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Adoption Subsidies and Environmental Impacts of Alternative Energy Crops

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Executive Summary

We provide estimates of the costs associated with inducing substantial conversion of land from production of traditional crops to switchgrass. Higher traditional crop prices due to increased demand for corn from the ethanol industry has increased the relative advantage that row crops have over switchgrass. Results indicate that farmers will convert to switchgrass production only with significant conversion subsidies. To examine potential environmental consequences of conversion, we investigate three stylized landscape usage scenarios, one with an entire conversion of a watershed to switchgrass production, a second with the entire watershed planted to continuous corn under a 50% removal rate of the biomass, and a third scenario that places switchgrass on the most erodible land in the watershed and places continuous corn on the least erodible. For each of these illustrative scenarios, the watershed-scale Soil and Water Assessment Tool (SWAT) hydrological model (Arnold et al., 1998; Arnold and Forher, 2005) is used to evaluate the effect of these landscape uses on sediment and nutrient loadings in the Maquoketa Watershed in eastern Iowa.

Keywords: adoption subsidy, cellulosic ethanol, energy crops, land use, SWAT, switchgrass, water quality.

ADOPTION SUBSIDIES AND ENVIRONMENTAL IMPACTS OF ALTERNATIVE ENERGY CROPS

It has been suggested that biomass energy crops such as switchgrass and agricultural crop residues could be used for the increased production of bioenergy in the Midwest while still preserving, or even improving, environmental quality in the region. Numerous studies at the field scale provide indications concerning the yield and energy potential associated with growing switchgrass and/or harvesting stover at the field scale, but there is a dearth of information concerning the landscape effects, particularly in terms of water quality, that might be associated with large-scale changes in cropping systems. Such changes might take very different forms (that is, toward more intensive cropping of continuous corn with large-scale residue removal or toward significant planting of perennial crops such as switchgrass), depending on economic conditions and the design of farm program payments.

The purpose of this briefing paper is to provide a starting point for discussion of these issues at the landscape level. To do so, we provide estimates of the costs associated with inducing substantial conversion of crop land to switchgrass production. To examine potential environmental consequences, we investigate three stylized landscape usage scenarios, one with an entire conversion of a watershed to switchgrass production, a second with the entire watershed planted to continuous corn under a 50% removal rate of the biomass, and a third scenario that places switchgrass on the most erodible land in the watershed and places continuous corn on the least erodible. For each of these illustrative scenarios, the watershed-scale Soil and Water Assessment Tool (SWAT) hydrological model (Arnold et al., 1998; Arnold and Forher, 2005) is used to evaluate the effect of these landscape uses on sediment and nutrient loadings in the Maquoketa Watershed in eastern Iowa.

It is important to recognize that the model and results presented here are exploratory in nature. A great deal is unknown about how large-scale switchgrass production would occur, how technology would evolve over time, how markets would develop and react to these changes, as well as a host of other variables. Additionally, the models employed here have not been extensively tested for the alternative energy crops we consider. Thus, the results should be viewed not as a final answer but as one of many first steps in identifying both the benefits and social costs that a large-scale move to the bioeconomy may bring.

Calculation of Required Returns to Switchgrass

Midwestern farmers will move acreage toward production of switchgrass only when the returns from growing switchgrass can compete with the returns from growing prevailing crops,—corn and soybeans. Currently, the returns over variable costs of production from growing corn and soybeans in either a corn-soybean rotation or a continuous corn rotation are projected to be approximately $250 per acre during the period covered by the next farm bill. This suggests that the returns over variable costs and annualized establishment costs to switchgrass production will need to approach this level before farmers will consider changing to switchgrass.

Duffy and Nanhou (2001) provide estimates of the annual cost of producing switchgrass and the annualized cost of establishing a stand of switchgrass. With a yield of four tons per acre, the cost is approximately $187/acre. A yield of six tons per acre raises the cost to $241 because of increased harvest cost. These costs include the cost of baling the switchgrass into large bales but do not include transporting the bales to an ethanol plant. While there is speculation that switchgrass yields could increase substantially above these levels, it is not likely that significantly increased yields will be common during the next 5 to 10 years without major research breakthroughs.

Adding these cost estimates to the projected returns from corn and soybeans gives the amount of revenue per acre that will be required to induce farmers to switch a significant number of acres to switchgrass. The break-even revenue level for switchgrass with a yield of four tons, a variable cost of $187, and a required return over costs of $250 is $437 or almost $110 per ton. The break-even revenue rises to $491 per acre with a yield of 6 tons per acre because of the higher production costs. The higher yield reduces the per-ton break-even price to about $82 per ton.

Without subsidy, a producer of cellulosic ethanol must be willing to pay a farmer at least this amount at the farmgate to induce a corn and soybean farmer to switch acres. The ability of the ethanol producer to pay for biomass depends on a number of factors including (1) the cost of transporting the harvested production from the farm to the plant, (2) the variable cost of converting the biomass to ethanol, and (3) the price of ethanol.

Transportation costs will depend on a number of factors, including distance traveled, fuel prices, and labor prices. A reasonable estimate for the total cost of delivering bales to a processing facility is $8.00 per ton.

Because there are no commercial-scale cellulosic ethanol plants in operation, it is quite difficult to determine what will be the variable cost of converting switchgrass to ethanol. English et al. (2006) assume that conversion costs decrease from $1.40 per gallon in 2006 to $0.73 per gallon in 2015. The average conversion cost for the farm bill period of 2008 to 2012 is $1.10 per gallon.

What ethanol prices will be in the future cannot be known. Ethanol futures are trading at about $1.75 per gallon, but the contracts extend out only one year. Most observers believe that ethanol prices could drop precipitously as total ethanol production approaches 13 to 14 billion gallons per year because this level of production will saturate the 10 percent blend market. To show the effects of lower prices, we calculate ability of pay for switchgrass at a price of $1.25 per gallon and a price of $1.75 per gallon.

The first step in this calculation is to convert everything to a per-ton basis. Using an ethanol yield of 70 gallons per ton of switchgrass yields a cost of $77 per ton of converting switchgrass to ethanol. Adding in the $8.00 transportation cost gives a total cost of $85 per ton. Revenue per ton of switchgrass is found by multiplying the price of ethanol by the ethanol yield per ton, which is $87.5 per ton at an ethanol price of $1.25 per gallon and $122.5 per ton at an ethanol price of $1.75 per gallon.

The maximum amount a processor will pay per ton of switchgrass equals the difference between revenue and cost. At the $1.25 per gallon price, this amount is $2.50 per ton. At the $1.75 per gallon, this amount is $37.50 per ton. Because both of these maximum prices are less than the per-ton break-even farmgate prices, no market for switchgrass will emerge without some sort of public support. The minimum amount of per-ton support needed equals the difference between the farmgate break-even price and the maximum willingness to pay of the ethanol producer. Table 1 reports these amounts. The required price subsidies range from $44.33 per ton to $106.75 per ton depending on switchgrass yields and the price of ethanol. Converting these per-ton subsidies into per-acre payments can be done simply by multiplying these per-ton subsidies by the yield per acre. The resulting per-acre payments range from a low of $265.98 per acre to $475.98 per acre.

Given the assumptions behind this analysis, the conclusion that can be drawn here is that the level of required payments will be quite high unless the price of ethanol unexpectedly increases or the cost of converting cellulose to ethanol drops significantly. Of course, on land where the returns to corn and soybeans are less than $250 per acre, then the required payments will also decrease. But high corn and soybean prices have dramatically increased returns to these crops, so much of the Iowa farmland is expected to have returns of these magnitudes over the farm bill period.

The most straightforward policy mechanism available to make these payments would be to have farmers enroll their land into some sort of biomass reserve program whereby in exchange for per-acre payments farmers will dedicate their land to biomass production. If the economic returns from converting cellulose to ethanol do not improve significantly above the levels previously identified, then farmers would not be required to actually harvest and sell their biomass crop to an ethanol producer. This would allow farmers and scientists to fine-tune biomass crop production techniques on a commercial scale without artificially forcing farmers to incur harvest costs and without having the ethanol producer actually have to transport the harvested biomass to a plant and convert it into ethanol unless the economic returns dictate that it makes sense. In this way, the maximum

TABLE 1. Price subsidies needed to make switchgrass competitive with corn and soybeans

	Price of Ethanol ($/gal)	
Switchgrass Yield(tons per acre)	1.25	1.75
	Subsidies Needed $/ton	
4	106.75	71.75
6	79.33	44.33

payment that would be required would equal the opportunity cost of land, which is $250 per acre.

In addition, it would make sense to have an additional alternative payment scheme for farmers willing to participate in field-scale trials of biomass crops and biomass systems (for example, intercropping, new crops, innovative collection and transportation approaches) other than straight switchgrass in order to learn more about other alternatives for energy production.

In short, a two-pronged policy approach might be implemented, one prong focused on getting a large amount of biomass crops in production to provide adequate feedstock in the future in anticipation of the development of technology that makes large-scale production economically viable (this would be the biomass reserve component) and the second prong focused on developing innovative alternatives that might eventually solve the current technological problems (a biomass innovation program).

As noted earlier, the biomass reserve program could be quite similar to the current Conservation Reserve Program (CRP), with one important difference. While farmers could offer to plant their land to biomass crops in exchange for per acre payments (ideally through an efficient bidding mechanism), they would retain the option of selling the biomass. This latter feature differs from the current CRP but would have the important benefit of providing an incentive to both farmers and processors to identify ways to solve the transport and conversion issues currently preventing economic viability of switchgrass production. The biomass innovation program might be modeled after the Conservation Innovation Grants program or possibly woven into a revised Conservation Securities Program.

Water Quality Effects

Background on the Water Quality Model

SWAT is a long-term, continuous, watershed-based model and operates on a daily time step. It was developed to predict the impact of land management practices on the hydrology and water quality responses for a watershed. In the SWAT modeling approach, a watershed is first divided into multiple subwatersheds and then the subwatersheds are further subdivided into smaller lumped units called hydrologic response units (HRUs).

HRUs are unique combinations of land use, soil, and management practices. Water balance and nutrient dynamics are computed at the HRU level and the resulting loadings are summed at the subwatershed level. Total loadings at the subwatershed level are then routed through streams and reservoirs to the watershed outlet. This model has been extensively used worldwide and has proven to be a very successful and useful tool in simulating hydrology and water quality response at the watershed level, as evidenced by over 200 peer-reviewed publications reported in the literature (Gassman et al., 2007).

In this study, SWAT was applied to the Maquoketa River Watershed in Northeast Iowa (see Figure 1), which drains an area of approximately 4,800 km^2 before entering the Mississippi River. The Maquoketa River is recognized as one of the major contributors of sediment and nutrients to the Mississippi stream system. Land use in the watershed is primarily agricultural, about 55% cropland (mostly corn and soybeans), 32% grassland (primarily pasture), 10% forest, and 3% urban area based on a periodic survey conducted by the U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS) in its National Resources Inventory (NRI) (Nusser and Goebel, 1997). Extensive use of chemical fertilizers on cropland is the major source of nutrient loadings from this watershed.

FIGURE 1. Location of Maquoketa River Watershed and watershed delineation for SWAT model application

The SWAT model is physically based and comprised of many parameters whose values are calibrated using measured data at the watershed outlet. Continuous flow and water quality measurement data are maintained by several government agencies, such as U.S. Geological Survey and Iowa Geological Survey Bureau. Model calibration results were evaluated using statistical measures to validate the model's ability to replicate watershed response. Figures 2 through 7 (at the end of the paper) present SWAT model calibration results for the Maquoketa River Watershed. The calibration results are strong, yielding very high correlations between model predictions for flow, sediment, and nitrates both in-sample and out-of-sample.

The Land Use Scenarios and Water Quality Projections

The calibrated SWAT model was used to conduct a sensitivity analysis to identify the water quality impacts of changing landscapes to crops that can be harvested for alternative energy purposes (for example, bioethanol production). Table 2 lists all scenarios with corresponding results for comparison to the baseline. The baseline of comparison represents the conditions in the watershed, which are based on the current cropping mix and land use in the Maquoketa. A summary of each scenario, management assumptions used in the analysis, and results follows.

Scenario 1. In Scenario 1, we convert all croplands, including lands that are already taken out of production in the existing baseline, to plant perennial warm-season grasses, such as switchgrass.

A key assumption in simulating this land use pattern was that no tillage of the soil was undertaken and spring fertilizer applications of 110 lb/ac of nitrogen fertilizer and 60

TABLE 2. Average annual values at the watershed outlet over a period of 20 years (1986-2005)

Description	Streamflow (mm)	Sediment Yield (Tons)	Nitrate (Tons)	Total N (Tons)	Total P (Tons)
Baseline	250	146,652	8,380	10,030	360
All switchgrass	255	22,780	4,673	4,697	65
Continuous corn, remove 50% biomass	257	180,054	20,738	25,067	857
Switchgrass or continous corn, remove 50% biomass	254	119,135	12,382	13,201	206

lb/ac of phosphorus fertilizer were applied. This land use scenario is predicted by the model to reduce sediment at the outlet of the watershed substantially, by 84%. Large reductions in nitrate (44%), total nitrogen (53%) and phosphorous (83%) were also predicted.

Scenario 2. In Scenario 2, we convert all cropland, including lands that are already taken out of production in the existing baseline, to continuous corn with the assumption of removing 50% biomass each year.

The management operation under this scenario assumes mulch-tillage operation and regular fertilizer application, including spring application (nitrogen - 60 lb/ac and phosphorus - 45 lb/ac) and fall application (nitrogen – 120 lb/ac and phosphorus - 90 lb/ac). This scenario increased sediment yield by 23% relative to the baseline, nitrate by 147%, total N by 150% and total P by 138% on an average annual basis. This is due primarily to the different tillage operation assumed and the higher fertilizer application compared to the baseline (57,441 vs. 35,972 tons of N fertilizer and 7,440 vs. 4,660 tons of P fertilizer).

Scenario 3. In Scenario 3, we convert all cropland, including lands that are already taken out of production in the existing baseline, to a combination of switchgrass and continuous corn (with 50% biomass removal) based on the designation of highly erodible land (HEL). Cropland is considered to meet the HEL designation if the Erosion Index (EI), as reported in the USDA NRI database, exceeds a value of 8 (USDA-NRCS, 2003).

For this scenario, continuous corn is placed on land that has an EI of less than 8 (land that is not considered highly erodible) and switchgrass is selected if HEL is equal to or greater than 8. This criterion allocates 53% to switchgrass and 47% to continuous corn of the total available land. Both land use types were assumed to have the same management assumptions as those described in scenarios 1 and 2. As expected, this scenario gives mixed results, with a reduction in sediment yield of 19% and a reduction in total P of 43% compared to the baseline. However, nitrate and total N in Scenario 3 increase by 48% and 32%, respectively.

Discussion

Conversion of land from annual row crop production to perennial switchgrass production could significantly reduce off-farm environmental impacts while simultaneously increasing the net greenhouse gas reduction from biofuels consumption. However, farmers will not begin to convert their land unless the financial returns from switchgrass production equal the returns from traditional crop production. Conditions that would increase the ability of cellulosic ethanol producers to pay for switchgrass include lower cellulose-to-ethanol conversion costs or higher ethanol prices. However, only lower conversion costs would reduce the relative disadvantage of switchgrass because higher ethanol prices would results in higher corn prices.

Conditions that would lower the cost of producing switchgrass include new and better machinery for planting and harvesting and improved switchgrass varieties. But machinery manufacturers and seed companies would have to divert research funds from high-return projects that focus on traditional crops to new projects with a much less certain return. Thus, it seems certain that few farmers will choose to change to switchgrass without new subsidies. These subsidies would have to be directly targeted at biomass production rather than ethanol production or biofuels production because new ethanol production subsidies would simply increase the demand for corn, not switchgrass, despite the potentially significant environmental advantages of expanded switchgrass production.

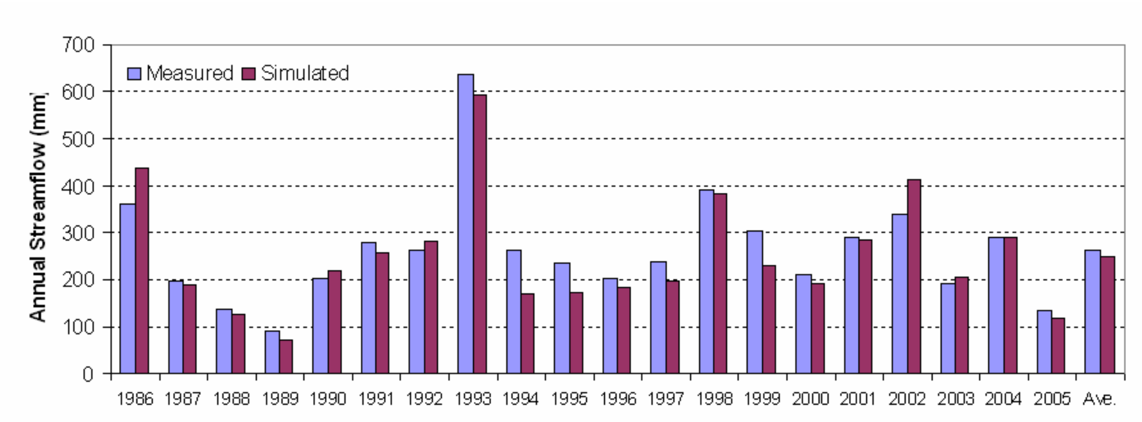

FIGURE 2. Annual streamflow comparison of SWAT simulated values and measured values at the watershed outlet

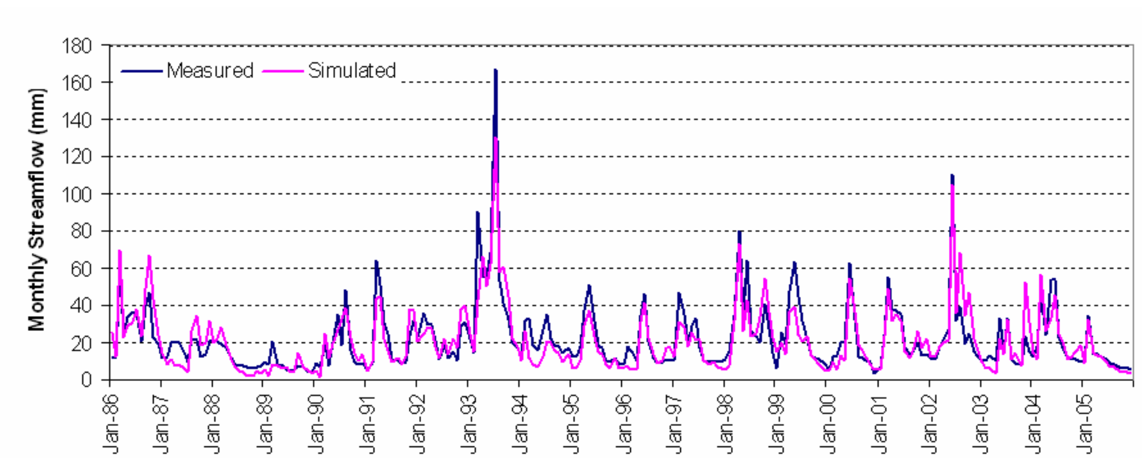

FIGURE 3. Monthly streamflow comparison at the watershed outlet

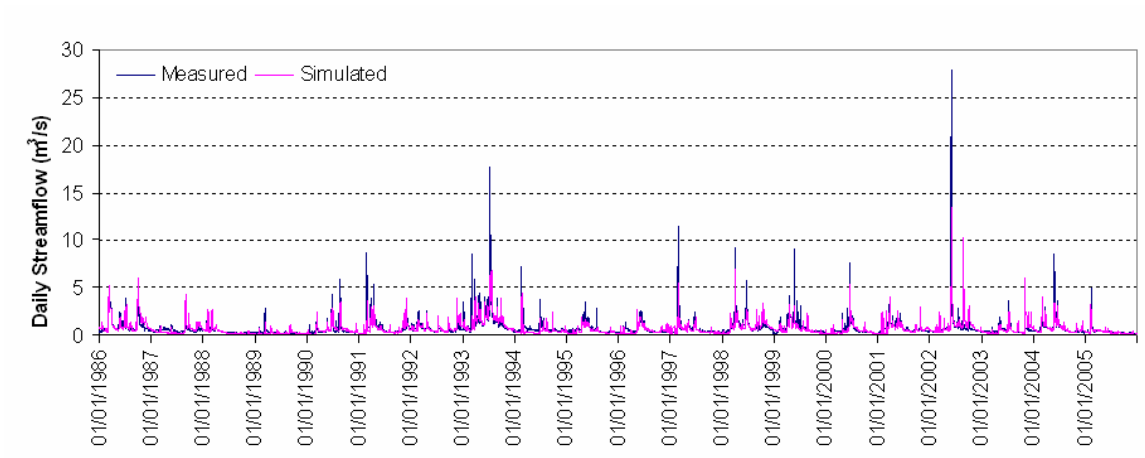

FIGURE 4. Daily streamflow comparison at the watershed outlet

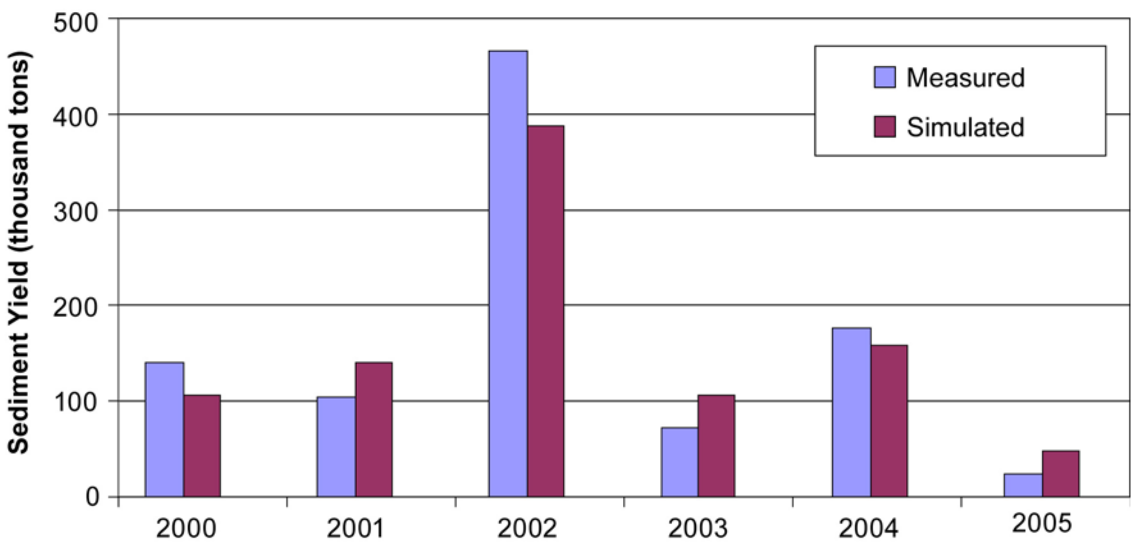

FIGURE 5. Annual sediment yield comparison between SWAT simulated values and the measured values at the watershed outlet

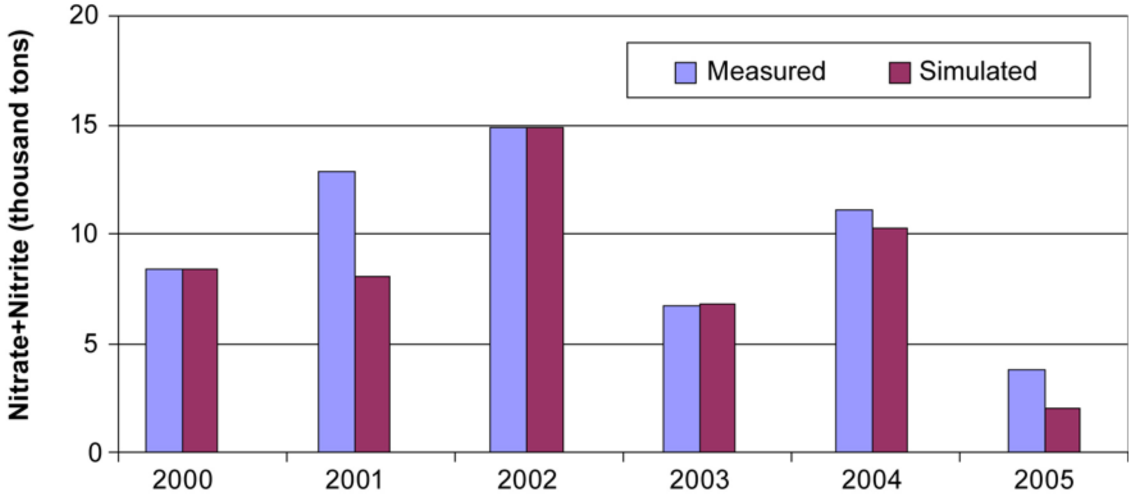

FIGURE 6. Annual nitrate loadings comparison between SWAT simulated values and the measured values at the watershed outlet

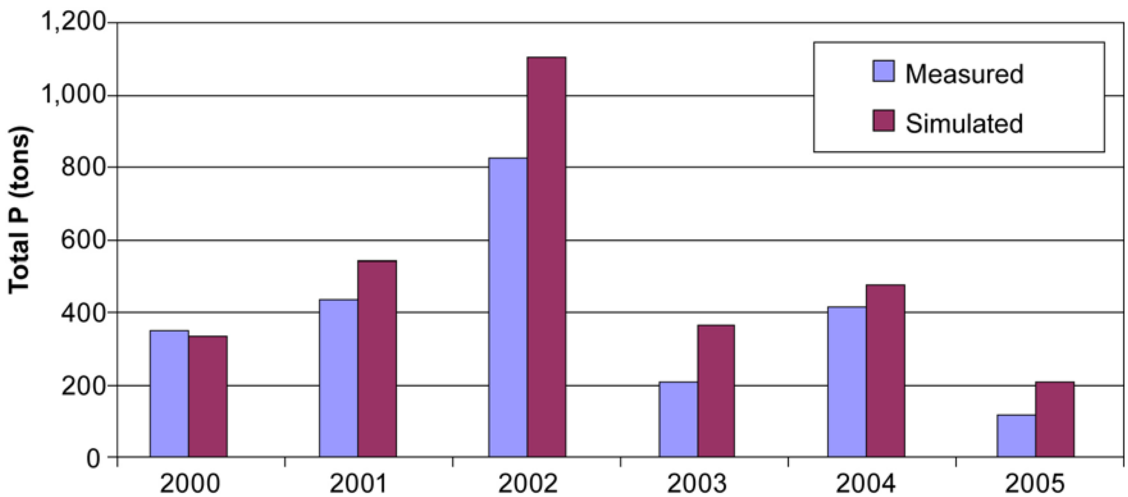

FIGURE 7. Annual total phosphorous comparison between SWAT simulated values and the measured values at the watershed outlet

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