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Micro-level econometric and water-quality modeling: simulation of nutrient management policy effects

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Micro-level econometric and water-quality modeling: simulation of nutrient management policy effects

by

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1. INTRODUCTION

Water quality concerns in the United States grow with every passing year, particularly in the Midwest. From the hypoxic zone in the Gulf of Mexico to fish kills, drinking water concerns, and diminished recreational opportunities in the corn belt, society is concerned about the quality of its water. While industrial and municipal point sources of pollution are quite well-regulated, nonpoint or diffuse sources, among them agricultural sources, are not. It is from this latter source that many of the existing problems originate.

Agriculture contributes to water quality problems by its use of fertilizers in the crop production process. Of the common fertilizer components, nitrogen and phosphorus are the major nonpoint contributors to impaired waters through most of the United States [58]. Excessive nitrate in drinking water can result in "blue baby" syndrome which can be dangerous or life-threatening to infants and is also suspected as a contributing factor to some forms of cancer. High concentrations of nitrogen and phosphorus in water leads to growth of algae. This detracts from recreational use of lakes and streams, causes unpleasant odors when the algae decay and consumes dissolved oxygen in water. The latter result has been linked to the hypoxic zone in the Gulf of Mexico.

Public policy has yet to effectively address concerns related to nonpoint source pollution. The U.S. Environmental Protection Agency (EPA) has attempted to introduce water quality standards by the establishment of Total Maximum Daily Loads (TMDLs). A TMDL is not accompanied by any pollution-reducing action or policy; currently the process of identifying and cataloging impaired waters is under way, albeit slowly.

Individual states are charged with the responsibility for identifying TMDLs in their watersheds. For each pollutant that results in a body of water failing to meet state water quality standards, the state is required to conduct a TMDL study. In addition to establishing a pollutant loading maximum, a TMDL assigns the amount of pollution that can be contributed by the sources of each pollutant and identifies both point and nonpoint sources. A water body (lake, stream, river) can have several TMDLs, each related to a specific pollutant. This process is ongoing and many states have long lists of water bodies without TMDLs but which are seriously impaired.

Once a TMDL has been established, there is still the problem of meeting the standard. States and the federal government are both struggling to find the means to achieve changes in pollution discharge that can allow compliance with established TMDLs. The slow pace and many of the difficulties associated with policy implementation arise from from the need for solutions tailored to a specific area or watershed. This aspect of the problem is most acute in areas where a large proportion of water body impairment is due to nonpoint sources of pollution. Many factors affect the transport of nonpoint source pollution: topography, weather, land use or management, vegetation, among others. Each area has a singular combination of these factors and thus a unique contribution of nonpoint source pollutants to the water quality problems that are experienced.

The Raccoon watershed in central Iowa is typical of many Midwestern watersheds. Much of its surface area is used for row crop production, largely in a corn-soybean crop rotation. Nitrogen and phosphorus fertilizer are applied at relatively high levels on the corn crop and constitute the primary nonpoint nutrient pollutant source in the watershed. A map of its general location appears in Figure 1.1 and a graphical representation of land use in the watershed can be found in Figure 1.2.

In the Raccoon watershed there are some small point sources in the form of municipal wastewater treatment facilities, a natural gas producer and a meat packing plant, but their contribution to nutrient loads is extremely small and as point sources they are

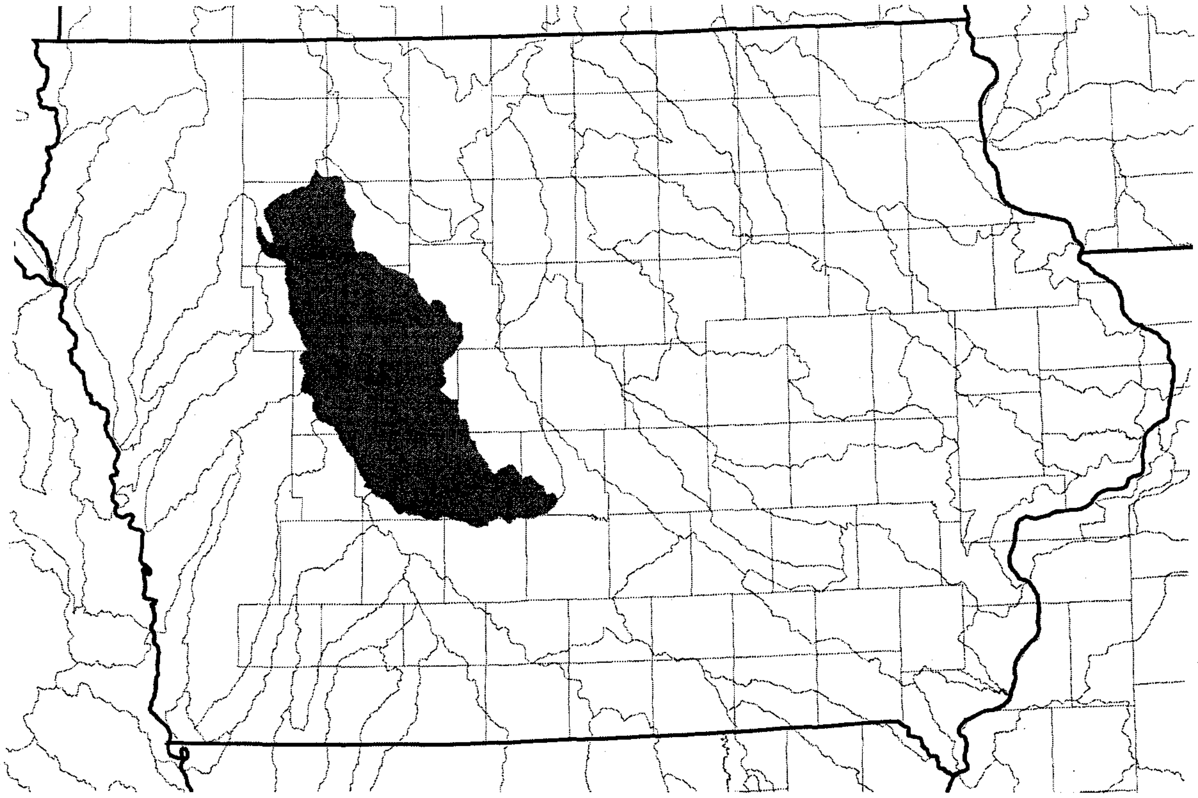

Figure 1.1 Location of the Raccoon watershed within the state of Iowa

already regulated.

There are two general water quality issues important to those affected by nutrient levels in the Raccoon watershed. One is nitrate levels at the Des Moines Water Works (DMWW). The DMWW provides drinking water for the Des Moines metro area, a population of nearly one-half million. It draws water from three sources: the Raccoon River, the Des Moines River and an infiltration gallery. In 1990 the DMWW invested in a nitrate-removal system in response to nitrate levels that exceeded drinking water standards. The DMWW activates this nitrate removal facility during periods of possible nitrate level increases. The costs of permanently removing nitrate from the water are much larger than the cost of disposal, so the removed nitrate is reintroduced to the river downstream from the DMWW. From there it continues on to the Mississippi river and eventually to the Gulf of Mexico. The facility cost $3.7 million to construct in 1990 and

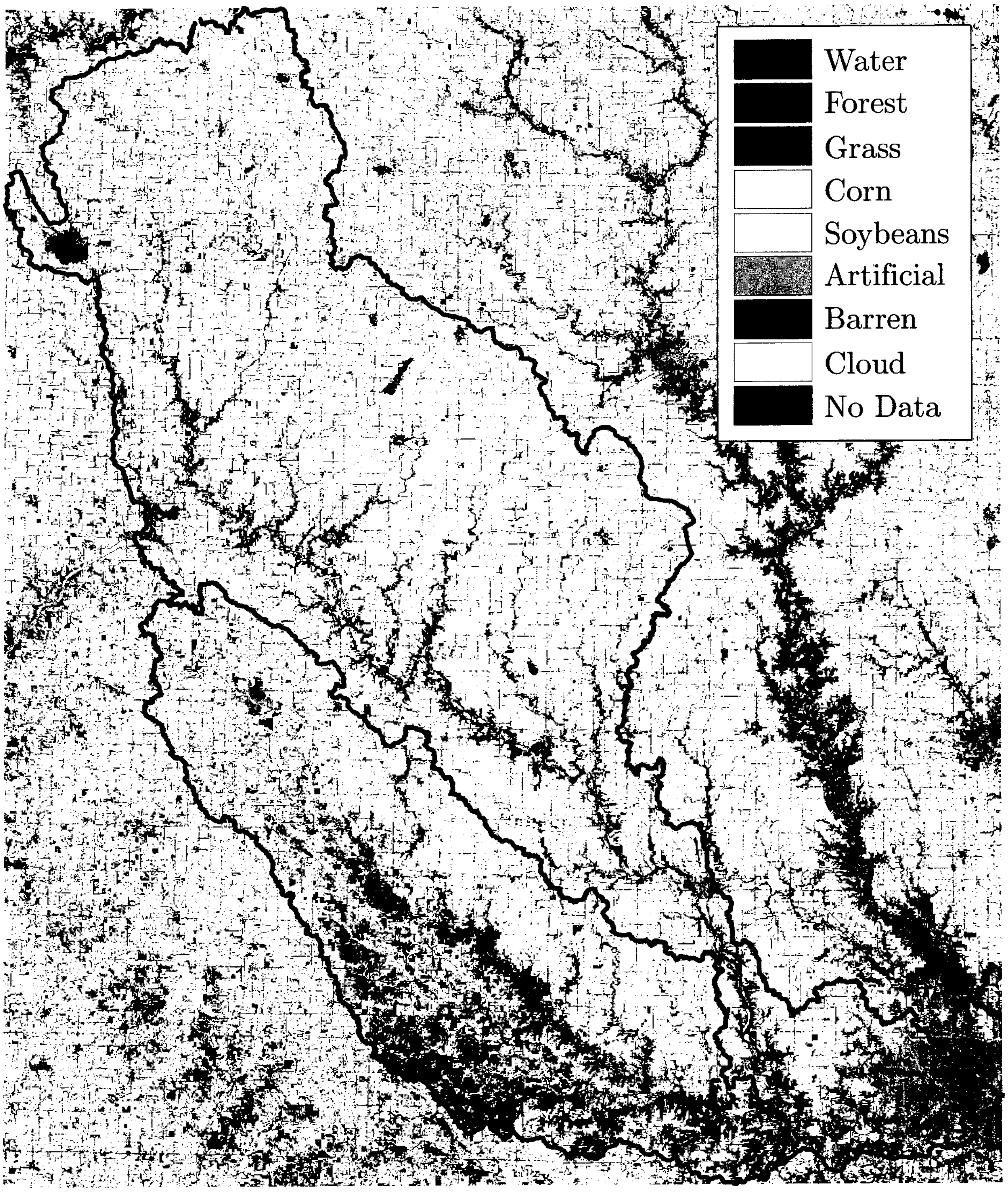

Figure 1.2 Major land uses in the Raccoon watershed (Iowa DNR)

runs on average 45 days per year. Average treatment volume on those days is 10 million gallons which incurs approximately \$3,000 in operating costs, suggesting a rough annual operating cost of \$135,000. This figure does not include cost associated with disposal of scrubbed nitrate (the nitrate is simply returned to the river and continues downstream) nor does it take into account capital costs.

Another important consideration in the impact of water quality degradation are the recreational activities to which the watershed area is host. Phosphorus is the limiting factor in the excess growth of algae that is visually unappealing, results in offensive odors, creates hypoxic or anoxic conditions leading to fish kills, and can contribute to dangerous levels of toxic cyanobacteria (similar to a freshwater "red tide"). Given these effects, phosphorus levels are a strong indicator of local freshwater quality. The Raccoon watershed contains nine lakes that offer significant recreational opportunities but which vary widely in water quality. For this reason, the impact of agricultural phosphorus use is an important factor in the quality of recreational opportunities available in the watershed.

1.1 Nutrients and Crop Yield

Studies addressing crop response to nitrogen and phosphorus input often report farmers applying amounts of these nutrients that exceed profit-maximizing levels [63], or simply make the assumption that farmers apply at levels considered excessive when compared to a crop's nutrient intake or requirements [22], [1]. Application of nutrients in excess of the crop's biological needs results in these nutrients entering waterways through runoff during rainfall, leading to the water quality problems discussed above.

The behavioral reason for over-application is often not made explicit, but there is some work that incorportes risk-averting behavior in application decisions—a discussion of several papers on this subject appears in Chapter 2. However, most evidence indicates that higher input levels tend to increase the variance of yield, making risk-aversion an unlikely candidate to explain this overapplication. Risk neutrality with uncertainty regarding the effects of input choice can provide a reasonable explanation for observed nutrient application levels without imposing this type of structure.

1.2 Methodology

The overall goal of this study is to develop a framework for assessing policies designed to improve water quality in a given watershed; here, the Raccoon River watershed. Policy assessment will be in the form of water quality improvement and economic impact on farm operators. These policies include a tax on each nutrient, a per-acre application cap, a cap-and-trade application right trading scheme and a uniform reduction in application levels. There are two primary objectives that must be met in order to construct a fully coupled economic and water quality model to serve as the assessment framework.

The first objective is the construction of a production model that captures the farm-level nutrient application decision. To this end, a micro-econometric field-scale model of nutrient application (nitrogen and phosphorus) is estimated using a Just-Pope style production function in conjunction with six years of USDA Agricultural Resource Management Survey (ARMS) data. This detailed field-level data set is combined with prices and spatially detailed soil data to provide the necessary inputs for econometric estimation. Predicted economic and behavioral outcomes of simulated policy scenarios at the farm level are integrated over the watershed area by linking the model results to the National Resources Inventory (NRI) data.

The second objective is the setup and calibration of a physical model that will predict the fate and transport of nutrients that are applied. Those that are not taken up by the crop find their way to waterways and have a detrimental impact on water quality as discussed above. The final output from the production model is interfaced with the

Soil and Water Assessment Tool (SWAT) which is then used to determine the changes in water quality that would result under each policy.

1.3 Overview

The next chapter presents a review of literature from three perspectives: economic studies focusing on nonpoint source issues relevant to the discussion in this paper, studies that develop or employ stochastic production functions and studies that specifically apply the physical model used here to an economic problem. Chapter 3 describes the development of the theoretical model employed and its application to the overall analysis. Chapter 4 provides an explanation of the estimation procedure used to fit the theoretical model as well as detailed explanations of the various data sets used in the estimation. Chapter 5 gives an overview of the physical water quality model used to simulate policy outcomes, background information on the watershed chosen for this study, and baseline water quality data for the watershed outlet. Chapter 6 catalogs the results of the simulations based on the entire menu of policy scenarios, and Chapter 7 concludes with a review of the results and discussion of the implications for policy choice, as well as directions for future research.

2. REVIEW OF LITERATURE

2.1 Introduction

The analysis on which this paper embarks relates to three general categories of literature. First, at its most basic level, it contributes to the broad body of work on regulation of nonpoint source pollution; more specifically those studies examining pollution that is a byproduct of agriculture. Secondly it addresses the importance of the mechanics of the analysis and the model used to support the methods utilized. For the economic model of Chapter 3 this means studies that utilize models incorporating risk into production processes and decisions. The third category deals with the water quality model described in Chapter 5 which is relatively new to the economics literature. The model itself has been put to use in many settings and the results of these modeling efforts appear in the literature of several physical science disciplines.

This chapter will summarize several important papers that represent the three categories described above. Section 2.2 chooses from a broad array of nonpoint source work in economics. Section 2.3 contains a discussion of the modeling of production with risk that is endogenous to inputs. Finally, Section 2.4 highlights work that applies the water quality model used in this paper jointly with economic evaluation.

2.2 Nonpoint Source Literature

The economics literature has much to say in addressing the problem of diffuse or nonpoint source pollution. One can read about a myriad of theories explaining production processes as they relate to diffuse pollution and its abatement. There are also dozens of unique and creative policy analyses, some with simulations of the possible effects on water quality, production, and other variables of interest.

With few exceptions, these studies focus on runoff or leaching from agricultural fields. Within this area itself most are concerned with nutrient loading in either surface or ground water, with some small mention of pesticides. This section seeks to provide an overview of the body of literature pertaining to nonpoint source pollution resulting from agricultural production.

While there is certainly significant overlap in subject within the literature, the following sections will present the material by organizing studies into three categories. The first and longest of these gives an overview of different means suggested to control nonpoint agricultural pollution. The second section details several studies that integrate economic models suggested in the first section with physical simulation models to gauge the possible effectiveness and efficiency of one or more policies. The final section takes a brief look at some more quantitative work that has focused on single watersheds and the management of nonpoint pollution within them.

2.2.1 Pollution Control Policies

Given the length and conceptual breadth of this section, presentation is simplified by further subdividing articles into categories. They are somewhat loosely organized into: (i) A section discussing some background theory and the use of ambient taxes, (ii) A collection of studies which concentrate on a particular policy instrument or combination of instruments, and (iii) Synopses of selected papers that focus on trading of pollution rights as a policy.

Theory, Background, Ambient Taxes

Griffin and Bromley [16] were among the earliest to formally develop the theoretical underpinnings of a model which analyzes agricultural runoff as a nonpoint externality. The motivation for this paper is the need for a theoretical base with which to examine problems related to nonpoint source pollution.

The authors identify three categories of nonpoint runoff issues. The first is that sediment, nutrient, and chemical removal are losses of production resources. These losses are costs borne by farmers. The second is a temporal externality that can exist when the discount rate of the farmer differs from that of society; this can result in the soil being "mined" too quickly. The third and final category is a spatial externality—the lost resources from runoff create pollution, with water being the primary transport mechanism. The bulk of the paper is devoted to developing theory and research methods to aid in developing policies to ameliorate these problems. Only the spatial type of externality is considered.

One key element to the discussion is that the authors assume it is either impossible or too costly to measure the marginal benefits of pollution reduction. Instead, they assume that there is some sort of benchmark or standard in place that stands in as a proxy for a given desirable level of benefits. This type of assumption is common throughout the literature.

The policy-relevant conclusions drawn are summarized in four suggestions for policy implementation. The first is what the authors term "nonpoint incentives," where emission determinants (inputs and/or outputs) are monitored. Examples of this might include input or effluent taxes. The second is a nonpoint "standard" where production activities are monitored. This would correspond to the concept of best management practice adoption. Along similar lines, the third policy suggestion is a set of individual management incentives for all production activities that produce pollution as a byproduct. The final suggestion is a system of standards that is dual to the individual management incentives.

These policy options and the general ideas presented appear in much of the work in this area. What is not explicity addressed is the means by which pollution can actually be measured in order to implement policy. A significant amount of work has been done under the assumption that an ambient level of pollutant serves as a guide in this sort of decision.

Segerson [52] outlines such an ambient-based system; taxes and bonuses designed to control nonpoint pollution in a watershed. Since the relationship between pollution discharge and ambient levels of pollution are stochastic and unobservable, the penalties and bonuses are applied to each contributing polluter in the watershed. The range of ambient pollution levels is represented by a probability distribution that is conditional on abatement practices undertaken by the polluters. The objective of the policy described is to increase the probability that the ambient pollution level falls below a chosen threshold value or standard.

In the event that the pollution level exceeds the threshold value, a tax is imposed on all nonpoint sources. This tax includes a fixed component in addition to an amount based on the ambient level's deviation from the standard. Thus there is an assured minimum penalty once the threshold is passed. It is not specified if these taxes and payments are made on a continuous time basis or only in the event of the ambient level crossing the threshold in either direction. In essence, polluters "gamble" on their tax liability in weighing the possible taxation from polluting versus the costs of abatement. Under a standard set of assumptions, this scheme can result in a socially optimal outcome but requires that the regulators have detailed information about each polluter.

Horan, et al. [20] build on previous work examining the use of ambient taxes in a nonpoint source setting. After a brief discussion on the lack of nonpoint source applications from the emissions-based incentives literature, they discuss the limitations of previously analyzed ambient-based schemes.

The authors begin with Segerson's idea of taxes based on ambient pollution levels, but expand the choice set available to the firm. Previous studies in both the emissions-based and nonpoint source arenas concentrate on a one-dimensional choice simply representing abatement. The particular characteristics in the example model are inputs, environmental drivers and multidimensional site characteristics.

Given that firms have more than a one-dimensional choice set, they show that a linear ambient tax that is state independent (a la Segerson) can only achieve efficiency under singular conditions. To overcome this limitation two alternative schemes are developed to overcome the shortcomings of a simple linear state-independent tax. One is based on Segerson's linear design with a tax rate determined ex post along with the ambient tax base. The other is a nonlinear ambient tax.

Xepapadeas [62] expands the subject of ambient pollution taxes to a dynamic setting. As was done in previous work, moral hazard problems are overcome by imposing taxes or subsidies on ambient pollution level deviation from a target. The framework of the model is an infinite-duration dynamic game. The process and effect of pollution itself has both dynamic and stochastic characteristics.

The incentive system involves the levying of charges based on deviation of pollution levels from a target or standard. Charges would be levied apparently instantaneously though it is unclear how this might specifically be implemented. The optimal taxes depend on assumptions make about firm/polluter strategy. If polluters follow a feedback strategy where they condition their emission choice based on current ambient levels, the required taxes are higher than they would be if the polluters have open-loop strategies.

The charges imposed on polluters are dependent on the marginal cost of the pollution, the discount rate and a physical decay rate attributed to the pollutant stock. Damages depend on the time path of the pollution stock. This is essentially a dynamic version of the static model suggested by Segerson. Since the solutions are different, the implication is made that using the static version in a dynamic world is suboptimal.

Although ambient taxes may be of theoretical interest, they are not considered feasible in empirical studies or actual policy implementation. Most of the more recent literature concentrates on other means of nonpoint source pollution control, such as those suggested by Griffin and Bromley, among others. These will be discussed in the subsection covering policy instruments.

In a unique exception that re-examines a basic theoretical assumption, Millock, et al. [40] take a novel approach to the nonpoint source pollution problem. They contend that the distinction between a point source and a nonpoint source exists only due to the cost of monitoring. That is, any pollution source can become a point source at the cost of acquiring sufficient monitoring technology.

The model introduced makes use of a costly monitoring technology which could take the form of physical monitoring equipment or a system of random site audits. Pollution as a part of the production process is considered under two externality cases. First, the case of an output externality where pollution is a unavoidable result of production and second, a residue externality in which case a waste of input or inputs is the cause of pollution.

The authors consider three different policy scenarios and seek to determine the optimal level of monitoring and taxation under each. In one, monitoring is considered unavailable (or available at an infinite price). In the second, monitoring is mandatory for all potential polluters, while the third considers voluntary adoption with incentives. The results of the analysis suggest that in the presence of monitoring costs no level of pollution is optimal; the regulator must trade off monitoring costs for input allocation efficiency.

Policy Instruments

There are several types of policy instruments typically examined in nonpoint pollution abatement studies. Focus is usually on influencing either the level of input (e.g., fertilizer) used in production, the technology or practices used in production (e.g., tillage method), or a combination of the two. Many studies are comparative, assessing the relative costs of two policies given a benchmark or target for pollutant level. This subsection will outline the methods and results of several such studies.

Jacobs and Casler [27] examine the social cost of implementing two nonpoint source pollution abatement policies. Effluent taxes are compared to uniform treatment or reduction. They note several previous arguments favoring effluent taxes as a policy instrument and come to similar conclusions in their empirical analysis of efficiency. However, their goal is to look at the distributional effects of the two policies.

Focusing on phosphorus discharge, the authors detail both the social costs and cost to farmers of reducing crop-production related phosphorus discharge into the Fall Creek watershed in central New York state. The analysis is conducted using an approximation of the proportion of phosphorus inputs entering the watershed and a linear programming model of agricultural production. Phosphorus reductions were modeled as shifts in crop rotations (e.g., substituting hay for corn). The net costs of these reductions are in the form of increased cost of purchasing feed from outside the area less the hay production cost differences as compared to corn. The results of the study indicate that effluent taxes have lower social costs, but incur a greater cost to farmers, raising questions about political acceptance and equity issues involved in implementation.

Cooper and Keim [11] study farmer adoption of a variety of water-quality-friendly land management practices. The practices are those identified by the USDA for the Water Quality Incentive Program (WQIP). The goals of the paper are to model the probability that a farmer not currently in the WQIP program adopts a practice (as a function of the incentive payment available) and to determine the number of acres enrolled given that a farmer joins the program.

The practices examined include integrated pest management, legume crediting, manure testing, split nitrogen application and soil moisture testing. Data is from the 1992 Area Studies dataset and from a contingent valuation survey distributed to respondents sampled in the Area Studies data. Two econometric models are presented. One to estimate adoption (by non-adopters) of the best management practices for which WQIP is available, the other to estimate the number of acres put into each practice by current WQIP participants.

The first model estimates farmers' willingness to accept payment in exchange for changing their land management methods. One problem the authors needed to overcome was the fact that the sample included only farmers who did not currently employ the practices in question. To deal with this, they estimated two sets of equations. The first models what they call the "sample selection" choice (whether or not a farmer actually participated in the WQIP) while the second models the "adoption" choice (the non-participating farmers' answer to the contingent valuation question).

A secondary goal of the research was to determine the acreage farmers might enroll in the practices. They were posed hypothetical questions about the amount of land they would choose to convert to using the WQIP practices. This is hampered by a potential source of bias because only those farmers answering affirmatively to the contingent valuation question were asked to complete the acreage enrollment section. To ameliorate this and the sample selection problem mentioned earlier, the authors devised a means of capturing all three relations in an extension of the Heckman procedure.

The main thrust of this paper was to determine farmers' willingness to accept changes in their land management in exchange for payment. At the time, WQIP incentive levels were set without any knowledge of farmers' "conservation supply," so to speak. Through estimation of their model, the authors offer a solution to this inefficiency. They are able to determine separate response relations for all five of the preferred practices. With this information, future programs may be better able to target levels of participation.

Peterson and Boisvert [46] develop a model of voluntary farmer participation in a policy designed to reduce agricultural pollution. The structure of the model is applied to simulate the effects in New York state corn production, and the results used to evaluate policy alternatives. The pollutant of interest is nitrogen applied as fertilizer.

Citing as motivation the lack of efficiency inherent in uniform policies, the authors proceed to outline a policy that allows abatement activities to vary by location. This is to be compared to a baseline or benchmark case of government command control, where individual regulations are assigned to each farmer. A predetermined emissions target is chosen to avoid the need to find the social cost of pollution. The goal is to design a self-selecting voluntary program that will achieve the same conditions as the baseline.

The results show that the payments needed for a voluntary program exceed farmers' cost of pollution control, that is, there is an additional cost to self-selection. Although these costs reduce the efficiency of the policy, they must be weighed against the cost and intrusiveness of implementing a command and control type policy. In addition self-selection can occur if the most productive group pollutes the least.

Khanna, et al. [36] compare the costs of several means of achieving a given level of pollution control. The pollution target is expressed in terms of expected levels, as regulations are assumed to only affect the deterministic portion of emissions. In addition to efficiency comparisons, the research also aims to examine the effect different policies have on agricultural production and consequently the amount of land under production. Comparisons are made based on numerical simulations.

Specific issues under study are the cost-effectiveness of alternative green payments relative to a least-cost pollution tax and the effects of these payments on the scale of aggregate agricultural production. The policies considered for pollution abatement are cost-share subsidies for technology adoption, input-reduction subsidies, and a combination of the two. In addition, two versions of each policy are analyzed: in one there are no restrictions on entry, whereas the other restricts participation to firms already operating at the time of policy implementation.

A micro-level discrete choice model is developed for the analysis. Land quality is allowed to be heterogeneous, and both production and pollution functions are specific to soil type and production technology. Pollution reduction takes place through a switching effect, intensive/extensive margin effects, and/or exit from production. The policymaker knows the distribution of soil types, aggregate pollution and input use and/or technology choices.

The numerical analysis is applied to irrigated cotton production in California's San Joaquin Valley. The input to be controlled is water and there are two types of irrigation technology, furrow and drip, with the latter being the costly conservation technology. The results indicate that a restricted combined green payment policy is the most efficient, and not far from the benchmark least-cost tax. The authors also found that most of the second-best policies under consideration were very close in efficiency to the benchmark.

Trading

In many ways, trading the right to emit a pollutant is just another policy tool. However, it has several unique characteristics that create issues not present with other methods of pollution control. A common topic is the choice of an optimal trading ratio, that is, the ratio at which nonpoint sources are allowed to generate pollution permits for point sources. There is also much discussion of implementation and monitoring issues.

Malik, et al. [39] address some shortcomings of other point-nonpoint source trading schemes analyses. In particular, they take issue with two common assumptions. The first of these is the assumption that nonpoint source loadings are deterministic, the second the assumption that nonpoint sources only differ in abatement costs and loading effects.

The authors argue that current recommendations and implementation of point-nonpoint source trading have established inefficient trading ratios. Ratio suggestions almost uniformly suggest that one point source unit pollution be equivalent to more than one nonpoint source unit.

A model is developed to determine appropriate trading ratios and the conditions that influence the ratio. The nonpoint sources generate pollution reduction by adopting a costly technology and face enforcement via random audits. The model captures both the uncertainty in the effect of the nonpoint controls on ambient pollution levels and the random nature of pollution loading.

The two types of uncertainty have independent effects on the optimal trading ratio; these effects can act in opposite directions. Ceteris paribus with respect to uncertainty, the curvature of the damage function determines the optimal ratio. Unfortunately, determining the optimal ratio has very high information requirements-the regulator needs to know both the damage function and the point sources' marginal abatement costs.

Horan [21] examines the issue of point/nonpoint source emissions trading. The goal of the article is to look at program design options in order to overcome problems in new and existing trading systems (e.g., low trade activity). Focus is on the choice of trading ratio, i.e., the rate at which nonpoint source abatement activities are allowed to generate excess permits for sale to point sources.

Expected nonpoint source pollution loadings are imperfect substitutes for point source loadings, so there is no basis for choosing a ratio of 1:1. Existing trading programs all have a ratio that exceeds this, ranging from 1.3:1 to 3:1. These ratios are usually justified by appealing to the existence of uncertainty associated with nonpoint source controls.

The author argues that there is a case for trading ratios below 1:1 based on economic theory. For a risk-averse society it would be important to have a lower ratio to encourage more nonpoint source reductions. The explanation for the current situation is that trading ratios as they exist now are designed to be politically optimal rather than economically optimal.

Via a political-economic model, the article goes into greater depth with regards to the issue of political/economic optimality, showing how differences in optimal trading ratios are due to risk perceptions.

Johansson (2002) [29] examines information asymmetries in the context of a point/nonpoint source trading scheme. In the framework presented, farmers misrepresent their abatement efforts when generating point source emission permits. This occurs due to imperfect but costly monitoring. The monitoring costs reduce the efficiency and effectiveness of policies.

The trading policies considered are compared empirically using simulations in a phosphorus-impaired watershed in southern Minnesota. Watershed data is used to estimate cost and benefit functions for restrictions on phosphorus discharge, and the policies are then evaluated in terms of realized social welfare. The results indicate that second-best policies can outperform first-best policies given that monitoring is costly. The analysis also shows that in the context of this model and watershed, trading programs significantly outperform uniform performance standards.

2.2.2 Physical Model Integration and Meta-modeling

While theory and consideration of policy options are essential, it is also important that realistic outcomes of policy be examined. For this reason many studies have paired physical models of pollution transport and concentration with economic policy models. In order to generate the types of inputs necessary for this sort of analysis, many researchers must rely on simulations from physical process models to build their economic models.[1] These can be very useful tools for policy evaluation and give a degree of realism to an analysis.

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[1] This is an example of using one model to estimate a separate economic model, or meta-modeling.

Helfand and House [19] consider the application of second-best policy instruments to encourage pollution abatement. The case is made in favor of these instruments over optimal instruments due to the latter's near-impossibility of implementation on any appreciable scale. The analysis proceeds in the context of a case study involving crop production in California. The pollutant is nitrate levels in groundwater.

The authors' primary goal is to tabulate and compare the cost effects of input taxes and a required input "rollback;" combinations of these over the two inputs (water and nitrogen fertilizer) are considered. By varying input levels, the Erosion/Productivity Impact Calculator (EPIC) physical model is used to generate "data" correlating input use, crop yields and pollution. Heterogeneity in soil type also exists, with one soil type being more productive in the sense of requiring fewer of both inputs. The less productive soil tends to leach more nitrogen in addition to increased input needs for similar yields.

The policy target was a 20% reduction in ambient nitrate levels in groundwater. Six uniform policies were considered: a uniform rollback on nitrogen application, a uniform tax on both inputs, a single tax on each of two inputs separately and an input application standard enforced on each of two inputs separately. The physical effects of policy were also evaluated using EPIC.

As a benchmark, the authors calculated the costs of implementing a first-best set of taxes on both inputs that varies by soil type. Three of the six second-best policies were very close (within 3%) to that benchmark in terms of costs, suggesting that uniform policies similar to those considered do not give up much in terms of efficiency.

Larson, et al. [37] present essentially the same model as Helfand and House with a more general theoretical development. Beginning with a field-level model, they determine conditions for the smallest deadweight loss tax policy that meets an environmental standard.

Citing jurisdictional difficulties in applying taxes to multiple inputs, the authors proceed with an examination of taxes on a single input. For the application, area and crop they find that the most efficient single tax policy is a water tax. The welfare cost of a water tax is not large, especially when compared to a nitrogen-only tax.

Vatn, et al. [59] introduce a large and complex interdisciplinary environmental modeling system. In terms of economic analysis, the model's ultimate purpose is to compare the effects of input policies with those of practice-change policies. Owing to the scale of the overall model, the study is able to cover nitrogen leaching, soil loss and phosphorus loss via simulation of simultaneous loss-creating processes.

The authors argue that modeling multiple effects of pollutants is important, especially at lower pollution levels, and that changes in practices also have effects that should be modeled integrally. In the particular case of phosphorus, they suggest that plant cover and tillage practices may be more important than nutrient input/output relationships.

Application of the integrated model in Norway indicates that catch- crop scenarios are the only policies with a substantial effect on combined nutrient loadings. Outside of this result, a nitrogen tax was found to be effective on emissions in areas with dairy production.

Ribaudo, et al. [51] examine the problem of nitrogen loading reductions in the Mississippi river basin and the resultant hypoxic conditions in the Gulf of Mexico. The analysis includes a comparison of the cost effectiveness of two approaches: fertilizer use reductions and wetland restoration. Of particular concern to the authors are larger economic effects outside of the policy region, e.g., commodity prices, agricultural production, erosion, et cetera.

The U.S. Agricultural Sector Mathematical Programming (USMP) model is used to evaluate market changes due to policy imposition. A spatial and market equilibrium model, it predicts how changes in farm/resource/environmental/trade policy, commodity demand, and technology will affect the supply of agricultural output, commodity prices, and use of agricultural inputs.

Nitrogen reduction scenarios of 10% through 60% are compared to wetland restoration scenarios of varying scale. The USMP model is used to trace out the social marginal cost for each policy. The authors find that for lower levels of nitrogen loss reduction, mandating a decrease in fertilizer use is superior to wetland restoration. However, above a certain level of nitrogen loss reduction, wetland reduction is predicted to be the more efficient means of achieving a particular goal. Unfortunately, the paper did not address scenarios involving combinations of the two policy types.

Johansson (2004) [30] assembles a modeling system that combines heterogeneous productivity and nutrient loading potential in agricultural land. Using a meta-model and frontier analysis, phosphorus abatement costs are constructed for farms. The resulting system is used to evaluate policies aimed at reducing phosphorus discharge by 40% in a Minnesota watershed.

The physical model used to generate nutrient loads and crop yields is the Agricultural Drainage And Pesticide Transport (ADAPT) model, which uses as inputs crop choice, residue management, fertilizer application, and weather variables. The watershed itself is separated into 18 "representative farms" which are land-type areas delineated by nine soil types with two location categories each; the categories are based on the farm's distance from a waterway.

Production on each farm/unit is simulated over 14 different combinations of practices (practices vary by crop rotation, tillage, and fertilizer application method and level) over a 50-year period. For each combination, abatement relative to a baseline practice set is calculated, as is the cost differential for practice changes from the baseline. To achieve in-stream loading estimates, a simple sediment delivery rate (proportion of applied phosphorus reaching the waterway) is used, one for each location category.

The policy objective is a 40% reduction in in-stream phosphorus loading. Four scenarios are considered: a percentage uniform reduction by each unit, retirement of land beginning with the least productive, retirement of land beginning with the most phosphorus loading potential, and heterogeneous abatement levels at each unit to achieve reduction at the lowest cost. Compared to the lowest cost scenario, the uniform reduction is next in cost, followed by highest loading potential and then lowest productivity land retirement. The suggestion is made that under the Conservation Reserve Program it may be most efficient to target land with high phosphorus loading potential before less-productive land.

2.2.3 Watershed Case Studies and other work

Physical models can provide excellent flexibility and are very attractive from an analytical point of view, but it is also important to work with more real, concrete evidence of policy effects. Some of this type of work is retrospective, while others are recommendations for future policy based on observations and measurements. It is also illuminating to look at case studies that, while not utilizing advanced modeling techniques, provide the details of specific water quality impairment in a region. Site-specific information and predictions are crucial to the success of any program seeking to ameliorate problems caused by nonpoint source pollution.

Johnsen [31] makes use of actual field experiment data and enumerates several means of producing reductions in phosphorus loading in waterways, concentrating on agricultural production in Norway. He considers two categories of phosphorus abatement: reductions in levels of erosion and reductions in the amount of phosphorus available for runoff. This can occur through a variety of measures and practices.

The abatement measures discussed are a fertilizer plan requirement, a tax on phosphorus content, manure timing restrictions, contouring, grassed waterways, tillage restrictions, and land retirement (cropland to woodland). The phosphorus-abating effects of each measure are based on either field-experiment-based models or direct field experiments conducted over the course of four years in several Norwegian sites.

Economic data comes from a national survey of farmers and the analysis appears to be essentially an accounting of costs of practice changes. The author concludes with recommendations for future policy, including a very large (150%) tax on phosphorus inputs, a ban on manure spreading outside of the growing season and a ban on fall tillage.

"Fox-Wolf Basin 2000," a non-profit group of watershed stakeholders in Wisconsin's Fox-Wolf River Basin, commissioned a report from Resource Strategies, Inc. [50] to explore the possibilities for reducing the level of phosphorus within the watershed. The goal of the project is to assess the effects of a point-nonpoint source trading program in the presence of an increased effluent phosphorus standard for point sources. Compliance cost surveys were sent to all point sources, with a favorable response rate from municipal waste treatment plants but only one response from the numerous industrial point sources. Because of this, the latter are excluded from the study. Nonpoint sources in the watershed include agricultural operations and urban storm water runoff. However, due to the paucity of data on urban runoff and agriculture's large phosphorus contribution, only changes in agricultural practices are considered as a means of reducing surplus phosphorus.

Thirteen municipal wastewater treatment plants provided abatement cost estimates, accounting for nearly 84% of the phosphorus delivered to the basin by treatment plants. It is noted that these are internal estimates, in some cases quite rough approximations. The cost estimates vary from as low as $1/lb. of phosphorus reduction to $500/lb. This large variance alone suggests that there could be a significant role for point-point source trading if a new standard were to be imposed.

Two types of phosphorus-reducing practices are used in cost calculations for agricultural operations. One, termed "upland sediment measures" includes varying degrees of conservation tillage, alternative crop rotations and buffer strips. The second, "barnyard practices," is made up of clean water diversions, concrete barnyards and manure storage pits.

County watershed technicians working for land conservation departments were surveyed to provide cost estimates for the best management practices identified. They selected a number of operations from their respective areas which are believed to have good potential for reducing phosphorus output by changes in management practices, but which are also not participating in a state-sponsored cost sharing program for green improvements. For practices which are already subsidized by the state (conservation tillage and nutrient management) calculations are based on the actual payments available. In addition to the costs of encouraging changes in land management, estimates of administrative costs are also elicited. These cover a huge range, from \$60 to \$800 per operation to assess possible gains in phosphorus reduction and the means to achieve them. The estimated control costs themselves are between \$3/lb. to \$117/lb. of phosphorus, with an average cost of approximately \$26/lb.

Dramatic differences in abatement costs across the two types of polluters indicates a welcome role for trading. Due to the fact that the pollution is not uniformly mixed, it will likely be necessary to divide the basin into three trading areas: the Upper Fox, Lower Fox and Wolf basins. Unfortunately, when the numbers for subdivisions of the basin are examined, only the Lower Fox displays a significant disparity in control costs between point and nonpoint sources. While trading may still be possible in the other two basins, there could be problems encouraging all parties to participate.

This report only considers scenarios in which point sources pay for reductions in agricultural contributions in order to exceed imposed emission limits. It would be very interesting to consider policies where restrictions are imposed on agricultural practices and farmers allowed to trade amongst themselves or even buy the privilege to pollute from point sources who are under-emitting. As evidence shows that farmers are the primary polluters in this and other watersheds, it is more efficient if they face controls similar to those imposed on point source polluters.

Parker [45] presents an overview of Maryland's 1998 Water Quality Improvement Act and its effects on the agricultural sector in the Chesapeake Bay area. The regulations put in place are possibly the most restrictive nonpoint source pollution laws in the country. A goal of the paper is to look at the distributional effects of this policy.

The genesis for the new law was a summer 1997 explosion in growth of a microbe that resulted in fish kills and health problems for humans exposed to the water in the bay. The reason for the large population of this microbe was a confluence of water temperature, salinity and an excess of phosphorus. Producers contributing to the phosphorus problem are poultry producers and crop growers in the area. The latter acquire manure from the former to apply to their fields, and likely were applying all that was available.

The new regulations require crop growers to have and implement nutrient management plans. Poultry producers must account for and dispose of the excess that crop growers can no longer apply. Three means of manure disposal or "alternative use" are suggested: generate energy, compost, or transport it out of the area.

Distribution of the policy effects is demonstrated to depend on the alternative use to which the manure is put. Composting and energy production both result in the costs being borne by poultry producers. The effect of transporting the manure outside the area is dependent on the strength of the poultry litter market, but is stated to be most likely in favor of crop growers. There are a few cost mitigation programs in place that will ameliorate or minimize the negative effects to either group affected by the regulations.

While economics-related in nature, a report by Faeth [14] is essentially a summary of three case studies. It contains a very large amount of information, from a broad discussion of the history of pollution mitigation and the Clean Water Act to the minutiae of each watershed under study. The nutrient under study is phosphorus, the source of the most impairment in freshwater areas similar to the three watersheds in the study, located in Michigan, Wisconsin and Minnesota.

As a document aimed at a wide audience, the details of the economic and physical models used to conduct the analysis were not presented. There are a number of interesting observations and questions generated by the investigation and discussion presented.

To begin with, a good case is made for the necessity of action to reduce nutrient loadings from their present level. The Michigan watershed (Saginaw Bay) adjoins the Great Lakes where 97% of the watersheds are considered impaired.

Evidence is presented to demonstrate the considerable role agriculture plays in current watershed impairment, and an inclusive list of the results of excess phosphorus: reduced water transparency, taste/odor/treatment problems, and oxygen depletion leading to fish kills and possible loss of desirable fish species. Compounding this is the fact that approximately 60% of the phosphorus used is not used by the crops on which it is applied.

There is also a lengthy discussion of the contribution of animal manure to phosphorus loading. Of note from this section is that consumers' increased preferences for poultry over beef have led to greater phosphorus output due to avian waste having a higher concentration per unit than cattle manure. The author makes the observation that "wastes from animal operations ware not controlled with anywhere near the same rigor as human wastes, even though, in the United States, waste from livestock is about 130 times greater than that from humans."

In introducing the concepts and mechanics of point/nonpoint source trading, reference is made to closed trading programs which usually include a mandatory maximum emission level and open trading programs where participation is typically voluntary, with participants generating "credits" to be banked/traded/used to meet regulation limits. Several examples of pilot programs are cited; particularly interesting is the Tar-Pamlico Basin of North Carolina. There, a group of point sources trade among themselves to stay under a cap. If they must exceed the cap, they can pay into a fund supporting a program encouraging farmers in the watershed to adopt nutrient-reducing practices.

An important benefit of a more balanced (vis-a-vis point and nonpoint sources) bearing of pollution mitigation responsibility could be substantial cost savings. The study indicates that reduced background pollution from agriculture could alleviate the need for advanced (and more expensive) water treatment. EPA estimates a net savings of $15 billion in these advanced treatment costs.

Although the particulars of the economic model were not described, an accounting of the menu of technologies allowed for both point and nonpoint emitters is provided. For point sources, there were six options for phosphorus output reduction: no treatment, standard chemical treatment, maximum chemical treatment, chemical removal with filtration, biological removal, and biological removal with filtration. For nonpoint sources tillage was the dimension of choice with five possible plans: moldboard plow, conventional till, mulch till, no-till, and ridge till. Only one choice dimension per emitter type appears to have been employed in the model.

As a baseline for the different loading scenarios, a least cost (first best) solution was calculated, to which all of the scenarios could be compared. Four policy scenarios were considered: a point source performance requirement, subsidies for "greener" agricultural practices, a point source requirement with trading and a trading program with subsidies.

In every case, increasing point source requirements was the highest-cost option, while a trading program with subsidies dominated the other three policies. This was uniformly the result across all three case studies. Cost of phosphorus reduction ranged from under $3/lb. to nearly $24/lb. in the worst case of a point source performance requirement. Obviously, tightening controls on point sources alone will be quite expensive. Absent are the particulars of how these trading markets would actually function. While it is understood that this is not a market simulation but rather a cost accounting exercise, there is a broad spectrum of issues that need to be addressed in comparing policy options. There are administrative and enforcement costs as well as the need for a location or clearinghouse for the market. Who or what can fill that role is an important question that remains un-addressed. Also missing is any mention of possibilities for nonpoint-nonpoint trading; for example, a market where permits to apply phosphorus are traded only among nonpoint emitters. One could even envision a two-tiered emission standard, one for point and one for nonpoint sources, chosen to optimize loading reductions per dollar in abatement costs.

2.3 Stochastic Production

The agricultural economics literature has given much attention to methods of production estimation involving input-related risk. There are several approaches to the problem of modeling risk via stochastic production functions, falling into two general categories. The first category is those modeling efforts that specify a production relation with technology that captures some risk aspect. Simpler versions of this method only vary the mean effect on yield, while more recent and useful approaches allow input use to affect mean and variance of output. The second category contains non-parametric methods that model the moments of the production output distribution as functions of the inputs, with the goal of capturing aspects of the yield distribution

2.3.1 Specified Technology

A seminal paper on the subject of the first category is Just and Pope [34], in which the authors develop a production function that allows input use to affect both a deterministic and stochastic production component while eliminating some of the drawbacks of earlier models. This paper is a theoretical exploration of which features are desirable in a production function incorporating risk, and which production functions are appropriate given these features. In particular, the authors formulate eight postulates they feel should be satisfied for a production function to be useful and appropriate to this type of modeling. Several of these postulates are standard assumptions for deterministic production functions or correspond to deterministic assumptions. A brief summary of these postulates follows, using the authors' notation of y for production output, X_i for input i, and ε for the stochastic disturbance with the general form of the production relation $y = f(X, \varepsilon)$.

1. Positive production expectations: $E[y] > 0$.
2. Positive marginal product expectations: $\frac{\partial E[y]}{\partial X_i} > 0$.
3. Diminishing marginal product expectations: $\frac{\partial^2 E[y]}{\partial X_i^2}$.
4. A change in the variance for random components in production should not necessarily imply a change in expected output when all production factors are held fixed: $\frac{\partial E[y]}{\partial V(\varepsilon)} = 0$ is possible.
5. Increasing, decreasing, or constant marginal risk should all be possibilities: $\frac{\partial V(y)}{\partial X_i} \leq$ *or* ≥ 0 possible.
6. A change in risk should not necessarily lead to a change in factor use for a risk-neutral producer: $\frac{\partial X_i^*}{\partial V(\varepsilon)} = 0$ possible, where X_i^* is the optimal level of input i.
7. The change in the variance of marginal product with respect to a factor change should not be constrained in sign *a priori* without regard to the nature of the input: $\frac{\partial V(\partial y/\partial X_i)}{\partial X_j} \leq$ *or* ≥ 0 possible.
8. Constant stochastic returns to scale should be possible: $F(\theta X) = \theta F(X)$ for scalar θ.

These eight postulates are used to evaluate and reject several production function specifications. An alternative to these is proposed, one which satisfies all of the postulates. This alternative makes use of an additively separate stochastic input-dependent function. The general form of this production function is

$$y = f(X) + h(X)\varepsilon, \text{ with } E[\varepsilon] = 0 \text{ and } V(\varepsilon) = \sigma. \tag{2.1}$$

where $h(X)$ is the stochastic input-dependent function.

The remainder of the paper is concerned with econometric estimation of this style of production function. A four-step estimation procedure is suggested, as is a discussion of the consistency and efficiency of the resulting estimators.

An application of the above stochastic production model approach appears in Just and Pope [35]; much of this paper reviews the theoretical discussion from Just and Pope [34] and applies it to the problem of modeling nitrogen fertilizer yield response in corn and oats. The estimation procedure is described in more detail and with reference to the chosen specification.

Two alternate function forms for the model, a Cobb-Douglas and a translog function, are applied to the data. The data is from controlled experiments on corn and oat production; the dependent variable being per bushel yield and the independent variable is nitrogen fertilizer application. The experimental nature of the data allows other variables to be held constant across field plots. It is assumed that variablility in effects from plot to plot are negligible due to their proximity.

For both corn and oats, results from estimation of the Cobb-Douglas specification finds nitrogen fertilizer to be a risk-increasing input. Estimation results of the translog specification, however, indicate that the marginal effects of fertilizer on yield variability depend on the level of fertilizer rates. Also of note is that for both crops the elasticity for variability is lower than that for the mean.

Anderson and Griffiths [2] make use of the modeling structure introduced by Just and Pope, applying it in a stochastic programming setting of efficient resource allocation under risk. They define the utility-maximization problem as a function of net financial return R, $U(R)$:

$$R = p_y Y - \sum p_i X_i - F$$

with Y as physical output, X_i factor inputs, F fixed cost, and the p's denoting relevant prices; the latter are assumed nonstochastic and known. Under the assumption that the expected utility can be expressed in terms of the mean and variance of R, the first order conditions for the optimum are laid out:

$$p_y \frac{\partial E[Y]}{\partial X_i} - redqp_y^2 \frac{\partial V(Y)}{\partial X_i} = p_i$$

with $redq$ measures the decision maker's trade off between mean and variance of returns. The authors choose a utility function with constant absolute risk aversion, the negative exponential: $U(R) = -\exp(-\theta R)$. They note the restrictive nature of this function, but cite its widespread use in both empirical and theoretical work, as well as some advantageous mathematical properties.

Love and Buccola [38] use these same preferences in their study of corn production under risk. They develop a model in the Just-Pope framework that accomplishes an important goal: joint estimation of risk preferences and technology. Of key interest is the ability of this modeling approach to provide consistent estimates of both factor demand relations and the relationship between inputs and output.

The authors choose a three-input Cobb-Douglas version of the model in equation (2.1), i.e. $f(\cdot) = AX_1^{a_1}X_2^{a_2}$ and $h(\cdot) = BX_1^{b1}X_2^{b2}$. Using their chosen risk preferences ($U(\pi) = -\exp(-\lambda\pi)$) and defining a profit function based on the technology specified, the farmer's optimization problem is constructed and first order conditions for its solution obtained. The structure of these conditions is such that closed-form solutions do not exist. This requires simultaneous estimation and some assumptions on the role of error terms in estimating these relations. The choice is made to append additive errors to the implicitly defined input demand relations, the assumption being that they represent random failures in optimization. In order to jointly estimate input demands and the production relation, the heteroscedasticity inherent in the technology specification is removed through manipulation of the production relation. This causes slight complication in estimation and recovery of parameters but is necessary to ensure consistent estimates.

The model is estimated using a nonlinear three-stage least squares procedure on Iowa corn data from three regions with three fertilizer inputs (nitrogen, phosphorus, and potassium). The resulting estimates are compared to those obtained using a standard Just-Pope model and a distribution-based model from Nelson and Preckel [42] via yield elasticities of mean and standard deviation with respect to the inputs. There is significant variation in these results, particularly in the direction of input effects on yield variation. This suggests that risk effects are possibly more difficult to estimate accurately than mean effects.

2.3.2 Moment-based Methods

Antle (1983) [4] seeks to move beyond the restrictions placed on yield distribution modeling due to the specification of a production function. He presents a more flexibile representation of stochastic technology that is based on the moments of the distribution of output. The goal is to allow modeling in which not only heteroscedasticity is possible, but also heteroskewness, heterokurtosis, and varying behavior in higher moments. Empirical evidence is presented that second, third, fourth, and higher moments may be functions of production inputs.

The motivation behind this approach is that the probability distribution of output is a unique function of its moments, i.e., the moments are the determining characteristics of a distribution. Implicit in this is that the behavior of firms under stochastic production is defined by the relationship between inputs and output moments.

The goal is to develop a production model that is completely general; that is, it does not impose arbitrary restrictions or structure on the moments as is done in models which specify a production technology. A drawback to this approach is that it focuses solely on stochastic structure and does not provide a useful means of working with deterministic components of production. Inputs do have an effect on output, but any specification of an input demand function would implicitly impose a production technology and represent exactly the type of restriction this method seeks to avoid.

A generalized least-squares method is used to obtain estimators of the moments; this is applied to a small milk production dataset. The results indicate that the first through third moments of production output are significant.

In further discussion and application of the moment-based approach, Antle [5] uses non-experimental farm production data to estimate risk attitudes. The study assumes a stochastic profit distribution that is conditional on input levels, and a utility function dependent on profit and a vector of parameters representing individual risk attitudes.

Moments of the profit distribution are assumed to be functions of the inputs, and a system of optimality conditions (first-order conditions for a maximum) is constructed based on this assumption and the addition of an additive error term. The latter is included to account for the approximate nature of the first-order conditions and to allow for random deviation from the optimal response. This is essentially the same type of assumption made in Love and Buccola's modeling of input demand equations in their primal system.

The moment-based model is applied to field-level data on Indian rice production, and the first through third moments are found to be significant. Significant variability in risk attitudes among the population were found, ranging from risk neutral to very risk averse.

Nelson and Preckel [42] seek to apply the moment-based concepts introduced by Antle, but improve efficiency of estimates by specifying a distribution function for output. They choose a conditional Beta distribution due to its ability to represent a skewed, bell-shaped density with a relatively small number of parameters. Application of the model is made to corn yield response to fertilizer inputs.

Rather than model the moments of the distribution directly as functions of inputs (the approach taken by Antle), the Beta parameters α and β are assumed to be log-linear functions of the inputs, $\alpha(x)$ and $\beta(x)$. Specific functions of α and β define all of the moments of the distribution. The first three moments of output are estimated using a maximum likelihood procedure.

Farm-level corn yield and input data from the Iowa Agricultural Experiment Station is used to estimate the distribution parameters, with nitrogen, phosphorus and potassium available as inputs. Soil variables were also available, and the data was separated into several subsets by region. The results from the estimation suggest that nitrogen and phosphorus tend to uniformly increase mean, variance and (postitive) skewness of yield in general, while the effect of potassium on the distribution is not consistent across regions.

2.4 Physical Watershed Modeling

The physical water quality model used here, SWAT, has been applied in several recent papers that seek to combine environmental and economic modeling techniques. A variety of approaches have been developed at several levels of detail. Some make use of SWAT to directly estimate or simulate water quality effects, while others use SWAT indirectly by calibrating other physical models to SWAT and observing environmental quality changes via the former. Economic modeling systems range from farm-level models to regional and national models.

Whittaker, et al. [60] uses point observations from farm-level survey results to compare two pollution abatement policies. The focus is on nitrogen inputs in the Columbia River Basin where safe nitrate limits are regularly exceeded. The two policies under consideration are an input tax on nitrogen and a so-called command and control policy that reduces nitrogen application by 25% at each point.

The economic model used, data envelopment analysis, is a linear programming framework that allows construction of a best management practice frontier over which a criterion can be evaluated. Profit maximization was used as the objective, and the solution for each point is obtained under the two competing policies. It is assumed that all nitrogen applied is in the form of anhydrous ammonia, applied only once before seeding.

To work with the watershed scale requirements of SWAT, a means of distributing the farm-level point data across the watershed is needed. This is obtained through estimation of the assumed underlying surface of farm-level data and properties of the sample area. The authors make use of the averaged shifted histogram estimator for this. Each subbasin (8-digit Hydrologic Unit Code in this case) in the SWAT setup is assigned the mode of the estimated nitrogen application surface for that subbasin.

The reduction policy of 25% is chosen as it apparently gives SWAT output results roughly equivalent to that of a 300% input tax. This tax level is the lowest that will induce reduced fertilizer application at every farm in the sample. Based on the results of the economic analysis comparing the two policy alternatives, the authors conclude that the tax is more efficient. However, depending on conditions, the policies could have comparable performance.

On a smaller watershed scale but using operation-level data, Osei, it et al. [44] use a representative farm model interfaced with SWAT and another physical model to examine costs associated with changes in manure application in a watershed. The watershed is located in an area of Texas with a large concetration of dairy producers and the nutrient of interest is phosphorus. The aim of the analysis is to estimate the costs of a change in manure application practice; specifically, incorporating solid dairy manure rather than broadcasting it.

The economic model is an optimization system designed for use in analyzing livestock and poultry operations. It is designed to capture farm-level economic impacts of changes in practices. The environmental model is the field-level Agricultural Policy Environmental Extender (APEX), a multi-field version of EPIC. APEX predicts edge-of-field sediment and nutrient losses, which in turn are used to construct inputs for SWAT.

Three application scenarios are considered, one where manure is applied based on nitrogen needs of the crop, and two where application is made based on phosphorus needs of the crop. In the latter case the two rates vary depending on whether or not organic phosphorus is included in determining available phosphorus. For each scenario the environmental and economic results are tabulated under two separate assumptions. In one, manure is broadcast on the fields, and in the other it is incorporated or plowed into the soil.

With incorporation, the reduction in phosphorus loss at the edge-of-field level ranges from around 20% to 40% relative to no incorporation depending on the application rate scenario. The economic impact of a change in practices to manure incorporation is found to be very small, in the range of 2% to 3% of net returns.

Qiu and Prato [47] conduct an analysis of practice changes in a watershed on a scale similar to Osei, *et al.*, but aggregate economic data at a larger scale. The goal is to model the impact of riparian buffers on in-stream concentration of atrazine jointly with the watershed-wide economic impact of changes in land allocation.

SWAT does not allow for placement of buffer strips, so a simple downward scaling of output results is supposed to simulate the usage of buffer strips. The watershed is populated with 37 different "farming systems" differentiated by crop rotation, tillage method, fertilizer application level (discrete: low, medium, high), and pesticide application level. There is also one unique system based on a grass with no chemical use that is a proxy for land in the Conservation Reserve Program (CRP). The allocation of land to each of these systems within the watershed determines the outcomes in both SWAT and the economic model.

The objective function for the economic model is total watershed net returns. A mathematical programming model is used and is based on the Cost and Return Estimator (CARE) enterprise budget calculator. The goal is to select an allocation of land use resulting in efficient atrazine abatement at each subbasin outlet such that net returns are maximized. Five levels of atrazine concentration are considered, and SWAT results yielding those levels are used as constraints.

Baseline allocations are established with the "worst" management practices and no riparian buffers, and associated with a baseline level of net returns. The optimal allocations involve only 5 of the 37 systems, and are cataloged both with and without buffers. To obtain the "value" of the buffers at each abatement level, the net returns with and without buffers are compared. This yields a gross value of the buffers; subtracting the opportunity costs of the land used for buffers (put into CRP, for example) allows calculation of a net value. If the cost of maintaining the buffers is below the net value, they are a cost-effective means of achieving the given atrazine abatement level.

Qiu and Prato [48] follow up on the above model by examining variations in riparian buffer characteristics across sub-basins. A linear regression model is estimated to assess the effect several buffer attributes have on its value as measured above. Using GIS data several characteristics are identified: stream length, channel slope, average land slope, percentage of cropped land and some soil attributes. Of the characteristics, only stream length and the percentage of cropped land had a positive effect on value. Others either had negative effects or were not significant.

Moving to a much larger scale, Atwood, *et al.* [6] demonstrate techniques necessary to disaggregate a large sector model for interface with SWAT on a statewide or nationwide basis. The authors' interest is in environmental and economic policy assessment with the analysis centering on the introduction of a new crop variety and its effects.

The economic model used is the Agricultural Sector Model (ASM), a mathematical programming framework that works at the state, regional, national and international levels. It determines a market equilibrium and the resulting effects on both resource use and prices. Effects of policy changes can be seen via a change in equilibrium.

A key step in conducting the analysis is the bridging of data needed for economic and physical modeling. This data is collected over different spatial units and raises several issues in how it can be aggregated or disaggregated. SWAT deals with data at the subbasin level, but ASM uses data based on much larger regions. The solution followed by these authors is to disaggregate ASM data to the county level based on information from the Census of Agriculture, National Resources Inventory and County Crops Data. Once the data is disaggregated to the county level, it is then aggregated to the subbasin level according to county surface contribution to each subbasin.

The economic model is applied jointly with SWAT runs on a large portion of Texas. The scenario examined is one in which a new crop variety is introduced. SWAT results indicate both improvements and worsening of water quality indicators depending on subbasin location. Economic effects include benefits for consumers, losses for producers (particularly those outside Texas) but a net gain at both U.S. and world levels.

Atwood, *et al.* [7] again apply ASM and SWAT jointly in pursuit of a more specific water quality policy scenario. They seek to quantify the costs of reducing nitrogen use in the Upper Mississippi River Basin. Excess nitrogen from the corn belt is cited as a major contributor to the hypoxia problem in the Mississippi outlet.

Using the EPIC model, the analysis calculates a specific reduction in corn yield associated with nitrogen application reductions. Simulating decreases in nitrogen application provides input for both SWAT and ASM and can be compared to a baseline in which there is no nitrogen reduction. Two levels of "nitrogen stress" are examined, 5% and 10%. The 10% N-stress level resulted in an approximate 5% reduction in nitrogen loads at the Mississippi River outlet according to SWAT simulations.

The net economic effect of the two policies provides an interesting insight into the interaction of yields, nutrients and profitability. Due to the commodity price effect, the 10% N-stress level policy had a smaller loss in net profits than the 5% N-stress level, -$16.4 million versus -$7.4 million.

3. FIRM LEVEL ECONOMIC MODEL

In this chapter the derivation of the economic model used to simulate and evaluate policy options is presented. The specification is explored and estimation results appear in Chapter 4. The first step in developing a modeling system to study alternative policies regarding nitrogen and phosphorus fertilizer use is to estimate a firm level production model that captures the key tradeoffs between nitrogen application, phosphorus application, and profitability.

3.1 Introduction

There are several requirements for a model that will allow proper interfacing with the SWAT physical water quality model. The primary need is that the model provide estimates of nutrient application rates that can change according to the abatement policies chosen. In addition, a means of comparing the policies in terms of the economic effects on producers is useful. An ability to measure the distribution of returns in the watershed to nutrient application under the policies will accomplish this, as the change in returns associated with each policy relative to the status quo can serve this purpose. A field-level model is sufficient as long as aggregations to the watershed level are possible.

The unit of analysis is a single firm or farm which maximizes expected returns from nutrient application through its choice of inputs, given location-specific environmental characteristics, input prices and the output price. Farmers are assumed to be risk-neutral . The inputs focused on in this study are two commercial fertilizers components which are heavily applied on corn crops: nitrogen and phosphorus. The following sections cover the modeling approach in detail.

3.2 The Farmer's Problem

The general econometric model used here is based on the heteroskedastic model first proposed by Just and Pope [35]. The farmer is assumed to maximize returns to fertilizer application, given some site-specific characteristics which include a general soil measure and relavent prices. The general form of the farmer's problem is

$$\max_{x} E[\pi(x, z)]$$

with x denoting inputs and z site characteristics.

A graphical representation of the relation between yield mean and variance appears in Figure 3.1. Lower fertilizer applications result in lower yields, but with less variability in those yields and the associated returns, representing heteroskedasticity in inputs. This is due to the existence of a base yield for most land; that is, at low levels of fertilizer input, yields tend to show little difference across farms. In these cases, fertilizer levels are the limiting factor for yield rather than site-specific characteristics. Conversely, higher levels of fertilizer application lead to higher yields on average, but numerous vagaries in weather, soil, land/crop management and other factors result in a wider spread of yield outcomes. Put another way, crops are receiving nutrients at or above their biological needs, and are limited by variables other than nutrient availability. Farmers applying higher levels of fertilizer are choosing input levels that will result in yields that are higher on average, but which are less likely to be in a given range of the mean yield for those fertilizer application levels.

The yield relation employs a Cobb-Douglas production function for both the mean and variance component. This choice of production technology requires the estimation

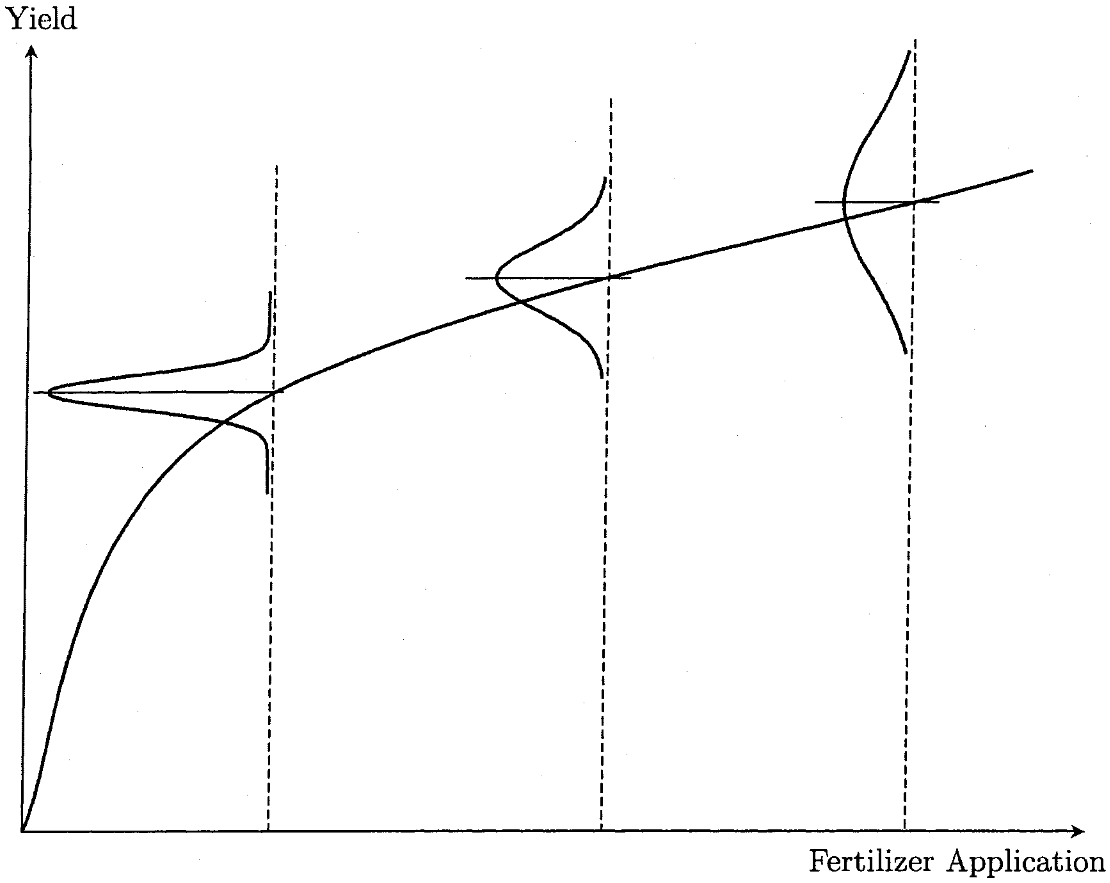

Figure 3.1 Relationship between yield mean and variability

of a relatively small number of parameters, an important consideration when limited instrumental variables are available. With the two inputs being considered here, the production technology is

$$y \;=\; Ax_1^{a_1}x_2^{a_2} + Bx_1^{b_1}x_2^{b_2}\varepsilon \tag{3.1}$$

where y is corn output measured in bushels per acre, x_1 is pounds per acre of nitrogen applied, x_2 is pounds per acre of phosphorus applied, A,B, a_i, b_i $(i = 1,2)$ are parameters to be estimated, and ε is a disturbance term distributed N(0,1). This imposes constant returns to acreage, which seems reasonable if it is assumed that farmers have already incurred most of their large capital costs (e.g., machinery) in choosing to be in production. With this construction and specific placement of the disturbance term, the inputs influence both the mean and variance of yield response. Specifically, the yield mean depends on the first term,

$$\begin{aligned} E[y] &= E[Ax_1^{a_1}x_2^{a_2}] + E[Bx_1^{b_1}x_2^{b_2}\varepsilon] \\ &= Ax_1^{a_1}x_2^{a_2}, \end{aligned}$$

and the variance depends on the second,

$$\begin{aligned} \text{Var}(y) &= \text{Var}(Ax_1^{a_1}x_2^{a_2}) + \text{Var}(Bx_1^{b_1}x_2^{b_2}\varepsilon) \\ &= B^2x_1^{2b_1}x_2^{2b_2}\text{Var}(\varepsilon) = B^2x_1^{2b_1}x_2^{2b_2}. \end{aligned}$$

With these specifics, the farmer's problem can be expressed as

$$\begin{aligned} &\max_{x_1,x_2}\left(E[(p(Ax_1^{a_1}x_2^{a_2} + Bx_1^{b_1}x_2^{b_2}\varepsilon) - r_1x_1 - r_2x_2)]\right), \text{or} \\ &\max_{x_1,x_2}\left(pAx_1^{a_1}x_2^{a_2} - r_1x_1 - r_2x_2\right), \end{aligned} \tag{3.2}$$

where r_1 and r_2 represent input prices, and p represents the output price.

3.3 Solution to the Farmer's Problem

The first-order conditions for interior solutions to (3.2) are

$$\begin{aligned} Apa_1x_1^{a_1-1}x_2^{a_2} - r_1 &= 0 \\ Apa_2x_1^{a_1}x_2^{a_2-1} - r_2 &= 0 \end{aligned}$$

which simply state that the farmer chooses x_1 and x_2 such that value marginal product of each input is equated to the price of the input. These yield the relations

$$\begin{aligned} x_1 &= x_2\frac{r_2a_1}{r_1a_2} \\ x_2 &= x_1\frac{r_1a_2}{r_2a_1} \end{aligned}$$

which together lead to input demand expressions

$$\begin{aligned} x_1(r_1, r_2, p) &= \left(\frac{r_1}{pAa_1} \left(\frac{r_1 a_2}{r_2 a_1} \right)^{-c_2} \right)^{\frac{1}{a_1+a_2-1}} \\ x_2(r_1, r_2, p) &= \left(\frac{r_2}{pAa_2} \left(\frac{r_2 a_1}{r_1 a_2} \right)^{-c_1} \right)^{\frac{1}{a_1+a_2-1}} . \end{aligned}$$

To jointly estimate these relations, it is assumed that there are some random errors associated with nutrient levels. These could take the form of measurement error in the data or several other factors outside of prices that might influence the application decisions.

One factor that influces the application decisions is soil quality. Incorporated into the constant "A" term is a site-specific measure of soil quality. This exogenous variables can be introduced into the equations corresponding to the first-order conditions through the formulation of the farmer's problem rather than simply assuming that they enter in some unknown fashion. In estimation of the model presented here this term is

$$A = \alpha_0 + \alpha_1(CSR),$$

where CSR is the soil Corn Suitability Rating associated with the farm location.[1] In the following discussion this decomposition is supressed for notational convenience. The estimable version of the first-order conditions is then

$$x_1 = \left(\frac{r_1}{pAa_1} \left(\frac{r_1 a_2}{r_2 a_1} \right)^{-a_2} \right)^{\frac{1}{a_1+a_2-1}} + v_1 \tag{3.3}$$

$$x_2 = \left(\frac{r_2}{pAa_2} \left(\frac{r_2 a_1}{r_1 a_2} \right)^{-a_1} \right)^{\frac{1}{a_1+a_2-1}} + v_2 \tag{3.4}$$

with correlated error terms $v_1, v_2 \sim N(0, \Sigma_v)$. Note that it should also be assumed that these are likewise correlated with ε, the disturbance term from the production relation.

To proceed with estimation of the parameters, it will be helpful to reformulate the production relation in order to remove the heteroscedasticity that is built into the pro-

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[1] This variable is further discussed in Section 4.1.

duction relation via the variance-influencing term $Bx_1^{b_1}x_2^{b_2}\varepsilon$. Subtracting the mean-influencing term $Ax_1^{a_1}x_2^{a_2}$ from the right hand side of (3.1) and dividing through by $x_1^{b_1}x_2^{b_2}$ results in

$$\frac{y - Ax_1^{a_1}x_2^{a_2}}{x_1^{b_1}x_2^{b_2}} = B\varepsilon. \tag{3.5}$$

Relations (3.4), (3.4), and (3.5) cannot be consistently estimated by ordinary least squares due to the cross-equation parameter restrictions and the correlation between the error components of each equation. Estimation using three-stage least squares will avoid these problems and is used here. Given a matrix of joint errors Σ for the system defined by (3.4)–(3.5), the element $\Sigma_{3,3}$ is B^2, the variance of the error term in equation (3.5) and other diagonal elements are similarly the variance of v_1 and v_2, with nonzero covariance allowed for the off-diagonal elements. Estimation proceeds with the system of equations as described in Chapter 4.3.

After obtaining parameter estimates for the system described above, it is necessary to obtain fitted values of the inputs to proceed with simulations of policy scenarios. For a given set of input and output prices, solutions for a range of CSR values can be obtained and the results used to perform the simulations needed for the physical water quality model. To accomplish this, the parameter estimates obtained from fitting (3.4)–(3.5) are used in conjunction with each observation's input/output prices and CSR to determine the x_1 and x_2 that result for the estimated input demand equations.

4. DATA DESCRIPTION AND ESTIMATION OF THE ECONOMIC MODEL

The purpose of this chapter is to describe the sources and construction of data used in the economic model presented in Chapter 3 and to present results of the estimation of that model. The data used for estimation and analysis can be placed into two general categories. One is the set of data and variables needed to estimate the econometric model outlined in Section 4.3. The second category is the data needed to calibrate and run the physical simulation model (SWAT) for the Raccoon river watershed. The data used in the SWAT model is described in Chapter 5.

4.1 Data

There are three types of data used for estimation of the economic model: corn production input and output data, site-specific soil data and other exogenous variables to be used as instruments, and input and output prices. This section will provide an overview of all data sources and describe the means by which they are linked to create a unified data set.

4.1.1 The Agricultural Resource Management Survey

The USDA's Agricultural Resource Management Survey (ARMS) is a detailed source of information on farms' resource use, financial condition, and production practices. Overseen by the USDA's Economic Research Service and National Agricultural Statistics

Service (NASS), its beginnings go back to 1975, though its form and scope changed somewhat in 1996 when it took its current name. It combines data that previously was collected under separate surveys known as the Cropping Practices Survey and the Farm Costs and Returns Survey.

The ARMS data consists of surveys of farm households on cropping practices, chemical application, and operational costs, and is intended for use in policy analysis. In 2001, survey coverage of corn and soybeans moved from annual collection to three-year rotating coverage, reducing its usefulness. The corn data available for this study runs from 1996-2001.

The ARMS data involves surveying on three levels, referred to by NASS as "phases." Surveying runs from June of the survey year through the following April. The initial step, Phase I, is a screening phase. Conducted during the summer, it collects information on the crops in production, livestock inventory, and sales values at sites selected for the survey.

Phase II, referred to as the "Production Practices Report," takes place in the fall and winter; information on field-level cultivation practices as well as chemical and resource use is collected from operators selected in Phase I. This is very similar to what had been collected in the Cropping Practices Survey prior to the inception of ARMS in 1996.

In the spring, a subsample of all farmers is surveyed for Phase III, a whole-farm cost of production survey called the "Costs and Returns Report." In addition to this global subsample, farmers growing a specific crop may also be sampled depending on the year. This phase contains more breadth of information than Phase II. For example, while Phase II concentrates only on the details of one particular crop, Phase III will contain a list of all crops grown on the farm and specific acreage allocated to them. While Phase II information is collected every year[1] for the major crops of interest in Iowa (corn and soybeans), Phase III information is collected only intermittently.

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[1] Up to 2001.

Surveys collect information from personal interviews with farmers. Surveyor training is provided via state statisticians who also perform quality control checks on the collected data. In addition to training, surveyors receive extensive documentation in the form of manuals which detail specific procedures, interpretation of responses, and numerous examples of typical responses. The final data set is not a true time series because it does not track the same farms year by year but is rather an annual sampling of all farms available to the surveyors.

Phase II survey results will provide nearly all of the variables necessary to fit the economic model: per-acre yield of corn for grain, application of total nitrogen, application of total phosphorus, crop residue on the field, and previous crop.[2] A short data description follows:

Yield Output of corn measured in bushels per acre.

Total Nitrogen Application of nitrogen to corn crop measured in pounds per acre. This is total pounds of nitrogen in the fertilizer, calculated from a commercial product description provided by the farmer.

Total Phosphorus Application of phosphorus to corn crop measured in pounds per acre. This is total pounds of phosphorus in the fertilizer, calculated from a commercial product description provided by the farmer.

Residue The percentage of residue left on the field following tillage operations. This is calculated from information the farmer provides on tillage passes and equipment.

Previous Crop The crop planted on the field the previous season. This is used to construct dummy variables for some of the most common rotations. The most common is the corn-soybean rotation.

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[2] The latter two variables are not used directly in the model but as instruments in the estimation procedure.

The missing pieces are soil information that will provide a measure of productivity potential, input and output prices for corn production, and soybean prices to be used as an instrument. Using a soil map and location information from the ARMS surveys it is possible to assign a CSR to each ARMS point. Soil data and the means by which it is merged with the ARMS points are described in section 4.1.2 below. Details regarding input and output price data appear in section 4.1.3. A complete copy of a Phase II questionnaire is included in Appendix C.

In a number of cases, there are missing values in the ARMS dataset. The missing values can be divided into two categories: missing location information (prevalent in 1996 data almost exclusively) and missing input/output data. Location information is required in order to assign soil property information with each observation, so data points without this information is not of use in model estimation. Table 4.1 lists the sample size for each year of ARMS Phase II for corn and the number of observations with missing location information.

Table 4.1 Missing location information by year

Year	**Number of observations**	**Number that are missing location**
1996	1009	760
1997	205	0
1998	213	0
1999	201	1
2000	190	2
2001	179	0
Total	1997	763

As can be seen in the table, nearly all of the missing values occur in the 1996 set. Interestingly, 1996 is also the year with the largest number of observations; removing those which are missing location information leaves 249 usable observations, very similar in size to the other five years of the sample. Before discarding these observations, it is important to examine what effect their removal has on the sample. Table 4.2 reports basic sample statistics for variables used in the estimation, grouped by availability of location data in 1996. As can be seen in the table, there is little difference between the two sub-samples and thus little of concern in excluding those observations lacking location information. This leaves 1,234 observations with valid location data.

Table 4.2 Sample comparison, 1996 observations with and without location

	With location		**Without location**	
Variable	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**
Yield	137.9208	30.93	136.15	32.76
Total Nitrogen	120.96	47.14	122.52	51.98
Total Phosphorus	44.05	35.64	43.28	33.31
Residue	28.40	17.02	29.33	17.77
Corn-soybean rotation dummy	0.66	0.48	0.70	0.46

Missing input and output data will also require the discarding of several observations. There are five observations missing residue values, and omitting yield values that are either missing or zero excludes 152 observations, leaving 1,077. There are four observations which have unusually large values for nitrogen application (greater than 300 pounds per acre); these are omitted as being inconceivably large. In fact, when examining the data at the survey level—the main ARMS data file is constructed from several subsections, one of which contains detailed fertilizer entries for each observation—these observations have information that conflicts with what is presented in the main data file. This leaves 1,073 observations. Nitrogen application levels of zero are also omitted for two reasons: (1) it is unlikely that any corn grower is not applying at least some nitrogen and (2) the model requires strictly positive values of the inputs. A Stone-Geary type production function (where x_1 is replaced by $x_1 - x_{\text{base}}$ in (3.1), with x_{base} some base level of nitrogen existing in the soil) was attempted but due to the relatively small number of zero-input observations had very poor fit. This excludes an additional 74 observations, leaving 999 observations. A similar exclusion of phosphorus applications that are missing or zero excludes another 178 observations. This is necessary for the model to run (a Stone-Geary version of production for phosphorus was also attempted without success, again likely due to a small number of zero observations) but is not ideal, as there is not as strong a rationale for excluding farmers who may apply no phosphorus. The final sample size for use in estimation is then 821 observations, and discussion of the "ARMS sample" from this point onward refers to this modified data set.

Table 4.3 contains sample statistics for this data set. Although the input and output variables have quite large ranges, the low and high end contain relatively few observations and the bulk of the distributions of those variables seem to be in a reasonable range. For example, while there are nitrogen applications that range from only 8 pounds per acre to a very large 300 pounds per acre, the interquartile range is from 110 to 153 pounds per acre. The distributions of phosphorus application and yield show similarly reasonable numbers.

Table 4.3 Statistics for the ARMS sample, $n = 821$

	Mean	**Standard deviation**	**Min**	**Max**	**1st Qrt**	**Median**	**3rd Qrt**
Yield	144.51	26.95	2.5	224	130	150	162
Nitrogen	128.57	42.14	8	300	110	133	153
Phosphorus	58.40	30.93	2.76	300	40	52	70
Residue	27.19	16.47	0	81	15	26	33
Corn-soy	0.78	0.41	0	1	1	1	1

Figure 4.1 shows a comparison between ARMS geographical coverage and the average total corn acreage in Iowa from 1996 to 2001. For reasons of confidentiality, ARMS data cannot be disclosed in aggregate if three or fewer observations are used to calculate the aggregate measure. Because there are a few counties with relatively low intensity of agricultural production and thus fewer than three observations, these counties must be merged with some other spatial unit to allow their inclusion in a summary. Rather than do this, the choice was made to base this comparison on Crop Reporting Districts,

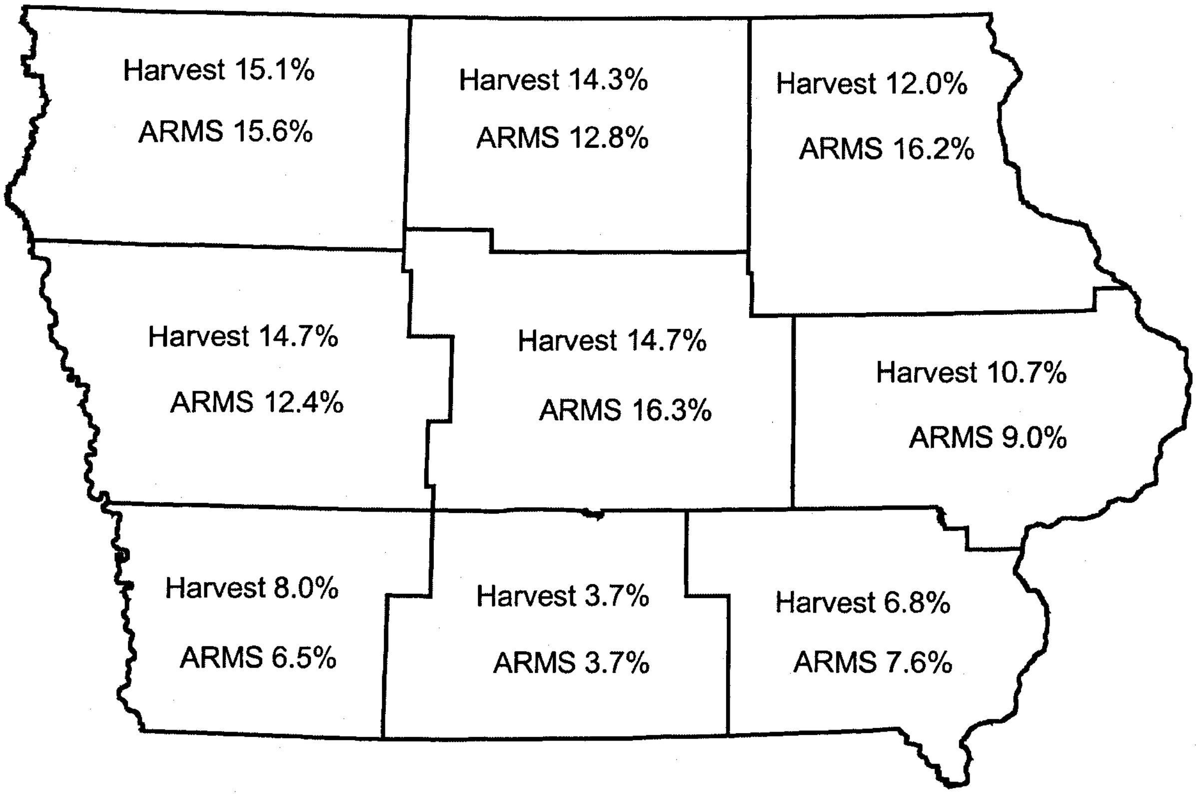

Figure 4.1 Comparison of ARMS sample point distribution and NASS total corn harvest acreage distribution, 1996-2001

which are collections of counties often used as a geographic unit in agricultural statistics; Iowa has nine Crop Reporting Disctricts. This makes the comparison easier to represent graphically without losing much information. The goal is to examine how closely the ARMS sample used here matches the true distribution of acreage in the state of Iowa. The percentage of total observations in each Crop Reporting Disctrict found in the ARMS sample appears as the bottom number in Figure 4.1 while the same percentage according NASS harvest acreage (USDA-NASS) [54] is the top number. As seen in the figure, there is a nearly 1:1 ratio of ARMS representation to measured acreage, with the largest discrepancy occurring in northeastern Iowa, an area with relatively little agriculture in the north but greater concentration in the south. Examination of individual county distribution supports this observation and explains the divergence in the two numbers for this district.

4.1.2 Soil data

One important piece of information that is lacking in the ARMS data is site-specific soil properties. Although location information (latitude and longitude) is provided in the surveys, due to confidentiality restrictions it is not possible to directly match the survey locations with a soil map. This section discusses the soil data, variable chosen, and the method by which soil data is assigned to ARMS data points.

Soil data is taken from the Iowa Soil Properties and Interpretation Database (ISPAID) [26]. This database is a compilation of soil survey data that has been assembled by the Iowa Cooperative Soil Survey, a group of government and extension agencies. It provides the most detailed spatial information available on Iowa soils. Due to confidentiality issues, it is not possible to interface the ISPAID data directly to the ARMS data.[3] To overcome this limitation, a statewide geographical grid is constructed and interfaced with the ISPAID in GIS form. Each point on the grid is then assigned soil properties based on its location relative to the ISPAID data. A program written in GAUSS, which is available at the NASS data access site, then matches ARMS data point locations to the closest corresponding point on the soil grid. The soil grid is approximately 300 by 650 points, with each point separated by 0.01 degrees. At Iowa's longitude and latitude, this corresponds to roughly half a mile east to west and two thirds of a mile north to south, so four grid points define an area of approximately one-third of a square mile.

Although there are dozens of variables available in the ISPAID dataset, it is necessary to choose from those that are also available in the National Resources (NRI) dataset for interfacing with SWAT in the Raccoon watershed. This is necessary because the NRI point is the basis on which the data will be matched for use in the water quality simulation model. A description of the NRI dataset can be found in Chapter 5 and a

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[3] The ARMS data can only be accessed at a NASS site, where GIS software is unavailable.

description of the matching procedure appears on page 60 of the current chapter.

The most useful and parsimonious of the soil variables available is the Corn Suitability Rating (CSR). The CSR reported in ISPAID is a relative ranking of all soils mapped in the state of Iowa based on their potential to be utilized for intensive corn production. It can be used as an index to compare one soil's potential yield against another. Ratings range from 100 for soils with no physical limitations, on minimal slopes, and will support continuous row crop production to a rating of 5 for soils that are not appropriate for row crops. The CSR values provided in the ISPAID set have associated with them a set of assumptions which include adequate managment, no irrigation, and tile drainage where necessary for production. A particularly attractive characteristic of the CSR as a measure of potential productivity is the fact that, even though average yields may rise or fall due to changes in management, technology, weather patterns, etc., the relative rankings of the soils will be unaffected.

4.1.3 Prices

The final piece needed for model estimation is input and output prices. There are several issues that must be confronted in constructing both sets of prices, and auxiliary data is needed to generate the input prices needed for the model. Information on data sources and procedures will be provided in this section.

Input prices

Base fertilizer prices were obtained from an annual USDA-NASS agricultural price compilation (USDA-NASS). Reported prices are for specific fertilizer blends—for example, 18-46-0 (Diammonium Phosphate or DAP) is 18% nitrogen, 46% phosphorus, and 0% potassium. Spatially, prices vary only by region, with Iowa being in the North Central region. Since different blends are more prevalent in some areas, prices for every blend are not available for each region. The full set of prices is included in Appendix A or for download from a NASS source [53].

The inputs used in estimation are measured in pounds of application, so it is necessary to devise a means of converting the prices associated with each blend to a price per pound of the nutrient itself. It would be possible to simply average the price per actual pound of nutrient content, but a more appropriate approach would be to use the fertilizer blends most commonly purchased in the state to construct a weighted average.

The Iowa Department of Agriculture and Land Stewardship (IDALS) maintains fertilizer sales data that tracks statewide use by blend [23]. Only two years of data are available, 2002-2003 and 2003-2004, but there are minimal differences between the distribution of blend popularity. The bulk of this distribution can be seen in Tables 4.4 and 4.5.

Table 4.4 Distribution of fertilizer sales by blend, most popular straight materials

Blend (N-P-K)	**Percentage of total 2002-2003**	**Percentage of total 2003-2004**
0-0-61	25.11%	26.71%
82-0-0	18.29%	18.03%
32-0-0	13.14%	15.96%
18-46-0	13.25%	12.98%
28-0-0	12.84%	10.43%
46-0-0	7.62%	6.75%
11-52-0	6.74%	6.40%

Source: http://www.agriculture.state.ia.us/fertilizertonreport.htm

Intersecting the set of blends from IDALS with those blends listed by USDA-NASS reveals that there are some fertilizer products that appear in one but not the other. This makes the task of devising a weighting scheme slightly more complicated. One of the straight materials and most of the blends are unavailable in the USDA-NASS prices. The missing straight material is 0-0-61, but since potash is not one of the nutrients in the model this is of no consequence. Only one of the blends listed in Table 4.5 is listed

Table 4.5 Distribution of fertilizer sales by blend, most popular blends

Blend (N-P-K)	Percentage of total 2002-2003	Percentage of total 2003-2004
2-6-35	27.08%	29.79%
3-10-30	28.78%	29.04%
4-10-10	6.50%	8.06%
9-18-9	5.45%	7.56%
7-21-7	6.99%	6.38%

Source: http://www.agriculture.state.ia.us/fertilizertonreport.htm

in the USDA-NASS price data. However, blends make up a much smaller portion of fertilizer sales than do the straight materials (see Tables A.2 and A.3 in Appendix A) and thus their exclusion will have little effect on the process of determining prices.

This leaves an abbreviated set of six blends and straight materials from which input prices can be constructed. Four of these blends provide nitrogen (82-0-0, 32-0-0, 28-0-0, 46-0-0) and two provide primarily phosphorus (18-46-0, 11-52-0).[4] The latter two will be used to weight phosphorus prices and the former set used to weight nitrogen prices. The percentage representation in the sales data is re-weighted based on these two sets, using the average of the 2002-3 and 2003-4 sales data. The resulting weights appear in Table 4.6.

Table 4.6 Weighting scheme for nutrient price calculations

Blend	(N-P-K)	N Weight	P Weight
N_1	82-0-0	0.352384595	
N_2	32-0-0	0.282388283	
P_1	18-46-0		0.666160412
N_3	28-0-0	0.225761436	
N_4	46-0-0	0.139465687	
P_2	11-52-0		0.333839588

Before these weights can be used, it is necessary to construct a per-pound nutrient price for each product. Let the per-ton price of each blend be represented by R_k^j where j

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[4] Although 18-46-0 and 11-52-0 contain nitrogen, they are considered straight materials by IDALS.

is the blend as indicated in Table 4.6 and k is the nutrient to which the weight belongs. For example, the price of 18-46-0 would be R_P^1. Also let θ_k^j be the fraction of the nutrient k in blend j and let w_j be the weight associated with blend j (the "weight" columns in Table 4.6). Using the full USDA-NASS prices, the price of a pound of nutrient in blend j is

$$r_k^j = \frac{\theta_k^j}{R_k}.$$

Once all of the r_k^js have been calculated, the final calculated price of nutrient k can be expressed as

$$r_k = \sum_j w^j r_k^j.$$

Once these annual prices are calculated, they are deflated to 1996 prices using the Consumer Price Index. At that point they are ready for use in model estimation.

Output prices

Output prices were obtained from the Iowa NASS office via a website database that has since been taken offline; currently, only statewide prices are available. However, the original prices are reprinted in Appendix A. The corn prices used for estimation vary by both year and county, the latter reflecting small spatial variations in prices received by farmers. Soybean prices, used as an instrument in estimation, were available from the same dataset and are also reported in Appendix A.

Summary

Table 4.7 contains summary statistics for the complete data set used in estimation. A total of 821 observations are available for use. The distribution of corn yield appears reasonable, with the interquartile range between 130 and 162. There are a few very large and very small values but a relatively compact distribution. The same is true of most of the input variables, although phosphorus values may be slightly higher than would be expected due to the removal of the zero-value observations. The rotation dummy indicates that approximately 80% of the farmers in the sample are following a corn-soybean rotation. Basic statistics are also provided for prices, with raw data available in Appendix A. Note that the ARMS sample is drawn from a different set of farms each year, and is therefore not a true time-series data set.

Table 4.7 Summary of data to be used in model estimation, $n = 821$

Variable	**Symbol**	**Mean**	**Standard deviation**	**Minimum**	**First Quartile**	**Median**	**Third Quartile**	**Maximum**
Yield	y	144.51	26.95	2.5	130	150	162	224
Nitrogen input	x_1	128.57	42.14	8	110	133	153	300
Phosphorus input	x_2	58.40	30.93	2.76	40	52	70	300
Residue		27.19	16.46	0	15	26	33	81
Corn-bean dummy		0.78	0.41	0	1	1	1	1
Corn suitability rating	CSR	66.92	21.04	5	58	72	81	100
Nitrogen price	r_1	0.2177	0.0411	0.1672	0.1712	0.2400	0.2576	0.2754
Phosphorus price	r_2	0.2708	0.0295	0.2297	0.2326	0.2691	0.2830	0.3136
Corn price	p	1.98	0.42	1.46	1.65	1.75	2.39	2.81
Soybean price		5.28	1.36	3.85	4.08	4.60	6.18	7.36

4.2 Joining ARMS and NRI Data

Because of SWAT's input needs (details follow in Chapter 5) and restrictions on the use of the ARMS data, it is necessary to devise a means of transferring the results of the estimated model to a form that can work with SWAT. The NRI provides the watershed-scale data needed to run SWAT and is easily applied to agricultural watersheds [28]. The common variable used to link the datasets is the soil suitability for corn production.

The NRI contains information on soil type, which includes a measure of corn yield potential. While it employs a different metric than the CSR described in Section 4.1.2, it is a comparable suitability measure. The particular variable is described as the "Non-irrigated Crop Yield (NIRRYLD)" and is defined as the per-acre expected yield in an average year under a high level of management [55].

Because the two measures, CSR and NIRRYLD, are on different scales (an index from 5 to 100 vs. an expected yield) some means of transferring between measures is needed. Several distribution-based methods were evaluated: matching by decile, matching by quartile, matching by halves, and a simple scaling of the entire range of NIRRYLD values. Using the sum of squared percentage deviations from the ARMS-based CSR distribution as a criterion, the simple scaling method most closely matched the NIRRYLD distribution to the ARMS-based CSR distribution. Details appear in Table 4.8. The simple scaling method maps the lowest and highest NIRRYLD values (50 and 170 bushels per acre) to the extremes of CSR value (5 and 100) and uniformly scales values that lie within the entire interval. A distribution comparison of the original ARMS-based CSR and simply scaled NRI CSR can be found in Figure 4.2.

The only point-specific variation in the ARMS-based model is by CSR. Once the model is estimated, parameters can be applied to NRI points and simulations can take place just as they would with the ARMS points. The results of these simulations are used to generate input for SWAT and are the physical translation/expression of the economic model.

Table 4.8 Percent deviation of NRI CSR distributions from ARMS-based CSR

Bin value	Deciles	Quartiles	Halves	Simple Scale
5	-2.25	-2.25	-2.25	-2.25
10	-0.02	-0.52	-0.52	-0.52
15	0.94	-0.57	-0.57	-0.57
20	1.24	1.10	1.10	0.81
25	-1.01	-1.01	-1.01	-1.31
30	1.17	-0.94	-0.94	-0.63
35	0.75	0.37	0.41	0.50
40	-0.24	1.27	1.23	0.48
45	3.97	0.89	0.89	0.71
50	-3.73	2.31	2.49	2.49
55	-1.63	-0.86	-1.04	-1.15
60	-1.95	1.48	1.48	-2.00
65	5.47	1.45	3.04	-0.52
70	-2.44	-2.44	-4.02	-2.08
75	5.98	-3.62	-4.65	-0.14
80	-9.66	6.82	0.96	-0.43
85	5.76	-1.13	4.95	2.06
90	-3.17	-3.32	-4.06	-0.38
95	-2.18	-2.03	-1.31	1.09
100	2.99	2.99	3.83	3.83
Sum of Squared Differences	268.46	112.57	126.00	45.99

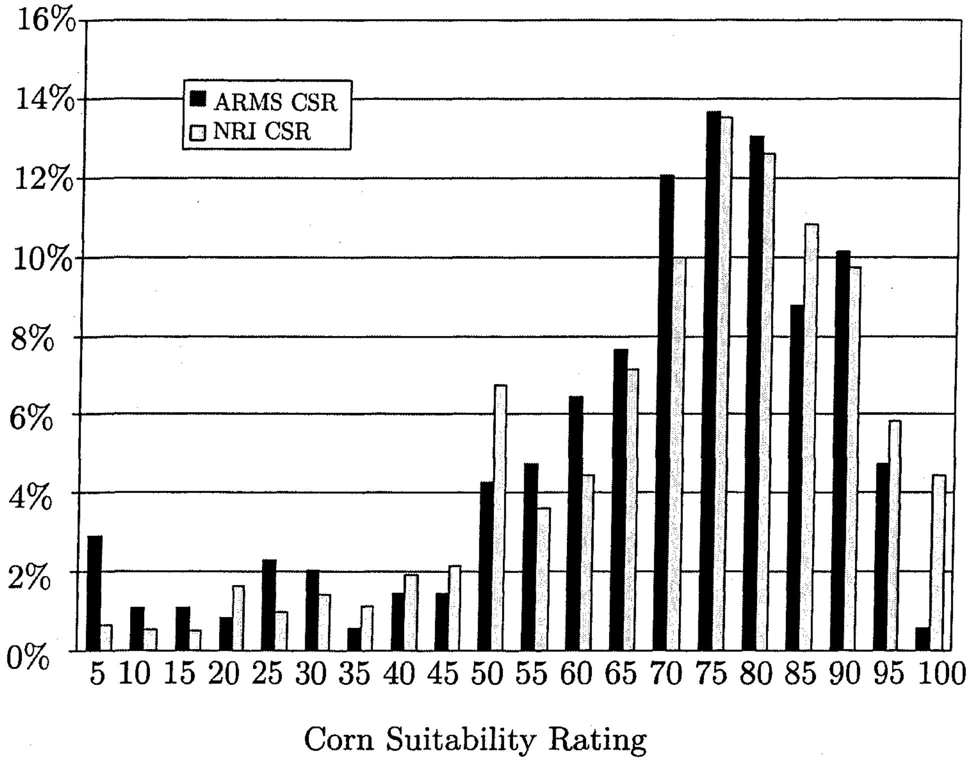

Figure 4.2 Distribution of CSR from ARMS soil matchup compared to converted CSR in the NRI data

4.3 Model Estimation and Results

This section applies the model developed in Chapter 3 to the data described in Section 4.1 above. The econometric means of estimation is described, and the results of the estimation process are presented. Section 4.3.1 will cover the estimation procedure in detail, with results appearing in Section 4.3.2.

4.3.1 Estimation Procedure

The model to be estimated is that described by equations (3.4), (3.4), and (3.5). It is helpful to restate the the system of equations to be estimated:

$$x_{1i} - \left(\frac{r_{1i}}{p_i A_i a_1} \left(\frac{r_{1i} a_2}{r_{2i} a_1} \right)^{-a_2} \right)^{\frac{1}{a_1 + a_2 - 1}} = v_{1i} \tag{4.1}$$

$$x_{2i} - \left(\frac{r_{2i}}{p_i A_i a_2} \left(\frac{r_{2i} a_1}{r_{1i} a_2} \right)^{-a_1} \right)^{\frac{1}{a_1 + a_2 - 1}} = v_{2i} \tag{4.2}$$

$$\frac{y_i - A_i x_{1i}^{a_1} x_{2i}^{a_2}}{x_{1i}^{b_1} x_{2i}^{b_2}} = B\varepsilon_i \tag{4.3}$$

where $A_i = \alpha_0 + \alpha_1(CSR_i)$ and $v_1, v_2, B\varepsilon$ are jointly distributed with a mean vector of zero and error matrix Σ. Input and output prices are subscripted i as they vary across observation, as does CSR. This system is estimated using a nonlinear three-stage least squares procedure in the Time Series Processor[5] (TSP) estimation package, the 3SLS function. In short, three-stage least squares is a combination of a Seemingly Unrelated Regression and two-stage least squares. Instrumental variables estimates are obtained taking into account the covariance between equation errors (i.e., the off-diagonal elements of Σ). The method used by TSP is that of Jorgenson and Laffont [33] in that the instrumental variables are applied to all equations.

The instruments used in estimation are the price of soybeans, residue left on the field (a measure of the tillage method used by the farmer), and a dummy variable

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[5] Although its original purpose was to estimate time-series models, TSP has long been used with cross-sectional and panel data.

indicating whether the farmer is following a corn-soybean or a continuous-corn crop rotation. Although it could be argued that the choice of crop rotation and tillage are endogenous, the assumption made here is that rotation and tillage choice are long run decisions and are thus exogenous in a given year. The instruments are assumed to be correlated with profitability of corn production and/or fertilizer input usage, but not related to individual farmers' errors.

4.3.2 Estimation Results

Parameter estimates and standard errors from three stage least squares estimation of the system appear in Table 4.9.

Table 4.9 Parameter estimates

Parameter	**Estimate**	**Standard Error**	**t-statistic**	**p-value**
α_0	26.11	12.0398	2.17	.030
α_1	0.75	0.1825	4.11	$< .001$
a_1	0.09	0.0013	69.72	$< .001$
a_2	0.05	0.0010	51.10	$< .001$
b_1	0.38	0.1696	2.24	.025
b_2	0.28	0.2386	1.18	.237

The signs of the estimated parameters are as expected: positive and indicative of decreasing returns for scale in production inputs, positive effect of CSR on yield and input choice, and increasing variability of yields with higher input levels. However, the heteroskedasticity effect for phosphorus is not statistically significant. This suggests that only nitrogen has a heteroskedastic effect on yield. The value of the residual variance, while not technically an estimate, can serve as a proxy for the value of B, the premultiplied term in yield variance. That residual variance, call it $\hat{B\varepsilon}$, is approximately 4.52 which suggests a value for B of 2.13.

5. WATER QUALITY MODEL AND THE STUDY AREA

This chapter describes the model used to evaluate water quality changes associated with the policy scenarios under study. General background information on the study area—the Raccoon River Watershed in central Iowa—is described and is followed by an explanation of the model's mechanics and an enumeration of its inputs and outputs as they relate to the application discussed in this paper. The chapter also describes the procedures for generating baseline economic and physical representations of the watershed.

5.1 The Raccoon Watershed

The Racoon River Watershed is comprised of approximately 9400 square kilometers (about 3600 square miles) of prime agricultural land. This is slightly more than 6% of Iowa's total surface area. Location and land use information can be seen in Figures 1.1 and 1.2. The Raccoon River is the main stream for the watershed and, along with its tributaries, drains at least part of seventeen Iowa counties (Figure 5.1). Most of the watershed is contained within the Des Moines Lobe geological formation (Figure 5.2). Soils in this area are extremely fertile.

Approximately 75% of the watershed's surface area is used for production of corn and soybeans [32]. Nitrogen and phosphorus fertilizer are applied at relatively high levels on the corn crop and constitute the primary nonpoint nutrient pollutant source in the watershed.

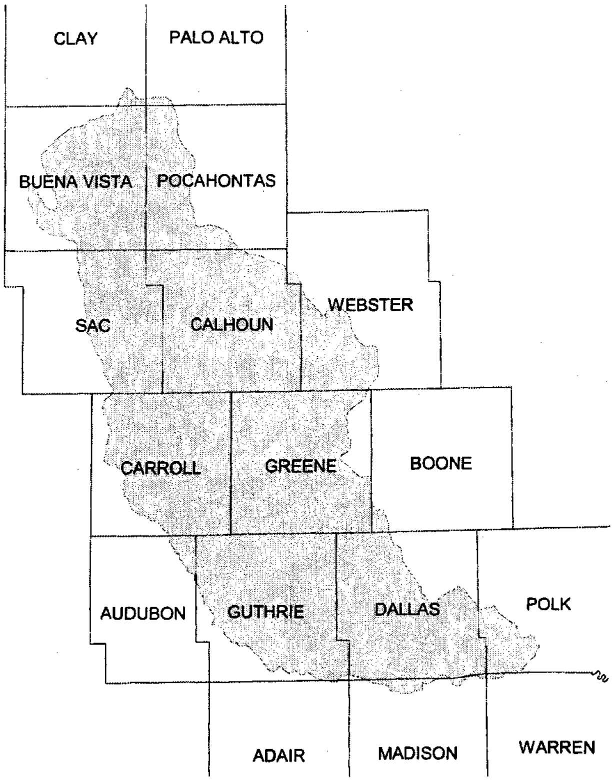

Figure 5.1 Raccoon watershed and contiguous Iowa counties

Nitrate levels have been a concern in the watershed for quite some time, because nitrate is a regulated drinking water contaminant. The Des Moines Water Works supplies about 17% of Iowa's population with drinking water and draws heavily from the Raccoon and an infiltration gallery associated with the river.

There are two general water quality issues important to those affected by nutrient levels in the Raccoon watershed. One is the nitrate levels at the Des Moines Water Works (DMWW). The DMWW provides drinking water for the Des Moines metro area, containing a population of nearly one-half million. It draws water from three sources: the Raccoon River, the Des Moines River, and an infiltration gallery. In 1990 the DMWW invested in a nitrate-removal system in response to nitrate levels that exceeded drinking water standards. The DMWW activates this nitrate removal facility during periods of possible nitrate level increases. The costs of permanently removing nitrate from the

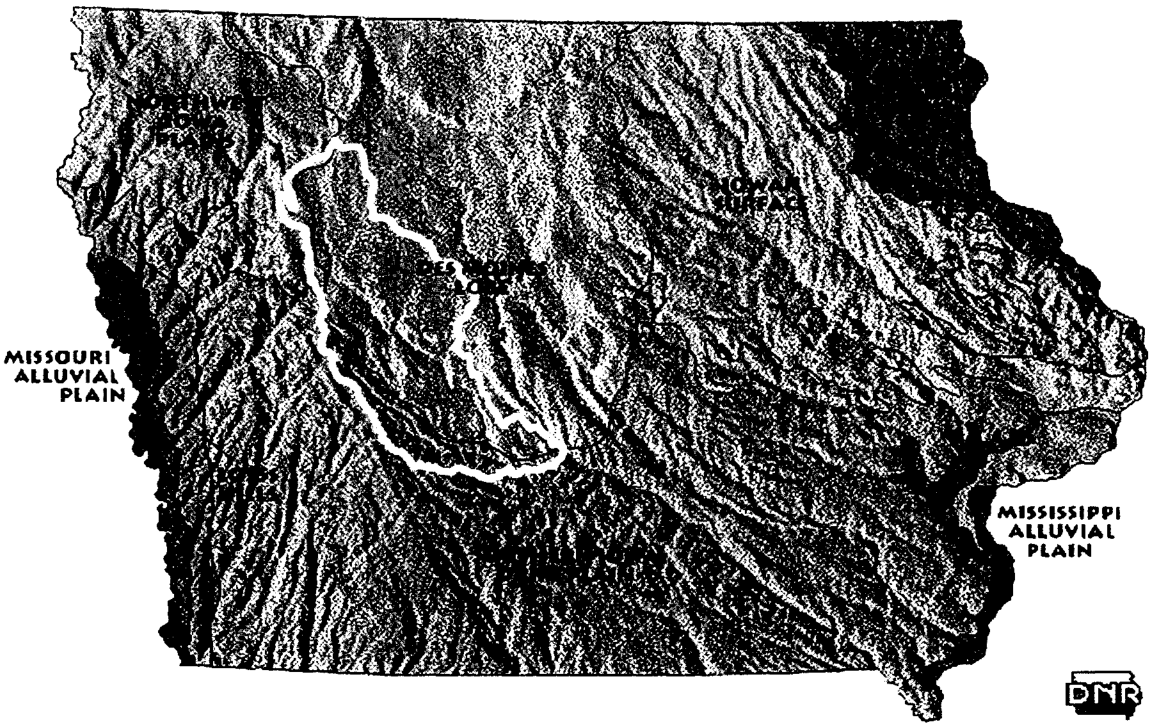

Figure 5.2 Iowa geological formations and the Raccoon River Watershed

water are much larger than the cost of disposal, so the removed nitrate is reintroduced to the river downstream from the DMWW. From there it continues on to the Mississippi river and eventually to the Gulf of Mexico. The facility cost $3.7 million to construct in 1990 and runs on average 45 days per year, at an average daily treatment volume of 10 million gallons of water for drinking. Daily cost at this volume is in the area of $3,000 for operating costs alone.

The impact of water quality degradation on the recreational activities in the watershed area is another important consideration. Phosphorus is the limiting factor in the excess growth of algae which is visually unappealing, results in offensive odors, creates hypoxic or anoxic conditions leading to fish kills, and can contribute to dangerous levels of toxic cyanobacteria (similar to a freshwater "red tide"). Given these effects, phosphorus levels are a strong indicator of local freshwater quality. The Raccoon watershed contains nine lakes that offer significant recreational opportunities but which vary widely in water quality. For this reason, the impact of agricultural phosphorus use is an important factor in the quality of recreational opportunities available in the watershed.

5.2 Background on the Soil and Water Assessment Tool

The Soil and Water Assessment Tool, or SWAT, is designed to simulate the effects of watershed management on water quality and water flow. It is primarily used for modeling non-point source contributions to nutrient and sediment loads within a watershed. Thus it is ideally suited for modeling the water quality effects of changes in agricultural nutrient application. It is an evolutionary step in the development of an earlier model, the Simulator for Water Resources in Rural Basins (SWRRB). The latter incorporated components of other pre-existing models designed to estimate crop growth, surface and ground water hydrology, nutrient and chemical transport, runoff or sediment transport, among others.

The main drawbacks to the SWRRB model were limitations on spatial applicability: it was limited in the number of sub-watersheds (or subbasins) allowed, and simply routed output from each subbasin directly to the main watershed outlet. For larger watersheds, the former restiction is problematic; the latter restriction was a consequence of the first, and produced less realistic simulations the larger the watershed. SWAT was developed as a way of integrating multiple SWRRB runs into one modeling system by routing from subbasin to subbasin, allowing the modeling of much larger and more complex watersheds.

5.3 Model Setup

The watershed under study is divided into many smaller parts, referred to as subwatersheds or subbasins. This is useful because different regions of the watershed often have unique combinations of many factors (e.g., land use, soil type) and must be considered

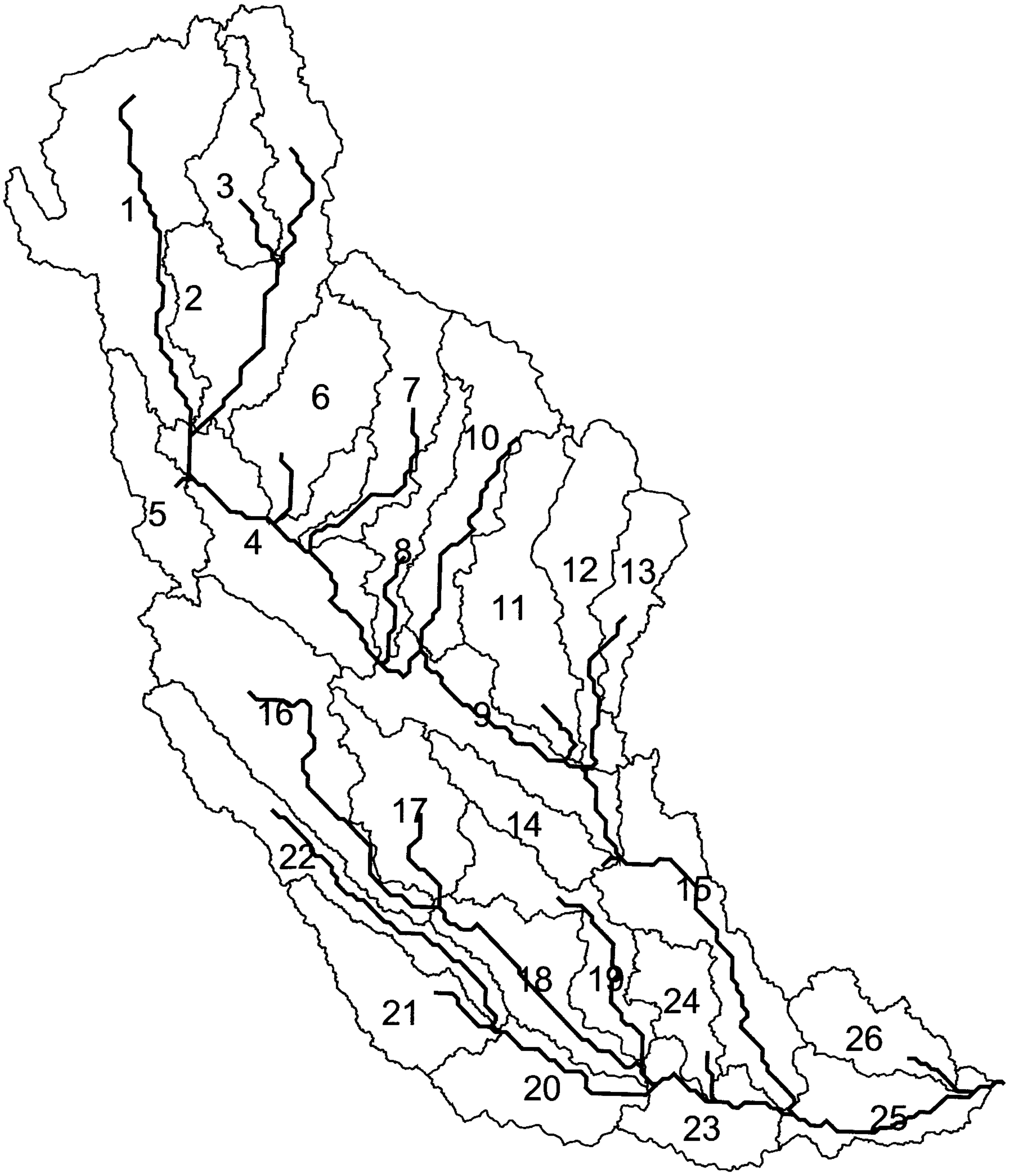

Figure 5.3 Raccoon watershed subbasins and stream routing

separately while remaining related spatially. Each subbasin has four general categories of characteristics:

1. Weather and climate
2. Ponds, reservoirs, or other bodies of water within the watershed
3. Groundwater and main channel routing
4. Land cover, soil, and land management.

Changes in one of the components of the last item on the above list, land management, will drive the differences in scenario results. Figure 5.3 shows the subbasins and stream routing as defined by SWAT for runs on the Raccoon river watershed. Although SWAT automatically delineates subbasins[1], it is possible to force this delineation process to create subbasins consistent with existing U.S. Geological Survey (USGS) Hydrologic Unit Codes (HUCs). In the simulations presented in Chapter 6 this has been done for the Raccoon river watershed, with subbasins geographically equivalent to 10-digit HUCs. The Raccoon watershed consists of two eight-digit HUCs. HUCs are used to organize watersheds in a hierarchy, with shorter length HUCs denoting larger watersheds. For example, the Raccoon watershed HUCs are 07100006 and 07100007, while the Upper Mississippi is 07; the Raccoon watersheds are subbasins of the Upper Mississippi. Likewise subbasins of the Raccoon would begin with 07100006 or 07100007 but have a longer HUC.

For land cover, soil, and land management characteristics, there is no explicit spatial variability in SWAT. To account for variability, it makes use of "virtual sub-subbasins" within each subbasin, called Hyrdologic Response Units (HRUs). These HRUs represent unique combinations of the primary characteristics. A simplified example of an HRU designation would be a given soil type, percentage of land in a certain crop or crop

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[1] SWAT uses digital elevation map information to create subbasins

rotation, and a particular level of nutrient application. Another HRU might have that same soil type but be forested rather than cropland and unmanaged in terms of crop or chemical application. In the simulations described in Chapter 4.3, the Raccoon watershed has 4,530 HRUs, with each subbasin containing anywhere from 80 to 267 HRUs. Subbasins with greater internal variation require more HRUs to capture that variability, while those with less variation can be simulated with fewer HRUs. Some land use combinations that make up a very small proportion of the overall land use are discarded, but the HRUs cover nearly all of the observed land use combinations. The data used to determine HRU designations for subbasins is derived from the National Resources Inventory (NRI). More details concerning the use of this data for SWAT simulations can be found in Chapter 4.1, and a complete description of HRUs and their use in the model are available in the SWAT documentation ([41]). The NRI data as it relates to SWAT inputs is also discussed in the next section of this chapter.

SWAT is a continuous-time model in that calculations are performed on a day-by-day basis, and it is designed as a long-term yield model. As it is not currently possible to model scenarios that change by year, simulations use one target year's prices to determine nutrient application behavior. Since the 1997 NRI data is used for many of the model inputs, SWAT is run for several years before and after 1997 and the results of a "snapshot" of the output from that year are examined.

5.4 Inputs and outputs

This section provides an overview of the type and variety of inputs required to run SWAT as well as the output that SWAT generates. A very useful interface for manipulating SWAT runs, called i_swat[2], has been developed at Iowa State University. This software allows for quick and easy manipulation of input files via a standard Microsoft

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[2] i_swat is available for download at http://www.public.iastate.edu/~elvis/i_swat_main.html

Access database and organizes all of the inputs needed into one file that can be used as a reference. In particular, the ability to directly control the land management files is important in implementing policy scenario driven changes.

Inputs

The general set of inputs required to run SWAT fall into five major categories: topography, weather, land use, soil, and management data. Topographical data is used to delineate the overall watershed into subbasins and also to provide slope-related parameters for the model. The data used for the simulations herein was sourced as a 90-meter resolution Digital Elevation Model from a U.S. Environmental Protection Agency (USEPA) called Better Assessment Science Intergrating point and Nonpoint Sources (BASINS).[3]

SWAT also requires daily climate information for each subbasin. The variables needed include precipitation amount, maximum and minimum ambient air temperature, solar radiation, wind speed, and relative humidity. A built-in weather generator[4] is provided, but it is also possible to utilize actual historical weather data. The latter has been done here in the case of precipitation and temperature, making use of data from the National Climatic Data Center (NCDC). This data is available for ten weather stations either in or adjoining the Raccoon watershed. SWAT's internal weather generator was used for the other required weather inputs, as were some missing precipitation and temperature values in the NCDC data.

The HRU subdivisions discussed above make use of land use, soil, and management data. These inputs were derived primarily from the 1997 NRI. The cropping histories provided in the NRI are used directly in SWAT. Soil layer information is obtained via a matchup process between NRI points and a soil database described in Baumer [8]. This database includes identification codes that allow the linking of its soil properties to NRI

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[3] See USEPA reference for download and other information.

[4] The weather generator uses records on long-term climate statistics for its simulations.

points.

Tillage data is generated from a model that combines data from the USDA Cropping Practices Survey (CPS) and the Conservation Tillage Information Center (CTIC).

Output from simulations of the economic model described in Chapters 3 and 4 is used to construct the fertilizer rates needed. Based on input prices, output price, and soil type, each NRI point has associated with it an application rate for nitrogen and phosphorus. From this baseline, fertilizer subfiles are modified according to the results of economic model simulations and the resulting SWAT runs used to compare policies.

Outputs

SWAT provides three general categories of output: flow, sediment load, and nutrient load. Flow is of peripheral interest here, as is sediment (except as it relates to phosphorus loads). Nitrogen and phoshphorus loads are the main indicators of water quality and it is their levels which are of primary interest. SWAT simulates a complete nutrient cycle for both nutrients.

The nitrogen cycle is simulated via five pools: two inorganic forms (ammonium and nitrate) and three organic forms (fresh, stable, and active). In the case of phosphorus, SWAT tracks six phosphorus pools in soil, three organic and three inorganic forms. Both nutrient cycles take into account mineralization, decomposition, and immobilization, with these processes allowed only when sufficient soil temperatures are reached. Calculations of nitrate export in the form of runoff, lateral flow, and percolation take into account the volume of water and average soil concentration of nitrate. A loading function handles organic nitrogen and phosphorus and estimates daily nutrient runoff loss based on concentrations in topsoil, sediment yield, and an enrichment ration. A more detailed description of the mechanics of nutrient transport and other output generation is available in the SWAT Theoretical Documentation.

SWAT reports all outputs variables at the subbasin level. Annual output values for a baseline model run of the Raccoon watershed can be found in Table B.1 of Appendix A. A description of the variables reported follows:

1. Subbasin number (see Figure 5.3 for subbasin numbering).
2. Subbasin area (in square kilometers).
3. Flow (in cubic meters per second at the subbasin outlet).
4. Sediment (in tons per unit time, monthly or yearly).
5. Organic nitrogen (in kilograms per unit time).
6. Organic phosphorus (in kilograms per unit time).
7. NO_3 as nitrogen (in kilograms per unit time).
8. NH_4 as nitrogen (in kilograms per unit time).
9. Mineral phosphorus (in kilograms per unit time).

Total nitrogen and total phosphorus can be calculated by summing individual nutrient load contributions. These values and their constituents form the basis for policy comparisons in terms of water quality effects.

6. POLICY SCENARIO SIMULATIONS

This section catalogs the results of 10-year SWAT simulation runs (1994-2003) on the Raccoon watershed. These runs vary only by nutrient application rates—weather, land management, and other input variables are identical. The output values reported are for 1997, the year from which the NRI observations used to construct the land-use and nutrient inputs are drawn.

Driving the SWAT runs are simulations of the economic model presented in Chapter 3 and estimated in Chapter 4; the interface of those modeling results and SWAT are as described in Chapter 5. Results from the NRI-based economic simulations provide disaggregated farm-level information for each scenario and nutrient application rates which are used for SWAT runs. This farm-level information can be aggregated through the NRI-point-specific expansion factor to arrive at watershed-level estimates of the economic impacts of each scenario, for example, total expected returns, total tax revenue (under a nutrient input tax policy).

A baseline scenario run is used as a reference to which each policy outcome can be compared. Ideally, the parameter(s) defining each policy scenario (e.g., a tax rate) would be tailored to result in identical water-quality outcomes. Given the complexity of SWAT, this is an extremely difficult task requiring extensive trial-and-error testing. The alternative, followed here, is to fix the watershed cost (the change in aggregate net returns from nutrient application) and compare the relative water-quality changes associated with each scenario. To accomplish this, one scenario is used as a benchmark. Not to be confused with the baseline, the benchmark is one policy scenario that is used to fix the change in aggregate net returns so that the policies can be compared to one another.

The layout of this chapter is as follows: Section 6.1 provides a general description of the scenarios that will be analyzed and Section 6.2 presents a detailed summary of the baseline economic models and SWAT runs. Section 6.3 covers the entire set of scenarios run using the economic model of Section 3.2. The chapter concludes with a discussion of the overall results in Section 6.4.

6.1 Scenario overview

Policy simulations are run using the economic model described in Section 3.2. Six sets of policies are considered at different reduction levels: 10% reduction in nitrogen application, 10% reduction in phosphorus, 10% reduction in both nitrogen and phosphorus, 20% reduction in nitrogen, 20% reduction in phosphorus, and 20% reduction in both nitrogen and phosphorus. These six percentage reduction policies will serve as the benchmarks for the other policy scenarios described below: a cap on per-acre application rates, a tax on the nutrient(s), and a cap-and-trade nutrient application right trading scheme. For scenarios in which both nutrients are simultaneously targeted some decisions must be made as to how to set the policy instrument (tax rate, cap level, et cetera); the procedures chosen are described in Section 6.3 below. The following is a description of the specific policies.

10 % Uniform reduction Application of the nutrient(s) at each NRI corn point is reduced by 10%. This scenario is used as a benchmark—the aggregate watershed net returns associated with it are used to determine the parameter(s) of the other scenarios.

20% Uniform reduction Application of the nutrient(s) at each point is reduced by 20%. This scenario is used as a benchmark for a second set of larger reductions.

Application cap A maximum per-acre allowable application of the nutrient is imposed. Farms applying at or below the cap are not affected relative to the baseline, but those applying above the cap are constrained and suffer a loss in net returns. The cap is chosen such that resulting aggregate net returns equal those under the uniform reduction scenario.

Nutrient tax A per-pound tax is imposed on the nutrient(s). For purposes of calculating aggregate returns, tax revenues are included in the total for the watershed. A tax rate resulting in this total being equal to the net returns associated with the uniform reduction scenario is used.

Application permit trading A fixed number of per-acre application permits is allotted to each farm (the total number of permits per farm is based on acreage). Farms are allowed to buy and sell these permits on a market depending on whether it is optimal for them to apply below or above their permit allotment. The allocation of permits is chosen to result in a market-clearing permit price that leads to watershed net returns equivalent to those under the uniform reduction scenario.

Combination policies Policies simultaneously targeting both nutrients are also examined. These require a choice to be made regarding the allocation of reductions between nutrients when choosing instrument levels under a fixed change in net returns. For the application cap scenarios, this was done by holding the ratio of N to P caps constant at the same ratio seen between mean N and P under the relevant uniform reduction. For the tax scenarios the tax rate was simply held to be the same percentage on both nutrients. The resulting per-pound input tax rates were used to set permit prices in the permit trading scenarios.

For accuracy in recording the output results, each scenario is assigned a code or name. Table 6.1 illustrates the 24 different policy scenarios that will be examined and

Table 6.1 Matrix of policy scenario labels

	Policy instrument			
Benchmark Reduction	**Uniform**	**Tax**	**Cap**	**Trade**
10% N	01	02	03	02t
10% P	04	05	06	05t
20% N	07	08	09	08t
20% P	10	11	12	11t
10% N and 10% P	13	14	15	14t
20% N and 20% P	16	17	18	17t

the names they are assigned. In terms of nutrient input levels, the "Nutrient tax" and "Application permit trading" scenarios will appear identical to SWAT even though they differ in economic effect. For this reason the trading scenarios are distinguished by adding the letter "t" to the code for each tax scenario. There are 18 distinct SWAT runs.

6.2 Baseline

This section describes the baseline conditions for the economic and physical models. Table 6.2 reports information related to the NRI corn points used to construct the baseline SWAT run from inputs of the economic model. The aggregate measures (watershed returns to nutrient application and total nutrient applications) are arrived at by multiplying the variables of interest at each NRI point by the point's expansion factor.

Table 6.2 Baseline input data

Mean N application (lbs./acre)	135.48
Mean P application (lbs./acre)	66.17
Mean yield (bu/acre)	152.41
Mean returns to nutrient application ($/acre)	$298.58
Total N application (tons)	62,711
Total P application (tons)	30,630
Watershed Returns ($)	$305,565,012

Table 6.3 displays the results of the baseline SWAT run, which applies the simulated nutrient application information summarized in Table 6.2. Values are annual totals for 1997 in a ten-year run measured at the outlet of the watershed, located in subbasin 25 (see the map in Figure 5.3).

Table 6.3 Baseline SWAT output

Flow (m^3/s)	64.94
Sediment (tons)	358,800
Sediment concentration (mg/kg)	56.63
Organic N (kg)	6,320,000
Organic P (kg)	829,900
NO_3 (kg)	7,527,000
Mineral P (kg)	2,049,000
Total N (kg)	18,787,000
Total P (kg)	2,878,900

SWAT output can also be tabulated at the subbasin level (10-digit HUC level). The baseline SWAT run output at this level can be found in Appendix B, Table B.1. Changes at the subbasin level are of principal interest when evaluating policies that target phosphorus, as it is the nutrient of interest for localized water quality problems.

6.3 Simulation results

This section describes simulations of the policy scenarios outlined in Section 6.1. Detailed information on the characteristics of both input from the economic model and output from SWAT is contained in Appendix B and a summary is presented here. Table 6.4 describes SWAT output via percentage changes in target nutrients relative to the baseline. It also provides information on the net loss in returns to nutrient application for each scenario.

The scenarios are grouped by nutrient target and reduction level. Of primary interest in "global" (entire watershed) water quality are nitrate levels, as this is the primary

Table 6.4 Simulation Summary

Scenario	**Change in NO_3**	**Change in Mineral P**	**Cost of policy**	**Cost/Ton of N input**	**Cost/Ton of P input**
Baseline					
10% N	-5.94%	0.10%	$161,269	$25.72	
10-N Tax/Trading	-6.70%	-0.44%	$161,270	$25.64	
10-N Cap	-7.08%	-0.24%	$161,270	$31.76	
10% P	-0.24%	-2.34%	$97,053		$31.69
10-P Tax/Trading	-0.60%	-2.15%	$97,055		$31.59
10-P Cap	-0.17%	-1.90%	$97,046		$39.14
20% N	-13.06%	-0.39%	$693,666	$55.31	
20-N Tax/Trading	-13.15%	-1.12%	$693,654	$55.15	
20-N Cap	-12.30%	-0.29%	$693,647	$64.13	
20% P	0.28%	-4.44%	$418,117		$68.25
20-P Tax/Trading	-1.00%	-4.49%	$418,130		$68.06
20-P Cap	-0.52%	-3.95%	$418,096		$79.17
10% N+P	-6.80%	-2.64%	$238,698	$38.06	$77.93
10-NP Tax/Trading	-6.27%	-2.44%	$238,678	$38.06	$77.93
10-NP Cap	-6.27%	-2.44%	$238,697	$47.03	$96.07
20% N+P	-12.90%	-5.08%	$1,024,515	$81.69	$167.24
20-NP Tax/Trading	-12.89%	-5.12%	$1,024,516	$81.69	$167.24
20-NP Cap	-12.54%	-4.44%	$1,024,517	$94.72	$193.73

threat to drinking water collected near the outlet of the watershed. For nitrates, response to policies across different reduction levels appears nearly linear. The 10%-base input reductions realize watershed outlet reductions of around 6% to 7% while 20%-base input reductions result in roughly a 12% to 13% load reduction at the outlet. Policies targeting phosphorus application behave in much the same way, with approximately 2% reductions at the outlet for lower input reductions and 5% output load reductions at the higher 20% level of input reduction. Changes in mineral P levels at the outlet do not necessarily provide a great deal of information about water quality in specific parts of the watershed, where it may be part of a "local" (subbasin-level) problem. This is explored in detail in Section 6.4 below.

The cost associated with each policy is simply the change in returns to nutrient application with respect to the baseline. The change in returns is calculated for each NRI point, then expanded over the entire watershed area. For scenarios involving a tax the revenue generated by the tax is included in determining the "new" returns. In general, phosphorus reductions are less costly than nitrate reductions. There are some small cost savings in the combined policies relative to separate nitrate and phosphorus-targeting policies, in addition to the slightly larger reductions achieved for both nutrients. The likely reason for this is that, due to the joint production impact of the two nutrients, expected yields are already impacted by reduction of one alone. Cost per ton of input is useful in comparing policies as a measure of input efficiency. However, it is the reduction in simulated output via SWAT that serves as the primary policy evaluation tool.

Appendix B contains more information on values used to compute some of the information reported in Table 6.4 and details on output from both the economic and SWAT models. Tables B.2 and B.3 report the main characteristics of the economic model and its simulations. Tables B.4 and B.5 provide detailed SWAT output measured at the watershed outlet for all of the scenarios.

6.4 Discussion

There are several interesting and notable features of these simulations. Among the more striking are the results for nitrogen reduction at the 10% level, summaries of which appear in the first three rows of Table 6.4. Although the application cap is the least efficient on the input side at a cost of $31.76 per ton of N input versus the uniform and tax/trading policies at $25.72 and $25.64, it achieves the greatest reduction in nitrate loading. This is likely due to spatial arrangement of points that are applying high nitrogen levels. With a large enough number of farms in runoff-susceptible areas applying at high levels, the cap is more efficient on the output side because these farms have a disproportionate influence on in-stream nutrient levels.

This result does not carry over to phosphorus targeting scenarios nor does it appear in the larger reductions. In the latter case it may be that stricter caps affect a larger portion of the sample and the spatial location of the heavy applications does not have the effect it does with looser caps.

However, in the instance of 10% N reductions the degree to which the cap is superior to other policies is not extremely large. Across policies (but within reduction levels) results do not vary greatly. This characteristic of the results is actually quite useful and suggests that the choice of policy in not necessarily critical, at least as it relates to loss of returns and water quality outcomes.

Another important characterstic of these policy simulations is not apparent from the watershed-scale results presented above. There is a great deal of spatial variation within and across scenarios at the subbasin level. This is of particular importance in examining policies targeting phosphorus application, as levels of that nutrient are the limiting factor in subbasin-scale or local water quality problems, particularly in lakes. The remainder of this chapter presents simulation outcomes at the subbasin level for phosphorus reductions.

Table 6.5 10-P Tax/trading scenario subbasin results

Subbasin	**Scenario 05**	**Subbasin**	**Scenario 05**
1	-3.60%	14	-4.06%
2	-3.54%	15	-2.41%
3	-3.80%	16	-3.15%
4	-2.87%	17	-3.64%
5	-4.34%	18	-2.46%
6	-4.81%	19	-3.69%
7	-3.08%	20	-2.70%
8	-4.24%	21	-3.78%
9	-2.61%	22	-3.31%
10	-4.81%	23	-2.30%
11	-3.87%	24	-5.92%
12	-3.36%	25	-2.15%
13	-3.70%	26	-2.96%

Table 6.5 lists the percentage changes in mineral P calculated at each subbasin's

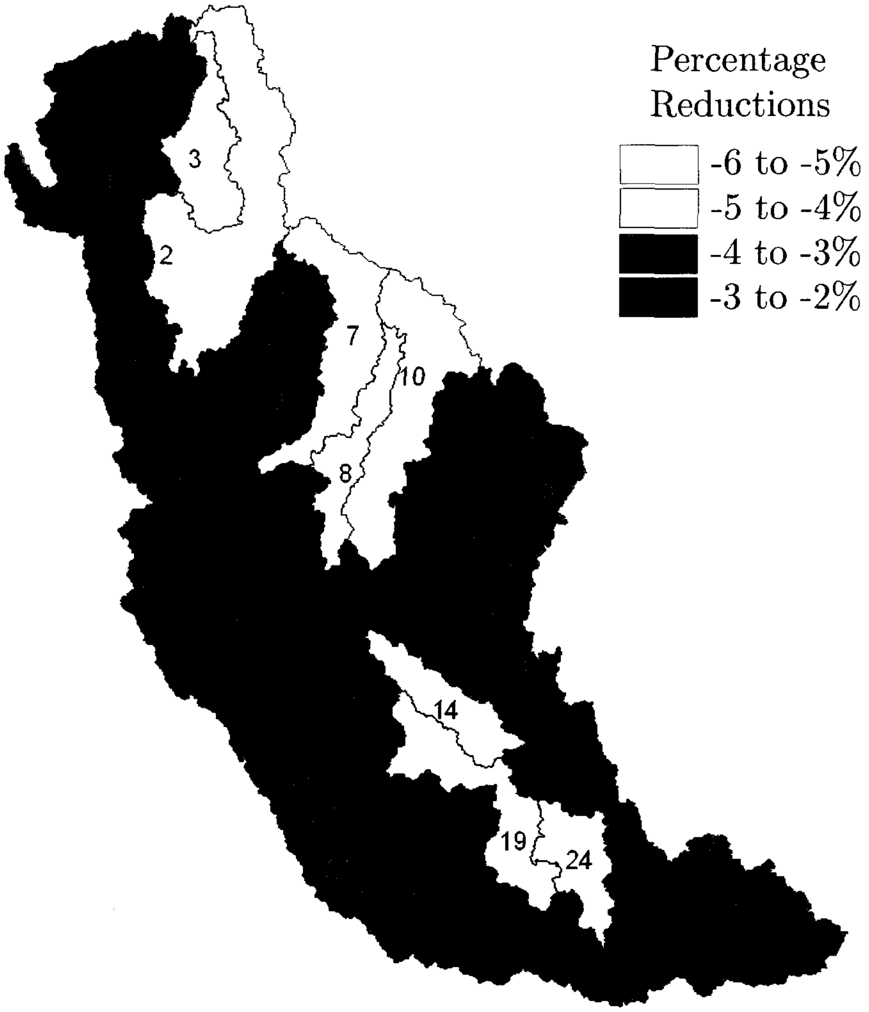


Figure 6.1 Subbasin-level Mineral P reductions, 10-P tax/trading scenario

outlet. While the outlet of the entire watershed (subbasin 25) indicates only a 2.15% reduction in load, it is apparent that much larger reductions occur in other parts of the watershed. There are several subbasins enjoying nearly 5% or greater reductions, and the watershed outlet appears to be one of the worst-performing areas. Figure 6.1 is a spatial representation of the information in Table 6.5 and shows which parts of the watershed experience smaller or larger reductions under the policy. There is some tendency for load reductions to be smaller near the outlet of the watershed, but even in lower reaches there can be larger reductions, for example in subbbasin 24.

Several subbasins contains lakes that experience varying states of impairment. Table 6.6 draws information from the Iowa Department of Natural Resources 303(d) lists of impaired waters [24], [25] and a water quality survey of Iowa's lakes [13]. These six lakes are each located within one of the 26 subbasins in the watershed, and the SWAT subbasin results can serve as an indicator of possible changes in water quality in the associated lake. The percentile rank rates each lake relative to others in Iowa—lower rank is poorer water quality. All of the lakes have been on the official lists of impaired waters (the absence of some in the 2004 list does not indicate that they are no longer impaired) and two have established TMDLs.

Table 6.6 Impairment rank of lakes in the Raccoon watershed

Lake	**Percentile rank**	**Subbasin location**	**Listed in 2002, 2004 303(d)**	**TMDL**
Swan Lake	1	16	yes, no	algae, turbidity
Black Hawk Lake	20	5	yes, yes	none
Storm Lake	40	1	yes, yes	turbidity
North Twin Lake	43	7	yes, no	none
Springbrook Lake	60	18	yes, no	none
Spring Lake	66	12	yes, yes	none

Table 6.7 Scenario results for lakes in the watershed, mineral P reductions

Lake	**Subbasin location**	**Scenario 04**	**Scenario 05**	**Scenario 06**
Swan Lake	16	-3.75%	-3.15%	-2.92%
Black Hawk Lake	5	-4.17%	-4.34%	-3.35%
Storm Lake	1	-3.54%	-3.60%	-2.94%
North Twin Lake	7	-4.85%	-3.08%	-3.89%
Springbrook Lake	18	-3.14%	-2.46%	-2.46%
Spring Lake	12	-3.65%	-3.36%	-2.79%

Table 6.7 lists the SWAT output associated with the three 10%-P reduction scenarios. There is a range of changes, but Swan Lake, the worst on the list in terms of impairment, has one of the smallest phosphorus reductions. North Twin Lake, near the middle of

the quality distribution for Iowa lakes, enjoys the greatest reductions. Interestingly, Scenario 04 (the uniform reduction) yields the greatest reduction for several of these subbasins/lake areas. For the rest of the lakes, however, the tax/trade policy (Scenario 05) gives the greatest subbasin reductions.

A full table of subbasin mineral P results are available in Appendix B, Table B.6 with accompanying maps in Figures B.1 through B.4. In some, there is a great deal of spatial variability across like-reduction policies, but in others there is very little. This is likely due to characteristics of the policy implementation that shift (or do not shift) the distribution of reductions across the input sample.

7. SUMMARY AND CONCLUSIONS

As major nonpoint contributors to impaired waters, agricultural application of nitrogen and phosphorus has an important impact on water quality. Because of this, development and analysis of policies designed to ameliorate nutrient-related water impairment is essential. This paper has presented a useful approximation of the effects of several possible policy avenues in the context of an actual watershed using both a hydrological model of nutrient transport in water and an economic model of policy impacts on agricultural production.

Summary of results

The costs of achieving nutrient reductions in the Raccoon watershed vary depending on the goal. Reductions of around 2% in phosphorus loads at the watershed outlet can be achieved by an approximate 10% decrease in phosphorus applications throughout the watershed under the most efficient policy. This comes at an estimated watershed-wide loss of nearly $100,000 in returns to nutrient application. There is a great deal of spatial variability in results within the watershed. Phosphorus reductions at the local or subbasin level can near 6% even when whole-watershed outlet reductions are in the 2% range. At larger levels of input reduction (roughly 20% reduction in whole-watershed application) greater decreases in phosphorus loads are realized. Watershed outlet improvements are in the area of 5% but subbasin improvements can attain over 10% reductions in phosphorus loading when the scale of analysis is the subbasin. The estimated watershed costs of this level of phosphorus reduction are slightly over $400,000–more than four times the cost of the smaller reduction. At the watershed outlet, policies involving a phosphorus tax or permit trading system are consistently more efficient than competing policies. This is not always the case when results are examined at the subbasin level.

Nitrate reduction policies are in general more costly but achieve larger percentage improvements in watershed outlet nitrate loading. An approximate 10% reduction in nitrogen application on the watershed leads to an estimated improvement of about 7% in nitrate load at the watershed outlet using the most efficient policy. Interestingly, the most efficient policy in terms of achieving nitrate reductions (an application rate cap) is not the most efficient in cost of input reduction. The cap is the most "expensive" in terms of the average cost of reducing a pound of nitrate application, but due to the spatial characteristics of the simulation sample, it achieves superior results at the outlet. Watershed-wide loss of returns at this level of input reduction is in the neighborhood of $160,000. Doubling the reductions in nitrogen application results in load reductions nearing 13% at the outlet under the most efficient policy, but with costs increasing to nearly $700,000. At these higher reduction levels, the application cap no longer dominates other policy options.

Policy scenarios that simultaneously target both nutrients are also considered. At low (10% input reduction) and high (20% input reduction) levels there are cost savings as compared to reducing only one nutrient. Reductions at the outlet are comparable or slightly superior to one-nutrient policies. A simultaneous 10% input reduction of nitrogen and phosphorus results in under $250,000 million in watershed losses while nitrogen and phosphorus-alone policy costs combine to over $250,000. The latter provides slightly inferior watershed outlet reductions for both nutrients. At the higher 20% reduction levels, the simultaneous policies are superior in cost (roughly $1 million for the watershed versus over $1.1 million) and outlet reductions.

Policy choice

These results have several implications for policy choice. First, there is relatively little variation in watershed outlet changes within policies given a fixed watershed cost level. Although some policies do offer slightly better performance than others, the difference in performance is not large. This suggests that other criteria can easily play a role in the choice of policy. For example, if an application rate cap is the easiest to implement but not necessarily the most efficient, very little will likely be lost if it is chosen in favor of an input tax or application right trading system.

Another important implication of the results is that the scale of analysis can play a major role. In the case of phosphorus reductions, small improvements at the watershed outlet do not tell the whole story. Improvements at the subbasin level are not only larger but also provide more information on localized water quality which is actually of more interest than at the full watershed scale due to the localized problems phosphorus loads create. This underlines the importance of modeling at a scale appropriate to the water quality changes needed or desired. Likewise, what may at first glance appear to be lackluster results can turn out to provide greater insight at other scales of analysis.

Future directions

There are many improvements and extensions that could be made to the analyses presented here. One assumption made in the construction of the economic model is that land-use change decisions are exogenous. Examples of these decisions are tillage method, crop rotation and use of other conservation practices such as grassed waterways. Modeling these jointly with nutrient application decisions would require a more complex economic model but would likely provide more flexibility for water quality improvements by supplying additional policy instruments. Water quality results would also improve when nutrient application reductions are combined with increased use of conservation practices.

Another application for this modeling framework is the allocation of nutrient reductions between point and nonpoint sources. The Raccoon watershed does not contain any large point sources of either nutrient, but the Des Moines Water Works does engage in costly nitrate reduction activity. The cost of 10% nitrate reductions is very close to the approximate annual nitrate scrubbing costs, suggesting an opportunity for an efficient tradeoff. It is possible that nitrate reductions could be more cheaply achieved by a combination of changes in agricultural application and the operation of nitrate removal filters. This would require a slightly different approach to the physical model, one which would deal with the peak nutrient events that trigger the need for nitrate removal.

A direct extension of the methods presented here is the application of the models to other watersheds. The approach is easily adapted to other watersheds in Iowa and with additional data could be applied to other parts of the corn belt with little modification. The general idea of aggregating nonpoint sources from a point-based economic model to a watershed-level analysis is an attractive proposition and could be employed in many analyses of nonpoint problems. Again, availability of data may pose significant challenges depending on the scale of the problem and the nature of the nonpoint sources.

A final possibility is a move to a dynamic framework. This would require a change in the way SWAT uses input files, as it is currently not designed to take more than one value over its run time for nutrient inputs. It may be possible to temporally daisy-chain SWAT runs with inputs that evolve over time, but this will require a great deal of testing and increase computational time and complexity.

APPENDIX A. DATA SET DETAILS

A.1 Fertilizer Prices

Table A.1 Fertilizer blend prices in \$/ton for North Central region (IL, IN, IA, MN, OH, MO), *1996-2001*

	Year					
Blend	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
0-15-40	186	182	189	195	183	189
3-10-30	170	164	165	178	168	173
6-24-24	232	225	228	233	223	222
8-32-16	249	240	235	234	224	225
9-23-30	220	210	214	215	202	208
10-20-10	207	217	206	200	202	202
10-34-0	252	251	254	252	244	261
11-52-0	307	278	273	272	249	251
13-13-13	223	223	210	208	209	235
16-0-13	171	175	160	131	176	185
18-46-0 (DAP)	297	277	266	267	243	247
19-19-19	244	232	218	217	210	235
Ammonium Nitrate	220	218	179	168	181	243
Anhydrous Ammonia	309	314	256	211	231	408
Nitrogen Solution, 28%	171	153	129	118	121	202
Nitrogen Solution, 32%	183	176	145	132	136	224
Sulfate of Ammonia	182	181	179	174	174	189
Urea	274	257	194	176	197	284

Table A.2 Distribution of fertilizer sales by blend, most popular straight materials

Blend (N-P-K)	Total Tons 2002-2003	Total Tons 2003-2004
82-0-0	564,635	646,954
34-0-0	21,365	21,865
21-0-0	10,326	12,914
12-0-0	7,593	8,334
46-0-0	235,291	242,306
28-0-0	396,329	374,274
32-0-0	405,687	572,844
8-24-0	8,835	8,957
10-34-0	41,066	41,478
11-52-0	208,105	229,773
18-46-0	408,989	465,795
0-46-0	3,513	4,552
0-0-61	775,038	958,577

Source: `http://www.agriculture.state.ia.us/fertilizertonreport.htm`

Table A.3 Distribution of fertilizer sales by blend, most popular blends

Blend (N-P-K)	Total Tons 2002-2003	Total Tons 2003-2004
2-6-35	20,816	22,912
3-10-30	22,119	22,337
3-18-18	1,721	1,384
4-10-10	4,996	6,196
6-24-6	4,137	3,236
7-18-6	3,545	3,134
7-21-7	5,375	4,907
8-19-3	2,229	2,046
9-18-9	4,185	5,814
9-23-30	2,162	1,976
10-34-8	2,931	*
13-13-13	1,396	1,276
28-3-3	1,246	1,690

*data not available for 2003-2004

Source: `http://www.agriculture.state.ia.us/fertilizertonreport.htm`

A.2 Output Prices

Table A.4 Corn prices, 1996-2001, Adair through Jasper counties

County	1996	1997	1998	1999	2000	2001
Adair	2.55	2.25	1.86	1.75	1.73	1.91
Adams	2.53	2.19	1.72	1.71	1.67	1.89
Allamakee	2.75	2.39	1.98	1.80	1.88	1.97
Appanoose	2.61	2.35	1.91	1.71	1.71	1.91
Audubon	2.57	2.35	1.79	1.66	1.68	1.84
Benton	2.72	2.52	2.01	1.85	1.84	1.99
Black Hawk	2.71	2.45	1.95	1.81	1.83	1.92
Boone	2.56	2.27	1.82	1.62	1.66	1.82
Bremer	2.64	2.35	1.88	1.76	1.75	1.92
Buchanan	2.62	2.44	1.84	1.76	1.85	1.92
Buena Vista	2.45	2.23	1.83	1.62	1.69	1.85
Butler	2.61	2.39	1.88	1.73	1.75	1.89
Calhoun	2.57	2.34	1.80	1.66	1.71	1.83
Carroll	2.52	2.29	1.81	1.72	1.70	1.82
Cass	2.59	2.30	1.81	1.67	1.76	1.90
Cedar	2.72	2.50	1.96	1.81	1.89	1.97
Cerro Gordo	2.47	2.30	1.79	1.70	1.65	1.84
Cherokee	2.58	2.29	1.80	1.62	1.64	1.82
Chickasaw	2.65	2.29	1.88	1.73	1.74	1.89
Clarke	2.52	2.31	1.82	1.67	1.81	1.96
Clay	2.47	2.24	1.77	1.60	1.71	1.87
Clayton	2.66	2.37	1.92	1.74	1.83	1.93
Clinton	2.76	2.46	2.01	1.85	1.85	2.00
Crawford	2.45	2.24	1.80	1.68	1.73	1.85
Dallas	2.58	2.32	1.87	1.69	1.70	1.87
Davis	2.70	2.46	1.89	1.75	1.75	1.94
Decatur	2.52	2.34	1.81	1.69	1.75	1.90
Delaware	2.77	2.38	1.95	1.80	1.85	1.91
Des Moines	2.79	2.49	2.05	1.81	1.88	2.03
Dickinson	2.51	2.29	1.80	1.65	1.66	1.87
Dubuque	2.68	2.38	1.94	1.77	1.85	1.98
Emmet	2.53	2.28	1.71	1.63	1.66	1.86
Fayette	2.63	2.35	1.84	1.79	1.84	1.98
Floyd	2.58	2.30	1.85	1.72	1.65	1.88
Franklin	2.45	2.25	1.80	1.69	1.74	1.86
Fremont	2.77	2.40	1.90	1.80	1.83	1.98
Greene	2.50	2.28	1.81	1.66	1.68	1.85
Grundy	2.53	2.30	1.90	1.67	1.76	1.89
Guthrie	2.66	2.35	1.86	1.66	1.71	1.86
Hamilton	2.51	2.21	1.78	1.66	1.69	1.82
Hancock	2.51	2.24	1.83	1.69	1.71	1.86
Hardin	2.51	2.31	1.88	1.69	1.74	1.87
Harrison	2.62	2.38	1.82	1.69	1.67	1.85
Henry	2.70	2.45	2.02	1.86	1.84	2.05
Howard	2.59	2.30	1.85	1.77	1.70	1.89
Humboldt	2.63	2.33	1.78	1.72	1.72	1.88
Ida	2.48	2.25	1.86	1.62	1.71	1.82
Iowa	2.65	2.44	2.01	1.80	1.87	1.97
Jackson	2.72	2.44	1.98	1.76	1.83	1.99
Jasper	2.66	2.37	1.93	1.74	1.78	1.93

Table A.5 Corn prices, 1996-2001, Jefferson through Wright counties

County	1996	1997	1998	1999	2000	2001
Jefferson	2.77	2.45	1.98	1.81	1.81	2.00
Johnson	2.73	2.43	1.98	1.87	1.79	1.98
Jones	2.61	2.41	1.94	1.83	1.86	1.99
Keokuk	2.79	2.45	2.00	1.78	1.86	2.02
Kossuth	2.48	2.23	1.75	1.68	1.70	1.88
Lee	2.72	2.51	1.99	1.86	1.96	2.11
Linn	2.81	2.58	1.91	1.77	1.88	2.01
Louisa	2.80	2.52	2.03	1.81	1.96	2.11
Lucas	2.68	2.32	1.92	1.71	1.96	2.12
Lyon	2.46	2.22	1.70	1.59	1.61	1.83
Madison	2.49	2.29	1.78	1.67	1.77	1.90
Mahaska	2.80	2.44	1.89	1.78	1.88	2.03
Marion	2.65	2.29	1.78	1.70	1.79	1.94
Marshall	2.75	2.43	1.90	1.75	1.76	1.89
Mills	2.62	2.33	1.81	1.75	1.70	1.90
Mitchell	2.69	2.33	1.79	1.70	1.72	1.89
Monona	2.54	2.28	1.74	1.62	1.67	1.81
Monroe	2.58	2.36	1.90	1.71	1.96	2.08
Montgomery	2.55	2.23	1.78	1.66	1.74	1.88
Muscatine	2.71	2.48	1.97	1.76	1.90	1.98
O'Brien	2.50	2.25	1.77	1.61	1.68	1.88
Osceola	2.51	2.29	1.71	1.61	1.69	1.89
Page	2.66	2.34	1.91	1.82	1.78	1.96
Palo Alto	2.56	2.28	1.80	1.71	1.75	1.89
Plymouth	2.55	2.25	1.80	1.59	1.71	1.86
Pocahontas	2.52	2.30	1.79	1.67	1.71	1.88
Polk	2.56	2.33	1.91	1.73	1.71	1.87
Pottawattamie	2.51	2.20	1.81	1.75	1.74	1.90
Poweshiek	2.54	2.34	1.91	1.77	1.75	1.91
Ringgold	2.56	2.34	1.79	1.79	1.87	2.02
Sac	2.53	2.27	1.79	1.61	1.71	1.81
Scott	2.76	2.47	1.95	1.82	1.89	2.01
Shelby	2.54	2.29	1.73	1.68	1.69	1.80
Sioux	2.57	2.27	1.77	1.63	1.71	1.85
Story	2.60	2.33	1.87	1.70	1.71	1.88
Tama	2.64	2.42	2.01	1.78	1.82	1.95
Taylor	2.52	2.18	1.83	1.78	1.75	1.89
Union	2.56	2.27	1.83	1.71	1.79	1.96
Van Buren	2.82	2.50	1.92	1.79	1.85	2.00
Wapello	2.66	2.36	1.88	1.73	1.78	1.96
Warren	2.65	2.32	1.86	1.69	1.77	1.92
Washington	2.72	2.42	1.99	1.78	1.78	1.97
Wayne	2.48	2.28	1.82	1.66	1.71	1.90
Webster	2.60	2.29	1.81	1.71	1.66	1.82
Winnebago	2.53	2.23	1.84	1.69	1.72	1.88
Winneshiek	2.72	2.39	1.95	1.76	1.72	1.90
Woodbury	2.53	2.27	1.78	1.61	1.68	1.81
Worth	2.52	2.30	1.83	1.69	1.73	1.87
Wright	2.58	2.29	1.82	1.63	1.71	1.87

Table A.6 Soybean prices, 1996-2001, Adair through Jasper counties

County	1996	1997	1998	1999	2000	2001
Adair	7.30	6.26	4.78	4.60	4.55	4.36
Adams	7.23	6.23	4.84	4.56	4.48	4.31
Allamakee	7.35	6.43	5.06	4.59	4.59	4.46
Appanoose	7.32	6.31	4.78	4.46	4.41	4.30
Audubon	7.34	6.29	4.80	4.50	4.46	4.34
Benton	7.47	6.41	4.83	4.60	4.52	4.36
Black Hawk	7.28	6.34	4.90	4.60	4.49	4.38
Boone	7.28	6.32	4.82	4.57	4.49	4.36
Bremer	7.34	6.36	4.78	4.59	4.43	4.39
Buchanan	7.36	6.35	4.87	4.59	4.50	4.40
Buena Vista	7.45	6.31	4.71	4.49	4.46	4.34
Butler	7.42	6.36	4.82	4.64	4.57	4.35
Calhoun	7.41	6.26	4.75	4.51	4.45	4.28
Carroll	7.42	6.28	4.81	4.48	4.38	4.26
Cass	7.30	6.32	4.77	4.60	4.51	4.33
Cedar	7.52	6.43	4.91	4.58	4.62	4.36
Cerro Gordo	7.26	6.39	4.79	4.64	4.58	4.38
Cherokee	7.20	6.31	4.76	4.49	4.46	4.32
Chickasaw	7.45	6.38	4.79	4.51	4.40	4.42
Clarke	7.17	6.23	4.67	4.51	4.38	4.27
Clay	7.27	6.29	4.84	4.42	4.45	4.33
Clayton	7.27	6.33	5.02	4.56	4.49	4.42
Clinton	7.50	6.35	4.94	4.51	4.60	4.41
Crawford	7.18	6.27	4.87	4.55	4.35	4.16
Dallas	7.42	6.35	4.81	4.60	4.48	4.41
Davis	7.58	6.44	4.77	4.60	4.51	4.43
Decatur	7.15	6.20	4.69	4.46	4.39	4.28
Delaware	7.59	6.55	4.97	4.64	4.57	4.47
Des Moines	7.78	6.55	4.95	4.66	4.62	4.46
Dickinson	7.40	6.33	4.68	4.48	4.46	4.35
Dubuque	7.44	6.51	5.03	4.62	4.55	4.43
Emmet	7.43	6.31	4.67	4.50	4.48	4.31
Fayette	7.31	6.31	4.91	4.61	4.56	4.44
Floyd	7.42	6.32	4.71	4.60	4.42	4.36
Franklin	7.25	6.29	4.71	4.59	4.44	4.33
Fremont	7.39	6.35	4.84	4.58	4.57	4.35
Greene	7.34	6.30	4.80	4.55	4.49	4.35
Grundy	7.30	6.33	4.75	4.52	4.45	4.30
Guthrie	7.50	6.35	4.88	4.50	4.47	4.34
Hamilton	7.43	6.34	4.71	4.48	4.45	4.33
Hancock	7.30	6.33	4.79	4.56	4.42	4.29
Hardin	7.27	6.33	4.81	4.51	4.46	4.33
Harrison	7.26	6.32	4.85	4.59	4.47	4.29
Henry	7.57	6.49	4.98	4.68	4.57	4.43
Howard	7.24	6.28	4.77	4.59	4.42	4.43
Humboldt	7.37	6.32	4.70	4.56	4.47	4.35
Ida	7.30	6.28	4.91	4.48	4.43	4.30
Iowa	7.38	6.41	4.83	4.60	4.56	4.46
Jackson	7.39	6.40	4.92	4.54	4.50	4.39
Jasper	7.42	6.39	4.83	4.54	4.59	4.33

Table A.7 Soybean prices, 1996-2001, Jefferson through Wright counties

County	1996	1997	1998	1999	2000	2001
Jefferson	7.46	6.39	4.87	4.62	4.57	4.45
Johnson	7.58	6.50	4.81	4.60	4.51	4.42
Jones	7.40	6.44	4.96	4.50	4.63	4.48
Keokuk	7.50	6.44	4.75	4.66	4.51	4.46
Kossuth	7.38	6.29	4.68	4.51	4.47	4.37
Lee	7.61	6.50	4.90	4.65	4.66	4.53
Linn	7.64	6.53	4.86	4.58	4.65	4.49
Louisa	7.79	6.46	4.96	4.66	4.63	4.43
Lucas	7.28	6.27	4.81	4.46	4.45	4.24
Lyon	7.21	6.22	4.66	4.46	4.37	4.22
Madison	7.38	6.36	4.79	4.51	4.53	4.32
Mahaska	7.54	6.33	4.80	4.62	4.64	4.49
Marion	7.36	6.24	4.71	4.52	4.41	4.26
Marshall	7.25	6.32	4.84	4.56	4.45	4.27
Mills	7.32	6.37	4.83	4.60	4.53	4.37
Mitchell	7.22	6.28	4.69	4.59	4.43	4.30
Monona	7.21	6.27	4.82	4.55	4.44	4.28
Monroe	7.27	6.27	4.76	4.46	4.45	4.31
Montgomery	7.28	6.25	4.81	4.57	4.51	4.33
Muscatine	7.69	6.46	4.83	4.68	4.56	4.48
O'Brien	7.44	6.33	4.71	4.44	4.40	4.27
Osceola	7.21	6.30	4.67	4.47	4.43	4.31
Page	7.31	6.36	4.80	4.60	4.56	4.40
Palo Alto	7.32	6.33	4.73	4.53	4.48	4.36
Plymouth	7.16	6.27	4.88	4.46	4.48	4.34
Pocahontas	7.40	6.30	4.69	4.52	4.50	4.36
Polk	7.43	6.38	4.81	4.60	4.49	4.40
Pottawattamie	7.28	6.22	4.76	4.60	4.64	4.35
Poweshiek	7.43	6.36	4.84	4.62	4.50	4.36
Ringgold	7.23	6.27	4.76	4.58	4.50	4.31
Sac	7.36	6.26	4.78	4.50	4.44	4.33
Scott	7.72	6.49	4.92	4.64	4.63	4.47
Shelby	7.25	6.28	4.75	4.50	4.46	4.29
Sioux	7.10	6.19	4.82	4.45	4.37	4.29
Story	7.35	6.32	4.74	4.51	4.47	4.33
Tama	7.38	6.39	4.88	4.59	4.51	4.36
Taylor	7.21	6.21	4.75	4.64	4.56	4.36
Union	7.28	6.26	4.80	4.46	4.45	4.29
Van Buren	7.81	6.55	4.83	4.63	4.52	4.46
Wapello	7.61	6.42	4.81	4.54	4.49	4.43
Warren	7.20	6.21	4.85	4.47	4.50	4.29
Washington	7.49	6.43	4.83	4.65	4.54	4.46
Wayne	7.01	6.18	4.68	4.48	4.35	4.22
Webster	7.39	6.32	4.74	4.53	4.48	4.32
Winnebago	7.33	6.29	4.81	4.59	4.47	4.34
Winneshiek	7.32	6.39	4.92	4.56	4.49	4.45
Woodbury	7.23	6.26	4.79	4.45	4.42	4.31
Worth	7.29	6.35	4.70	4.46	4.42	4.31
Wright	7.38	6.35	4.75	4.57	4.47	4.31

APPENDIX B. SIMULATION RESULTS

Table B.1 Baseline model data by subwatershed, annual measures

Subbasin	Area drained (km^2)	Flow (m^3/s)	Sediment (tons)	Organic N (kg)	Organic P (kg)	NO_3 (kg)	NH_4 (kg)	Mineral P (kg)
1	895	10.34	716,300	1,715,000	299,300	890,300	390,200	183,500
2	1,137	5.29	17,060	862,500	151,200	336,800	159,900	73,500
3	220	1.18	67,380	222,300	39,560	119,500	41,730	20,540
4	6,406	24.12	168,800	3,521,000	561,600	2,283,000	1,125,000	536,700
5	224	1.38	95,730	307,500	55,250	188,900	48,820	23,260
6	385	2.22	116,100	405,500	74,000	255,900	58,460	28,510
7	331	1.89	74,030	281,600	51,630	199,600	39,640	19,810
8	189	1.07	41,500	174,400	31,910	113,100	22,490	11,330
9	13,550	40.90	300,300	5,329,000	809,200	4,041,000	2,022,000	1,036,000
10	424	2.42	101,700	370,400	67,840	251,900	53,620	26,630
11	450	4.48	276,300	836,400	151,300	378,500	149,900	75,990
12	769	5.46	40,110	945,800	165,400	461,200	216,400	104,100
13	196	1.95	109,700	364,400	66,190	169,200	61,170	31,370
14	186	1.82	106,400	345,700	61,890	167,700	59,260	30,070
15	19,800	45.23	223,300	5,018,000	706,600	4,643,000	2,335,000	1,288,000
16	654	4.38	380,400	865,800	154,000	574,700	182,300	87,820
17	319	3.09	224,900	611,600	109,200	276,100	109,700	53,610
18	2,229	9.32	46,550	1,386,000	222,200	1,008,000	504,000	219,600
19	301	1.99	78,280	276,300	51,340	207,900	37,720	20,060
20	1,669	6.61	21,700	920,700	151,500	777,000	328,300	140,900
21	319	2.19	137,600	244,600	46,580	233,700	36,000	17,470
22	374	2.46	522,000	710,100	127,100	347,600	155,300	68,810
23	7,363	19.81	117,000	2,409,000	361,200	2,242,000	924,000	509,300
24	176	1.04	46,580	187,200	33,720	79,340	26,550	13,510
25	36,820	65.65	358,800	6,320,000	829,900	7,527,000	3,605,000	2,049,000
26	210	0.58	36,070	145,100	26,280	87,050	21,660	10,810

Table B.2 Input scenario characteristics

Scenario	**Mean N app (lbs/ac)**	**Mean P app (lbs/ac)**	**Mean Yield (bu/ac)**	**Mean Returns ($/ac)**	**N Cap (lbs/ac)**	**P Cap (lbs/ac)**	**Tax (%)**	**N Tax or permit price ($/cwt)**	**P Tax or permit price ($/cwt)**
Baseline	135.48	66.17	152.41	298.58					
10% N	121.93	66.17	150.92	298.42					
10-N Tax	121.89	65.49	150.83	295.49			10.00%	$2.40	
10-N Cap	124.79	66.17	151.23	298.43	133.18				
10-N Trading	121.89	65.49	150.83	298.42	122.41			$2.40	
10% P	135.48	59.56	151.55	298.48					
10-P Tax	134.64	59.54	151.46	296.72			10.46%		$2.96
10-P Cap	135.48	60.95	151.73	298.49		65.05			
10-P Trading	134.64	59.54	151.46	298.48		59.79			$2.96
20% N	108.39	66.17	149.28	297.90					
20-N Tax	108.31	64.74	149.09	292.08			22.37%	$5.37	
20-N Cap	112.43	66.17	149.71	297.91	115.78				
20-N Trading	108.31	64.74	149.09	297.90	108.77			$5.37	
20% P	135.48	52.94	150.60	298.17					
20-P Tax	133.70	52.90	150.41	294.66			23.45%		$6.64
20-P Cap	135.48	54.92	150.85	298.18		56.56			
20-P Trading	133.70	52.90	150.41	298.17		53.12			$6.64
10% N+P	121.93	59.56	150.07	298.34					
10-NP Tax	121.93	59.56	150.07	294.00			9.41%	$2.26	$2.66
10-NP Cap	124.80	60.94	150.55	298.35	133.19	65.04			
10-NP Trading	121.93	59.56	150.07	298.34	122.45	59.81		$2.26	
20% N+P	108.39	52.94	147.51	297.58					
20-NP Tax	108.39	52.94	147.51	288.97			20.98%	$5.04	$5.94
20-NP Cap	112.43	54.90	148.19	297.60	115.78	56.53			
20-NP Trading	108.39	52.94	147.51	297.58	108.84	53.16		$5.04	

Table B.3 Input scenario characteristics

Scenario	Tax Revenue	Pretax returns	Total returns	N appl (tons)	P appl (tons)	Cost of policy	Cost per ton of N	Cost per ton of P
Baseline			$305,565,012	62,711	30,630			
10% N			$305,403,743	56,440	30,630	$161,269	$ 25.72	
10-N Tax	$2,993,763	$302,409,980	$305,403,742	56,421	30,314	$161,270	$ 25.64	
10-N Cap			$305,403,742	57,633	30,630	$161,270	$ 31.76	
10-N Trading			$305,403,742	56,421	30,314	$161,270	$ 25.64	
10% P			$305,467,959	62,711	27,567	$97,053		$ 31.69
10-P Tax	$1,802,972	$303,664,987	$305,467,957	62,321	27,558	$97,055		$ 31.59
10-P Cap			$305,467,966	62,711	28,151	$97,046		$ 39.14
10-P Trading			$305,467,957	62,321	27,558	$97,055		$ 31.59
20% N			$304,871,346	50,169	30,630	$693,666	$ 55.31	
20-N Tax	$5,950,923	$298,920,423	$304,871,358	50,132	29,964	$693,654	$ 55.15	
20-N Cap			$304,871,365	51,895	30,630	$693,647	$ 64.13	
20-N Trading			$304,871,358	50,132	29,964	$693,654	$ 55.15	
20% P			$305,146,896	62,711	24,504	$418,117		$ 68.25
20-P Tax	$3,592,693	$301,554,202	$305,146,882	61,888	24,486	$418,130		$ 68.06
20-P Cap			$305,146,916	62,711	25,349	$418,096		$ 79.17
20-P Trading			$305,146,882	61,888	24,486	$418,130		$ 68.06
10% N+P			$305,326,314	56,440	27,567	$238,698	$ 38.06	$ 77.93
10-NP Tax	$4,440,891	$300,885,423	$305,326,334	56,440	27,567	$238,678	$ 38.06	$ 77.93
10-NP Cap			$305,326,315	57,636	28,145	$238,697	$ 47.03	$ 96.07
10-NP Trading			$305,326,334	56,440	27,567	$238,678	$ 38.06	$ 77.93
20% N+P			$304,540,497	50,169	24,504	$1,024,515	$ 81.69	$ 167.24
20-NP Tax	$8,802,007	$295,738,490	$304,540,496	50,169	24,504	$1,024,516	$ 81.69	$ 167.24
20-NP Cap			$304,540,495	51,894	25,341	$1,024,517	$ 94.72	$ 193.73
20-NP Trading			$304,540,496	50,169	24,504	$1,024,516	$ 81.69	$ 167.24

Table B.4 SWAT simulation output

Scenario	**Flow (m^3/sec)**	**Sediment (tons)**	**Sediment Concentration (mg/kg)**	**Organic N (kg)**	**Organic P (kg)**	**NO_3 (kg)**	**NH_4 (kg)**	**NO_2 (kg)**	**Mineral P (kg)**
Baseline	65.06	358,800	56.63	6,320,000	829,900	7,527,000	3,605,000	1,335,000	2,049,000
10% N	65.24	361,100	56.83	6,252,000	832,200	7,080,000	3,566,000	1,325,000	2,051,000
10-N Tax/Trading	65.28	359,700	56.69	6,214,000	829,400	7,023,000	3,546,000	1,317,000	2,040,000
10-N Cap	65.21	360,000	56.71	6,217,000	830,200	6,994,000	3,544,000	1,317,000	2,044,000
10% P	65.03	358,600	56.59	6,318,000	823,800	7,509,000	3,604,000	1,333,000	2,001,000
10-P Tax/Trading	64.96	359,300	56.68	6,330,000	825,700	7,482,000	3,599,000	1,335,000	2,005,000
10-P Cap	65.07	358,900	56.63	6,326,000	826,000	7,514,000	3,610,000	1,335,000	2,010,000
20% N	65.35	361,000	56.82	6,130,000	830,400	6,544,000	3,483,000	1,301,000	2,041,000
20-N Tax/Trading	65.27	359,900	56.69	6,107,000	826,000	6,537,000	3,473,000	1,297,000	2,026,000
20-N Cap	65.44	361,100	56.82	6,151,000	831,400	6,601,000	3,497,000	1,306,000	2,043,000
20% P	65.06	359,200	56.68	6,331,000	819,100	7,548,000	3,611,000	1,336,000	1,958,000
20-P Tax/Trading	65.08	359,500	56.73	6,321,000	819,900	7,452,000	3,601,000	1,334,000	1,957,000
20-P Cap	65.05	359,500	56.69	6,334,000	821,700	7,488,000	3,612,000	1,337,000	1,968,000
10% N+P	65.19	359,900	56.70	6,208,000	822,900	7,015,000	3,531,000	1,315,000	1,995,000
10-NP Tax/Trading	65.19	360,000	56.73	6,220,000	824,100	7,055,000	3,547,000	1,317,000	1,999,000
10-NP Cap	65.24	360,000	56.73	6,220,000	824,100	7,055,000	3,547,000	1,317,000	1,999,000
20% N+P	65.31	360,600	56.78	6,116,000	816,700	6,556,000	3,478,000	1,299,000	1,945,000
20-NP Tax/Trading	65.31	360,600	56.77	6,115,000	816,700	6,557,000	3,478,000	1,299,000	1,944,000
20-NP Cap	65.35	360,600	56.75	6,153,000	820,900	6,583,000	3,508,000	1,306,000	1,958,000

Table B.5 Comparison of SWAT simulation output

Scenario	**% change Organic N (kg)**	**% change Organic P (kg)**	**% change NO_3 (kg)**	**% change NH_4 (kg)**	**% change NO_2 (kg)**	**% change Mineral P (kg)**
Baseline						
10% N	-1.08%	0.28%	-5.94%	-1.08%	-0.75%	0.10%
10-N Tax/Trading	-1.68%	-0.06%	-6.70%	-1.64%	-1.35%	-0.44%
10-N Cap	-1.63%	0.04%	-7.08%	-1.69%	-1.35%	-0.24%
10% P	-0.03%	-0.74%	-0.24%	-0.03%	-0.15%	-2.34%
10-P Tax/Trading	0.16%	-0.51%	-0.60%	-0.17%	0.00%	-2.15%
10-P Cap	0.09%	-0.47%	-0.17%	0.14%	0.00%	-1.90%
20% N	-3.01%	0.06%	-13.06%	-3.38%	-2.55%	-0.39%
20-N Tax/Trading	-3.37%	-0.47%	-13.15%	-3.66%	-2.85%	-1.12%
20-N Cap	-2.67%	0.18%	-12.30%	-3.00%	-2.17%	-0.29%
20% P	0.17%	-1.30%	0.28%	0.17%	0.07%	-4.44%
20-P Tax/Trading	0.02%	-1.20%	-1.00%	-0.11%	-0.07%	-4.49%
20-P Cap	0.22%	-0.99%	-0.52%	0.19%	0.15%	-3.95%
10% N+P	-1.77%	-0.84%	-6.80%	-2.05%	-1.50%	-2.64%
10-NP Tax/Trading	-1.58%	-0.70%	-6.27%	-1.61%	-1.35%	-2.44%
10-NP Cap	-1.58%	-0.70%	-6.27%	-1.61%	-1.35%	-2.44%
20% N+P	-3.23%	-1.59%	-12.90%	-3.52%	-2.70%	-5.08%
20-NP Tax/Trading	-3.24%	-1.59%	-12.89%	-3.52%	-2.70%	-5.12%
20-NP Cap	-2.64%	-1.08%	-12.54%	-2.69%	-2.17%	-4.44%

Table B.6 Mineral P reductions by subbasin, all P-related scenarios

	Scenario											
Subbasin	**04**	**05**	**06**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1	-3.54%	-3.60%	-2.94%	-7.08%	-7.08%	-6.27%	-4.20%	-3.81%	-3.81%	-8.07%	-8.07%	-6.98%
2	-4.31%	-3.54%	-3.32%	-7.43%	-7.21%	-6.61%	-4.07%	-4.35%	-4.35%	-8.61%	-8.61%	-7.58%
3	-4.92%	-3.80%	-3.89%	-8.23%	-7.55%	-7.21%	-4.19%	-4.92%	-4.92%	-9.35%	-9.35%	-8.18%
4	-3.02%	-2.87%	-2.38%	-5.65%	-5.72%	-4.97%	-3.39%	-3.26%	-3.26%	-6.54%	-6.54%	-5.68%
5	-4.17%	-4.34%	-3.35%	-7.87%	-7.22%	-7.27%	-4.86%	-4.39%	-4.39%	-8.99%	-8.99%	-8.04%
6	-4.35%	-4.81%	-4.17%	-8.56%	-8.87%	-7.75%	-5.86%	-5.93%	-5.93%	-9.61%	-9.61%	-9.26%
7	-4.85%	-3.08%	-3.89%	-7.22%	-8.88%	-7.27%	-5.35%	-5.50%	-5.50%	-9.24%	-9.24%	-8.33%
8	-3.71%	-4.24%	-3.27%	-8.21%	-8.21%	-7.86%	-5.74%	-4.94%	-4.94%	-10.15%	-10.15%	-7.77%
9	-2.70%	-2.61%	-2.22%	-5.11%	-5.37%	-4.61%	-3.09%	-2.90%	-2.90%	-5.97%	-5.97%	-5.35%
10	-4.99%	-4.81%	-4.24%	-8.26%	-9.13%	-7.51%	-5.82%	-5.56%	-5.56%	-10.14%	-10.14%	-8.94%
11	-4.09%	-3.87%	-4.43%	-7.72%	-8.54%	-7.70%	-4.71%	-4.83%	-4.83%	-9.41%	-9.41%	-9.01%
12	-3.65%	-3.36%	-2.79%	-6.61%	-7.23%	-6.16%	-3.65%	-3.27%	-3.27%	-7.68%	-7.68%	-7.59%
13	-4.56%	-3.70%	-4.34%	-7.81%	-8.32%	-7.27%	-4.91%	-4.88%	-4.88%	-9.31%	-9.31%	-9.21%
14	-3.59%	-4.06%	-3.39%	-8.65%	-8.08%	-6.82%	-4.79%	-4.59%	-4.59%	-9.08%	-9.08%	-8.21%
15	-2.56%	-2.41%	-2.10%	-4.74%	-4.89%	-4.19%	-2.80%	-2.64%	-2.64%	-5.43%	-5.43%	-4.89%
16	-3.75%	-3.15%	-2.92%	-7.29%	-7.07%	-6.47%	-4.13%	-3.97%	-3.97%	-8.19%	-8.19%	-7.12%
17	-4.50%	-3.64%	-3.53%	-8.34%	-7.41%	-7.18%	-4.94%	-4.63%	-4.63%	-8.93%	-8.93%	-8.11%
18	-3.14%	-2.46%	-2.46%	-5.92%	-5.60%	-5.19%	-3.37%	-3.10%	-3.10%	-6.47%	-6.47%	-5.65%
19	-4.89%	-3.69%	-4.29%	-8.67%	-6.53%	-6.83%	-5.78%	-4.09%	-4.09%	-10.27%	-10.27%	-8.42%
20	-2.63%	-2.70%	-2.41%	-5.18%	-5.25%	-4.97%	-3.12%	-3.05%	-3.05%	-6.03%	-6.03%	-5.46%
21	-3.72%	-3.78%	-3.43%	-7.33%	-7.38%	-7.27%	-4.46%	-4.41%	-4.41%	-8.64%	-8.64%	-7.61%
22	-3.28%	-3.31%	-2.86%	-6.44%	-6.48%	-6.02%	-3.69%	-3.66%	-3.66%	-7.16%	-7.16%	-6.69%
23	-2.69%	-2.30%	-2.18%	-5.07%	-4.83%	-4.56%	-2.98%	-2.83%	-2.83%	-5.77%	-5.77%	-4.93%
24	-4.89%	-5.92%	-3.55%	-9.18%	-10.14%	-8.88%	-6.37%	-7.11%	-7.11%	-11.92%	-11.92%	-8.07%
25	-2.34%	-2.15%	-1.90%	-4.44%	-4.49%	-3.95%	-2.64%	-2.44%	-2.44%	-5.08%	-5.12%	-4.44%
26	-4.53%	-2.96%	-3.89%	-7.53%	-7.31%	-6.66%	-4.26%	-4.07%	-4.07%	-8.78%	-8.77%	-7.22%
Minimum	-2.34%	-2.15%	-1.90%	-4.44%	-4.49%	-3.95%	-2.64%	-2.44%	-2.44%	-5.08%	-5.12%	-4.44%
Maximum	-4.99%	-5.92%	-4.43%	-9.18%	-10.14%	-8.88%	-6.37%	-7.11%	-7.11%	-11.92%	-11.92%	-9.26%

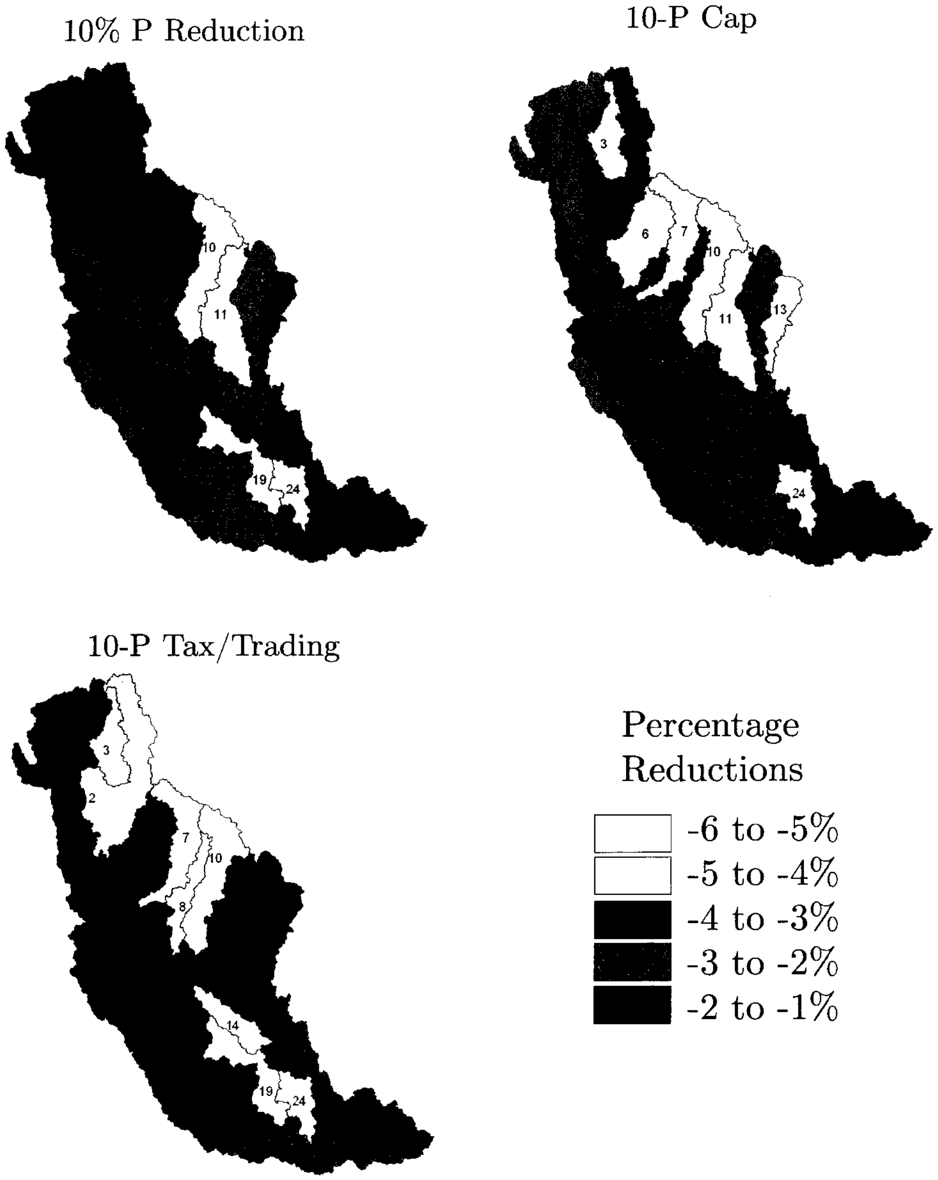
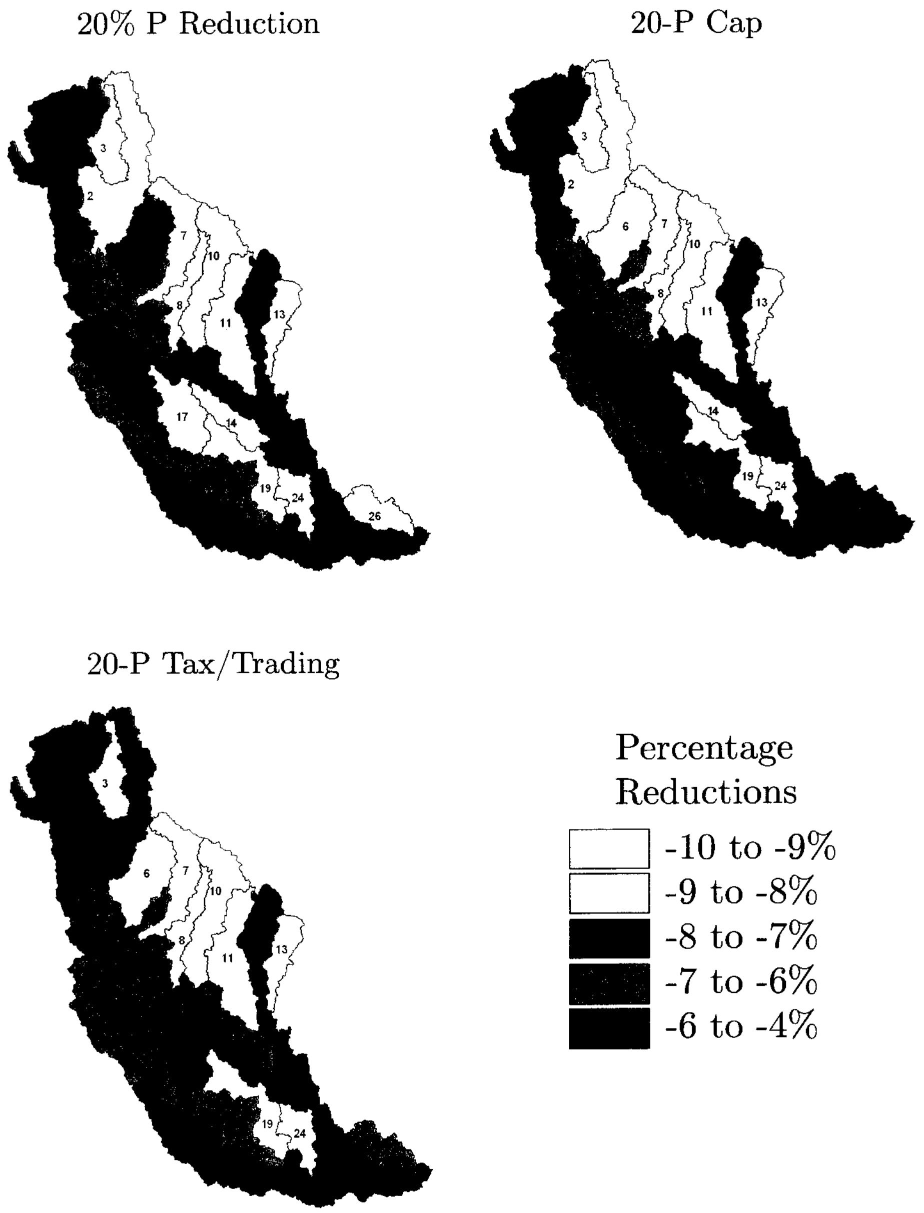


Figure B.1 Subbasin comparison, 10-P scenarios



20% P Reduction

20-P Cap

20-P Tax/Trading

Figure B.2 Subbasin comparison, 20-P scenarios

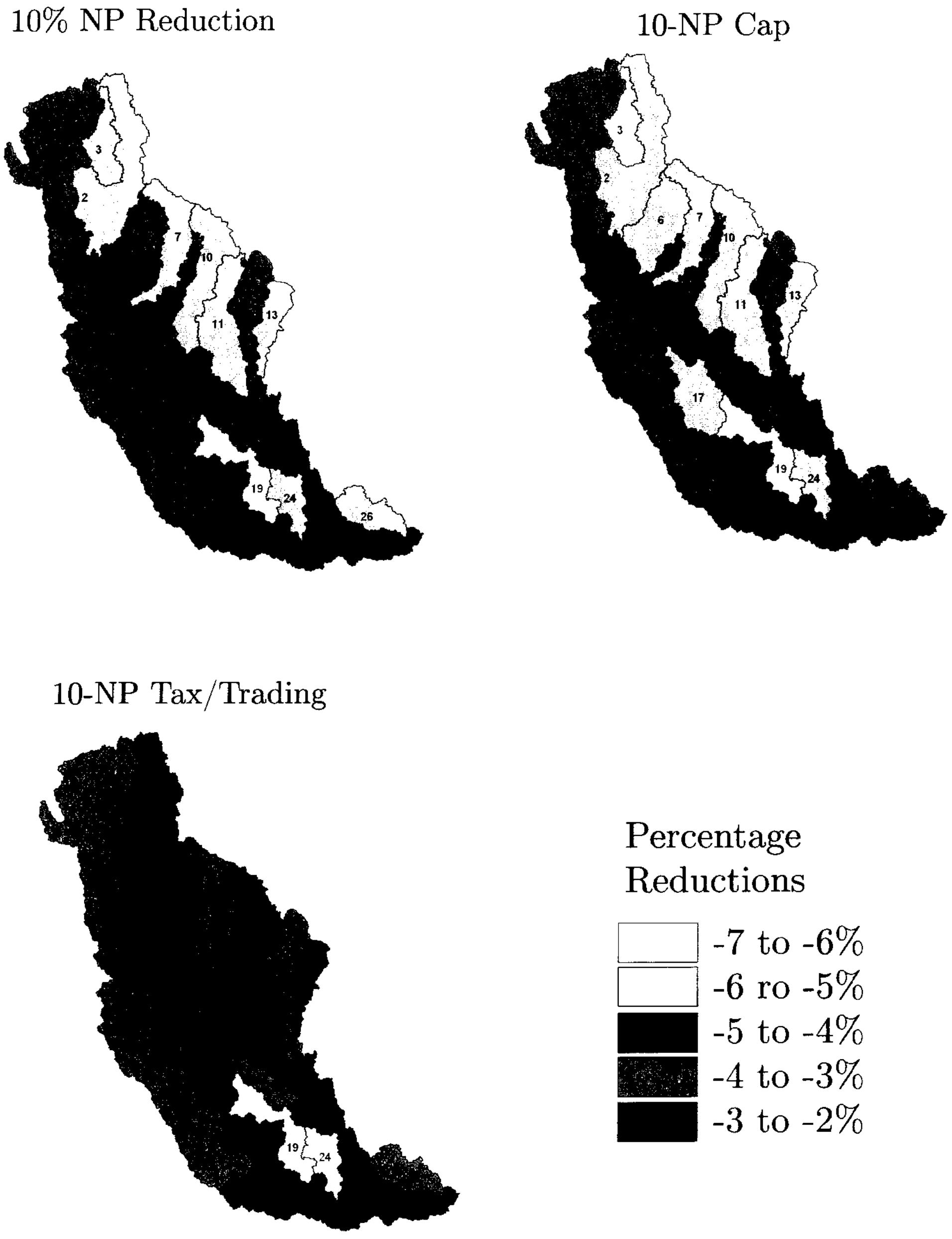


Figure B.3 Subbasin comparison, 10-NP scenarios

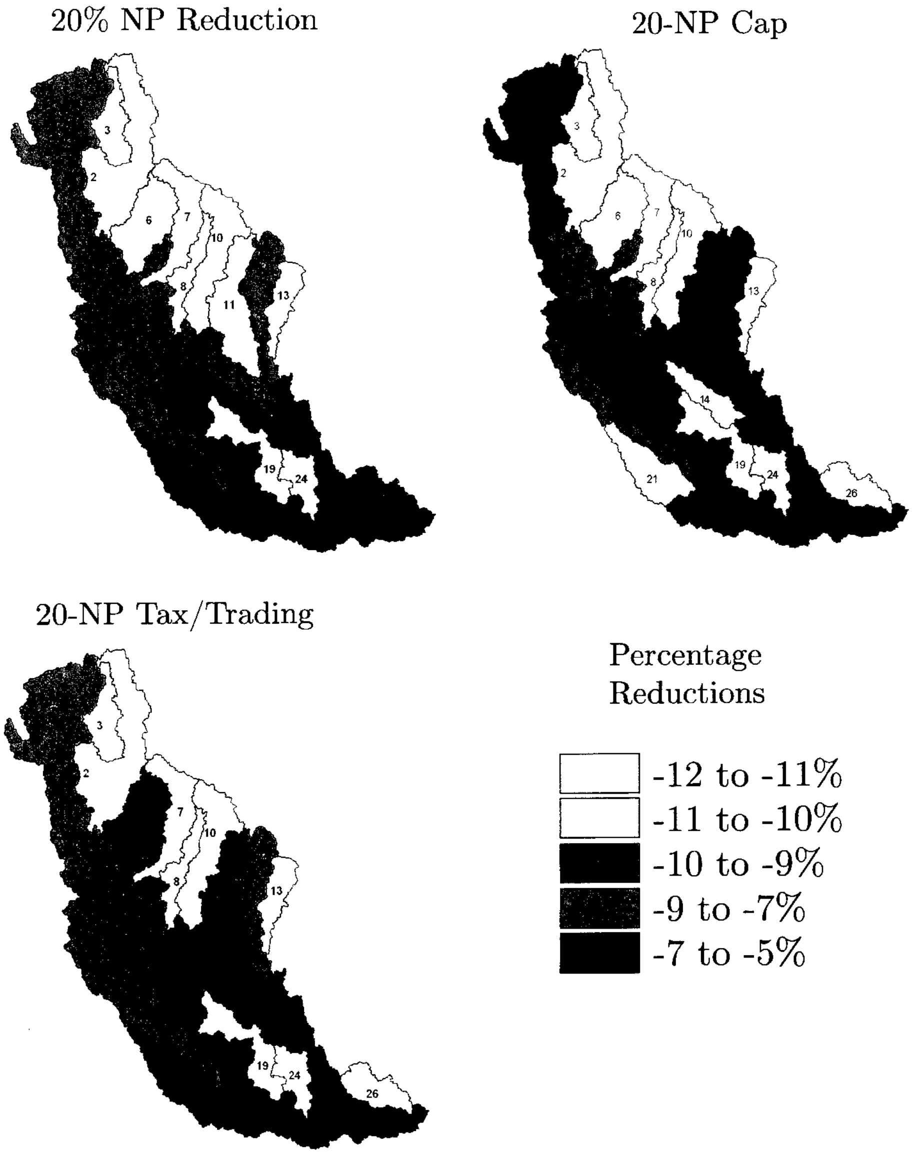


Figure B.4 Subbasin comparison, 20-NP scenarios

APPENDIX C. ARMS QUESTIONNAIRES

NATIONAL AGRICULTURAL STATISTICS SERVICE
U.S. Department of Agriculture
Rm 5805, South Building
1400 Independence Avenue, S.W.
Washington, D.C. 20250-2000
202-720-7017

AGRICULTURAL RESOURCE MANAGEMENT STUDY
CORN PRODUCTION PRACTICES REPORT
for 2000

Form Approved
O.M.B. Number 0535-0218
Approval Expires 10/31/03
Project Code 906
Phase II

VERSION	ID	TRACT	SUBTRACT	T-TYPE	TABLE	LINE
5	_ _ _ _ _ _ _ _ _ _ _	01	__ __	0	000	00

ERS

CONTACT RECORD

DATE	TIME	NOTES

R CODES	
3 - COMPLETE 5 - OUT OF SCOPE 8 - REFUSAL 9 - INAC./INCOMPL.	0910
OPTIONAL	0002
OPTIONAL	0003

INTRODUCTION
[*Introduce yourself, and ask for the operator. Rephrase in your own words.*]

We are collecting information on practices to produce corn and need your help to make the information as accurate as possible. Authority for collection of information on the Corn Production Practices Report is Title 7, Section 2204 of the U.S. Code. This information will be used for economic analysis and to compile and publish estimates for your region and the United States. Response to this survey is confidential and voluntary.

We encourage you to refer to your farm records during the interview.

BEGINNING TIME [*MILITARY*] 0004 **H H M M** **BEGTI**

SCREENING BOX 0006 **SCRN**

[***ENUMERATOR NOTE*: *If Screening box is code 1, complete the Screening Supplement. If Screening box is not coded, begin with Section A.***]

OFFICE USE
Completion Code 3 = ZERO TARGET 0008

☐ [*Name, address and partners verified and updated if necessary.*]

POID _ _ _ _ _ _ _ _ _	**POID** _ _ _ _ _ _ _ _ _
PARTNER NAME	*PARTNER NAME*
ADDRESS	*ADDRESS*
CITY *STATE* *ZIP* *PHONE NUMBER*	*CITY* *STATE* *ZIP* *PHONE NUMBER*
POID _ _ _ _ _ _ _ _ _	**POID** _ _ _ _ _ _ _ _ _
PARTNER NAME	*PARTNER NAME*
ADDRESS	*ADDRESS*
CITY *STATE* *ZIP* *PHONE NUMBER*	*CITY* *STATE* *ZIP* *PHONE NUMBER*

A CORN FIELD SELECTION A

1. **How many acres of corn did this operation plant for the 2000 crop year?**
   [▸ *If no acres planted, review Screening Survey Information Form. Make notes, then go to item 4 of* ***Conclusion.***] . . . . **TOTAL PLANTED ACRES** 0019 **A0100** ______

3. I will follow a simple procedure to make a random selection from the corn fields planted for the 2000 crop.

   What is the TOTAL number of corn fields that were planted on this operation? . . . . **TOTAL NUMBER OF FIELDS PLANTED** 0020 **A0300** ______
   [*If only 1 field, enter 1 and go to item 5.*]

4. **Please list these fields according to identifying name/number or describe each field. Then I will tell you which field has been selected.**
   - [*If there are more than 18 fields make sure item 3 is* ***TOTAL*** *fields planted, and list only the 18 fields closest to the operator's permanent residence.*
   - *If respondent is unable to identify or describe the fields, use the Field Selection Grid Supplement.*]

FIELD NAME, NUMBER OR DESCRIPTION	FIELD NAME, NUMBER OR DESCRIPTION
1 ______	10 ______
2 ______	11 ______
3 ______	12 ______
4 ______	13 ______
5 ______	14 ______
6 ______	15 ______
7 ______	16 ______
8 ______	17 ______
9 ______	18 ______

APPLY "RANDOM NUMBER" LABEL HERE

5. **[ENUMERATOR ACTION:**
   Circle the pair of numbers on the above label associated with the last numbered field in item 4. Select the field according to the number you circled on the label, and record the selected number. If only 1 field, enter 1.] . . . . **SELECTED FIELD NUMBER** 0021 **A0500**

6. **The field selected is (*field name/number/description*). During this interview, the corn questions will be about this selected corn field.**
   [*Be sure the operator can identify the selected field.*]

OFFICE USE
OY Field Substituted
0022 **A0600**

B FIELD CHARACTERISTICS---SELECTED FIELD B

1. **How many acres of corn did this operation plant in this field for the 2000 crop?** . . . . ACRES 0735 B0100

2. **Were the acres in this field--** . .
   1 owned by this operation?
   2 rented for CASH?
   3 SHARE rented?
   4 used RENT-FREE?
   . . . . CODE 0736 B0200

5. ***What year did you start operating this field?*** . . . . YEAR 0737 B0500

   a. Do you EXPECT to be operating this field for the next 5 years (through the 2005 crop year)? . . . . YES = 1 CODE 0738 B05a0

7. **On what date was this field planted?** . . . . YYYYMMDD 0739 B0700

10. **What was the seeding rate per acre the first time this field was seeded?** . . . .

UNITS PER ACRE	UNIT CODES for Seeding Rate 1=POUNDS 2=CWT. 4=BUSHELS 25=KERNELS/SEEDS
0740 B1001	0741 B1002

19. **Which type of corn seed type was used--**
    [Show Seed Type Code List from Respondent Booklet, and choose one code.]

   a. in this field in 2000? . . . . CODE 0743 **B19a0**

   b. in this field in 1999? 744 **B19b0**
      [Leave blank if different commodity planted in 1999.] . . . .

SEED TYPE - CORN

1 Genetically-modified **herbicide resistant** seed variety
2 Non-genetically-modified **herbicide resistant** seed variety
3 Genetically-modified **Bt** variety for insect resistance
4 Stacked gene variety
(*both genetically-modified insect and herbicide resistance*)
6 *Variety planted not described above*

20. [*If item 19a is NOT equal 6, ask--*]
    Resistant seed varieties offer several benefits.
    Did you choose the resistant seed variety used on this field primarily to--

1 Increase yields through improved pest (*weed or insect*) control?
2 Decrease pesticide input costs?
3 Decrease machinery costs?
4 Improve ability to use or ease of using reduced tillage or no-till systems?
5 Improve ability or ease or rotating crops?
6 Save management time or labor or improve ease of management?
7 Adopt more environmentally friendly practices?
8 For some other reason(s)? [*Specify* ____________________]

. . . . CODE 0745 B2000

B FIELD CHARACTERISTICS---SELECTED FIELD B

		CODE
21. **Has harvest of this field been completed?**	**YES = 1**	0746 **B2100**

22. ***Now I need information about the acres harvested (or to be harvested)* and the yields from this field.**

1 **How many acres in the corn field** were (will be)--	**ACRES**	2 **What yield per acre did you get** (do you expect to get) **for--** **UNITS PER ACRE**	3 **UNIT CODES** 1=POUNDS 2=CWT 3=TONS 4=BUSHELS
a. harvested for grain?	0747 **B22a1**	0748 **B22a2**	0749 **B22a3**
b. harvested for silage or green chop?	0750 **B22b1**	0751 **B22b2**	0752 **B22b3**
c. harvested for seed for planting?	0753 **B22c1**	0754 **B22c2**	0755 **B22c3**
d. abandoned?	0756 **B22d1**		
e. used for some other purpose?	0757 **B22e1**		

CROP CODE LIST for item 26
PREVIOUSLY PLANTED CROP was--

1 Alfalfa hay
11 Hay, all other
190 Barley
3 Dry Beans
85 Canola
310 Clover
6 Corn for grain
5 Corn for silage
196 Tobacco, flue cured
193 Tobacco, burley
281 Cotton, Upland
282 Cotton, Pima
302 CRP
311 Grasses other than clover
94 Mustard
15 Oats
31 Sweetpotatoes
16 Peanuts
17 Dry Peas
20 Potatoes
21 Rice
22 Rye
98 Safflower
25 Sorghum for grain
24 Sorghum for silage
26 Soybeans
28 Sugarbeets
30 Sunflowers
142 Vegetables
163 Wheat, durum
164 Wheat, other spring
165 Wheat, winter
318 ***No crop planted** during this period*

26. **Next I need to know what crops were previously PLANTED on this field, including cover crops.**

1 **What crop was PLANTED on this field in--**	**CROP NAME**	**CROP CODE**	2 **Was this crop irrigated?** **YES = 1**
a. **FALL** of 1999?		0758 **B26a1**	0759 **B26a2**
b. **SPRING/SUMMER** of 1999? ..		0760 **B26b1**	0761 **B26b2**
c. **FALL** of 1998?		0762 **B26c1**	0763 **B26c2**
d. **SPRING/SUMMER** of 1998? ..		0764 **B26d1**	0765 **B26d2**
e. **FALL** of 1997?		0766 **B26e1**	0767 **B26e2**
f. **SPRING/SUMMER** of 1997? ..		0768 **B26f1**	0769 **B26f2**

B FIELD CHARACTERISTICS---SELECTED FIELD B

1		2		3
27. In 2000, did your land-use practices for this field include--	CODE	**In what year were the** (*column 1*) **established in this field?** YEAR	[*If* (*column 1*) *were established before operator began operating this field, enter code 1.*]	**In 2000, did** (*or will*) **the Federal or State government pay an annual rental payment for keeping this conservation practice in place?** [*YES=1*]
a. terraces? .... **YES = 1**	0770 **B27a1**	0771 **B27a2**	0772 **B27aX**	
b. temporary or permanent levees? **YES = 1**	0773 **B27b1**	0774 **B27b2**	0775 **B27bX**	
c. grassed waterways? .... **YES = 1**	0776 **B27c1**	0777 **B27c2**	0778 **B27cX**	0779 **B27c3**
d. filter strips or riparian buffers on or adjoining the field? ...... **YES = 1**	0780 **B27d1**	0781 **B27d2**	0782 **B27dX**	0783 **B27d3**
e. contour farming? .... **YES = 1**	0784 **B27e1**			
f. strip cropping? .... **YES = 1**	0785 **B27f1**			
g. underground outlets such as tile drainage? .... **YES = 1**	0786 **B27g1**			
h. other drainage channels or diversions? .... **YES = 1**	0787 **B27h1**			

	CODE
28. **Has the Natural Resource Conservation Service (NRCS) classified any part of this field as "Highly Erodible"?** .... **YES = 1**	0788 **B2800**
29. **Have you been notified by NRCS that this field contains a wetland?** .... **YES = 1**	0789 **B2900**
30. **In 2000, did you receive technical assistance for planning, installing, maintaining, or using conservation practices or systems on this field?** (***Include*** *grassed waterways and filter strips or riparian buffers on or adjoining this field.* ***Include*** *assistance from any source whether paid for or free.*) .... **YES = 1**	0790 **B3000**
31. **In 2000, did you** (*or will you*) **receive cost-sharing or incentive payments for conservation practices on this field** [*Be sure to consider grassed waterways and filter strips or riparian buffers on or adjoining this field.*]**?** (***Include*** *payments received from any source by either the owner or operator.* ***Exclude*** *rental payments for keeping the land in these practices.*) .... **YES = 1**	0791 **B3100**

B FIELD CHARACTERISTICS---SELECTED FIELD B

32. **During 2000, did any formal plan of the following types cover this field and, if so, in what year was the plan implemented?** *("Formal plan" is a written plan prepared in accordance with Federal, State, or Conservation district standards.)*		**CODE**	**YEAR IMPLEMENTED**
a. Conservation plan specifying practices to reduce soil erosion? . . .	**YES=1**	0792 **B32a1**	0793 **B32a2**
b. Comprehensive nutrient management plan specifying practices for applying both fertilizer and manure?	**YES=1**	0794 **B32b1**	0795 **B32b2**
c. Nutrient management plan specifying practices for land application of manure only?	**YES=1**	0796 **B32c1**	0797 **B32c2**
d. Pest management plan specifying pesticide use and/or other practices for controlling weeds, insects, or plant disease? . . .	**YES=1**	0798 **B32d1**	0799 **B32d2**
e. Irrigation water management plan specifying practices for applying or conserving irrigation water?	**YES=1**	0800 **B32e1**	0801 **B32e2**

33. **Was the corn crop on this field covered by Crop Insurance in 2000?**

		CODE
☐ **YES** - [*Enter code 1 and continue.*]	**YES=1**	0802 **B3300**
☐ **NO** - [*Go to **Section** C.*]		

If YES, which coverages did you obtain?
[*Enter code for all that apply.*]

a. **Basic catastrophic insurance** (Federal CAT) bought for a flat fee and protects against crop loss greater than 50% of average yield, at 55% of the price. . . .	**YES=1**	0803 **B33a0**
b. **Buy-up insurance** for higher levels of yield and price protection *(such as 65% of yield and 100% price)*.	**YES=1**	0804 **B33b0**
c. **Federal Revenue insurance** include Income Protection (IF), Crop Revenue Coverage (CRC), and Revenue Assurance (RA).	**YES=1**	0805 **B33c0**
d. **Other Federal Crop insurance** *(Group Risk Plan, Adjusted Gross Revenue, Group Risk Income Protection, etc.)*	**YES=1**	0806 **B33d0**
e. **Other Private Crop insurance** *(Hail, wind, freeze, etc.)*	**YES=1**	0807 **B33e0**

NOTES and CALCULATIONS:

8

C FERTILIZER and NUTRIENT APPLICATIONS---SELECTED FIELD C

		CODE	EDIT TABLE
1. **Were commercial FERTILIZERS applied to this field for the 2000 corn crop?** . . . . YES=1	0808	C0100	0201

2. [*If COMMERCIAL fertilizers were applied, continue, else go to item 7.*]

		NUMBER
3. **How many trips were made across this field to apply commercial fertilizers for the 2000 crop** (*include applications made by airplanes and commercial applicators*)?	0809	C0300

4. **Now I need to record information for each application.**

CHECK LIST

INCLUDE

- ☐ Custom applied fertilizers
- ☐ Fertilizer applied in the fall of 1999 and those applied earlier if this field was fallow in 1999
- ☐ Commercially prepared manure

EXCLUDE

- ☐ Micronutrients
- ☐ Unprocessed manure
- ☐ Fertilizer applied to previous crops in this field

	T-TYPE	TABLE
	2	001
LINE 99	OFFICE USE LINES IN TABLE	0213

LINE	2 → → → MATERIALS USED [*Enter percentage analysis or actual pounds of plant nutrients applied per acre.*] [*Show Common Fertilizers in Respondent Booklet.*] N Nitrogen	P_2O_5 Phosphate	K_2O Potash	3 What quantity was applied per acre? [*Leave this column blank if actual nutrients were reported.*]	4 [*Enter material code.*] 1 Pounds 12 Gallons 19 Pounds of actual nutrients	5 When was this applied? 1 In the fall Before seeding 2 In the spring Before seeding 3 At seeding 4 After seeding	6 How was this applied? 1 Broadcast, ground without incorporation 2 Broadcast, ground with incorporation 3 Broadcast, by air 4 In seed furrow 5 In irrigation water 6 Chisel, injected or knifed in 7 Banded/Sidedressed in or over row 8 Foliar or directed spray 9 Spot treatments	7 How many acres were treated in this application? ACRES
01	0205	0206	0207	0208	0209	0210	0211	0212 .__
02								
03								
04								
05								
06	0205	0206	0207	0208	0209	0210	0211	0212 .__
07	0205	0206	0207	0208	0209	0210	0211	0212 .__
08	0205	0206	0207	0208	0209	0210	0211	0212 .__

Data entered on this table are in the "CRN00F" file.
See data dictionary for variable names.

T-TYPE	TABLE	LINE
0	000	00

C FERTILIZER and NUTRIENT APPLICATIONS---SELECTED FIELD C

T-TYPE	TABLE	LINE
0	000	00

	UNITS PER ACRE	UNIT CODES 1=POUNDS 2=CWT. 4=BUSHELS
7. **What was your yield goal** (*or expected yield*) **for this field?**	0810 C0701	0811 C0702

8. **Was a soil test for phosphorus performed on this corn field in 1999 or 2000 for the 2000 crop?** . . . . YES = 1		CODE 0812 C0800
a. [*If phosphorus test done, ask--*] **How many pounds of phosphorus** (*per acre*) **were recommended** (*by the phosphorus test*)?		POUNDS PER ACRE 0813 C08a0
9. **Was a soil test for nitrogen performed on this corn field in 1999 or 2000 for the 2000 crop?** . . . . YES = 1		CODE 0814 C0900
a. [*If nitrogen test done, ask--*] **How many pounds of nitrogen** (*per acre*) **were recommended** (*by the nitrogen test*)?		POUNDS PER ACRE 0815 C09a0

10. ***[Enumerator Action: Refer to the Fertilizer Table, column 2.***
If nitrogen (N) *was applied, complete items 11 and 12.*
If NO nitrogen applied, skip to item 13.]

11. **Was the amount of nitrogen you decided to apply to this field based on--**

		CODE
a. Routine practice (*operator's own determination based on past experience, yield goal, etc.*)?	YES = 1	0816 C11a0
b. Results of a soil or plant tissue test?	YES = 1	0817 C11b0
c. Crop consultant recommendation?	YES = 1	0818 C11c0
d. Fertilizer dealer recommendation?	YES = 1	0819 C11d0
e. Extension Service recommendation?	YES = 1	0820 C11e0
f. Cost of nitrogen and/or expected commodity price?	YES = 1	0821 C11f0

12. **Did you use any product to slow the breakdown of nitrogen on this field?** (*For example a nitrification inhibitor such as N-Serve or a urease inhibitor such as Agrotain*)	YES = 1	0822 C1200
13. Was a **plant tissue test** performed on this field in 1999 or 2000 for the 2000 corn crop?	YES = 1	0823 C1300

C FERTILIZER and NUTRIENT APPLICATIONS---SELECTED FIELD C

CODE

15. **Is lime ever applied to this field?** . . . . **YES = 1** 0824 **C1500**

a. [*If no lime applied, go to item 16–else continue.*]

YEARS

On average, how many years are there between applications of **lime** to this field? 0825 **C15a0**

TONS PER ACRE

b. How many tons of **lime** were applied per acre the last time it was applied to this field? 0826 **C15b0**

CODE

16. **Was sulfur applied to this field for the 2000 crop?** . . . . **YES = 1** 0827 **C1600**

a. [*If sulfur applied, ask–*]

POUNDS PER ACRE

How many pounds of sulfur were applied per acre? 0828 **C16a0**

CODE

17. **Was gypsum applied to this field for the 2000 crop?** . . . . **YES = 1** 0829 **C1700**

18. **Were micronutrients applied to this field for the 2000 crop?** . . . . **YES = 1** 0830 **C1800**

a. [*If micronutrients applied, ask–*]

Did the micronutrients include **zinc**? . . . . **YES = 1** 0831 **C18a0**

19. **Was manure applied to this field for the 2000 corn crop?**
(***Exclude commercially prepared manure.***)

CODE

☐ **YES -** [*Enter code 1 and continue.*] 0832 **C1900**
☐ **NO -** [*Go to* ***Section*** **D.**]

ACRES

a. How many acres was manure applied to? 0833 **C19a0**

b. What was the total amount of manure applied to this field? . . . .

TONS PER ACRE	**OR**	**TOTAL TONS**
0835 **C19b1**		0834 **C19b2**
OR		**OR**
GALLONS PER ACRE	**OR**	**TOTAL GALLONS**
0837 **C19b3**		0836 **C19b4**

MILES

c. What is the hauling distance between the manure storage and the manured field? 0838 **C19c0**

NUMBER

d. How many trips did it take to complete the manure application to the entire field? 0839 **C19d0**

e. What was the percent of manure applied–?

PERCENT

(1) in the fall before planting? . . . . **+** 0840 **C19e1**

(2) in the spring before planting? . . . . **+** 0841 **C19e2**

(3) after planting? . . . . **+** 0842 **C19e3**

100%

C FERTILIZER and NUTRIENT APPLICATIONS---SELECTED FIELD C

manure–*continued*

f. Was the manure–	1 Dry Broadcast *without* incorporation? 2 Dry Broadcast *with* incorporation? 3 Liquid Broadcast *without* incorporation? 4 Liquid Broadcast *with* incorporation? 5 Injected/knifed in?	CODE 0843 C19f0
g. Was the major source of the manure from–	1 Beef cattle? 2 Dairy cattle? 3 Hogs? 4 Sheep? 5 Poultry? 6 Equine? 7 Biosolids (*municipal sludge,food waste, etc.*)? 8 Other (*Specify*____________)?	CODE 0844 C19g0
h. Was the manure–	1 Produced on this operation? 2 Purchased? 3 Obtained at no cost off this operation?	CODE 0845 C19h0

20. **Were the manure APPLICATION RATES to this field influenced by State or local restrictions?** . . . . **YES = 1** 0846 **C2000**

a. [*If YES, ask*–]
What basis was used to determine these manure application rate restrictions– **C20a0**

CODE

(1) Nitrogen requirement of the crop? . . . . **YES = 1** 0847 **C20a1**

(2) Phosphorus requirement of the crop? . . . . **YES = 1** 0848 **C20a2**

D PESTICIDE APPLICATIONS---SELECTED FIELD D

1. **Including both custom applications and applications made by this operation, let's list all the chemicals used on this field for the 2000 corn crop.**

	CODE	EDIT TABLE
Were any herbicides, insecticides, fungicides or other chemicals used on the corn field for the 2000 crop? . . . . YES = 1	0849 *D0100*	0301

[Probe for applications made in the fall of 1999 (and those made earlier if this field was fallow).]
[If no pesticides applied, go to Section E.*]*

***Include** defoliants, fungicides, herbicides, insecticides and pesticides.* ***Include** biological and botanical pesticides.*	***Exclude** fertilizers reported earlier and seed treatments.*

	T-TYPE	TABLE
	3	001
LINE 99	OFFICE USE LINES IN TABLE	0319

NOTES	LINE	2 **What products were applied to this field?** *[Show product codes from Respondent Booklet.]*	3 **Was this product bought in liquid or dry form?** *[Enter L or D.]*	4 **Was this part of a tank mix?** *[If tank mix, enter line number of first product in mix.]*	5 **When was this applied?** 1 BEFORE planting 3 AT planting 4 AFTER planting	6 **How much was applied per acre per application?**	OR 7 **What was the total amount applied per application in this field?**	8 *[Enter unit code.]* 1 Pounds 12 Gallons 13 Quarts 14 Pints 15 Ounces 30 Grams
	01	0305		0306	0307	0308 •__ __	0309 •__ __	0310
	02	***Data entered on this table are in the "CRN00P" file. See data dictionary for variable names.***						
	03							
	04							
	05							
	06							
	07	0305		0306	0307	0308 •__ __	0309 •__ __	0310
	08	0305		0306	0307	0308 •__ __	0309 •__ __	0310
	09	0305		0306	0307	0308 •__ __	0309 •__ __	0310
	10	0305		0306	0307	0308 •__ __	0309 •__ __	0310
	11	0305		0306	0307	0308 •__ __	0309 •__ __	0310
	12	0305		0306	0307	0308 •__ __	0309 •__ __	0310
	13	0305		0306	0307	0308 •__ __	0309 •__ __	0310
	14	0305		0306	0307	0308 •__ __	0309 •__ __	0310

2. *[For pesticides not listed in Respondent Booklet, specify –]*

LINE	**Pesticide Type** (Herbicide, Insecticide Fungicide, etc.)	**EPA No. or Tradename and Formulation**	**Form Purchased** (Liquid or Dry)	**Where Purchased** *[Ask only if EPA No. cannot be reported.]*

D PESTICIDE APPLICATIONS---SELECTED FIELD D

APPLICATION CODES for column 9

1 Broadcast, ground without incorporation
2 Broadcast, ground with incorporation
3 Broadcast, by air (*Aerial application*)
4 In seed furrow
5 In Irrigation water
6 Chisel/injected or knifed in
7 Banded in or over row
8 Foliar or directed spray
9 Spot treatment

LINE	9 How was this product applied? *[Enter code from above.]*	10 How many acres in this field were treated with this product? ACRES	11 What was the number of times applied? NUMBER	12 What was the PRIMARY target pest for this application? *[Show Target Pest codes from Respondent Booklet.]*	13 Prior to this application was this years pest problem-- 1 worse than normal? 3 normal? 5 less than normal? 7 unknown? 9 not applicable?	14 Were these applications made by-- 1 Operator, Partner, Family member? 2 Custom applicator? 3 Employee / Other?
01	0311	0312 •__	0313	0314	0315	0316
02						
03						
04						
05						
06						
07	0311	0312 •__	0313	0314	0315	0316
08	0311	0312 •__	0313	0314	0315	0316
09	0311	0312 •__	0313	0314	0315	0316
10	0311	0312 •__	0313	0314	0315	0316
11	0311	0312 •__	0313	0314	0315	0316
12	0311	0312 •__	0313	0314	0315	0316
13	0311	0312 •__	0313	0314	0315	0316
14	0311	0312 •__	0313	0314	0315	0316

Data entered on this table are in the "CRN00P" file.
See data dictionary for variable names.

T-TYPE	TABLE	LINE
0	000	00

E PEST MANAGEMENT PRACTICES--SELECTED FIELD E

T-TYPE	TABLE	LINE
0	000	00

1. **Now I have some questions about your pest management decisions and practices used on this field for the 2000 corn crop. By pests, we mean WEEDS, INSECTS and DISEASES.**

2. **Let's begin with questions about scouting this field for pests.**

1 **Was this corn field scouted for--**	YES=1	② [*If* **YES**, *ask*–] **Who did the majority of the scouting for** [*column 1*]**--** 1 Operator, Partner or Family member? 2 an Employee? 3 Farm supply or Chemical dealer? 4 Independent Crop consultant or Commercial scout? CODE
a. weeds?	0850 E02a1	0851 E02a2
b. insects?	0852 E02b1	0853 E02b2
c. diseases?	0854 E02c1	

5. [*If field SCOUTED, ask*–]

Were written or electronic records kept for this field to track the activity or numbers of weeds, insects or diseases? . . . . **YES = 1** CODE 0855 **E0500**

E PEST MANAGEMENT PRACTICES--SELECTED FIELD E

6. **[Enumerator Action:** ***Were*** **HERBICIDES** ***used (pesticide product codes 4000-4999), Section*** **D,** ***item 1 column 2?*]**

☐ **YES** - *[Continue.]* ☐ **NO** - *[Go to item 9.]*

		CODE
7. **Did you apply herbicides to this corn field BEFORE weeds emerged?**	YES = 1	0856 E0700

[If item 7 = YES, ask--]
Did you decide to apply herbicides BEFORE weeds emerged on this corn field based on--

a. a routine treatment for weed problems experienced in previous years?	YES = 1	0857 E07a0
b. field mapping of previous weed problems?	YES = 1	0858 E07b0
c. recommendations from a *chemical dealer*?	YES = 1	0859 E07c0
d. recommendations from an *independent crop consultant* ?	YES = 1	0860 E07d0
8. **Did you apply herbicides to this corn field AFTER weeds emerged?**	YES = 1	0861 E0800

[If item 8 = YES, ask--]
Did you decide to apply herbicides AFTER weeds emerged on the corn field based on--

		CODE
a. a routine treatment?	YES = 1	0862 E08a0
b. type and/or density of weed(s) present?	YES = 1	0863 E08b0
c. recommendations from a *chemical dealer*?	YES = 1	0864 E08c0
d. recommendations from an *independent crop consultant* ?	YES = 1	0865 E08d0

9. **[Enumerator Action:** ***Were*** **INSECTICIDES** ***used (pesticide product codes 1000-2000), in Section*** **D,** ***item 1 column 2?*]**

☐ **YES** - *[Continue.]* ☐ **NO** - *[Go to item 11.]*

10. **Did you decide to apply insecticides to this corn field based on--**

		CODE
a. a preventative schedule?	YES = 1	0866 E10a0
b. scouting data compared to University or Extension guidelines for infestation thresholds?	YES = 1	0867 E10b0
c. standard practices or history of insect problems?	YES = 1	0868 E10c0
d. local information (*from other farmers, radio, TV, newsletters, etc.*) that the pest was or was not present?	YES = 1	0869 E10d0
e. your (the operator's) own determination of the infestation level?	YES = 1	0870 E10e0

E PEST MANAGEMENT PRACTICES--SELECTED FIELD E

OTHER PEST MANAGEMENT PRACTICES

			CODE
11. **Was protection of beneficial organisms a factor in your pest control decisions for this field?**	**YES = 1**	0871	**E1100**
12. **Did you apply or release any beneficial organisms to control pests in this field?** . .	**YES = 1**	0872	**E1200**
13. **Did you use water management practices, such as controlled drainage or irrigation scheduling, to control pests in this field?** *[Exclude chemigation.]*	**YES = 1**	0873	**E1300**
14. **Did you use tilling, chopping, mowing, burning of field edges, lanes, ditches, roadways or fence lines to control pests in this field?**	**YES = 1**	0874	**E1400**
15. **Did you clean equipment and implements after completing field work to reduce the spread of pests from this field?**	**YES = 1**	0875	**E1500**
16. **Did you cultivate this field for weed control during the growing season?**	**YES = 1**	0876	**E1600**
a. *[If YES, ask--]* How many times did you cultivate this field for weed control during the growing season?		0877	**E16a0**
			CODE
17. **Did you consider pest resistance when selecting which variety to plant in this field?**	**YES = 1**	0878	**E1700**
18. **Did you treat the seed used in this field or purchase seed that was treated for disease control?**	**YES = 1**	0879	**E1800**
19. **Did you adjust planting or harvesting dates to control pests?**	**YES = 1**	0880	**E1900**
20. **Did you use soil analysis to detect the presence of soilborne pests or pathogens in this field?**	**YES = 1**	0881	**E2000**
21. **Did you alternate pesticides** (*use pesticides with different mechanisms of action*) **to keep pests from becoming resistant to pesticides in this field?**	**YES = 1**	0882	**E2100**
22. **Did you adjust row spacing or plant density to control pests in this field?**	**YES = 1**	0883	**E2200**
23. **Did you rotate crops on this field during the past 3 years to control pests?**	**YES = 1**	0884	**E2300**
28. **Did you do any other type(s) of pest management to control pests in this field?**	**YES = 1**	0885	**E2800**
a. *[If YES, ask--]* What did you do? *[List other activities.]*			
______________________________		0886	**E28a1**
______________________________		0887	**E28a2**
______________________________		0888	**E28a3**

E PEST MANAGEMENT PRACTICES--SELECTED FIELD E

PEST MANAGEMENT INFORMATION

29. [*Show Pest Management Information Sources code List.*]

What was your primary outside source of information on pest management recommendations for the 2000 corn crop?

PEST MANAGEMENT INFORMATION SOURCES CODE LIST [*Choose one.*]

1 Extension Advisor, Publications or Demonstrations (County, Cooperative or University)
2 Farm Supply or Chemical Dealer
3 Commercial Scouting Service
4 Independent Crop Consultant or Pest Control Advisor
5 Other Growers or Producers
6 Producer Associations, Newsletters or Trade Magazines
7 Electronic Information Services (*DTN, Internet, World Wide Web, etc.*)
8 Other - (*Specify* ____________________)
9 None - *Operator used no **outside** information source.*

[*Choose one source and enter code.*]
0889 **E2900** ____________

PEST MANAGEMENT TRAINING

30. **Have you (the operator) attended any training session on pest identification and management since October 1, 1999?** . . . . YES = 1

CODE
0890 **E3000** ____________

OFFICE USE
0340 **ECC**

F FIELD OPERATIONS --- SELECTED FIELD F

2. **Including custom operations, I need to list field work performed by machines on this field for the 2000 corn crop. Please...**
   - Begin with the first field operation after harvest of previous crop, (*If fallow during 1999, list operations starting with fall 1998.*)
   - List the operations in order ***through seeding***, and
   - Maintain the order of tandem hook-ups.

CHECK LIST

Include all field work using machines for–

☐ Land Forming
☐ Tillage
☐ Preparing for Irrigation before seeding
☐ Planting

Exclude

☐ Lime & Gypsum applications
☐ Fertilizers & Pesticides applications
☐ Operations that occur after planting
☐ Harvesting & Hauling

CODES FOR COLUMN 5

1 You (The Operator)?
2 Partner?
3 Unpaid Worker?
4 Paid Part-time or Seasonal Worker?
5 Paid Full-time Worker?
6 Custom Operator?

2 SEQUENCE NO.	**3 What operation or equipment was used on this field?**	**4** *[Record machine code from Respondent Booklet.]* **CODE**	**5 Who was the machine operator–** *[Enter code from above.]*	***[If CUSTOM** (column 5 is code 6) **skip columns 9 & 10.]*** **9 How many acres were covered? 1/ ACRES**	**10 How many acres were covered per hour? ACRES PER HOUR**	**11 In what month and year was this operation done? MM YY**
0351		0352	0353	0357 .	0358 .	0359
0361		0362	0363	0367 .	0368 .	0369
0371	***Data entered on this table are in the 'CRN00T" file. See data dictionary for variable names.***					
0381						
0391						
0401						
0411						
0421		0422	0423	0427 .	0428 .	0429
0431		0432	0433	0437 .	0438 .	0439
0441		0442	0443	0447 .	0448 .	0449
0451		0452	0453	0457 .	0458 .	0459
0461		0462	0463	0467 .	0468 .	0469
0471		0472	0473	0477 .	0478 .	0479
0481		0482	0483	0487 .	0488 .	0489
0491		0492	0493	0497 .	0498 .	0499

OFFICE USE
0032

1/ *For backhoes, disk border maker, ditch closer, ditcher, levee-plow disk, quarter drain machine and rear mounted blade, enter total HOURS, not acres. Then leave column 10 blank.*

F FIELD OPERATIONS --- SELECTED FIELD F

			CODE
8. **Was there (will there be) a yield monitor on the equipment used to harvest this corn field?**	YES = 1	0891	**F0800**
a. *[If YES, ask--]* Was (will there be) a yield map produced from this harvest using information from the yield monitor?	YES = 1	0892	**F08a0**
(1) *[If item 8a is YES, ask--]* Was a custom service/consultant hired for this activity?	YES = 1	0893	**F08a1**
9. **Regardless of when done, have the soil properties of this field been mapped** (*by grid or otherwise*)**?** *[Mapped is intended to mean that a GPS unit was used to geo-reference the location of different soil properties.]*	YES = 1	0894	**F0900**
10. **Was this field remotely sensed** (*by airplane or satellite*) **and an image produced either before or during the 2000 growing season?**	YES = 1	0895	**F1000**
a. *[If YES, ask--]* Was a custom service/consultant hired for this activity?	YES = 1	0896	**F10a0**
11. **Was variable rate technology (VRT) used for--**			
a. fertilization or liming?	YES = 1	0897	**F11a0**
(1) *[If YES, ask--]* Was a custom service/consultant hired for this activity?	YES = 1	0898	**F11a1**
b. seeding?	YES = 1	0899	**F11b0**
(1) *[If YES, ask--]* Was a custom service/consultant hired for this activity?	YES = 1	0900	**F11b1**
c. pesticide applications?	YES = 1	0901	**F11c0**
(1) *[If YES, ask--]* Was a custom service/consultant hired for this activity?	YES = 1	0902	**F11c1**

NOTES and CALCULATIONS:

G **IRRIGATION** -- SELECTED FIELD G

1. **How many acres in this field were irrigated for the 2000 corn crop?** . . . . **ACRES** 0903 **G0100**

[*If field irrigated, continue. If NOT irrigated, go to Section J.*]

2. **Now, I have some questions about the irrigation of this field for the 2000 corn crop.**

   a. What type of irrigation system was used to irrigate this field?

   [*Show **System Type Codes**. If more than 1 system used, enter Sytem Type Code for system covering the most field acres.*] . . . . **SYSTEM TYPE CODE** 0904 **G02a1**

   b. What was the total quantity of water applied to this field during the entire growing season?

   [***Include** ALL water used from both on-farm and off-farm sources.*] . . . **INCHES PER ACRE** 0905 **G02b1** **OR** **TOTAL ACRE FEET** 0906 **G02b3**

   [If operator cannot provide item 2b, ask--]

   (1) What is the total number of hours that water was applied to this field during the growing season? . . . . **TOTAL HOURS** 0907 **G02b5**

   (2) How many gallons per minute were applied? . . . . **GALLONS PER MINUTE** 0908 **G02b7**

   c. What percent of ALL water used to irrigate this field came from surface water sources? . . . . **PERCENT** 0909 **G02c1**

   d. What was the number of times this field was irrigated during the growing season? . . . . **NUMBER** 0911 **G02d1**

3. **Was any water purchased to irrigate this field?** (***Include** landlord's share and purchases from all sources.*) . . . . **YES = 1** **CODE** 0912 **G0300**

   a. [*If water purchased, ask--*]

   What percent of the water used on this field was purchased? . . . . **PERCENT** 0913 **G03a0**

9. **Were wells used to supply irrigation water for this field?** . . . . **YES = 1** **CODE** 0914 **G0900**

11. **Is the runoff from this field primarily--** . . . . **CODE** 0915 **G1100**

RUNOFF CODES
1 retained at the end of the field with no re-use?
2 re-used to irrigate on the farm?
3 collected in evaporation ponds on the farm?
4 drains from the farm?
5 there is no runoff?

NOTES and CALCULATIONS:

J OPERATOR and OPERATION CHARACTERISTICS J

1. **In 2000, was this operation's LEGAL STATUS–**

1 Individual (*Sole/family Proprietorship*)?
2 A legal Partnership?
3 A Family-held Corporation?
4 A Non-family Corporation?
5 Other, *Including estates, trusts and cooperatives*? (*Describe* ______________________)

CODE
0035 . . . . . J0100

2. **In 2000, what was your (*the operator's*) major occupation?** . . . .

1 Farm or ranch work
2 Hired manager
3 Something else
4 Retired

CODE
0036 . . . . J0200

3. **What is the *highest* level of formal education you (*the operator*) have completed?** . . . .

1 Less than high school
2 High school diploma or equivalency (GED)
3 Some college
4 Completed 4 year degree (BA or BS)
5 Graduate school

CODE
0037 . . . . . . J0300

4. **In what year did you (*the operator*) begin making day-to-day decisions for any farm/ranch?** . . . .

YEAR
0038 J0400

5. **Now I would like to classify the total acres operated in terms of total gross value of sales.**

Considering–
! all crops sold,
! all livestock, poultry (*including commercial broilers*), and products (*milk, eggs, etc.*) sold,
! all sales of crops, livestock or poultry, produced under contract,
! all sales of any miscellaneous agricultural products,
! all government payments received,
! landlord's share of government payments and crops sold in 2000;

What code represents the total gross value of sales you expect for this operation in 2000?

☐ 1 Less than $1,000
☐ 2 $ 1,000 – $ 2,499
☐ 3 $ 2,500 – $ 4,999
☐ 4 $ 5,000 – $ 9,999
☐ 5 $ 10,000 – $ 19,999
☐ 6 $ 20,000 – $ 24,999
☐ 7 $ 25,000 – $ 39,999
☐ 8 $ 40,000 – $ 49,999
☐ 9 $ 50,000 – $ 99,999
☐ 10 $ 100,000 – $ 249,999
☐ 11 $ 250,000 – $ 499,999
☐ 12 $ 500,000 – $ 999,999
☐ 13 $ 1,000,000 and over

→ CODE
0039 J0500

6. **Of the farm income reported, which of these categories represents the largest portion of the gross income from the operation?** . . . .

CODE
040 J0600

FARM TYPE CODES

1 GRAINS and OILSEEDS
2 TOBACCO
3 COTTON
4 VEGETABLES and MELONS
5 FRUIT TREE, NUTS and BERRIES
6 NURSERY, GREENHOUSE and FLORICULTURE
7 OTHER CROPS
8 BEEF CATTLE
9 DAIRY
10 HOGS
11 SHEEP, GOATS, WOOL and MOHAIR
12 EQUINE
13 POULTRY and EGGS
14 AQUACULTURE
15 OTHER ANIMALS

CONCLUSION

LOCATION OF SELECTED FIELD

1. **I need to locate the selected field of corn on this map.**

   What county is the selected corn field in?

   Field description . . . .

	COUNTY NAME	**OFFICE USE COUNTY FIPS CODE**
What county		0010 **Z0100**

2. **[ENUMERATOR ACTION:**
   Mark map to indicate where the selected corn field is located.
   Be sure the "X" marked on map is in county identified above.]

4. **Would you like to receive a copy of the results of this survey in the mail?**
   (Results will also be available on the Internet at *http://www.usda.gov/nass/*) . . . . **YES = 1** — **CODE** 0099 **Z0400**

RECORDS USE

5. [*Did respondent use farm/ranch records to report--*]

		CODE
a. [***fertilizer** data?*]	**YES = 1**	0011 **Z05a0**
b. [***pesticide** data?*]	**YES = 1**	0012 **Z05b0**

SUPPLEMENTS USED

6. [*Record the total number of each type of supplement used to complete this interview.*] . . . .

	NUMBER
FERTILIZER APPLICATIONS	0041 **Z0601**
PESTICIDE APPLICATIONS	0042 **Z0602**
FIELD OPERATIONS	0043 **Z0603**

RESPONDENT

1 **OPERATOR/MANAGER/PARTNER**
2 **SPOUSE**
3 **ACCOUNTANT/BOOKKEEPER**
4 **OTHER**

. . . . **CODE** 0101 **RESP**

Respondent's name . . . . ______________________

Phone . . . . (________) ______________________

ENDING TIME [*MILITARY*] . . . . **MILITARY TIME** H H M M 0005 **ENDTI**

DATE: . . . . **YYYYMMDD** 0007 **DATE**

ENUMERATOR NAME ______________________ . . . . **ENUMERATOR ID** 0098 **ENUM**

EVALUATION 0100 **EVAL**

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