Value of Information for Targeting Agro-pollution Control:

A Case Study of the Lower Susquehanna Watershed

by

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(ABSTRACT)

Targeting farms with low costs of reducing agro-pollution has been suggested as a means to reduce control costs. The potential to use better information to reduce costs of achieving a regulatory performance standard was evaluated. Using the Lower Susquehanna watershed as a case study, three strategies to target reductions in nitrogen runoff from dairy farms were studied: 1) no information -- uniform allocation, 2) perfect information -- cost-effective allocation, and 3) partial information - estimated cost-effective allocation. From no information to perfect information, more detailed information about the farms' marginal compliance costs with a reduced nitrogen runoff standard was collected. Two strategies to target the performance standards, the private and social cost-effective allocation (private cost-effective allocations minimized farm compliance costs while social cost-effective allocations minimized the sum of compliance plus transaction costs) were also compared.

Each strategy's total control cost (compliance plus transaction costs) were estimated for a 237 dairy farm sample with a modified microparameter (bieconomic) model which preserves the watershed heterogeneity. Because cost-effective

performance standards involve large transaction costs, they were compared to two design standards which have lower transaction costs.

It was found that targeting problem farms in the Lower Susquehanna watershed could save nearly $3 million for the sampled 237 farms. Extrapolating this result to the 6,662 dairy farms in the watershed could save the state more than $55 million over a uniform allocation of responsibility. Results also show that the social cost-effective allocation of control responsibilities (based on marginal compliance plus transaction costs) in targeting policies targets only 50 percent of the dairy farms with a mean control cost per pound of $11 compared to $47 per pound with the uniform performance standard applied to all the farms.

This study suggests that a few farms in the Lower Susquehanna should be targeted a large reduction burden. Criteria to target these farms should be: somewhat larger farms with steep and long slopes, on soil hydrological groups C and D, close to surface water, that have no or few best management practices in place, and grow large amounts of corn. Cost-effective practices for dairy farmers in the Lower Susquehanna are manure incorporation and storage, eliminating or reducing winter manure spreading, and using more strip-cropping.

The value of perfect information was found to exceed the value of partial information in the study area because the total control costs were lower. Compliance costs for perfect information under the social cost-effective allocation were $853,911 compared to $968,121 under the partial information strategy. Total transaction costs were $126,996 for the perfect information and $74,368 for the partial information strategy. Total control costs were $980,907 for the perfect information and $1,042,489 for the partial information strategy. Results for the private cost-effective allocation were similar. The private cost-effective targeting strategy did not differ significantly from the social cost-effective targeting strategy mainly because aggregate compliance costs make up 99% of the total control costs.

The two regulatory design standards requiring manure storage and strip-cropping on more erosive soils were also evaluated. However, neither design standard achieves the 40 percent nitrogen delivery reduction goal in the watershed.

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CHAPTER ONE: WATER QUALITY AND AGRICULTURE

1.1 BACKGROUND

Over five hundred billion dollars have been spent on water pollution control since the Federal Water Pollution Control Act of 1972 (Intergovernmental Task Force on Monitoring Water Quality). Yet, in 1992, one third of the assessed waters in the nation did not meet the standards states have set for them (U.S. EPA, 1994). Through the last decades, water quality improvement has been achieved mainly through technology-based performance standards on municipal and industrial point sources (Kashmanian et al.; Portney). Nonpoint sources have not been controlled and their relative importance has increased to the extent that they are now the major contributors to water nutrient enrichment problems (Letson; Portney; U.S. EPA, 1992). Agriculture is a major contributor to nonpoint source pollution. Up until recently, the public transaction costs (in terms of information, contracting, and enforcement costs) to protect water quality from agricultural nonpoint source pollution (agro-pollution) had, perhaps, exceeded the gains from internalizing the related environmental costs (Krier and Montgomery).

Nonpoint sources are harder to regulate because of the complex monitoring and enforcement activities involved (Jacobson, Hoag, and Danielson) and the difficulty in monitoring flows of pollutants at reasonable cost (Shortle and Dunn 1986; Carlson, Zilberman, and Miranowski) on so many farms. However, controlling nonpoint sources of pollution might, in many cases, be cheaper in terms of compliance costs than applying stricter standards to point sources (Portney; Letson; Shortle 1984; Kashmanian et al.; Lyon and Farrow).

The economic benefits from controlling agro-pollution have seldom been estimated but are believed to be significant as agro-pollution is now the major obstacle to meeting water quality standards. Ribaudo (1989b) estimated the benefits of controlling annual offsite damages from soil erosion to be over $10 billion (1990 dollars), not including savings from reduced maintenance of reservoirs and channels filled by sedimentation. However, Portney estimated that given the actual policies, the national cost of controlling point sources of water pollution in 1985, $25 to $30 billion, was significantly larger than the most likely benefits, $5.7 to $27.7 billion. This difference suggests a need for more cost-effective control approaches such as controlling nonpoint sources and targeting areas where benefits exceed costs.

1.2 AGRO-POLLUTION PROBLEM

Although section 319 of the Clean Water Act gave states wide latitude in controlling agro-pollution implementation, in practice, states rely mostly on education, technical assistance, and voluntary cost-shared field management practices (Malik, Larson, and Ribaudo). Voluntary instruments have been favored because of historical precedent, and the difficulty of monitoring farms' loadings at reasonable costs.

As implemented, education and technical assistance are not likely to achieve the desired water quality (Shortle and Dunn 1991). Also, cost-share programs may not be cost-effective because they are inflexible regarding which practices are cost-shared, and farmers who need cost-share may not be the ones who get it (Clark II et al.; Shortle and Dunn 1991; Ribaudo 1992). For example, farmers owning lands with the highest levels of erosion potential or with the lowest costs of erosion reduction may not volunteer to participate in cost-share programs (Ogg, Johnson, and Clayton; Park and Sawyer), and the most cost-effective practices on a farm may not be subsidized (Dunn and Shortle). Also, expensive structural practices such as terraces tend to be cost-shared while inexpensive conservation tillage and nutrient management plans are not.[1]

The Chesapeake Bay consortium estimated that reducing nitrogen and phosphorus loadings to the Chesapeake Bay by 40 percent would restore the Bay to its designated use by the year 2000 (Modeling Subcommittee of the Chesapeake Bay Program). The states of Maryland, Pennsylvania, and Virginia and the District of Columbia, supported by the Environmental Protection Agency (EPA), want to achieve this goal at minimum cost. To do this, the states must discover or have the market discover the least-cost allocation of pollution reduction responsibilities among the polluters.

1.2.1 Agro-pollution measurement problem

Desirable water quality is not emerging via the workings of the market because

[1] This tendency is changing. For example in Pennsylvania, to receive cost-share money, a nutrient management plan must be implemented.

property rights for clean water are not well defined, and because of the presence of high transaction costs -- the private and public costs of writing and enforcing contracts as well the associated information costs. There is an implicit "common property" use of water bodies as waste sinks. Although individuals may care about the cleanliness of the Bay, they have no rights to stop nonpoint source polluters from dumping pollutants in it because of the difficulty of tracing nonpoint source pollutants to the their source. Polluters have no incentives to reduce their loadings as it is costly to do so and because other farmers may continue to pollute, inhibiting any effect they could have had on the water quality.

In the Bay Drainage Area, the major sources of water pollution are nonpoint or diffuse, with farms being the most important contributors to loadings. Neither farmers nor control agencies have perfect information about the pollution processes. Loadings depend on stochastic weather events, and agro-pollution sources (mainly farms) are heterogeneous. These characteristics imply that: the pollution process is not practically observable; correcting instruments must be site-specific to minimize compliance costs (Griffin and Bromley) and hence associated transaction costs will be high. When transaction costs are high, private contracting is unlikely and government actions to correct problems are difficult.[2] The lack of well-defined property rights and high transaction costs implies that: 1) if the government decides to do nothing, water quality is

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[2] Although some actions may be better than no policy at all (Chavas).

sacrificed, 2) incentives or standards -- control instruments -- must be introduced if the desired level of water quality is to be achieved and 3) transaction costs will be an important share of the total control cost.

1.2.2 Agro-pollution control research

A large body of literature compares the relative efficiency of an array of agricultural water pollution control policies (Moffitt, Zilberman, and Just; Jacobs and Casler; Kramer et al.; Johnson, Atwood, and Thompson; Taylor, Adams and Miller; Amanor-Boadu; Thomas and Boisvert; Braden, et al.). These studies find control costs of market-based policies (pricing, tradable permits) to be lower than those of regulatory policies.

Considering that these studies assume control agencies have perfect information, that nonpoint source measurement problems are disregarded, and that the costs compared in these theoretical studies are solely private costs, farmers' compliance costs, it is not surprising that many of these studies find market-based policies dominating regulatory policies. In fact, Tietenberg shows that with only one source of pollution (or equivalently if many sources are identical), perfect information, and certainty, market-based policies such as taxes, subsidies, and transferable permits achieve water quality control at the least aggregate compliance costs. Aggregate compliance costs are the sum of the private compliance costs across farms in a watershed to achieve an ambient water quality.

Transaction costs, that is, the opportunity costs of the resources consumed in assigning, monitoring, and enforcing responsibility for reducing nonpoint source pollution (usually borne by government agencies) are likely to be large. Thus, transaction costs, which are the very reason why nonpoint sources were not controlled in the first place, are ignored in many of these studies due to lack of data on such costs. The usual cost-effectiveness criteria (which Stavins (1993) called cost-effectiveness without transaction costs and will be called private cost-effectiveness in this study) may lead to the wrong selection of "best" policies because it implicitly assumes that the opportunity costs of the agency's resources in the control process are zero.

Past literature has concentrated on minimizing private compliance costs while ignoring public transaction costs (Easter; Shoemaker, Ervin, and Caswell). Farm site variability suggests a trade-off between public administrative costs and private cost-effectiveness for all policies, including that of market-based policies. This trade-off arises because market-based policies such as fertilizer or nitrogen runoff taxes must be tailored to farms to preserve their cost-effectiveness. Given the nature of agro-pollution, tailored policies might have a high opportunity cost of the resources consumed in carrying out this allocation (Crocker). Easter goes so far as to state that the major costs incurred in controlling agro-pollution will be the public transaction costs rather than the private aggregate compliance costs.

Once transaction costs are included in the analysis it is unclear which policy is more cost-effective in term of aggregate compliance plus transaction costs. Pollution taxes and quotas cannot be assumed to minimize the sum of public transaction costs plus private compliance costs of controlling agro-pollution (Malik, Larson, and Ribaudo; Helfand and House). The cost-effectiveness of each policy must be established on a case-by-case basis.

The level of private compliance costs of each policy is a function of (1) the degree of flexibility left to farmers in selecting ways to reduce nonpoint source pollution, (2) the level of information farmers have about costs and benefits of alternative practices to achieve the watershed emission reduction, and (3) the level of information used by the control agency to set the policies. Transaction costs also vary with the policy instrument used and the targeting strategy. Thus the total costs of each policy, aggregate private compliance plus public transaction costs, must be considered ex ante to achieve social cost-effectiveness. Social cost-effectiveness is used throughout the dissertation to refer to policies which minimize the sum of private compliance plus public transaction costs. In this study, transaction costs include the control agency's costs of controlling pollution, they do not include the private costs of litigation nor the private costs of locating and trading.

1.3 INCREASING THE EFFECTIVENESS OF AGRO-POLLUTION CONTROL

Generalized strategies to prevent water quality degradation and to preserve farm profitability are difficult to derive due to the farm sector's heterogeneity. Most studies accounting for agro-pollution measurement problems and uncertainty have used a second-best criterion to compare policies. A second-best policy is one in which environmental goals are determined exogenously and the least cost policy to achieve the goal is identified. First best criteria, where marginal compliance costs are set equal to the marginal benefits of control, have seldom been used because of the difficulty of measuring benefits.

Targeting agro-pollution control has emerged as a response to the spatial variability of agro-pollution and the associated wide variation in compliance costs. Incentive programs have emerged to deal with the non-observability of loadings and the impossibility of inferring loadings from ambient water quality or input use. However, transaction costs have received little attention in the search for cost-effective control of agro-pollution (Shoemaker, Ervin, and Caswell; Shortle and Dunn 1991; Stavins 1995; Russell and Shogren).

1.3.1 Targeting

To be cost-effective, agro-pollution control must be targeted (Harrington, Krupnik, and Peskin; Batie 1994). Targeting increases social cost-effectiveness by allocating more control responsibility to farms with low compliance costs and large loadings (priority farms) and by reducing the number of sources that must be included. Two levels of targeting are referred to in the literature, aggregate- and micro-targeting.[3]

[3] See Appendix A for a review of the history and background of targeting programs.

Aggregate targeting is defined here as the targeting of scarce national funds to states, regions or watersheds to maximize net social benefits resulting from water quality protection (Ribaudo 1986, 1989b). Areas of the country (priority areas) where the net benefits (benefits - costs[4]) from public actions are greatest should be targeted first (Batie 1994a). Then priority farms and eventually fields within these larger targeted areas should be micro-targeted.

Micro-targeting is defined as the targeting of scarce financial resources to those specific areas, farms or habitats within a watershed that would improve environmental quality the most relative to costs, if farming practices were to be changed (Batie 1994a; Dickinson, Rudra, and Wall; Braden et al.). Thus targeting accounts for spatial differences by discriminating between farms' potential loadings within and between watersheds (Shortle 1994). To discriminate among farms, information about farm cost of pollution control is needed.

1.3.2 Transaction costs

To target priority farms, different levels of information must be collected depending on which policy instrument is being implemented. For example, more selective targeting is more information intensive and more costly to administer than broader targeting strategies, and the decrease in farms' compliance costs should be weighed against the extra transaction expenditures. Bosch, Batie, and Carpentier note

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[4] These costs may include farmers' compliance costs, higher food prices to consumers, and government expenditures on water quality protection programs inclusive of transaction costs.

that the transaction costs associated with targeting must be included to evaluate potential cost-savings from targeting, a practice that has generally not been done in previous studies.

Even if one assumes that every policy is implemented to achieve the same water quality standard, various policies would still require different levels and types of compliance and transaction costs. Enforcing and contracting costs associated with a design standard should be lower than performance standards or taxes linked to a flow of pollution, but farmers have less flexibility to respond to design standards and hence are likely to have higher compliance costs. A design standard dictates what or how farmers are to farm their lands, or conversely what technology cannot be used to farm their lands. Again, a marginal decrease in farm compliance costs from added flexibility must be weighed against the associated higher transaction costs.

1.4 PROBLEM STATEMENT

Animal waste, sediment, nutrients, and pesticides are by-products of agricultural production that potentially can enter water bodies as pollution. It is essential that agro-pollution be controlled to achieve national and regional water quality objectives. In the present setting in which conservation practices to reduce water quality degradation are voluntary, compliance costs are internal to the farms, but damage costs are externalities. An excessive amount of water pollution, and too few expenditures on control result

(Tietenberg). Various voluntary, regulatory, and market-based policies and their social cost-effectiveness must be empirically evaluated to identify the policy that achieves water quality at minimum costs (Crocker; Malik, Larson, and Ribaudo; Helfand and House).

1.4.1 Policy choices

Estimated performance standards based on an accepted formula (Abler and Shortle), design standards (Batie 1994a; National Research Council), and a combination of design and performance standards (Shabman and Milon) have been proposed to control agro-pollutants. Firms tend to prefer performance standards to effluent taxes and tradable permits[5] because they reduce profit the least and output standards because they generate rents for the industry. Control agencies tend to prefer performance standards to taxes when the farmers' response functions are unknown and compliance costs are known and tend to prefer taxes when compliance costs are unknown. Market-based policies are becoming more popular in the eyes of control agencies because they offer economic incentives to improve on the performance standards.

Performance standards applied to farms imply determining: 1) the sum of the farms' loading for the pollutant of interest and 2) the performance standard that will reach the desired ambient water quality. Thus, performance standards in this study are defined as the set of management practices that achieves each farm's mandated reduction in pollution.

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[5] Assuming that firms must buy the initial permits.

By definition, the performance standard has lower aggregate compliance costs than the design standard, but its complexity implies higher public transaction costs (Braden).

Performance standards can be targeted at farms using either no information in which the standard is uniformly applied to all farms; partial information in which only the characteristics highly correlated with compliance costs are used to target; or perfect information in which all the necessary information is collected to achieve the cost-minimizing allocation of control responsibilities. As more information is used to target farms, the aggregate compliance costs to achieve the desired water quality decrease. The quantity of information collected should be increased so long as the present value of the cost savings with the additional information is increased by more than the cost of the information, *and* the sum of compliance and transaction costs is less than the costs of the next best alternative--controlling point sources or another nonpoint source control policy instrument. This rule can be applied by estimating the value of various levels of information.

A design standard which imposes a specific management practices uniformly among farms requires the least amount of information[6] because control agencies are likely to dictate practices to be used with the economy of information and enforcement costs in mind (Hahn referenced in Kohn). For instance, dictated control technologies are likely to differ from those farmers would have voluntarily chosen because control agencies take

[6] Unlike point source pollution, agro-pollution generally cannot be treated before release, design standards are thus defined as regulations which require that a certain conservation practice be used or that selected inputs and/or outputs be restricted in some way.

into account the effect of the prescribed technology on marginal compliance costs *and* transaction costs (Letson, Crutchfield, and Malik). Design standards mandate the use of one or more conservation practices uniformly across farms. Because they do not account for variations in farm compliance costs, they impose larger costs on farms with high abatement costs and smaller costs on farms with low compliance costs, resulting in failure to minimize aggregate compliance costs compared to a performance standard that mandates the set of cheapest practices for each farm.

1.4.2 Estimating the value of information

Table 1.1 presents the expected relationships between the policies' private compliance and transaction costs. Aggregate private costs are shown to increase as the policy's targeting precision decreases (from left to the right), while transaction costs decrease. The targeted performance standard based on perfect information about farm compliance cost is likely to have the least compliance costs, but higher information costs than other standards.

Targeting farms based on marginal compliance costs estimated with partial information would increase the aggregate compliance costs compared to the perfect allocation but should save on information costs. Contracting/administration and enforcement costs may be smaller with partial information than with perfect information if fewer farms are targeted. The value of perfect information, defined as the difference between the total control costs with no information and total control costs with perfect information, and the value of partial information defined as the difference between the

Table 1.1 Relative Performance of Alternative Standards and Information Levels

	Type of Standards and Levels of Information Used to Target Standards			
Cost of Standards[a]	Targeted Performance			Design
	Perfect Information	Partial Information	No Information	Uniform
Private				
Compliance	low	low/medium	medium	high
Public Transaction Costs				
Information	high	medium	medium/low	low
Contracting\ Administration	medium	medium	high	medium
Enforcement	high	medium	high	medium
Total control costs	?	?	?	?

[a] Costs are aggregated over farms to get watershed level costs of achieving a water quality standard.

total control costs with no information and total control costs with partial information, indicate whether the increased costs of more or better information outweigh the aggregate compliance cost savings.

Performance standards may not be the most cost-effective instrument to control nonpoint source pollution. Information to target performance standards has no value if a simple design standard has lower total control costs than the lowest cost performance standard. Design standards are expected to have lower transaction costs, but higher compliance costs than other policies in Table 1.1. Comparing columns one and two to four illustrates the potential for targeting a performance standard (a mix of design standards) as opposed to an easily enforced design standard. The sum of private and public costs for alternative policy instruments is an empirical question of great interest to policy makers. The question of which instrument has the lowest control costs can be answered by computing the value of information for each policy. Research is needed: 1) to determine which policy has the largest value of information (or minimizes social costs of achieving water quality objectives), 2) which economic and physical characteristics are indicative of the farms' marginal compliance costs and can be used to target farms with partial information and reduce total control costs, and 3) whether the cost-effective policy varies between watersheds.

1.4.3 Objectives

The goal of this dissertation is to identify a social cost effective targeting strategy to control agro-pollution in the Lower Susquehanna Watershed.

Specific Objectives

For the Lower Susquehanna Watershed:

1. estimate the value of information for micro-targeting agro-pollution performance standards to farms; and

2. compare the potential for targeted performance standards (based on perfect and partial information) to reduce private compliance and public transaction costs of achieving a performance standard compared to a uniform design standard.

Answering these questions will allow two hypotheses to be tested:

a) the value of partial information is larger than the value of perfect information;

b) aggregate transaction costs are larger than aggregate compliance costs.

Because only one watershed is studied, the question of how the social cost effective level of information varies across watersheds will have to await further analysis. Although urban sources -industrial sites, commercial developments, and streets - as well as forestry and mining operations are significant nonpoint source contributors, only agricultural sources are considered in this analysis. Because nitrogen runoff is the most troublesome nutrient problem in the Chesapeake Bay (U.S. EPA 1994), this research concentrates on nitrogen runoff.

1.5 RESEARCH METHODS AND PROCEDURES

1.5.1 Methods

A framework is developed to evaluate the watershed's social cost-effective policy. Any framework to study the economic and environmental effectiveness of controlling nonpoint sources must be flexible, site-specific, and source-specific (U.S. EPA 1984). The framework proposed here works as follows: the decision process starts by selecting the policy instrument and the information level for targeting fields, farms, counties or other units, which together form a policy (Figure 1.1). The total costs and pollution levels of each policy are then computed. Compliance costs and pollution levels are estimated with a microparameter model (Bosch, Carpentier, and Heimlich) which preserves the watershed's heterogeneity.[7] The public transaction costs of implementing each policy is estimated and total public and private costs are summed. The procedure is repeated until all the feasible policy alternatives (policy instruments and information levels for targeting) are considered and the social cost-minimizing policy is identified.

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[7] The microparameter model's name refers to the model's use of a distribution of micro-units (fields, farms) with fixed characteristics that affect production and pollution to estimate aggregate compliance costs (Johansen).

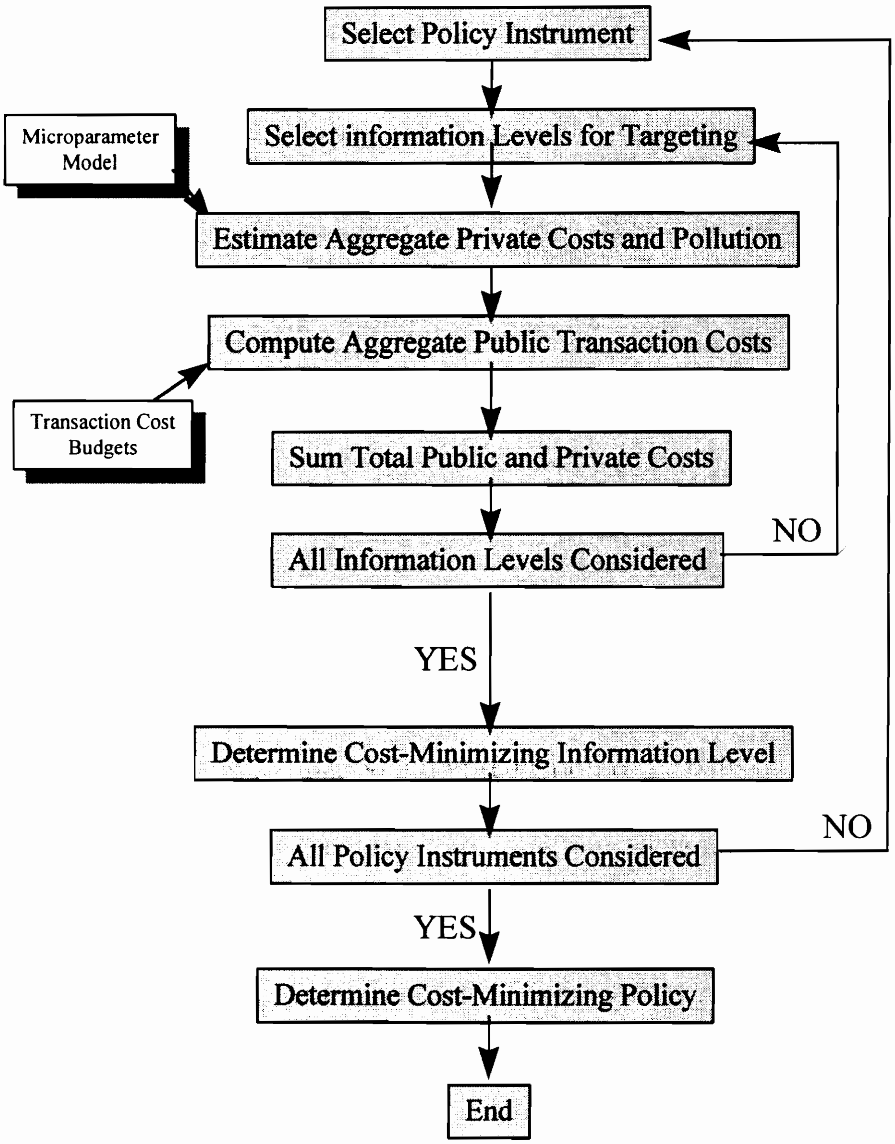

Figure 1.1 Steps for Achieving a Water Quality Standard at Least Cost.

1.5.2 Data

The bioeconomic model uses the Lower Susquehanna watershed Area Studies Survey data to implement a modified microparameter approach (Antle and Capalbo) to estimate the value of information for targeting performance standards (Bosch and Carpentier). Each farm in the model can respond to exogenous changes by intensive or extensive margin adjustments. Intensive margin adjustments involve changing the inputs per acre or livestock feed rations and extensive margin adjustments are represented in the model by the possibility to idle land and reduce livestock production. Spatial variability is accounted for by applying the model to multiple farms in the Lower Susquehanna watershed (the watershed) using reported practices and endowments from the Area Study surveys. The Area Studies report specific management practices on a randomly selected field and more general information (total acres in each crop, number of animals, sales, and so on) about the farm to which the field belongs. Each sample field's physical and hydrological characteristics are also available by linking information from the Natural Resources Inventory (NRI) to the Area Studies survey.

The Lower Susquehanna Watershed (the Watershed), a tributary to the Chesapeake Bay, consists of 5 million acres out of which 1.5 million are under agriculture. The Basin located mainly in Pennsylvania contributes an estimated 130 million pounds of nitrogen and 4 million pounds of phosphorus to the Chesapeake Bay (Hamlett and Epp). The largest single source of nutrient pollution in the Basin is agriculture (U.S. EPA 1992a). Consequently, the Watershed was chosen by the Economic Research Service, the National Agricultural Statistics Service, and the Natural Resource Conservation Service to conduct a detailed survey of field and farm level agricultural and conservation practices. NRI sample sites were selected as sample points for the Area Studies survey. The NRI, which is conducted every five years, contains numerous physical attributes of randomly selected cropland and pasture land sites. Linking the two sets of data permits the simultaneous economic and environmental evaluation of agricultural activities using a modified microparameter model.

The public transaction costs of implementing each of these policies are estimated. Transaction costs are estimated in a two-step process. The key operations involved in the administration of the current cost-share program administration were identified through phone interviews with agents of the Natural Resources and Soil Conservation Service (NRCS) and the Pennsylvania Department of Environmental Protection (PA DEP) which are in charge of developing farm plans to help achieve the 40 percent reduction in nitrogen and phosphorus delivery to the Chesapeake Bay. Costs of these operations were imputed with the help of experts including the agents interviewed.

1.6 OUTLINE OF THE DISSERTATION

This dissertation is organized to reflect the various components of an agro-pollution control decision making model to support policy making. Chapter Two presents the methods used to target nonpoint source pollution control and the microparameter submodel. A presentation of the conceptual model that brings the microparameter and transaction costs submodels together appears in Chapter Three. This model, which can be used to study the social cost-effective allocation of pollution in the presence of transaction costs is followed by the transaction cost budgets. Results obtained using the microparameter model with no restrictions on nitrogen runoff are compared to results from the Area Studies Survey in Chapter Four. Policy results for the regulatory and perfect information policies in the Lower Susquehanna Watershed are presented in Chapter Five. The methods to elicit and empirically estimate the value of partial information and the cost-minimizing policies appear in Chapter Six. Policy implications and needs for further research based on the results of carrying out objectives One and Two conclude this study in Chapter Seven.

CHAPTER TWO: REDUCING CONTROL COSTS BY TARGETING AGRO-POLLUTION CONTROL

2.1 INTRODUCTION

It is assumed that the Lower Susquehanna watershed has been targeted because pollution reduction there offers the most benefit to society relative to other watersheds. To maximize both economic and environmental goals, benefits from production should be maximized subject to minimizing environmental damages. This problem would entail estimating a value function for environmental goods and a welfare function for production goods. Success in estimating welfare functions is limited, and estimating the value of environmental goods is a contentious issue (Braden et al.). Instead, the Bay Consortium's goal of reducing nitrogen delivery in the watershed by 40 percent[1] is entered as a constraint on the farmers' optimization problem.[2]

Micro-targeting implies that pollution reduction responsibilities will be apportioned according to a predetermined targeting rule. Two decisions must be made: 1) which farms to target, and 2) what each targeted farm's control burden should be. To make these decisions, information on farms' nitrogen delivery and compliance costs must be collected. The problem can be seen as a recursive one, where a policy

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[1] The Bay Agreement stipulates that nutrients entering the Chesapeake Bay must be reduced by 40 percent by the year 2000 (Virginia Department of Environmental Quality).

[2] This substitution is commonly done in practice.

instrument is chosen first based on personal preferences and previous study results. Once the level of information which minimizes the cost of each policy is selected, then the least cost control policy can be chosen. Because instruments and levels of information are not continuous, the policy and information level which minimizes costs among the discrete set of alternatives is chosen.

An estimated nitrogen pollution performance standard is used to show the value of information in targeting agro-pollution policies. Shadow prices associated with a performance standard are the tax (subsidy) or permit prices farms would face under cost-effective market-based policies. For example, control agencies may choose to collect the information to establish a source-specific standard such that farms control nitrogen delivery at the same level as they would have under a market-based policy (perfect targeting). Estimated performance standards' (or other policies linked to the flow of pollution) transaction costs may exceed any benefits in the reduction of aggregate compliance costs compared to other policy instruments. Thus, the performance standards total control costs are compared to two design standards.

2.2 METHODS

2.2.1 Design standards

Design standards are not targeted in this study; they impose a fixed management practice X_k on all farms. Thus the information level is fixed once the design standard is chosen.

2.2.2 Performance standards

Assuming that producers are price takers and maximize profits they

$$MAX\ \pi_i = MAX \sum_l P_l Y_{il}(X_{ikl}(d_i)) \tag{2.1}$$

subject to:

$$\sum_k \sum_l e_{ikl}\ (Y_{ikl}, X_{ikl}, d_i) \leq z_i(I) \tag{2.2}$$

where the variables are summed over l and k to yield farm level inputs and outputs for a production system.

$$\sum_l B_{ikl} X_{ikl} \leq b_{ikl} \tag{2.3}$$

here Y is a multioutput production function $f_l(x_{.}, x_2, \ldots x_k)$ producing l crop and livestock activities linked by limits on total land and labor input. In agriculture, pollution control takes the form of reallocatiodn of land to crops (changes in rotations), tillage practices and so on, thus the change in activity is reflected in X_{lk}, the level of the kth input (management practices) associated with enterprise l on farm i. d_i is an indicator of environmental characteristics on farm id, and P_l is output l's net return. e_{ikl} is the nitrogen delivery function associated with management practice X_{lk} and output l on farm i. The sum of the e_{ikl} gives the farms' initial or baseline nitrogen delivery. $z_i(I)$ is the level of nitrogen allowed on farm i byd policy I, where I=1 to 4

(1=uniform performance standard, 2=perfectly targeted performance standard, 3 = partial information performance standard, and 4= uniform design standard).

Assuming that at least some amount of X is used, the first order conditions for a cost-effective allocation of control responsibility are that:

$$P_{il}\frac{\partial Y_{il}}{\partial X_{ikl}} = \lambda_i \left[\frac{\partial e_{ilk}}{\partial Y_{il}}\cdot\frac{\partial Y_{il}}{\partial X_{ilk}} + \frac{\partial e_{ilk}}{\partial X_{ilk}}\right] \qquad \forall i \tag{2.4}$$

The marginal value products at equilibrium equal the marginal propensity to pollute times the shadow price of pollution (λ) --how much profit is given up per unit of N for the last unit reduced as can be seen by taking the partial of the Lagrangian with respect to z_{ij}.

The marginal propensity to pollute is composed of the indirect effect of a change in X on the production of Y and the direct effect of a change in X (Carlson, Zilberman, and Miranowsky). Taxing inputs on each farm at a level equal to $\lambda_i \bullet [\partial e_{ilk}/\partial Y_{il} \bullet \partial Y_{il}/\partial X_{ilk} + \partial e_{ilk}/\partial X_{ilk}]$ would insure that farmers weigh the change in profit from a one unit reduction resulting from a change in practice X against the shadow value (or tax) on that unit.

2.2.3 Baseline

Nitrogen deliveries for the baseline farms (e_i) and watershed ($\sum e_i$) are first estimated with no constraint on deliveries by setting z_i to a large number for each of the farms. This unconstrained scenario provides an upper bound on the watershed revenues. By varying j, a range of shadow prices (λ_{ij}, the linear programming approximation of marginal costs[3]) on farm i for j levels of nitrogen delivery corresponding to 100, 80, 60, 40, and 20 percent reduction of the baseline or unconstrained case are found. These shadow prices can be used along with the baseline nitrogen delivery, e_i, to determine the allocation of control responsibility among farms with various levels of information. Information is discrete and is assumed to take on three values, I=1 no information, I=2 perfect information, I=3 partial information.

2.2.4 Uniform performance standard (I=1)

Without any information about farms' costs of controlling nitrogen delivery, the agency might allocate a reduction in nitrogen delivery equally among farms. In this case, each farm's allowed runoff (z_i) is 60 percent of its baseline (e_i). Let π_{i1} be the revenue on farm i under a uniform performance standard and $\Sigma\pi_{i1}$ be the watershed total revenue where the 1 subscript refers to uniform allocation. This uniform allocation requires no information to allocate the farm's reduction but does require information on an individual farm's baseline delivery and on control effectiveness of practices in order to determine each farm's required practices to achieve the standard. The required practices could be monitored to determine compliance.

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[3] Marginal costs of imposing a restriction on output such as limiting nitrogen runoff are estimated by minimizing the costs of producing a fixed output, while in the linear programming, outputs are allowed to change.

2.2.5 Perfect information (I=2)

Targeting the reduction in nitrogen delivery to farms with low compliance costs would result in lower total aggregate compliance costs than uniform allocation. A cost-effective performance standard which minimizes total aggregate compliance costs can be found by noting that z_i, the constrained amount of nitrogen delivery equals the baseline delivery, e_i, minus the required reduction r_i. The optimal reduction on farm i, r^*_i, can be found by minimizing:

$$\sum_i \sum_j \lambda_{ij} r_{ij} \tag{2.5}$$

where r_{ij}, the amount of nitrogen delivery reduction for which a shadow price j is imputed on farm i, is subject to the limitation:

$$r_{ij} \leq j \cdot e_i \tag{2.6}$$

on the amount of nitrogen delivery that can be allocated to the shadow price associated with a j nitrogen delivery reduction (Bosch, Batie, and Carpentier). For example, if $\lambda_{ij=80}$ and $\lambda_{ij=60}$ are estimated for the ith farm, then each shadow price applies to a reduction of up to 20 percent of the baseline delivery for farm i. Finally, the sum of the reductions across farms must achieve the 60 percent performance standard (40 percent loading reduction) in the watershed, 0.6•Z.

$$\sum_i \sum_j r_{ij} \geq .4\ Z \qquad (2.7)$$

Solving this constrained optimization problem yields the allocative cost-effective performance standard among farms z^*_i (where $z^*_i = e_i - r^*_i$). The watershed level of input, output, and nitrogen deliveries resulting from this allocation is found by replacing the z_i in (2.2) with the z^*_i's and rerunning the model.

Let $\Sigma\pi_{i2}$ be the sum of net farm revenues corresponding to a 40 percent reduction over the watershed with perfect information. This benchmark scenario maximizes the value of the nitrogen delivery or represents the minimum control costs to abate 40 percent of the watershed nitrogen delivery. The net value of perfect information is:

$$V_2 = \sum_i (\pi_{i2} - \pi_{i1}) - (TC_2 - TC_1) \qquad (2.8)$$

where TC_2 represents the transaction costs to target these farms including information costs to identify farm operators, collect farm data from the operators, and code, store, and analyze the data as well as contracting and enforcement costs (Bosch, Batie, and Carpentier). TC_1 are the transaction costs of the uniform performance standard: information, contracting, and enforcement. Information costs for the uniform standard include estimating baseline nitrogen delivery for each farm in order to estimate each farm's required reduction.

Three factors foster high enforcement costs with the perfectly targeted standard: a large number of farmers and practices to check, potential difficulties in observing practices adopted by farmers, and non-cooperation from farmers because they feel the standards are unfair. Site-specific modeling may be used to increase farmers' awareness of critical sites and practices which would eventually decrease enforcement costs (Shortle 1994; Shortle et al.; McSweeny and Shortle 1989; Huang and Leblanc 1994; Shortle and Dunn 1986; Harrington et al.). Whether the sum of compliance plus transaction costs are lower for perfect information compared to a uniform performance standard or a design standard is an empirical question addressed in Chapter Five.

2.2.6 Partial information targeting (I=3)

Policy makers may not desire or be able to collect perfect information. Also, because the cost-effective policy will vary across watersheds, it may not be practical to collect perfect information for each watershed. Instead, it would be valuable to develop rules or economic and physical conditions under which certain types of policies (control instruments and level of information for targeting the instrument) perform better to limit a priori the set of policies to evaluate.

This approach is similar to agronomists' attempts to "typify" site-propensity to leach or erode based on soil and hydrological types, for example. However, economists strive to achieve cost-effectiveness and add economic characteristics to those proposed by agronomists for targeting sites. An important economic characteristic is the site or farm marginal compliance cost or its linear programming equivalent, the shadow price of the nitrogen runoff delivery constraint.

Bioeconomic model simulations including linear programming can maximize profits subject to input and environmental pollution constraints. These models can be used to estimate farmers' costs of complying with various levels of constraints on pollution. Bioeconomic models predict changes in production and net returns associated with changes in pollution constraints.

When many farms are evaluated, estimating the response of each farm to changes in pollution constraints may be computationally expensive. Instead, metamodels can be used to summarize the information and perform sensitivity analysis (Blanning; Lakshminarayan et al.; Lakshminarayan, Bouzaher and Johnson). Metamodels are regression models summarizing area-wide (eventually state and country-wide) input/output relationships. For example, metamodels have been used in agriculture to summarize physical model predictions of pesticide concentrations under various physical characteristics (Lakshminarayan et al.).

The major disadvantage of metamodels is that they are not based on theory. Simulation inputs and outputs are examined and a functional form is specified in an ad hoc way (Blanning). In this study, the problem is overcome by summarizing shadow prices for various nitrogen delivery constraints using Euler's equation as explained below. The model's inputs are the bioeconomic inputs (combinations of crops, input management practices, and physical characteristics) and its outputs are milk production, nitrogen deliveries, and shadow prices. Basing the model on economic theory increases the likelihood that the model can be applied to other watersheds and increases the confidence that the coefficients of the model are not sample-dependent.

Shadow prices obtained from the nitrogen loading constraint in the linear programming model are regressed on farms' economic activities using ordinary least squares (OLS). The coefficients obtained can be used to predict partial information shadow prices. The model is specified with Euler's equation (Varian):

$$\sum_k \frac{\partial Y}{\partial X_k} X_k = \epsilon(Y)\ Y \tag{2.9}$$

where Y is the output, X_k are the k inputs and the return to scale ϵ equals one because the linear programming production functions are linearly homogenous (Leontief production function). Bringing inputs related to total nitrogen available to plants (TN) to the left-hand side we obtain:

$$\frac{\partial Y}{\partial TN} TN = Y - \sum_{\substack{k \\ k \neq TN}} \left(\frac{\partial Y}{\partial X_k}\right) X_k \tag{2.10}$$

Multiplying the marginal products by the price of output, P, and dividing both sides by TN we get:

$$P \frac{\partial Y}{\partial TN} = \frac{P\,Y}{TN} - \sum_{\substack{k \\ k \neq TN}} \left(P \frac{X_k}{TN} \frac{\partial Y}{\partial X_k}\right) \tag{2.11}$$

where the marginal value product of TN in the production of output Y is a linear function of average revenues per TN minus the sum of the marginal value products of other inputs (management practices)[4] times each input divided by TN. As specified the model has no intercept. TN is the available nitrogen to plants from all sources including precipitation, soil organic matter, fertilizer, and manure. Linear homogeneity ensures that doubling available TN doubles Y.

Euler's equation determines the marginal value product associated with nitrogen (TN) available to plants. However, the shadow prices are profit loss associated with a reduction in allowable total nitrogen delivery (TND). The relationship between $\partial Y/\partial TN$ and $\partial Y/\partial TND$ can be expressed as:

$$\frac{\partial Y_i}{\partial TN_i} = \frac{\partial Y_i}{\partial TND_i} \cdot \frac{\partial TND_i}{\partial TN_i} \tag{2.12}$$

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[4] Input use and management practices are used interchangeably here as changes in practices directly affect input use. For example, reduced nitrogen application rate can be accompanied by manure and soil testing and better timing of manure application.

where TND for farm i is obtained through:

$$TND_i = \sum_m \gamma_{im} \cdot TN_i \tag{2.13}$$

The γ_{im} are the interaction terms or slope shifters that modify the relationship between TN and TND according to the landscape and management practices on farm i ($0 < \gamma_{im} < 1$). Taking the derivative of TND with respect to TN yields γ_i. Replacing the left-hand side in (2.11) with λ_i and dividing by the right-hand side by the adjusted TNi yields the estimatable equation:

$$\lambda_i = \frac{P_i \cdot Y_i}{\gamma_i TN_i} - \frac{x_{i2}}{\gamma_i TN_i} - \ldots\ldots - \frac{x_{ik}}{\gamma_i TN_i} + \epsilon_i \tag{2.14}$$

In (2.13) the average or marginal productivity of Y_i is adjusted for the difference between total nitrogen applied and nitrogen available to crops. The measurement of variables and estimation techniques used to estimate the metamodel are discussed in Chapter Six.

Equation (2.13) can be used to predict shadow prices in other regions with similar production systems and resource endowments. These estimated shadow prices can be used to set site-specific taxes, target voluntary or regulatory programs, or provide the information necessary for a pollution permit trading market. For the partial information performance standard, these estimated shadow prices are used to decide which farms to target and their preliminary control burden. The final allocation of control to the targeted farms is determined with the partial information shadow prices through equations (2.5) to (2.7). That is, control burdens are allocated to the lowest shadow price first, and so on, until enough units have been allocated to attain the desired reduction.

The value of partial information to target agro-pollution control is

$$\sum_i (\pi_{i3} - \pi_{i1}) - (TC_3 - TC_1) \tag{2.15}$$

where TC_3 and TC_1 are the transaction costs for the partial information and no information scenarios and π_{i3} and π_{i1} are farm i's profit when pollution control responsibilities are allocated using partial information and no information. Once most production systems and climatic areas of the country have been covered, the conceptual model presented above can be applied by decision makers to compare levels of information for targeting performance standards and to identify the cost-effective information level for their region.

2.3 ECONOMIC AND PHYSICAL MODELING

To evaluate the targeting policies above, baseline production and pollution must be estimated and pollution reduction under the various performance standards evaluated. The prevalent approach is to use bioeconomic models to estimate pollution and economic returns from alternative practices as farm characteristics are varied (Dosi and Moretto; Shortle 1984). Bioeconomic models may include mathematical programming routines to optimize farm, watershed or regional returns subject to limits on pollution (Ellis, Hughes, and Butcher).

2.3.1 Farm modeling

Mathematical programming models are useful to integrate multiple constraints and options. Multiple control strategies can be evaluated at the same time, and the sensitivity of the results to changing data inputs and model parameters can easily be analyzed. The programming model can easily be augmented with new production techniques and additional activities (Wossink, de Koeijer, and Renkema). Thus, various input or output taxes, emission standards, and design standards or any mix of them can be accommodated easily.

2.3.2 Physical modeling

Because farmers are not expected to possess better information about the polluting and control process than the control agency, physical modeling might be necessary (Dosi and Moretto) to obtain this information for farmers and to tailor incentives to site characteristics. Farmers cannot easily measure how much of each pollutant leaches or runs off from their land under various best management practices (BMPs) because the relationship between agro-production and pollution is diffuse, uncertain, and subject to lags. First, loadings depend not only on farmers' practices but also on precipitation. Farmers' ex ante choice of management practices based on expected precipitation may no longer be cost-effective once the weather is realized. Second, loadings must be monitored over the entire field because agro-pollution is diffuse. Finally, agro-pollution reduction may not be immediately apparent, but may only become obvious after many years.

Output from simulation models can then be used to provide farmers with a schedule showing the relationship between estimated erosion and management practices. Models to make these analyses should provide for simultaneous analysis of various factors such as weather and soil characteristics and should incorporate surface and groundwater impacts (Lee and Lovejoy). Simultaneous analyses of pollution and economic impacts of policies can be conducted by combining physical models such as EPIC (Erosion Productivity Impact Calculator) (Williams et al.), CREAMS (Chemical, Runoff, and Erosion from Agricultural Management Systems) (Knisel) or GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) (Leonard, Knisel, and Still) with economic models. Alternatively, the physical relationships can be directly incorporated in the economic model.

2.3.3 Econometric modeling

Econometric models are also used to model economic and environmental responses to policies. The metamodeling approach uses physical models such as EPIC to generate changes in yields and loadings under numerous input, management practice, soil, precipitation, and hydrology conditions. This simulated data is then used in regressions to estimate pollution changes and compliance costs of various policies. For example, yields and loadings are regressed on the input variables. Because the input parameters and the dependent variables are correlated, seemingly unrelated regressions (SUR) are used, and the approach is called metamodeling (Bouzaher and Shogren; Lakshminarayan, Bouzaher, and Johnson). A recent application of the method by Bouzaher et al. uses a bioeconomic model and a metamodel to evaluate policies to protect ground and surface water.

Helfand and House took a similar approach in their study of nitrogen pollution from lettuce growing on two California soils. The number of alternative simulations possible in EPIC is quasi-infinite, and searchers have to limit themselves to a reasonable set of alternatives. Helfand and House generated 750 simulations and yet their analysis only includes change in water and nitrogen input, a fairly limited number of inputs (or management practices) for one crop. This method does not consider the farm location, endowment, current practices, or physical characteristics necessary for prioritizing and targeting problem farms.

2.3.4 Microparameter approach

The spatial and technological diversity of agro-pollutants and farms is not reflected in most studies, which are based on representative farms. Thomas and Boisvert; Fox, Umali, Dickinson; Taylor, Adams, and Miller; and Wossink, de

Koeijer, and Renkema incorporated farm physical characteristics in their models but did not preserve the link between farms' economic characteristics and physical endowments, because they modeled representative farms. These models cannot accurately estimate the distribution of farms' abatement costs within a watershed. Microparameter models are labeled as such because they preserve observable micro-level input-output and output-pollution relationships (Wu and Segerson). To predict policy effects within a watershed, one needs to know not only how many acres (extensive margin) and how inputs per acre (intensive margin) will be adjusted, but also the location of these farms in order to predict environmental impacts which are site-specific. Opaluch and Segerson; Antle and Just (1991, 1992); Just and Antle; and Antle and Capalbo have recommended that the site specificity of agro-pollution problems be accounted for with microparameter distribution models. These models can account for diverse site characteristics and farm characteristics and yet provide accurate aggregate estimates of the impacts of policies on farmers and on the associated pollution for a region. Micro- and aggregate-level analyses are linked through a statistical representation of the physical environment and the production units (Antle and Capalbo).

Microparameter distribution models assume that producers maximize profits subject to fixed distributions of farm economic and physical characteristics. Policy responses result from a two-step process where farmers find the input bundle maximizing profits for a given crop and then determine the profit-maximizing crop mix for a particular parcel. This approach provides a statistical means to aggregate inputs, outputs, and loadings across parcels in the survival region (farms with positive profits). The agricultural pollution-loading impact depends on the distribution of crops produced across parcels and the distribution of input and farming practices across parcels (Bosch and Carpentier). The appropriate unit of analysis is a parcel of land with homogeneous physical and economic characteristics (Antle and Capalbo; Segerson and Wu).

Application of the microparameter approach requires extensive socioeconomic and physical data on numerous sites within a watershed in order to estimate farm production and pollution responses to policy or price changes. Economic and physical data should be collected jointly to preserve correlations between these characteristics. Lack of such jointly collected data may prevent application of the microparameter approach (Shoemaker, Ervin, and Caswell). Wu and Segerson limit the microparameter model to estimating changes in extensive margins. In their approach farmers decide how to allocate their acreage across crops. Each acre is categorized by physical characteristics affecting yields such as soil type, permeability, and underlying geological structure (Wu and Segerson).

2.3.5 Modified microparameter approach

The bioeconomic model used in this study uses survey data to implement a modified microparameter approach (Antle and Capalbo) to policy analysis (Bosch and

Carpentier). Each farm in the model can respond to exogenous changes by intensive or extensive margin adjustments. Spatial variability is accounted for by applying the model to multiple farms in the watershed using survey-reported practices and endowments. Consistent with the microparameter approach, the model contains farm-specific parameters related to production and pollution which are fixed in the short run. However, returns and pollution are estimated with a mathematical programming model which permits a detailed representation of the farm at each site, as opposed to being estimated statistically. The model is validated by comparing modelled livestock and crop production with no constraints on nitrogen delivery with survey results. Pollution loadings resulting from agricultural practices are assumed to be certain.

Earlier work has linked simulation and survey data for aggregate analysis. FEDS (Firm Enterprise Data system) budgets have been combined with the Natural Resource Inventory (NRI) data to estimate net returns and soil productivity (Heimlich), and changes in rental payment and net income with alternative strategies for retiring land in the Conservation Reserve Program (Huang et al.) at NRI points. The approach described here is similar to that of Heimlich and Huang et al. but uses optimization to model the whole farm as opposed to a single enterprise at the survey point (Bosch and Carpentier). The Area Studies agricultural production (Resources and Technology Division) survey data at statistically selected NRI points provides the data on farm and site characteristics.

CHAPTER THREE: TRANSACTION COSTS OF TARGETING AGRO-POLLUTION CONTROL

3.1 DEFINITION OF TRANSACTION COSTS

The transaction cost literature is primarily concerned with private transaction costs that relate to the organization of the firm. The externality literature also mostly refers to private transaction costs in relation to the Coase theorem, which stipulates that in the absence of transaction costs among firms, the externality problem can be resolved by specifying complete well-defined property rights (Coase). That is, Pigouvian taxes are not necessary to correct externalities in the absence of transaction costs.

As discussed in Chapter Two, the large number of farms, the difficulty of observing farm practices and diffuse and uncertain agro-pollution, imply large transaction costs for reducing pollution through the market. Thus, some government actions must be undertaken to achieve pollution reduction. Governmental actions to control agricultural pollution involve information, contracting, and enforcement costs by governments. After defining these costs, this chapter proposes a framework to account for transaction costs in designing social cost-effective targeted policies. Social cost-effective policies minimize the aggregate compliance costs plus public transaction costs of control. Finally, empirical estimates of transaction costs are developed for each targeting strategy in this dissertation (except for partial information costs which appear in Chapter Six, where the variables needed to target farms with partial information are elicited).

Krier and Montgomery define information costs as the costs to collect the knowledge necessary to achieve a more efficient allocation of a given resource. In this dissertation the presumed goal of the policy maker, however, is to minimize total control costs -- the sum of aggregate compliance costs and transaction costs -- to achieve social cost-effectiveness. Information costs depend on the policy used -- where a policy is a combination of a targeting strategy and information level. Polinsky and Shavell define administrative costs associated with a Pigouvian tax as the "cost of monitoring the externality-generating activity, the time spent completing forms, and the expense of resolving disputes over tax liability" (p. 386). The definition applies to performance standards by replacing the word tax by loadings. Private transaction costs associated with a market for trading pollution rights are defined as the cost to inspect and measure the goods to be transferred, draw up contracts, consult with lawyers or other experts, and transfer title" (Stavins 1993, p. 3). The definition of transaction costs used in this study is more limited due to lack of data.

Information costs for the policies discussed in this study include the costs of targeting farms: 1) gathering information about actual farm practices and loadings which may vary by state of nature. Information costs are made up of the i) fixed costs of gathering the information to allocate control responsibilities (which vary with the policy selected) and ii) variable costs of gathering and updating information about targeted farms. 2) identifying practices for each farm that achieve the farm's allowed loading for performance standards, and 3) modeling activities to estimate aggregate compliance costs for the perfectly or partially targeted performance standards.

Information costs increase as the useful life of the information decreases. Information costs also increase as the usefulness for other purposes or agencies of the information collected decreases. Information costs also increase with the difficulty of observing prescribed practices. For example, a policy requiring information about the presence of a permanent structure is less information-expensive than one requiring observing a rotation every year.

Government contracting costs are defined here as administrative and staffing costs involved in contacting the targeted farms, in reaching an agreement with the farmer, and in writing up the contract to create the legal status necessary to implement policies. A contract is a mutually agreed upon set of specifications about the range of activities and practices to be followed on the farm as well as compensation, if any. Mitigation costs are not included. Contracting costs that vary directly with the number of contracts and the heterogeneity of the contract have been disregarded when borne by the government (Shoemaker, Ervin, and Caswell). Krier and Montgomery mention the existence of contracting costs but concentrate on information and enforcement costs.

There might be economies of scale in writing specialized contracts. Once the government staff has written the first contract, additional similar contracts should be relatively inexpensive to write (Easter). However, if the farm sector is highly variable, all contracts may have to differ greatly.

Enforcement activities determine whether or not practices have been adopted and impose penalties on non-complying farms (Letson, Crutchfield, and Malik; Shortle and Dunn, 1984, 1991). Farms must be visited (audited) or aerial pictures must provide evidence that practices agreed on are in place. More frequent visits or checks on the farm and greater penalties for non-compliance increase the incentive for farmers to comply and hence increase the likelihood of obtaining the desired ambient water quality. In theory, if the marginal expected fine is set equal to the marginal compliance costs, fines are never levied and enforcement costs include only the visit costs (Letson, Crutchfield and Malik) and the cost of collecting marginal cost information to set the fine (a fact usually not acknowledged). Also, large fees are politically infeasible[1] and spot checks may have to be numerous, increasing enforcement costs. The type of contracts and the complexity and observability of the practices also affect enforcement costs. The present study implicitly assumes that all farms comply with the performance standard.

Any strategy will eventually involve monitoring water quality to measure program success. The performance goal or type of mandatory design standards may have to be adjusted accordingly. These costs are not considered in the present study as they do not vary among the targeting strategies.

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[1] Imposing large fees on farmers may lead to bankruptcy, in which case the water quality may still not be achieved and the program is very unpopular.

3.2 AGENCY OBJECTIVES IN CONTROLLING AGRO-POLLUTION

In this study it is assumed that the agency's goal is to minimize total social welfare costs of achieving the agro-pollution goal. These social costs include: 1) the change in welfare due to changes in prices and property rights, 2) aggregate compliance costs, and 3) transaction costs. Assuming input and output substitutions in the watershed do not affect prices, social costs are the same as transaction plus aggregate compliance costs given the initial sets of ownership rights.

Compliance costs are borne by the farmers and include the costs of switching their production system in order to achieve their pollution reduction responsibility. Transaction costs are assumed to be borne by the agency and depend on the level of information collected, the number and complexity of individual contracts written, and the ease of enforcement of each policy.

Elected governments want to favor their constituencies and will take into consideration the political costs of alternative policies. Political costs associated with different allocations of responsibility and different property rights affect various groups (such as farm types, tax payers, and water users) differently. For example, if the farm sector (more precisely dairy farms in this study) are severely affected, they are not likely to cooperate and thus could significantly raise enforcement and contracting costs. This dissertation does not account for these political costs explicitly. In the next section a framework to choose among alternative agro-pollution control targeting policies based on aggregate compliance and transaction costs, given an initial distribution of property rights, is presented.

3.3 MODEL

To minimize total control costs the agency must choose the targeting strategy and the level of information (Figure 1.1). Design standards are uniformly applied, thus the level of information is predetermined. These policies' costs are calculated in Section 4.3 and 4.4 of this Chapter.

For the performance standards, three levels of information are compared in this study: 1) no information, 2) perfect information, and 3) partial information. Uniform targeting (I=1) refers to collecting baseline nitrogen deliveries information only, no information is used to allocate control burdens among farms. Perfect information (I=2) is defined as collecting farms' marginal compliance costs and estimated nitrogen deliveries in order to equalize farms' marginal compliance costs across the watershed and attain a cost-effective allocation. Partial information targeting (I=3) requires less information than the cost-effective allocation but more than the uniform allocation. Farms are targeted based on marginal compliance costs predicted using farm management and physical characteristics (see Chapter Six).

Private compliance costs for each level of information for the performance standard are estimated through equations (2.1) to (2.3). The model ALLOCATI, a linear programming model is used to carry out a cost-minimizing allocation of reductions among farms (see Appendix B). ALLOCATI can find the allocation which minimizes aggregate compliance costs only (private cost-effective) and the allocation which minimizes the sum of aggregate compliance and public transaction costs (social cost-effective allocation). The following adaptation from Stavins (1993) demonstrates the effect of transaction costs on the conditions for social cost-effective control allocation.

To achieve their allowed nitrogen deliveries, $z_{iI,}$ farmers maximize net returns subject to constraints as described in Equations 2.1 to 2.3. The difference between the unconstrained (baseline) profits (π_i) and restricted profits (π_{iI}) are the farm costs (C_{iI}) of meeting the constraints for level of information I. Assuming that prices in the watershed are unaffected by the control activity, the agency minimizes the total costs of achieving Z, a specific level of nitrogen delivery as follows:

$$MIN \sum_i C_{iI}(r_{iI}) + TC_{iI}(r_{iI}) \tag{3.1}$$

subject to

$$\sum_i [e_i - r_{iI}] \leq Z \tag{3.2}$$

and

$$0 \leq r_{iI} \leq e_i \qquad \forall_i \tag{3.3}$$

Because a performance standard gives farmers flexibility to achieve the required standard, it can be assumed that farmers minimize their compliance costs to achieve the standard z_i. z_i is the difference between the initial pollution (e_i) and the reduction (r_i) secured by farm i (Equation 3.1). $C_i(r_{iI})$ is the cost of achieving a level of nitrogen reduction r on farm i, with policy I. The sum of each farm's allowed level of pollution z_{iI} has to be less than the allowed watershed loading ($\Sigma z_{ij} = Z$) (Equation 3.2). TC_{iI} are the transaction costs associated with policy I. Equation 3.3 limits the reduction on farm i to be less than the baseline loadings. The Kuhn-Tucker conditions for this inequality constrained optimization are:[2]

$$\frac{\partial C_{iI}}{\partial r_{iI}} + \frac{\partial TC_{iI}}{\partial r_{iI}} - \lambda \geq 0 \tag{3.4}$$

$$r_i \left[\frac{\partial C_{iI}}{\partial r_{iI}} + \frac{\partial TC_{iI}}{\partial r_{iI}} - \lambda\right] = 0 \tag{3.5}$$

$$\sum_i [e_i - r_{iI}] - Z \leq 0 \tag{3.6}$$

$$\lambda\left[\sum_i [e_i - r_{iI}] - Z\right] = 0 \tag{3.7}$$

$$\lambda \geq 0 \tag{3.8}$$

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[2] Assuming that the abatement functions are convex within their relevant ranges.

where λ is the Lagrange multiplier indicating the savings of incremental increases in nitrogen deliveries z_{iI}.[3] Marginal costs are positive and the a farm is assigned a positive reduction level if the farm satisfies (3.4) with equality and zero otherwise.

Equations (3.4) and (3.5) differ from the usual private cost-effective conditions; for farms with positive reduction, the *sum* of the marginal compliance costs and marginal transaction costs must be equal among the farms. At the social cost-effective allocation, for those farms assigned a positive level of reduction, the farms' marginal costs of compliance *plus* marginal transaction costs must be equal to the cost savings, λ, when Z is relaxed by one unit. The total cost to society is not C_I $(=\sum C_i)$ alone, but C_I *plus* $TC_I(=\Sigma TC_{iI})$. Aggregate compliance costs are assumed to be negatively related to the information level. Collecting the information to minimize compliance costs is expensive, thus enough variability in the expected marginal compliance costs must be present to justify this intensive information collection.

Equation (3.4) and (3.5) have important implications for regulatory policies; if the sum of the marginal compliance plus transaction costs for farm i are greater than λ, these farms have $r_{iI} = 0$ for the social cost-effective allocation. If the agency had perfect control (and information) it would require each farm that satisfies equation (3.4) with equality to have a positive level of reduction r_{iI} and for farms that satisfy (3.4) with inequality $r_{iI} = 0$.

The resulting allocation is the same as if the farms internalized the costs of

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[3] λ can be interpreted as the savings from relaxing the nitrogen runoff constraints by one unit or the cost of restricting nitrogen runoff by one more unit.

transactions. The agency weighs the marginal transactions cost of targeting one more farm versus the reduction in aggregate compliance costs if a farm already targeted were allocated more reduction. Given that a level of information has been selected, fewer farms are targeted than otherwise when transaction costs are taken into account. Targeting farms with greater pollution or lower compliance costs has the potential to reduce total control costs, but the information costs necessary to target fewer farms may exceed the reduced compliance costs. A strategy that uses less information may be socially more cost-effective. Thus, the total control cost for each policy must be compared.

3.3.1 Theory: Accounting for transaction costs

Equations (3.4) to (3.8) can be related to Equations (2.5) to (2.7) to obtain a social cost-effective allocation by replacing $\partial C_{iI}/\partial r_{iI}$ with λ_{ij}, $\partial TC_{iI}/\partial r_{iI}$ with $\partial TC_i/\partial j$ (=MTC_{ij}) where $r_j = j \bullet e_i$ and j takes on discrete 20, 40, 60, and 80 percent reductions in runoff. MTC_{ij} can be constant, increasing, or decreasing in r_j and it can be zero implying that TC_{iI} are "fixed" per farm -- not dependent on the control burden imposed on the farm. Increasing marginal costs can result from more law suits and enforcement to collect the fine or from a higher auditing rate necessary to monitor compliance as the incentive to default increases with higher restriction levels. Increasing marginal transaction costs are ruled out in this study because the auditing rate is 100 percent. That is the expected fine equals marginal abatement costs removing any incentive to cheat.[4]

[4] Assuming the expected fine (= auditing rate * fine) = marginal abatement costs removes any incentive to cheat.

Marginal transaction cost depends on whether the farm is targeted or not; MTC > 0 if the farm is targeted. However, in targeting farms most of the information costs in deciding which farms to target and how much reduction to achieve are "fixed" per farm, and not dependant on the level of reduction. These are cost for driving to the farm, completing questionnaires, preparing a farm folder and so on. Thus, once a farm is targeted TC are assumed to be "fixed" per farm and MTC = 0 after the first pound of nitrogen reduction implying that MTC is independent of how much control burden is put on the farm.

The cost of achieving the 40 percent reduction in nitrogen deliveries in the Lower Susquehanna watershed is minimized as follows:

$$\min \sum_{i} \sum_{j} [\lambda_{ij} + MTC_{ij}] \cdot r_{ij} \tag{3.9}$$

subject to:

$$r_{ij} \leq j \cdot e_{i} \tag{3.10}$$

$$\sum_{j} r_{ij} \leq \sum_{j} j \cdot e_{i} \tag{3.11}$$

and

$$\sum_{j} \sum_{i} r_{ij} \geq .4\ Z \tag{3.12}$$

Where λ is the shadow price associated with a j percent pollution reduction on farm i as before and the policy subscript has been omitted for clarity. MTC_{1j} is high for the first pound abated and drops to zero thereafter -- once the farm is targeted there are no extra transaction costs of reducing nitrogen deliveries. Enforcement costs could increase in j (Polinsky and Shavell, Kohn), but this effect is not accounted for here. In ALLOCATI, transaction costs are pro-rated over the first j (20 percent) loading reduction under the assumption that 1) if a farm is targeted then at least a j percent reduction is obtained and 2) transaction costs are not affected by the level of reduction j.

Equation (3.9) minimizes the total control costs of achieving Z in the watershed, while accounting for the fixed costs of "buying" the first pound (MTC). Equation (3.10) restricts the maximum pollution allowed at price λ_{1j} to j percent (20 percent here), the interval for which shadow prices were estimated; it is the same as Equation (2.6). Equation (3.11) restricts the reduction of pollution on each farm to be less than the reductions for which shadow prices were computed. For example if, shadow prices were obtained for 20, 40, 60 and 80 percent standards, no more than 80 percent of the loading can be reduced on each farm because no shadow price was computed for the last 20 percent. Equation 3.12 is the same as equation 2.7; it requires total reduction to be 40 percent of baseline loadings in the watershed. As in Chapter 2 solving the system yields z^*_{ij} that can be replaced in the bioeconomic model to get watershed levels of input, output, and nitrogen deliveries.

3.3.2 Limitations: Property rights and distributional effects

Litigation might be important in controlling agro-pollution not only because little is known (and certain) about the movement and fate of nonpoint source pollution but also because property rights over "public" rivers and bays and "private" use rights on the farms are not well-defined.

The four policies in this study imply different property rights. Under a mandatory policy, the perfectly and partially targeted performance standards take away from the targeted farmers the right to pollute, but not from non-targeted farms, thereby changing the structure of property rights. For example, a targeted farm may have lower resale value than a non-targeted farms because of the loss of right to pollute attached to the land. Subsidizing targeted farmers implies that by restricting what practices can be used on the farm, agencies take away farmers' rights and must therefore compensate them.

The uniform performance standard takes away the right to use certain practices on all farms. The standard could be written such that if farmers are in compliance they are immune from liability; they would then preserve their "limited" rights to pollute. Political costs associated with targeted performance standards are likely to be higher than uniform design standards or uniform performance standards because the standard takes rights away from targeted farmers. Design standards affect farmers that had not previously implemented the prescribed practice on their farms. For example, a standard requiring all farms to have manure storage only affects farmers without manure storage. Thus, the "land rights" of farms who already have storage have not changed and the money invested (less depreciation) can be recovered in the selling price (assuming that manure storage facilities increase the farm's value). Standards prescribing non-permanent or non-structural investments such as requiring a type of tillage system or restricting when manure can be spread could reduce the value of the land by reducing the right it confers, this loss cannot be recovered at resale time.

Cost-effectiveness allocation of control burden is not an absolute concept, but rather is relative to existing property rights, policy and government structures (Randall).[5] Existing government support programs and assumed or defined property rights affect prices and the negotiating power of different agents, hence a different cost-effective allocation of resources will result from each initial set of existing policies and property rights (Randall). Accepting the cost-effectiveness allocations implicitly assumes the existing allocation of resources is socially optimal (Bromley). Recognizing this limitation, this study identifies the minimum total costs to control agro-pollution under current property rights by generating information about how much compensation would have to be made to make farmers as well off as without the policy.

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[5] Under perfect competition and complete property rights, the prices at which commodities exchange in the market reflect these commodities' social values. If these prices are disturbed by government programs, they may not reflect social values anymore.

3.3.3 Partial analysis

To estimate the total social costs of each policy, a general equilibrium model allowing price changes should be used if the policy is national in scope or affects large regions. In this study the watershed size, and its agricultural output are small enough to justify fixed prices. However, if the standard were applied to the whole Chesapeake Bay prices would have to be endogenous and price-elasticity used to adjust farms' output and input purchases, especially if the standard is uniformly applied. By targeting farms, the aggregate economic effect in the watershed is reduced which tend to increase the value of information and diminish the importance of endogenous prices.

3.4 TRANSACTION COSTS

Data on transaction costs are lacking. The procedure used here is to identify the activities required to target and enforce nitrogen runoff reductions and to estimate their costs using budgeting. A description of the activities involved to collect the necessary information to contract and to enforce the policies is provided in the next section. Activities and the number of hours per activity were derived through phone interviews with the Pennsylvania and Virginia Natural Resources Conservation Services and the Pennsylvania Department of Environmental protection (see Appendix A) as well as from interviews with researchers experienced in running crop simulation models for farm level analysis. Estimated hours are multiplied by hourly wages (including benefits) for field staff or technicians ($23, Faulkner), nutrient management experts and agricultural engineers ($25, Faulkner), and attorneys ($32, Lee), respectively.

Transaction costs vary with the agency[6] charged with collecting the information and writing and enforcing contracts. The agency that would be in charge of administering the policy is unknown, thus most likely costs from the above agencies are used to estimate potential transaction costs. Costs for each strategy are annualized over a ten-year horizon.

3.4.1 Uniform estimated performance standard

This section documents transaction costs for the uniform performance standard. Information activities and costs are reviewed first, followed by contracting and enforcement activities and associated costs.

3.4.1.1 Information

Under the uniform standard farms are not targeted, a 60 percent performance standard is uniformly applied to all farms. The agency must still estimate a baseline pollution loading level e_i and a set X_i of practices that achieves the 60 percent performance standard on each farm (or 40 percent reduction). Once the baseline is established, practices that achieve the standard must be identified, thus under a regulatory approach, all performance standards are perfectly targeted design standards.

It would not be practical to monitor pollution from each farm, thus simulation

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[6] In accordance with the Coastal Zone Management Act, Pennsylvania passed a law requiring manure management plans and manure storage depending on the dairy herd size, but there is no mention as to which agency would enforce the policy (Young).

models that predict the flow and path of pollution under the farm conditions are used to estimate the baseline. To run these models, agency personnel must acquire farm physical and cultural practices. Information costs derived for a ten-year horizon with annual information updates are annualized and presented in Table 3.1.

Information is collected by an agent traveling, on average, 30 miles to visit each farm at $0.25 per mile (Table 3.1). On average traveling time is one hour because conservation districts offices tend to be located in the center of each county. The Pennsylvania DEP Conservation Districts take 28 hours on average to develop whole farm nutrient management plans for the Pennsylvania Chesapeake Bay Program, while the Pennsylvania Natural Resource Conservation Service (NRCS) takes 8 hours to develop BMPs. An average of the two requirements, 18 hours, is used for the uniform performance standard. In Table 3.1 these 18 hours are divided into 13 hours spent traveling to farms and gathering information and five hours spent establishing the set of practices that potentially could reduce nitrogen deliveries by 40 percent on farm i (included in the 38 hours). The visits also help identify alternative practices that the farmer is aware of that might be introduced to reduce nitrogen deliveries.

A physical model is used to verify that practices will reduce nitrogen deliveries by the required amount. Physical models, such as EPIC (Erosion Productivity Impact Calculator) (Williams et al.) already exist but must be calibrated and adjusted for the watershed characteristics. EPIC for example, is calibrated with monitoring results

Table 3.1 Per Farm Annual Transaction Costs: Uniform Performance Standard[a]

Activities	Actor	Hours	Costs ($)	Present Value	Annualized[b] Costs
Information					
•Travel to farm[c,d]	Technician	1	31	31	4
•Gather field boundaries, soils, crops, and management practices information	Technician	13	299	299	39
•Calibrate EPIC obtained baseline	Technician	13	299	299	39
	Expert	4	100	100	13
•Delivery ratios	Technicians	2	46	46	6
•Establish X_{lk} available to farm[e]; run EPIC	Technician	38	874	874	113
•Draft the plan	Expert	2	50	50	6
•Yearly update baseline	Technician	12	276	2131	276
Annual information costs					496
Contracting					
•Travel to farm	Technician	1	31	236	31
•Present plan	Technician	2	46	355	46
•Draw contract	Attorney	1	32	247	32
Annual contracting costs					109
Enforcement					
•Travel to farm	Technician	1	31	236	31
•Assess practices	Technician	2.4	55.2	426	55
Annual enforcement costs					86
Total annual transaction costs					690

[a] Costs are based on a ten-year horizon and a real interest rate of 5 percent.
[b] Annualization factor equal to 7.7217 from Lee et al. Appendix Table 4, n=10, I=5. Column totals may not add up due to rounding errors.
[c] Travel costs include an average of 30 miles at $0.25/mile and an hour of technician travel time.
[d] Hourly wages are $23, $25, and $32 for technicians, experts and attorney respectively.
[e] Where X_{lk} is the set of practices achieving 40 percent TND on the farm.

when existent, but most often in collaboration with an agronomist or a soil scientist. EPIC is run for every soil/crop/management practice and, with the help of an expert familiar with crop simulation models, input parameters are adjusted until the resulting nitrogen deliveries are believed to be reasonable estimates. This process could take a technician four hours to set up and 45 minutes per rotation to run. An average dairy farm in the watershed has twelve rotations,[7] thus it takes 13 technician hours to establish the baseline. An additional four hours of the expert's time to "validate" the results are also needed (Parsons).

EPIC estimates runoff to the edge of the field; these estimates must be adjusted for the distance, ground cover, and slope of the flow path to the receiving body of water in order to compute delivery of nutrients to surface water. Assuming this information has been collected during the farm visit, nitrogen deliveries can be calculated using delivery ratios (Shanholtz and Zhang). Distance and flow path are easier to assess through GIS but can be derived from Soil Survey Maps and Natural Resources Conservation Services knowledge of the terrain in their counties. EPIC erosion and nutrient estimates can also be used with the Chesapeake Bay Program model to estimate delivery (Wagner). Estimating nitrogen deliveries may take two technician hours annually.

Once the baseline is established for the farm, technicians are assumed to need 38

[7] Based on the bioeconomic model, SUSFARM, baseline results.

hours to pull out the farm's file, change the input parameters obtained from the farm visit and run the model for approximately ten management practices per farm until the set X_{lk} of practices that reduce nitrogen loadings has been identified. An additional two hours is required for the expert to draft the plan. Each year the set of crop and practices must be updated to account for changes in individual farm cropped area, crop substitution, and other changes affecting the farm plan, adding 1.5 day (12 hours) per year to the baseline costs. The present value of the additional yearly costs and the immediate costs are annualized to $496 (see Appendix C for details).

3.4.1.2 Contracting

Contracting involves going back to farms to discuss possible plans with farmers and reaching an agreement. Farmers must be presented with the set of practices X_{lk} for their farms and allowed to choose their preferred practices which is assumed to take two hours. An attorney can then write the contract with the practices agreed upon and the farmer has to visit the office to sign. The contract is renewed each year to account for changed economic conditions. Contracting costs amount to $109 per year (Table 3.1)

3.4.1.3 Enforcement

Enforcement consists of verifying that the practices in place are those agreed to by the farmer and formalized in the contract. This verification can be accomplished through self-reporting and spot checks or visits to each farm. Farm adjustments are likely to be complex and involve more than one BMP as well as a nutrient management plan, thus the 3.4 hours estimate from the Virginia Natural Resources and Conservation Service (NRCS) is used. The Virginia NRCS verifies that farms participating in commodity programs are in compliance with their farm plans by checking that the crops, rotations, tillage, and residue levels are in accordance with the farm plans, which are similar activities as would be required under a performance standard.

3.4.2 Perfect information performance standards

Targeting with perfect information entails high information costs because it involves determining baseline nitrogen deliveries and collecting each farm's compliance costs for alternative practices in order to find the cost-effective allocation of nitrogen deliveries among farms. Any mandatory variable performance standard will be hard to enforce due to perceived unfairness. The allowable set of practices and compliance costs will vary among farms, which may lead to equity problems and to some opposition. However, the equity problem will arise with any cost-effective program, farms closer to surface water bodies are more affected, for example, than farms further away. The targeting strategy presented here can also be used to allocate cost-share funds in a voluntary program and for implementing voluntary nutrient reduction trading programs, which may be easier to enforce. Furthermore, given the pollution reduction imposed on the farm, the procedure identifies the cost-minimizing practices for the farms; information that farmers do not have to generate.

3.4.2.1 Information

Information costs for the perfect information standard are divided into fixed and variable costs. The costs of collecting the information to allocate responsibilities among farmers is fixed once the policy is chosen, while the variable costs are the plan drafting costs and annual costs of updating information for targeted farms. The initial costs of visiting the farm and calibrating EPIC are the same as for the uniform standard (Table 3.2).

Farmers make management decisions for the farm as a whole. For example, a farmer not only decides whether to grow corn in rotation with alfalfa with reduced tillage, but also how much of each crop is needed to ensure adequate feed, depending on soil quality and yields. Thus, a bioeconomic model is needed to estimate the private cost-minimizing allocation of responsibilities among farms. The bioeconomic model used in this dissertation has the advantage of simultaneously estimating cost-minimizing practices and their nitrogen deliveries. The calibrated model such as EPIC which is described above would be used to provide estimates of site-specific nitrogen deliveries from alternative practices to the bioeconomic model.

To build the economic side of the model, input and output prices can be gathered from different state agencies and farmers. Practices in use in the watershed and that must be modeled are well-known to extension agents and NRCS agents or soil conservationists that work closely with farmers. For management practices not in used

Table 3.2 Per Farm Annual Transaction Costs: Perfectly Targeted Performance Standard[a]

Activities	Actor	Hours	Costs ($)	Present Value	Annualized[b] Costs
Targeted farms					
Information					
•Travel to farm[c,d]	Technician	1	31	31	4
•Gather field boundaries, soils, crops, and management practices information	Technician	13	299	299	39
•Calibrate EPIC obtained baseline	Technician	13	299	299	39
	Expert	4	100	100	13
•Delivery ratios	Technicians	2	46	46	6
•Build bioeconomic model and interface	Expert			9	1
•Establish X_{lk} available to farm[e]; run EPIC	Technician	38	874	874	113
•Predict farms' shadow prices	Technician	6	138	138	18
•Draft the plan	Expert	3	75	75	10
•Yearly update of best practices	Technician	16	368	2842	368
Annual costs					610
Non-targeted					
Information					
•Travel to farm[c,d]	Technician	1	31	31	4
•Gather field boundaries, soils, crops, and management practices information	Technician	13	299	299	39
•Calibrate EPIC obtained baseline	Technician	13	299	299	39
	Expert	4	100	100	13
•Delivery ratios	Technician	2	46	46	6
•Build Bioeconomic model	Expert			9	1
•Establish X_{lk} available to farm[e]; run EPIC	Technician	38	874	874	113
Total					215

Table 3.2 Continued

Activities	Actor	Hours	Costs ($)	Present Value	Annualized Costs
Contracting					
•Travel to farm[c,d]	Technician	1	31	31	31
•Discuss plans	Technician	2	46	355	46
•Travel to farm[c,d]	Technician	1	31	31	4
•Evaluate farmers' proposed alternative,	Technician	2	46	355	46
•Draw contract	Attorney	1	32	247	32
Annual cost					158
Enforcement					
•Travel to farm[c,d]	Technician	1	31	31	31
•Assess plan	Technician	2.4	55	426	55
Annual cost					86
Total annual transaction costs targeted farms					854

[a] Costs are based on a ten-year horizon and a real interest rate of 5 percent.
[b] Annualization factor equal to 7.7217 from Lee et al. Appendix Table 4, n=10, i=5.
[c] Travel costs include an average of 30 miles at $0.25/mile and an hour of technician time.
[d] Hourly wages are $23, $25, and $32 for technicians, experts and attorney respectively.
[e] Where X_{lk} is the set of practices achieving 40 percent nitrogen reduction on the farm.

in the watershed, demonstration farm and other watershed costs can be adapted to the watershed. Cost information for individual cultural practices is available from the farmers as well as many other sources (Hamlett and Epp; Chesapeake Bay Program).

The model used in this study to estimate the cost-minimizing practices to achieve pollution reductions was contracted as a co-op agreement with the Economic Research Service of the USDA. Based on the researchers' experience in developing this model, it is estimated that three years of a systems analyst time would be required to design and support the model (3 years at $44,000/year including fringe benefits). This would include time required to write the model with user-friendly interfaces, update the model annually based on changing economic conditions, write the documentation, train technicians to use the model, and answer user questions over ten years that the model is used. The systems analyst's time over the ten years is also needed to support and debug the model and train new employees.

These costs are divided by 13,596, the number of farms in the Lower Susquehanna watershed.[8] Thus, modeling costs per farm annualized over ten years are $1. The bioeconomic model is updated every year for price changes and new practices and their nitrogen deliveries (from EPIC) for an additional 16 hours, four more hours

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[8] The watershed contains parts or all of 24 counties. The 1991 Agricultural Census reported number of farms for these counties, 29,807, was adjusted to 13,596 based on the ratio of agricultural acres in the Watershed 1,528,700 acres to the farm acres for all farms in the counties 3,351,431.

than the uniform standard to reflect the added complexity of the perfectly targeted standard. Practices associated with the cost-effective allocation of responsibility z_i become what targeted farmers are advised to do.[9] Technicians are assumed to need 38 hours to run EPIC as explained in the previous section. However, for the perfect information strategy these practices must be inserted into the bioeconomic model to obtain shadow prices, which requires another 6 hours.

A user-friendly interface is needed to present the model results including, nitrogen deliveries, gross margins, and farm output, for different precipitation, prices, costs, level of pollution allowed, and practices. If farmers participate in the definition of the set of practices and understand the model input, output, and relationships, their acceptance of the program could be significantly increased. The interface could have a template where a series of questions related to farm-specific physical and economic characteristics appear on the screen to be answered by the agent or the farmer. Once all the questions are answered, the agent is prompted to enter a level of required reduction in nitrogen deliveries. A list of practices that achieve this level of reduction appears on the screen as well as estimated farm output and total gross margins. The farmer then decides whether the selected practices are agreeable or if additional constraints must be imposed to find practices that are acceptable.

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[9] Although farmers are proposed what the model estimated being the practices that minimize the cost of achieving their pollution reduction, the farmer has the option to use costlier practices for other reasons, if they prefer.

The expert is assumed to need three hours to draft the plan and practices are updated each year as for the uniform performance standard amounting to an annualized information cost for the targeted farms of \$610 per farm. Some farms will not be targeted due to their high compliance costs. In this study, plans do not need to be drafted nor the information updated for non-targeted farms and contracting and enforcement are zero thus annualized transaction costs for non-targeted farms are \$215 (Table 3.2).

3.4.2.2 Contracting

Farmers are presented with a level of pollution reduction to achieve and the cost-minimizing practices to achieve the reduction. In practice, farmers are presented with a variable design standard perfectly targeted to farms to emulate what farmers would have done if they had information about their farm's nitrogen deliveries and were imposed a tax on nitrogen deliveries equal to $\lambda \bullet \partial e_i / \partial Y_i$. The contracts require farmers to implement the practice that the model identified as reducing pollution levels on the farm by $j \bullet e_i$. Contracting costs may be higher than the uniform performance standard because 1) farmers may have preferences for other practices, 2) farmers may disagree about which practices are cost-minimizing on their farm, or 3) farmers may disagree with the level of reduction imposed on their farm. Assuming that the allocation is fixed but that farmers can offer alternative practices, the technician is likely to have to go back to the office and repeat the analysis with the proposed alternatives, therefore doubling the costs of contracting compared to the uniform performance standard (Table 3.2). Finally, an hour of attorney time is required to legalize the document, for a total contracting cost of $125 per farm.

3.4.2.3 Enforcement

Farms must have implemented the agreed-upon practices to be in compliance with the standard for nitrogen runoff reduction. A lengthy visual assessment of farm practices may be required to ascertain that the intricate set of practices in the contract has been applied. As for the uniform standard, it is assumed to take 2.4 hours to ensure that the plan is implemented and maintained (plus traveling time). Enforcement costs amount to $86 for a total transaction cost for targeted farms of $854. The possibility that enforcement costs would be higher as the reduction level on each farm is increased due to increased farmers' resistance as manifested in legal suits and other ways, is not accounted for here.

3.4.3 Manure design standards[10]

Although, conceptually, design standards are similar to the performance standard, they differ in that design standards impose one (or many) management practice X_{lk} on all farms regardless of farm characteristics and initial nitrogen deliveries. When a site-specific model is used to establish the performance standards

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[10]Partial information performance standard transaction costs are covered in Chapter Six.

the set of permissible management practices is farm-dependent.

The costs of implementing design standards will depend on: 1) the practice mandated, and 2) on how many farms do not already have the practice in place. For example, mandating that farms have manure storage facilities only affects farms without manure storage, and mandating strip-cropping on erodible lands affects only farms with highly erodible lands.

Under the Coastal Zone Management Act (PL 101-508) confined units with more than 70 dairy cows must have manure storage facilities and manage their runoff by an appropriate waste utilization system (U.S. EPA, 1993). The Act does not affect operations with less than 20 dairy cows and simply requires appropriate waste utilization systems for operations with more than 20 dairy cows and less than 70. The standard was implemented in this study by requiring farms without manure storage to build manure storage facilities for each livestock type equal to six months of total manure production. Eighty one dairy farms in the watershed sample did not have manure storage.

3.4.3.1 Information

This standard simply requires that the agency identify farms without manure storage. NRCS agents located in each county probably already know most farms which do not have manure storage and their location. An hour of field staff time should be sufficient to drive to the farms that are believed to not have manure storage and confirm their presence or absence. Information costs (including travel costs) for the manure standard are $4 in Table 3.3.

3.4.3.2 Contract

A design standard, X_k, defined as six month storage for all livestock is implemented through a regulatory statute that applies to all farmers; thus contracting costs should be relatively low. Farmers must be notified (0.5 hour) to build manure storage and it is up to them to comply or to face judiciary penalties. This notification cost is annualized to $1 per farm. In practice, farmers are also given information as to the cost of various manure systems (not included here).[11]

3.4.3.3 Enforcement

Farmers without manure storage would have to mail or present in person proof of manure storage construction to their conservation district or NRCS office. New livestock producers could be required to show that the building plans include manure storage sufficient for the farm capacity as a condition to get a building permit. A visit to the farm should be done each year to ensure that storage is adequate for the number of livestock confinement units. Two hours of technician time should be sufficient to do the verification and file the proof. The annualized transaction cost is $82.

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[11] In Pennsylvania, for example, $200,000 per year over five years was appropriated for technical support for the Nutrient Management Law (HOUSE BILL No. 100).

Table 3.3 Per Farm Annual Transaction Costs: Manure Storage Design Standard[a]

Activities	Actor	Hours	Costs ($)	Present Value	Annualized[b] Costs
Information					
•Travel to farm[c,d]	Technician	1	31	31	4
Contracting					
•Notify farmers	Technician	0.5	12	12	1
Enforcement					
•Travel to farm[c,d]	Technician	1	31	236	31
•Verify storage facilities	Technician	2	46	355	46
Annual					77
Total annual transaction costs					82

[a] Costs are based on a ten-year horizon and a real interest rate of 5 percent.
[b] Annualization factor equal to 7.7217 from Lee et al. Appendix Table 4, n=10, i=5.
[c] Travel costs include an average of 30 miles at $0.25/mile and an hour of technician time.
[d] Hourly wages are $23 for technicians.

3.4.4 Strip-cropping design standard

Nitrogen delivered in sediment is a major part of total nitrogen delivery, hence, controlling sediments should significantly reduce total nitrogen delivery. To maintain a high level of crop production, sediment loss per year must not exceed the T-factor -- the rate at which a specific soil forms new soil--also called the soil loss tolerance (U.S. EPA, 1994). Strip-cropping alternates strips of row crop tilled by plowing across the slope (contour plowing) and close-grown crops (higher canopy) such as small grains or hay and is recommended on steep slopes (Dillaha).

The Universal Soil Loss Equation, A=RKLSCP, estimates the annual soil movement in tons per acre (A) as a function of 5 factors: rainfall (R), erodibility (K), slope and length (LS), crop (C) and management (P) factors. Larger factors imply higher erosion rates. C=1 for bare unprotected soil and P=1 when no strip-cropping, contour, terraces or other management practices are present. C-factors are higher for row crops than for small grains or other close-grown crops and are higher for conventional tillage that turns the soil over compared to conservation tillage that leaves more residue cover on the ground.[12] Better management practices such as strip-cropping lessen the P-factor. Farmers can abate sediment nitrogen by switching to rotations with lower C- or P-factors, while R, K, LS are site-specific and fixed. The C

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[12] No-till is the least disturbance tillage, but it is already widely used in the bioeconomic model (SUSFARM) baseline with no restrictions as it is less expensive than reduced or conventional tillage. Thus, it could not be considered as a possible design standard.

and P factors for specific crop rotation, tillage and conservation practices are based on values suggested in the Pennsylvania Technical Guide (USDA, 1991).

A simplified standard is used in this study whereby farms located on highly erodible land must use strip-cropping for growing corn. That is, if RKLS the "uncontrollable" part of the USLE equation multiplied by the C-factor for corn silage (C=.08) exceeds the soil's T-factor, the farm is targeted and must strip-crop all acres of corn with small grain or alfalfa. The design standard was applied to corn because it is the major row crop on dairy farms in the watershed. The corn silage C-factor was used rather than the corn grain factor because it is higher and potentially produces more erosion. Corn silage's C-factor is higher than that of corn grain because stalks are harvested leaving minimal ground cover.

3.4.4.1 Information

To determine whether the USLE does or does not exceed the T-factor, the USLE parameters, R, K, LS must be collected and compared to site-specific T-factors. R, K, and LS, are already collected by the USDA as part of the National Resources Inventory (Natural Resources Conservation Service) for almost a million points in the U.S.. For other farms, NRCS iso-erodent maps of the United States contain rainfall (R) factors (Wischmeier and Smith). Soil erodibility factors (K) and T-factors are determined from NRCS soil survey maps which are almost complete for the entire country (Tim et al.). The LS (topographic) factor is based on the length and steepness of fields, which is available from the U.S. Geological Survey Digital Elevation Models (DEMs). However, this information is generally not reliable for estimating LS (Shanholtz). In Virginia, after the DEM approach failed to yield acceptable results, NRCS agents were asked to estimate the soil/slope/length relationships that produced better results (Shanholtz).

In the first year of the program, a farm visit would determine the field and farm boundaries (four hours), and the location of soils that meet the definition of highly erodible soils.[13] The information can be incorporated in the land's deed and then such highly erodible land cannot change ownership without informing the control agency. Thus, farm boundaries must be updated once a year to confirm which farms must comply with the strip-cropping requirement, which adds another half hour to the information activities. The RKLS information collection costs at the beginning of the program and updating costs are annualized and added to the other information costs, both add up to $27 (Table 3.4).

3.4.4.2 Contracting

Farms that were identified as having fields with high potential soil loss erosion are notified that if corn is planted on these fields it must be strip-cropped. There is not a contract written between the farmer and the control agency, rather legislation specifies the location of

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[13] For farm participating in the government programs the location of highly erodible lands is already known and on file at Farm Service Agency (formerly Agricultural Stabilization and Conservation Service (ASCS)) offices, but relatively few dairy farms in this study participate in commodity programs.

Table 3.4 Per Farm Annual Transaction Costs: Strip-cropping Design Standard[a]

Activities	Actor	Hours	Costs ($)	Present Value	Annualized[b] Costs
Information					
•Travel to farm[c,d]	Technician	1	31	31	4
•Gather R, K, LS information	Technician	4	92	92	12
•Yearly update of the deed	Technician	0.5	12	89	12
Annual					28
Contracting					
•Notify farmers	Technician	0.5	12	12	1
Enforcement					
•Travel to farm[c,d]	Technician	1	31	236	31
•Verify corn field for strip-cropping	Technician	2	46	355	46
Annual					77
Total annual transaction costs					105

[a] Costs are based on a ten-year horizon and a real interest rate of 5 percent.
[b] Annualization factor equal to 7.7217 from Lee et al. Appendix Table 4, n=10, I=5. Column totals may not add up due to rounding errors.
[c] Travel costs include an average of 30 miles at $0.25/mile and an hour of technician time.
[d] Hourly wages are $23 for technicians.

farms to which the standard applies. An annual letter would be sent to farmers owning lands to which the standard applies for an annualized total of $1.

3.4.4.3 Enforcement

Whether strip-cropping is practiced can be ascertained by annual visits to these farms or by farmers' self-reporting and by spot checks. Because the crop planted and residue cover must be evaluated on each corn field, an estimated 3 hours is assumed to be required annually. Total transaction costs for the strip-cropping standard are $105.

CHAPTER FOUR: TARGETING AGRO-POLLUTION AND PERFECT INFORMATION LEVELS: EMPIRICAL RESULTS

In this chapter, the modified microparameter model used to evaluate the cost-effectiveness of the performance and design standards presented in Chapter Two is described. The model data requirements and limitations are discussed. The model baseline results are then presented and validated against the Area Studies survey information (see explanation below). Finally, the economic and environmental practices associated with more constraining nitrogen delivery constraints are discussed.

This modified microparameter (farm specific bio-economic) model can replicate the decision-making process of each farm separately, thus circumventing many of the problems associated with modeling a representative farm for a region. The effect of various policies on potential nitrogen deliveries and farmers' control costs can be aggregated at the watershed level (see Chapter 5) by simple summation over the farms. The nonpoint source pollution problems is thus transformed into a point source problem (Antle and Capalbo).

4.1 DATA NEEDED AND METHODS

Farms are diverse in at least four respects: technology use, farm size, physical characteristics, and location. Including these four factors in the microparameter model requires detailed land use, management, and soil quality data for each farm. These data were obtained from the Natural Resources Inventory (NRI) sites which are randomly selected points on the landscape throughout the United States for which detailed hydrological, topographical, and other soil and site characteristics are collected every five years, and from the Area Studies Surveys collected by the National Agricultural Statistics Service, the Economic Research Service, and the Natural Resource Conservation Service.

The Area Studies survey includes detailed economic and management data on more than 500 randomly selected in the Lower Susquehanna watershed (weighted for soil hydrological groups) NRI sites. Input quantities and timing of application and management practices are available for each selected field located on a NRI site. Sales, total acres in each crop, labor use, and livestock enterprises are also available for the whole farm that includes this field. However, the detailed field -level information on physical characteristics had to be extrapolated to the whole farm.

The farms on which the surveyed fields were located were classified into eight farm types according to their major commodity sales. The focus in this study is on dairy farms because they make up 246 of these 500 sample farms. Only 237 dairy farms were generated out of the 246 sites/fields. Eight were discarded because they have missing values for the R, K, and LS factors (USLE factors) used to compute erosion and one farm had missing value for dairy facilities. Classified by sales categories, 37 percent of the dairy farms in the watershed have sales between $0 and $99,999, 39 percent between $100,000 and $249,999, 17 percent between $250,000 and $499,999, and 7 percent have sales exceeding $500,000. Two hundred thirty two of these dairy farms are located in Pennsylvania and fourteen in Maryland, 80 in Lancaster county, and 42 in Bedford and Cumberland counties. Less than 20 farms are located in each of the other counties.

4.2 SUSFARM STRUCTURE

The farmer's constrained optimization problem presented in Chapter Two (equations (2.1) to (2.3)) is solved using a linear programming model (SUSFARM) designed for farms in the Lower Susquehanna River watershed (Bosch, Carpentier, and Heimlich). SUSFARM is written in GAMS (General Algebraic Modeling System (Brooke, Kendrick, and Meeraus) and solved with MINOS (Modular In-core Nonlinear Optimization System) which solves large and complex linear and nonlinear programming problems. Input files containing the land, livestock, and management practices information specific to each farm (from the Survey) are read by GAMS and each farm is solved one at a time (the procedure is automated through a loop).

SUSFARM is first solved for the enterprises and technologies that maximize total gross margins subject to fixed land and livestock capacity and soil types to obtain the baseline. Nitrogen delivery levels are then sequentially reduced (simulating levels of nitrogen performance standards) and chemical use, nitrogen runoff and leaching, farm total gross margins and practices are simultaneously determined for each farm at each level. SUSFARM enterprise and production technology choices are presented in the next section followed by the baseline results.

4.2.1 SUSFARM economic model

Farmers are assumed to maximize their total gross margins from the sale of livestock, milk and crops subject to the individual farm's fixed land, livestock, and manure capacity constraints derived from the survey and subject to crop and livestock nutrient requirements. Crop and livestock product sale prices are Pennsylvania weighted average prices for 1988-1992 and production costs and input prices (pesticides, fertilizer and other variable inputs) are from Pennsylvania Cooperative Extension Farm Enterprise Budgets. All costs and prices are expressed in 1992 dollars. Fixed costs including depreciation, interest on intermediate and long-term debt, property taxes, insurance, rent and leases, full-time hired labor, and other miscellaneous overhead expenses are not included. The supply of fixed family labor per season is based on USDA Farm Cost and Return Survey averages for dairy farms. Seasonal labor can be hired at a fixed wage of $6.00 per hour.

4.2.2 Livestock enterprises

Poultry broilers, beef cow-calf, and hog farrow-to-finish can be produced with a unique ration. Four rations are available for the dairies: alfalfa-corn silage, corn silage only, alfalfa hay only, and alfalfa haylage, which require various mixes of crops that can be grown or bought. Milk production per cow is a function of herd size as reported by Ford, feed requirements are in turn a function of milk production. Dairy farms are divided into four sizes in terms of mature breeding stock: less than 50 head, between 50 and 70 head, 70 to 90 head, and 90 head and above. Livestock facilities' constraints are assumed to be fixed in the short run and the optimal herd size cannot exceed the number of livestock each farmer reported in the Survey.

Balance equations ensure that all manure produced is spread. No more than 25 percent of manure production can be spread in any season unless the farmer reported having manure storage facilities or constructs some at a fixed cost per unit of manure capacity. The per ton manure spreading and storage costs are synthesized based on machinery and labor requirements for spreading (Ritter). An upper limit of 20 tons of manure (dry matter basis) spread per acre is also imposed to keep the model from dumping unrealistically high rates of manure on small areas of land.

4.2.3 Crop enterprises

SUSFARM allows farmers to grow alfalfa, corn grain, corn silage, grass pasture, wheat, soybeans, oats, grass hay, and rye cover. These crops account for nearly 93 percent of the crops reported in the Survey (Table 4.1). Each farm's total land availability is that reported by the farm in the survey after deducting any land respondents reported having in the Conservation Reserve Program (CRP) and land estimated to be used for roadways, farmstead, woodland, ponds, and wasteland. Farms' total cropland was not provided directly in the survey, but was obtained by summing (for each farm) all land reported in harvested crops. The remainder of land is

Table 4.1 Crop Alternatives Reported by Area Study Survey Respondents

Crop	% of Total Response[a]
Hay	
Alfalfa	16.7
Other	13.1
Small grain	
Rye	0.4
Wheat	4.2
Oats	1.8
Corn	
Field	23.3
Silage	12.2
Soybeans	5.1
Pasture	15.9
Total	92.7

[a] Sample responses from the crop reported being grown on the sample sites in the Area Study weighted based on sampling weights.

available for pasture. Balance equations require crops produced or feeds purchased to equal or exceed livestock feed requirements plus sales. Alfalfa, corn grain, soybeans, oats, and grass hay can be bought and sold. Wheat can only be sold while soybean meal can only be purchased.

Crop yields are based on the soil type at the sample site extrapolated to the whole farm (Serotkin). Crop nutrients can be supplied through a combination of animal manure and commercial fertilizer. Nitrogen is also obtained from precipitation, legume fixation and carryover, and mineralization of soil organic matter. Manure nutrient content equals the amount of plant available nitrogen, phosphorus, or potash per ton of manure (in dry matter) minus (in the case of nitrogen) nitrogen volatilization losses before, during, and after spreading and seasonal runoff and leaching between the time of application and crop uptake. A manure testing charge is assessed to determine nutrient content of each ton of manure spread.

SUSFARM distinguishes 36 rotations which have some combination of four tillage types (Table 4.2): conventional, reduced, no-till, and none; nine crops (Table 4.1); and contour strip-cropping and no-strip-cropping. Rotations listed in Table 4.3 refer to a sequence of crops produced with a given technology on one acre (Bosch, Carpentier, and Heimlich). The estimated effectiveness of strip-cropping in reducing erosion is taken from the USDA (1991), while annualized costs of implementing contour strip-cropping are taken from Camacho. Enterprises and production technology in turn affect both runoff and leaching of nitrogen.

Table 4.2 Tillage Methods by Crop Reported by all Area Study Survey Respondents in the Lower Susquehanna River Basin[a]

		Tillage types				
	Number Cases	Conven-[b] tional	Reduced	No-till	None[c]	Total[d]
Crop		Percentage responses				
Alfalfa	242	12	3	2	83	100
Other hay	114	4	4	0	92	100
Barley	14	49	0	34	17	100
Rye	2	100	0	0	0	100
Wheat	45	33	39	4	23	99
Oats	23	51	38	11	0	100
Corn grain	315	34	42	25	0	101
Corn silage	135	44	49	7	0	100
Soybeans	66	52	35	13	0	100

[a] The number of cases and percentage responses are weighted based on sampling weights. The only responses included are those for which only one crop was grown on the field during 1991.
[b] Conventional tillage refers to moldboard plowing and other conventional tillage methods where old crop residue is completely turned under prior to planting. Reduced till refers to tillage in which 30 percent or more of existing residue is left on the soil surface prior to planting. No-till is tillage in which only planting and spraying are done on cropland.
[c] None refers to pasture, alfalfa, and hay already established.
[d] Row totals may not sum to 100 because of rounding.

Table 4.3 Rotations Available in the Susfarm Model

Rotation name	Description
Non-strip-cropping	
CORG1ALF	4 years notill corn grain, 1 year conventional till alfalfa establishment, 3 years established alfalfa
CORG2ALF	4 years reduced till corn grain, 1 year conventional till alfalfa establishment, 3 years established alfalfa
CORS1ALF	4 years notill corn silage, 1 year conventional till alfalfa establishment, 3 years established alfalfa
CORS2ALF	4 years reduced corn silage, 1 year conventional till alfalfa establishment, 3 years established alfalfa
CORG2OH	4 years reduced corn grain, 1 year conventional till hay establishment, 3 years established hay
CORS2OH	4 years notill corn silage, 1 year conventional till hay establishment, 3 years established hay
CORG1SB	1 year notill corn grain, 1 year notill soybeans
CORG2SB	1 year reduced corn grain, 1 year reduced soybeans
CORGOAH	3 year conventional corn grain, 1 year reduced till oats, 3 years hay interseeded in oats
COGW2H	3 year reduced corn grain, 1 year reduced till wheat, 3 years hay inter seeded in wheat
CSRYE3	double cropped conventional corn silage and rye cover
CONTCOG1	continuous notill corn grain
CONTCOG2	continuous reduced till corn grain
CONTCOS1	continuous notill corn silage
CONTCOS2	continuous reduced till corn silage
CONTPAST	continuous reduced till pasture with reseeding every 6 years
CONTOAT	continuous reduced till oats
CONTRYE	continuous reduced till rye cover
CONTWT	continuous reduced till wheat
Idle land rotations	
PASFAL	pasture land idle
CROPFAL	cropland idle

Table 4.3 Continued

Strip-cropping

CORG1ALFST	4 years notill corn grain, 1 year conventional till alfalfa establishment, 3 years established alfalfa
CORG2ALFST	4 years reduced till corn grain, 1 year conventional till alfalfa establishment, 3 years established alfalfa
CORG3ALFST	4 years conventional till corn silage, 1 year conventional till alfalfa establishment, 3 years established alfalfa
CORS1ALFST	4 years notill corn silage, 1 year conventional till alfalfa establishment, 3 years established alfalfa
CORS2ALFST	4 years reduced till corn silage, 1 year conventional till alfalfa establishment, 3 years established alfalfa
CORS3ALFST	4 years conventional till corn grain, 1 year conventional till alfalfa establishment, 3 years established alfalfa
CORG2OHST	4 years reduced till corn grain, 1 year conventional till hay establishment, 3 years established hay
CORS2OHST	4 years notill corn silage, 1 year conventional till hay establishment, 3 years established hay
CORGOAHST	3 year conventional till corn grain, 1 year reduced till oats, 3 years hay inter seeded in oats
COGW2HST	3 year reduced till corn grain, 1 year reduced till wheat, 3 years hay inter-seeded in wheat
CORSOAHST	3 year conventional corn silage, 1 year reduced till oats, 3 years hay inter-seeded in oats

Program crop rotations

NONPCORG	acres in rye cover but that count toward the corn grain base and receive 85 percent payment[a]
NONPCORS	acres in rye cover but that count toward the corn silage base and receive 85 percent payment
NONPOAT	acres in rye cover but that count toward the oats base and receive 85 percent payment
NONPWT	acres in rye cover but that count toward the wheat base and receive 85 percent payment

[a] Farmers participating in the government commodity program can put their base acres under conservation cover and receive 85 percent of the deficiency payment for the particular commodity.

4.2.4 Government program participation

Sixteen percent of the surveyed dairy farms participate in the corn commodity program and six percent in the wheat program. Only five percent of the dairy farms report participating in oats and barley programs, thus their base acres for oats and barley are summed and oats proxies for both program crops. Program crops modeled are thus wheat, corn, and oats. Base acres are relatively small with 21 percent of participating farmers having a corn base less than 50 acres. Fifty percent of farmers with oat bases and 43 percent of farmers with wheat bases have bases not exceeding 50 acres (compared to average farm cropland of 279 acres).

Participating farms must have a total of each program crop planted or considered planted (1) at least as large as their base acres minus set aside and flex acres and (2) less than their base acres minus set aside acres.[1] Set aside requirements are 7.5, 15 and 0 percent of the base acres of corn, wheat and oats, respectively (Table 4.4 second column). Flex acres are fixed at a maximum of 15 percent. Payments are calculated as deficiency payments times the county-specific program yields (last column in Table 4.4) and received only for each enrolled (base) acres minus the required set-aside acreage and flex acres.[2]

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[1]Rules with respect to commodity program participation changed drastically in 1996 with the Federal Agricultural Improvement and Reform Act (USDA, 1996); this study is based on the 1990-1995 program requirements.

[2] In fact, acres of a program crop can exceed the base if these acres are used as part of the flex acres for another program crop. This optional flexing possibility was not

Table 4.4 Set Aside Requirement and Deficiency Payment per Crop and Payment for a Particular County Yield for Pennsylvania 1991

Crops	Set aside percent	Deficiency payment ($/bushel)	Program yields (bushel/acre)	Payment ($/acre)
Corn	7.5	0.41	83.4	34.19
Wheat	15.0	1.35	32.7	44.15
Oats	0.0	0.35	52.3	18.31

Source: Agricultural Stabilization and Conservation Service. Program yields are for Adams county.

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modeled because of its complexity and because other studies indicate that farmers tend to either idle flex acres or plant them to the same program crop (Zulauf and Tweeten).

Program participants can also enter the 0-85 program and idle any fraction of their base minus set aside and 15 percent flex and receive 85 percent of the deficiency payment for these acres. Acres left idle under a conserving use (in the model assumed to be continuous rye cover) are considered planted and count toward meeting the crop base. Both corn grain and corn silage, which are distinct crops in the model, count toward meeting the model maximum and minimum constraints for corn production.

4.3 SUSFARM physical model

Nutrient, sediment and pesticide deliveries to ground or surface water are not only a function of management practices but also of the local topography, underlying geology and hydrology, weather, and soil types. Shallow aquifers, for example, are more susceptible to contamination by pesticide and nitrogen leaching, while poor, drainage soils have a slow infiltration rate and high potential for surface runoff (reflected by the hydrological groups in SUSFARM). Dairy farms are mainly located on Chester, Duffield, Hagerstown, Berks, and Glenelg soil with most farms on soil hydrological group B (139 farms) and C (80 farms).[3] Conceptually (but not practically) various technologies could be used on the same field made up of many soil types because ideal technologies vary with soil types and slopes.

The use and timing of farming operations differ among farm size and types

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[3] Soil specific data including permeability, available water holding capacity, and hydrologic soil groups are obtained for each sample point from the SOILS5 database (USDA, 1992).

influencing the farm's pollution function. Technologies or management practices also depend on the size of the farms. Large dairy and poultry operations often pose environmental problems because not enough land is available for environmentally sound manure management. SUSFARM can account for different farm types, but only dairy farms are analyzed in this study.

4.3.1 Nitrogen application and losses

Plant nutrient requirements can be met by a combination of manure and commercial fertilizer sources applied during four seasons. Nitrogen losses and nitrogen contributions to crops from fertilizer and manure spreading are calculated according to how, when, and where spreading occurs. The model contains two methods of nitrogen application: surface applied and incorporated for each season. The application methods are important in determining total nitrogen volatilization and runoff. For instance, if manure is incorporated at planting time (in the spring and fall) less runoff and volatization losses occur than if the manure is not incorporated (see Appendix D for more details).

Mass-balance equations require nitrogen from mineralization of soil organic matter, precipitation, commercial fertilizer, manure, legume fixation and legume carryover to equal or exceed crop uptake after accounting for nitrogen leaching and runoff. Nitrogen fixation by legumes is optional in the model; if a farmer has excess manure to spread, nitrogen from legume fixation can be ignored from the calculation.[4] A one cent per pound "tax" is charged against each pound of nitrogen runoff and leaching to force the model to consistently allocate manure nitrogen to legumes fixation in the baseline (Bosch, Heimlich, and Carpentier). Without this insignificant tax the model is indifferent between acquiring nitrogen from manure (which needs to be disposed of anyway) and from fixation. The tax ensures that nitrogen from manure is first credited to the crop and then the remaining crop requirement is fulfilled through legume fixation. The model is not recursive and excess nutrients in one year are not carried over to the next. It would be important in the future to study the effect of nitrogen accumulation on targeted farms.

4.3.1.1 Soluble nitrogen runoff

Soluble nitrogen runoff in overland flow (rain runoff in each season) is a function of annual rainfall, the partition of rainfall into runoff and infiltration, and the background and applied nitrogen available to runoff. The watershed is divided into three regions with a representative weather station. From each station (central, east, and west) 40 years of daily rainfall are averaged and classified into daily rainfall classes of 0.25 inch of rain interval (0.01 to 0.25, 0.26 to 0.50, 0.51 to 0.75 and so on up to 5.0 inches and above). The average amounts of rainfall in each daily rainfall class are used in SUSFARM to partition runoff and infiltration -- the driving hydrological

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[4] This assumption is not critical because legume crops would use applied nitrogen if available and fix nitrogen if not applied.

variables that determine nitrogen runoff and leaching. In addition to daily rainfall amounts, daily runoff depends upon a curve number that is itself a function of the land use (crop and tillage systems) and hydrological soil groups A to D (USDA, 1986).

Total soluble nitrogen runoff arises from both background sources and from nitrogen application. Background sources including inorganic nitrogen in soil water, precipitation, and mineralization of soil organic matter are calculated as the pounds per acre of nitrogen in these media that run off for each rotation (Yagow et al.). Nitrogen runoff from applied nitrogen occurs between the time of manure and fertilizer application and crop uptake and depends on the farm's physical characteristics, precipitation intensity, as well as the timing and method of application. Timing alternatives are represented by four seasons of application for manure and commercial fertilizers. [5]

The most efficient season of manure application (in terms of lowest nitrogen loss in leaching and runoff) is during the summer when the plants need it and when the precipitation is least. Nutrients (in manure) applied in other seasons are available to runoff and leach until the next summer when crop are planted. However, with the exception of pasture it is not possible to spread manure on crops during the summer (in

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[5]To illustrate the dependence of runoff on the season of application, SUSFARM was run three times for an acre of reduced-till corn grain. The model was forced to apply dairy manure to meet crop requirements. Applications were first made entirely in the fall, then in the winter, and finally in the spring. Total nitrogen runoff amounts are 4.075 pounds for the fall application, 4.056 for the winter application, and 2.209 for the spring application.

the model). For spring planted crops, the best that can be done is to spread manure before the crop planted is planted in the spring in which case it is available to leach and runoff (subject to precipitation intensity) only one season (in the model)[6] until the plants require it. Manure applied in fall to spring-planted crops will be susceptible to runoff and leaching during the entire year. Winter application leaves nutrients available to runoff during the winter, spring, and summer. The winter runoff coefficient is adjusted to reflect higher runoff potential from manure spreading on frozen grounds (Bosch, Carpentier, and Heimlich) and winter application results in only slightly lower nitrogen runoff and delivery than the fall application.

SUSFARM also allows manure to be surface applied or incorporated; incorporating manure eliminates volatization of inorganic nitrogen in manure and reduces surface runoff (Penn State Agronomy Guide). Within the model, manure incorporation is only allowed on conventional or reduced tillage crops and in the spring and fall seasons. Summer manure application is only allowed on established hay and pasture. Farms can also build manure storage facilities in order to spread manure closer to the time of crop nitrogen uptake resulting in less runoff. Further details are provided in Appendix D.

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[6] In the model, seasons are calculated from March to May (spring), June to August (summer), September to November (fall), December to February (winter). Seasons are calculated from the beginning of the first month (eg. March) till the end of the last month (eg. May).

4.3.1.2 Sediment-bound nitrogen

Annual nitrogen loss in sediment is a fraction of the annual per-acre sediment erosion for each crop rotation as calculated from the Universal Soil Loss Equation (USLE) (Wischmeier and Smith). Sediment erosion is calculated in tons per acre as R•K•LS•C•P as described in Chapter Three. All crop, pasture, or fallow activities have a pre-assigned C-factor.

The geographic location of a farm relative to bodies of water and tributaries affects nitrogen runoff damage in two ways. Indirectly, location alters the damage function because it determines how much pollution reaches surface and ground waters. Potential to reach surface waters is accounted for in SUSFARM through the delivery ratio. The sediment delivery ratio takes into account the indirect effect of location. The ratio, which is a function of the distance to the next body of water, the land cover along the flow path from fields to the receiving water body, and the slope of the flow path to the receiving water body, is used to estimate soil delivery from the edge of the field to the stream as a proportion of total sediment erosion (see Appendix D).[7]

The location at which pollutants enter bodies of water directly affects ambient water quality. For example, if pollutants enter where the assimilative capacity of the water is high, the resulting concentration is low, and vice versa if they enter at a point of low flow or assimilative capacity. This effect is not accounted for in this study as the

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[7] Soluble nitrogen delivery to nearest water body is assumed to equal soluble nitrogen runoff from the field.

stated Chesapeake environmental goal is in terms of nitrogen delivery reductions and not ambient water quality (although ambient quality is the ultimate goal).

4.3.1.3 Nitrogen leaching

Leaching estimates depend heavily on precipitation entering the soil and on soil water holding capacity (available from the NRI). Nitrogen leaching is the sum of the nitrogen leached 1) from background soil nitrogen, 2) between the time of fertilizer spreading and crop uptake, and 3) from excess crop available nitrogen (see Appendix D). Background leaching depends on soil water concentration of nitrogen and the water that leaches from the root zone. Leaching from nitrogen application is the product of the proportion of rainfall occurring between application and crop uptake, the increased soil concentration of nitrogen from application, and the estimated annual volume of water that leaches from the soil profile.

Available nitrogen that is not taken up by plants and does not leach or run off between application and plant uptake is defined to be excess nitrogen. Leaching of excess nitrogen is a direct function of the soil porosity and precipitation that percolates into the soil (Appendix D). In a dynamic framework, crop available nitrogen at the end of a growing period would be the starting value for the next growing period. SUSFARM does not account for this carryover.

4.3.2 Field level information limitation

In this study individual farms were generated by extending the characteristics of a site/field (from the Area Studies Survey) to a whole farm assuming homogenous soils for the whole farm. Given the variability in the watershed landscape, this assumption may affect the findings about the value of information on large farms having many more fields. Further research is needed to determine how results on the value of information are affected when farm location relative to surface water and soil characteristics are allowed to vary within farms.

Although information on manure storage was only available for a subsample (22 percent) of the farms and the presence of manure storage had to be randomly allocated to farms given the proportion of farms with manure storage in the sub-sample (Bosch, Carpentier, and Heimlich, p.11). Whether errors were introduced by this random allocation could be tested by repeating the analysis with a different set of farms for whom availability of storage is known.

4.3.3 Single pollutant limitation

Although nitrogen, phosphorous and sediments are modeled, only nitrogen delivery and leaching are restricted under the performance standards, with leaching limited not to exceed the baseline level. This study concentrates on nitrogen runoff because of the limited success in controlling nitrogen in the Chesapeake Bay and because phosphorus is already declining due to point source control. Furthermore, consistent shadow prices were needed to achieve this study's goal of valuing information in agro-pollution control. Controlling nitrogen and phosphorous at once would likely result in non-continuously decreasing shadow prices for nitrogen delivery or leaching. Further research should focus on developing empirical methods to control more than one pollutant at once and ensuring that shadow prices associated with restricting both pollutants increase with the restriction level.

Another approach would be reduce the sum of nitrogen delivery and leaching, as was done above for delivery only to assess the effect of adding leaching nitrogen losses on farm marginal costs of controlling nitrogen losses. This scenario would implicitly assume that there is a direct relationship between leaching and water movement to the Bay. Accounting for leaching would increase total nitrogen delivery and hence perhaps decrease farm private compliance costs. Compliance costs may or not decrease because SUSFARM has fewer alternatives to control nitrogen losses by leaching and soluble runoff compared to sediment-bound nitrogen. Farms generating large amount of leaching are not necessarily the same as those generating large nitrogen delivery thus, the value of information could change substantially.

4.4 BASELINE MODEL RESULTS

In this section baseline results are validated and results for the various performance standards are presented.

4.4.1 Validation

SUSFARM's runoff estimates were adapted from Yagow et al. who developed from a small agricultural watershed an annual runoff model to estimate nitrogen runoff and leaching. Yagow's model, a yearly model, was linearized to fit the linear structure of SUSFARM and divided into seasons to account for the seasonal variations in nitrogen runoff delivery. Soil properties, precipitation pattern, and crop yield potential in SUSFARM were changed to reflect Virginia conditions including a Frederick loamy soil for which Yagow's model is calibrated. SUSFARM runoff estimates for corn grain and corn silage grown on similar soils were compared to Yagow's (personal communication) to verify that the integrity of Yagow's model was preserved.

These verification runs revealed consistent results with Yagow's annual model. Soluble nitrogen runoff was estimated at 1.62 lb per acre by SUSFARM compared to 1.64 lb in Yagow's model for corn grain reduced tillage. Runoff resulting from an acre of corn silage reduced till in SUSFARM is 2.10 pounds, 0.45 lb above Yagow's estimate, 1.65 pounds. Under similar conditions, corn silage results in higher runoff than corn grain because less residue is left to cover the ground after harvest and thus corn silage has a higher curve number (NRCS).[8] These estimates suggest that SUSFARM's linearized and seasonal adaptation of the small watershed model is a reliable adaptation. These estimates may be low compared to other studies as Yagow's runoff estimates were low compared to two test watersheds (Yagow et al.).

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[8]Curve numbers are a method develop by the NRCS for estimating runoff from rainfall excess. The curve number depends on the soil type, antecedent soil moisture, and cover types.

The baseline mean production values for the 237 simulated farms are compared to reported means for the watershed to assess the capacity of SUSFARM to reproduce farmers' actual behavior. In the model's baseline, mean simulated corn acreage is 114 acres, 74 percent of the mean reported acres in the survey (Table 4.5). No grass hay and 102 acres of alfalfa were modeled compared to 94 acres of alfalfa and hay (total hay in Table 4.5) per farm reported in the survey. The baseline yields a mean of 1 acre in oats, 2 acres in rye, and 59 acres of wheat for a total of 62 acres in small grain compared to 39 reported in the survey. The model has 41 acres in pasture in the baseline, while 4 acres are reported; however many farms may have failed to report their acres of pasture.[9] In the survey sample, 27 farms participate in the government program. These farms produce their base acres in the baseline; they do not participate in the 0-85 program. Overall, the baseline model reflects reasonably well reported corn, hay, and small grain acres and all cropland acres are cultivated.

In Table 4.5, the mean number of dairy cows in the baseline is one unit less than the 137 reported in the Survey.[10] Poultry units defined as the number of birds per year, are within 79 percent of the actual number, 2,539 units. This close agreement occurs because simulated livestock enterprises cannot exceed livestock numbers

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[9]When asked what crop they were growing, farmers may not have considered pasture as a crop.

[10]All livestock are measured as units of mature breeding stock.

Table 4.5 Area Study Survey Statistics Versus Simulated Statistics

Enterprise	Reported[a] acres (1)	Simulated[b] acres (2)	Ratio (2)/(1)
Crop[c]			
Total corn	154	114	0.74
Total hay	94	102	1.09
Wheat	15	59	3.93
Soybean	22	0	0.00
Total oats/ barley[d]	19	1	0.05
Pasture & grasses[e]	4	41	10.25
Rye	4	2	0.50
Tobacco	1	0	0.00
Sorghum	3	0	0.00
Green Peas	1	0	0.00
Potatoes	1	0	0.00
Set-aside	2	0	0.00
Total acres	320	319	1.00
Livestock[f]	Number	Number	Ratio
Dairy cows	137	136	0.99
Cattle	26	14	0.54
Hogs	44	17	0.39
Poultry	2539	2014	0.79

[a] Mean acres or number of animals reported in the survey for 245 dairy farms.
[b] Mean acres or number of animal simulated with the model for 237 dairy farms.
[c] Barley, tobacco, grasses, and sorghum are not modeled because of their low importance in the watershed.
[d] Oats is a proxy for oats and barley in the model, hence the sum of the acres under the two crops is compared to the simulated oat acres.
[e] Pasture land was determined by subtracting farmstead, cropland, forest and water areas from the total farm area.
[f] Livestock are reported in mature breeding unit equivalents with the exception of poultry.

reported in the survey and because the dairy and poultry enterprises are profitable resulting in binding livestock capacity constraints for most farms. Modeled hogs and other cattle are underestimated with only 54 percent and 39 percent of the cattle and hogs reported in the survey. However, these enterprises are relatively small with an average of 44 hogs and 26 other cattle per farm reported in the Survey. Of the farms reporting other cattle, hogs, and poultry, 55, 58, and 62 percent report having less than 50 cattle, hogs, and poultry, respectively.

4.4.2 Gross margins and shadow prices

Total nitrogen delivery, sediment nitrogen delivery plus soluble nitrogen runoff, was reduced in intervals of 20 percent of the baseline levels. Leaching is only restricted to not exceed the baseline level. Mean total gross margins, π_{ij}, shadow prices, λ_{ij}, and estimated pollutants for each scenario are presented in Table 4.6 along with their standard deviations (in parentheses). The performance standards simulated are presented in the first row of Table 4.6. The second row indicates how many of the 237 farms modeled can achieve each performance standard. The only performance standard that all farms can achieve is 80 percent. One farm cannot meet the 60 percent, eight farms the 40 percent, and 33 farms the 20 percent performance standard. This incapacity to meet the standards may be due (in order of importance) to (1) farms participating in government commodity programs being required to maintain a minimum amount of land under production, (2) farms already having most conservation practices in place and thus having few means (in the model) to further control nitrogen reduction, (3) farms on soil and at locations with high propensity to deliver nitrogen.

Even the 0-85 program, which allows base acres to be put under rye cover and 85 percent of the deficiency payments to be collected, cannot achieve the standard. Participating farms could be expected to participate in the 0-85 program if the eligible base could be planted to a cover crop with a C-factor less or equal to the fallow land C-factor. In the model, the fallow land C-factor is lower than the rye cover C-factor because the soil must be disturbed to establish annual rye cover. A perennial ryegrass cover would have a C-factor equal to the fallow land C-factor but was not modeled in this study because farmers would have to commit the land to a cover for several years (defeating the purpose of flex acres). Simulated total gross margins (gross receipts minus variable costs) vary among farms from $9,386 to $830,514 with a mean of $134,472. The diversity among farms in terms of profit-maximizing livestock and crop enterprises, given their economic and physical endowments, is reflected in the relatively large variability of total gross margins as measured by the coefficient of variation (C.V.= (standard deviation/mean)*100), which averages 84. As displayed in Table 4.6, total gross margins decrease at an increasing rate as the performance standard becomes less permissive reflecting that abatement is more costly at more stringent levels of restriction. For example, the first 40 percent reduction in total nitrogen delivery causes a 14 percent average decline in total gross margins from the baseline (from $134,472 to $118,488),

Table 4.6 Mean Gross Margins, Shadow Prices and Pollutants for the Baseline and Four Performance Standard Cases[a]

Performance standard[b]	Base	80	60	40	20
Number of farms[c]	237	237	236	229	204
Economic Values ($)					
Mean total gross margins	134,472	130,100	118,488	93,120	48,043
	(113,276)	(109,886)	(98,978)	(76,913)	(38,957)
Shadow prices	0	97	279	558	861
	(0)	(162)	(331)	(610)	(883)
Mean Pollutant Delivery (per farm)					
Sediment (tons)	252	198	144	92	41
	(685)	(621)	(397)	(263)	(133)
Sediment nitrogen (lbs)	610	478	349	223	100
	(1661)	(1309)	(962)	(638)	(321)
Soluble nitrogen runoff (lbs)	242	203	163	120	85
	(241)	(211)	(176)	(127)	(88)
Total nitrogen delivery (lbs)	852	681	511	343	185
	(1747)	(1397)	(1050)	(710)	(373)
Sediment phosphorous (lbs)	288	226	165	105	47
	(786)	(621)	(458)	(302)	(153)
Nitrogen leaching (lbs)	3204	3096	2984	2709	2260
	(2866)	(2797)	(2720)	(2428)	(2100)

[a] Standard deviations are given in parentheses
[b] Performance as a percentage of the baseline runoff
[c] Number of dairy farms for which a solution was obtained.

while the next 40 percent causes an average decline of 147 percent (from $118,488 to $48,043).

The marginal value of delivering one more pound of nitrogen, the shadow price, increases (from left to right) from $0 to $861 as the runoff tolerance level decreases, at least doubling with each 20 percent reduction imposed on the farms except for the last 20 percent reduction ($558 to $861). Shadow prices are highly variable at all levels of nitrogen reduction implying high returns to targeting. This variability reflects the differences in total crop acres, soil characteristics, and management practices among the farms.

4.4.3 Farms' mean delivery

In the baseline, shown in Table 4.6, sediment-bound nitrogen composes 72 percent of total nitrogen deliveries and decreases by slightly more than the 20 percent reduction imposed on total nitrogen runoff, while soluble nitrogen runoff decreases by slightly less than the imposed reduction. Thus sediment nitrogen is abated faster than soluble nitrogen--resulting in an increased proportion of total nitrogen runoff made up of soluble runoff at higher levels of abatement. The portion of total nitrogen delivery made up of sediment nitrogen decreases to 54 percent with the 20 percent performance standard. According to the model, it is relatively less expensive to control sediment nitrogen than soluble nitrogen. Sediment nitrogen control is cheaper because (1) there are more alternatives to reduce sediment-bound nitrogen than to reduce soluble nitrogen and

(2) sediment nitrogen losses are generally larger in absolute value.

The modeled fixed relationship between sediments and sediment-bound nitrogen and phosphorous is apparent in that mean values of each decrease by the same percentage: 22, 43, 63, and 84 percent for the 20, 40, 60, and 80 percent standards even though no restriction is imposed on phosphorous nor on sediments.

The high variability in nitrogen deliveries at all levels of abatement (C.V.= 205 on average) reflects the heterogeneity of the farms with respect to flow path cover, distance to surface water, farm size, slope, soil types, and other physical characteristics. Mean nitrogen leaching decreases at a slower relative pace than other pollutants as the nitrogen delivery performance standard becomes more stringent. For example, a 20 percent abatement in nitrogen delivery results in only seven percent less nitrogen leaching than the baseline, while an 80 percent abatement results in 71 percent reduction. Although relatively large in absolute value, the nitrogen leaching C.V. is almost constant -- varying only from 93 to 90 from the least to the most restrictive standard.

4.4.4 Livestock enterprises

The dairy and cattle herds decrease in size as the standard becomes more restrictive, while hog production increases (Table 4.7). Poultry numbers are constant throughout, the only variation in the reported average is due to a change in the number of farms (due to the removal of farms that cannot meet their delivery constraints). Poultry production is less affected by the total nitrogen delivery constraint because feed is provided by the integrators and the constraint only affects litter disposal. Curtailing total nitrogen delivery restrains other livestock more than poultry because the constraint affects both manure handling and feed procurement.

To achieve the 80 percent performance standard, livestock rations are shifted toward rations that minimize the number of acres needed to meet livestock feed requirements. More hogs (20) fed a corn grain-soybean based ration and less cattle (7) fed a hay-based ration are raised than in the baseline. Dairy cows are shifted away from alfalfa rations to corn silage and haylage rations. On average, three cows previously fed an alfalfa ration are now fed a corn silage ration that requires no alfalfa, less hay, less corn grain and more soybean meal (bought) than the alfalfa ration. Another cow is switched to a haylage ration requiring more corn grain and less soybean meal than the alfalfa ration. Corn grain and soybean meal can be bought at a relatively lower price than alfalfa while corn silage cannot be bought, but can provide roughage for cows on less acres allowing more acres to be idled.

Mean manure production decreases by only eight tons, however, manure spread in the winter is more than halved to 12 tons compared to the baseline 31 tons (Table 4.7). By building manure storage facilities (9 more tons on average), farmers have more flexibility to apply the manure closer to plant uptake in the spring (or the fall for wheat), which reduces needed commercial nitrogen because less nitrogen in manure is lost to the environment. Eighty tons of manure are incorporated, more than twice the baseline 39

Table 4.7 Mean Livestock and Manure Activities for the Baseline and Four Performance Standards

Performance Standard	Base	80[a]	60	40	20
Number of farms[b]	237	237	236	229	204
Livestock Enterprises (mature breeding units)					
Cows	136	135	132	118	79
Hogs	17	20	34	21	29
Poultry[c]	2014	2014	2023	2084	1872
Other Cattle	14	7	2	0	0
Feed ration[d]					
Hay/corn silage	0	0	0	0	0
Corn silage	2	5	13	26	29
Alfalfa	134	129	115	80	10
Haylage	0	1	4	13	39
Manure spreading (tons dry matter)					
Winter	31	12	3	0	0
Spring	110	106	96	79	37
Summer	102	105	98	46	7
Fall	44	55	73	115	121
Total manure	286	278	270	240	165
Commercial nitrogen	17	15	11	6	2
New manure storage (tons dm)	0	9	20	28	32
Manure incorporated	39	80	118	146	124

[a] An 80 percent performance standard allows 80 percent of the baseline total nitrogen delivery. It is equivalent to a 20 percent abatement policy.
[b] Number of dairy farms for which a solution was obtained and the from which the mean was calculated.
[c] Poultry average increases because farms that can achieve the standard have poultry, the same number of poultry is divided by fewer farms.
[d] Total feed rations measured in number of mature breeding dairy cows fed with each ration.

tons; incorporation is also made possible by building storage since manure can only be incorporated in the fall or spring. Manure application in the fall increases because more wheat, which uses nutrients in the fall, is planted (Table 4.8).

To achieve the 60 percent performance standard, intensive adjustments (such as changes in timing and method of manure application and changes in tillage) are no longer sufficient and the primary means of controlling nitrogen delivery are to reduce the number of animals and land in production (extensive margin adjustments).[11] This trend continues for the 40 and 20 percent standards. For example, the number of cows milked declines to 79 at the 20 percent performance standard and most cows are fed haylage and corn silage rations. This substitution occurs despite the higher corn silage C-factor (associated with higher erosion rates) because corn silage and haylage rations are less expensive per cow once farmers are forced to idle land and buy feed to meet their nitrogen delivery constraints. For example, when all feeds (except soybean meal) are grown on farm, the alfalfa ration is the least expensive ration ($211.56 per cow on soil productivity group 1); while when increasing amount of feeds are bought the corn silage ration is the least expensive -- $1146 compared to $1437 per cow for the alfalfa ration (including only the costs of raising crops and buying feeds).

Practices and enterprises in Table 4.7 that decrease constantly as the performance standard becomes less permissive are: the number of cows and other cattle, the number

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[11] Extensive margin adjustments are defined as changes in enterprise size, while intensive margin adjustments are changes in the enterprise technology.

of cows on the alfalfa feed ration, manure spread in the winter and spring, total manure production, as well as commercial nitrogen application. These practices and enterprises are positively correlated with total nitrogen delivery. Practices and enterprises that farmers choose to increase to achieve the performance standard are: the amount of corn silage and haylage ration fed, manure spread in the summer and the fall, new manure storage, and incorporation of manure. These practices are negatively correlated with total nitrogen delivery. As the standard becomes less permissive, less manure is produced (by reducing the number of cows) and eventually all manure is spread in seasons with plant uptake: spring, summer, and fall.

4.4.5 Crop management and practices

The herd size decrease and shift in rations with the performance standard are accompanied by a decrease in most crop acreage, and an increase in feed bought except for soybean meal (Table 4.8). Substitution of wheat and rye for corn is positively correlated with lower total nitrogen delivery. Acres planted to wheat, which has a low propensity soil erosion and soluble runoff increase with the stringency of the standard. Rye increases indicating that more base acres are flexed to a cover and oats decreases because farms participating in the commodity program (the only farms growing oats) are eliminated from the statistics.

Table 4.8 Mean Management Practices and Crops for the Baseline and Four Performance Standards

Performance Standard	Base	80[a]	60	40	20
Number of farms[b]	237	237	236	229	207
Crop Enterprises (acres)					
Crop and pasture acreage	320	315	304	273	211
Alfalfa	102	98	81	49	13
Corn grain	57	52	33	10	2
Corn silage	57	56	52	39	11
Pasture	40	36	29	12	1
Wheat	59	68	99	142	143
Rye[c]	2	3	7	9	13
Oats	1	1	1	0	0
Idle cropland	0	0	5	22	82
Idle pasture	66	71	77	91	93
Conventional till	20	20	16	10	3
Reduced till	70	90	127	162	147
No-till	113	96	64	33	12
None	182	180	172	162	186
Strip-cropped acreage	91	138	150	88	26
Feed bought					
Alfalfa (tons)	2	2	2	11	113
Corn grain (bu)	3031	3343	4566	5669	5749
Soybean Meal (cwt)	1599	1584	1550	1244	600
Other hay (tons)	1	1	3	29	62

[a] An 80 percent performance standard allows 80 percent of the baseline total nitrogen delivery. It is equivalent to a 20 percent abatement policy.
[b] Number of dairy farms for which a solution was obtained.
[c] Rye acres are farms participating in government set-aside acres.

Crop and pasture acres idled increase with the performance standard as adjustments to the extensive margins are intensified. Cropland is idled to achieve performance standards stricter than 80 percent (five acres at the 60 percent standard up to 82 acres at the 20 percent performance standard). Pasture land idled increases from 66 acres in the baseline to 93 acres for the 20 percent performance standard. Farms not participating in government programs idle land to meet the standards stricter than 80 percent. An average (over all farms) of five acres of cropland at the 60 percent performance standard, 22 acres at the 40 percent, and 82 acres at the 20 percent standard are idled. Idle land has a low C-factor of 0.013 because the soil is undisturbed, (compared to 0.1 for rye cover which must be planted each year) thus land is idled instead of being put into the 0-85 program.

Manure incorporation requires some tillage, thus, reduced tillage increases at the expense of no-tillage to accompany the increase in manure incorporation shown in Table 4.7. The decrease in alfalfa, pasture, and hay acreage which all use no tillage ("none") once established, is offset by the increase in pasture and cropland idled which also use no tillage keeping the use of no tillage ("none") relatively constant.

Stripcropping acres, which reduce sediment-bound nitrogen delivery, increases up to the 60 percent performance standard to decline thereafter indicating that strip-cropping is a cost-effective management practice to abate the initial nitrogen pollution on most farms. For most farms, the acres of corn-alfalfa rotation, the main rotation that is strip-cropped, decline for the 60 and 80 percent abatement levels causing a reduction in strip acres beyond the 60 percent standard. The reduction in acres cultivated and better nutrient management result in a constant decrease in commercial nitrogen bought (shown in Table 4.7).

4.5 SUMMARY

SUSFARM was shown to reflect farming practices and nitrogen runoff delivery in the Lower Susquehanna watershed. Practices under the various performance standards can be summarized as follows.

The first 20 percent abatement in total nitrogen delivery results primarily in intensive margin adjustments such as manure incorporation, manure storage, less winter manure spreading and more strip-cropping. There are some adjustments at the extensive margins (five pasture acres idled and one cow less produced). Manure production is reduced by decreasing the number of hogs and cattle. Further abatement (beyond 20 percent) requires a decrease in total nitrogen applied on the farm, commercial and organic, as reflected in the more drastic decrease in the number of livestock and crop acreage. Crop acreage changes are triggered by switching to cow rations with more purchased feed inputs, which allows for less land-intensive milk production.

Better nutrient management, a shift in the mix of crops, and a reduction in crop acres also result in a decrease in commercial nitrogen bought from 17 tons in the baseline to two tons at the 20 percent performance standard. The emphasis on nutrient management plans to decrease nitrogen delivery at least cost is consistent with the Susquehanna River Basin Commission's emphasis on nutrient management plans to abate nutrients in the watershed.

CHAPTER FIVE: TARGETING AGRO-POLLUTION: PERFECT INFORMATION LEVEL RESULTS

The cost-effectiveness of targeting depends on the available level of information. For example, performance standards can be targeted with no information (uniform performance standard), perfect, or partial information (the partial information performance standards is discussed in Chapter Six). Results for the no information and perfect information performance standards are presented in this Chapter along with results of two design standards. These policies, and the associated value of information are compared and contrasted after a presentation of the two strategies for allocating burdens, the private cost-effective and social cost-effective allocation. Next, the values of perfect information are presented. The reader is reminded that social cost-effectiveness in this study refers to an allocation which minimizes the sum of transaction plus aggregate private compliance costs. Private (or allocative) cost-effectiveness refers to an allocation which minimizes only aggregate private compliance costs. The Chapter concludes with some limitations and implications for further research. Farm constructs described in Chapter Four are referred to as a farm or farm sample below.

5.1 UNIFORM ALLOCATION

The uniform allocation has all farms abate 40 percent of their baseline nitrogen delivery. Results of this simulation appear in column two of Table 5.1. In column one,

Table 5.1 Comparisons of a Uniform and a Perfectly Targeted Performance, and Two Design Standards

	Baseline	Standards			
		Performance		Design	
		Uniform[a]	Perfect Information	Manure Storage	Strip[b] Crop
Total gross margins ($)	134,472	118,488	130,871	134,278	133,601
Nitrogen delivery (lbs/farm)	852	511	511	845	647
Leaching	3,204	2,984	3,105	3,106	3,380
Livestock Enterprises (mature units)					
Cows	136	132	135	136	136
Hogs	17	33	21	17	16
Poultry	2,014	2,023	2,014	2,014	2,040
Other Cattle	14	2	6	14	8
Manure spreading (tons dm)					
Winter	31	3	16	19	30
Spring	110	96	115	121	107
Summer	102	98	102	111	107
Fall	44	73	49	35	44
Total manure production	286	270	282	286	285
Manure incorporated	39	118	55	40	38
New manure storage	0	20	5	17	2
Crop Enterprises (acres)					
Crop acreage total	386	386	386	386	382
Alfalfa	102	81	98	102	105
Corn grain	57	33	52	57	53
Corn silage	57	52	55	57	56
Pasture	41	29	37	41	41
Wheat	59	98	70	59	59
Rye	2	7	2	2	3
Idle land	0	5	0	0	0
Idle pasture	66	80	71	66	68
Conventional till	20	16	20	20	21
Reduced till	70	127	85	70	70
No-till	113	64	102	113	108
Strip-cropped acreage	91	150	145	91	148
Commercial N (tons)	17	11	16	17	16

[a] For a 60 percent performance standard or a 40 percent reduction in nitrogen delivery.

[b]Three farms participating in the commodity programs could not meet the constraint and were eliminated from the analysis of the strip-cropping design standard.

the baseline mean total gross margins, shadow prices, pollution levels and activities are repeated from Table 4.6, 4.7, and 4.8 for convenience. The average total gross margins for all farms decrease from the baseline by 10 percent to $118,488. The total nitrogen delivery in the Lower Susquehanna watershed (the watershed), 201,825 pounds, is reduced by 80,730 pounds for an average loading per farm of 511 pounds. Total leaching which was restricted to not exceed the baseline 3,204 pounds decreases slightly to 2,984 pounds. There is thus, no trade-off between surface and groundwater protection in this study.

The number of dairy cows and other cattle decrease to 132 (2 percent) and two mature units (600 percent) respectively while hogs double to 33 heads. The substitution of hogs for cows causes a reduction in alfalfa and corn grain planted, while wheat acres increase to 93 acres. Wheat straw is used on farm while wheat grain is sold to supplement milk revenues. Corn silage decreases by only five acres as the dairy ration is switched from an alfalfa ration (in the baseline) to a silage ration. In addition to these intensive margin adjustments, five acres of cropland and eleven acres of pasture land are idled indicating that on average to achieve the 40 percent reduction in nitrogen delivery, extensive margin adjustments are needed as well.

The construction of 20 tons of manure storage allows winter spreading to decrease to three tons (from 31). Reduced tillage acreage increases by 81 percent while no-till acreage is reduced to accompany the 44 percent increase in manure incorporation (118 pounds). Fall manure application increases by 66 percent and most of the manure applied in the winter has been eliminated. Nearly 50 percent of planted acres are strip-cropped. Strip-cropping and incorporation of manure along with a switch to a silage base dairy ration appear to be the least costly practices to achieve the 40 percent performance standard.

5.2 PERFECT INFORMATION PERFORMANCE STANDARD

The allocation of control burdens that achieve the 40 percent reduction in nitrogen delivery at least costs is found using perfect information about each farm's marginal compliance cost curve. This curve is approximated using each farm's shadow prices at 20, 40, 60, and 80 percent reduction in nitrogen delivery elicited in Chapter Four. These marginal costs and baseline levels of delivery are used by ALLOCATI -- the GAMS model that minimizes aggregate compliance costs of achieving the 40 percent standard -- to find the cost-effective allocation of control burdens. Results presented below are for the private cost-effective allocation (the social cost-effective allocation results are showed in section 5.4.1).

The perfect information standard is achieved by the same management practices as the uniform standard, but at a much lower intensity resulting in a mean total gross margin of $130,871 (Table 5.1). No cropland is idled, five tons of manure storage are built, and manure application closer in time to the crop-uptake season allows a reduction of commercial nitrogen applied to an average of 16 tons. Ninety nine farms are not targeted -- their loadings and gross margins are the same as in the baseline. These 99 farms are not targeted because their marginal compliance costs are high relative to other farms.

Seven farms reduce 80 percent of their baseline and together abate 42,487 pounds -- accounting for 53 percent of the total nitrogen delivery abatement. Eleven farms abate 60 percent of their baseline, 27 farms abate 40 percent of their baseline, and 93 farms abate 20 percent of their baseline for total reductions of 17,632, 12,723, and 8,001 pounds, respectively. Thus, in the watershed, 18 farms reduce 75 percent and 45 farms reduce 88 percent of the watershed required reduction in nitrogen delivery.

These 18 farms have high delivery in the baseline because (1) they tend to be on the sites with the highest nitrogen delivery potential, that is, in terms of soil runoff potential, slope steepness, and closeness to water courses and (2) they tend not to use any management practices to reduce nitrogen runoff which include manure storage and strip cropping. This combination of large initial delivery and few management practices (and thus many alternatives left to control delivery) results in very low marginal compliance costs for these farms. For example, the seven farms that reduce 80 percent of their baseline have mean baseline delivery of 7,587 pounds and mean shadow prices of $1, $2, $18, and $29 per pound for the first 20, 40, 60, and 80 percent reductions respectively. On the other hand, the mean delivery for all the farms targeted is 1,146 pounds and the shadow prices are $19, $194, $565, and $1119 per pound for each performance standard, respectively. Farms not targeted have mean baseline delivery of 442 pounds only and the associated shadow prices are $206, $439, $866, and $1715 for the 20, 40, 60, and 80 percent reduction levels. Overall control costs (in terms of reduced total gross margins) with perfect targeting are $12,383 less per farm than under a uniform standard and only 58 percent of the farms are targeted.

The perfect information strategy as described here does not account for transaction costs. Transaction costs associated with the private cost-effective allocation may be high. For example, with the private cost-effective allocation 36 farms abate less than 50 pounds of nitrogen delivery, and 71 abate less than 100 pounds. Targeting these farms (at a fixed targeting cost per farm) results in high transaction costs per pound controlled. The social cost-effective allocation results which account for transaction costs are presented in section 5.1.

5.3 UNIFORM DESIGN STANDARD

The total control costs of two design standards, believed to cost-effectively control nitrogen delivery in the watershed, are compared to the total control costs of the performance standards. This comparison is meant to test whether the low transaction costs associated with the design standards could compensate for their higher aggregate compliance costs. These two design standards are required manure storage facility and required strip-cropping on steep slopes.

5.3.1 Manure storage

Farms without manure storage, 81 farms in the sample, were required to build manure storage facilities for each of their livestock and poultry equal to six months of the farm's total manure production. Those without manure storage spread manure equally in the four seasons as constrained by SUSFARM. The standard only curtails an average of seven pounds of total nitrogen delivery, but decreases farms' mean gross margins by $871. The reduction in nitrogen runoff from this design standard is limited, because most farms already have storage (66 percent) and, as explained in Chapter Four, the model might understate baseline soluble runoff. Because the standard only applies to farms without storage, the discussion below concerns only the 81 farms that do not have manure storage in the baseline.

Once the standard is imposed, these farms build six months worth of storage,[1] the minimum required by the standard. Spreading can thus be shifted away from the winter and fall to the spring and summer reducing soluble runoff by 20 pounds per farm. This shift arises because once manure storage has been built it is more advantageous to apply manure at the time of plant uptake (thus reducing leaching and runoff losses).

In Table 5.2 manure spreading in the winter decreases from 50.47 to 17.25 tons with manure storage, while spring spreading increases to 83.64 tons, 32.97 tons more

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[1] The model has four discrete seasons, and farms without manure storage must apply one forth of the manure in each season. Thus farms without manure storage have an automatic three months of manure "piling" or inventory allowed.

Table 5.2 Sources of Applied Nutrients per Season for the 81 Farms Targeted with the Manure Storage Design Standard

	Manure Tons Spread				Commercial Fertilizer Tons Applied[a]			
	Winter	Spring	Fall	Summer	Winter	Spring	Fall	Summer
Before								
Corn grain	17.06	10.00	9.97					8.37
Corn silage	17.07	15.20	0.50					3.37
Alfalfa	0.46	0.28	3.02			4.13	3.94	
Pasture	14.38	18.96	11.24	48.74				1.40
Rye		0.29	0.16					
Wheat	1.56		23.14			0.80	0.19	
Total[b]	50.47	50.67	48.80	48.05		--	--	--
After								
Corn grain	7.49	37.50						8.77
Corn silage	3.37	32.94	0.75					3.17
Alfalfa		0.29	0.51			4.44	3.78	
Pasture	2.10	12.47		76.50				1.30
Rye		0.44						
Wheat	4.30		19.44			0.76	0.14	
Total	17.25	83.64	20.70	76.50		--	--	--

[a] Commercial fertilizers are nitrogen fertilizer for all crop with the exception of potassium for alfalfa.

[b] It is meaningless to sum the tons of nitrogen and potassium.

than without manure storage. More manure is spread in the summer on pasture (the only crop grown for which spreading is allowed in the summer), because summer spreading reduces nitrogen losses and more nitrogen remains available to crops and because it is less expensive to spread manure in the summer than in other seasons. SUSFARM increases manure spreading costs in the spring, fall, and winter to reflect lower machinery efficiency in worsening conditions (summer has the lowest cost, then fall, then spring, and finally the winter). Lower leaching and runoff delivery in the spring compensates for the higher cost of spreading in the spring compared to the fall resulting in increased spreading in the spring.

Not all spreading occurs in the spring, however. Due to the farm heterogeneity, some farms in the watershed continue spreading manure in the winter because they have low enough labor (opportunity) costs in the winter to compensate for the higher nutrient lost. Spreading in the fall also continued on some farms because they grow more wheat which uptakes its nutrients in the fall. Once storage facilities are built, fall spreading occurs primarily on wheat and on alfalfa that needs the potassium in the manure. It is less expensive to spread manure in the fall than in the spring because of the seasonal cost adjustments and because there is no loss in potassium content of manure associated with the seasons. When manure is applied on alfalfa, herbicide costs increase (in SUSFARM) to control the extra weeds.[2]

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[2] In practice, farmers apply manure to alfalfa only when manure becomes a waste (when there is no other land to spread it on) because they believe spreading manure on alfalfa

Total manure spread is the same before and after the standard is imposed, but slightly less commercial fertilizer is applied as manure nutrients are used more efficiently. All the commercial applications are timed to take place when crop uptake can occur. Commercial nitrogen is applied in the summer for corn grain, corn silage, and pasture and commercial potassium is applied in the spring if the alfalfa is being established and in the fall once alfalfa is established (Table 5.2). Remaining practices are similar to the baseline outcome. Mean leaching decreases from 2,637 to 2,354 pounds, due to seasonal adjustment in manure spread, and total nitrogen delivery is 607 pounds (175 of which are soluble) compared with 626 (195 of which are soluble) pounds in the baseline for the same 81 farms.

In summary, the impact of manure storage on nitrogen reduction is limited because 1) most farms already have storage, 2) some spreading continues in the winter, and 3) SUSFARM may understate nitrogen runoff.

5.3.2 Strip-cropping

The standard, applied to 106 farms, curtails 205 pounds of nitrogen delivery reducing total gross margins to a mean of $133,601 (Table 5.1). The area strip-cropped increases by 63 percent from the baseline result to 148 acres (this outcome is only two

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seeds weeds (Wolfe). Applying manure does not seed weeds but provides nitrogen to help weeds better compete with alfalfa which fixes its own nitrogen (Wolfe). This competition necessarily leads to higher seed regeneration. In SUSFARM herbicides are applied every other year to maintain the same protein yield as when alfalfa has no weed competition.

fewer acres than the uniform performance standard). Less hogs and cattle are produced, thus reducing the manure spread. Other practices are similar to the baseline practices. The standard does not achieve the 40 percent total nitrogen delivery reduction and would have to be combined with other policies to achieve this goal. The strip-cropping standard is the only policy for which a trade-off exists between surface and groundwater water quality; leaching increases by two percent while nitrogen delivery decreases by 24 percent.

5.4 POLICY COMPARISON

In the next section the two strategies for allocating control burdens with perfect information are compared. The targeted performance standards are then compared to the uniform and design standards successively. The section concludes with an extrapolation of costs from the sample to the farm population.

5.4.1 Social versus private cost-effective allocation for the watershed

Allocation with perfect information can be done by equating the shadow prices of nitrogen runoff reduction thus yielding the private cost-effective allocation of control burdens. To find the social cost-effective allocation, however, control burdens must be allocated to equate marginal compliance costs plus marginal transaction costs (MTC) among farms ($\lambda_i + MTC_i$). As described in Chapter Three, transaction costs are assumed to be "fixed" per farm -- which is equivalent to a large marginal transaction cost associated with the first pound targeted on a farm and a zero marginal transaction cost for additional pounds targeted on the same farm.

In Table 5.3, the aggregate private compliance costs and public transaction costs associated with each allocation are presented. The social cost-effective allocation has 119 farms reduce the 80,609 required pounds of nitrogen delivery in the watershed (118 farms are not targeted) compared to 138 farms when marginal transaction costs are not taken into account in the allocation of burdens (the private cost-effective allocation). The 19 farms no longer targeted had an average burden of 37 pounds (varying form 4 to 218 pounds) of reduction under the private cost-effective allocation. Three farms previously targeted 290 pounds, 355 pounds, and 495 pounds respectively, are now targeted 323, 709, and 878 pounds.

Targeted farms under the social cost-effective allocation control on average 678 pounds each compared to 585 pounds each under the private cost-effective allocation. Three farms abate a greater percentage of their baseline (40 and 60 percent) to compensate for the 19 farms (previously controlling 20 percent of their baseline) no longer targeted once transaction costs of targeting more farms is taken into account. The small difference in the average aggregate compliance costs per farm, $3,601 for the private cost-effective allocation and $3,603 for the social cost-effective allocation, is explained by the small difference in marginal control costs of the 19 farms no longer targeted ($46 per pound) and farms abating more ($53 per pound) with the social cost-effective allocation. The per pound compliance costs averaged out over all farms rounds up to$11 for both standards.

Table 5.3 Total Control Costs to Achieve the 40 Percent Reduction in Nitrogen Delivery with Performance and Design Standards

	Performance Standards			*Design Standards*	
Costs/ Information	Perfect Information Private Cost-Effective Allocation	Perfect Information Social Cost-Effective Allocation	Uniform Performance Standard	Storage Manure	Strip-Cropping
Number of farms targeted	138	119	237	81	106
Pounds control per farm targeted	585	678	341	997	762
Farm aggregate compliance costs[a]	853,437	853,911	3,788,208	45,978	206,427
Per farm compliance cost ($)	3,601	3,603	15,984	194	871
Compliance/lb ($)	11	11	47	28	4
Public Transaction Costs ($)					
Total information[b]	105,465	97,960	117,552	324	2,862
Information targeted	84,180	72,590	117,552	324	2,862
Information non-targeted	21,285	25,370	0	0	0
Contracting and enforcement	33,672	29,036	46,215	6,318	8,268
Total transaction costs	139,137	126,996	163,767	6,642	11,130
Transaction costs/farm	587	536	691	82	165
Transaction costs/lb	2	2	2	12	1
Watershed Level Costs ($)					
Total control costs	992,574	980,907	3,951,975	52,620	217,557
Total control costs/farm	4,188	4,139	16,975	276	976
Total control cost/lb[c]	12	12	48.9	39	5

[a] Compliance and transaction costs per farm are averaged over 237 farms.
[b] At a minimum information is needed to decide which farms to target (information non-targeted) and more information is then needed to decide how much reduction to impose on targeted farms (information targeted).
[c] The difference between total control costs per pound and the sum of farm and transaction costs per pound is due to rounding.

As discussed in Chapter Three, transaction costs are determined by budgeting costs for information collection, contracting, and enforcement activities. Information cost, is made up of the information costs for the farms targeted and those not targeted, and is only $7,505 less for the social cost-effective standard than the private cost-effective standard. This small difference occurs because only 19 fewer farms are targeted than under the private cost-effective allocation and because some information must still be collected for these farms in order to decide not to target them.

Contracting and enforcement costs are less for the social cost-effective allocation than the private cost-effective allocation because a smaller number of farms is targeted. The difference in total transaction costs when marginal transaction costs are used in the allocation of control burdens, $12,141 ($139,137 - $126,996), is minor compared to the sum of transaction costs plus aggregate private compliance costs of $992,574 and $980,907 resulting in similar total costs per pound, $12, for both allocations. The gain in transaction costs for the social cost-affective allocation is almost completely offset by the loss in compliance costs.

Thus, in this dissertation omitting transaction costs in allocating farm nonpoint source pollution reduction does not overly bias the allocations of burdens among farms. However, accounting for transaction costs in the allocation of burden does have significant distributional effects (nineteen farms are better off and only seven farms are worse off). This conclusion must be interpreted with caution as the importance of transaction costs could be significantly larger if litigation costs were included in the transaction costs estimates.

5.4.2 Targeted versus uniform performance standard

The uniform performance standard's compliance costs and transaction costs both exceed the targeted performance standard's costs. Information, contracting, and enforcement costs are larger because 237 farms are targeted as opposed to 138 farms and 119 farms with the two perfect information strategies. The main difference between the two types of standards is in terms of the compliance costs ($3,602 averaged for private and social targeted standards) per farm compared to $15,984 per farm for the uniform standard.

Compliance costs are larger because the uniform standard is allocatively inefficient. Transaction costs per farm ($587 and $536 for the two perfect information performance standards) and $691 for the uniform performance standard are similar. Interestingly, the transaction costs per pound curtailed are similar, $2 per pound, for all nitrogen performance standards studied. Thus, it is the reduction in total compliance costs alone that differentiates total control costs between the targeted and uniform standard. Given our farm sample, this result refutes Kohn's hypothesis that transaction costs would be more important than compliance costs in the social cost-effectiveness of policy.

5.4.3 Design and performance standards comparison

When applied to agro-pollution sources, performance standards are defined as the least cost combination of practices that achieve the pre-determined environmental goal (40 percent nitrogen delivery reduction). Thus, the cost-effective performance standard is the "best" mix of design standards to achieve the required performance standard. The design standards' private compliance costs could not be less than compliance costs of the performance standard (perfectly targeted design standards). The design standards' aggregate compliance plus transaction costs could be lower if the decrease in transaction costs was sufficient to outweigh the increase in compliance costs.

The manure storage curtails 1,659 (7 pounds times 237) pounds at $28 per pound and the strip-cropping standard curtails 48,585 pounds at $4 per pound (presented in the last two columns of Table 5.3). Neither the manure storage nor the strip-cropping standard achieves the 40 percent required reduction in nitrogen. The small amount of nitrogen curtailed associated with the manure storage standard reflects its relative ineffectiveness to abate nitrogen delivery when most farms already have manure storage.

Although the strip-cropping standard has the least per pound private compliance costs for the pounds curtailed, it would be misleading to compare this design standard with the performance standards directly because it only abates 24 percent of total watershed delivery. The per pound cost for the last 32,145 pounds is likely to be higher (reflecting the increasing compliance costs). For example, the per pound compliance costs to curtail 20 percent of the baseline nitrogen delivery with the private cost-effective allocation is only $3.

Total transaction costs per farm and for all farms in Table 5.3 are significantly less than those of the performance standard as hypothesized in Chapter One. Transaction costs per farm are only $82 and $165 for the manure and strip-cropping standard, respectively, because these practices are easy to observe and to verify. Transaction costs per pound of nitrogen delivery curtailed are least for the strip-cropping ($1) (compared to $2 for the performance standards and $12 for the manure storage standard).

5.4.4 Cost extrapolation to the farm population in the watershed

For the 237 sample farms modeled, a reduction in 40 percent of the nitrogen delivery can be achieved at a cost of $980,907 by targeting 50 percent of the sample farms. This result is extrapolated to the whole Lower Susquehanna watershed by assuming that 49 percent of the 13,596 farms in the watershed are dairy farms (forty-nine percent of the farms in the watershed sample are dairies). Half of the 6,662 dairy farms would be targeted at total compliance cost of $23,983,200. This figure is computed by multiplying the total farm compliance costs ($3,600) times the number of farms (6,662). The total transaction cost would be $3,570,832 (6,662 farms• $536 average transaction costs per farm) for a total compliance cost of $27,554,032.

5.5 VALUE OF INFORMATION AND IMPLICATIONS

5.5.1 Value of information

Information has a value because it increases the cost-effectiveness of policy-making. The value of information is expected to be high in controlling agro-pollution because of farm heterogeneity and associated differences in compliance costs even within watersheds. In this study, perfect information allows policy makers to set control burdens equal to marginal compliance costs (for regulatory policies) and to trade runoff reductions from high to low cost farms until all gains from trade are captured (for market-based policies).

The value of perfect information is computed by comparing the total control costs with perfect information to the total control cost with the least information necessary to achieve the 40 percent reduction in nitrogen delivery for the Lower Susquehanna watershed. Results below are a function of this definition.

For the sample farms in the watershed, the gross private value of perfect information is $2,934,771 ($3,788,208 - $853,437) aggregate compliance costs with a uniform allocation minus aggregate compliance costs with the perfect information performance standard. The gross social value of information is slightly lower, $2,934,297 ($3,788,208 - $853,911), because the marginal transaction cost of targeting one more farm and the marginal compliance cost are both considered in the allocation of control responsibility.

The net values of information are net of transaction costs. Transaction costs for the private cost effective allocation by design are higher than for the social cost effective allocation of control responsibilities, but the difference is slight, $36,771 (total transaction in column three minus in column four) for the social allocation and $24,630 (total transaction cost in column two minus in column four) for the private allocation. Thus, the net private and social values of information are $2,959,401 and $2,971,068 respectively -- more than the gross value of information since the uniform performance standard' transaction costs are higher than the targeted standards. The gross value of information represent 99.2 (private allocation) and 98.8 (social allocation) percent of the net value of information indicating that (1) most of the savings from information are saving in compliance costs and the farm sector reaps most of the benefits from collecting perfect information to target nitrogen delivery responsibilities and that (2) adding marginal transition costs to marginal compliance costs in deciding which farms to target does not significantly affect savings in total control costs (savings are less than $12,000).

Substantial savings in transaction and compliance costs can be reaped by collecting perfect information to target performance standards. The transaction costs to identify farms with low relative marginal compliance costs is lower than the benefits that can be reaped by targeting these farms. These results also imply that cost-effectiveness of cost-share funds could be greatly increased by targeting cost-share funds to farms with the lowest marginal compliance costs.

Only dairy farms are analyzed in this study. The Area Study Survey in the Lower Susquehanna watershed also contains other cattle farms, poultry farms, and cash-crop farms. Large poultry operations often pose environmental problems because not enough land is available for environmentally sound manure management. Including these other farm types with potentially different nitrogen delivery compliance costs might influence the allocation and show even higher values of information.

5.5.2 Transaction costs

Social benefits are barely affected when marginal transaction costs are added to the marginal compliance costs in order to decide which farms to target. The value of collecting perfect information to target farms when transaction costs are disregarded, $2,959,752, is 99.6 percent of the value of information when transaction costs are considered to determine the cost-effective allocation of control burdens. This result could change significantly if the costs of litigation were included in the transaction cost estimates.

Litigation costs, when farms do not comply, can significantly increase enforcement costs as illustrated by the Pennsylvania Department of Environmental Protection Water Management Division case below. Over the last five years, the division investigated an average of 77 civil complaints per year. On average 7 percent of the farms (2 farms) per year do not comply and require advance settlement processes. These cases on average involve 23 attorney hours and 115 specialist hours (Table A.3) to process. In addition, water sample analyses (at $50 each) and an additional 30 field staff hours is required to enforce the agreed practices. Though, no data is available to estimate the farmers' private litigation costs, they are expected to be high as well.

Transaction cost estimates in this study were obtained by budgeting activities required for information, contracting, and enforcement and are approximations at best because data on transaction costs are lacking. The effects of errors in transaction costs on the social control costs should be relatively small, however, because: 1) transaction costs are small compared to the private compliance costs and results are not sensitive to small changes in transaction costs. Halving marginal transaction costs causes only a seven percent increase in the number of farm targeted, 127 farms. Doubling marginal transaction costs decreases the number of farms targeted by 16 percent to 100 farms. Similarly, dividing (multiplying) marginal transaction costs by four increases (decreases) the number of farms targeted by 12 percent (59 percent) to 133 farms (75) farms. Results are thus more sensitive to underestimation of transaction costs than underestimation. If for example, transaction costs were doubled after adding litigation costs, 16 percent fewer farms could be expected to be targeted and compliance costs would be slightly higher. Overall the number of farms targeted is relatively insensitive to the transaction cost estimates.

5.6 IMPLICATIONS

The value of information found in this study indicates potential for (1) targeting total nitrogen delivery control responsibilities, (2) point-nonpoint source trading, or (3) targeting voluntary cost-share control programs, each of which have different contracting and enforcement costs. In Chapter Three, it was shown that transaction costs to society must be taken into account to minimize the sum of public and private control costs. The benefits of collecting (modeling) marginal compliance costs can be exploited through pollution reduction trading if a threat of uniformly applying the 40 percent reduction to all farms is credible. Under a trading system, the trading prices for the rights to pollute that would emerge are the shadow prices for nitrogen delivery constraints approximated with SUSFARM.

Under the uniform performance standard and allowable trade, the information about low marginal cost farms could be disclosed to farmers with higher abatement costs to allow them to achieve their standards at least costs by trading with low cost farms. Regulating farms to reduce their nitrogen deliveries by 40 percent is technically equivalent to giving them the right to deliver 60 percent of their baseline nitrogen. The environmental authority could certify trade among farmers using a bio-economic model to verify that the resulting nitrogen delivery is 40 percent less from the baseline. The 119 farms that were allocated zero reduction in pollution would be among the "buyers" and those allocated a large part of the reduction would be "sellers" of the right to deliver nitrogen to streams. The trading and pollution tax policies have the advantage of minimizing distortion and inequities (assuming that permit or tax revenues are redistributed to the watershed farmers). A trading system which allows performance standards to vary among farms would be preferred by farmers, if there were a believable threat that a uniform performance standards would be implemented, as they result in less aggregate compliance costs to farmers (especially if savings are redistributed). Targeted cost-share programs should offer cost-share only to farms targeted in the perfect information scenario and for the practices adopted by these farms once targeted. Tax payers would then get the maximum pollution reduction for their money and farmers would be as well off as before; the value of information would be obtained by the public.

5.6.1 Implications for farms participating in government programs

Given the 0-85 alternative available to farmers participating in government program, these farms would have been expected to have lower compliance costs, everything else equal, than non-participating farms. However, participating farms have large compliance costs and many of them cannot achieve the more stringent standards. This counter-intuitive results can be explained by two factors: the rye-cover C-factor is higher than the idle land C-factor and these farms have lower baseline runoff due to set-aside.

In SUSFARM, farms participating in government commodity programs must plant their base acres at least to a rye cover. Participating farms can idle only land not enrolled in a government crop program and the C-factor attached to rye production is higher than the C-factor for idle land because the land must be turned over to plant rye. Whereas the C-factor for idle land was based on perennial cover.

Participating farms already have 15 percent of each of their base in set-aside (rye cover) with a relatively low C-factor (compared to other crops). These farms may also already have more management practices in place than the average farm perhaps because they also participate in cost-share programs requiring them to have a farm management plan in place. It may be expensive to abate nitrogen on these farms unless they are given some flexibility to plant these acres. This issue is not discussed extensively because the Federal Agricultural Improvement and Reform Act (FAIR Act) of 1996 gives farmers the flexibility to plant their acres to other crops or idle them.

5.7 CONCLUSION

A bio-economic model that reflects diversity among dairy farms in the Lower

Susquehanna watershed was used to evaluate four policies to achieve the watershed goal of 40 percent reduction in nitrogen delivery. Two performance standards, one using perfect information and one using no information (uniform allocation), and two design standards were evaluated. Farm nitrogen compliance costs increase as policies are based on less and less information indicating that information has great potential to reduce control costs in the watershed. The value of perfect information (to target performance standards) was estimated at close to three million dollars for the sampled 237 dairy farms.

Extrapolating this value to the 6,662 dairy farms in the watershed yields an estimated $27.6 million value of perfect information. This large value of information for the Lower Susquehanna watershed warrants considerations in further attempt to meet the 40 percent reduction goal set for the whole Chesapeake Bay; imposing a uniform performance standard or uniform cost-sharing can impose millions of dollars in additional costs to society to achieve the same standard.

The two strategies used to target farms with perfect information, both have an average farm compliance cost per pound abated of $11, the uniform performance standard $47, the manure standard, $28, and the strip-cropping standard, $4. However, neither of the design standards achieves the 40 percent reduction goal set for the Chesapeake Bay. The private and social cost-effective allocation yielded similar results showing that for this watershed, social costs of ignoring transaction costs in allocating control burdens are minimal. This similarity partly results from the low transaction costs per pound controlled compared to the farm private compliance costs. Transaction costs vary from $12 for the manure storage standard to $1 per pound for the strip-cropping standard.

For this sample, the minimum cost of achieving the 40 percent reduction in nitrogen delivery standard was estimated at $980,907 for the private cost-effective allocation and $992,574 for the social cost-effective allocation. If distributional and litigation effects were included, however, the social allocation could be warranted.

CHAPTER 6
ESTIMATION OF THE PARTIAL INFORMATION MODELS: PROCEDURES AND RESULTS

6.1 REGRESSION BACKGROUND AND DATA

This chapter tests whether transaction plus compliance costs -- total control costs -- of achieving 40 percent nitrogen delivery reduction in the Lower Susquehanna can be decreased (value of information increased) by targeting farms using only partial information. In Chapter Four, perfect information shadow prices (derived from the constraint on total nitrogen delivery (TND) in SUSFARM) were used as proxies for compliance costs in order to target levels of nitrogen delivery reductions to farms. This perfect information allocation minimizes total control costs, but at the expense of large information costs: $72,590 for targeted farms and $25,370 for non-targeted farms. Information costs associated with non-targeted farms are the costs of finding out that these farms should not be targeted.

The partial information allocation is carried out in two steps. Instead of using detailed site-specific information and farms' baseline information to simulate shadow prices and target farms, in this chapter, shadow prices are estimated with the metamodel developed in Chapter Two. First, farms are targeted or eliminated from consideration by using estimated shadow prices and estimated nitrogen deliveries. Then, perfect information is assumed to be collected about the remaining farms to do the final targeting. Both steps are carried out in ALLOCATI by simply replacing the input files containing the perfect and partial information shadow prices and baseline nitrogen delivery respectively (see Appendix C). In this dissertation the terms 'estimated' and 'partial information' shadow prices are used interchangeably. The value of partial information is computed and compared to the value of perfect information found in Chapter Five. If the value of partial information is larger than the value of perfect information, predicted shadow prices from the metamodel are accurate enough to reduce total control costs. Otherwise perfect information should be used.

The marginal compliance costs of reducing nitrogen delivery or farms' shadow prices depend on farms' actual practices and physical characteristics. In the short-run, farmers faced with environmental constraints will minimize the costs of producing milk subject to land, labor, and nitrogen delivery constraints. The best management practices (BMPs) to implement for each farm depend on their mix of input and output, location, and other social and physical characteristics. It is this mix of input, output, location, and other characteristics that must be identified to predict which farms have low compliance costs and thus should be targeted.

The metamodel and the data used in estimating the metamodel are presented in the next section. Then farms targeted various levels of nitrogen delivery reduction in Chapter Four are characterized. These farm characteristics and their trends are then used to decide which variables to include in the metamodel. In the next section, transaction costs to achieve the partial information allocation are presented followed by the economic and environmental results of the partial information strategy and policy implications.

6.2 SHADOW PRICES METAMODEL

From Chapter Two, TND_i is expressed as $\gamma_i \bullet TN$ (total available nitrogen), with $0 < \gamma_i < 1$. γ_i is estimated based on the farm characteristics as follows:

$$TND_i = (\sum_m \gamma_{im}) \cdot TN_i \tag{6.1}$$

and approximates the fraction of TN_i delivered given farms' m characteristics. Outputs and inputs in (2.11) are divided by the derivative of TND with respect to TN ($=\gamma_i$) to yield j estimable equations:

$$\lambda_{ij} = \frac{P_i \cdot Y_i}{\gamma_i TN_i} - \frac{x_{i2}}{\gamma_i TN_i} - \ldots\ldots - \frac{x_{ik}}{\gamma_i TN_i} + \epsilon_i \tag{6.2}$$

where j are the levels of nitrogen delivery reductions. As the nitrogen loading constraint is intensified, the associated shadow price i for level of reduction j (λ_{ij}) increases at an increasing rate. Output and inputs variables are divided by the total nitrogen available to plants on farm i (TN_i) which includes total nitrogen stored in the soil, or fixed and carried over by legumes, or imported to the farm through manure, and commercial applications, or precipitation, net of runoff and leaching.[1] P_i are the dairy enterprise gross margins.

SUSFARM's output (Y) for farm i is brought to the left-hand-side to restrict its coefficient to one as dictated by Euler's equation. The restricted equation:

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[1]The model accounts for limited mineralization of soil organic matter and legume carry over; it does not consider carry over of excess nitrogen in subsequent years.

$$\lambda_{ij} - \frac{P_i \cdot Y_i}{\gamma_i \cdot TN_i} = - \sum_{\substack{k \\ k \neq N}} \frac{\partial Y_i}{\partial X_{ik}} \cdot \frac{P_i \cdot X_{ik}}{\gamma_i \cdot TN_i} \tag{6.3}$$

has the k (X_k) milk production inputs (corn grain, corn silage, alfalfa and hay, corn bought, labor, pasture) from Table 4.7 and 4.8 for explanatory variables.

The schedule of shadow prices is approximated by four levels (j) of nitrogen delivery reductions in SUSFARM. Optimally, the metamodel in (6.3) would be estimated with output and inputs at each level of nitrogen delivery reduction j. To be useful as a decision making tool, however, the model must be estimated with observable variables prior to the implementation of a policy (such as performance standards). In this study, SUSFARM's baseline levels of inputs and outputs are used as proxies for what control agencies could observe prior to targeting farms. Thus, λ_{ij} in Equation (6.3) varies for the four levels, but inputs (X_i and TN_i) and output (Y_i) are the same and equal to the baseline level. The predictions are expected to worsen with the stringency of the standard because the inputs and outputs at higher restriction levels are likely to differ increasingly more from the baseline. However, the baseline data are the only data available at the time of implementing the policy.

6.2.1 Output (Y)

Dairy farms in SUSFARM are classified as such because more than fifty percent of these farms' income comes from dairy enterprises including milk, cull cows, bull calves, and heifer sales. Output (Y_i) in Equation (6.3) is the product of milk per cow

(MILK) and the number of cows on farm i. Annual milk production per cow is assumed to vary by farm size: 155 cwt per cow for farms with less than 50 cows, 160 cwt for farms with between 50 and 70 cows, 165 cwt for farms with between 70 and 90 cows, and 170 cwt for farm with more than 90 cows (Ford). P_i is computed as the difference between the milk price per cwt, \$13.50 and marketing costs, \$1.07. The per-cow cost of purchased vitamins, minerals, and soybean meal, \$40.47, is subtracted while the value of sale of culls, bulls, and heifers, \$271.03 is added and non-feed variable costs \$288.80 are subtracted. Revenues are divided by total milk production to bring the gross margin on a per pound of milk unit.

For example, if farm i was modeled producing 100 cows, P_i equals ((\$13.50 - \$1.07) + [\$271.03 - \$288.80 - \$40.47/170]), or \$12.09 and Y_i is 170 cwt of milk. Other outputs such as hogs, cattle, poultry, and cash crops are important for some farms but cannot be added as legitimate regressors, because Euler's equation does not extend to multi-output production functions. The resulting regression might be less efficient since some available information is not used to explain the farm's output.

6.2.2 Inputs

Inputs into dairy farming are feed, labor, land (for feed grown on-farm), water, and capital. In the model, feed can be bought or grown on-farm. Alfalfa-hay, soybean meal, and corn are bought to feed the cows but only corn grain (CORGBT) and hay are included. Because only five farms modeled by SUSFARM buy alfalfa and four buy other hay, the sum of the alfalfa and hay, HAYB, was included as a regressor instead of each crop individually. Soybean meal is not included as an explanatory variable because it is bought in fixed proportion to the number of dairy cows (depending on the ration used) carrying no extra information; one can recover the information from the number of cows and the feed ration used.

Crops grown to feed the cows entered as regressors are corn grain (CORG), corn silage (CORS), and pasture (PAST). Alfalfa is not included because it is grown in a 1:1 ratio with corn; rotations including alfalfa are four years corn grain or four years corn silage and four years alfalfa (see Table 4.3 for details) and, thus, is perfectly linear with the sum of the acres in corn silage and corn grain. Corn, alfalfa, and pasture acres represent 81 percent of the total acres planted on all farms in SUSFARM's baseline. Other crops such as rye, wheat, and oats are not included in the metamodel although they may provide cover for the set-aside acres (rye), or provide straw (oats and wheat) for the animals.

When feeds are grown on the farm, nutrients, pesticides, water, and crop labor must also be added to the potential regressor list. Total phosphorus is not included because it is highly correlated with TK_i and thus, does not add any information to the regression (based on soil testing results in the study area). Total nitrogen (TN_i) and potassium (TK_i) available to plants depend on the soil stocks of these elements and the production system used and would not be easily observed, but can be estimated from the sample data. Farmers decide how much and how to produce and then adjust production to satisfy their nitrogen loading constraints. Thus, TN and TK are estimated first and used recursively in the shadow price equations. In Equations (6.4) and (6.5) standard deviations appear in parentheses. Total nitrogen (TN_i) is regressed on total land, manure production, and commercial nitrogen as:

$$\begin{gathered}\hat{TN}_i = \underset{(0.4185)}{-0.782} + \underset{(0.0017)}{0.0342} \cdot TOTLAND_i + \underset{(0.0016)}{0.0307} \cdot MANPROD_i + \underset{(0.00003)}{0.001} COMMN_i \\ R^2 = .98; \qquad F(3,233) = 4774;\end{gathered} \tag{6.4}$$

commercial nitrogen (COMMN), total land area (TOTLAND), and tons of manure production (MANPROD) alone explain 98 percent of the variation in the total pounds of nitrogen available to plants (TN). Each farm's output and input in the metamodel are divided by this estimated TN_i as explained earlier.

$$\begin{gathered}\hat{TK}_i = \underset{(0.882)}{0.109} - \underset{(0.0027)}{0.0323} \cdot TOTLAND_i + \underset{(0.0033)}{0.0689} \cdot MANPROD_i + \underset{(0.00002)}{0.00016} \cdot COMMK_i \\ R^2 = .93; \qquad F(3,233) = 962;\end{gathered} \tag{6.5}$$

Commercial potassium purchase and manure production explained 93 percent of the variation in potassium available to plants (Equation 6.5).[2] Better predictions could be obtained by including soil potassium content (which in some counties is high), but information on stock of potassium would be harder to obtain in practice and was not included.

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[2] Potassium available to plants is the sum potassium present in the soil and potassium added through commercial or manure sources.

The numerous pesticide requirements vary with the crop and the tillage systems and are assumed to be constant for given crops. Labor (LABOR) is the sum of family labor fixed for all farms at 5,726 hours per year[3] plus seasonal hired labor obtained from SUSFARM. Irrigation is not widely used in Pennsylvania; SUSFARM estimated water input comes from annual precipitation amount averaged for the three weather station, one located in each region in SUSFARM. However, precipitation amounts are similar for all farms in the region offering little variability as a regressor and were not included in the regression. Capital investment is fixed in SUSFARM and not included in the metamodel.

6.3 THE TOTAL NITROGEN DELIVERY METAMODEL

Following a review of the differences between targeted and non-targeted farms (where targeting is based on perfect information as described in Chapter Five), total nitrogen deliveries are estimated for each farm. The first derivative of nitrogen delivery with respect to nitrogen available is then used in the shadow price regressions as illustrated in equations (6.1), (6.2), and (6.3). The reader is reminded that Euler's equation is manipulated to estimate the shadow prices as a function of output and input use in dairy production. The equation is then divided by the first derivative (of nitrogen delivery with respect to nitrogen available) to adjust Euler's equation to measure the effect of changes in total nitrogen delivery instead of total available nitrogen input.

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[3] An average for dairy farms from the Pennsylvania Farm Costs and Return Survey.

6.3.1 Targeted versus non-targeted farm characteristics

Chapter Four's private cost-effective scenario is reproduced in greater detail in Table 6.1 to illustrate the difference between targeted and non-targeted farms. The reader is reminded that the private cost-effective allocation minimizes aggregate compliance costs of achieving the 40 percent total nitrogen delivery reduction (in contrast with the social cost-effective allocation that minimizes aggregate compliance plus transaction costs). In the first row, the five levels of reduction that could be allocated to a farm vary from 0 percent (not-targeted) to 80 percent of the farm's nitrogen baseline total nitrogen delivery. As indicated in the second row, 99 farms are not targeted, 93 farms are targeted 20 percent of their baseline, and only seven farms are allocated a reduction of 80 percent of their baseline total nitrogen delivery.

Non-targeted farms have low total nitrogen delivery compared to targeted farms and zero mean control burdens. Both mean nitrogen delivery and mean nitrogen delivery reductions allocated to farms increase with the percent reduction levels. Mean total nitrogen delivery reduction, for instance, increases from zero to 6,066 pounds while mean total nitrogen delivery increases from 442 pounds to 7,587 pounds. Seven farms bear 53 percent of the responsibility to control total nitrogen delivery (7•6,066=42,462 lbs). As expected, mean shadow prices are larger for non-targeted farms than targeted farms. For instance, shadow prices for farms not targeted are approximately 206, 220, 48, and 59 times larger than the farms targeted 80 percent of their baseline for the 20, 40, 60, and 80 percent reduction levels. Table 6.1 also confirms the inverse relationship between shadow prices and total nitrogen delivery and allocated delivery reductions for all shadow prices.

Table 6.1 Farm Mean TND, TND Reduction, and Some Output and Inputs for Farms Assigned Various Levels of TND Reductions with Perfect Information

	Percent					Total Farms
Reduction levels	0	20	40	60	80	
Number of farms[a]	99	93	27	11	7	237
Mean TND (lbs)[b]	442	516	1,023	2,672	7,587	201,368
Mean TND reduction (lbs)	0	103	409	1,600	6,066	80,685
Shadow prices (λ_j)						
20 percent ($/lb)	206	25	10	9	1	
40 percent ($/lb)	439	277	29	16	2	
60 percent ($/lb)	866	730	353	42	18	
80 percent ($/lb)	1,715	1,475	579	129	29	
Size variables						
COWS (number)	70	84	65	97	71	
CROPLAND (acres)	339	304	245	362	467	
TN (tons)	32	31	24	31	48	

[a] Number of farms targeted each level of reduction with the private cost-effective allocation.
[b] Total nitrogen delivery in the baseline.

Non-targeted farms tend to be smaller than targeted farms as reflected by lower number of dairy cows (COWS) and total cropland (CROPLAND) in the first column (compared to the other four columns) although the trend is not uniform (Table 6.1). Total nitrogen available and the size of the farm alone do not explain all the variation in total nitrogen delivery nor in the reduction of total nitrogen delivery (from farms' baseline) that should be targeted to these farms. Total nitrogen available to plants is only weakly correlated with the baseline nitrogen delivery (Table 6.1). The number of cows, cropland acres and total nitrogen fluctuate among the reduction levels indicating that additional variations such as farm location and management practices already in place contribute to the variation in total nitrogen delivery and to the allocated reduction. These sources of variations are explained below.

6.3.2 Interaction terms

There are few post-production treatments for agro-pollution such as those that exist for point sources (e.g. a stack chimney or end-of-the-pipe treatment). Instead, production practices are switched to better management practices (intensive margin adjustments) or land is taken out of production (extensive margin adjustments) to attain assigned or desired reductions. From Equation (2.2) the total nitrogen delivery shadow prices vary negatively with initial loadings and with initial loading allocations. If farms already follow good management practices, they already have reduced much of their pollution (have low loadings) and have already used the inexpensive alternatives to control total nitrogen delivery. Farms with good management practices and located away from receiving bodies of water, have, other things equal, higher compliance costs (shadow prices) and should not be targeted. Wu et al. also find that higher tax rates must be imposed on regions with lower baseline nitrogen runoff and leaching than regions with higher nitrogen runoff, to reduce nitrogen runoff and leaching by the same amount in two subregions of the Southern High Plains.[4]

Baseline levels of nitrogen delivery depend on the farm physical characteristics and management practices. Thus, current farm management practices are potential interaction candidates to adjust downward the nitrogen delivery given the total nitrogen on farm i. Table 6.2 presents the practices and physical characteristics of farms targeted various levels of nitrogen reduction with the private cost-effective allocation (from Chapter Five). Three characteristics affecting soluble runoff -- water holding capacity (AWC), permeability, and bulk density -- are nearly constant throughout. Soil hydrological groups (NA to ND) are a classification given by the Natural Resources Conservation Service to soils of the United States to describe their permeability (infiltration)[5] and runoff potential (Novotny and Chesters). These groups were obtained from the SOILS5 file corresponding to the sample farm. Soil hydrological group A (NA) has high infiltration rate and high sand and gravel content. Group D (ND) has high

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[4] If a tax was imposed on total nitrogen delivery to reduce it by 20 percent, each farm's shadow price at 20 percent of their baseline corresponds to the tax they would face to cost-effectively allocate control burdens.

[5] Infiltration depends on permeability of soils and subsoils, soil moisture, vegetation cover, and other parameters (Novotny and Chesters).

surface runoff potential and slow infiltration rate with fine texture (Novotny and Chester). Groups B and C lie somewhere in the middle. Soil group A is set equal to one if the farm's soil is A and 0 otherwise, and similarly for soil group B, C, and D. Other things equal, a farm on soil group A would have lower soluble runoff than a farm on soil B, and farm on soil B lower total nitrogen delivery than a farm on soil group C and so on. As the control burden increases, the percentage of farms located on soil hydrological group C increases and on groups B and A decreases.

The slope steepness (slope percent) is larger for farms targeted more control responsibility while distance to a water body is significantly smaller and slope function and weighted cover[6] of the flow path to the body of water are modestly smaller.[7] Other characteristics do not have such a clear trend (indicating lower correlation between them and the total nitrogen deliveries). The percentage of farms with storage and strip-acres generally are lower, though irregularly, as total nitrogen delivery control responsibility increases. Soil clay content and slope length generally are higher for farms targeted higher reduction percentages. Farm mean sediment and soluble runoff are also presented in Table 6.2 to illustrate the influence of sediment-bound nitrogen delivery which almost triples at each level of control, while soluble runoff is fairly constant.

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[6] The slope function is the average slope to the receiving body of water and weighted cover (an average for the NRI polygon based on NRI sample points) is a measure of the ground cover capacity to capture eroding sediments. The slope function measures the effect of intervening flow path slope (between field and surface water) on the tendency for sediment particles to be trapped or slowed before they reach surface water. The slope function is inversely related to flow path slope. See Appendix D for more details.

[7] Slope information was available from the NRI file.

Table 6.2 Mean Farms Physical Characteristics and Management Practices by Levels of TND Reduction allocated with Perfect Information

	Percent					Total Farms
Reduction levels	0	20	40	60	80	
Number of farms[a]	99	93	27	11	7	237
AWC (in./in.)	0.1	0.1	0.1	0.1	0.1	
Permeability (in./hr)	1.0	0.9	0.9	0.9	0.9	
Bulk density	1.3	1.3	1.3	1.3	1.3	
NA (percent)	2.0	4.3	0.0	0.0	0.0	
NB (percent)	70.7	47.3	48.1	18.2	28.6	
NC (percent)	22.2	38.7	33.3	81.8	71.4	
ND (percent)	5.1	9.7	18.5	0.0	0.0	
Distance (ft)	1530	1484	1049	713	539	
Slope percent	6.7	6.0	8.0	12.0	17.4	
Slope function	0.75	0.79	0.77	0.71	0.69	
Weighted cover	0.50	0.51	0.49	0.49	0.49	
Clay (percent)	21.0	21.1	22.6	21.4	26.5	
Slope length (ft)	227.3	180.6	275.2	350.6	303.6	
Strip-acres	173.8	42.2	7.1	31.1	0.0	
Manure storage (percent)	79.8	68.8	55.6	90.9	57.1	
Manure production (lbs)	268.2	306.6	243.6	366.9	296.7	
Manure application (percent of total)						
Winter	8.3	12.3	17.4	8.0	5.0	
Spring	39.3	37.9	34.7	39.8	41.7	
Summer	38.9	33.8	27.6	34.5	44.1	
Fall	13.5	16.0	20.4	17.7	9.3	
Manure incorporated (percent of total)						
Incorporated	14.5	13.1	15.1	8.7	14.3	
Nitrogen deliveries (lbs)						
Soluble runoff	230.0	241.3	215.0	352.7	346.4	
Sediment-bound runoff	211.8	274.5	808.0	2319.0	7240.7	

[a] Number of farms targeted various levels of reduction that sums up to the total 237 farms.

Farms targeted to control more than 20 percent of their baseline nitrogen delivery have the majority of their delivery made up of sediment runoff which is less expensive to control than soluble runoff.

Table 6.2 suggests several important variables and their signs that should be expected in estimations of shadow prices and nitrogen delivery. When rotations are strip-cropped, less sediment delivery occurs compared to rotations without strip-cropping. The higher the strip-cropped acres the lower the nitrogen deliveries, thus the NSTRIP sign should be negative. Distance is used in the delivery ratio computations and is negatively related to deliveries (see Appendix D). Thus, even if a farm has steep slope and poor management, the delivery is near zero (for sediment-bound nitrogen) if the farm is far enough from a water body. Distance is positively related to shadow prices because the delivery ratio is computed such that farms closer to the water have more of their runoff reduction translated into total nitrogen delivery reduction (as well as having higher initial loadings). Because the Area Study Survey sample was stratified to include more sites with soil hydrological group B and C (the most predominant soil), only six dairy farms are located on group A and 19 on group D, which may affect the significance and signs of the hydrological variables. Below, characteristics significantly different between the targeted and non-targeted farms were entered as interaction terms in the total nitrogen delivery estimations in Equation (6.3).

6.3.3 The total nitrogen delivery model results

Results from the total nitrogen delivery regression appear in Table 6.3. Total nitrogen delivery was estimated with OLS for the 237 farms without intercept. Each explanatory variable's name starts with an "N" to indicate that total nitrogen is multiplied by each farm characteristic (the interaction terms) to account for the discrepancy between total nitrogen and total nitrogen delivery. The summation of the products of each coefficient multiplied by the level of the corresponding physical characteristic or management practice m on farm i should be less than one and greater than zero to reflect the fact that total nitrogen delivery is less than total available nitrogen (Equation 6.1). The first three variables shown in Table 6.3, NA, NB, and NC account for the four different hydrological groups in the watershed. Three variables follow accounting for the number of strip-acres (NSTRIP), the distance to water (NDIST), and the field slope (NSLPE).[8] The last three variables are binary variables equal to one if the soil productivity group equals the digit indicated in the name of the variable and zero otherwise. Variables are jointly significant with a F-value of 39.53 and explain sixty one percent of the variation in total nitrogen delivery. With the exception of the soil hydrologic group coefficients, all coefficients have the right signs and magnitude.

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[8] To improve the fit, strip-acres and manure spreading in each season could be entered as a fraction of total cropland and total manure spreading, respectively.

Table 6.3 TND Estimation Results

Variables	Estimates[a]
NA	-11.5962
	(19.3720)
NB	23.1975
	(9.2621)
NC	28.3356
	(7.1215)
NSTRIP	-0.0185
	(0.0046)
NDIST	-0.0026
	(0.0008)
NSLPE	342.2111
	(36.3046)
N1	-20.6165
	(8.4363)
N2	-8.4346
	(7.4217)
N3	-21.0988
	(7.7985)
R^2=.61;	F=39.53

[a] Standard errors in parentheses.
[b] Estimated with 237 farms

Soil group D (ND) which should have the highest total nitrogen delivery was left out of the regression to avoid perfect collinearity. Thus, other soil groups should have negative signs because their runoff is less compared to D. NSTRIP has a negative coefficient indicating that strip-cropping has a tendency to reduce sediment erosion and delivery. The coefficient of NDIST is negative as expected. Field slopes play a large role in sediment delivery. Steeper slopes (NSLPE) have more propensity to erode soil and slope has a positive coefficient as expected.

The soil productivity groups (N1 to N4), obtained from the Pennsylvania Agronomic Guide reflect the degree to which soil depth and drainage can limit crop yield (Serotkin). Soil productivity groups one (N1) is mainly associated with soil hydrologic groups B (NB). For example, of the 116 farms with soil productivity 1, 84 percent have soil hydrologic group B and 16 percent have soil hydrologic group C. Soil productivity group two (N2) is associated with five farms with soil hydrologic group A (NA). Soil productivity group 3 (N3) is almost exclusively associated with soil hydrologic groups C (NC), while soil productivity 4 (N4) is almost equally distributed between soil hydrologic groups C and D. The N3 coefficient is larger and more negative than those of N2 and N1 reflecting its greater association with more runoff-prone hydrological group C. When the units in which the strip-cropped acres, distance in feet, and the percent slope are taken into consideration, these variables' coefficients are of the same magnitude. It is possible that some of the variation in TND could be picked up by the soil productivity groups, thus explaining the wrong signs on the soil hydrological groups. If total nitrogen delivery would have been estimated on a per-acre basis as opposed to for the whole farm, some of the variation associated with farm size might have been eliminated.[9]

6.4 ESTIMATED SHADOW PRICE RESULTS

Shadow prices are approximated with the two step regressions presented above where total nitrogen deliveries are estimated first with interaction terms between farm characteristics and total available nitrogen as shown in Equation 6.1. The estimated derivative of TND with respect to TN (γ_i) is then multiplied by estimated TN and used to estimate shadow prices as shown in Equations (6.2) and (6.3). In addition to improving predictions, estimating total nitrogen delivery first and then estimating shadow prices removes collinearity that would be severe between milk output and then crop acreage. Shadow prices for farms with positive predicted total nitrogen delivery are estimated as follows. All 200 farms that could achieve the four performance standards (thus having a positive and limited shadow prices at all reduction levels) had their shadow prices regressed on the crop variables divided by the product of the first derivative of total nitrogen deliveries with respect to total available nitrogen and total available nitrogen (Equation 6.3).

Shadow prices for the twenty six farms that had infinite shadow prices and

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[9] Future research should adjust total nitrogen delivery by dividing it by the total farm acres to control for size. TND should also be estimated with a probit model since its coefficients are limited to be between 0 and 1.

positive predicted total nitrogen delivery were predicted using regression coefficients from these 200 farms. These farms' physical characteristics were replaced in the regression equation and their mean total nitrogen delivery calculated. Eleven farms with negative estimated total nitrogen delivery were assumed to have near zero delivery and thus were removed from consideration (as non-targeted) before the cost-effective allocation stage.

6.4.1 Estimation results

Estimated shadow price coefficients along with their standard errors are presented in Table 6.4. Equation (6.3) was estimated with baseline information for 200 farms (without intercept to indicate that when total nitrogen deliveries are zero the shadow prices are zero). The independent variables represent X_{ik} in Equation (6.3).
The estimated coefficients in Table 6.4 represent each variable's contribution to the shadow price ($P_i \cdot \partial Y_i/\partial X_{ik}$). All variables names begin with an "A" indicating that they have been divided by the estimated derivative of total nitrogen delivery with respect to total available nitrogen (γ_i). The 'N' at the end of the variables indicate that they have been divided by total available nitrogen (TN) as well.

The two corn variables, corn grain (ACORG) and corn silage (ACORS) have a numerically large effect, 26.5 and -198.4 respectively on the 20 percent reduction level (and on other reduction levels). Judging by the size of the corn bought (ACORGB) standard errors compared to its coefficients, ACORGB has little explaining power except for the 20 percent reduction.

Table 6.4 Estimated Coefficients of Variables Predicting Shadow Prices at 20, 40, 60 and 80 Percent Nitrogen Delivery Reduction[a]

	Reduction Levels			
	20	40	60	80
Independent Variables	Coefficients	Coefficients	Coefficients	Coefficient
ACORGN	26.5227	46.2553	43.6408	300.6417
	(12.0449)	(22.0636)	(43.0463)	(75.8966)
ACORSN	-198.4378	-309.3222	-432.5550	-517.9679
	(22.2682)	(42.0636)	(79.5827)	(140.3154)
ACORGB	-0.2512	-0.1099	-0.0451	0.5100
	(0.0855)	(0.1615)	(0.3056)	(0.5388)
AHAYB	-6.1227	-12.5728	-47.8034	-3.5493
	(4.9833)	(9.4132)	(17.8093)	(31.4003)
ATLABOR	0.3494	1.1195	-0.3245	2.4368
	(0.5570)	(1.0521)	(1.9905)	(3.5096)
ATOTKN	-70.1218	177.0962	638.1636	745.6321
	(54.7814)	(103.4798)	(195.7796)	(345.1865)
APASTN	54.7102	53.3390	23.3907	19.2457
	(10.4582)	(19.7551)	(37.3759)	(65.8989)
Adj. R^2	.98	.91	0.54	0.35
p	0.0001	0.0001	0.0001	0.0001

[a] Standard errors are in parentheses.

Hay bought (AHAYB) tends to be less significant as indicated by higher standard errors relative to its coefficients. Total potassium (ATOTKN) appears to be more important at higher levels of restriction, coefficients increase with the reduction levels from -70.12 to 745.63. Pasture acreage (APASTN), on the other hand, appears to be more important at lower levels of restrictions as its coefficient decrease with more restrictive standards (from the left to the right in Table 6.4).

Although some R^2 values are low in Table 6.4, each regression has a p-value of 0.0001 indicating significant F-statistics. In theory, shadow prices at each level of restrictions should be estimated with practices and input used at each of these levels. As expected, the explaining power decline from .98 for the 20 percent reduction shadow price estimation to .35 for the 80 percent reduction shadow prices arises because all four equations are estimated with the baseline farm practices. The baseline practices approximate relatively well practices at the 20 percent reduction standard, but are less suitable proxies for the 40, 60 and 80 percent reduction standards.

For variables with high coefficients relative to their standard errors, the absolute value of the coefficients increases with the reduction level to account for larger shadow prices (because there is no intercept). The results suggest that corn acres could be a potential variable to target farms with low shadow prices. Total potassium, though harder to measure, may also be important. Pasture acres could also be used to target small (20 percent) reduction levels.

With the exception of farms with relatively high total nitrogen delivery, made up mainly of soluble runoff, shadow prices estimated by SUSFARM (assumed to be the true shadow prices) are estimated reasonably well by the predicted shadow prices. The fit is hindered by large variability of shadow prices at low levels of nitrogen delivery combined with a few farm having very high nitrogen delivery and low shadow prices (Figure 6.1). As a result, farms with close to zero true shadow prices have negative predicted shadow prices. These shadow prices were set to zero for the allocation model (ALLOCATI).

Shadow prices for the 26 farms with infinite shadow prices were estimated from the regression coefficients by replacing these farms' inputs into the regression model, but these shadow prices bear little resemblance to the "true" shadow prices.[10] These poor "in-sample" predictions result from the few alternatives to further control total nitrogen delivery, once BMPs are in place and the farm has manure storage.

6.4.2 Estimation issues

Values for differences in fit (DFFITS) and differences in parameters (DFBETAS) revealed the presence of four potentially influential observations.[11] Inspection of the farms with high DFFITS and DFBETAS reveals that these farms are more likely to be located on soil group A or to have a majority of their total nitrogen deliveries arising from

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[10] The predictions are poor for all levels of reduction.

[11] DFFITS estimate the effect on the errors of removing one observation from the sample at a time and re-estimating the errors. The process is repeated n time and yields n prediction error residuals ($y_i - \hat{y}_{i,-i} = e_{i,-i}$). The i indicates the ith observation and -i indicates that the ith observation was removed from the data to predict the ith shadow price.

DFBETAS is a similar statistic measuring the change in each coefficient when observations are successively removed, the coefficients estimated, and the observation replaced.

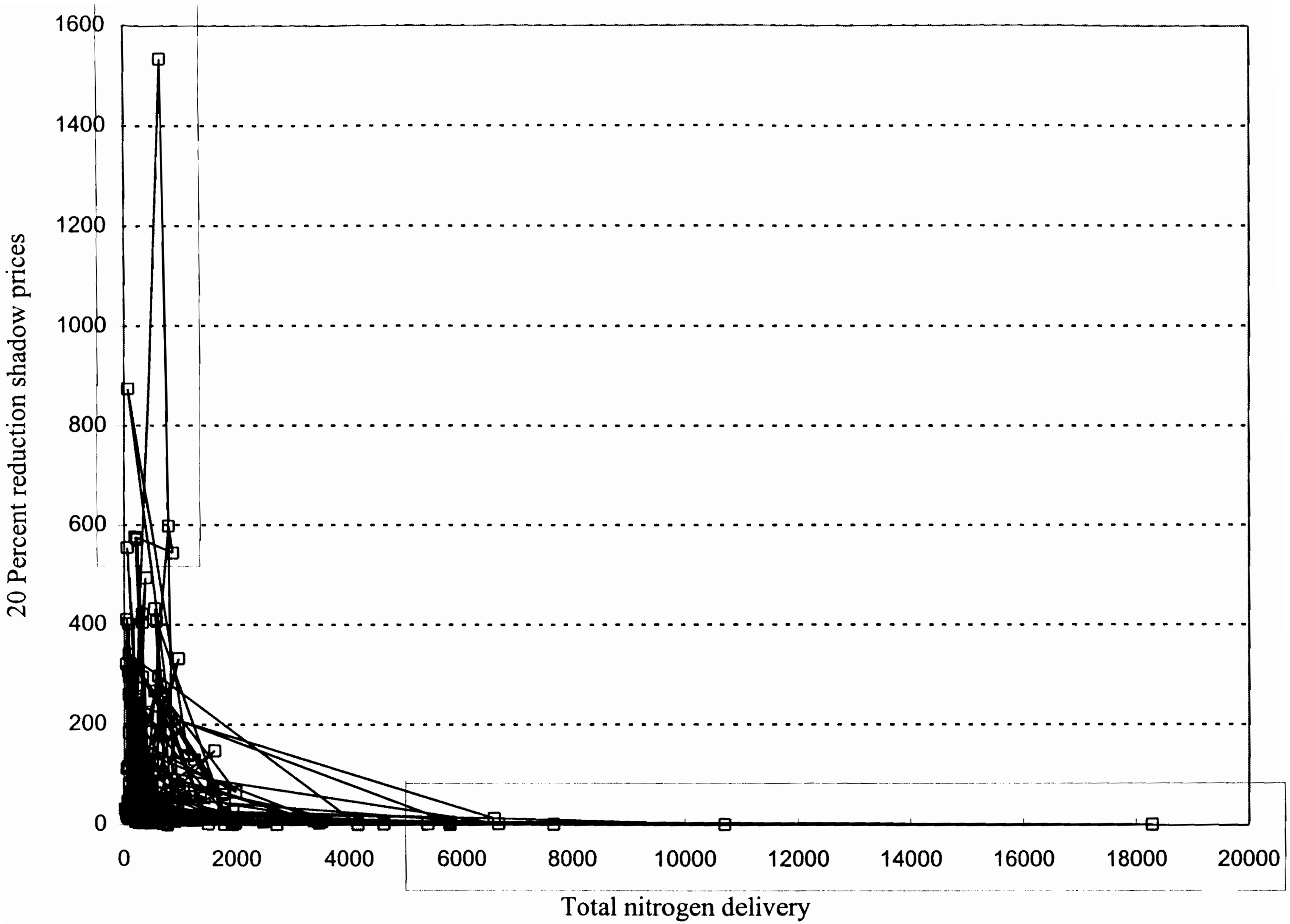

Figure 6.1 Shadow Prices and Total Nitrogen Delivery Relationship

soluble runoff rather than sediment-bound runoff. These shadow prices can have high influence on the coefficients.

The area studies stratified sample does not fully capture the difference in estimated shadow prices among hydrological groups, a seemingly important factor in a farm's compliance costs (as approximated by their nitrogen delivery constraint shadow prices). It is more difficult to estimate farms' shadow prices for dairy farms on soil group A and D because the sample for these farms is too small causing the model parameters to be unstable or to change significantly with the addition and omission of a few observations. Sample fields in the survey data have a weight attached to them that could have been used to run a weighted regression. It was, however, decided that the weights appropriate for fields (sample points) were not appropriate for farms.

6.5 PARTIAL INFORMATION TRANSACTION COSTS

Transaction costs for the partial information scenario are derived from the information used in the metamodel. The next section itemizes information, contracting, and enforcement costs assuming that: 1) the estimated coefficients obtained in Table 6.4 are available to the agency from previous research in similar watersheds and 2) labor costs for the pollution control agency are the same as in Chapter 3. Technicians are paid \$23 per hour, experts familiar with soil and crop simulation models \$25 per hour, and attorneys \$32 per hour. To keep consistent comparisons, baseline and loading reductions for targeted farms are assumed to be estimated with a biophysical model such as EPIC and the bioeconomic model under both the perfect and partial information strategy. The difference in total control costs between perfect and partial information is due to the lower cost of deciding which farms to target using partial information and to the different number of farms targeted and different levels of reduction assigned to targeted farms. Targeting with partial information could have been done differently perhaps yielding a different value of partial information. In this study, it was decided to use full information to assign allocations to the targeted farms because a model such as SUSFARM would be needed to determine the practices that would achieve the targeted reductions. Practices would need to be identified so they could be contracted and enforced.

6.5.1 Information

To identify farms to target, technicians visit the farms to collect the information necessary to run the total nitrogen delivery metamodel. The information includes the number of strip-cropped acres, the field slope, the distance between the farm and the receiving water, and the farms' soil hydrological groups and soil productivity groups. Total farm land, commercial nitrogen, commercial potassium, and manure production (through the number of animals) are also needed to predict total nitrogen and total potassium used in the total nitrogen delivery and shadow price equations. To predict shadow prices, agents must also collect information on acres in corn grain, corn silage, and pasture, corn grain and hay bought, and hired labor.

Technicians would need an hour to travel to farms and six hours to gather information on the farm location, farm boundaries, acres in corn and pasture, total farm land, and number of cows raised. Soil maps can then provide soil hydrologic and productivity groups. Commercial nitrogen bought and hired labor can be collected through tax reports, dealer records, or during the farm visit.

One of the six hours of the technicians' time is needed to input the data to the regression model and estimate the total nitrogen delivery and nitrogen delivery shadow prices. The other five hours of the six hours are required to collect the on-farm information and substitute farms' characteristics into the ALLOCATI model used to minimize Equation (3.9) subject to (3.10), (3.11), and (3.12), and decide which farms to target. In Table 6.5, the annualized social cost to decide which farms *not* to target is $22. Farms not targeted are removed from consideration.

For targeted farms, an additional visit is required to collect additional information. The perfect information procedure explained in Chapter Five is repeated for targeted farms. Farm practices and resources information is collected to run the bioeconomic model and obtain "perfect information" shadow prices. These marginal compliance cost proxies are then used in the ALLOCATI model to decide how much reduction to target to each remaining farm. As for the perfectly targeted standard, an additional three hours are required for the expert to draft the plan. Each year, the set of crop and practices must be updated to account for changes in individual farm cropped area and crop substitution, adding 2 days (16 hours) per year to the baseline costs. Other information does not need to be updated as it is constant over time. The total annualized information cost for targeted farms is $610 (Table 6.5). This cost is the same as was derived for perfect information in Chapter Three.

6.5.2 Contracting and enforcement

Contracting and enforcement involve going back to farms to discuss possible plans with farmers and reaching an agreement and verifying that these practices are in place. Both should be the same as the perfectly targeted standard described in Chapter Five involving visiting farms and updating farm management practices based on discussions with the farmers.

6.6 POLICY ANALYSES

6.6.1 Partial information performance standard

Predicted shadow prices and predicted total nitrogen delivery are initially used to allocate control responsibilities among farms as in Equations (3.9) to (3.12). Each farm is allocated a reduction equal to 0, 20, 40, 60, or 80 percent of their baseline nitrogen deliveries sequentially from the highest to lowest shadow prices until the 40 percent reduction for the watershed is achieved.[12]

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[12] No farm can be allocated more than 80 percent reduction because no shadow price can be computed for the last 20 percent of the loadings.

Table 6.5 Per Farm Annual Transaction Costs: Partial Information Targeted Performance Standard[a]

Activities	Actor	Hours	Costs ($)	Present Value	Annualized[b] Costs
Targeted farms					
Information					
•Travel to farm[c,d]	Technician	1	31	31	4
•Gather field boundaries, soils, crops, and management practices information	Technician	13	299	299	39
•Calibrate EPIC obtained baseline	Technician	13	299	299	39
	Expert	4	100	100	13
•Delivery ratios	Technicians	2	46	46	6
•Build bioeconomic model and interface	Expert			9	1
•Establish X_{lk} available to farm[e]; run EPIC	Technician	38	874	874	113
•Predict farms' shadow prices	Technician	6	138	138	18
•Draft the plan	Expert	3	75	75	10
•Yearly update of best practices	Technician	16	368	2842	368
Annual costs					610
Non-targeted					
Information					
•Travel to farm[c,d]	Technician	1	31	31	4
•Gather field boundaries, soils, crops, and management practices information	Technician	6	138	138	18
Total					22

Table 6.5 Continued

Activities	Actor	Hours	Costs ($)	Present Value	Annualized Costs
Contracting					
•Travel to farm[c,d]	Technician	1	31	31	31
•Discuss plans	Technician	2	46	355	46
•Travel to farm[c,d]	Technician	1	31	31	4
•Evaluate farmers' proposed alternative,	Technician	2	46	355	46
•Draw contract	Attorney	1	32	247	32
Annual cost					158
Enforcement					
•Travel to farm[c,d]	Technician	1	31	31	31
•Assess plan	Technician	2.4	55	426	55
Annual cost					86
Total annual transaction costs targeted farms					854

[a] Costs are based on a ten-year horizon and a real interest rate of five percent.
[b] Annuity factor equal to 7.7217 from Lee et al. Appendix Table 4, n=10, i=5.
[c] Travel costs include an average of 30 miles at $0.25/mile and an hour of technician time.
[d] Hourly wages are $23, $25, and $32 for technicians, experts and attorneys, respectively.
[e] Where X_{lk} is the set of practices achieving 40 percent nitrogen reduction on the farm.

The farms not targeted are discarded at this stage. The final allocation is obtained by replacing the perfect information shadow prices and total nitrogen delivery in ALLOCATI (for the farms targeted).[13] Mean practices for each standard are presented in Table 6.6. These practices are similar to the perfect information standard but total gross margins for the private cost-effective allocation are lower (by $314 per farm) than under the perfect information standard ($130,871 per farm). Compared to the perfect information private cost-effective allocation, manure production is down two tons, cattle production up five animals, five fewer tons of manure are incorporated and ten fewer acres are strip-cropped than with the perfect information private cost-effective strategy. The difference in compliance costs arises mainly because different farms are targeted.

6.6.2 Social cost-effective policy for the watershed

When marginal transaction costs are taken into account, the partial information strategy targets 28 fewer farms than the private cost-effective allocation (82 versus 110 farms, Table 6.7). Both the per pound compliance costs and per pound transaction costs are similar with the private and social cost-effective allocations. As mentioned earlier, transaction costs might have been underestimated. Sensitivity analysis was performed revealing that halving marginal transaction costs results in ten more farms being targeted. The

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[13] The 40 percent reduction to be achieved for the watershed should be based on the total estimated nitrogen delivery using partial information since this is the only information available for nontargeted farms. In this study the 40 percent reduction to be achieved was based on perfect information for all farms to allow comparison with the perfect information strategy. Total estimated TND based on partial information was 204,785 pounds and total estimated nitrogen based on perfect information was 201,824 pounds.

partial information allocation is less responsive to changes in marginal transaction costs than the perfect information allocation, which decreases the number of farms targeted by 14 when marginal transaction costs are reduced by half.

Compared to the social cost-effective allocation with perfect information strategy, the social cost-effective allocation with partial information targets 37 fewer farms (119-82). The social value of partial information, $2,909,486, is $61,582 less than the social value of perfect information. The social value of partial information is computed as total control costs with the social cost-effective allocation ($1,042,489, Table 6.7) minus total control cost with the uniform performance standard ($3,951,975, Table 5.3).

The private cost-effective allocation with partial information has 28 fewer farms targeted than the perfect information strategy for a total of 110 targeted farms. The difference between the private value of partial information and the private value of perfect information is only $32,682. The private value of partial information is computed as total control costs with the private cost-effective allocation ($1,025,256, Table 6.7) minus total control cost with the uniform performance standard ($3,951,975, Table 5.3). Although transaction costs are lower with the partial than with the perfect information strategy, both the private and social values of perfect information exceed the private and social values of partial information, respectively. Thus, unless ways to improve prediction are identified or to reduce transaction costs, targeting with perfect information may be preferred to targeting with partial information.

Table 6.6 Means Gross Margins and Practices for the 237 Farms for the Perfectly Targeted Performance Standards and Partial Information Performance Standards[a]

	Performance Standards		
	Perfect Information	Partial Information	
	Private Cost-Effective Allocation	Private Cost-Effective Allocation	Social Cost-Effective Allocation
Total gross margins ($)	130,871	130,557	130,387
Nitrogen delivery (lbs/farm)	511	511	511
Cost/lb reduced ($)[b]	11	12	12
Leaching	3,105	3,107	3,123
Livestock enterprises (mature units)			
Cows	135	135	134
Hogs	21	21	21
Poultry	2,014	2,014	2,014
Other Cattle	6	11	12
Manure spreading (tons dm)			
Winter	16	20	22
Spring	115	110	109
Summer	102	100	99
Fall	49	50	50
Total manure production	282	280	280
Manure incorporated	55	50	49
New manure storage	5	4	3
Crop Enterprises (acres)			
Crop acreage total	386	386	386
Alfalfa	98	97	97
Corn grain	52	52	51
Corn silage	55	55	55
Pasture	37	37	37
Wheat	70	72	72
Rye	2	2	3
Idle land	0	0	0
Conventional till	20	19	19
Reduced till	85	84	84
No-till	102	104	104
Strip-cropped acreage	145	135	128
Commercial N (tons)	16	16	16

[a] For a 60 percent performance standard or a 40 percent reduction in nitrogen delivery.
[b] Computed by dividing the change in total gross margin by the change in total nitrogen delivery.

Table 6.7 Total Control Costs to Achieve the Water Quality Standard in the Watershed under Perfect and Partial Information Strategies for the Private and Social Cost-Effective Allocations

Costs/	Targeted Performance			
Policies	Perfect Information		Partial Information	
	Private Cost-Effective Allocation ($)	Social Cost-Effective Allocation ($)	Private Cost-Effective Allocation ($)	Social Cost-Effective Allocation ($)
Private Compliance Costs				
Number of farms targeted	138	119	110	82
Pounds controlled per targeted farm	585	678	734	985
Per farm compliance costs ($)	3,601	3,603	3,915	4,085
Compliance/lb ($)	11	11	12	12
Social Transaction Costs ($)				
Total information	105,465	97,960	70,656	54,360
Information targeted	84,180	72,590	67,100	50,020
Information non-targeted	21,285	25,370	3,556	4,350
Contracting and enforcement	33,672	29,036	26,840	20,008
Transaction costs	139,137	126,996	97,496	74,368
Transaction costs/farm	587	836	411	314
Transaction costs/lb	2	2	1	1
Watershed Level Costs ($)				
Farm aggregate compliance costs	853,437	853,911	927,760	968,121
Total control costs	992,574	980,907	1,025,256	1,042,489
Total control costs/farm ($)	4,188	4,139	4,326	4,399
Total control costs/lb[a]	12	12	13	13

[a]The difference between total compliance costs per pound and the sum of farm and transaction costs per pound is due to rounding error.

6.7 POLICY IMPLICATIONS

Assuming that the results above hold when all farm types in a watershed are considered and that the assumptions implicit in the ordinary least squares model hold, for watersheds such as the Lower Susquehanna it pays to collect perfect information to target agro-pollution control. This result occurs for three reasons: 1) high heterogeneity of farms in the watershed, 2) difficulty in predicting shadow prices in the presence of a few farms with very large shadow prices and very low nitrogen delivery and few farms with very low shadow prices and very high nitrogen delivery, and 3) difference in information costs between the partial and perfect information strategies are too small to compensate for higher farm compliance cost.

Farm heterogeneity ensures that both the values of perfect and partial information are large for a watershed because a uniform allocation cannot accurately approximate the cost-effective allocation of the control burden. A large difference among farms compliance costs is obtained even though only dairy farms are considered. The value of information for the watershed should increase as more farm types are incorporated in the analysis. Watersheds uniform in their landscape and farm types would not be expected to have a large value of information.

The second reason that perfect information outperforms partial information relates to statistical concerns and will be explained with Figure 6.1. In Figure 6.1 shadow prices for the 20 percent performance standard are plotted against total nitrogen deliveries.[14] Farms in the horizontal rectangle are farms to target; they have large nitrogen deliveries and low shadow prices. In the social cost-effective strategy with perfect information, the eleven farms in this rectangle abate 67 percent of the total 80,730 pounds abated. They are not outliers because they fit the trend of the data, but differ from farms in the vertical rectangle because they have large sediment-bound runoff and low shadow prices.

Farms in the vertical rectangle are "outliers" in this sample because they have similar total nitrogen deliveries but higher shadow prices than most farms.[15] Total nitrogen delivery on these farms tends to be smaller and is mainly made up of soluble runoff. Their shadow prices are higher because of the limited available technology to abate soluble nitrogen: building storage (for farm without storage), planting crops less prone to runoff, applying less manure, changing the seasonal spreading of manure or fertilizers, and incorporating manure.

In the model these alternatives secure less reduction in nitrogen delivery, with the exception of manure incorporation, than do practices to curtail sediment-bound nitrogen such as strip-cropping and idling land. Total nitrogen delivery predictions for these farms are poor and removing them from the data set changes the parameter estimates by many standard deviations (resulting in high DFFIT and DFBETAS).

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[14] The other performance standards have similar plots.

[15] High influence points, which pull predictions in their direction, that are also high leverage points are outliers (Myers).

For example, the eleven farms with negative predicted total nitrogen delivery have soluble runoff making up an average of 91 percent of their actual total nitrogen delivery. These farms have numerous BMPs in place and have low sediment runoff (most of them below 20 pounds). Adding seasonal spreading, soil water holding capacity, soil permeability, and soil bulk density (characteristics important in runoff calculation) as interaction terms in Equation (6.3) did not correct for the negative total nitrogen deliveries.

The presence of these two opposite groups of farms makes it difficult to fit the curve in Figure 6.1 and might affect the estimated value of partial information. That is, the wrong farms are targeted the wrong amount of control responsibilities, increasing aggregate compliance costs. However, it should be noted that even with these estimation difficulties, compliance costs for partial information were only about 10 to 15 percent greater than with perfect information depending on whether a private or social cost-effective allocation was used. As indicated by the larger value of perfect information, the decrease in information costs is not sufficient to compensate for the higher aggregate compliance costs. A better strategy would allocate less control burdens to more farms (to approximate better the perfect information strategy) or reduce transaction costs and thus, increase the value of partial information.

Finally, the definition of "partial information" drives the transaction costs estimates. In this study, partial information was assumed to differ from the perfect information only for the non-targeted farms. Other assumptions would result in different transaction costs, increasing or decreasing the value of partial information. If the entire allocation had been done with partial information, the burden to allocate to each farm would have been estimated based on estimated total nitrogen delivery and shadow prices. Though, another procedure would also be needed to determine the least-cost mix of practices to be contracted and enforced on each farm. Information costs associated with both the partial information and perfect information strategy are likely to decrease over time as more is known about the significant variables that make farms "targetable" and with the number of studies that generalize results such as this study's results making it even more reasonable to control nitrogen deliveries.

It is too soon to conclude that the value of perfect information will exceed the value of partial information in all watersheds across the country. More studies are needed to corroborate the results before any assertions can be made. As more watersheds and sites are monitored and the links between agricultural production and total nitrogen delivery are understood, predictions of total nitrogen delivery and farm compliance costs could be significantly improved. Better predictions of farm costs would allow the development of simple indicators of farms to be targeted and reduce the total control costs with partial information.

CHAPTER SEVEN: CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

7.1 SUMMARY

Nonpoint sources are a major contributor to water quality in the Chesapeake Bay. Farming activities in the Lower Susquehanna watershed are important nonpoint sources of phosphorous and nitrogen deliveries to streams and ultimately to the Chesapeake Bay (Bosch, Batie, and Carpentier). Agricultural nonpoint sources, however, are expensive to control due to their diffuse nature and spatial variability. Therefore, targeting, defined as controlling only farms which are major contributors and have low control costs, is a way to increase the cost-effectiveness of nonpoint source pollution control.

Policymakers need to know which targeting strategy for agricultural nonpoint source pollution (agro-pollution) control minimizes the costs of achieving desired water quality. The goal of this study was to identify the cost-effective level of information that should be collected to target agro-pollution. In the process, the value of information for targeting three nitrogen delivery control strategies, targeting with perfect, partial, and no information, and two design standards were compared. The values of partial and perfect information were estimated as the difference in total control costs -- aggregate compliance plus transaction costs -- with partial or perfect information, respectively, and the costs of the uniform allocation to achieve the same watershed-level 40 percent reduction in nitrogen delivery. Nitrogen delivery was defined as nitrogen in soluble or sediment-bound form that reaches surface water. Transaction costs in this study are defined as the control agency's costs of collecting and processing the information necessary to target farms with perfect partial and no information, as well as to write, and enforce contracts. Transaction costs do not include private or public litigation costs.

Unexpectedly, the value of perfect information exceeded the value of partial information in the study area. The value of information arises mainly from the difference in aggregate compliance costs between the perfect and partial information burden allocation. Differences in transaction costs were relatively small because transaction costs were a small share of total control costs.

Two design standards also analyzed, manure storage and strip-cropping standards, could not achieve the 60 percent performance standard -- preventing direct comparisons with the performance standards.

Two targeting strategies for allocating control burdens for a given level of information were also compared. Private cost-effective targeting assigns control burdens using marginal compliance costs only and cost-effective targeting assigns control burdens using marginal compliance costs plus marginal transaction costs. Including marginal transaction costs to allocate control burdens did not significantly affect total control costs mainly because 99.2 percent of total control costs are aggregate compliance costs. It would thus require a large change in transaction costs to affect the results.

7.2 BACKGROUND

The farming sector is a major contributor to water nutrient enrichment problems in the country. Agro-pollution is difficult to control, because there are numerous farms contributing relatively small stochastic loadings that cannot easily be traced back to their sources. This complexity is expected to be accompanied by large public transaction costs to regulate or implement market-based policies to control agro-pollution.

Targeting priority farms has been suggested as a means to reduce control costs. Several empirical analyses have shown that various targeted policies (targeting Conservation Reserve Program (CRP)) land and cost-share money are two examples) have the potential to reduce control costs. However, no empirical analysis of both the transaction and private control costs of controlling agro-pollution has been made (to the knowledge of the author). Furthermore, there is no consensus as to what the targeting strategy and level of information should be to achieve the desired environmental goals at minimum total control costs which include compliance plus transaction cost.

Using the Lower Susquehanna watershed as a case study, three strategies to target reductions in nitrogen runoff from dairy farms were studied: 1) no information --

uniform allocation, 2) perfect information -- cost-effective allocation, and 3) partial information - estimated cost-effective allocation. From no information to perfect information, more detailed information about the farm's marginal compliance costs with a decreasing performance standard is collected.

Stavins (1993, 1995), Braden, and others expressed concern that policies linked to the flow of pollution (such as performance standards, pollution tax, pollution trading) may have transaction costs sufficiently large to offset the reductions in compliance costs compared with simple design standards. Targeting strategies were compared to two design standards thought to be effective to control nitrogen delivery in the watershed.

Similarly, the private and social cost-effective targeting policies were identified to test whether the traditional private cost-effective definition (compliance costs only) differs significantly from the social cost-effective allocation of burdens (inclusive of compliance costs plus transaction costs) in targeting policies.

This dissertation's specific objectives are (1) estimating the value of information for micro-targeting agro-pollution performance standards to farms, (2) comparing the potential for targeted performance standards (based on perfect and partial information) to reduce private compliance and social transaction costs of achieving a performance standard compared to a uniform design standard.

7.3 METHODS

Both compliance and transaction costs were estimated to determine the total control costs associated with two design standards and three performance standards.

7.3.1 Case study

In response to the Bay nutrient enrichment problem, the three states (Maryland, Pennsylvania, and Virginia) adjacent to the Bay and the District of Columbia have agreed to reduce nutrient loadings by 40 percent by the year 2000. The Lower Susquehanna, a watershed located primarily in Pennsylvania and a tributary to the Chesapeake Bay was chosen by the USDA as one of its nine Area Studies Survey sites in the country.

The Area Studies survey reports detailed farming and conservation practices for the farm (field) located on randomly selected Natural Resources Inventory (NRI) sample sites. These NRI sample points contain extensive soils and hydrological information. By linking this data set with the Survey data, the environmental effects of farming practices can be linked to the economic decision making process and relevant policies designed.

The allocation of burdens that minimizes aggregate compliance costs, equalizes the marginal compliance costs across farms as if farmers were facing a price for nitrogen loadings and internalizing these costs in their production decisions. Shadow prices associated with various performance standards from the microparameter (bioeconomic) model are used as proxies for these compliance costs for the perfect information strategy. These shadow prices were then estimated (econometrically) with a metamodel to obtain the partial information control costs.

7.3.2 Transaction costs

Transaction costs for each policy are estimated in Chapter Three by assigning costs to the key operations involved in the current cost-share program administration. Key operations and their labor requirements were identified through phone interviews with public officers in Pennsylvania as well as other experts. Operations included information collection activities -- collecting farm characteristics and practices information to model these farms to achieve a more efficient allocation of control burdens; contracting activities -- administrative tasks involved in contacting the targeted farms, in reaching an agreement with the farmer, and in writing up the contract; and enforcement -- visiting (auditing) farms to get the evidences that practices agreed on are in place. The person-hours necessary to collect information, contract with each targeted farm and enforce each policy were estimated, valued, and summed up to total transaction costs. Neither private nor social litigation costs were included in the transaction costs calculation.

7.3.3 Compliance costs

In Chapter Five, each policy's aggregate compliance costs are estimated for each of the 237 dairy farms (located on sample NRI points) with a modified microparameter model which preserves the watershed heterogeneity. Farmers are assumed to maximize revenues from the sale of livestock, milk and crops subject to individual farm's fixed land, livestock, and manure capacity constraints derived from the Area Study survey of the Chesapeake Bay and crop and livestock nutrient requirements. To maximize net revenues, the model chooses 1) the livestock to produce and the size of the herd, 2) the ration to be fed to the herd, 3) the acreage for each crop, (4) the crop rotations and tillage types to use, 5) whether to use contour strip-cropping, 6) the source of crop nutrients and timing and method of application, 7) which crops to purchase and sell, and 8) the amount of labor to hire. The physical model computes nitrogen runoff and leaching, phosphorous runoff and sediment delivery as a function of the choices made in the economic sub-model and the farm's physical characteristics.

Total soluble and sediment-bound nitrogen runoff and delivery to nearest surface water for the selected activities is calculated in the baseline and sequentially restricted to discover each farm's constrained optimal activities. Compliance costs at various levels of nitrogen control are measured as the difference between the objective function in the baseline and in the constrained scenario. The shadow prices associated with each level of nitrogen delivery are used as proxies for the marginal compliance costs to control nitrogen loadings on each farm.

7.4. RESULTS

Transaction costs, composed of information, contracting, and enforcement costs, increase with the amount of information used to allocate nitrogen control responsibilities, but decrease with the decrease in the number of farms targeted. Information costs are moderate when all farms are allocated the same control burden (uniform standard) and high when using specific information to target problem farms. However, contracting and enforcement costs decrease as more information is used and less farms are targeted. In addition to this transaction costs trade-off, there is a trade-off between transaction and compliance costs.

Aggregate compliance costs are at their minimum when perfect information is used to allocate control burdens (equalizing marginal compliance costs among farms). As less information is used, aggregate compliance costs increase because some farms with low control costs are not allocated enough control responsibilities and farms with high control costs are allocated excess burdens compared to the cost-effective allocation.

If the decrease in aggregate compliance cost is less than the increase in transaction cost for collecting better information to estimate shadow prices, then less information should be collected. This rule was applied in this study by computing the value of perfect and partial information to target performance standards.

The social value of perfect information, $2,971,068 exceeds the value of partial

Table 7.1 Total Control Costs to Achieve the 40 Percent Reduction in Nitrogen Delivery From 237 Farms in the Lower Susquehanna Watershed under Perfect and Partial Information Strategies

	Targeted Performance Standards	
	Perfect Information Social Cost-effective Allocation ($)	Partial Information Social Cost-effective Allocation ($)
Social value of information[a]($)	2,971,068	2,909,486
Number of farms targeted	119	82
Information	97,960	54,360
Contracting	18,802	12,956
Enforcement	10,234	7,052
Transaction costs	126,996	74,368
Farm aggregate compliance	853,911	968,121
Total control costs	980,907	1,042,489

[a] The social value of information is the value of information when transaction costs are used in the allocation of control burdens.

information by $61,582 for the 40 percent reduction goal for the watershed and targets 37 more farms (Table 7.1). A smaller number of farms targeted is responsible for the lower information, contracting, and enforcement costs with the partial information strategy. This lower transaction costs (by $52,628) is not enough to compensate for higher compliance costs (by $114,210) resulting in a lower net value of information with the partial information strategy.[1] For dairy farms in the Lower Susquehanna it pays to collect perfect information to target agro-pollution control. The higher transaction cost associated with cost-effectively targeting spatially, physically, and economically different farms is compensated by the lower watershed aggregate compliance cost.

The first hypothesis (a) the value of partial information is larger than the value of perfect information is refuted for the Susquehanna watershed. The reduction in compliance costs with the perfect information scenario offsets the higher transaction costs. This result may have arisen because (1) only dairy farms were included in the study, (2) the definition of partial information used is limited, and (3) the high variability of the watershed justifies collecting perfect information. Including more farm types in the analysis would increase farm compliance costs variability and perhaps would have given more power to the partial information regressions. The definition of

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[1] The values of perfect and partial information are calculated as the difference between the sum of the compliance and transaction costs for the partial and perfect information strategy, respectively, and the uniform performance standard.

partial information used in this study included making use of full information to target farms once non-targeted farms have been eliminated using partial information. Other definitions of partial information may have resulted in different values of partial information.

The second hypothesis (b) total transaction costs are larger than private aggregate compliance costs is also refuted. Transaction costs account for less than one percent of the total control costs in the Lower Susquehanna. The value of perfect information is $2,934,771. The portion made up of transaction costs was found to be only $24,630 for the private cost-effective allocation and $36,771 for the social cost-effective allocation.

Targeting problem farms in the Lower Susquehanna watershed could save nearly $3 million for the sampled 237 farms. Extrapolating this result to the 6,662 dairy farms in the watershed could save the state more than $55 million over a uniform allocation of responsibility[2]. Savings are likely to be underestimated because only dairy farms are included in this study. The social cost-effective allocation of control responsibilities targets only 50 percent of the dairy farms with a mean control cost per pound of $11 compared to $47 per pound with the uniform performance standard

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[2] It costs $3,951,975 to reduce 40 percent of the nitrogen runoff on the 237 sample farms. Extrapolation to the 6,662 dairy farms in the watershed indicates it would cost $82,979,202 to control all the dairy farms, $55,425,170 more than targeting farms with perfect information.

applied to all the farms.

The value of information to target nonpoint source control responsibilities is also evidenced by looking at the distribution of control responsibilities among farms. A few problem farms account for most of the 201,842 pounds of (modeled) nitrogen runoff delivery. These problem farms were allocated most of the 80,843 pounds to be reduced (40 percent reduction from the baseline). Of these 80,843 pounds, 60,121 pounds were allocated to 18 farms, and 72,844 pounds were allocated to 46 farms (Table 7.2). Statistical analysis of Chapter Five farms targeted 60 and 80 percent of their baseline and those not targeted are showed in Table 7.1 to illustrate the difference in characteristics for farms highly targeted and those not targeted.

Problem farms (high nutrient contribution to surface water) tend to have more cows and more cropland than others but not significantly so. These farms have significantly different physical and topographical characteristics than other farms. They are closer to surface water, they are mostly on soil hydrological group C and D (having higher surface runoff potential), and they tend to be on steeper and longer slopes than non-targeted farms. The seven farms targeted 53 percent of the total nitrogen reduction, for example, are less than 600 feet from the water, six of them are on soil hydrological group C, their soils have a higher clay content than other farms, their land slopes at 17 percent, they do not use strip-cropping, and only 50 percent of them have manure storage. Their marginal compliance costs are relatively low showing they have many

Table 7.2 Targeted Farms Compared to Non-targeted Farms

	Non-targeted Farms	Targeted 60% of their baseline	Targeted 80% of their baseline	Total
Number of farms[a]	118	11	7	
Total delivered runoff (lbs)	47,534	29,387	53,111	
Total reduction burden (lbs)	0	17,632	42,489	60,121
Mean MC/lb 20%[b] ($)	179	9	1	
Mean MC/lb 40%[b] ($)	449	16	2	
Mean permeability (in/hr)	0.99	0.89	0.91	
Mean clay content (%)	21	21	27	
Mean hydro B (%)	0.73	0.18	0.29	
Mean hydro C (%)	0.19	0.82	0.71	
Mean storage[b] (%)	0.77	0.91	0.57	
Mean strip acres (acres)	148	31	0	
Mean slope (%)	6	12	17	
Mean cows (no)	65	97	71	
Mean delivery ratio (dec. fraction)	0.32	0.53	0.61	
Mean distance (ft)	1514	714	539	

[a] Values are means for the number indicated in each column.

[b] Marginal compliance costs for the first 20 percent reduction in nitrogen delivery.

[c] Percentage of farmers with manure storage capacity.

options to control nitrogen loadings, $1 per pound for the first 20 percent and $2 per pound for the next 20 percent (MC 40%). Farms not targeted already use strip-cropping and other management practices.

Private cost-effective targeting policies did not differ significantly from social cost-effective targeting policies mainly because aggregate compliance costs make up 99% of the total control costs. Social cost-effective targeting however, could differ from private cost-effective targeting if litigation costs were added to the transaction costs which would reduce the proportion of total control costs made up by compliance costs. Litigation costs were omitted because perfect compliance was assumed to result from the 100 percent monitoring rate of farmers' actions and the lack empirical data on litigation costs. Litigation costs, when farms do not comply, can significantly increase enforcement costs. More litigation cost data, including both private and public costs, are needed to test whether the social and private cost-effective allocations would differ greatly and how it would change the value of information to target farms.

Because cost-effective performance standards involve large transaction costs, they were compared to design standards which have lower transaction costs. The two design standards analyzed in this study vary significantly in their cost-effectiveness to control agro-pollution. The manure storage standard had the highest total control cost per pound of nitrogen reduced ($49) and the strip-cropping standard the least total control cost ($5). However, neither design standard achieves the 40 percent nitrogen delivery reduction goal in the watershed. Unless a combination of design standards that achieve the 40 percent reduction and that have sufficiently low transaction costs are found, targeted performance standards would be favored.

7.5 IMPLICATIONS

This study suggests that a few farms in the Lower Susquehanna should be targeted a large reduction burden. Criteria to target these farms should be: somewhat larger farms with steep and long slopes, on soil hydrological group C and D, close to surface water, that have no or few management practices in place, and grow large acres of corn. Cost-effective practices for dairy farmers in the Lower Susquehanna are manure incorporation and storage, eliminating or reducing winter manure spreading, and using more strip-cropping. Incentives (disincentives) should be put in place to encourage the adoption of these practices for dairy farms that fall in the category to be targeted.

It is too early to extrapolate these results to other watersheds. More work is needed to allow for extrapolation as it would greatly reduce the national control costs of agro-pollution. Satellite imagery and existing soil, slope, and crop acre information could be used to screen for farms to be targeted and to generalize to larger areas. More detailed information can then be collected for these farms to decide how to allocate responsibilities among them.

In this study, the value of information for perfectly targeting performance standard was the larger than the value of targeting with partial information. This value of information could be compared to the values of information for incentive-based policies also requiring information on the part of the control agency: nitrogen reduction permits and taxes. To implement a nitrogen reduction permit system, the control agency needs estimates of nitrogen delivery for all farms in order to control exchange of nitrogen permits (and perhaps decide which farms can participate in the trade). Similarly, farmers' marginal compliance costs must be known and delivery estimated to implement and enforce a nitrogen loading tax. The value of information associated with these two policies could be compared to the value of information for targeted performance standard. The value of information differences for these two systems compared to the performance standard arise solely from a difference in transaction costs. Although litigation costs associated with a tax may be very large. In the long run incentive-based policies may have induced greater technology development and adoption as farmers may try to exceeds their standards thus lowering aggregate compliance costs. A trading system where farms allowed to participate must meet the criteria displayed by problem farms earlier may have a lower social cost than the perfect information performance standard .

7.6 RECOMMENDATIONS

Limits of this research and its findings suggest the additional needed work as described in the following sections.

7.6.1 Pollutant and income uncertainty

Loadings are certain in the model; they were estimated with average precipitation for 40 years to give annualized results and to facilitate policy analysis. The value of information could also account for risk reduction. Risk from uncertain deliveries and the effect of farmers' risk aversion could be added by adding a MOTAD or target MOTAD specification to represent uncertain states of nature for a pre-determined planning horizon (Tauer). To specify the problem under risk, data such as aversion to risk or minimum desired incomes, and appropriate planning horizons would have to be acquired. Possibly farms with lower risk-aversion would be targeted if pollution control practices increase risk, because it would be "less costly" for them to adopt alternative practices. All farms are currently assumed to be risk-neutral, thus the value of information could increase if risk-aversion was included in the analysis and information on risk attitudes was available.

The effect of stochastic deliveries on the allocation of control burdens and its associated costs should be studied. For example, farms targeted may be different if loadings were stochastic, thus implying higher aggregate compliance costs. Farm loading probability could be added through a chance-constrained programming specification (Hazell and Norton). Under this scenario farms would be targeted based on their probability of delivering nitrogen runoff to surface water and their marginal control costs (a weighted marginal costs approach). The value of information may or not decrease if less farms with lower probability to deliver but with slightly higher compliance costs were targeted (total compliance costs could not decrease from the risk-neutral situation).

Research is also needed to study the intra-farm variability of loadings and how it would affect the value of information. For instance, what would be the effect on the value of information if only a small fraction of a farm targeted displayed the characteristics that make this farm being targeted? The marginal costs of controlling nitrogen deliveries on the rest of the farm (with different characteristics) would increase rapidly. Without accounting for this intra-farm variability the value of information would be overstated.

7.6.2 Static pollutants

The bioeconomic model in this study is static and does not model nutrient accumulation processes over time. A dynamic model could improve the nitrogen and phosphorus loadings predictions by accounting for previous nutrient accumulations in the soil and changes in soil quality. Total nitrogen delivery would increase thus decreasing compliance costs. The outcome, however, will depend on whether the standard applies immediately or applies to some years in the future to allow for the lagged effect of the control practices. Including nitrogen accumulation over time would also change the allocation of burdens over time and thus the value of information.

7.6.3 Alternative policy instruments

Helfand showed that when firms vary in their propensity to pollute, which is the case in agriculture, standards on allowable input or output can be more efficient than performance standards. It would be interesting to compare the value of information obtained under different standards to make recommendations regarding possible over or under estimation of the value of information as a function of the standard used. Standards on allowable manure and nitrogen application per acre could also be compared to the above performance standards and the analysis repeated to compare total cost-effectiveness of the two types of standards. Further work is also needed to estimate the effectiveness of packages of design standards such as filter strips plus strip-cropping, plus split nitrogen application.

Further estimations and analysis of the partial information results are warranted to better identify problem farms with partial information. For example, the stratified sample used in this study under represented soil A and D and may not have fully capture the variance among farms based on their soil hydrological group (an important criterion according to the results above). This statistical problem might have partially contributed to the lower value of partial information.

7.6.4 Model transportability

Finally, the usefulness of the model depends on its transportability and its capability to be generalized for regional and national policy analysis. Transportability is defined by the ease with which the model is adapted to different physical, economic and political environments. The model is fairly transportable since farms parameters are included as input files used by GAMS. These files could be replaced with parameters for other watersheds without changing the core of SUSFARM. It's generality depends on how representative the physical and economic characteristics of the case study are compared to other watersheds.

This study pioneered in estimating the value of information for targeting agro-pollution control at the watershed level while modeling each farm. The usefulness of this study will increase as more farm and watershed case studies such as this one are conducted and allow for generalizations across farm types and watersheds. This approach will eventually lead to less-complicated, lower-cost methods (indicators) of targeting problem areas and farms. National total control costs of agro-pollution to achieve water quality goals could thus be significantly reduced.

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APPENDIX A: A REVIEW OF TARGETING RESEARCH AND POLICIES

A.1 INTRODUCTION

Up to recently, receiving bodies of water for agro-pollution have been considered as a "rival good" for which exclusion or transaction costs exceeded the potential benefits from limiting access. In watersheds which have agriculture as the predominant source of pollution, however, controlling agricultural emission may be necessary and a less expensive means to achieve desired water quality once the less expensive point source alternatives have been exhausted. Accordingly, nonpoint sources are gradually being incorporated into legislation such as the Clean Water Act Reauthorization (PL 100-104), the 1990 Amendments to the Coastal Zone Management Act (PL 101-508), the agricultural commodity programs including the 1985 Food Security Act (PL 99-198), the 1990 Food, Agriculture, Conservation and Trade Act (PL 101-624), and the Federal Agriculture Improvement and Reform Act of 1996 (HR 2854),

Targeting agricultural sources is increasingly considered as a method to reduce the cost of controlling nonpoint source pollution. This appendix reviews the history and research related to targeting agro-pollution in the United States.

A.2 HISTORY

As a result of the first National Resource Inventory in 1977, the concept of targeting control efforts to critical areas was introduced in 1981 by the U.S. Department of Agriculture (USDA). It was realized that many natural resource problems are geographically concentrated (Nielson 1986a, 1986b) and that concentrating agencies' scarce resources to problem areas could reduce both private and public costs. Public costs, for example, could be reduced by better coordinating action of agencies dealing with agricultural institutions such as the Natural Resources Conservation Service, Agricultural Stabilization and Conservation Service, Economic Research Service, Agricultural Research Service, and extension services (Nielson, 1986a). With the 1985 Food Security Act (PL 99-198), national funding to control water quality was to be macro-targeted to states who would in turn target priority areas (Ogg, Johnson, and Clayton; National Research Council). This transfer of authority to states demonstrates a recognition that one simple nationwide blanket strategy would not be effective or efficient (Easter).

Most states offered cost-sharing to implement conservation practices on a voluntary basis. However, past voluntary programs did not have the intended results (Ogg, Johnson, and Clayton), perhaps because farmers did not recognize their contribution to the water quality problem (Nielson, Miranowski, and Morehart), or because of insufficient or nonexistent targeting strategies. Bosch et al. found that although farmers were concerned about the effect of pollution on water quality, they did not feel they themselves were contributing to the problem, even when their surveyed fields had high potential for water quality damage. Batie (1994b) references six studies reporting farmers' underestimation of their actual soil erosion rates.

Batie (1994a) defines targeting as investing in regions, and in enterprises within these regions, that contribute to the problem, where the economic benefits from achieving the goals per dollar invested are greatest. On the other hand, Ogg, Johnson, and Clayton define targeting as designating funds to adequately treat the soils accounting for most of the nation's erosion and erosion loadings - irrespective of the ambient effect and damages to water users.

Prior to the 1985 Food Security Act, government efforts to control erosion were directed at on-site productivity protection and were macro-targeted at the state level. Soil erosion rate (Clark II, Haverkamp, and Chapman), soil detachment, surface roughness, and slope (Dickinson, Rudra, and Wall), particle size (Setia and Magleby) and productivity reduction index (Runge, Larson, and Roloff) were suggested to target conservation funds. These criteria assume that when erosion from fields decreases, water quality improves, creating societal benefits. This assumption may be faulty in three ways: 1) erosion is not an economic externality but delivery of sediment to water bodies is, 2) water quality may not improve with reduced sediment delivery, and 3) even if it does, the demand for improved water quality may be low in that area and hence the corollary social benefits will be small.

The emphasis was shifted to off-site impacts of erosion in 1985 after studies showed greater off-site than on-site damage costs (Fox, Umali and Dickinson; OECD; Ribaudo, 1989b). It was not until the late 1980's that economic criteria were suggested for targeting purposes. Ribaudo (1986, 1989b) established that compliance costs can be decreased by targeting cost-share or other policy instruments to areas where the demand for water quality is high, or low-cost opportunities to curtail pollution exist. Setia and Osborn found a 39 percent decrease in subsidy costs in the short run, if cost-share payments are targeted at soil groups based on their marginal costs of erosion reduction (an economic targeting criterion).

A.3 RESEARCH

Many researchers have scrutinized the potential cost-efficiency of targeting (Park and Sawyer; Ogg, Johnson, and Clayton; Lee, Lovejoy, and Beasley; Fox, Umali, and Dickinson; Setia and Osborn; Setia and Algozin; Setia and Magleby) and searched for the best criteria or proxies to target control funds (Carpentier, Bosch, and Batie; Dickinson, Rudra and Wall; Fox, Umali and Dickinson; Maas, Smolen, and Dressing; Setia and Magleby) or both (Ribaudo, 1986, 1989a). Five empirical studies on targeting efficiency (Park and Sawyer; Lovejoy, Lee, and Beasley; Setia and Magleby; Setia and Osborn; and Mapp et al.) found an increase in programs' cost-effectiveness when cost-share programs are targeted to the most highly erodible land. Similarly, targeting an atrazine ban to highly leachable areas was found to have the potential to reduce abatement cost and loadings (Setia and Algozin). Non-targeted regulatory policies have farmers for whom compliance costs are high clean up "too much" compared to those with low compliance costs (Shortle and Dunn 1991). Targeting farmers: 1) with high loadings, 2) at locations where pollution severely affects water quality, and 3) where the demand for improved water quality is high reduces administrative and other transaction costs as well as minimizing the financial burden on the agricultural sector. In the limit, pollution control can be allocated among farms (and other sources) to achieve the total reduction desired at minimum costs. Furthermore, targeting farms could be used to "... protect good actors' from unnecessary costs and inconveniences (assuming the costs of compliance were borne by the producer)" (Batie, 1994b).

It is still unclear, however, what targeting criteria should be used, that is, how much and what type of information needs to be compiled for targeting. For instance, cost-shared or performance standards could be targeted at soil types, farming practices, farm types, areas within a watershed or whole watersheds. Each criterion requires a different level of data aggregation. The targeting strategy to improve wildlife habitat for instance may be different than a strategy to improve recreational water quality. Whichever is the environmental goal, targeting will remain an important policy tool in the future as reflected in its incorporation in the recently passed 1996 Federal Agricultural Improvement and Reform Act (USDA, 1996).

3.1 Information for targeting

Most agree agro-pollution problems must be controlled by targeting problem areas. The "best" criteria to target these areas, however, are unknown. The choice of criteria is important for cost and environmental effectiveness. These types of effectiveness are measured by the changes in water quality (over time) resulting from particular targeting policies and the costs to achieve these changes. Targeting strategies based on economic criteria (such as marginal abatement costs) are more cost-effective than targeting strategies based on physical/pollution-related criteria such as sediment delivery rates (Fox, Umali, and Dickinson; OECD; Ribaudo 1989a). In the context of targeting, the quality of information about the land parcels being considered for pollution control is translated into the level of targeting and the quality of the targeting scheme. Performance of targeted policies has been assessed based on how much private expenditures are reduced when the policy is targeted with a particular targeting scheme, compared to uniform policies.

Perfect information allows the authority to micro-target cost-shared and performance standards at homogeneous parcels with lowest marginal costs of abatement and hence better approximate minimum control costs. Thus, targeting to homogeneous parcels is the best targeting level and marginal costs are the best targeting scheme for minimizing private compliance costs, while uniform allocation and design standards may entail the largest private compliance costs. The levels of targeting from broad to finer strategies are discussed below.

3.2 Macro-targeting

Macro-targeting identifies geographic areas (watersheds, counties, states) where the nation would get most water restoration for their money. National cost-effectiveness - getting the most benefit out of the public money spent - implies targeting using benefit and cost criteria (Ribaudo, 1986, 1989a; van Vuuren, Giraldez, and Stonehouse; Fox, Umali, and Dickinson; Bosch, Batie, and Carpentier). In a static framework, a fixed budget to reduce water pollution could be assigned to the project with the highest monetary net benefit, and then to the next highest and so on until the budget is exhausted (van Vuuren, Giraldez, and Stonehouse; Batie 1994b). In a dynamic framework, money would be allocated to projects which maximize the net present value of benefits. Alternatively, the agency could set the ambient water quality, determine the loading level most likely to achieve this goal, then determine the cost-effective allocation of these loadings to emitting sources.

Benefits from water pollution reduction are a function of demand for clean water and would only occur if the policy reduces the limiting factor, and reduces it enough to achieve the designated use for the water body[1] (van Vuuren, Giraldez, and Stonehouse). The Tennessee Valley Authority measures their cost-share programs' success by changes in the level of the Index of Biotic Integrity from poor to fair or good. Crutchfield, Feather

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[1] Limiting factors are location and use specific. For example, if the water is used for drinking, the limiting factor may be bacterial content. Reducing the occurrence or concentration of any other pollutants generates no benefits unless bacterial content is reduced (van Vuuren, Giraldez, and Stonehouse).

and Hellerstein estimated rural water quality benefits in Minnesota by regressing a water quality indicator for each lake on agricultural practices in adjacent counties. In their study, the link between changing agricultural practices and water quality benefits depends upon both the recreational demand defined as a function of the water quality and the agricultural practices affecting that water quality. In general, the national variability among watersheds and the fairly aggregated data required for macro-analysis makes macro-targeting cost-effective.

3.3 Micro-targeting

Micro-targeting refers to targeting control efforts to micro-units (within the macro-targeted areas) to generate the most benefits from public funds used to regulate, monitor, and/or enforce. For a cost-effective program, farms with lower costs of pollution abatement or farms which contribute most to the pollution problem should be constrained more heavily. How well these farms are targeted depends on the quality of the targeting scheme, that is, how closely the targeting scheme is related to marginal costs of pollution reduction. Given the physical, spatial, economic and management diversity of farms, the cost of complying with different agro-pollution policies will vary from parcel to parcel of homogeneous land. Operational research suggests that different levels of pollution reduction will be required from parcel to parcel if the goal is minimization of social control costs, and if the farms have different compliance cost functions (Henderson and Quandt). Targeting programs to parcels of land with the smallest marginal costs of pollution control would result in lower social control costs. However, control agencies do not have perfect information (to target parcels) nor are they likely to collect it because it implies estimating a production and loading function for each parcel. Over a large area, the smallest production function and loading function estimated, given available data, is likely to be at the farm and in fewer cases, at the field. These critical fields and farms must be identified, and this process is not without cost.

Although targeting water quality efforts will reduce farmers' compliance costs, it is still unclear whether total costs are reduced after accounting for transaction costs (Bosch, Batie, and Carpentier). The level and quality of information collected must be considered with care as gathering additional information may not be worth the costs (Liu). Marginal compliance costs could be derived for a representative farm and a tax set at that level. However, Pigouvian taxes have not been used to control agro-pollution and a tax may not be a politically feasible tool to address the problem.

At the national level, high spatial diversity implies high potential benefits from targeting. It is likely to be less expensive to macro-target watersheds than micro-target farms, fields or soil groups. At the local level, the likelihood of sediment, nutrients, or chemicals reaching a body of water (including aquifers) is a function of local topography, hydrology, weather, soil type, farming practices and timing of the farming operations. Watersheds with high physical variability are more likely to generate benefits from targeting (Mapp et al. and Fox, Umali, and Dickinson) and a higher value of information. In an empirical study of two watersheds in southwest Ontario, a watershed with high variability and one with almost uniform physical characteristics, the net benefits from targeting conservation practices were ten times greater for the variable watershed than the uniform watershed (Fox, Umali, and Dickinson). Most benefits of targeting come from a decrease in the number of hectares put under conservation for each targeting scheme in order to achieve the water quality standard. For example, targeting areas with rates of sediment delivery greater than 30 percent, includes 18 percent of the land area under crop production in the variable watershed, as opposed to 90 percent when all soils in the watershed are targeted uniformly (Fox, Umali, and Dickinson). The rate of sediment delivery is the proportion of sediment movement as calculated by the USLE that is delivered to a stream. Thus targeting has the greatest potential when farms are heterogeneous.

3.4 Targeting strategies and level of information

The ability of targeting strategies to increase the cost-effectiveness of programs to reduce agro-pollution depends on two things: 1) how well the targeting scheme approximates marginal costs of pollution reduction and 2) the number of acres/farms affected. The simplest targeting strategies depend on one variable only, for example, targeting all dairy farms. Any combination of two or more variables forms another scheme. The targeting scheme most likely to minimize control costs is the one with the highest correlation coefficient with farmers' pollution abatement costs for a targeted pollutant.

Agro-pollutants by definition are diffuse and numerous requiring micro-modeling. The cost of simulating the complex economic and physical environment and collecting the data may mitigate any gains in reduced compliance costs (Shortle, 1994), if not carefully thought out. Information costs could be reduced if parameters used to target were easily observable, inexpensive to collect, or had a long useful life and were correlated with the marginal abatement costs. Perhaps some physical and socio-economic characteristics are correlated to farmers' costs of pollution reduction and could be used as proxies to target agro-pollution control policies.

For dairy farms in the Lower Susquehanna, preliminary analysis by Bosch, Carpentier, and Batie has identified manure storage to be highly correlated with the nitrogen leaching shadow price, and distance to the stream with the nitrogen delivery shadow price. Parsons, Pease, and Bosch found from a farmer survey that farm management practices might be more important than farm physical characteristics in predicting nitrogen leaching and runoff. This finding would suggest greater returns to collection of data on input use and timing, rotation, tillage, and other management practices than soil types and other physical factors. This finding also suggests higher information costs because a data set of farm management practices has a shorter useful life and is more subject to change with economic conditions than a data set of physical characteristics.

APPENDIX B: THE MODEL TO ALLOCATE NITROGEN DELIVERY REDUCTIONS AMONG FARMS

ALLOCATI is a mixed integer program written in GAMS to allocate nitrogen delivery reductions to farms. The model reads the three data files containing information for each farm: Farm.inc, Base.inc, and Full.inc. Farm.inc lists the set of sample farms in the watershed. Base.inc lists for each farm the baseline nitrogen delivery and leaching. Full.inc lists each farm's perfect information marginal compliance costs at the four performance standard levels (J20, J40, J60, and J80 percent reduction). For the partial information cost-effective allocation, Full.inc is replaced by Partial.inc which lists each farm's perfect partial marginal compliance costs at the four performance standard levels (20, 40, 60, and 80 percent reduction). The same model is also used to achieve the private and social cost-effective allocation. For the private cost-effective allocation, marginal transaction costs (MTCFARM) is set to 0 by including a "*" in the first column of the line that starts with SCALAR MTCFARM and end with /640/ (the program thus ignores this line).[1]

```
$TITLE Cost effective allocation of pollution reduction
OPTIONS LIMROW = 0, LIMCOL  =0, SOLPRINT=ON, SYSOUT=OFF;
$OFFSYMLIST OFFSYMXREF OFFUELLIST OFFUELXREF
```

[1] $640 is the perfect information marginal transaction cost. This value is set to the partial information marginal transaction cost for the partial information simulation.

```
OPTION LP=MINOS5;
OPTIONS ITERLIM=15000;
SET J reduction levels /J20, J40,J60,J80/
SET P pollution /LEACH, RUN/
$INCLUDE "FARM INC"
$INCLUDE "BASE INC"
PARAMETER ALLOW(F,J) pollution reduction avail each shad price int;
   ALLOW(F,J) = ((.2*BASE(F,"RUN")))
DISPLAY "ALLOW here", ALLOW;
SCALAR NITREDN  N runoff reduction reqd for whole watershed /.4/ ;
SCALAR MTCFARM marginal transaction cost per farm that reduces N runoff /640/;
* SCALAR MTCFARM marginal transaction cost per farm that reduces N runoff /0/;
PARAMETER WBASE base N runoff for the watershed;
 WBASE = SUM(F, BASE(F,"RUN"))
DISPLAY "wbase here", WBASE;
$INCLUDE "FULL INC"
VARIABLES
Z(F,J) N runoff reduction at each shadow price level for each farm
TZ(F) total farm reduction in N delivery
SUMTZ total watershed reduction in N delivery
TOTMTC total transactions costs for the watershed
DUM1(F) dummy variable to account for transaction costs for target a farm
DUM2(F) expands dummy variable to force all transaction cost to be paid
*  on farms which reduce N runoff
MAXN(F) maximum allowed N on the farm to be outputted to SUSFARM
VSP total value of shadow prices for N runoff reduction
;

POSITIVE VARIABLES Z ;
BINARY VARIABLES DUM1;

EQUATIONS TOTVSP define objective function
TOTMTCEQ sums total transaction costs
DUM2CST(F) expands dummy variable to equal 20 percent N runoff interval
TOTZ(F) sum reductions in N delivery from each farm
SUMTZEQ sums reductions in N delivery from watershed
TOTNCST total N runoff reduction required in the watershed
ZCST(F,J) interval constraints on delivery shadow prices
DUM(F,J) forces transaction cost to be paid if N reduction allocated
MAXNEQ(F) subtract reduction from the base to yield allowed N loading
```

```
;
TOTVSP..  SUM((F,J), SHAD1(F,J)* Z(F,J)) + SUM(F, DUM1(F)*MTCFARM)
         =E= VSP;
TOTMTCEQ.. TOTMTC =E= SUM(F, DUM1(F)*MTCFARM);
DUM2CST(F)..  DUM1(F) * ALLOW(F,"J20") =E= DUM2(F);
OTZ(F)..   TZ(F) =E= SUM(J, Z(F,J));
SUMTZEQ..  SUMTZ =E= SUM(F, TZ(F));
TOTNCST..  SUMTZ =G= (NITREDN * WBASE);
ZCST(F,J).. Z(F,J) =L= ALLOW(F,J);
MAXNEQ(F).. MAXN(F) =E= BASE(F,"RUN") - TZ(F);
DUM(F,J)..  DUM2(F) =G= Z(F,J);
FILE OUT1 /PDREDUTC TWICE/ ;
FILE OUT2 /PDSTARTC TWICE/ ;
MODEL ALLOCATN /ALL/;
SOLVE ALLOCATN USING MIP MINIMIZING VSP;
* the "put" statement create a file to be read and analyze in GAMS or SAS
PUT OUT1
LOOP(F,
PUT F.TL:5.0;
PUT TZ.L(F):7.0;
PUT /);
PUT /;
UT OUT2
PUT "PARAMETER MAXNALLW(F) maximum n allowed on each farm/"/
LOOP(F,
PUT F.TL:5.0;
PUT MAXN.L(F):7.0;
PUT /);
PUT "/;"/
PUT /;
```

APPENDIX C: TRANSACTION COSTS IN THE CHESAPEAKE BAY

C.1 PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION'S CHESAPEAKE BAY PROGRAM

The Pennsylvania Department of Environmental Protection's Chesapeake Bay Program (the Program) staff has eight nutrient management specialists and conservation districts' nutrient technicians and engineers located in 42 conservation districts that offer technical support to farmers in the Lower Susquehanna Watershed.[1] These technicians and agricultural engineers perform outreach activities, handle participation requests, and develop farm nutrient and sediment management plans. Nutrient management plans ensure that nutrients are applied at the time of plant uptake and in quantity needed by the plants. Thus soil and manure nutrient content analyses are performed to accurately account for these sources of nutrients. A nutrient management plan is mandatory for participation in the cost-share program because it was found to be the most cost-effective practice in the Watershed by the Susquehanna River Basin Commission.

Farmers volunteer to participate at their conservation district office where they fill out an application form. Conservation district technicians then set priorities for the requests according to farmers' needs and the seriousness of the nutrient and/or erosion problems on the farm. During their first visit, technicians assess the farm practices and

[1] Some counties chose not to participate in the program because they have eeither no or very small parts of the county draining into the Lower Susquehanna river, or those lands draining to the River are not under agricultural use. Farms in 38 counties are eligible to participate in the Pennsylvania Chesapeake Bay program.

problems by walking over the fields (visual assessment) and using pre-existing NRCS plans to control erosion on the farm (if such plans already exist). In the county office, the technician and the nutrient management experts write a preliminary plan. A second visit to the farm is made to finalize the plan and reach an agreement with the farmer. Finally the contract is written and signed by the farmer and the soil nutrient specialist.

The contract stipulates the practices to be implemented and their duration, the amount cost-shared, and a mandatory nutrient management plan. The duration of the contract is the useful life of the implemented BMPs with the longest useful life. For example, if the practice is a grass waterway with a life expectancy of ten years, the grass waterway and nutrient management plans must be maintained for ten years. Structural practices are contracted out through a bidding process. The contract to implement the practices is given to the highest bidder and must be made under the supervision of conservation district technicians to insure that it is made in accordance with the Pennsylvania DEP standards. Collecting information and writing contracts take on average 28 hours (Wagner). The first visit to collect the necessary information to write the first draft of the plan (possible practices the farmers can implement) falls into the information category (19 hours). Subsequent visits and finalization of the plan write-up fall into the contracting category (Table C.1). Travel time averages 30 minutes as there is a conservation district office centrally located in each county. District conservationists are also in charge of enforcing nutrient management plans and

Table C.1 Hours per Activity and Costs to Develop a Nutrient Management Plan

Activity	Technician (hours)	Expert (hours)	Costs[a] ($)
Information			
Travel (2 roundtrips)	2		46
Gather information	10		230
Write preliminary plan	4	3	167
Total information hours and costs	16	3	443
Contracting			
Travel to farm	2		46
Reevaluate with farmers	4		92
Write final contract	2		46
Final agreement	1		23
Total contracting hours and costs	9		207
Total enforcement hours and costs	3		69

Source: Wagner (1996). Pennsylvania Department of Environmental Protection's Chesapeake Bay Program.

[a] Technicians hours are $23 and experts hours are $25.

the additional 15 different BMPs eligible for cost-sharing. Practices are enforced through annual visits to the farms that last approximately three hours.

By 1995, 902 farm owners had contracts with the conservation districts. These plans only represent 60 percent of the plans technicians worked on (Wagner). Another 40 percent were written for non cost-share farms. Thus, 1,497 nutrient management plans were written and 902 enforced by technicians over the last 10 years. Once a contract is written, it is revised internally for wording by the central office, and then by the controller's and the governor's offices. These costs are not accounted for here, but are likely to be significant.

C.2 PENNSYLVANIA NATURAL RESOURCES CONSERVATION SERVICES

Soil erosion control plans are written and evaluated by NRCS offices present in each county. It takes approximately 4 hours for NRCS staff to develop a plan at $25 per hour (Smith). Between the time the plan is written and when the farmer implements it, adjustments are made to account for economic changes, farmers' preferences and other unforeseen factors requiring an extra 4 hours (Table C.2). Plan enforcement takes one hour at $25 (Smith). Smith estimates that to these costs 30 percent overhead costs should be added to account for vehicle and gas expenses, and other visit and administrative costs to write the plans. Thus, NRCS spends $260 to develop plans and $33 to enforce them.

Table C.2 Hours per Activity and Costs to Write and Enforce BMP

Activity	Expert (hours)	Costs ($)
Information		
Travel to farm	1	25
Gather information	3	75
Total information hours and costs including overhead[a]	4	130
Contracting		
Write preliminary plan	2	50
Reevaluate with farmers	1	25
Write final contract	1	25
Total contracting hours and costs including overhead[a]	4	130
Enforcement		
Travel to farm	1	25
Total enforcement hours and costs[a]	1	33

Source: Smith (1996). Pennsylvania Natural Resources and Conservation Services.
[a] Includes 30 percent overhead costs.

C.3 PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION

Enforcement costs are higher when farms do not comply, as illustrated by the Pennsylvania DEP Water Management Division dealing with complaints regarding acute environmental contaminations by manure. The division responds to civil complaints when a severe water quality problem is reported. Over the last five years, an average of 77 investigations per year have been conducted by the division. It takes approximately 5 field staff hours to visit the site and evaluate whether the problem arises because of manure handling and storing problems. Twenty percent of the investigations are justified in which case a letter of violation is written (two hours) and sent to farmers (15 per year) indicating the corrective measures and a deadline by which the farmer must provide proof that the changes have been made. Another 2.3 hours is spent to enforce compliance through a visit to the farm.

On average seven percent of the farms (two farms) per year do not comply in which case advanced settlement procedures must be undertaken. The procedures vary from case to case but require on average 23 attorney hours and 115 specialist hours (Table C.3). Finally, the contracts are enforced through water sample analyses (40 percent of the time) at $50 each and an additional 30 field staff hours.

The costs above are those borne by the agencies directly involved in the process. Other costs not estimated are those incurred by the Pennsylvania State University extension services, Farm Service Ageny, and EPA.

Table C.3 Hours per Activity and Costs to Examine Water Quality Complaints

Activity	Technician	Expert	Attorney	Costs
Contracting with compliance				
Visit the site[a]	1			23
Identify farm	1			23
Gather information	3			69
Write violation letter	2			46
Contracting hours and costs with compliance	7			161
Contracting in the absence of compliance				
Contracting hours and costs with compliance	7			161.00
Advance settlement agreement		115		2,875
Court settlement			23	759
Contracting hours and costs in the absence of compliance	7	115	23	3,795
Enforcement				
Travel to site/farm	1			23
Evaluate	1.3			30
Samples (2 per sites)				100
Enforcement hours and costs	2.3			143
Total transaction costs with compliance				304
Total transaction costs in the absence of compliance				3,938

Source: Young (1996). Pennsylvania Natural Resources and Conservation Services.
[a] Of the 77 yearly investigations 15 require actions.

C.4 VIRGINIA NATURAL RESOURCES CONSERVATION SERVICES

Conducting the Status Reviews for the erosion control compliance requirements of the Federal Agricultural and Commodity Programs in Virginia costs on average $85 per tract. Tracts can be a field or groups of field farmed by a farmer and are assigned a number for which the Farm Service Agency keeps track of cropping practices. These costs presented in Table C.4 are the most complete and detailed found for the area.

Table C.4 Hours per Activity and Costs to Enforce the Federal Agricultural and Commodity Programs

Activity	Technician (hours)	Expert (hours)	Costs $/tract
Status Reviews[a]			
Drive to farm	1		23.00
Review of practices	2.4		55.20
Loading software			2.30
Training time			2.00
Check up			2.60
Travel operating costs			15.76
Data manipulation			37.41
Total Status Review			138.27
Quality Reviews[b]			
Drive to farm		1	25.00
Review practices		2	50.00
Training			22.00
Travel Costs			37.26
Total Quality Reviews		3	134.26
Total per tract	3.4	3	272.53

Source: Faulkner (1995). Virginia Natural Resources and Conservation Services.

[a] All tracts are reviewed.

[b] Quality Control on 7.5 percent, 104 tracts.

APPENDIX D: NITROGEN RUNOFF COMPUTATION IN SUSFARM[1]

Nitrogen runoff depends on precipitation and other hydrologic factors. Total precipitation (snowfall plus rainfall) is partitioned into runoff and infiltration (Yagow et al.). The watershed is divided into three annual precipitation zones and a weather station is selected to represent each zone. Daily precipitation records for approximately 40 years are available for each station. Rainfall is partitioned based on the Natural Resource Conservation Service (NRCS) curve number approach (USDA, 1986). Average rainfall is calculated for each of the 0.25 inch daily rainfall classes at each site. Daily runoff ($RAINRUN_i$) for daily precipitation amount ($PCPCLASS_i$) is estimated as:

$$RAINRUN_i = \frac{(PCPCLASS_i - 0.2\cdot((1000/CNFACTOR) - 10))^2}{PCPCLASS_i + 0.8\cdot((1000/CNFACTOR) - 10))} \qquad \text{(D.1)}$$

CNFACTOR, the "curve number" depends on land use and hydrologic soil group (USDA, 1986). Cultural practices and soils that are more prone to runoff are represented by higher curve numbers. The total annual rainfall runoff from rainfall (RAINRUNX) is calculated as the sum of daily runoff.

Winter runoff is increased by raising the curve number to account for frozen ground based on relationships found in Novotny and Chesters (p. 622). Runoff is also adjusted to account for runoff from snowmelt based on the assumption that ten percent

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[1] This Appendix is heavily based on sections of Bosch, Carpentier, and Heimlich.

of annual runoff in this watershed is due to snowmelt (USDA, 1979). Estimated annual rainfall runoff is 90 percent of total runoff (or overland flow). Overland flow (OVERFLO) for crop c, tillage t, soil hydrology group h, and precipitation region j is:

$$OVERFLO_{cthj} = \frac{RAINRUNX_{cthj}}{0.9} \tag{D.2}$$

Interflow is the portion of percolation that reemerges as runoff. The portion of leaching made up of interflow ($INTERFLO_{r=rotation,c=crop,t=tillage}$) is defined as:

$$INTERFLO_{rct} = \left(\begin{matrix}LEACHING\\INDEX\end{matrix}\right)_{rct} \cdot (0.01 + (0.164 \cdot (BPERM/APERM)^{0.5}) \tag{D.3}$$

LEACHING INDEX, a function of soil water holding capacity, represents the amount of percolation that leaches to groundwater or reemerges in runoff as interflow. BPERM/APERM is the ratio of permeability in the B soil horizon to permeability in the A horizon, 0.164 is a calibration constant (Yagow et al.), and 0.01 here and in the following equations is a factor to convert units to kg/ha.[2]

Soluble Nitrogen Losses

The Yagow et al. runoff calculations are adapted to fit the linear programming model. NRUN1, runoff from "background sources", nitrogen in rainfall, mineralization of organic nitrogen in the soil, and nitrogen in soil pore water is calculated on a pounds

---

[2] The calculations presented by Yagow et al. are in metric units; the SUSFARM model's parameters are in English equivalents. To improve readability, we do not show the factors for the metric to English conversion here.

per acre basis as:

$$NRUN1_{rct} = CSOIL1_{rct}[(0.443 \cdot OVERFLO_{cthj} \cdot 0.2 \cdot 0.01) + (0.089 \cdot INTERFLO_{rct} \cdot 0.01)] + (0.244 \cdot 0.6 \cdot OVERFLO_{cthj} \cdot 0.75 \cdot 0.01) \qquad \text{(D.4)}$$

$CSOIL1_{rct}$ is the concentration (mg/l) of soluble nitrogen in runoff from background sources. The terms in the first set of parentheses represent the runoff-extracted nitrogen load, 0.443 is a calibration constant for runoff from overland flow, and 0.2 is a runoff extraction coefficient (Yagow et al.). Nitrogen that leaches below the root zone and reappears in runoff through interflow is calculated in the second set of parentheses; 0.089 is a calibration constant for nitrogen in interflow (Yagow et al.). The last set of parentheses shows estimates of the precipitation contribution to surface runoff, 0.244 is a calibration constant for runoff of soluble nitrogen in rainfall, 0.6 is the nitrogen concentration of precipitation (mg/l), and 0.75 is the proportion of precipitation nitrogen that ends up in surface runoff that is delivered to streams (Yagow et al.). CSOIL1 is:

$$CSOIL1_{rct} = \frac{(QPORE + (0.05 \cdot 73) + INF_{rct})}{0.01 \cdot (QSOIL + PERCINDX_{rcthj})} \qquad \text{(D.5)}$$

QPORE represents the quantity of nitrogen in soil pore water in the top centimeter of soil at saturation (kg/ha); 0.05 is a scaling factor (Yagow et al.); and 73 is the nitrogen mineralized from soil organic nitrogen (Kg/ha). QSOIL is the soil water in the top cm of soil at saturation in mm and is obtained by multiplying the soil porosity by 10. $PERCINDX_{rct}$ the mm precipitation that percolates into the soil, is calculated by subtracting overland flow from total precipitation.

INF_{rct} represents kg of nitrogen in rainfall that infiltrates the soil. Yagow et al. assume a 25 percent reduction in soluble nitrogen from precipitation reaching streams, resulting in:

$$INF_{rcthj} = 0.6 \cdot PERCINDX_{rcthj} \cdot 0.75 \cdot 0.01 \quad \text{(D.6)}$$

where 0.6 is nitrogen concentration in precipitation (mg/l) and 0.75 is the portion of rainfall nitrogen delivered to streams. Rainfall nitrogen enters runoff in two ways: 1) as direct runoff in equation (D.4); and 2) by percolating into the soil (equation (D.6) and thereby adding to the concentration of soluble nitrogen in soil that is extracted by runoff.

QPORE, a function of the bulk density, is calculated as:

$$QPORE = 0.5 \cdot (1 - (BULKDENSITY/2.65)) \quad \text{(D.7)}$$

where the term in parentheses (1-BULKDENSITY/2.65) is the soil porosity (gms/cc).

Nitrogen runoff per ton of fertilizer or manure between the time of spreading and crop uptake is calculated by multiplying the increase in soil nitrogen concentration per ton of fertilizer applied (CSOIL2) by the volume of runoff that occurs via overland flow and interflow. The equation for runoff from a ton of fertilizer or manure of type n applied with technique z in season s to crop rotation r, crop c, and tillage type t is:

$$\begin{aligned} NRUN2_{rctnzs} = {} & CSOIL2_{rctnz} \cdot (PCPTOSUM_s / TOTPCP) \cdot \\ & [(OVERFLO_{cthj} \cdot (RUNFACT_z / 100) \cdot 0.2 \cdot 0.01) \\ & + (INTERFLO_{rct} \cdot 0.089 \cdot 0.01)] \end{aligned} \tag{D.8}$$

$RUNFACT_z$ equals 50 for incorporated fertilizer or manure and 100 for unincorporated fertilizer or manure, thus halving but not eliminating runoff extraction of nitrogen in the top soil layer with incorporation; and 0.2 is the runoff extraction coefficient. PCPTOSUM is the amount of precipitation estimated to occur between the time of spreading and crop nitrogen uptake, which is the end of summer for spring-planted crops and spring for fall-planted crops. PCPTOSUM is calculated based on historical weather patterns at the three weather stations selected to represent the watershed. TOTPCP is total annual precipitation.

CSOIL2 is the nitrogen content of one ton of fertilizer or manure of type n divided by the volume of water that percolates into the soil from rainfall or is already in the top cm of soil. In equation form:

$$CSOIL2_{rctnz} = NETNUT1_{nz} / (0.01 \cdot (QSOIL + PERCINDX_{rcthj})) \tag{D.9}$$

NETNUT1 represents the nitrogen content per ton of fertilizer or manure after nitrogen volatilization and denitrification[3].

Sediment Erosion and Delivery

Sediment erosion. Sediment erosion per acre of crop rotation (SED_r) is calculated using the Universal Soil Loss Equation (USLE) (USDA, 1991; Wischmeier and Smith, 1978).

$$SED_r = \sum_c \sum_t RFACTOR \cdot KFACTOR \cdot \cdot LSFACTOR \cdot CFACTOR \cdot PFACTOR \cdot ROTAC_{rct} \quad \text{(D.10)}$$

The C (crop cover for a given crop) and P (conservation practice) factors for specific crop rotation, tillage and conservation practices are based on values suggested in the Pennsylvania Technical Guide of the Soil Conservation Service (USDA, 1991).

Sediment delivery. Sediment delivery that reaches the stream as a proportion of total sediment erosion, DELIVRAT, is calculated as (Shanholtz and Zhang, 1988):

$$DELIVRAT = e^{-WTDCOV \cdot TOTDIST \cdot SLOPEFN} \quad \text{(D.11)}$$

e is the base of natural logarithms. WTDCOV is the weighted average cover factor for the intervening crop, pasture, and wood land, between the site and surface water. Total

---

[3]A portion of N in animal manure is in the organic form and becomes plant available over several years. For Pennsylvania, it is estimated that 44 to 54 percent of organic N becomes plant available over a four-year period (Serotkin). Here it is assumed that equal amounts of manure have been applied in previous years and that 54 percent of manure organic N from the current and previous years' applications becomes plant available during the growing season. Thus, NETNUT1 equals inorganic N that remains after volatilization and denitrification plus 54 percent of organic N.

distance (TOTDIST) is the distance from the site to the nearest surface water. WTDCOV is computed by attaching a weight of 0.4233 to cropland, 0.71 to pasture land, and 1.1842 to wood land (Shanholtz and Zhang, 1988). SLOPEFN represents a factor to account for slope of the flow path between the site and the nearest surface water. The equation for SLOPEFN is (Heatwole et al. 1987):

$$SLOPEFN = e^{-16.1 \cdot (SLOPTOSTR + 0.057)} + 0.60 \qquad (D.12)$$

where SLOPTOSTR is the average slope (decimal fraction) of land along the flow path from the site to surface water.

Distance to nearest water body is recorded for each NRI point including those associated with the Area Studies points. The geo-referenced location of each farm is not available, hence cover and slopes are determined for all NRI points located in the same NRI polygon as the indicated point and a weighted average value is used.[4]

Nutrient Losses In Sediment.

Sediment nitrogen loss may be adsorbed to sediment and delivered to streams with sediment. Sediment nitrogen as a proportion of delivered sediment is computed as (Yagow et al., 1993):

$$NSED = 0.475 \cdot NERAT \cdot NORG \qquad (D.13)$$

[4] An NRI polygon refers to the polygon formed by the intersection of county boundaries, major land resource area (MLRA) boundaries, and eight-digit hydrologic unit area boundaries surrounding the NRI point.

where 0.475 is a calibration factor. NORG is the soil nitrogen content estimated as a decimal fraction and calculated as follows (Yagow et al. 1993):

$$NORG = (3.35 + (0.33 \cdot CLAY)) \cdot 0.0001 \tag{D.14}$$

CLAY represents the average percent clay content of the soil. NERAT is a dimensionless enrichment ratio for soil N. NERAT reflects the greater tendency of nitrogen to adhere to the finer silt and clay particles that are more likely to be eroded than the coarser soil particles. NERAT is (Yagow et al. 1993):

$$NERAT = 7 \cdot CLAY^{-0.35} \tag{D.15}$$

NERAT declines with increasing amounts of clay indicating that the need to adjust estimated nitrogen content for enrichment declines as more of the soil content is made up of clay.

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Education:

1996 **Ph.D. in Agricultural and Applied Economics -Natural Resources and Environmental Economics.**
Polytechnic Institute and State University,
Blacksburg, Virginia.

1990 - 1994 **M.S. in Agricultural Economics - Resources and Environmental Economics**
McGill University, Ste-Anne de Bellevue, Québec, Canada.

1990 **B.S. in Agricultural Economics**
McGill University, Ste-Anne de Bellevue, Québec, Canada.

1985 - 1987 **Diploma in Pure and Applied Sciences - Pure and Applied Sciences**
College of General and Professional Studies (CEGEP) du Vieux Montréal,
Montréal, Québec, Canada.

Experience:

1996 - **Post Doctoral Fellow- Outposted in Acre, Brazil**
Carry out and disseminate, in collaboration with Research Fellow, research on arresting deforestation and resource degradation in the forest margins of Brazil. Including helping Research Fellow develop the data collection instrument, applying the instrument, processing the information collected, and building a model to represent the decision process of small farmers and extractivists in the tropical forest margins.

1992 -1996 **Research assistant**
Studied the implications of GIS technology for the design and implementation of targeted nonpoint pollution programs as part of a cooperative agreement with the Economic Research Service (USDA). Contributed to the production of internal reports, external presentations, and the modeling efforts in GAMS and SAS.
Advisors: Dr. Sandra Batie and Dr. Darrell Bosch.
Virginia Tech, Blacksburg, Virginia.

Experience ***Continued*:**

Summer 1992 **Organizing Member of a Youth Initiative Project in Chile**
Fund-raiser and coordinator of a development project in Chile. Learned Spanish. Participated in farm operations and social activities with non-governmental agricultural and economic development organizations in Chile. Produced final report.
Coordinator: Colette Coudé
Canadian Center for International Research and Cooperation,
Montréal, Québec.

Winter 1992 **Faculty lecturer**
Prepared and taught a principle of macroeconomics class to more than 30 first year undergraduates in the department of agricultural economics.
Supervisor: Dr. Randall Westgren
McGill University, Ste-Anne de Bellevue, Québec.

1990 - 1991 **Research assistant**
Disaggregated the agricultural sector of Statistics Canada's Input-output model for Agriculture Canada. Involved extensive data collection, a complete literature review, modeling (GAUSS) and preparation of reports and presentations for Agriculture Canada.
Advisor: Dr. Paul Thomassin
McGill University, Ste-Anne de Bellevue, Québec.

Summer, 1990 **Supervisor, horticultural farm**
Supervised and coordinated field activities and sale of vegetables and flowers.
Supervisor: M. Pierre Goyette
Les Jardins Goyette, Les-Cèdres

1989 - 1990 **Research assistant**
Translated questionnaires into French. Conducted telephone interviews with farmers and financial institutions.
Supervisor: Dr. Paul Thomassin
McGill University, Ste-Anne de Bellevue, Québec.

Summer, 1989 **Student research intern**
Participated in elaborating questionnaires for a "Low Input Sustainable Agriculture" project, funded by the USDA. Interviewed farmers. Supervisor: Dr. Sandra Batie and Dr. Dan Taylor Virginia Tech, Blacksburg, Virginia

1988 - 1991 **Supervisor and coordinator** (part time)
Hired, trained and managed staff. Produced reports and collaborated on project evaluation. Employer: Christine Beausoleil, Assistant Director **Cogem Research Marketing, Montréal, Québec**

Publications and Presentations:

1996 **Carpentier, C. Line**. Value of Information for Targeting Agro-pollution Control: A Case Study of the Lower Susquehanna Watershed. Dissertation submitted to the Faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

1996 **Carpentier, C. Line**. "Economic Instruments to Control Erosion". p.77-110 in Exploring Alternatives: Potential Application of Economic Instruments to Address Selected Environmental Problems in Canadian Agriculture. eds. A. Weersink and J. Livernois. Environment Bureau Agriculture and Agri-Food Canada. Ottawa, Ontario. April.

1995 Bosch, Darrell, J. and **C. Line Carpentier**. "Accounting for Spatial Variability in the Analysis of Agricultural Nonpoint Source Pollution". In Proceedings of the Southern Information Exchange Group 70: Economics and Management of Risk in Agricultural Resources held in Gulf Shores, Alabama. March. Forthcoming.

1995 Bosch, Darrell, J. and **C. Line Carpentier**, and R. Heimlich. " A Farm Model for Evaluation Nonpoint Source Pollution Abatement Programs." SP-94-03, Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, Blacksburg, February, 1995.

1994 **Carpentier, C. Line**. M.S. Thesis. "Agriculture and the Environment: An Economic-Ecologic Input-Output Model of the Canadian Economy." 121 pp. McGill University.

1994 **Carpentier C. Line**, Darrell J. Bosch, and Sandra S. Batie. " Improving the Economic Effectiveness of Geographic Information Systems for Water Quality Protection." Presented at the Annual Meeting of the Soil and Water Conservation Society, Norfolk, VA, August 7-10.

1994 **Carpentier, C. Line** and Darrell J. Bosch. "Using Adaptive Management and GIS to overcome Informational Barriers to Pollution Reduction Trading." Presented at the Annual Meeting of the American Agricultural Economic Association. San Diego, CA, August 7-10. Abstract in American Journal of Agricultural Economics 76 (December 1994): 1272.

1993 Trant, D. F., D.R. Coote, **C. Line. Carpentier**, and H.L Trepanier. "Estimating Changes in Gross Agricultural Soil Erosion by Water- A Case Study for Manitoba." Statistics Canada, Ottawa, Ontario.

1993 Bosch, J. D., Sandra S. Batie, and **C. Line Carpentier**. "The Value of Information for Targeting Water Quality Protection Programs Within Watersheds. "The Regional Workshop on the Economic Issues Associated with Nutrient Management Policy held by Southern Region Information Exchange Group 10. Raleigh, NC. October. 13

Publications and Presentations, ***Continued ...***

1992 **Carpentier, L.C.**, and Thomassin, P.J. "Optimal Land Use for an Urban Forest Resource: A Compromise Programming Approach." Presented at the International Conference on Forestry and the Environment: Economic Perspectives. Banff, Manitoba. March 9-12.

1992 Thomassin, P.J, **L.C. Carpentier**, and Martin Cloutier. "Development of a Disaggregated Input-Output Model for Agriculture." (Ste-Anne-de- Bellevue, PQ, Dept. of Agricultural Economics. McGill University).

Professional Services:

1993 - present	Article reviewer for the **Canadian Journal of Agricultural Economics**.
1993 '94	President of the Agricultural Economics Graduate Students Association, Virginia Tech.
1993 '94	Graduate student representative on the department Graduate Advisory Committee.
1991 -'92	President of the Agricultural Economics Graduate Student Association, McGill.
1990 -'91	Vice-President of the Agricultural Economics Graduate Student Association, McGill.
1990, Summer	Organizing Member of the McGill Academic Bowl Team held during the 1990 AAEA Meeting in Vancouver.
1989 -'90	Vice-President external affairs for the College of Agriculture, McGill University Student Society.
1989 -'90	Participation on the Ad Hoc Committee on Environmental Studies of McGill University.
1988 -'89	Vice-President Finance for the College of Agriculture, McGill University Student Society.

Additional Information:

Farm Experience: Manage farm operations and harvesting on a relative's corn farm and on rented land.

Computer Knowledge: MS-DOS, Wordperfect, DBase, Lotus, Quattro Pro, Lindo, ESP, GAMS, GAUSS, SAS, Windows, Word for Windows and Mac, Harvard Graphics, Power Point for Windows and Mac.

Languages Skills: Fluent in both French and English. Fluent in Portuguese (reading, speaking and verbal understanding) and Good verbal understanding and reading ability in Spanish.

Awards and Recognition:

Student award from the Professional Women's Association of Macdonald Campus, McGill University, 1989.

Summer fellowship in the Department of Agricultural and Applied Economics at Virginia Tech, 1989.

International Week President Service Award, Virginia Tech, 1995.

Professional Societies:

Canadian Agricultural Economics Association.
American Agricultural Economics Association.
Soil and Water Conservation Society.
Land and Resources Economists Electronic Conference.