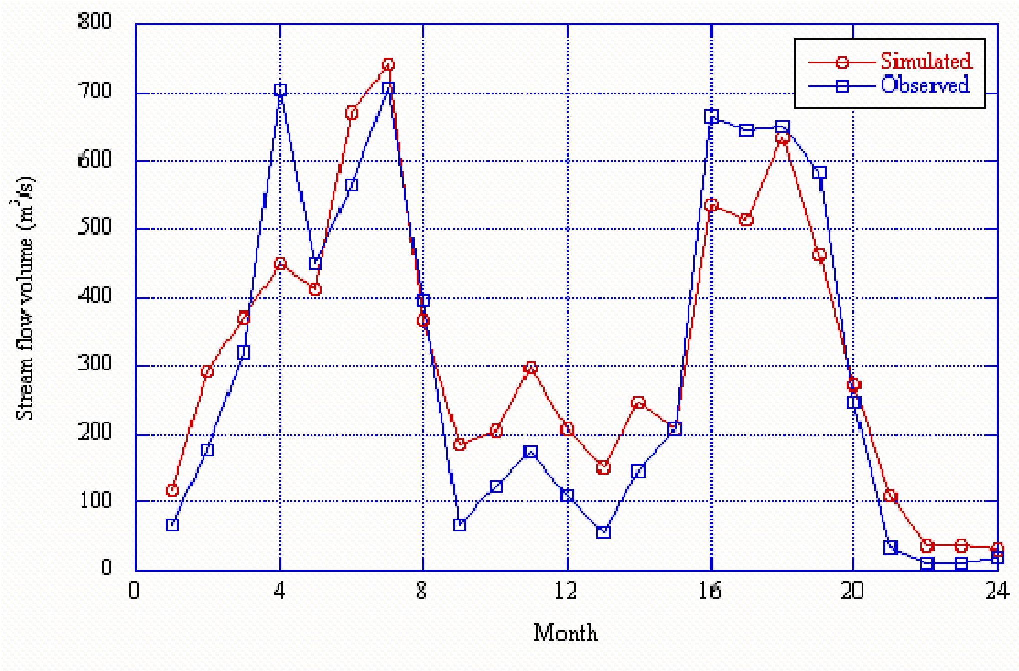

Figure a. Simulated and Observed Streamflow in the Des Moines River at Ottumwa, Iowa 1