Cost-Effectiveness of Alternative Environmental Policies for Reducing Non-Point Source Pollution in Public Water Supplies

by

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Abstract

This study predicts farmers' response to policy alternatives aimed at alleviating non-point source pollution problems in a municipal water supply in Pike County, Illinois. The framework integrated simulation models with optimization models of the watershed to assess environmental policies. Results show how farmers are likely to alter agricultural management practices.

Introduction

The threats of contamination of food and drinking water posed by the use of agricultural chemicals are prominent issues in the public debate over agricultural and environmental policies in the United States. Whether perceived or real, threats to human health are especially potent topics of public discussion. Given this kind of atmosphere in the public rhetoric, efforts to development public policy would benefit from clearer understanding of the economics of contemporary agriculture and how it is likely to respond both to policy alternatives and to other variables within the farmers' decision environment. Developing better tools for performing spatial analysis of non-point source pollution control policies remains a major challenge to meeting this need for understanding.

The Midwestern states generate over half the value of the United States' agricultural outputs, plant over half of its cropland acres, produce over half of its agricultural exports, and account for over half of its agricultural assets (Illinois Department of Agriculture, 1984), and Illinois plays prominently in these statistics. The 1982 Census showed that 80.7 percent of the land in Illinois is farmland of which 86.2 percent was classed as cropland. Corn, the foundation of Illinois agriculture, is grown on 82 percent of the Illinois farms and on 50 percent of the cropland acres and the combination of corn and soybeans accounts for 87 percent of crop sales in the state.

Atrazine is the primary and most important herbicide widely used in the production of corn. Over 60 percent of all corn acreage has some atrazine applied. This pesticide is subject to regulation in Illinois and the applicable drinking water standard (maximum contaminant levels, MCL) is .003 mg/l or 3 ppb. In addition to the drinking water standard, the adverse impact of atrazine runoff on the environment may be seen directly in fish kills reported each year to state conservation and environmental protection agencies (Felsot et al.). The Illinois EPA has recorded numerous surface-water supplies contained by atrazine in Illinois. Detections in Lake Pittsfield from 1991 and 1992 ranged between 1.90 ppb and 13 ppb. Taylor further suggested that the best way to address the pesticide contamination problem is to implement preventive agricultural management practices in the watershed of the public water supply intake. This study considers the circumstances of a public water supply reservoir that has experienced significant atrazine contamination from surface water and shallow groundwater from its largely agricultural watershed. The focus is on how farmers in the watershed would be likely to change their production practices under different remedial policies. This approach also serves to identify the voluntary production system changes which may have the same consequences as those induced by regulation.

The physical processes that deliver atrazine over or through the soil to surface water are naturally complex, and the spatial dimension plays such a crucial, interactive role that the processes are inherently site-specific. This creates a dilemma for analysts attempting to construct models for examining atrazine runoff control policies. On the one hand, site-specific modeling can capture the complexity, but the results produced are not easily generalized. On the other hand, an aggregate model may produce more widely applicable results, but its construction must abstract from site-specific complexity. Both approaches are compromises (White).

Policies to control Atrazine Pollution

This research attempts to combine the technology of a geographic information system (GIS) with existing soil-crop response and sediment and chemical transport simulators to improve capabilities of analyzing and summarizing the spatial dimension of atrazine runoff. The objective is to compare alternative patterns of crop production practices, which reduce the level of atrazine in the Lake Pittsfield public water supply. This objective is achieved by constructing a computer simulation and optimization model to represent agriculture in the Lake Pittsfield watershed. This model is then used to identify agricultural production practices, which maximize net returns under alternative policies to reduce the level of atrazine in the public water supply. Policy alternatives that are examined include:

1) restriction on atrazine runoff,
2) fine or tax on atrazine runoff,
3) restriction on atrazine use, and
4) tax on atrazine use.

All policy alternatives are evaluated both with and without the availability of cyanazine (trade name: Bladex) as a substitute for atrazine. A mathematical programming approach has been taken to model the effects of different policies, because several scenarios can be analyzed easily once a model has been constructed.

Previous Studies

A number of studies have examined the impacts of alternative tillage systems on environmental measures including erosion, sediment production and nutrient loading, but atrazine contamination has received little attention. Nelson and Seitz focused on soil loss and nitrogen use, ignoring other pollutants such as atrazine either in runoff or attached to sediment. Braden and Johnson identified land management practices that minimized the cost of reducing sediment delivery from a small Illinois watershed. Setia et al. compared tillage systems for cost effectiveness in reducing sediment and nutrient loadings to Illinois' Highland Silver Lake. Sergeson focused on flexibility provided by best management practices in controlling pollution and found that they do not always provide minimum cost abatement strategies. Braden et al. discuss a number of studies concerning economic and spatial targeting of nonpoint pollution abatement efforts. Baumol and Oates have suggested some approaches for correcting externalities. These include: Pigouvian taxes, input taxes, standards, and transferable pollution permits. Identifying the above policies, Shortle and Dunn found that properly specified incentives to encourage desired management practice outperform runoff standards and direct controls.

More studies have evaluated the effects of policy alternatives such as taxes and discharge or in-stream standards to reduce pesticides in surface and groundwater. Anderson, Opaluch, and Sullivan estimated the relationship between aldicarb applications and its concentrations in groundwater. They assessed the effect on net income of pollution standard that restricted aldicarb pollution to the maximum contaminant level (MCL) in streams draining potato fields in Rhode Island. Rola, Chavas and Harkin estimated the farm level impact of restricting or banning aldicarb use on Wisconsin's potato farm profit. They found that the cost of aldicarb regulation is borne primarily by farmers who are being forced into more expensive production methods. Swinton, Lybecker and King analyzed the impacts that local input taxes and restrictions on the use of atrazine and other triazine herbicides had on optimal weed management. They suggested that an input tax that is less than the ban-equivalent and a Pigouvian tax on effluent are two options for minimizing the negative farm-level effect of herbicide restrictions. Liu, Carlson, and Hoag found that removing an individual herbicide from use does not guarantee groundwater quality improvement. In addition, the effect of a multiple cancellation differs from the sum of the effects of individual cancellations. Studying the effects of prices, tillage practices, crop rotation, farm programs, and application timing and methods on chemical use, Lin et al., suggested that herbicide demand in U.S. corn production is own-price inelastic. A high tax would be needed to reduce herbicide use on corn and, in the past, farmers who participate in farm programs have used more herbicides than no participants. The switch from conventional tillage with the moldboard plow to other tillage systems (including conservation tillage) does increase herbicide use. Shumway and Chesser found a 25 % ad *valorem* tax on pesticide would have a major impact on cropping patterns and on total pesticide use in the South Central Texas Reporting District. Taylor et al. found that bans on broad groups of pesticides will decrease net crop income nationally.

Study Area

The Lake Pittsfield watershed is located on Blue Creek (a tributary of the Illinois River) in the eastern portion of Pike County, which is in west-central Illinois between the Illinois and Mississippi Rivers. The watershed has an area of 11.15 square miles (7,136 acres or 2,888 hectares). The lake is the municipal water supply for Pittsfield, Illinois and is located about 3 miles northeast of that city of about 4,400 residents.

Lake Pittsfield has a surface area of 218 acres (88.3 hectare) at its normal pool capacity of approximately 2,773 acre-feet. Since its construction in 1961, the lake has had a history of accelerated loss of capacity due to sediment coming from the largely agricultural watershed. This history includes numerous studies of the accumulated sediment within the lake and monitoring of sediment loads in the tributary streams.

The topography and drainage patterns differ from east to west in the watershed. The eastern portion is characterized by gently rolling hills with a few level ridge tops. In contrast, the western portion is more broken, conforming more generally to the preglacial bedrock. The main valley is broad with gentle side slopes. The gradients of the main stem and the tributaries of Blue Creek are moderate, with a total range in elevation within the watershed of about 206 feet.

The majority of upland soils within the watershed have been developed in moderately thick loess overlying weathered glacial till. Most of the soils were developed under forest vegetation. The steeper side slopes nearer the streams have formed in exposed glacial till or limestone residue. These soils are much more heterogeneous than on the upland. The limited areas of bottomland soils are cumulative formations in silty deposits derived from erosion of the uplands. The pattern is similar to that found throughout the rest of the watershed.

The selected study area is a contiguous group of sub watersheds that provide a reasonable sample of the landscape, soil types, and management patterns found in the watershed as a whole. This project developed a computer representation based on this physical setting to use as a simulated test platform for comparing alternative pollution control strategies.

Modeling Framework and Data Specification

Conceptual Model

The integrated approach used in this analysis links computer simulations models that predict yields, sediment production and atrazine runoff from crop rotations, with an optimization model that predicts the response of a profit maximizing decision-maker to alternative policy scenarios. Modeling the movement of sediment and unwanted chemicals into the reservoir requires that the movement of chemicals and soil particles from the fields into the lake to be estimated. The transport mechanisms are sensitive to management factors (e.g., tillage used and crop grown) as well as to natural landscape and weather variables. These relationships are simulated in a computer model of chemical and sediment transport through the watershed, thereby linking crop production decisions to reservoir water quality.

Once the physical watershed has been simulated and the farmer decision-making has been modeled, policies aimed at reducing pollution and sedimentation are introduced. Comparing how the model responds to the policies allows us to comment on the relative impacts of the policies.

An analytical problem at the center of this project is how to aggregate landscape characteristics so that the simulated behavior is an adequate representation of the watershed and is sensitive to the management alternatives being analyzed, while remaining computationally practical. The general strategy for spatial aggregation has been: 1) to divide the watershed into sub watersheds with each having an area similar to that of a typical agricultural field, 2) to select a set of these sub watersheds for further analysis, 3) to sort the resulting sample of sub watersheds into classes, and 4) develop a simulation model of each class. This approach enables systematic expansion of the results to reflect the responses that can be expected from the entire watershed.

Geographic Information System (GIS)

For mapping and spatial analysis, the project employed a public domain GIS system called GRASS (Geographical Resources Analysis Support System) version 4.1. An extensive GIS database that was available for the Lake Pittsfield Watershed has been of great value in our spatial aggregation strategy.

In addition to providing various maps of the watershed such as soil types, land use, elevations and stream locations, the GRASS system is used to actually delineate the pattern of sub watersheds used as the basis for the subsequent modeling. A GRASS algorithm (r.watershed) systematically subdivides a watershed into various numbers of smaller basins depending on the parameters chosen for the algorithm. Through an iterative process, this algorithm has been used to create subdivisions of the size and internal homogeneity needed for our simulation modeling. A group of 29 contiguous subwatersheds draining a particular farm provides the cross-section of the watershed used as the basis for the simulation models.

After delineating the sub watershed boundaries, GRASS is again used to analyze their characteristics. GRASS provides summaries of the extent and the location of cropland, grassland and forestland within each of the 29 sub watersheds. These summaries enable the classification of the sub watersheds into four groups based on predominant sequences of land use, from the top of the slope down to the stream. Type I sub watersheds are essentially all cropland draining directly into a stream. Type II sub watersheds have cropland draining across grassland and then into the stream. Type III sub watersheds typically have cropland draining across forestland and then into the stream. And, type IV sub watersheds are entirely no cropland.

GRASS is also used to summarize other predominant characteristics of the sub watersheds that are needed to specify the crop growth and hydrological transport simulations. A critical step in simulating the behavior of each sub watershed type is to identify and determine the area extent of representative soil types, including their slopes. Developing a workable simulation of hydrological transport also requires that the general shape (concave, uniform or convex) of the slope within each sub watershed be characterized. Basins that are Type I are all cropland located on upland flat ground draining directly into small, seasonal stream channels. Type II basins are more complex with areas of flat upland cropland draining across a gently convex slope with at least some grassland (on the steeper slopes) between crops and a more permanent stream channel. Type III basins contain some even steeper slopes that are generally forested and are at the lower end, again, of a convex slope between relatively flat upland cropland and the stream channel. Type IV basins are the steepest areas of the watershed and contain no cropland at all.

Soil and Crop Response Simulator

The Erosion-Productivity Impact Calculator (EPIC) developed by the USDA Agricultural Research Service and Soil Conservation Service (Williams, Jones and Dyke 1990) is used to estimate and compare crop yields across the range of soil, tillage, and rotation combinations being examined in this study (Table 1). EPIC is a multicrop and multiyear crop growth simulation model that uses soil information, daily weather data, and detailed schedules of crop production activities to simulate plant growth and soil erosion. The water quality version of EPIC (EPIC-WQ) includes subroutines to estimate the movement of nutrients and pesticide from the field. In addition to its role as a yield prediction tool, EPIC-WQ serves two other valuable functions in this study.

EPIC-WQ is used as part of the preliminary analysis of the soil types present in each sub watershed type. This preliminary analysis identifies the soils similar enough in their behavior that they could be aggregated and represented in the model as a single soil. The characteristics used to identify the representative soils specific to each sub watershed were productivity, slope class, and erosion phase.

Soil properties were taken from the Soils-5 database. Each representative soil is modeled in the EPIC-WQ simulator for each tillage/rotation combination and the model is run for a period of 60 years. The weather sequence used in these 60-year simulations is based on a set of statistical parameters computed from observed climatic conditions at the Griggsville, IL weather station, located approximately two miles northwest of the watershed.

EPIC-WQ is also used to identify specific storm sequences, which produce excessive atrazine surface runoff losses. These storm sequences are then used in the level-level simulation of pollution generation and transport using another model called, AGNPS, which is described in the next section.

For each sub watershed type, a single yield is reported for each rotation/tillage combination. These yields are computed by first weighing the 60-year average yields from each representative soil by the relative extent of that soil within the basin. The weighted sub watershed yield is then calibrated to the Pike county site by applying a correction factor accounting for the difference between the simulated yields and the observed county averages[1].

The EPIC model simulates the behavior of an acre of homogeneous of soil subjected to several years of statistically generated weather. The model then simulates plant growth and yield, soil erosion, pesticide movement and other processes that occur within the soil column. For our purposes, the EPIC model provides a detailed simulation of crop yields and the point of origin of many of agriculture's troublesome by-products, however it does not simulate the transport processes that move the by-products off the site. In order to estimate the levels of atrazine and sediment being delivered to Lake Pittsfield, the modeling effort must also include a way to model the hydrologic response of watershed to rain events.

Sediment and Chemical Transport Simulator

A second computer model widely used in the U.S. provides the needed tool for simulating off-site transport. The Agricultural Non-Point-Source pollution model, AGNPS, is a computer simulation model developed

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The correction factor is the Pike County average crop yields observed over the 1989-93 seasons divided by a simulated base yield. The simulated base was computed using simulated yields from all the soils in the watershed, assuming a mulch by the USDA Agricultural Research Service to analyze the water quality of runoff from agricultural watersheds. AGNPS predicts total and peak runoff, erosion, sediment delivered, and the runoff concentrations of nitrogen, phosphorus, COD (chemical oxygen demand) and pesticides resulting from single storm events for all points in a watershed (Young, *et al.*).

AGNPS is used in this study to model the generation and delivery of atrazine and sediment from the field to the nearest stream. In modeling the generation of the pollutants, it duplicates some of the capabilities of EPIC. However, EPIC is incapable of providing the spatial interactions required to estimate ultimate transport of pollutants off-site to a delivery point some distance away. The overlap of models creates some redundancy but it also provides an opportunity to check the performance of the models against one another.

AGNPS is structured so that the subject watershed is divided into a grid of square cells that are uniform in size but which can be individually described to reflect spatial variability of the watershed being modeled. The list of cell descriptors includes general landscape characteristics (curve number; slope %; slope shape; slope length; aspect and the presence of a channel, impoundment or gully erosion). In cells where a stream channel is present, other parameters are required (gradient %, side slope % and Manning's roughness coefficient). Intrinsic soil characteristics are also required (USLE erodibility factor, surface condition and texture). The management of the land is reflected in still other variables (USLE cropping factor, nitrogen and phosphorus fertilizer applications, and pesticide characteristics and application). A critical parameter that must be entered for each cell is its aspect or, more specifically, the neighboring cell into which it drains. By specifying a flow path for each cell, all of the cells are interconnected and the drainage network of the watershed is established.

Once the watershed is fully described in terms of a network of interconnected cells, a rain event can be described and when the model is run it reports the watershed's response to that storm cell-by-cell from the ridgeline down to the outlet. AGNPS output includes: volume and peak flow of water runoff, mass of sediment (by particle size class), mass and concentration of pesticide, nitrogen and phosphorus. In this project, our interest is in the total

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tillage production system.

amounts of water, sediment and pesticide (in this case atrazine) delivered to the surface water.

Crop Production Budgets

Tillage Systems

The choice of clean-till versus no-till, clean-till versus mulch-till, or mulch-till versus no-till may have an impact on atrazine runoff and soil loss. These tillage practices (Table 1) are among the principal tillage alternatives currently being used in Illinois. The USDA Natural Resource Conservation Service (NRCS) makes categorical distinctions between these practices. Clean-till leaves less than 30% residue cover after planting. Mulch-till involves limited tillage that retains at least 30% residue cover after planting. No-till involves planting directly into undisturbed residue from the previous crop. Pesticide use is typically assumed to be higher for a no-till system than for clean- or mulch- till.

Crop Rotations

A central component of the combined model is the economic decision-making behavior of farmers. Crop budgets have been developed to reflect the growing conditions and yields experienced by farmers in Pike County, Illinois. These budgets have been tailored to assure that for each different cropland type (i.e., sub watershed type) being modeled. The differences in costs and input quantities for each possible combination of crop rotation, tillage and herbicide program are reflected. Each cropland type is unique in terms of the production inputs required as well as the resulting crop yield, sediment production, atrazine output, etc. Based on these differences in how cropland types respond to production choices a profit maximizing linear program shifts the available cropland into different production patterns as market or policy constraints are varied.

Mathematical Programming Model

The objective of the single-period linear programming (hereafter LP) to maximize profit subject to a number of possible constraints including: nonpoint pollutant emissions (amount of atrazine runoff and sediment), amount of pesticide used (atrazine and cyanazine), crop rotations (continuous corn, soybeans, corn after soybeans, wheat and wheat after soybeans), watershed types (cropland, grassland, and forestland), tillage practices (clean, mulch, and no-till), and farm profit. Pollution-control standards and incentives are examined in the short-run. The changes in watershed profit, crop mix (including rotation and tillage practices) and physical outputs between the unrestricted model and model scenarios under imposed strategies provide a way of evaluating policy effectiveness and farm-level reduced profit. The primary decision maker is assumed to be a risk-neutral independent farmer who maximizes profit. In the benchmark scenario profit is maximized without environmental constraints. With pollution-control constraints or tax, an additional decision maker is a social regulator that sets an amount of tax or allowable levels of pollutant losses or atrazine use. This behavior is modeled using a LP.

The principal activities are crop activities that differ by crop rotations, soil types and tillage practices. The rotations are chosen to allow for crop substitutions in response to production constraints on atrazine runoff. Each crop activity uses land and other inputs, produces saleable output and generates an amount of sediment and atrazine runoff. Physical inputs and expenses from the crop production budgets; yields and weather behavior from EPIC-WQ; runoff, atrazine and sediment delivery from AGNPS; as well as prices and other information are combined in the LP to represent the essential elements of the watershed and the crop production choices available within it. The model constraints are: land area, environmental quality, and various constraints due to crop rotations. Environmental quality constraints are placed on atrazine application or runoff. Constraint levels are manipulated to determine what management practices can economically reduce pollutant losses. In addition to the resource dimensions built into the model (e.g., total acres, crop acres, extent of different soil types, hydrologic landscape, etc.) the set of initial assumptions also includes: the number of acres in the farm's corn and wheat bases, the required "set-aside" for each program crop, the percentage of corn base "normal flex acreage" (NFA), the supported prices for corn and wheat, and market prices for soybeans and hay.

Atrazine outflow from an agricultural watershed is an episodic phenomenon produced by precipitation patterns. Monitoring evidence indicates that the pulses of high levels of atrazine that threaten or exceed quality standards for drinking water are the result of storm events occurring soon after application of atrazine. The LP includes atrazine runoff coefficients representative of a pattern of three spring rains that, based on EPIC-WQ simulations, produced a total atrazine runoff that would have a probability of being exceeded only one year out of ten. The coefficients themselves were obtained through AGNPS modeling of the selected three-storm patterns, followed by calibration of the results using monitoring data from the watershed. The calibration enabled the inclusion of a realistic background level of atrazine that seems to have its origin in the tile flow and shallow groundwater that sustain the base flows of streams.

In general, the purpose of an LP model is to select the best course of action from a set of feasible alternatives, subject to a set of constraints. In this project, the LP allocates cropland to combinations of available alternative crop production systems (e.g., corn after soybeans using mulch tillage and atrazine) so as to maximize the profit of the overall farming enterprise without violating any constraint that might be imposed. Although the decision logic embodied in an LP is conceptually straightforward, it can take on considerable complexity as more and more choices, interactions or constraints are added to the decision to be made.

The predicted responses of each different type of cropland are built into the LP so that as cropland acres are allocated to production choices, relevant outputs (e.g., crop yield, atrazine input and output, and sediment output) are computed and either subjected to imposed constraints or simply accumulated and reported. Simultaneously, these direct outputs are transferred through additional computations (e.g., yield is multiplied by a selling price to compute income, inputs are multiplied by purchase prices to compute costs, and costs are subtracted from income to compute profit).

Empirical Results

The linear programming model has been used to evaluate the effectiveness of ex ante regulations (restricting effluent discharge or input, input tax) and ex-post policies (effluent taxes) and compare their impacts on farm income (net only of variable costs), acreage, atrazine application and runoff. The LP model enabled the analysis of management choices and input constraints which farmers face when regulations, taxes and physical limitations are imposed. The LP model was used to represent profit maximizing decisions expected under different circumstances or constraints. For example, the amount of atrazine leaving the simulated watershed is the primary parameter constrained in simulating a policy restricting the concentration level in the lake. Alternatively, a tax or fine imposed on each unit of atrazine runoff to simulate how an incentive policy to reduce atrazine effluent by impacting the decision maker's profit. Results of the simulation framework are presented in tables 1 and 2.

Base Case Analysis

Tables 1 and 2 present the benchmark solution (0% reduction) that is a profit-maximizing production plan with no restrictions on either atrazine application or atrazine runoff. This production plan results in the maximum levels of: profit ($146743), atrazine used (769.59 lbs), atrazine runoff (5.117 lbs), and sediment (343.348 tons) from the watershed. The farm income averages $152 per acre of cropland. In addition, the pattern of production shows that corn is produced in all types of sub watersheds using no-till tillage rather than mulch-till or clean-till.

Atrazine Runoff Restriction versus Pigouvian Tax on Atrazine

Two levels of atrazine runoff restriction were presented (with atrazine runoff reduced by 93 without cyanazine or 100 and 80 percent of the baseline case) with sediment losses unconstrained (Table 1). The effect is to decrease atrazine use and to stabilize (with cyanazine as an option) or increase sediment (without cyanazine as a substitute). Reducing the amount of atrazine runoff causes mulch- and clean-till practices to enter optimal production plans (in the absence of cyanazine) at pesticide runoff levels of 20% and 7%, of the baseline, respectively. From a policy standpoint, the costs of baseline of economic efficiency may be compared with the costs of other policies that are opportunity costs incurred under circumstances where the farmer voluntarily takes on the challenge of reducing atrazine levels, and achieves each level of removal at the lowest possible opportunity cost. The cost of the atrazine removal is the opportunity cost associated with complying with each specified level of atrazine reduction. In other words, it is the difference between the profit at a particular target level of clean-up and the unconstrained profit at zero clean-up. There are costs incurred as atrazine runoff is increasingly restricted, but with cyanazine substitutes for atrazine. Farm incomes range from a high $146743 (unconstrained scenario) to $142504 (atrazine ban policy) or to $127412 (93 % reduction without the presence of cyanazine). Achieving the same levels of atrazine removal become considerably more expensive in the absence of the cyanazine substitute. In the absence of such substitute, removal of 100% of the atrazine is infeasible. The infeasibility arises because of the model requires a minimum acreage of corn because of the Federal commodity program for corn, but it contains no production alternatives completely free of either atrazine or cyanazine.

The marginal costs of the environmental quality constraint obtained from the quality constraints shadow price range from 0 to $1860 per pound or to $5888 per pound for scenarios with or without cyanazine, respectively. These shadow prices may be interpreted as Pigouvian taxes required to achieve the given percentage reduction in atrazine runoff. Two tax levels are shown in table 1 (with and without cyanazine as a substitute). With the presence of cyanazine, no-till practices substitute for clean-till practices only at lower amount of tax. In the absence of cyanazine, as the amount of taxes increases, no-till practices substitute for mulch-till tillage system. At the highest level of pigouvian tax, mulch-till practices are used on all types of sub watersheds. In addition, in all scenarios, the pattern of production shows that all of the corn in sub watershed Type I and most of it in Type II is being produced using mulch tillage rather than no-till. This shift in tillage allows corn to be grown with atrazine but with much less atrazine runoff, because the system incorporates it immediately upon application.

Results also show reducing atrazine runoff (without cyanazine) control strategy that is optimal for atrazine input reduction may be sub optimal with respect sediment (Heimlich and Clayton, 1982). Practice such as no till that controls erosion does not reduce atrazine runoff. This result is consistent with that found by Braden et al. (1991).

Atrazine Input Restriction versus Input Taxes

Farm impacts of on atrazine input restriction are evaluated with and without the presence of cyanazine as a substitute. Results reported in table 2 showed how such a policy may induce the farmer to achieve some levels of clean-up. The choices remaining to the farmer can vary considerably from those remaining when a maximum level of atrazine runoff is mandated. The results in this case where cyanazine is available, are similar, but differ. It is showed that where the applied herbicide is reduced 40% (with cyanazine) and 20% (without cyanazine), achieves about a 1.1% (with cyanazine) and 5.2% (without cyanazine) reduction in farm income. However, reducing input another 40% (with cyanazine) and 5% (without cyanazine) results in 1.1% and 1.9% further reduction in farm income, respectively.

The shadow values of input constraints reflect taxes required to achieve the given percentage reduction in input use. The tax-on-atrazine-input scenario identifies the single point at which a tax on atrazine input produces a change in management. This point is where the atrazine input tax is equal to the difference in price between atrazine and cyanazine. Below that level, the farmer pays the tax, but above it, cyanazine is used instead and results in 100% atrazine removal.

Without the benefit of having cyanazine as a backup, there are only two feasible solutions representing 20% and about 25% reductions in atrazine input (Table 2). Reducing atrazine inputs more than this is infeasible, because in the absence of a cyanazine option and with a required minimum corn base, the last feasible solution point when output is limited requires about 75% of the total atrazine input. This scenario differs because since 100% removal is impossible (without cyanazine) all of the solution points include tax payments on the remaining atrazine (Table 2). In addition, because 100% atrazine removal is infeasible, an ever-escalating fine on atrazine output could theoretically impose a liability equal to all of the farmer's income ($146,743 or $450 per minimum corn acre).

Conclusions and Discussions

Results of this study have produced a number of insights into the efficacy and cost of different pollution reduction policies. It is clear that as long as atrazine can be replaced by an alternative chemical that is comparatively effective and affordable, compliance with atrazine restrictions is relatively painless to the farmers. The change is simple and the opportunity cost is minimal. However, in the absence of such a substitute, compliance becomes a much more complex, difficult and expensive task. The different scenarios contained only a limited range of alternatives from which the simulated decision maker must select. It was possible to demonstrate how the presence of the government acreage reduction program for corn conflicts with the elimination of chemicals associated with its production.

Mathematical programming models discussed in the study allocated acres and fractions of acres of land area to any combination of several production choices. The possible patterns of production were so numerous that they comprise an essentially continuous set of choices. For further research, a mathematical programming can also be formulated to include options that must be selected in discrete, indivisible units. It may be expanded to include a choice of this type in order to consider scenarios in which wetlands, filter strips or sediment basins are installed to trap pollution before it reaches the lake. In the model each structural "unit" may have a specified interception efficiency and pollutant storage capacity. A unit will remove a specified fraction of the pollutant in the runoff it intercepts, up to the unit's specified capacity.

With this kind of formulation, a mathematical programming model can be instructed to install enough of these intercepting structures to assure a desired reduction in atrazine production. The profit that this scenario will generate can then be compared to the profit attainable under a scenario where the same atrazine reduction is attained without the structures. The difference will be the value of the structures.

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Table 1: Impacts of Runoff Standard and Tax on Net Returns, Acreage, Atrazine Application and Runoff

Scenarios	Net Farm Returns ($)	Crop Production			Atrazine Application (pounds)	Atrazine Runoff (pounds)	Sediment (tons)
		Type 1	Type II (acres)	Type III			
Baseline							
Unconstrained	$146,743	254.47	302.40	365.90	769.59	5.12	343.35
With Cyanazine Option							
Atrazine runoff reduction							
80%	$144,399	254.47	302.40	365.90	344.05	1.02	343.35
100%	$142,504	254.47	302.40	365.90	0.00	0.00	343.35
Pigouvian tax							
$1250/lb	$142,612	254.47	302.40	365.90	356.80	1.06	343.35
$1860/lb	$142,504	254.47	302.40	365.90	0.00	0.00	343.35
Without Cyanazine Option							
Atrazine runoff reduction							
80%	$138,211	297.94	302.40	322.40	613.36	1.02	791.89
93%	$127,412	254.47	302.40	365.90	570.67	0.32	1 310.46
Pigouvian tax							
$4924.57/lb	$141,410	297.94	302.40	322.40	678.72	1.57	634.58
$5888.16/lb	$137,670	297.94	302.40	322.40	602.31	0.93	818.47

Table 2: Impacts of Input Standard and Tax on Net Returns, Acreage, Atrazine Application and Runoff

Scenarios	Net Farm Returns ($)	Crop Production Type 1 (acres)	Type II	Type III	Atrazine Application (pounds)	Atrazine Runoff (pounds)	Sediment (tons)
Baseline							
Unconstrained	$146,743	254.47	302.40	365.90	769.59	5.12	343.35
With Cyanazine Option							
Atrazine input reduction							
40%	$145,047	254.47	302.40	365.90	461.75	1.39	343.35
80%	$143,352	254.47	302.40	365.90	153.90	0.46	343.35
Without Cyanazine Option							
Atrazine input reduction							
20%	$139,077	254.47	302.40	365.90	615.67	2.97	757.41
25%	$136,333	254.47	302.40	240.90	570.70	1.23	878.31
Input tax							
$48.93/lb	$109,288	254.47	302.40	365.90	736.18	4.83	459.42
$61.02/lb	$101,511	254.47	302.40	365.90	643.95	4.06	681.38