The Cost of Clean Water:
Assessing Agricultural Pollution Reduction at the Watershed Scale

Silvia Secchi*†, Philip W. Gassman*, Manoj Jha*, Lyubov Kurkalova,
Hongli H. Feng, Todd Campbell and. Catherine L. Kling.

Center for Agricultural and Rural Development
Iowa State University
Ames, Iowa 50011-1070
www.card.iastate.edu

All authors are at the Center for Agricultural and Rural Development, Iowa State University, 578 Heady Hall, Ames, Iowa 50011-1070.

* These authors contributed equally to this work.
† Corresponding author. Ph: (515) 294-6173; E-mail ssecchi@iastate.edu.

The authors gratefully acknowledge support from the Iowa Department of Natural Resources for conducting this research.

The Cost of Clean Water:
Assessing Agricultural Pollution Reduction at the Watershed Scale

One sentence summary:
This study combines economic models with a watershed-scale hydrologic model to simultaneously assess economic costs and water quality benefits due to widespread agricultural pollution reduction in a large, intensively-cropped landscape.

Abstract:
We combine economic models and data on land use with the Soil and Water Assessment Tool, a watershed-scale hydrologic model, to estimate the costs of water quality improvements from the hypothetical placement of a broad set of conservation practices in the State of Iowa. The modeling systems captures the complex interactions between economic decisions, land use, conservation practices, and ambient water quality and is developed and implemented at a fine enough spatial scale to represent the full richness and diversity of this landscape. We identify sets of conservation practices and their location on cropland landscapes, and estimate their costs and water quality impacts. Annual costs range from $303 to $321 million. Predicted sediment, total P, and nitrate decreases ranged from 6% to 65%, 28% to 59%, and 6% to 20%, respectively, relative to the baseline.

The Cost of Clean Water:
Assessing Agricultural Pollution Reduction at the Watershed Scale

This study provides an estimate of the costs of nonpoint source pollution control in a large, intensively managed agricultural landscape and outlines a methodology to simultaneously assess economic costs and water quality benefits. The need for such information is acute. Twenty-five years after the Clean Water Act (CWA) was passed, states reported to the United States Environmental Protection Agency (USEPA) that nearly 40% of waters were too polluted for basic uses (1); as of May 2005, the number of water bodies reported as impaired numbered nearly 30,000 nationwide. In the last decade, the Herculean effort of establishing and approving total maximum daily loads (TMDLs) for each of these impaired waters has begun in earnest, with nearly half of the impaired waters now having been assessed (2). These TMDLs require that the sources of a water body's impairment be identified and a goal for reduced loadings from each source be established. While progress is being made in TMDL development, the adoption of conservation practices remains largely voluntary. Thus, fundamental questions remain about how and to what extent the nation's waters will, in fact, be improved.

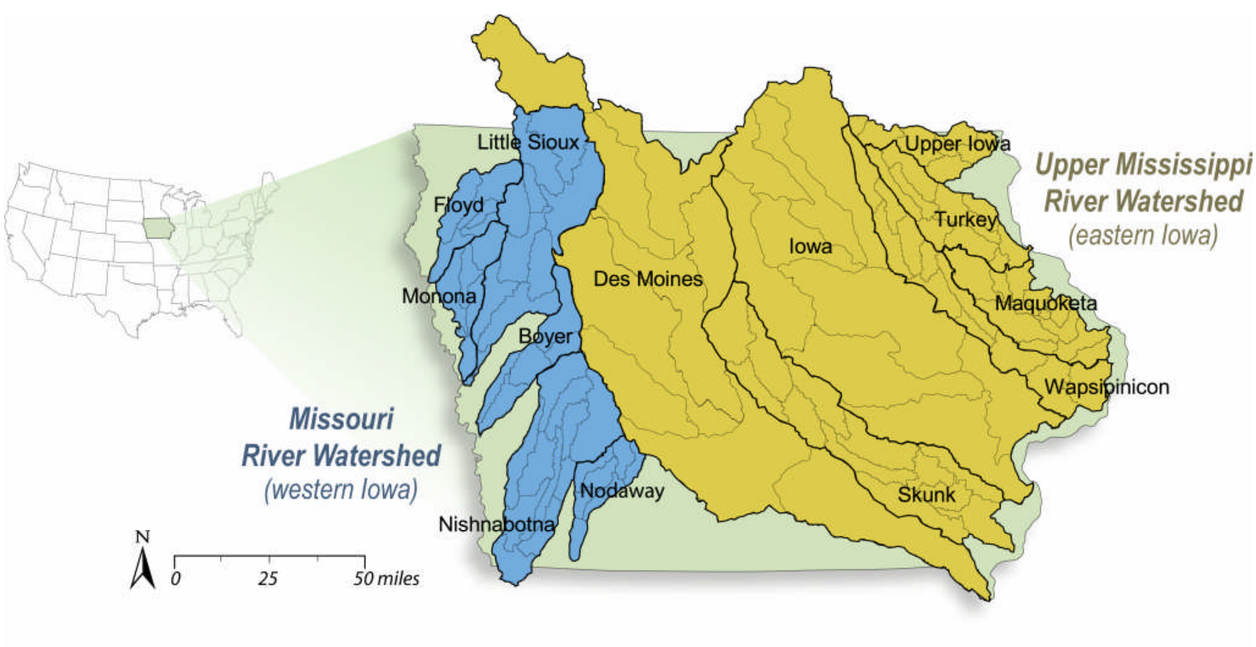
In support of this effort, significant data collection and research efforts are underway to improve the scientific base upon which TMDLs can be established and to improve understanding of how changing agricultural practices might reduce impairments (3,4). While these efforts are critical to developing the necessary physical science knowledge base, they largely sidestep the most fundamental social and economic questions upon which policy design and water quality standards hinge. Such questions include, How much will fundamental changes in agricultural land use and management cost? How pervasive must such changes be before notable water quality improvements occur? Are these costs worth the water quality benefits? How can policy be designed to attain water quality improvement more cost effectively?

Recognizing the importance of the cost component in social decision making, the 2000 Clean Watersheds Needs Survey reports two versions of the total cost of mitigating nonpoint source pollution problems, or needs, which are defined as water quality or public health problems and their associated abatement costs. The documented total nonpoint source cost (according to the reporting states) was $13.8 billion (versus $167.4 billion for point sources), and the abatement costs for agricultural cropland were $0.5 billion of this total. However, lacking the resources to develop such estimates, many states failed to make reports or provided only minimal data; therefore, the USEPA also estimated the nonpoint source needs for the nation and projected the total costs to be $21.5 billion, with agricultural cropland accounting for $4.44 billion (5). To obtain these estimates, the USEPA identified a set of conservation practices and their extent of usage on the landscape and then estimated the costs of those practices. However, a significant limitation of the USEPA methodology is that the analysis did not include any estimation of the resulting water quality. Thus, the financial needs have no relationship to a predicted or even desired water quality level. Since it is likely that the costs of conservation practices increase with increases in the desired water quality, it is important that any financial need be associated with a water quality target.

In this research, we present an alternative methodology for assessing the nonpoint source needs of states. We combine economic models and data on land use and conservation practices with the Soil and Water Assessment Tool (SWAT) watershed-based hydrologic model (6) to estimate the costs of obtaining water quality changes from the hypothetical placement of a broad-based set of conservation practices. Our analysis is comprised of three steps in the following sequence: (a) identify the set of practices (the policy) and their location on the landscape; (b) estimate the costs of the set of practices, and (c) estimate the water quality benefits associated with these sets of practices. There are at least two important limits to this approach: the practices chosen and their location on the landscape are not necessarily those that achieve a given water quality reduction at the least costs and the water quality level achieved may not satisfy the water quality goals. However, both of these issues could be solved by an iterative process akin to a numerical maximization whereby the set and location of practices is varied to approach an optimal solution. Our study takes the first step and illustrates the essential elements of the approach.

We performed the study by estimating the statewide costs of conservation practice adoption and predicting environmental impacts with SWAT for the 13 major watersheds that lie entirely or largely in Iowa (Figure 1). These watersheds range in size from 2,051 km^2 to 37,496 km^2 and together cover 87% of the state (7). Thus, there is some geographic mismatch between our cost and water quality study regions (8). However, the approach captures the reality of politically based, program-driven costs while generating environmental outcomes using natural watershed boundaries.

Figure 1. The study area and watershed delineations



We identified conservation practices on the basis of the physical characteristics of the agricultural land in collaboration with the Iowa Department of Natural Resources. The practices analyzed include grassed waterways, terraces, contouring, conservation tillage, land set-aside such as the Conservation Reserve Program (CRP), and nutrient management strategies. The choice of practices emphasizes the local water quality concerns related largely to sediment and phosphorus loads. The primary data source used in the analysis is the 1997 National Resource Inventory (NRI) database (9). The NRI provides information on the natural resource characteristics of the land, cropping history, conservation practices used by producers, and other data for some 15,781 cropland and CRP physical points in Iowa. Because the data are statistically reliable for state and multi-county analysis of non-federal land, they are representative of the agricultural land in Iowa. The key unit of our analysis is an NRI point, which is treated as a producer with a farm size equal to the number of acres represented by the point. This is the sequence adopted in identifying the practices:

Step 1. Retire all cropland within 100 ft. of a waterway, placing it in land set-aside.

Step 2. Retire additional cropland to reach a 10% total land retirement figure statewide on the basis of the NRI Erosion Index.

Step 3. Terrace the remaining cropland with slopes above 7% in western Iowa (Figure 1) and above 5% for the remainder of Iowa.

Step 4. Implement contouring on all remaining cropland with slopes above 4%.

Step 5. Install grassed waterways on remaining cropland that have slopes of 2% to 7% in western Iowa and 2% to 5% in the rest of Iowa.

Step 6. For all cropland with slopes of 2% or greater that is not retired and not already in conservation tillage, place 20% in no-till and 80% in conservation tillage (10).

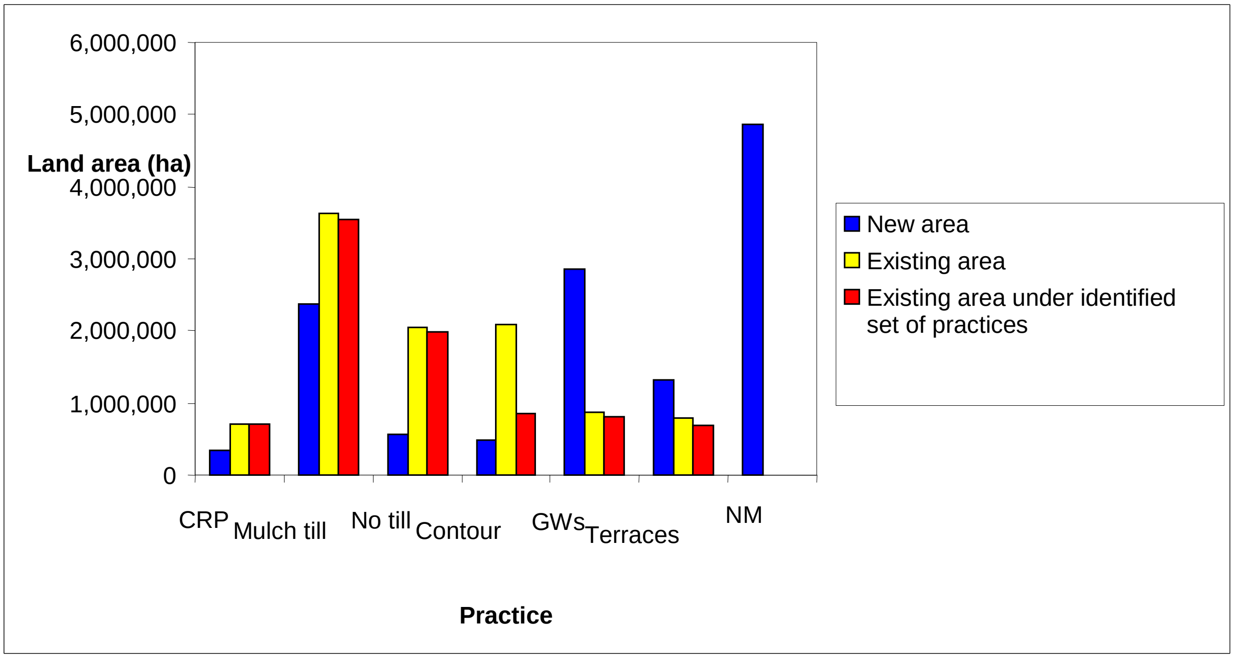
Step 7. Implement nutrient management by reducing fertilizer rates on all corn acres by 10%.

Following the selection step, our goal was to estimate the opportunity cost associated with the change in land use or adoption of these conservation practices. The opportunity cost is the minimum amount of compensation necessary for the farmer or landowner to voluntarily adopt the practice. It includes the direct costs of implementing the practice as well as any lost revenue associated with undertaking the practice relative to conventional approaches, compensation necessary for any increased risk and/or any other undesirable consequences of the practice for the farmer or landowner. For some practices, data limitations or incomplete understanding of the agronomic consequences of a practice mean that direct costs or predictions of lost revenues are used as proxies for the complete opportunity cost. A unique data source on the costs of conservation practices is unavailable. Therefore, we have developed a methodology to combine economic models with available cost data. Discrete choice economic models of land retirement and conservation tillage were supplemented by estimates of the costs of the other conservation practices on the basis of existing conservation programs. Note that implementing a program to achieve the full adoption of the identified set of conservation practices may cost significantly more than the opportunity costs. For example, if a subsidy program is implemented that compensates both existing adopters of a conservation practice as well as new adopters, the program costs will include payment to both groups, whereas the opportunity costs would include the costs of new adopters only.

Our final step involved configuring the SWAT simulations for the 13 watersheds. To perform the SWAT analysis, each watershed was subdivided into subwatersheds (Figure 1) and then further subdivided into Hydrologic Response Units (HRUs), which possess common land use, soil, and management characteristics. A SWAT calibration and validation exercise was performed for the Raccoon River Watershed, which lies within the Des Moines River Watershed and has been intensively monitored for stream flow and sediment and nutrient loads. Further flow calibrations were performed for all 13 study watersheds. Comparisons between simulated and measured values indicated that SWAT accurately captured observed trends (9). The calibrated SWAT model was first executed for the baseline and then run with the conservation practices in place to predict the changes in water quality attributable to the scenario. Additional details on the SWAT assumptions are provided in the supporting documentation (9).

The area involved in the conservation practice scenario was substantial. Figure 2 shows the statewide summaries of both existing and "new" (our set of identified practices) area. The total area represented by the individual practices exceeds the total statewide cropland area, because multiple practices are simulated for most land area units (11). The area of existing conservation practices for which we include costs is smaller than the actual existing area because some cropland is shifted into alternative, more effective practices. Of particular note, the identified set of practices almost triples the amount of cropland that is terraced in the state. The land retired from active production increases by almost 50% from the baseline while the conservation-till area expands by more than 60%. Nutrient management affects almost half of the cropland area in the state. The area in grassed waterways is the total cropland area affected by the practice; only 2% of that area is actually converted into grassed waterways.

Figure 2. Area of practices (existing area not applicable for nutrient management)



The social costs of the conservation practices are reported as the full annual costs in Table 1. They range from about $300 million to $320 million, depending on the specific values chosen for practice costs (for some, a lower and upper bound estimate are used). Land set-aside and conservation tillage costs account for the highest outlays, because the high cost of terraces is spread through a 25-year life span.

The environmental effects of the scenario are listed in Table 2 for the 13 watersheds. The predicted sediment decreases ranged from 6% for the Little Sioux River Watershed to 65% for the Turkey River Watershed. Sediment reductions were estimated to be greater than 30% and 40% for nine and seven of the watersheds, respectively. The predicted decreases in total P losses ranged from 28% for the Upper Iowa Watershed to 59% for the Turkey River Watershed with the majority of the decreases exceeding 40% relative to the baseline. Nitrate reductions of 6% for the Des Moines River Watershed to 20% for the Nishnabotna River Watershed were predicted for the scenario, reflecting the impact of the reduced nitrogen fertilizer applications.

The annualized costs of implementing our identified set of conservation practices are predicted to be as high as a third of a billion dollars, with reductions in sediment and phosphorous of over 60%. Nitrate reductions are predicted to amount to 20% at most. The chosen set of conservation practices appears both effective and expensive, although it is interesting to put the expense in the context of commodity program payments, which, in Iowa, have averaged about $15 billion a year since the 2002 farm bill. These payments are projected to be around $25 billion in 2005. Direct payments for Iowa in 2003 (the last year for which the data were available) well exceeded half a billion dollars.

Whether this set of conservation practices meets (or exceeds) the needs of nonpoint source pollution control depends upon whether these reductions are considered adequate or not. The methods presented here provide a basis for quantifying and evaluating the trade-offs that improved water quality requires. The results of studies such as this can provide society and policymakers with the basis on which to seriously address questions such as how much water quality improvements represent a desirable goal and how to achieve water quality reductions in cost-effective ways. Our results also suggest that the considerable resources being expended in agricultural payment programs might be adequate to achieve considerable water quality gains if farm programs were structured to reward effective conservation practices. Such a shift could have the additional benefit of making U.S. agricultural policy more acceptable to the World Trade Organization.

Notes

1. USEPA. 2002. National Water Quality Inventory 2000 Report, available online at http://www.epa.gov/305b/2000report/.
2. USEPA. 2005. National Section 303(d) List Fact Sheet 2005, available online at http://oaspub.epa.gov/waters/national_rept.control.
3. USEPA. 2005. Wadeable Streams Assessment: The States Assess the Nation's Streams, available online at http://www.epa.gov/owow/monitoring/wsa/.
4. Mausbach M J., and A. R. Dedrick. 2004. The Length We Go: Measuring Environmental Benefits of Conservation Practices. *Journal of Soil and Water Conservation*, 59 (5): 96A-103A.
5. The remainder of the costs were largely due to hydromodification, landfills and urban nonpoint sources. USEPA 2003 Clean Watersheds Needs Survey 2000 - Report to Congress available online at http://www.epa.gov/owm/mtb/cwns/2000rtc/toc.htm
6. Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams. 1998. Large Area Hydrologic Modeling and Assessment Part I: Model Development. *J. American Water Resources Association* 34(1):73-89.
7. Further information on the watershed characteristics and the general methodology is available from the authors upon request.
8. For the cost analysis we consider all regions in the state and exclude the pieces of the watersheds that fall outside of the state boundaries. Thus, the costs and water quality benefits we report are not quite consummate: one represents a political boundary, while the other represents a natural system boundary. Direct comparisons between the aggregate cost and water quality benefit comparisons may be misleading, although per acre costs and/or per outlet of the watershed measures can still be appropriately compared.
9. U.S. Department of Agriculture. 2000. *Summary Report: 1997 National Resources Inventory (revised December 2000)*, Natural Resources Conservation Service, Washington, DC, and Statistical Laboratory, Iowa State University, Ames, Iowa, available online at http://www.nrcs.usda.gov/technical/NRI/1997/summary_report/.
10. We use the definition of conservation/mulch tillage as tillage that leaves over 30% residue, while no-till is used for the tillage practices that leave over 60% residue.
11. Note also that the existing CRP acres are as of 1995, since that is the most recent data contained in the 1997 NRI.

Table 1. Annualized social costs (in million dollars)

Land Set-aside	Conservation Tillage	Contour (Low)	Contour (High)	Grassed Waterways (Low)	Grassed Waterways (High)	Terraces	Nutrient Management	Total (Low)	Total (High)
96	97	12	24	11	17	53	33	303	321

Table 2. Annual average baseline loadings (1980-1997) and percent reductions due to the policy scenario

	Baseline loadings and percent reductions due to scenario									
Watershed	Sediment		Nitrate		Organic N		Total N		Total P	
	(1,000 t)	(%)	(1,000 t)	(%)	(1,000 t)	(%)	(1,000 t)	(%)	(1,000 t)	(%)
Floyd	244.7	30	7.3	13	1.5	54	8.8	20	0.5	52
Monona	192.4	10	5.0	17	0.8	41	5.7	20	0.3	42
Little Sioux	594.0	6	26.2	11	3.4	51	29.6	15	1.5	49
Boyer	3,231.3	35	15.2	16	6.6	54	21.8	27	2.8	53
Nishnabotna	507.4	43	3.3	20	1.4	53	21.7	30	2.8	52
Nodaway	507.4	45	3.3	11	1.4	47	4.7	22	0.5	45
Des Moines	2,202.1	10	38.1	6	25.7	41	63.8	20	7.2	37
Skunk	4,982.5	63	30.0	13	5.0	54	35.1	19	2.5	51
Iowa	3,433.8	13	53.9	6	54.5	51	108.4	29	8.5	48
Wapsipinicon	1,902.0	64	29.9	9	3.2	52	33.1	14	1.3	50
Maquoketa	1,274.6	46	14.8	9	3.6	59	18.4	19	1.1	56
Turkey	1,371.4	65	12.4	10	2.6	62	15.0	19	0.9	59
Upper Iowa	880.4	50	3.7	10	1.1	40	4.9	17	0.4	28