CEEPES: An Evolving System for Agro-environmental Policy

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CEEPES: AN EVOLVING SYSTEM FOR AGRO-ENVIRONMENTAL POLICY

Although this may seem a paradox, all science is dominated by the idea of approximation.
— *Bertrand Russell*

Nonpoint source pollution from agricultural production is now front-and-center in the policy debate over potential sources of environmental degradation (see, for example, Shortle and Dunn 1986; Russell and Shogren 1993). Although partially related to scientific advances in measurement and detection, perceived risks due to chemical loading have intensified the pressure to more closely coordinate agricultural and environmental policy (Cohen, Eiden, and Lorber 1986; Johnson, Wolcott, and Aradhyula 1990). But strategies to coordinate these policies have been impeded by a serious information gap on the explicit environmental and economic trade-offs of various public and private actions. Although most decision makers would agree that securing this information is critical for more effective agro-environmental policy, the question remains as to the best course of action.

This paper charts one course: CEEPES—the comprehensive environmental economic policy evaluation system—an integrated system designed to systematically evaluate trade-offs from alternative agro-environmental policies. CEEPES combines diverse simulation models into an integrated policy evaluation system that estimates a set of ecological and economic indicators. Our goal is to develop a flexible framework that allows CEEPES to evolve as new policy questions arise. We facilitate flexibility by constructing CEEPES around four key components that can incorporate additional economic and physical models—policy space, agricultural decision, fate and transport, and environmental and health risk.

Integrated modeling systems have become a concrete tool to improve our understanding of the environmental repercussions of agricultural production, the interactions between agricultural and environmental factors, and the policy feedback vital to the efficient design of institutions for environmental protection. Agro-environmental modeling systems range from the farm-level systems used to study localized impacts of resource policies such as conservation compliance and sustainable agriculture to watershed models. For example, the watershed model SEDEC estimates the economic and technological impacts of soil conservation policies on individual land management units within a watershed. SEDEC integrates an economic decision model with a sediment transport and delivery model to optimize the location of abatement measures, key to targeting nonpoint pollution model to optimize the location of abatement measures, key to targeting nonpoint pollution (Bouzaher, Braden, and Johnson 1990). But at the regional level, CEEPES is perhaps the most comprehensive agro-environmental modeling system built to date.

In addition, the integration of CEEPES also departs from the standard economic and geophysical modeling approaches. Compared with economic models operating at the county or state level, geophysical process models operate over relatively limited time and space scales, often at a point. Congruence of these scales is achieved through the construction of a statistical metamodel that summarizes the calibrated geophysical process models at the needed spatial and temporal scales. Metamodels used in the trade-off analyses have scientific integrity in terms of experimental and sampling error. This contrasts to other approaches where the geophysical features of ecological and economic systems with statistical relations include little or no prior information.

This paper first describes why CEEPES was constructed. We define the broad CEEPES components in the third section. The fourth section discusses the lessons learned over the course of development. Finally, we summarize the results of the recent application of CEEPES to atrazine policy, soil carbon sequestration, and livestock waste.

Why CEEPES?

Agricultural productivity in the United States and other developed countries has improved significantly over the last several decades, due in part to the introduction and expanded use of agricultural chemicals. Government agricultural programs that encouraged increased yields also encouraged high inputs of agri-chemicals (see Gardner 1987; Reichelderfer and Hinkle 1989). In the last four decades, pesticide and nutrient use in U.S. agriculture has significantly increased, remaining at high levels especially in intensive crop cultivation areas. Between 1964 and 1986, for example, agricultural pesticide use more than tripled (USDA 1985). In 1982, more than 90 percent of U.S. row crop acreage and about 45 percent of U.S. small grain crop acreage were treated with herbicides. By the early 1980s, the threat of groundwater contamination from conventional field applications of agricultural pesticides and nutrients had become a major policy concern (Barnes 1976; Hallenbeck and Cunningham-Burns 1985; Holden 1986). In 1989, the EPA identified 74 pesticides in the groundwater of 38 states (NGA 1989). The EPA study demonstrated that while misuse and point discharges were the main sources of contamination, some contamination was the result of normal use in crop production.

The continuing concern in the United States for potential health risks from agri-chemical use is revealed by the passage of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), repeated amendments, restrictions on registration of certain chemicals, legislation to reduce farmer exposure, the current debate on food safety, and introduction of pesticide-record keeping in the 1990 Farm Bill (Bosso 1987). But increasing evidence of agri-chemicals in groundwater, pesticide residuals in the food chain, and the possibility of atmospheric exposure has sharpened regulators' interest to further evaluate the environmental economic trade-offs. Expanding regulation of agricultural chemical use and broadened and indirect forms of regulation are likely, as indicated by trends in state legislation as well (Wise and Johnson 1990). Improved information on the relevant trade-offs is necessary for efficient policy intervention, and to guide the compliance of private decision makers.

A key to CEEPES is the linking of pesticide and nutrient fate to cultivation practices, application rates, soils and climatic conditions, tillage practices (agricultural production technology), and parameters of agricultural income maintenance policies in order to provide more accurate measures for risk-benefit trade-offs. Experiments combining important prior information in biogeophysical processes and examining alternative policies using specific sets of incentives, rewards, and restrictions can be conducted with CEEPES. But since uncertainty prevails in pesticide fate and risk assessment, CEEPES must be viewed as a framework approximating trade-offs and associated policy evaluation. Policy problems related to pesticide use and health and environmental risk involve uncertainties that cannot be completely resolved by the information from CEEPES or other quantitative modeling systems. Rather than providing "push-button" answers to policy problems, the intent of CEEPES is to narrow the range of uncertainty for policy judgments. Certain results from the modeling system will be sufficiently robust to be accepted as valid information for the policy debate. At the same time, other elements, perhaps critical to the design and operation of pesticide regulatory policies, will involve substantial uncertainty. The contribution of CEEPES to policy analysis is to focus debate on the issues, about which there is true uncertainty, by formally using available scientific information on biological and geophysical processes and modern concepts of statistics and experimental design. An additional contribution is to identify gaps in information and direct attention to urgently needed research. The result will be more enlightened and socially desirable agricultural and environmental policies.

What Is CEEPES?

Figure 1 illustrates the general CEEPES framework. The four major components of CEEPES—policy, agricultural decision, fate and transport, and health and environmental risk—are designed to support a modular research strategy and discussions on how to configure the system to explore different agricultural and environmental policy issues. Figure 1 also highlights the major information flows among the four components.

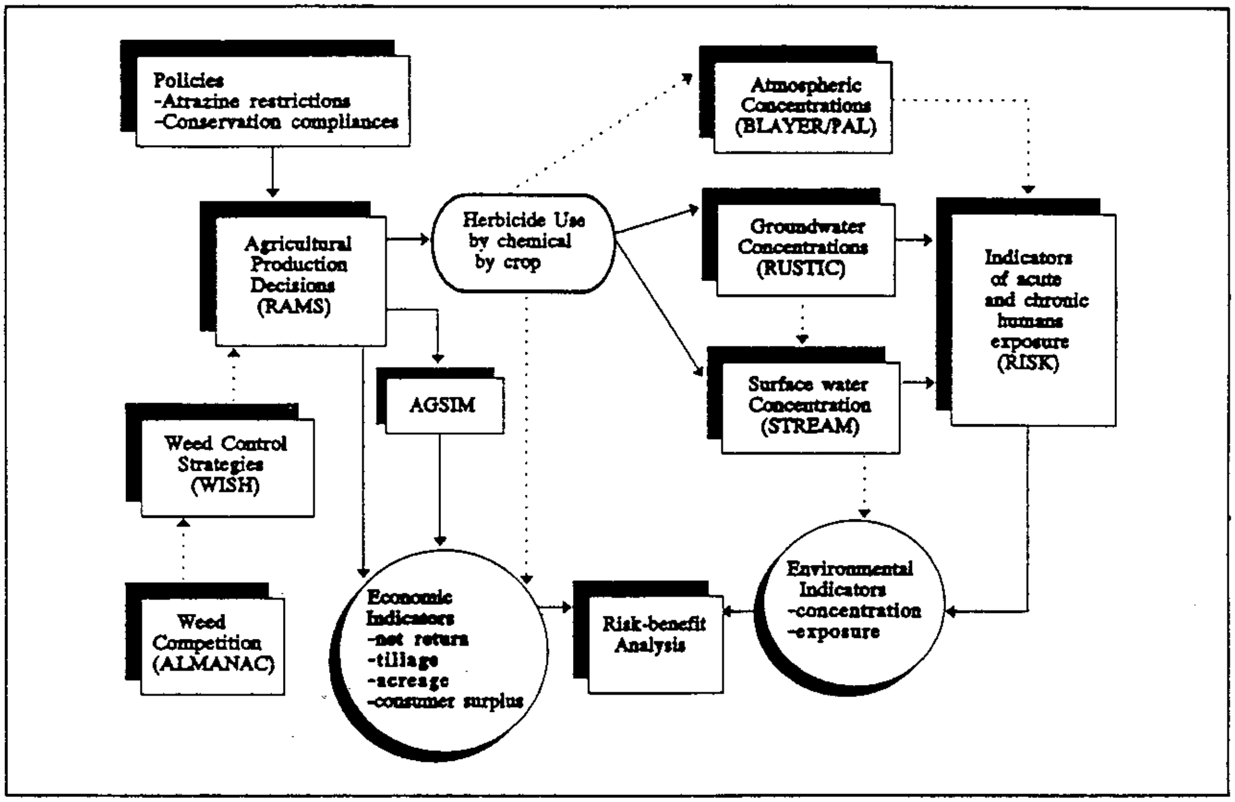


Figure 1. Information flow in CEEPES

Policy Component

We divide the policy component into two parts—agricultural programs and environmental regulations. The policy space develops the major links between regulatory instruments and the agricultural decision component. Examples of programs include commodity and conservation titles of the 1990 Farm Bill, pesticide registration and cancellation and use restrictions, drinking water standards, taxes, prices, quotas or allocations, acreage set-aside restrictions, subsidies, and cropping practice restrictions. Both indirect and direct policy instruments are included. Examples of indirect instruments include price stabilization, farm income maintenance, and conservation programs; these are currently viewed as designed primarily to reduce health risk and environmental damages. Direct policy interventions include restrictions that limit the active compounds available for agricultural production through registration, timing of application rates and other use restrictions, and taxes or subsidies. Another example is the imposition of drinking water and other water quality standards to reduce potential health risks. An important feature of the policy space is —targeting." Targeting involves the selective application of abatement measures to individual chemicals moving through a particular medium, under specific production technologies, within specific geographic or environmental conditions or both. But perhaps of more importance is the possibility within CEEPES to directly target actual damages, thus enabling conservation programs and policies to be more focused.

The design of CEEPES begins with a focus on specific policies or regulations and associated performance measures or outcomes. The goal is to evaluate the trade-offs between or among the performance measures as influenced by the implementation of policies and the exogenous factors. This objective then guides the structure of the other components in terms of scope, level of aggregation, use of key linkages, and the necessary calibration exercises.

Agricultural Decision Component

The agricultural decision component can include modules ranging from micro firm level to market to sector levels. For specific policy exercises, these models are linked in corresponding hierarchial structures. The content and structure of the component will in part be determined by available operational economic models and the need for geographic detail. When the micro and macro models are linked they can be used to simulate behavior and performance indicators tied to agricultural and environmental policies. The policy instruments that directly and indirectly control environmental quality, health risks, and the agriculture sector are introduced in the firm, state, regional, commodity market, and sector modules. We aggregate by employing the metamodel strategy used in the fate and transport component—calibration of micro models, experimental design and simulation, and response surface estimation.

The impacts of regulations on producer behavior depend on the opportunities for input substitution. Understanding the set of substitutes is critical. If substitutes are readily available, a restriction will have little, if any impact. Otherwise, producers will modify their behavior to achieve higher profits. Given the available choices all with various advantages and disadvantages, the agricultural decision component selects alternative resource allocations, given criteria such as cost minimization or profit maximization.

The resource allocation decisions are input into the biogeophysical component to estimate changes in yields, chemical fate, and other intermediate and final performance indicators. The intermediate biogeophysical outcomes can then feed back into the agricultural decision component. For example, if the policy component restricts chemical concentrations in water, the constraints are first introduced into the biogeophysical component, then alternatives are entered into the agricultural decision component to determine an associated optimal resource allocation decision.

Since the most reliable biogeophysical results are obtained at the field level, the links between the agricultural decision and biogeophysical component occur at the micro level and are statistically aggregated as appropriate. The outcomes generated include regional production patterns, aggregate output, input use, values of fixed resources, and management practices. At present, responses to uncertainty and risk are studied outside the agricultural decision component. In the future, risk attitudes and preferences will be modeled, making the outcomes of the agricultural decision component more encompassing in terms of behavior.

Indirect regulations or policy impacts enter in a more complex manner. The conservation reserve, for example, introduces alternative activities for land use. Conservation compliance causes shifts in tillage practices and rotations to obtain commodity program benefits. The commodity programs provide price and production conditions, including set-aside requirements, paid diversions, and cross compliance. The commodity programs also affect the more aggregated modules of the agricultural decision component. Market equilibrium prices and different implicit prices for producers participating in commodity programs influence commodity prices and agricultural sector performance.

Fate and Transport Component

This component includes the following models: plant growth, groundwater models (root zone model and integrated root zone, vadose, and aquifer model), surface water (watershed model and agriculture nonpoint source pollution model, river basin model, and instream concentrations); and atmospheric transport (long-range and short-range models). These models incorporate detailed phenological, biological, and geophysical relationships. Factors contributing to the exchange among modules at the soil surface included type of crop, rotation, tillage practices, climate, fertilizer and pesticide use, management, soil, and conservation practices. The daily nature of the crop canopy and residue, the soil surface, and tillage impacts interact with climate to determine the surface conditions. These factors influence the interaction between ambient atmospheric conditions and the soil surface. Examples include volatilization of chemicals into the atmosphere, runoff and percolation, chemical loadings, and evapotranspiration.

The fate and transport component also simulates interactions within the plant root zone of the soil profile. Conditions in the root zone influence the availability of water and nutrient uptake by the plant, water movement and associated chemical transport, and the plant canopy. These interactions are conditioned by previous rotations and cultivation practices, soil types, and other factors that reflect the availability of water and chemicals carried in water transport. This information must be supplied exogenously or from linked models in this component.

Major linkages exist between the fate and transport, agricultural decision, and health and environmental risk components. The fate and transport component transmits data on chemical concentrations to both the agricultural decision and the health and environmental risk components. Chemical fate refers to concentrations of residuals in the air, water, and food supply. Producer actions such as cultivation systems, pesticide applications, cultural practices, production patterns, and other factors condition the plant process module of the fate and transport component, which in turn provides yield levels and other information to the agricultural decision component. Musser and Tew (1984) and Ellis, Hugh, and Butcher (1990) review the applications of biophysical models in agricultural production, and discuss the link with economic models for policy analysis. Bryant and Lacewell (1989) consider problems of calibrating crop simulation models, which puts into focus (1) the multidisciplinary nature of the expertise required to build such models, (2) the need for a systems approach to model building and closely related methodologies, and (3) the significant computation and data management requirements.

The Health and Environmental Risk Component

Environmental indicators complete the picture of the welfare impacts of a policy scenario in a study region. Since a single average indicator of water quality across a study region would be almost meaningless, we consider results indicating both *relative risk* to humans and aquatic life, and the spatial distribution of these indicators identifying the most vulnerable soils. In addition, results are separated by tillage, surface water and groundwater, and chemical.

The health and environmental risk component estimates the concentration of agri-chemicals and compares the level to indicators of human and ecological health. Human health impacts include drinking water and air, while the ecological models include terrestrial and aquatic impacts. Key inputs to these indicators are from the fate and transport and agricultural decision component. For example, the drinking water and air modules obtain information concerning both chemical fate and concentrations in surface water, groundwater, and air from the fate and transport component.

The peak and average chemical concentration levels found in surface and groundwater are transformed into a unitless measure of risk that we call an *exposure value*, whereby pesticide-specific benchmarks for human health and aquatic habitat are used to weight the relative importance of pesticide concentrations. The term *exposure value* is used to prevent confusing such values with estimates of absolute risk. Instead, their purpose is solely for comparing policies and practices and serving as rough indicators of water quality. Using a benchmark for environmental hazards, such as drinking water Maximum Contaminant Levels (MCLs) for long-term exposures and ten-day Health Advisories for short-term exposures, we calculate the exposure for each chemical for both peak and average long-term levels. The exposure value normalizes concentration levels, thereby allowing us to compare risks across herbicides and across policies. If the exposure value exceeds unity, the concentration exceeds the benchmark. A chemical detected in ground or surface water represents a greater risk the larger the exceedance of the benchmark. Note that more reliance should be placed on relative differences between exposure values than on absolute concentrations (USEPA 1992).

The estimated health and environmental risks serve as performance measures for the policy component. These estimates are primarily related to acute and chronic carcinogenic and noncarcinogenic effects of chemical residuals. Calculation of risk across the modules uses the concept of *dose*. Dose often involves an appropriate lifetime-adjusted (chronic) and short-term (acute) effect level derived from laboratory animal experiments with the application of a safety factor or conservation assumptions. Dose is the common unit of exposure that relates concentration to risk generated from each of the modules. Accumulations of dosage per unit of time and population densities generate the estimated risk assessments transmitted to the policy component.

The air module is similar in structure. Volatilization of pesticides into the air is related to pesticide application rates, application method, and climatic conditions. Human health risks are estimated to individuals and to populations. CEEPES then uses both the benefits from the agricultural decision component and the risk estimates from the health and environmental risk component as the system evaluation measures.

What We Have Learned

We have learned three broad lessons over the last decade in the construction of the CEEPES system—the necessity for a well-defined policy space, detailed input substitution set, and integration by metamodeling.

Policy Space

Anticipate and define the policy early in the modeling process. Early and explicit identification of current and future policy choices is critical, since without a well-defined, focused set of policy alternatives to work from, the construction of the system will be tentative, at best. Policymakers must appreciate that without their early guidance, many modeling decisions will be irreversible or reversible at prohibitive costs. Researchers not requesting explicit information on the policy component information in advance will be subject to higher costs, problems with timing and likely produce results that are not in a useful form for the decision makers.

Understanding policy options is especially relevant for agriculture since producers serve two masters—the U.S. Department of Agriculture (USDA) and the Environmental Protection Agency (EPA). Both agencies have unique incentive systems that will affect the behavior of profit maximizing producers. The EPA can unilaterally restrict or ban selected agri-chemicals, while the USDA can unilaterally set price subsidies to output so that intensive agri-chemical use is promoted. Since the EPA is responsible for maintaining the integrity of water quality in the United States, the agency promotes a preventive strategy. For example, if a pesticide has or is expected to exceed reference risk levels, under the authority of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Federal Food, Drug, and Cosmetic Act (FFDCA), the EPA can regulate its use through a Special Review. Based on the EPA's risk assessment and rebuttal testimony by the registrant, the EPA's regulatory options are to continue registration with no changes, modify use by restricted application or timing, or cancel use.

The USDA has an impact on the agricultural sector with its set of commodity programs. The forerunner to current USDA policy started in the New Deal era of the 1930s. With the stated objectives of stabilizing output supply, farm income, and price, an intricate set of program incentives has evolved over the past 50 years for most major commodities. While soil erosion has always been a concern, the USDA's attention to general environmental issues, such as water quality, is more recent. The Food Security Act of 1985 and the Food, Agricultural, Conservation, and Trade Act of 1990 signaled the change. These Acts directly tied program participation to environmental quality. The cross-compliance measures of swampbuster, sodbuster, and conservation compliance were created to restrict the environmental damages associated with introducing new land into production.

The need to coordinate and integrate agricultural and environmental policy seems obvious. Unilateral acts generally expend valuable resources at no gain in environmental quality. Modeling nonpoint source pollution requires identification of the current layers of unilateral policies and possible new coordinated policy options. An integrated modeling system like CEEPES can be used to determine which, if any, of the new coordinated policy options are attractive to both economic and environmental concerns. The modeling system can act as a focal point for the debate. Ideas can be systemically explored ex ante. One question the system can address is whether it is more efficient to readjust or patch up the current layer of policies or to redesign the system and start anew.

An example of an integrated policy would be to evaluate the trade-offs between the EPA's restrictions on chemical use and the USDA's allowance for increased flexibility in crop production decisions. Flexibility would allow the producer to plant crops other than the program crop without losing access to the program payments. An integrated modeling system could evaluate the risks and benefits of allowing more flexibility with fewer restrictions. As the producer gains flexibility, chemical restrictions become less important. The flexibility-restriction trade-off is just one example. The argument can be applied more generally.

Input Substitution

Understanding input substitution is essential. Alternative policy strategies provide different incentives to agricultural producers that may cause them to change their input sets. Unless there is the unlikely policy of, for example, a complete ban on all pesticides, we need to know how producers will substitute inputs in order to maximize their returns. It may well be that the producer has a set of nearly perfect substitutes to a targeted chemical so that a ban will have trivial economic impacts at no gain in environmental quality. The other side is that the input set is unique so any policy restriction will cause great economic damages.

We illustrate by considering an input substitution model for weed control in corn and sorghum production. The Weather Impact Simulation on Herbicide (WISH) was developed to simulate the effects of policy on trade-offs in weed control management (see Bouzaher et al. 1992 for details). The WISH model simulates more than 300 alternative weed control strategies for corn and more than 90 strategies for sorghum.

Assume farmers trade expected pest damage for expected application cost when deciding to adopt a pest control strategy. All weed control strategies are aimed at full control (i.e., under ideal weather conditions, and if applied properly, would result in virtually no yield loss). Under ideal conditions, cost would be the basis for choosing a weed control strategy. But weather conditions can be too wet for farmers to get into the field to apply herbicides or cultivate, or can be too dry during the critical times for herbicides to be effective, implying additional application cost or yield losses or both. *Uncertainty* is defined as the probability a given herbicide strategy is ineffective. An environmental policy such as a herbicide ban or a modification of application technology will change the set of efficient weed control strategies.

Based on herbicide timing of application and effectiveness, mode of application, targeted weeds, and observed farming practices, a herbicide decision tree represents the average farmer's most likely management approach to pest control. Farmers have a main strategy for weed control and a back-up strategy in case of a failure of the main strategy. All this information is combined to define two key elements:

1. The structure of a herbicide strategy, assumed to be made up of a primary herbicide treatment applied on an early preplant, preplant, preemergence, or even postemergence basis, and a secondary herbicide treatment (mainly postemergence) that would be applied only if the primary substrategy fails for reasons mainly related to weather. A herbicide strategy structure is completed by specifying a *time window of application* and a *time window of effectiveness* for each of its primary and secondary components, and for each weed group.

2. The list of all feasible herbicide strategies, established by tillage practice and by timing of application and scope of control of each herbicide in the strategy. The list is built with the policy

specifications in mind. These feasible strategies are individually simulated to determine their yearly cost, labor requirements, application rates, and percentage effectiveness for each weed group and each of two soil texture characteristics, and clay.

WISH reads the herbicide strategy table and a weather file containing daily average information on temperature, rainfall, and wind. For each herbicide strategy over a period of 50 years of weather history, starting with the primary application, the model considers rainfall and wind and records the percentage of acres treated during the window of application; it also records the application rate and cost for each chemical used, and any cultivation requirements. Time advances and weather conditions are checked during the window of effectiveness. An indicator variable cumulatively records the percentage effectiveness of the primary strategy for each weed group. If this variable is less than one, the secondary application is triggered and the same information is recorded. It is important to note that the main objective of this simulation is to capture the effect of those special years (too dry or too wet) where a farmer may have to apply herbicide more than once and still sustain some yield loss (in addition to higher cost), or does not have time to apply herbicide and sustains a major yield loss. The model assumes that three days are enough for a farmer to treat all his acres and fixes planting dates for corn (May 10) and sorghum (June 1), and provides for handling of special cases where strategies involve split applications (part preemerge and part postemerge) or entirely postemerge applications. The impact of weed competition on crop yields was simulated using ALMANAC—Agricultural Land Management Alternatives with Numerical Assessment Criteria (Jones and O'Toole 1986). ALMANAC is a process model that simulates crop growth, weed competition, and the interactions of management factors for a variety of soil properties and climatic conditions.

Metamodels and System Integration

If we are interested in determining the ecological and economic impacts of national policy, then rerunning simulation models of fundamental processes for every new policy becomes prohibitively expensive. It is costly to run and rerun every process model as the dimensions of the outcome space and geographic region expands. Bouzaher et al. (1993) argue that researchers can appeal to metamodels and response surfaces to increase research efficiency. Metamodels are simply functional representations of the process models—a statistical model of the actual simulation model. The concept of a metamodel corresponds with a hierarchical modeling approach whereby we proceed from a complex and "messy" real phenomenon to a well-structured simulation model and then to modeling the relationship between inputs and outputs of the simulation model itself. Response surfaces are estimated on the basis of an experimental design focusing on the relevant parameters for the problem at hand.

The metamodeling approach serves three key purposes. First, metamodels are a practical method to integrate temporal and spatial dimensions of different models. This abstraction focuses the system on the key parameters of interest to policymakers. Second, the response surfaces can be applied to link the set of process models into the desired integrated system. Third, metamodels avoid repeated calibrations. This integration is the key for successful integrated modeling, avoiding the need to rerun the original process model for each new policy alternative.

Consider how metamodeling works with the ALMANAC model that explains the process of weed competition on crop yield, and how the process can improve our understanding of the loading effect of different agri-chemical strategies on the environment. The simulation model is built by physical scientists and simulates the processes describing the growth of individual plants and their competition for important resources like water, nutrients, and light, all within specific management, climatic, and environmental conditions. The complexity of the model stems, in part, from the large number of parameters that require calibration and the time and cost needed to generate information for a large number of locations.

We note that these models were initially designed as research tools to study very small-scale phenomena (growth processes of individual plants or competition between two plants within a square meter) and, when projected at the regional level, present challenging aggregation and computational problems. The use of a metamodel in this case is much more than a simplifying step, as would be the case for a conventional simulation model. A key feature of the methodology is to statistically sample from micro data to build parametric forms for prediction at the macro level; that is, while the individual samples are based on very small area features, the metamodel is used to first integrate and then distribute these features over very large areas. Sampling is carried out after a testing phase aimed essentially at factor screening and parameter selection.

The full experimental design phase identifies the exogenous variable to be sampled and the response variables to be recorded; it also determines the minimum number of simulation replications given time or budget constraints or both. Finally, the last step consists of building statistical response functions for the variables of interest (e.g., crop yield, plant biomass, chemical concentration). This step is similar to any model building step with its many facets including diagnostics, variable selection, model specification, estimation, residual analysis, and hypothesis testing, but it differs in one fundamental respect in that the metamodel summarizes relationships but not causality. This metamodeling approach was used to estimate yearly yield loss response functions for corn, corn silage, sorghum, and sorghum silage. Significant parameters in these functions are slope, percent sand, percent clay, bulk density, organic water, pH, weed, weed density, and weather station.

Metamodels are also important to estimate environmental consequences. The Fate and Transport models use information on agricultural activity in each geographic unit to produce damage-relevant concentration measures for each damage category, the geographic unit where the chemical was applied, and other geographic units that may be affected by pollutant transport. For example, given an agricultural activity in a rural central Corn Belt geographic unit, the fate and transport component estimates shallow groundwater concentrations relevant to domestic wells and surface water concentrations in the area. The component transforms a vector describing agricultural activity in all geographic units into a vector of ambient concentration measures for each medium in all geographic units. The concentration measures can include expected values, information on the probabilities of various concentrations, or the distributions of concentrations over time and space. Outcomes of greatest interest are 24-hour peak concentrations for acute toxicity and annual average concentrations for long-term exposure.

The core of the Fate and Transport system is the Risk of the Unsaturated/Saturated Transport and Transformation of Chemical Concentrations (RUSTIC) model (Dean et al. 1989). RUSTIC is an extension of the Pesticide Root Zone Model (PRZM), which was developed to simulate one-dimensional pesticide transport only through the soil root zone (Carsel et al. 1984). Two additional models, VADOFT and SAFTMOD, are linked to PRZM to simulate pesticide movement in the variably saturated vadose zone and saturated zone. PRZM can be linked directly to SAFTMOD if the simple water balance routine used in PRZM is adequate for the conditions being simulated.

Based on our metamodeling approach, chemical concentration response functions were estimated at 1.2 meters (the root zone), 15 meters, and edge-of-field runoff for both corn and sorghum. The 15-meter depth corresponds to that used in monitoring studies. Both average and peak chemical concentrations in surface and groundwater are a function of chemical parameters (e.g., Henry's constant, organic carbon partitionary coefficient [KOC], decay rate), soil parameters (e.g., percent sand, organic matter, bulk density, soil depth, water retention capacity), management parameters (e.g., tillage, timing of application), and weather station.

Applications to Atrazine and Water Quality

Since its registration in 1959, atrazine has become the most widely used herbicide in U.S. corn and sorghum production—estimated at 52 million pounds of active ingredient within the midwestern United States (USDA 1991). Not surprisingly, atrazine is also the most widely detected pesticide in surface and groundwater; it is 10 to 20 times more frequent than the next most detected pesticide (Belluck, Benjamin, and Dawson 1991). The levels detected, often exceeding the Maximum Contaminant Level (MCL) of 3 parts per billion (ppb), has prompted USEPA to consider two policy options—a ban on atrazine or a ban on the set of triazines (atrazine, cyanazine, and simazine).

Figure 2 illustrates the CEEPES study region for the atrazine study. In the study region, baseline atrazine used in the CEEPES system is approximately 39 million pounds active ingredient on corn and about 3.3 million pounds active ingredient on sorghum. The use of all triazines combined is about 60 million pounds active ingredient for corn and 3.3 million pounds active ingredient for sorghum.

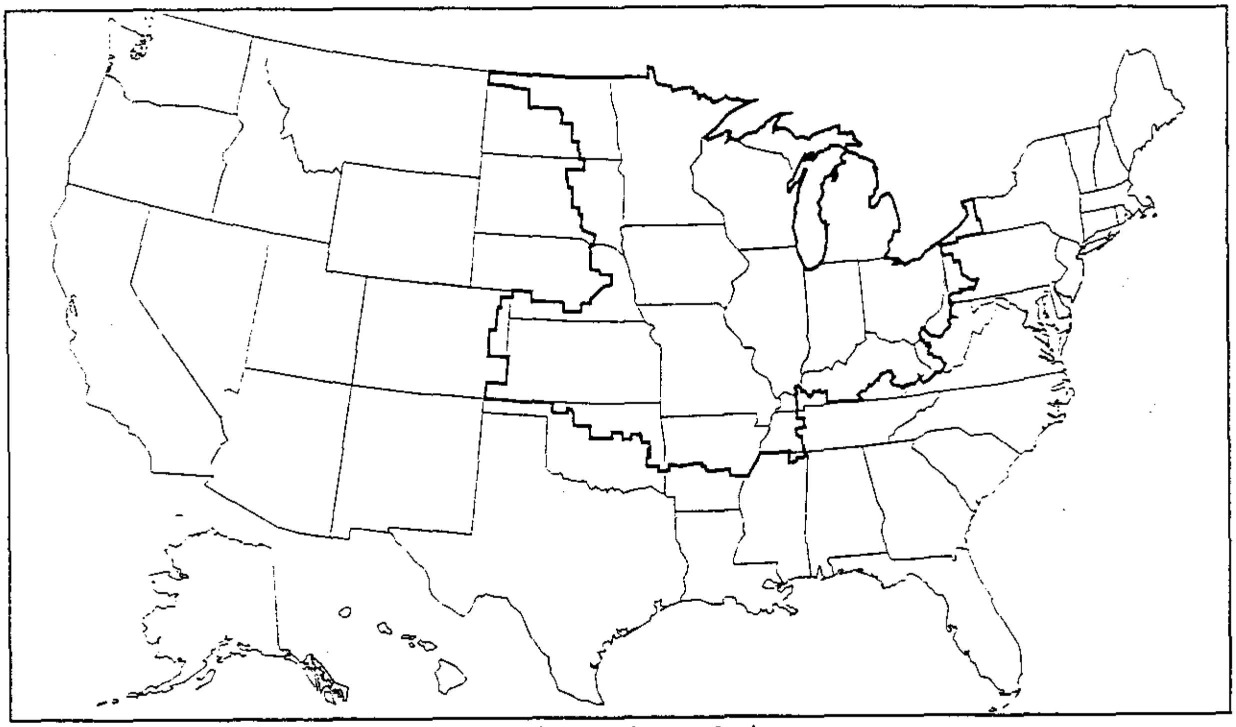


Figure 2. CEEPES study region for the atrazine analysis

Economic Impacts

Table 1 presents changes in the percentage of acreage of major crops. For both an atrazine or triazine ban, corn acreage and corn yields decline with increases in soybean acreage and soybean yields. For the atrazine ban, corn acreage decreases by 3 percent from the baseline of 72.6 million acres and soybean acreage increases by 4.1 percent from the baseline of 44.2 million acres. Sorghum acreage increases slightly (0.7 percent and 1.9 percent), offsetting some of the production loss due to yield decreases. Corn yield decreases by 2.8 percent for an atrazine ban and 4.1 percent for a triazine ban. Yield decreases for sorghum are much larger, at 5.7 percent and 6.8 percent for the two scenarios.

Table 1. Percentage changes in crop acreages from baseline for chemical restrictions

	Atrazine Ban	Triazine Ban
	percent	
Corn	-3.0	-2.7
Sorghum	0.7	1.9
Barley	0.0	0.0
Cotton	0.0	0.0
Hay	-1.6	-0.0
Oats	1.3	2.3
Soybeans	4.1	3.9
Wheat	2.6	1.1

Table 2 shows that the cost of weed control per acre would increase between $6.00 and $8.00 for corn and less than $1.00 for sorghum. In corn, banning atrazine requires the use of more costly weed control strategies that achieve a comparable level of control. However, in sorghum, banning atrazine leads to heavier reliance on comparably costly, less effective strategies. Under an atrazine ban, average application rates for other triazines also increased. The average application rate for cyanazine and simazine on corn increases by 249 percent and 133 percent given an atrazine ban. This implies an increase in active ingredients by 0.94 pounds and 1.34 pounds for cyanazine and simazine. Table 3 summarizes the changes in acres treated with triazines for both corn and sorghum. We separated the acres treated with weed control strategies with an atrazine rate of no more than

Table 2. Cost change per treated acre

	Atrazine Ban	Triazine Ban
	U.S. dollars	
Corn	6.70	8.25
Sorghum	0.64	0.12

1.5 pounds per acre (50.3 million acres of corn in the baseline). In addition, we note a significant increase in the use of cyanazine for sorghum and simazine for corn under an atrazine ban. This can be attributed partly to our current restriction of no significant crop injury from these two triazine herbicides. This restriction will be examined as we continue to work with weed scientists from the study region.

For the Corn Belt, Figure 3 provides more detail on the changes in application rates and acreage treated for 15 different herbicides. Of particular interest are the rate increases for cyanazine, simazine, and other chemicals such as dicamba, bromoxynil, bentazon, pendimethalin, and 2,4-D under an atrazine ban. Chemical rates reflect average use over 50 years of weather. Because the weather does not permit application in every year, the values reported are lower than the average rate that is applied when weather permits. Figure 3 also shows the impacts of restricting the use of sulfonylureas (nicosulfuron and primisulfuron) in conjunction with an atrazine ban and a triazine ban.

Table 4 summarizes herbicide use in the study region. With an atrazine ban, total triazine use increases by 27 percent in corn and decreases by 84 percent in sorghum. In addition, we observe large increases in nontriazine and total herbicide use under both policy scenarios because the substituted weed control strategies entail relatively high application rates.

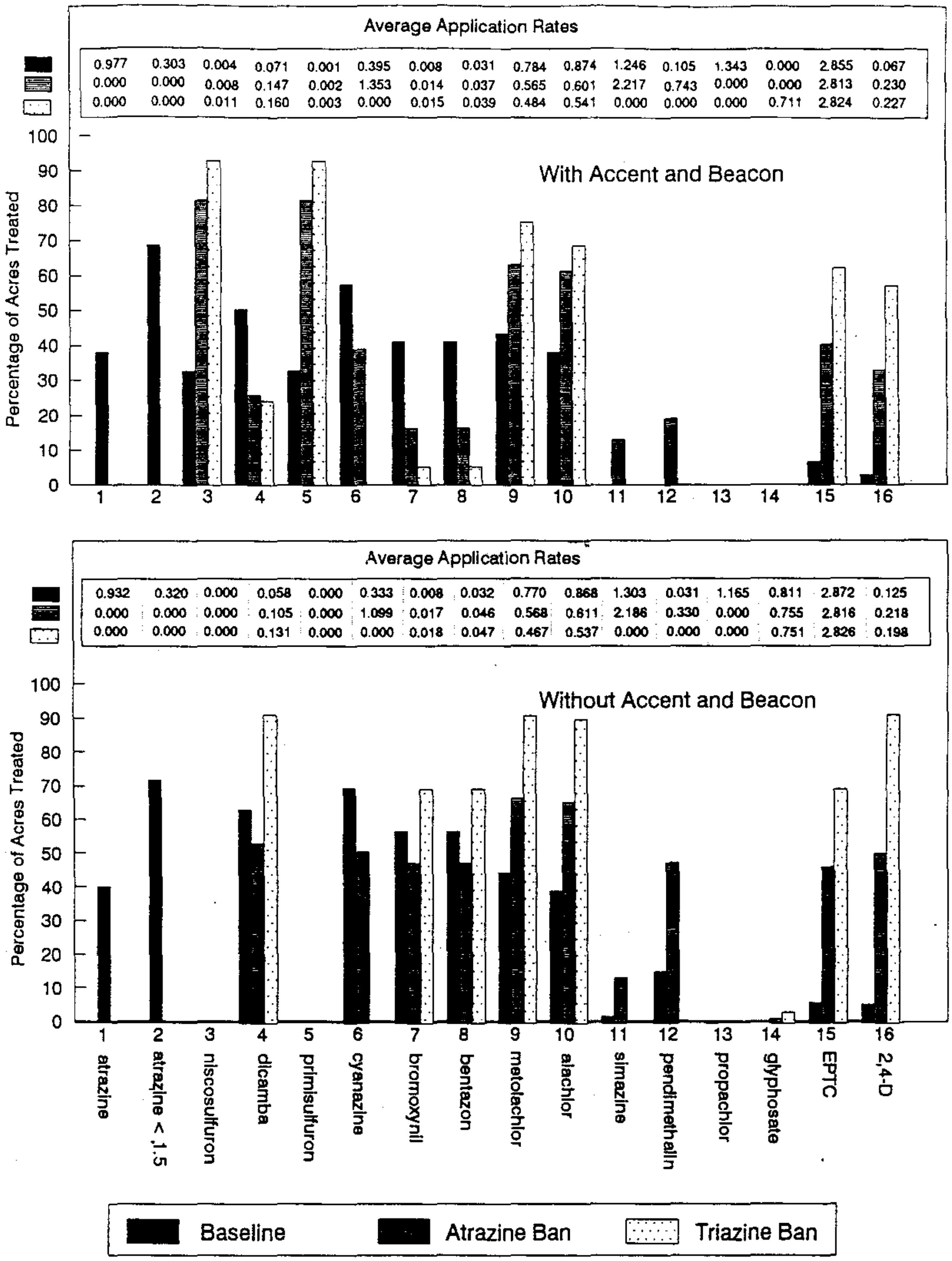
The welfare measures associated with yield and cost impacts of an atrazine or triazine ban were estimated using the AGSIM model developed by Robert Taylor of Auburn University (Taylor 1987; Penson and Taylor 1992). Table 5 presents both short-term (1993-96) and long-term (2005-08) welfare effects, including producer income, domestic consumption, foreign consumption, and government outlays. In the short term, the average annual decreases in total economic welfare for the nation would be about $660 million under an atrazine ban and $920 million under a triazine ban. With an atrazine ban, crop producers in the Corn Belt bear a large share of the burden. Producer income from crops is reduced by $234 million in the region. For a triazine ban, some of the losses in the Corn Belt are offset by higher corn prices and the loss in producer income of $168 million is less

Table 3. Acres treated in study region

	Current Use in CEEPES	Atrazine Ban	Triazine Ban
	mil. acres	percent change	
Atrazine (>1.5 lb/acre)			
Corn	22.9	-100	-100
Sorghum	1.1	-100	-100
Atrazine (<1.5 lb/acre)			
Corn	2.1	-100	-100
Sorghum	50.3	-100	-100
Cyanazine			
Corn	39.4	-46	-100
Sorghum	0.1	200	-100
All Herbicides			
Corn	5.8	>200	-100
Sorghum	--	--	--

Table 4. Herbicides used in study region

	Current Use in CEEPES	Atrazine Ban	Triazine Ban
	mil. lb a.i.	percent change	
Atrazine			
Corn	38.9	-100	-100
Sorghum	3.3	-100	-100
All Triazines			
Corn	60.7	27	-100
Sorghum	3.3	-84	-100
Nontriazines			
Corn	53.7	97	>200
Sorghum	9.2	31	31
All Herbicides			
Corn	112.7	60	49
Sorghum	12.5	1	-4



Note: Units are pounds of active ingredient per acre - rates reflect years when weather prohibits primary application

Figure 3. Percentage of corn acres treated by chemicals and average application rates for the Corn Belt

than with the atrazine ban. Some regions would see an increase in producer income (most likely in noncorn and nonsorghum areas outside of the study region) due to an increase in certain commodity prices. Under the two restrictions, significant short-term decreases occur in government expenditures, while losses occur in net livestock income due mainly to the combined effect of a decrease in corn production and an increase in corn and sorghum prices.

Table 5. Aggregate economic effects of atrazine and triazine restrictions

	Atrazine Ban		Triazine Ban	
Welfare Effects	Short-Term	Long-Term	Short-Term	Long-Term
Producer Income	-531	-312	-673	-423
Domestic Consumer Effect	-406	-421	-548	-553
Foreign Consumer Effect	-294	-134	-395	-186
Government Outlays	(-572)	(-18)	(-695)	(-21)
Total Economic Effect	-659	-849	-921	-1,141

Input Substitution Effects

The use of herbicides under the various scenarios is indicated by the distribution of corn and sorghum acres treated by different herbicide strategies. In the baseline, more than 65 percent of corn acres and more than 60 percent of sorghum acres are treated with a mix of strategies containing at least one triazine herbicide. Under a triazine ban, 27 percent of corn acres and 9 percent of sorghum acres would be treated with rotary hoe and row cultivation as the main strategy. In addition, more than 50 percent of corn acres would be treated with strategies involving alachlor, metolachlor, butylate, EPTC, dicamba, and 2,4-D, and more than 90 percent of sorghum acres would be treated with strategies involving alachlor, metolachlor, dicamba, 2,4-D, and propachlor.

The use of nicosulfuron and primisulfuron as a back-up strategy increases considerably when atrazine and all triazines are banned but this does not reflect potential problems with weed resistance or crop injury. Figure 3 demonstrates what would occur if nicosulfuron and primisulfuron were not allowed. In this case, other back-up strategies including bentazon, bromoxynil, pendimethalin, dicamba, and 2,4-D in various combinations would be substituted.

The major rotation shifts occur between continuous corn, which decrease 16 and 16.5 percent under an atrazine and triazine ban, and corn-soybean rotation, which increase by 11 and 10.4 percent under the two restrictions. These changes are important because they occur for some of the most prominent rotations. By shifting to a corn-soybean rotation, savings in nitrogen fertilizer and insecticide applications are possible, which is a beneficial shift as far as water quality is concerned.

Environmental Impacts

Environmental indicators complete the picture of the welfare impacts of an atrazine ban and a triazine ban in the study region. Since a single average indicator of water quality across the study region would be almost meaningless, we present results indicating both *relative risk* to humans and aquatic life, and the spatial distribution of these indicators identifying the most vulnerable soils. In addition, results are separated by tillage, surface water and groundwater, and chemical.

The peak and average chemical concentration levels found in surface and groundwater are transformed into a unitless measure of risk we call an *exposure value*, whereby pesticide-specific benchmarks for human health and aquatic habitat are used to weight the relative importance of pesticide concentrations. The term *exposure value* is used to prevent confusing such values with estimates of absolute risk. Instead, their purpose is solely for comparing policies and practices and serving as rough indicators of water quality. Using a benchmark for environmental hazards, such as drinking water Maximum Contaminant Levels (MCLs) for long-term exposures and ten-day Health Advisories for short-term exposures, we calculate the exposure for each chemical in the following way:

$$\textit{Exposure Value (hazard - weighted exposure)} \quad = \quad \frac{\textit{predicted concentration}}{\textit{environmental benchmark}}$$

for both peak and average long-term levels. The exposure value normalizes concentration levels, thereby allowing us to compare risks across herbicides and across policies. If the exposure value exceeds unity, the concentration exceeds the benchmark. A chemical detected in ground or surface water represents a greater risk as the benchmark exceedance becomes larger. Note that more reliance should be placed on relative differences between exposure values than on absolute concentrations (USEPA 1992).

Table 6 presents the human health exposure values for surface water from peak loadings, by chemical and tillage, under baseline use and under an atrazine ban and a triazine ban in corn production. Each line in this table represents the percentage of soils with concentrations exceeding the benchmark for human toxicity. For example, the first row in Table 6 shows that atrazine concentration levels exceeded the short-term benchmark of 100 parts per billion (the drinking water maximum contamination level for short-term exposure) in 43, 43, and 8 percent of the soils cultivated under conventional tillage, reduced till, and no-till systems. Under an atrazine ban a higher proportion of soils have chemical concentrations exceeding the benchmark in surface water under all three tillage systems (e.g., dicamba, cyanazine, simazine, and bentazon with conventional tillage; dicamba, cyanazine, and metolachlor with reduced tillage; and metolachlor with no-till). Note that for groundwater, all average concentrations are below the long-term exposure benchmarks for all soils and all tillage systems, under both an atrazine and a triazine ban.

Figure 4 illustrates the aquatic vegetation exposure values from corn production for the two policies. The majority of aquatic exposure values exceed the aquatic benchmarks, which have only been proposed as standards by EPA or have been derived according to EPA guidelines, often by more than a factor of 20.

The CEEPES analysis leads to a number of conclusions. With an atrazine ban we estimate a decrease in both producer and consumer surplus and an overall economic loss of $660 million for the entire country. Chemical concentrations in groundwater appear not to exceed EPA benchmark values for any herbicide with any tillage in any region. But by banning atrazine, producers would shift to other triazines (simazine and cyanazine) and other nontriazines (dicamba, bentazon, alachlor, metolachlor) leading to triazine and nontriazine concentrations in surface water that could significantly exceed benchmark values. Increased exposure values from substitute weed control practices sometimes exceed that before the ban, with different impacts by soil and tillage type. Because the atrazine ban would result in decreased producer and consumer surplus and declines in surface water quality, there could be an overall decrease in welfare. We observe minor shifts in tillage for all crops due to Conservation Compliance but we observe a major shift away from continuous corn to a corn-soybean rotation. Overall, the benefit of an atrazine ban is questionable.

With a triazine ban, producer and consumer surplus would decrease more than under an atrazine ban, with an overall economic loss of $900 million. But under a triazine ban no herbicide average concentrations in groundwater exceed the benchmark values. Exposure values in surface water exceeding the utility are predicted for dicamba, bentazon, alachlor, and metolachlor on a smaller

Table 6. Exposure distribution in surface water for the three scenarios of soils with concentrations exceeding EPA benchmarks

	Conventional Till	Reduced Till	No-till
Baseline		percent	
Atrazine	43.10	42.87	8.08
Atrazine <1.5	14.75	15.80	2.38
Dicamba	18.14	0.00	0.00
Cyanazine	24.91	0.92	0.00
Bentazon	2.39	45.90	0.00
Metolachlor	3.01	8.91	0.00
Alachlor	20.83	32.65	0.00
Simazine	86.95	67.66	40.12
Propachlor	6.65	38.44	.
Atrazine Medium Decay	33.65	34.13	4.72
Atrazine Slow Decay	28.31	26.06	4.26
Atrazine Fast Decay	11.73	0.01	1.13
Atrazine Ban			
Dicamba	35.08	1.21	0.00
Cyanazine	35.57	90.15	0.00
Bentazon	67.74	0.00	.
Metolachlor	0.06	26.93	12.63
Alachlor	4.70	31.61	18.28
Simazine	98.68	42.57	40.05
Triazine Ban			
Dicamba	26.66	5.60	0.00
Bentazon	51.41	84.96	.
Metolachlor	0.00	13.59	0.00
Alachlor	0.67	0.00	0.00

Note: Bromoxynil, Butylate, Glyphosate, Nicosulfuran, Pendimethalin, Primisulfuron, and 2,4-D had zero probability of exceedance in all three scenarios.

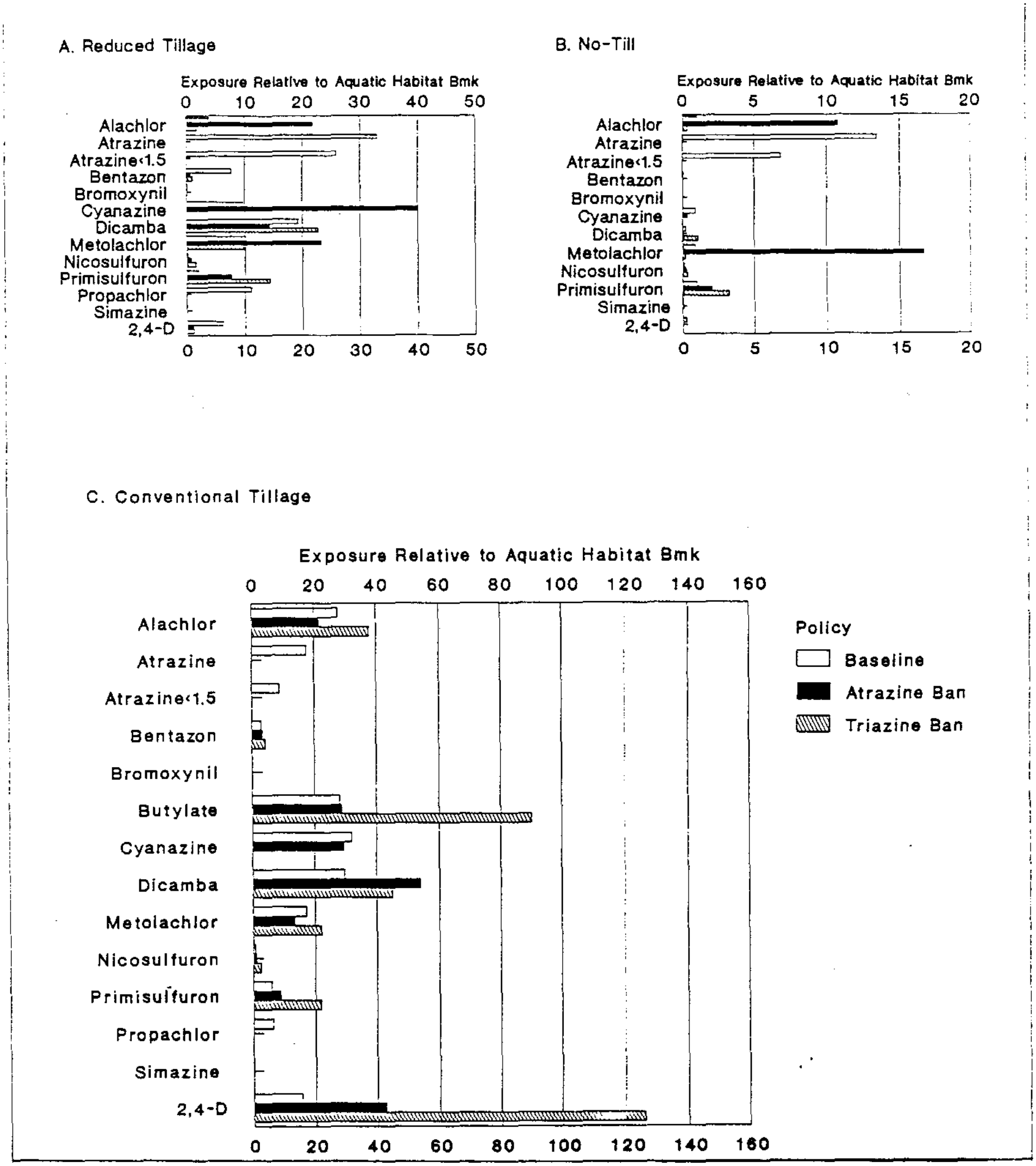


Figure 4. Aquatic risk

Note: On all these graphs the benchmark line is not shown because it is supposed to be set at the value 1.0 on the horizontal axis.

proportion of soils, and only under conventional and conservation tillage. The new low-dosage herbicides, nicosulfuron and primisulfuron, are predicted to be used more widely and result in concentrations well below their human health benchmarks. However, there are major uncertainties associated with these chemicals regarding pest resistance and their hazard to aquatic and nontarget terrestrial vegetation. Overall, the costs to agricultural producers and consumers are higher with a triazine ban, but the exposure values decrease because of lower herbicide concentrations.

Future Application of CEEPES

Soil Carbon Sequestration

Recently there has been widespread documentation of increasing levels of CO_2 and other greenhouse gases in the atmosphere. The balance of carbon stored in the atmospheric, terrestrial, and oceanic pools is beginning to shift disproportionately toward the atmosphere leading to predictions of global climate change. It is estimated that agricultural soils store 1,500 billion kilograms of carbon, twice the amount held in the atmosphere. The agricultural activities carried out on any particular tract have a significant capacity to affect the amount of carbon stored in the soil. Policies designed to encourage or compel the adoption of practices or land use patterns that promote the build-up of soil organic carbon may influence reduced emissions of carbon gases as well as potential economic costs to producers and consumers. Depending upon their design and implementation, policies may have considerable regional and national impacts on agricultural profitability, land use patterns, soil erosion, and the use of pesticides and fertilizers.

A CEEPES configuration was set up to evaluate the economic and environmental impacts of policies aimed at increasing the organic carbon in agricultural soils in the major crop producing midwestern states. CEEPES was linked to CENTURY, a soil organic formation model, which estimates soil organic carbon levels over time under alternative assumptions about agricultural practices and land use. The interface between the two models was accomplished through management practices, including crops, tillage, and rotations predicted by the agricultural decision component of CEEPES.

By targeting conservation tillage and winter cover crops (aimed at increasing biomass production), we show that producer net returns decrease by less than 4 percent. Stored soil organic carbon increases by as much as 14 percent, soil erosion decreases, and fertilizer use also decreases, thus resulting in important environmental gains.

Livestock and Nitrates

Livestock production accounts for approximately one-half of gross receipts to agriculture in the United States. The livestock industry in the agricultural sector has become increasingly concentrated, creating problems of waste disposal and significant potential for point and nonpoint source ground and surface water pollution. The current patchwork of regulations and management approaches for livestock units is generally inefficient both from the viewpoint of the profitability of livestock/agricultural operations and protection of the environment. For improved management of environmental impacts of livestock operations an integrated and comprehensive policy analysis system is required. CEEPES can be configured to evaluate systems for the design and evaluation of management strategies and environmental impacts of livestock operations. Harmonizing livestock production with other economic activities that contribute to significant economic growth in rural areas will be a major environmental policy issue of the 1990s.

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