CEEPES: An Overview of the Comprehensive Economic Environmental Policy Evaluation System

Stanley R. Johnson, Paul E. Rosenberry, Jason F. Shogren,
and Peter J. Kuch

Staff Report 90-SR 47
December 1990

CEEPES: An Overview of the Comprehensive Economic Environmental Policy Evaluation System

by Stanley R. Johnson, Paul E. Rosenberry,
Jason F. Shogren, and Peter J. Kuch

Staff Report 90-SR 47
December 1990

Center for Agricultural and Rural Development
Iowa State University
Ames, Iowa 50011

Stanley R. Johnson is Charles F. Curtiss Distinguished Professor of Agriculture and director of CARD; Paul E. Rosenberry is affiliate professor of economics with CARD; Jason F. Shogren is assistant professor of economics and head of the Natural Resources and Conservation Policy Division, CARD; and Peter J. Kuch is senior agricultural economist with the Office of Policy Analysis, EPA.

Prepared under Cooperative Agreement Number CR813498-01-2 between the Office of Policy Analysis, U.S. Environmental Protection Agency, Washington, D.C., and the Center for Agricultural and Rural Development, Iowa State University.

CONTENTS

FIGURES

TABLES

PREFACE

The Comprehensive Economic Pesticide Policy Evaluation System (CEPPES), as CEEPES was originally called, was developed in 1986 under a cooperative agreement between the Office of Policy Analysis of the Environmental Protection Agency (OPA/EPA) and the Center for Agricultural and Rural Development at Iowa State University (CARD/ISU). CEPPES was designed to analyze agricultural and environmental policies. It was structured to accommodate the important interrelationships among environmental and agricultural policies in the United States. Integrated policy analysis can discern and demonstrate efficient strategies to attain targeted levels for the agricultural sector, human health, and environmental performance.

During the period of the first cooperative agreement, 1986 to 1988, the general structure of CEPPES was developed using components and modules as building blocks. State-of-the-art models were studied and integrated into a policy analysis framework. CEPPES was then applied to two broad-scale agricultural/environmental policy analyses: an assessment of a ban on corn rootworm insecticides and an assessment of the implications of targeting the conservation reserve to improve water quality.

The first documentation of CEPPES was made available in 1988. This report is an updated version of the overview chapter presented in CEPPES (1988). CEPPES has now been expanded to include plant nutrients in addition to pesticides, and the name of the system has been changed to Comprehensive Economic Environmental Policy Evaluation System (CEEPES).

This report is therefore intended to serve as an overview of the revised and expanded policy evaluation system. Future reports and books will further document and demonstrate the analytical system.

CEEPES integrates available models and systems (economic, biological, and chemical fate and transport), called modules, into a framework that can be used in agricultural and environmental policy analysis. These policies include controlling agricultural chemical contamination. The system has the capacity to trace pesticide fate, agricultural income, prices of agricultural commodities, and other features useful in assessing costs and benefits inherent in various policy scenarios.

Neither CEPPES nor CEEPES would have been possible without the efforts of researchers who pioneered and developed the models being used to simulate each module. These models are complex and require input from many disciplines. Incorporating process models into integrated analytical systems can improve cross-disciplinary cooperation and communication necessary for environmental policy research. Scientific and political agreement appears to be easiest at the coefficient level rather than at the impact level. However, once coefficient and program logic are agreed upon, agreement on impact is easier. As new process models are developed, they will be tested and incorporated into CEEPES. CEEPES will therefore continue to be expanded and will evolve as an analytical system, with broader applicability to new environmental and agricultural policy issues as they arise.

ACKNOWLEDGMENTS

The development of the Comprehensive Economic Environmental Policy Evaluation System (CEEPES) has been a product of cooperation among Peter J. Kuch and Andy Manale and associates at the Office of Policy Analysis of the U.S. Environmental Protection Agency; Robert F. Carsel and associates at the Environmental Research Laboratory, Office of Research and Development, EPA, Athens, Georgia; the Center for Agricultural and Rural Development, Iowa State University, with an ISU interdisciplinary team; Jimmy Williams and associates at the U.S. Department of Agriculture-Agricultural Research Service Grassland Soil and Water Research Laboratory, Temple, Texas; and Burton C. English and associates at the University of Tennessee. Future cooperation with other field laboratories and regional offices of the Environmental Protection Agency is planned.

The authors express sincere appreciation to Amy Lilienfeld for her invaluable editorial assistance.

The Interdisciplinary Team

The Iowa State University interdisciplinary team was formed when it became apparent that increased scientific input was needed for the biogeophysical and health and environmental risk components. The team members who have assisted in the development and application of CEEPES are listed in the following table. Team members have used components and modules of CEEPES in a variety of environmental research and policy contexts.

Iowa State University Interdisciplinary Team

Name	Office/Area	Department
James R. Gilley	Chair	Ag. Eng. Dept.
Howard Johnson	Hydrologist	Ag. Eng. Dept.
Carl Anderson	Modeler	Ag. Eng. Dept.
James Baker	Tillage	Ag. Eng. Dept.
John Pesek	Chair	Agronomy Dept.
Alfred Blackmer	Nitrogen	Agronomy Dept.
Richard Cruse	Roots	Agronomy Dept.
Richard Fawcett	Weeds	Agronomy Dept.
Thomas Fenton	Soils	Agronomy Dept.
Mike McCorcle	Climate	Agronomy Dept.
Gerald Miller	Soils	Agronomy Dept.
Robert Hartzler	Weeds	Agronomy Dept.
Michael Owen	Weeds	Agronomy Dept.
Stanley R. Johnson	Administrator	CARD/Econ. Dept.
Satheesh Aradhyula	World Module	CARD/Econ. Dept.
E. Kwan Choi	Risk Analysis	CARD/Econ. Dept.
Phil Gassman	Biogeophysical Component	CARD/Econ. Dept.
Derald Holtkamp	State/Regional Module	CARD/Econ. Dept.
Paul Rosenberry	Biogeophysical Component	CARD/Econ. Dept.
Jason Shogren	Natural Resources	CARD/Econ. Dept.
Leland Thompson	National/Regional Module	CARD/Econ. Dept.
Pat Westhoff	Commodity Market Module	CARD/Econ. Dept.
Alicia Carriquiry	Statistics	CARD/Stat. Dept.
Harold Stockdale	Chair	Entomology Dept.
Jon Tollefson	Insects	Entomology Dept.
Dennis Keeney	Director	Leopold Center
James Swan	Associate Director	Leopold Center
Jerry Hatfield	Director	Soil Tilth Lab
Thomas Colvin	Tillage	Soil Tilth Lab
Tom Kaspar	Roots	Soil Tilth Lab
Dennis R. Starleaf	Chair	Economics Dept.
Michael Duffy	Sustainable Agriculture	Economics Dept.
Robert Jolly	Economics	Economics Dept.
Joe Herriges	Economics	Economics Dept.
USDA		
Jay Atwood	Modeler	USDA/ERS Collab.
Richard Cabe	Experimental Design	USDA/ERS Collab.
EPA		
Peter J. Kuch	Economist	US EPA
Andy Manale		US EPA
Bob Carsel		US EPA

Introduction

Modern market economies fail to allocate resources efficiently when the actions of one group have unintended effects on others. A prime example of market failure is the growing evidence of environmental degradation and health risks associated with agricultural pesticide use (USGS 1983; CF 1984, 1987; OTA 1984; O'Hare et al. 1985; Nielsen and Lee 1986; Batie and Diebel 1989; NGA 1989; Wise and Johnson 1990). Although partially related to scientific advances in measurement and detection (USGS 1983; Cohen et al. 1984; CF 1984; OTA 1984; Cohen, Eiden, and Lorber 1986; Cohen 1987), the increasing evidence is correlated with increased pesticide use over the past several decades (Baker 1985; CAST 1985; Gianessi 1986). Fears of pesticide "loading" in the environment have created public pressure to reduce potential health risks from residuals in the food chain and exposure to contaminated surface and groundwater (Pye and Patrick 1983; Rajagopal 1984; ASIWPCA 1985; U.S. EPA 1986a, 1986b; Feliciano 1986; Holden 1986; Johnson 1987).

As public pressure mounts, policymakers are gaining interest in new, broader forms of regulation (Wise and Johnson 1990). Traditionally, the U.S. Environmental Protection Agency (EPA) has been primarily responsible for pesticide regulation (NRC 1980; Dycus 1984; Durenburger 1986; Bosso 1987; Rausser 1990). Although state-level regulations exist, they have not been directed at surface and groundwater quality, with the exception of California and Iowa (Holden 1986; Belsie 1987; Duffy and Traxler 1987; Batie and Diebel 1989; Wise and Johnson 1990). Debate at the federal and state levels over alternative regulatory policies has been stymied somewhat by a lack of information about potential environmental and economic impacts.

In a period of high visibility for pesticide-related health risk and environmental degradation, it is important that outcomes of policies be anticipated accurately (Taylor and Frohberg 1977; CAST 1980; Wise and Johnson 1990). Since both pesticides and their regulation have costs and benefits to society (CAST 1980; Milon 1986; McGartland 1986), enlightened legislation must reflect an awareness of their incidence, recognizing and balancing the trade-offs (NRC 1980; Halstead 1987; Johnson 1987; Young 1988; Reichelderfer and Hinkle 1989).

In 1986, OPA/EPA and CARD/ISU formulated a cooperative agreement entitled "Comprehensive Economic Environmental Policy Evaluation System" (CEEPES). CEEPES is an operational policy modeling system. An important intent of CEEPES is to develop a tool for evaluating the regulation of agricultural pesticide use. CEEPES can provide information to environmental policymakers, assisting them in identifying superior regulatory instruments (see Baumol and Oates 1971, 1988). The project involves identifying and comparing efficient and administratively manageable approaches to more comprehensive pesticide regulation.

The purpose of this report is to provide an overview of the CEEPES modeling system. CEEPES has two primary objectives:

- To provide comprehensive indicators of economic and societal impacts of alternative pesticide and nutrient regulations; and
- To identify key information needed to assess the implications of pesticide and fertilizer regulation. These informational needs include input data for both the agricultural decision and biogeophysical components, and are necessary to help determine the impacts of pesticide use on agriculture, health, and the environment.

CEEPES comprises four core components: policy, agricultural decisions, biogeophysics and health and environmental risk. Each component consists of an amalgamation of computerized process models. Specific data bases are required for each of the process models, which are organized, integrated, and linked together to form the modules of the four major components.

To determine potential research needs for the CEEPES project, a pilot study was undertaken encompassing the Upper Mississippi River Basin (Figure 1). This area was chosen because of an abundance of available economic and agricultural data. Many of the process models currently used for CEEPES were initially calibrated to this pilot area (CEPPES Documentation 1988). The main objective of the pilot study was to provide empirical results showing the suitability of previously published process models and economic modeling systems used as building blocks for CEEPES.

This paper proceeds as follows. The second section provides background information about agricultural pesticide use that has led to the current policy issue of potential health risks and environmental degradation. The four core components of the CEEPES modeling system--policy, agricultural decisions, biogeophysics, and health and environmental risk--are then presented. Research needs identified by the CEEPES pilot study are delineated: aggregation issues, time and space scales, missing technical information, health and environmental risk, and agricultural decision responses. The advantages of CEEPES as a research tool and suggestions for future study are described in the final section.

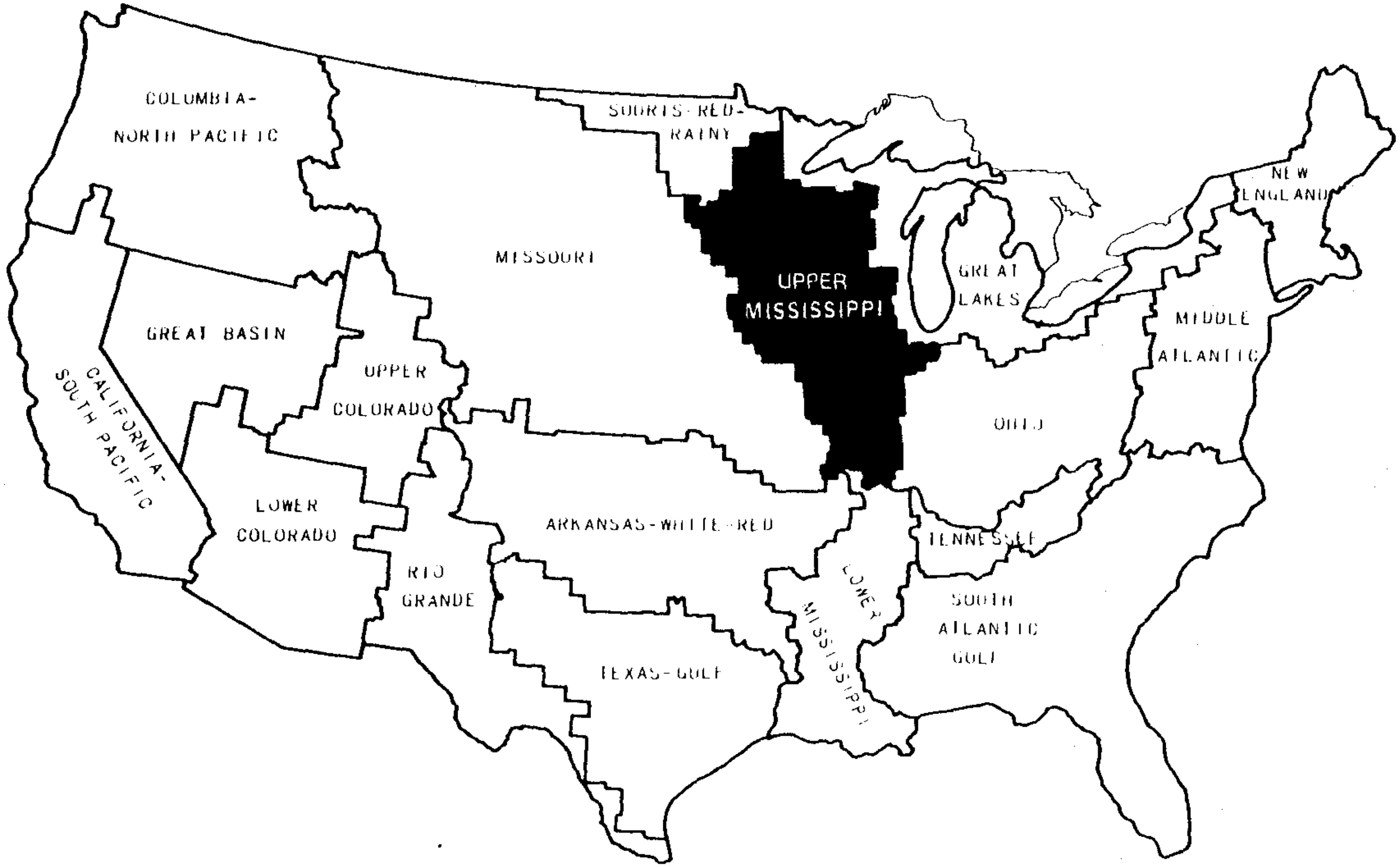

Figure 1. River basins with county boundaries

The Policy Issue

Agricultural production in the United States and other countries has improved significantly over the last several decades, in part due to the introduction and expanded use of agricultural chemicals (Antle and Capalbo 1986; Wise and Johnson 1990). Increased productivity has resulted in the adoption of government policies adjusting resource markets to maintain agricultural incomes (Raucher 1986; Gardner 1987; Reichelderfer and Hinkle 1989). In the 1980s, decreased demand due to slower rates of economic growth, trade restrictions, Third World debt, international finance restructuring, and other factors increased government and societal costs of programs subsidizing agricultural incomes (FAPRI 1986). An implication of continuing subsidization policy is continued government involvement in supply management and substantial income transfers to agriculture (Headley and Lewis 1967; Ericksen 1976; FAPRI 1986).

The public perception that farm programs encourage high inputs of pesticides and nutrients, coupled with an increasing awareness of pesticide and nutrient-related health and environmental risks, suggests an interesting possibility for designing more effective and comprehensive policies toward agriculture and chemical use (Reichelderfer and Hinkle 1989). With current crop production technologies, pesticide and nutrient use and subsequent loading to the water are directly related to agricultural production levels and patterns (Burton 1982; Ferguson 1985; Copeland and Zinn 1986; Gianessi 1986). These crop production patterns are, in turn, partly determined by domestic and foreign government agricultural programs (Reichelderfer and Phipps 1988). One can ask, is it possible to reorient government programs for agriculture to reduce the environmental health risks associated with pesticide and nutrient use? The answer is "yes"; there are apparent complementarities. The political process has already recognized these complementarities in the Conservation Reserve and Conservation Compliance provisions of the Food Security Act of 1985. But policy research has yet to design and evaluate integrated environmental and agricultural policies.

Increased pesticide use in agricultural production is relatively new (Hallberg 1986a, b, c). Between 1964 and 1986, agricultural pesticide use more than tripled (USDA 1985). In 1982, more than 90 percent of row crop acreage and about 45 percent of small grain crop acreage in the United States were treated with herbicides (Duffy 1982; Gianessi 1986; CF 1987; Johnson 1987). More recent information for Iowa indicates herbicide use has continued to increase due to reduced tillage (although this is argued not to be necessary by Fawcett [1986]), larger planted acreage, higher prices, and other factors. From 1979 to 1985, the active ingredients in major herbicides applied in Iowa increased to 13,442,000 pounds from 12,668,000 pounds for soybeans and to 44,775,000 pounds from 44,011,000 pounds for corn (Wintersteen and Hartzler 1987)(Table 1). Clearly, current U.S. and European Community (EC) agricultural policies promoting increased yields have stimulated the increased use of pesticides (Choi and Johnson 1987; Gardner 1987). In general, pesticide and nutrient use levels in U.S. agriculture and subsequent loadings to the water system have increased markedly in the past and are remaining at these high levels, especially in intensive crop cultivation areas (CAST 1980; Ferguson 1985; Reichelderfer and Phipps 1988).

Evidence of health risks from pesticides began to receive public attention in the early 1960s (Carson 1962; MacIntyre 1987; Rausser 1990).

Table 1. Major herbicides used in soybean and corn production, Iowa, 1979 and 1985

Herbicide	1979 Acres Treated (%)	1979 Active Ingredients (1,000 lb.)	1985 Acres Treated (%)	1985 Active Ingredients (1,000 lb.)
		Soybeans		
Amiben	13.8	1,606	13.0	1,386
Basagran	5.6	459	13.9	798
Dual	0.6	139	7.8	1,472
Lasso	29.1	4,224	12.3	2,119
Poast	--	--	1.4	23
Prowl	1.0	89	5.4	487
Sencor/Lexone	40.8	1,594	43.0	1,763
Treflan	60.8	4,535	63.2	4,664
Sonalan	--	--	7.0	517
Roundup	0.3	22	13.0	213
		Corn		
Atrazine	32.9	6,642	48.0	9,590
Banvel	19.4	832	20.3	774
Bladex	32.7	8,513	33.9	10,366
Buctril/ Brominal	--	--	3.0	250
Dual	4.6	1,535	30.5	8,480
Eradicane	0.6	381	1.3	815
Genate/Sutan	29.7	13,597	8.9	3,958
Lasso	40.7	11,357	33.1	9,754
2,4-D	18.2	1,154	18.9	788

SOURCE: Wintersteen and Hartzler 1987.

This concern about pesticides was manifested in the passage of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), repeated amendments, restrictions on certain chemicals, legislation to protect farmers from exposure to dangerous chemicals and in the current debate in Congress about food safety, and attempts to introduce pesticide-related provisions in the upcoming farm bill (Bosso 1987). The predominant regulatory statute, FIFRA (Federal Insecticide, Fungicide, and Rodenticide Act), was revamped in 1972 by the Federal Environmental Pesticide Control Act (FEPCA). FEPCA gave EPA the authority to weigh the costs and benefits of pesticide use when making regulatory decisions, broadening EPA's authority to include environmental risks (Aidala 1986; U.S. EPA 1986a; Wise and Johnson 1990). Concern about health risks to farmers and applicators remains a primary motivation for EPA regulation (Davis 1987a, b).

By the late 1970s and early 1980s, the threat of groundwater contamination from conventional field applications of agricultural pesticides and nutrients became a major policy concern (Barnes 1976; NSF 1983; CF 1984; OTA 1984; Soren and Stelz 1985; Hallenbeck and Cunningham-Burns 1985; Hallberg 1986a; Holden 1986). Awareness of the potential for groundwater contamination by agricultural pesticides and fertilizers (Blackmer 1984, 1985) has increased as additional data accumulate. By 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. The growing evidence that pesticide levels in groundwater are sufficiently high to cause health risk (Abt 1987a), combined with evidence of pesticide residuals in the food chain, and the possibilities of exposure to pesticides volatilized into the atmosphere, has heightened interest in evaluating the economic trade-offs of augmenting pesticide registration with broadened and indirect forms of chemical regulation.

In the CEEPES study area, nine herbicides and three insecticides were detected in Iowa groundwater (Table 2). Concentrations of these pesticides were at levels of less than one part per billion (Johnson and Splinter 1983; Hallberg 1985, 1986b). In certain "hot areas," however, concentrations have been found to be 100 times this level, largely due to leaching from chemical storage and handling facilities. Iowa, Illinois, Minnesota (states in the pilot study area), and California lead all other states in estimated applications of pesticides (Fruhling 1986).

The risk level from pesticide and fertilizer residuals and how it should be evaluated economically, relative to the benefits of chemical inputs in agriculture, present continuing and difficult problems (see Shogren 1990b; Shogren and Crocker 1990a, b). Evidence of health risks from pesticide use is becoming increasingly available. Human health implications of long-term exposure to pesticides at low levels can be estimated only with approximation methods (CAST 1980; Abt 1987a). Risk assessment procedures are used to project impacts on population levels (Abt 1987a, b; Shogren 1990a). Models for assessing health risks, however, require detailed information on pesticide fate. An important function of CEEPES is to link pesticide and nutrient fate to cultivation practices, application rates, soils, and parameters of agricultural income maintenance policies, thereby leading to more accurate risk assessment estimates.

Managing pesticide use through direct and indirect regulations, including supply control and income maintenance for agriculture, provides an

Table 2. Summary of pesticide data from groundwater quality monitoring, Iowa, before 1986

Common Name of Active Ingredient	Maximum Concentration ug/l	% of All Detections	Months of Detection
<u>Herbicides</u>			
Alachlor	16.6	15	1-12
Atrazine	13.0	72	1-12
Chloramben[a]	1.7	< 1	7
Cyanazine	13.0	13	1-12
Dicamba[a]	2.3	2[a]	3,6,7
Metolachlor	9.0	9	1-7,11,12
Metribuzin	4.4	10	1-12
Trifluralin	0.2	1	6,7
2,4-D[a]	0.2	< 1	4
Fonofos[a]	0.9	2	4,6,8
Sulprofos[b]	1.4	< 1	5
Terbufos[b]	12.0	5	5

SOURCE: Kelley et al. 1986.

[a]Analyzed by different methods, so N is not the same as for other herbicides.

[b]Detected in only one study.

opportunity to develop effective and efficient policies. However, any policies to minimize societal costs of restricted pesticide use will require continuing information since pesticides are important to agricultural productivity. Output from CEEPES will provide information on a wide range of policy trade-offs (Edwards and Langham 1976; Sharp and Bromley 1979; Miranowski 1980; Pimentel et al. 1980; Kramer et al. 1984; McGartland 1986). These trade-offs include benefit/cost, benefit/risk, and risk/risk. Or in other words, do the benefits outweigh the costs involved, or do they outweigh the increased risks, or does total risk decline?

CEEPES Structure

The four major components of CEEPES are for policy, agricultural decisions, biogeophysics, and health and environmental risk. The system is designed to permit both study of general policy alternatives and to provide outcomes for selected pesticide and nutrient regulations. Figure 2 illustrates the detailed CEEPES design, including the four major components. Figure 2 also shows how information flows among the components. For example, pesticide and nutrient fate, expressed in concentrations and masses, is the key link between the biogeophysical and the health and environmental risk components. Cultural practices, production patterns (involving different soil types and geophysical characteristics), and nutrient and pesticide use levels are provisionally determined in the agricultural decision component and then transmitted to the biogeophysical component.

The process models used in CEEPES are complex, but most can be operated on microcomputers. Choices of process models to represent modules were made after examining a number of available alternatives. The number and

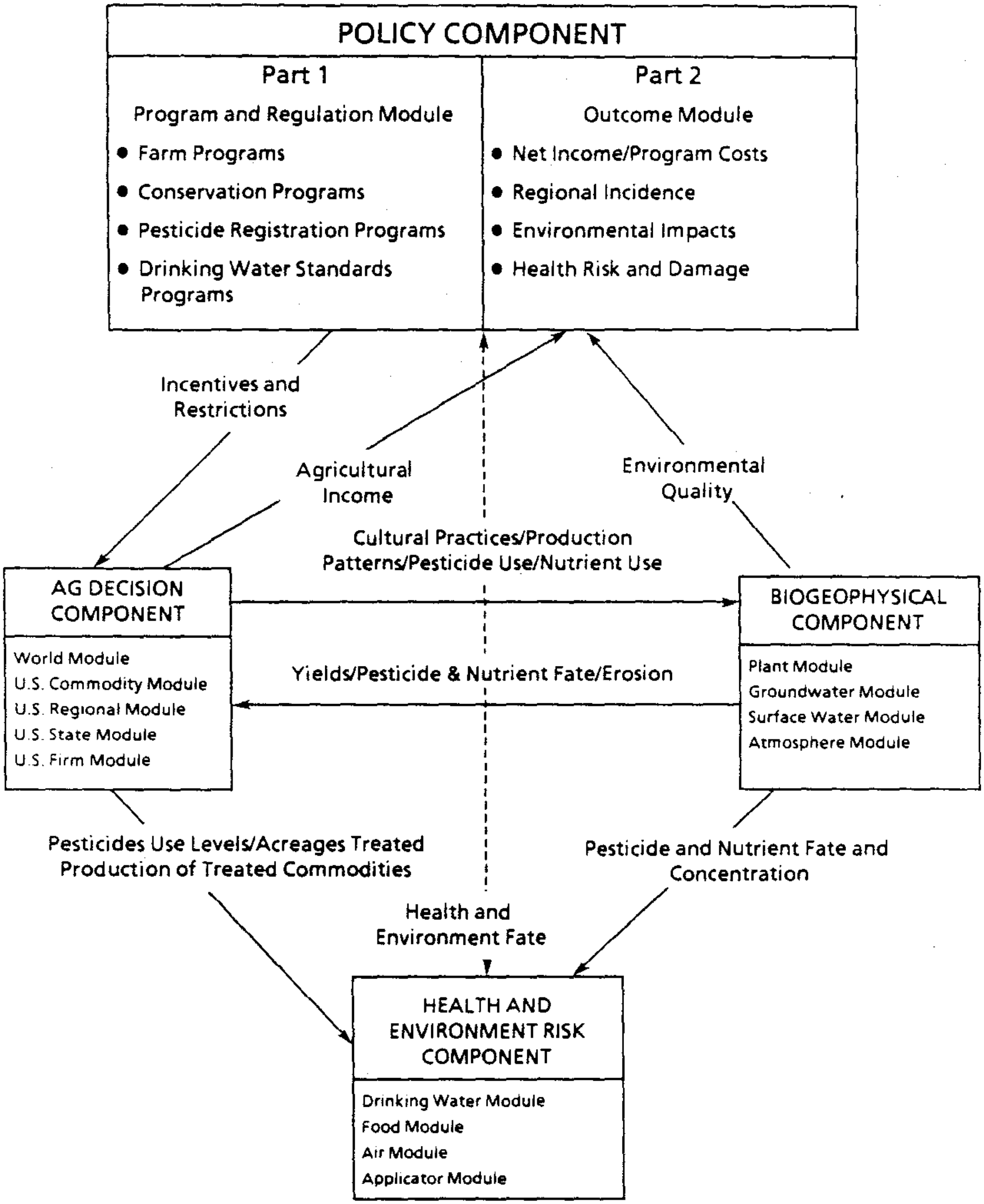

Figure 2. Comprehensive Economic Environmental Policy Evaluation System

complexity of the models make the system very data intensive. Major information sources for the system include:

- Weather
- Soils
- Biological systems
- Geophysical structures
- Food consumption
- Population
- Water sources
- Production practices
- Agricultural supply and use
- Water quality
- Prices
- Income and employment
- Supply control policy parameters
- Demand control policy parameters

A number of large-scale data bases have been specially assembled and prepared in each component of CEEPES. In addition, previously existing CARD data bases have been edited and expanded. Descriptions of the major data bases for each component are discussed in the appropriate component sections. Since many of the data bases and process models incorporate different time and space scales, a major complication in the design and application of CEEPES is the reconciliation of these disparities. Consequently, the linkages between the modules within and among the components require careful attention to time and space dimensions.

Examples of these linkages are discussed in the following component sections.

The Policy Component

The policy component is divided into the program and regulation module and the outcome module (Figure 2). The program and regulation module develops major linkages between regulatory instruments and the agricultural decision component. The outcome module considers major outputs generated by CEEPES components. Examples of outcomes include changes in net income, regional comparative advantages, chemical loadings to the environment, and risk and damage to human health and wildlife.

Examples of programs considered in the program and regulation module include 1990 commodity and conservation programs, pesticide registration and cancellation and use restriction programs, drinking water standards programs, taxes, prices, quotas or allocations, supplemental information, acreage set-aside restrictions, subsidies, cropping practice restrictions, and a long-term conservation reserve. Specific program provisions will be introduced in a future paper about the system.

Note that these examples include both indirect and direct policy instruments. Examples of indirect programs would be price stabilization and farm income maintenance. Neither of these is usually implemented to directly reduce the risk of pesticide-induced health and environmental damages. The same is true for conservation programs that provide structures to control surface water runoff, define best management practices, and determine land use. An example of direct policy intervention is "pesticide use restriction," which limits the active compounds available for agricultural production through registration, use restrictions, and taxes. Another example is the imposition of drinking water standards, which also apply directly to health and environmental risk.

The outcome module of the policy component does not yield independent outcomes; changes in one outcome may precipitate changes in another. These outcome module interdependencies will also be affected by the selections made in the program and regulation module. In addition, factors outside the policy component (such as international commodity markets and retaliatory actions) also affect outcomes. Therefore, the most reliable economic results will be obtained if policies or policy options are studied for impacts in a hierarchy of decision models, beginning at the micro firm level and ending at the macro world level. For example, if implementation of a local policy decreases firm-level production, then subsequent price adjustments will occur at the aggregate level. The price adjustments influence production and demand in other trade-related areas, which will also affect the local area where the process began.

The Agricultural Decision Component

Figure 3 illustrates the structure of the agricultural decision component of CEEPES. The internal linkages among the modules within this component are largely recursive. For example, the regional module may receive information from the firm or producer module, while the world module receives information from the regional module. The U.S. commodity module operates parallel with the world and U.S. regional modules, providing short-term impact analysis and a check on output from the other modules.

Although a fully integrated hierarchical representation of the agricultural decision component would be preferred (Taylor and Frohberg 1977; Taylor 1980), its structure has been determined in some respects by available operational economic models and the need for geographic detail. These models correspond to specific major modules as follows:

- World Module--Basic Linked System, CARD/IIASA
- U.S. Commodity Market Module--CARD/FAPRI Commodity Marketing and Trade Models
- U.S. Regional Module--CARD Regional Resource Model

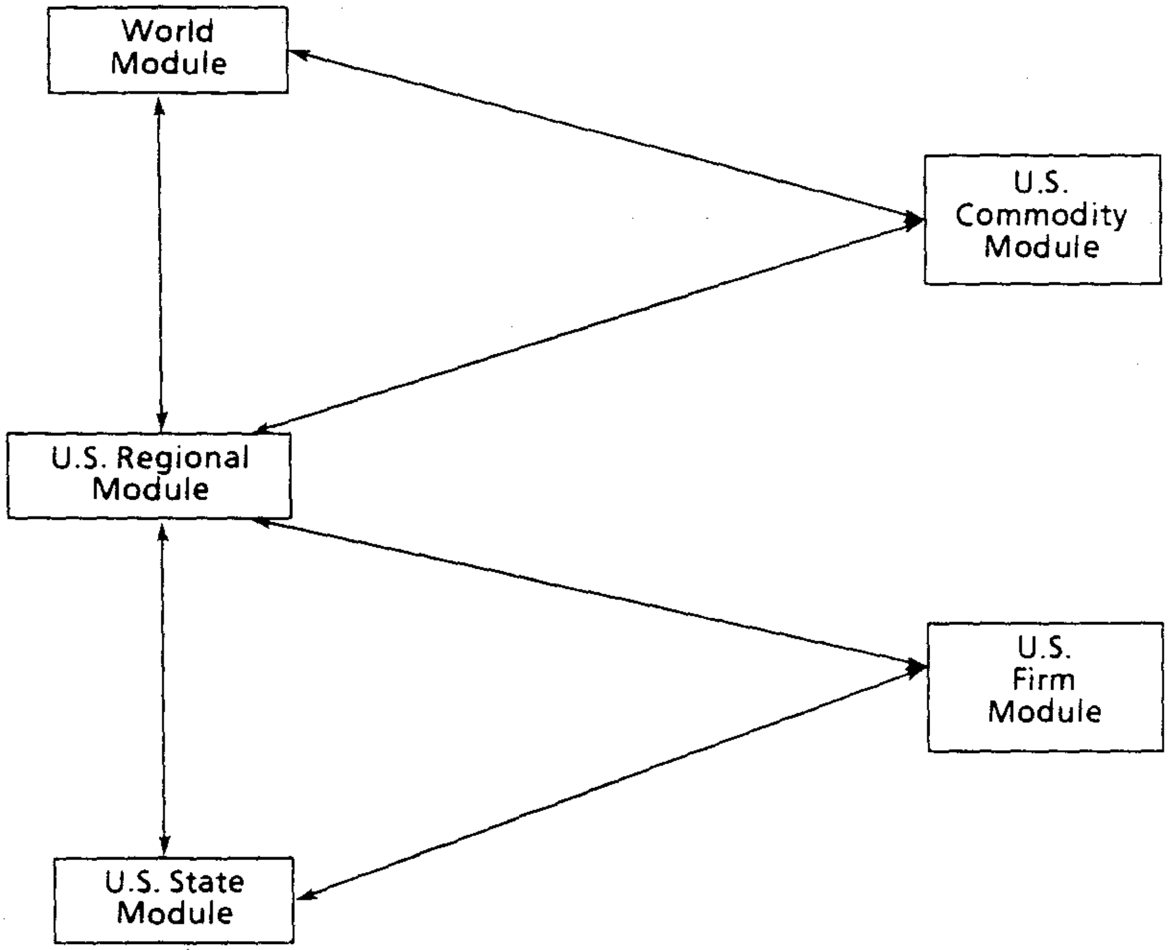

Figure 3. The agricultural decision component of CEEPES

- U.S. State Module--CARD State Modeling System
- U.S. Firm Module--Farm Level Simulator

These models, except for the state modeling system, were all originally developed for purposes other than CEEPES. However, when the models are linked together properly, they can be used to develop behavioral relationships 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, and world modules.

The impact of pesticide regulations on producers will depend upon the availability of perfect substitutes. If perfect substitutes are available, then pesticide restriction will have no impact; however, if perfect substitutes are not available, producers will be affected because they will be forced to modify their behavior. If many choices are available, with various advantages and disadvantages, the agricultural decision module is used to make alternative resource allocations, given constraints such as cost and effectiveness. The results are entered into the appropriate biogeophysical module to estimate changes in yields and chemical fates. Biogeophysical results are then reentered into the agricultural decision component in an iterative fashion. For example, if the policy component restricts chemical concentrations in water, the constraints are first introduced into the biogeophysical component. Then, biogeophysically determined alternatives are entered into the agricultural decision component to determine optimal resource allocation decisions. Since the most reliable biogeophysical results are obtained at the field level, these linkages occur between the agricultural decision and biogeophysical components at the micro level. The outputs generated include regional production patterns, aggregate output, input use, values of fixed resources, and cultivation practices. At present, responses to uncertainty and risk are studied outside the agricultural decision component.

Indirect regulations enter the U.S. regional module in a more complex manner. Examples of indirect regulations are agricultural commodity supply control programs, conservation compliance, and Conservation Reserve programs. The Conservation Reserve 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 U.S. commodity and world modules. Market equilibrium prices and different implicit prices faced by producers participating in commodity programs influence solutions in the commodity and world modules.

Major links to other CEEPES components are from the firm and regional modules. Figure 3 illustrates the type of information exchanged within the agricultural decision component. Note that the system builds on the CARD/FAPRI Commodity Market and Trade Model, the CARD Regional Resource Model, the farm-level simulator, and the Basic Linked System (BLS), or sector, model. State-level models were developed to directly investigate trade-offs between environmental and agricultural commodity programs.

The major data bases for the agricultural decision component, aside from those used in the regional and firm modules, are economic. The world and commodity modules require annual supply and use information for major agricultural commodities; average annual farm, wholesale, and retail prices;

and information on export markets for major agricultural commodities. At the international level, both modules require similar information from other countries. Since the commodity market and trade and sector models are dependent on input costs and macroeconomic conditions (interest rates, inflation, income growth rates) in domestic and foreign economies, these conditioning data must also be supplied. Most of these data are available through the Wharton Econometric Forecasting Associates (WEFA), a subcontractor with CARD/ISU on the project, and from FAO.

The Biogeophysical Component

The biogeophysical component of CEEPES includes the plant process, surface water, atmospheric, and groundwater modules. Figure 4 illustrates the four modules and the exchanges that occur among them. Factors contributing to the exchange among modules at the soil surface include 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 phenomena. 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 biogeophysical component also simulates interactions in 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

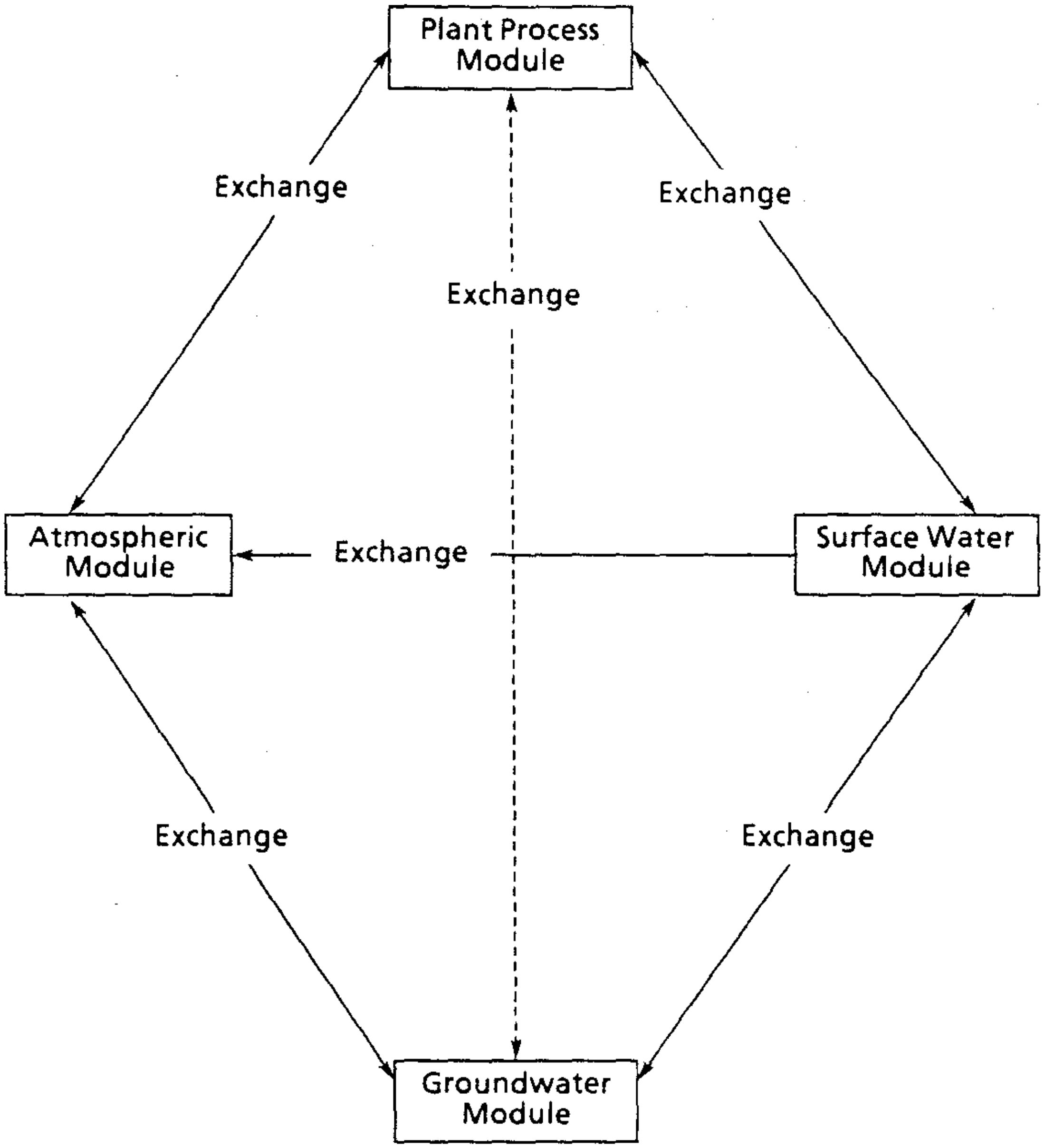

Figure 4. The biogeophysical component of CEEPES

conditioned by previous rotations and cultivation practices, soil types, and other factors that reflect the availability of water and chemicals carried in water transport.

Each module includes the following subprocess models:

- Plant Process Module
  --Plant Growth Model: The Erosion Productivity Impact Calculator (EPIC)
- Groundwater Module
  --Root Zone Model: Pesticide Root Zone Model (PRZM)
  --Integrated Root Zone, Vadose, and Aquifer Model: Risk of Unsaturated/Saturated Transport and Transformation for Chemical Concentrations (RUSTIC)
- Surface Water Module
  --Watershed Model: Simulator for Water Resources in Rural Basins (SWRRB), and Agriculture Nonpoint Source Pollution Model (AGNPS)
  --Riverbasin Model: Hydrologic Simulation Program-Fortran (HSPF)
  --Instream Concentrations: Stream Transport and Agricultural Runoff of Pesticides for Exposure Assessment (STREAM)
- Atmospheric Module
  --Long-Range Atmospheric Transport Model: Iowa State University Planetary Boundary Layer Model (BLAYER)
  --Short-Range Atmospheric Transport Model: A Gaussian-Plume Algorithm for Point, Area, and Line Sources (PAL)

These process models incorporate detailed phenological, biological, and geophysical relationships (Figure 5). The initial approach was to acquire these models, develop the required data bases, and operate them for validation, testing, and development of consistent linkages.

These subprocess models can generally be divided into two classes. One class simulates the exchanges taking place in a naturally occurring chain of events, like water percolation and transport of pollutants through the root zone, unsaturated zone, and aquifer. The other class includes substitute models that generally perform the same function, but differ in data requirements or in applicability to different problems or areas.

Major linkages exist among the biogeophysical, agricultural decision, and health and environmental risk components. The biogeophysical component transmits chemical fate information to both the agricultural decision and the health and environmental risk components. Chemical fate involves residuals in the air, water, and food supply. Producer or agricultural decisions such as cultivation systems, pesticide applications, cultural practices, production patterns, and other factors condition the plant process module of the biogeophysical component, which in turn provides yield levels and other information to the agricultural decision component.

The different time and space scales within and between components of CEEPES have generated linkage problems (Svetlosanov and Knisel 1982; Gorelick 1983; Aller et al. 1985; DeCoursey 1985; Detroy 1986). For example, many modules have daily time steps and are at the point level, whereas other modules are based upon annual timesteps and are at firm, state, regional, and world levels.

Reconciliation of these disparities has been successfully achieved within the biogeophysical component by running sufficient points and time periods through appropriate modules to represent a specified geographic area

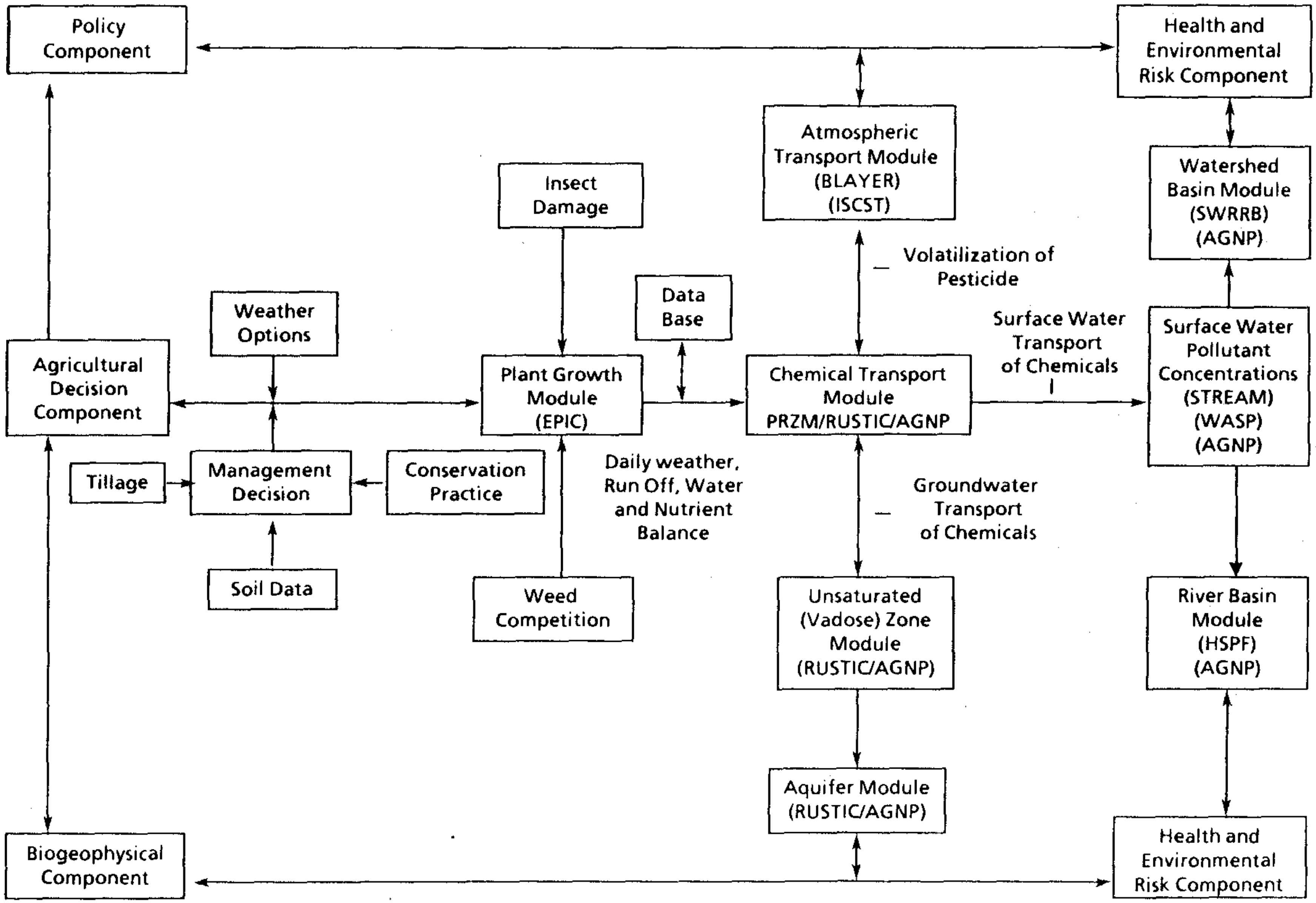

Figure 5. Diagram of the modules to be used in the biogeophysical component of CEEPES

and time period, respectively. From these generated data, pollutants and crop yields become inputs to other modules within the biogeophysical component and with modules of other components in compatible unit form. A problem with this reconciliation is the time and expense of gathering necessary input data and the large number of module runs required for satisfactory representation. The difficulty of providing a sufficient number of module runs to provide compatible input data to other components increases proportionately as the geographical areas increase. These different time and space scales of component inputs and outputs will require more technical information and analysis as CEEPES continues to evolve and be applied in new research projects.

The Health and Environmental Risk Component

The health and environmental risk component includes four modules, which operate in parallel fashion rather than interactively. Whereas the agricultural decision and biogeophysical components involve the interlinking of modules, reflecting a sequence of physiological and economic processes, the health and environmental risk component is a collection of evaluative modules that operate more or less independently. Figure 6 illustrates the difference between the structure of the health and environmental risk component and those of the agricultural decision and biogeophysical components.

The health and environmental risk component modules are for drinking water, air, food consumption, and applicator. Key inputs to these modules are from the biogeophysical and agricultural decision components of CEEPES. In fact, each of the modules within the health and environmental risk component is driven by data directly obtained from those two components.

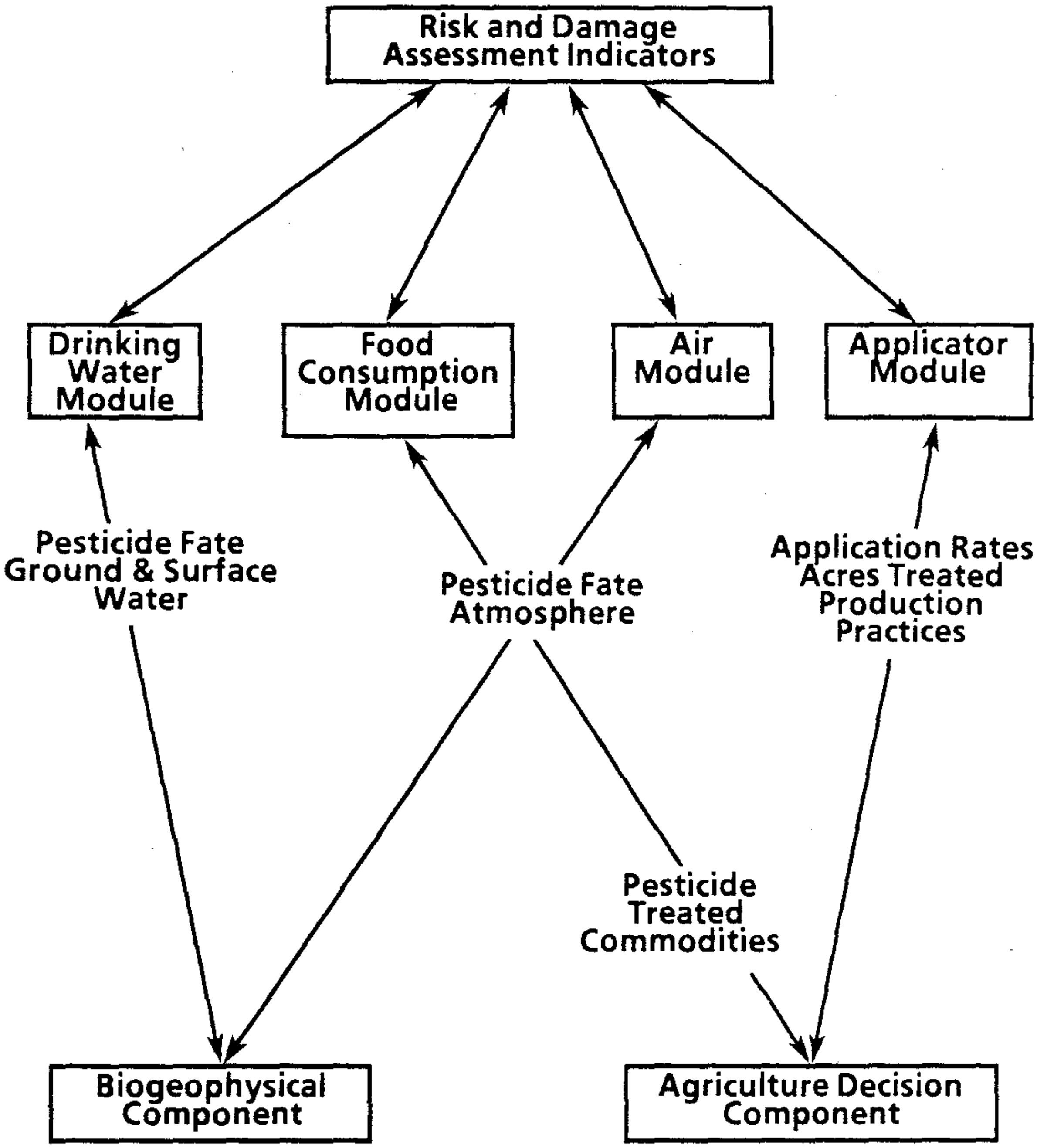

Figure 6. Linkage between Health and Environmental Risk Component and Biogeophysical and Agricultural Decision Components of CEEPES

For example, the drinking water and air modules obtain information concerning both chemical fate and concentrations in surface water, groundwater, and air from the biogeophysical component (Abt 1987a, b). The food consumption module obtains information regarding total quantities of chemically treated commodities from the agricultural decision component. Finally, the applicator module obtains information on chemical application rates, patterns of application, and frequency of application (cultural practices) from the agricultural decision component.

The modules within the health and environmental risk component produce estimates of health and environmental risks. These estimates are (presently) related to carcinogenic effects and other effects of chemical residuals.

The comparability in evaluating health risks among the modules involves the concept of a "dose" is calculated. The risk reference dose often involves an appropriate lifetime-adjusted effect level derived from laboratory animal experiments with the application of a safety factor. The does is the common unit of exposure to pesticides generated from each of the modules of the health and environmental risk component. Accumulations of doses per unit of time and population densities generate the estimated exogenous health risk for the damages and cost assessments (see Shogren 1990a).

The drinking water module was developed using U.S. population densities, water supply sources, and water supply treatment (Abt 1987).

The food consumption module is national. The aggregate food supply or food basket is determined from the USDA Nationwide Food Consumption Survey.

The food basket is then evaluated for evidence of chemical residuals using Food and Drug Administration (FDA) data on residues by crop. The implied consumption levels for pesticide residuals are then translated into indicators of health risk.

The air module is similar in structure to the applicator module. Volatilization of pesticides into the air is related to pesticide application rates, application method, and climatic conditions.

The applicator module, which focuses on a major source of potential health risks, is regional (Blair and Thomas 1979; Cantor 1982; Burmeister et al. 1983; Buiesching 1986). The applicators themselves are the population at risk. Information on agricultural application practices, the number of applicators involved, the frequency and rate of application, the types of pesticides applied, and other factors directly affecting exposure is required to model associated health and environmental risks. For the applicator module, these complicated interactions are currently modeled using acreage treated as a proxy.

CEEPES is a cooperative venture. According to the cooperative agreement between the EPA and ISU, the construction and operation of the health and environmental risk component of CEEPES is being undertaken by the EPA.

Research Needs

The experience gained from the CEPPES pilot project was used to develop the national CEEPES. A number of research needs were identified and are reviewed here.

Aggregation

Aggregation is a major problem in national economic policy analysis. This is especially true for CEEPES, given the attempt to provide consistent and useful information from the agricultural decision and biogeophysical components. Choices about the design of the biogeophysical component will predetermine aggregation possibilities. These relate, for example, to whether representative watersheds, a sampling of watersheds, or an aggregate model approximating all watersheds should be used. This choice should be made by balancing the benefits and costs of model enhancement and study area problems. Careful evaluation of aggregation bias will be required to identify the limitations placed on the scientific integrity of the system outputs.

Time and Space Scales

The difficulty of providing a sufficient number of module runs to provide compatible input data among various modules in the biogeophysical component and to other components increases proportionately for geographic areas larger than regions. Therefore, available statistical procedures, such as experimental design (Cochran and Cox 1957; Box and Draper 1987), need to be used to reduce the number of module runs currently required. The data generated for statistically determined points could then be statistically expanded to represent the desired geographical area. An added advantage of the experimental design would be to have statistical properties, such as confidence intervals, for the expanded data.

Missing Technical Information

A major problem has been the absence of complete information on the correlation between crop yields and the use of pesticides and fertilizers. Usually, only cost or expenditures on pesticides or chemicals are reported. These relationships can be simulated using plant process models. However, these response relationships are critical to the economic policy evaluation and deserve special attention in all studies.

Another important data gap is in the unsaturated and saturated zones in the groundwater module of the biogeophysical component. To provide the linkage between chemical use and fate, information about the biological and chemical processes in the unsaturated and saturated zones is needed (Pimentel and Levitan 1986). Chemical half-lives in the vadose and saturated zones represent an important data gap. More research and development work will be required if the transformation of pesticides in the vadose zone is to be accurately modeled or tracked.

Health and Environmental Risk

Within the health and environmental risk component, carcinogenic impacts of pesticide residuals are estimated. However, it is likely there are other health risks, both acute and chronic, from pesticide residuals. The health and environmental risk component must be extended to encompass other possible consequences of exposure. Also, the linkages to the health and environmental risk component use a number of proxies--for example, acreage treated as an indicator of applicator risk--that will have to be refined and verified.

Agricultural Decision Responses

The approach used to develop the production module of the agricultural decision component has been to synthesize individual or farm decisions using a linear programming framework. The correspondence, however, between the decisions synthesized within this framework and the econometrically estimated supply and demand models and the sector indicators is weak. In addition, there is little empirical data to anticipate producer responses to policies designed to affect pesticide and fertilizer use rates. These responses will have to be incorporated into the linear programming framework. An important reason for producers to use pesticides is to deal with yield risk. Adequately reflecting yield risk and producers' response to risk is a particular problem (Miranowski, Ernst, and Cummings 1974). The information available for estimating the coefficients of the response function in the production module of the agricultural decision component is historical and experimental, often not reflecting producer behavior in relation to the regulations or policies to be explored (Pope 1982).

Policy and CEEPES

A great deal of uncertainty exists about the impacts of policies, pesticide fates, the incidence of damages, and many other factors. Therefore, since uncertainty exists, it is necessary to investigate second best approximations to state contingent policies. A general framework for determining second best approximations is suggested in the CEPPES Documentation (1988).

The objective of such a theoretical investigation is to determine preferred policies or policy regimes. Information on preferred policy regimes can provide direction for choices of the more detailed and specialized policy exercises investigated with CEEPES. The theoretical or stylized models are examined to provide results on types of preferred policies or regimes. Experiments implementing these preferred policies in detail using specific sets of incentives, rewards, and restrictions are being undertaken within the CEEPES system.

The outcome, or abatement trade-off information, is summarized in the outcome module of the CEEPES policy component. The policy intervention is, in general, designed to determine the equilibrium between supply and demand for abatement. Of course, conceptually, this equilibrium of supply and demand for abatement should be achieved with efficient policies (Griffin and Bromley 1982; Greene et al. 1985). In principle, from CEEPES it should be possible to develop abatement supply and demand schedules. Unfortunately, with the uncertainties of the regulatory process, efficient state contingent regulations are at best difficult to identify (see Crocker 1984). Moreover, the choice of efficient policy instruments is especially problematic if the forms of regulation considered are in large measure indirect. Results in this case are highly specialized to the modeling system. The compromise for the operational model is to produce indicators of abatement trade-offs. An array of indicators will be produced by CEEPES that will relate to income and welfare, region, and health risk.

Often policymakers must use their own value judgments to weigh trade-offs across multiple objectives that are not directly comparable (Hoag and Manale 1990). A study by Hoag and Manale (1990) developed a framework that combines technical information from CEEPES concerning fate and transport of seven corn rootworm insecticides through the mediums of groundwater, surface water, and air in Iowa. The study demonstrates that the ranking of insecticides was different by medium. The authors conclude: "Unless cross media environmental effects are considered, social welfare may not be increased to its fullest potential" (p. 31). Arbitrary value schemes were also used to demonstrate how objective value judgments can be utilized to help decision makers. Example results were that 80 percent of total risk was contributed by three pesticides. One pesticide was hazardous in all mediums, and two pesticides out of the seven caused relatively little danger in any of the mediums.

This decision framework or "expert system" is expressed mathematically by Hoag and Manale as

$$\text{Risk}_{i,j} = \text{Exposure to chemical}_i/\text{Benchmark of chemical}_{i,j}, \qquad (1)$$

where exposure is the amount of chemical i delivered into environmental medium j over the study period, and the benchmark is the EPA health standard or other benchmark of concern.

$$\text{Relative Risk}_{i,j} = \text{Risk}_{i,j}/\sum_i \text{Risk}_{i,j}. \qquad (2)$$

The relative risk of each pesticide is expressed as a percentage of total risk within each medium by comparing the risk of exposure to rootworm insecticide i in medium j (groundwater, surface water, or air) to the sum of exposure to all insecticides in that particular medium.

$$\text{Weighted Risk}_i = \sum_j (\text{Relative Risk}_{i,j}) \times (\text{Medium Weight}_j), \qquad (3)$$

where the weighted risk of pesticide i is the sum of the relative risk of pesticide i on medium j times the weight of each medium j. The weights for each environmental medium are expressed as fractions of one and should be consistent (if A is superior to B and B is superior to C, then A is superior to C). Value-weighted risks are normalized to one.

Conclusions

Modeling a system of these dimensions identifies a number of technical and conceptual problems critical to both the effective design of the system and the usefulness of its output for policy analysis (Shortle and Dunn 1986). Policy problems related to pesticide use and health and environmental risk involve uncertainties that will not be completely resolved by the information from CEEPES or from any other quantitative modeling system. Rather than providing "push-button" answers to policy problems, the intent of CEEPES will be to narrow the range for policy judgment. Certain results from the modeling system will be sufficiently robust so they can be accepted into the policy debate. At the same time, other elements, perhaps critical to the design and operation of pesticide regulatory policies, will involve substantial uncertainty. A major contribution of CEEPES to policy analysis will be to focus debate on the issues about which there is true uncertainty. The result of this clarification will be more enlightened and socially desirable policies for regulating pesticides and nutrients in those sectors of the economy most directly affected by these regulations.

The number of possible direct and indirect policies to alter health and environmental risk from pesticides and fertilizers and the need to choose efficient instruments for their implementation places a heavy burden on CEEPES. In addition to producing timely policy evaluations, essentials of the quantitative computerized models must be communicated with transparency if their outputs are to be utilized effectively.

The use of components and the incorporation of modules based on established process models will enable technical specialists in many disciplines to evaluate the system's structure and performance. Applying CEEPES to environmental policy analysis will always be an interdisciplinary activity.

A major contribution of CEEPES will continue to be the organization and integration of scientifically validated process models for quantitative policy evaluation. Its contribution will best be characterized as providing information to decision makers about the interaction of various components affected by alternative policies and about the relative impacts of those alternatives. The motivation for CEEPES is the potential to effectively merge agricultural and environmental policies in order to reduce health and environmental risk from agricultural chemical use in conjunction with efficient and productive agriculture.

REFERENCES

Abt Associates Inc. 1987a. Pesticide Drinking Water Exposure/Risk Methodology. Washington, D.C.

____________. 1987b. Pesticide Dietary Risk Methodology. Washington, D.C.

Aidala, James. 1986. Pesticide Regulation: 1985 Amendments to FIFRA. Congressional Research Series 86-796 ENR. Washington, D.C.: Library of Congress. August.

Aller, Linda, Truman Bennett, Jay Lehr, and Rebecca Petty. 1985. DRASTIC: A Standardized System for Evaluating Ground Water Pollution Using Hydrogeologic Settings. EPA/600/2-85/018. Washington, D.C.: U.S. Government Printing Office.

Antle, J.A., and S.M. Capalbo. 1986. "Pesticides and Public Policy: A Program for Research and Policy Analysis." In T.T. Phipps, P.R. Crosson and K.A. Price (eds.) Agriculture and the Environment. Washington, D.C.: Resources for the Future.

Association of State and Interstate Water Pollution Control Administrators (ASIWPCA). 1985. Proceedings of the National Retreat on Goals, Expectations, and Future Directions of State Nonpoint Source Management Programs. Washington, D.C.

Baker, J.L. 1985. "Sources and Fates of Material Influencing Water Quality in the Agricultural Midwest." Perspectives on Nonpoint Source Pollution, U.S. EPA. EPA/440/5-85/001. Washington, D.C.

Barnes, J.M. 1976. "Hazards to People." In D.L. Gunn and J.G.R. Stevens (eds.) Pesticides and Human Welfare. Oxford: Oxford University Press.

Batie, S.S., and P.L. Diebel. 1989. "Managing Agricultural Contamination of Groundwater: State Strategies." Unpublished manuscript. Blacksburg, Virginia: Department of Economics, Virginia Polytechnic Institute and State University.

Batie, Sandra, Leonard Shabman, and Randall Kramer. 1986. "U.S. Agriculture and Natural Resource Policy: Past and Future." In C.F. Runge (ed.) The Future of the North American Granary: Politics, Economics, and Resource Constraints in North American Agriculture. Ames, Iowa: Iowa State University Press.

Baumol, William J., and Wallace E. Oates. 1971. "The Use of Standards and Prices for Protection of the Environment." Swedish Journal of Economics 73:42-54.

____________. 1988. The Theory of Environmental Policy. 2nd ed. New York: Cambridge University Press.

Belsie, Laurent. 1987. "Iowa ready to get tough on groundwater contamination." Christian Science Monitor. March 23.

Blackmer, A.M. 1984. "Losses of Fertilizer-N from Soils." In Proceedings from Iowa's 37th Annual Fertilizer and Ag-Chemical Dealers Conference. CE-2081. Ames: Iowa State University, Cooperative Extension Service.

__________. 1985. "Integrated Studies of N Transformations in Soils and Corn Responses to Fertilizer-N." In Proceedings from Iowa's 38th Annual Fertilizer and Ag-Chemical Dealers Conference. CE-2158. Ames: Iowa State University, Cooperative Extension Service.

Blair, A., and T.L. Thomas. 1979. "Leukemia Among Nebraska Farmers: A Death Certificate Study." American Journal of Epidemiology 110:264-73.

Bosso, C.J. 1987. Pesticides and Politics: The Life Cycle of a Public Issue. Pittsburgh: University of Pittsburgh Press.

Box, George E.P., and N. R. Draper. 1987. Empirical Model-Building and Response Surfaces. New York: John Wiley and Sons.

Buiesching, D. 1986. A Study of Cancer Deaths Among Illinois Farmers Through Death Certificates. Champaign-Urbana: University of Illinois.

Burmeister, L.F., G.D. Everett, S.F. Van Lier and P. Isacson. 1983. "Selected Cancer Mortality and Farm Practices in Iowa." American Journal of Epidemiology 118:72-77.

Burton, Robert O. 1982. Reduced Herbicide Availability: An Analysis of the Economic Impacts on U.S. Agriculture. Ph.D. Dissertation. West Lafayette, Indiana: Purdue University.

Cantor, K.P. 1982. "Farming and Mortality from Non-Hodgkins Lymphoma: A Case Control Study." International Journal of Cancer 29:239-247.

Carson, Rachel. 1962. Silent Spring. Boston, Mass.: Houghton Mifflin Co.

Choi, E.K., and S.R. Johnson. 1987. "Regulating Uncertain Externalities in An Open Economy." Draft manuscript. Ames: Iowa State University.

Cochran, William G., and G. M. Cox. 1957. Experimental Designs. New York: John Wiley and Sons.

Cohen, Stuart. 1987. "Agricultural Chemicals and Ground Water: Developing a National Strategy." Paper Presented at the Institute for Agriculture Ground Water Symposium. Washington, D.C. March 4.

Cohen, S.Z., C. Eiden, and M.N. Lorber. 1986. "Monitoring Ground Water for Pesticides." In W. Garner, R.C. Honeycutt, and H.N. Nigg (eds.) Evaluation of Pesticides in Ground Water. ACS Symposium Series 315. Washington, D.C.: American Chemical Society.

Cohen, S.Z., S.M. Creeger, R.F. Carsel and C.G. Enfield. 1984. "Potential Pesticide Contamination of Groundwater from Agricultural Uses." In R.F. Krueger and J.N. Seiber (eds.) Treatment and Disposal of Pesticide Wastes. Washington, D.C.: American Chemical Society.

Comprehensive Environmental Pesticide Policy Evaluation System (CEPPES) Documentation. 1988. Ames: Center for Agricultural and Rural Development, Iowa State University.

The Conservation Foundation (CF). 1987. Groundwater Protection. Washington, D.C.: The Conservation Foundation.

____________. 1984. State of the Environment: 1984. Washington, D.C.: The Conservation Foundation.

Copeland, Claudia, and Jeffrey A. Zinn. 1986. "Agricultural Nonpoint Pollution Policy: A Federal Perspective." Congressional Research Service 86-191 ENR. Washington, D.C.: Library of Congress.

Council for Agricultural Science and Technology (CAST). 1980. Social and Economic Impacts of Restricting Pesticide Use in Agriculture. Report No. 86. Ames, Iowa: CAST.

__________. 1985. Agriculture and Groundwater Quality. Report No. 103. Ames, Iowa.

Crocker, Thomas. 1984. "Scientific Truths and Policy Truths in Acid Deposition." Economic Perspectives on Acid Deposition Control (T. Crocker, ed.). Boston: Butterworth, pp. 65-80.

Davis, Joseph A. 1987a. "Pesticide Law Overhaul: Back to Square One?" Congressional Quarterly Weekly Report 45(8).

____________. 1987b. "States' Rights vs. National Regulations: Modern Variations on a Familiar Theme." Congressional Quarterly Weekly Report 45(8).

DeCoursey, Donn G. 1985. "Mathematical Models for Nonpoint Water Pollution Control." Journal of Soil and Water Conservation (Sept.-Oct.):408-13.

Detroy, Mark. 1986. "Area and Vertical Distribution of Non-Point Pollutants in the Iowa River Alluvial Aquifer, Iowa County, Iowa." Paper presented at the National Water Works Association Agricultural Impacts on Ground Water Conference, Omaha, Nebraska.

Duffy, Michael. 1982. Pesticide Use and Practices, 1982. Economic Research Service, Ag. Information Bulletin #426. Washington, D.C.: U.S. Department of Agriculture.

Duffy, Michael, and Greg Traxler. 1987. "Institutions and Their Effect on Agricultural Chemical Policies." Draft Manuscript. Ames, Iowa: Iowa State University.

Durenburger, David. 1986. "Groundwater Policy: A Need for Federal Participation." Forum for Applied Research and Public Policy 1(1):79-86.

Dycus, J.S. 1984. "Development of a National Groundwater Protection Policy." Boston College Environmental Law Review 11:211.

Edwards, W.F., and Max R. Langham. 1976. "Public Welfare in Relation to Alternative Pesticide Policies." Journal of Environmental Economics and Management 3:295-308.

Ericksen, Milton H. 1976. Use of Land Reserves to Control Agricultural Production. Economic Research Service ERS-635. Washington, D.C.: U.S. Department of Agriculture.

Fawcett, Richard S. 1986. "Overview of Pest Management for Conservation Tillage Systems." Unpublished manuscript. Ames: Iowa State University.

Feliciano, Donald V. 1986. Agricultural Effects on Ground Water Quality. Congressional Research Service 86-891 ENR. Washington, D.C.: Library of Congress.

Ferguson, Walter L. 1985. Pesticide Use on Selected Crops: Aggregated Data, 1977-80. ERS Ag. Information Bulletin #494. Washington, D.C.: U.S. Department of Agriculture.

Food and Agricultural Policy Research Institute (FAPRI). 1986. The Food Security Act of 1985 One Year Later: Implications and Persistent Problems. FAPRI Staff Report #3-86. Ames: Iowa State University.

Fruhling, Larry. 1986. "Water in Iowa Tainted by Farming Chemicals: The Ugly Side of a Bountiful Harvest." The Des Moines Register. May 4.

Gardner, B.L. 1987. "Causes of U.S. Farm Commodity Programs." Journal of Political Economy 95:290-310.

Gianessi, L.P. 1986. A National Pesticide Usage Data Base. Washington, D.C.: Resources for the Future.

Gorelick, S.M. 1983. "A Review of Distributed Parameter Groundwater Management Modeling Methods." Water Resources Research 19(2):305-19.

Greene, Catherine R., R.A. Reamer, G.W. Norton, E.G. Rajotte, and Robert M. McPherson. 1985. "An Economic Analysis of Soybean Integrated Pest Management." American Journal of Agricultural Economics 67(3):567-72.

Griffin, Ronald C., and Daniel W. Bromley. 1982. "Agricultural Runoff as a Nonpoint Externality: A Theoretical Development." American Journal of Agricultural Economics 64(3):547-52.

Hallberg, G.R. 1985. "Agricultural Chemical and Groundwater Quality in Iowa: Status Report 1985." In Proceedings from Iowa's 38th Annual Fertilizer and Ag-Chemical Dealers Conference. CE-2158. Ames: Iowa State University, Cooperative Extension Service.

__________. 1986a. " Nitrates in Groundwater in Iowa." In Proceedings from Iowa's 39th Fertilizer and Chemical Association Conference.

__________. 1986b. Agrichemicals and Water Quality. Colloquium on Agrichemical Management and Water Quality. Washington, D.C.: National Academy Press.

__________. 1986c. "From Hoes to Herbicides: Agriculture and Groundwater Quality." Journal of Soil and Water Conservation 41(6):357-64.

Hallenbeck, William H., and Kathleen M. Cunningham-Burns. 1985. Pesticides and Human Health. New York: Springer-Verlag.

Halstead, John. 1987. "Managing Risk and Uncertainty in Agricultural Non-Point Source Contamination of Groundwater: Sources and Solutions." Draft manuscript. Blacksburg, Virginia: Virginia Polytechnic Institute.

Headley, J.C., and J.N. Lewis. 1967. The Pesticide Problem: An Economic Approach to Public Policy. Baltimore: The Johns Hopkins University Press.

Hoag, Dana, and Andy Manale. 1990. "Comparing Risks of Corn Rootworm Insecticides Through Groundwater, Surface Water, and Air Contamination." Presented at the Symposium on Communicating Scientific Models to Users, Denver, Colorado.

Holden, Patrick W. 1986. Pesticides and Groundwater Quality: Issues and Problems in Four States. Washington, D.C.: National Academy Press.

Johnson, L., and R. Splinter. 1983. Pesticides in Iowa Rivers. Iowa City, Iowa: University of Iowa, Hygienic Laboratory.

Johnson, S.R. 1987. "Midwest Use of Pesticides and Changing Agricultural Needs." Presented at Pesticides and Groundwater: A Health Concern for the Midwest Conference. St. Paul, Minnesota.

Kelley, R.D., G.R. Hallberg, L.G. Johnson, R.D. Libra, C.A. Thompson, R.C. Splinter and M.G. DeTroy. 1986. "Pesticides in Ground Water in Iowa." Presented at the National Water Works Association Agricultural Impacts on Ground Water Conference, Omaha, Nebraska.

Kramer, R.A., W.T. McSweeny, W.R. Kerns, and R.W. Stavros. 1984. "An Evaluation of Alternative Policies for Controlling Agricultural Nonpoint Source Pollution." Water Resources Bulletin 2(6):841-46.

MacIntyre, A.A. 1987. "Why Pesticides Received Extensive Use in America: A Political Economy of Agricultural and Pest Management to 1970." Natural Resources Journal 27:533-77.

McGartland, Al. 1986. "The Use of Pesticides in U.S. Agriculture: A Comprehensive Analysis of Benefits and Costs." Unpublished manuscript. Washington, D.C.: Environmental Protection Agency.

Milon, J. Walter. 1986. "Optimizing Nonpoint Source Controls in Water Quality Regulations." Unpublished manuscript.

Miranowski, John A. 1980. "Estimating the Relationship Between Pest Management and Energy Prices, and the Implications for Environmental Damage." American Journal of Agricultural Economics 62(5):995-1000.

Miranowski, John A., Ulrich F.W. Ernst, and Francis H. Cummings. 1974. Crop Insurance and Information Services to Control Use of Pesticides. EPA/600/5-74/018. Washington, D.C.: Environmental Protection Agency.

National Governors' Association (NGA). 1989. Agriculture and Water Quality. Washington, D.C.

National Research Council (NRC). 1980. Regulating Pesticides. Washington, D.C.: National Academy of Sciences.

National Science Foundation (NSF). 1983. Workshop on Groundwater Resources and Contamination in the United States (Summary and Papers). Washington, D.C.: NSF.

Nielsen, Elizabeth G., and Linda K. Lee. 1986. "The Magnitude and Costs of Groundwater Contamination from Agricultural Chemicals: A National Perspective." Paper presented at the American Agricultural Economics Association Meetings, Reno, Nevada. July 27-30.

Office of Technology Assessment (OTA). 1984. Protecting the Nation's Groundwater from Contamination. OTA-O-233. Vol. I and II. Washington, D.C.: U.S. Congress.

O'Hare, M., D. Curry, S. Atkinson, S. Lee, and L. Canter. 1985. Contamination of Ground Water in the Contiguous United States from Usage of Agricultural Chemicals. Norman, Oklahoma: Environmental and Ground Water Institute.

Pimentel, David, and Lois Levitan. 1986. "Pesticides: Amounts Applied and Amounts Reaching Pests." BioScience 36(2):86-91.

Pimentel, D., D. Andow, R. Dyson-Hudson, D. Gallahan, S. Jacobson, M. Irish, S. Kroop, A. Moss, I. Schreiner, M. Shepard, T. Thompson, and B. Vinzant. 1980. "Environmental and Social Costs of Pesticides: A Preliminary Assessment." Oikos 34:126-40.

Pope, Rulon. 1982. "Empirical Estimation and the Use of Risk Preferences: An Appraisal of Estimation Methods That Use Actual Economic Decisions." American Journal of Agricultural Economics 64(2):376-83.

Pye, Veronica I., and Ruth Patrick. 1983. "Ground Water Contamination in the United States." Science 221(August):713-18.

Rajagopal, R. 1984. Groundwater Quality Assessment for Public Policy in Iowa. Chicago: The Joyce Foundation.

Raucher, Robert L. 1986. "The Benefits and Costs of Policies Related to Groundwater Contamination." Land Economics 62(1):33-45.

Rausser, G.C. 1990. "The Evolution and Coordination of U.S. Commodity and Resource Policies." In R.E. Just and N. Bockstael (eds.) Commodity and Resource Policies in Agricultural Systems. New York: Springer-Verlag.

Reichelderfer, K., and M.K. Hinkle. 1989. "Environmental Interests and Agriculture: The Evolution of Pesticide Policy." In C.S. Kramer (ed.) Political Economy of U.S. Agriculture: Challenges for the 1990s. Washington, D.C.: Resources for the Future.

Reichelderfer, K., and T.T. Phipps. 1988. Agricultural Policy and Environmental Quality. A Briefing Book issued in conjunction with a briefing. Washington, D.C.: National Center for Food and Agricultural Policy, Resources for the Future.

Sharp, Basil M.H., and Daniel W. Bromley. 1979. "Agricultural Pollution: The Economics of Coordination." American Journal of Agricultural Economics 61(4):591-600.

Shogren, Jason. 1990a. "A Primer on Environmental Risk Analysis." CARD Staff Report 90-SR 46. Ames, Iowa: Center for Agricultural and Rural Development. Iowa State University.

___________. 1990b. "The Impact of Self-Protection and Self-Insurance on Individual Response to Risk." Journal of Risk and Uncertainty (forthcoming).

Shogren, Jason, and Thomas Crocker. 1990a. "Risk, Self-Protection, and Ex Ante Economic Value." Journal of Environmental Economics and Management (forthcoming).

___________. 1990b. "Adaptation and the Option Value of Uncertain Environmental Assets." Ecological Economics (forthcoming).

Shortle, J., and J. Dunn. 1986. "The Relative Efficiency of Agricultural Source Water Pollution Control Policies." American Journal of Agricultural Economics 68(3).

Soren, Julian, and W. G. Stelz. 1985. "Groundwater Contamination by Aldicarb Pesticide in Eastern Suffolk County, Long Island." In Perspectives on Nonpoint Source Pollution. Washington, D.C.: U.S. EPA.

Svetlosanov, V., and W.G. Knisel (eds.). 1982. European and United States Case Studies in Application of the CREAMS Model. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Taylor, C.R. 1980. "The Nature of Benefits and Costs of Use of Pest Control Methods." American Journal of Agricultural Economics 62(5):1007-11.

Taylor, C. Robert, and Klaus K. Frohberg. 1977. "The Welfare Effects of Erosion Controls, Banning Pesticides, and Limiting Fertilizer Application in the Corn Belt." American Journal of Agricultural Economics 59(1):25-36.

United States Department of Agriculture (USDA). 1985. Pesticide Assessment of Field Corn and Soybean: Corn Belt States. Washington, D.C.: Economic Research Service.

United States Environmental Protection Agency (U.S. EPA). 1986a. Agricultural Chemicals in Ground Water Strategy: Problem Statement. Briefing paper prepared by EPA Workgroup on Agricultural Chemicals in Ground Water.

__________. 1986b. Pesticides in Ground Water: Background Document. Washington, D.C.: Office of Ground-Water Protection.

United States Geological Survey (USGS). 1983. National Water Summary 1983--Hydrogeologic Events and Issues. Water-Supply Paper 2250. Washington, D.C.: United States Geological Survey.

Wintersteen, W., and R. Harztler. 1987. 1985 Iowa Pesticide Use Survey. Ames: Iowa State University. Cooperative Extension Service.

Wise, S.J., and S. Johnson. 1990. "A Comparative Analysis of State Regulations for Use of Agricultural Chemicals." In R.E. Just and N. Bockstael (eds.) Commodity and Resource Policies in Agricultural Systems. New York: Springer-Verlag.

__________. 1989. "State Initiatives in Pesticide/Groundwater Contamination Policies." Paper presented at the 1989 International Winter Meeting of the American Society of Agricultural Engineers, New Orleans, Louisiana. December 12.

Young, M.D. 1988. "The Integration of Agricultural and Environmental Policies." Presented at the 18th European Seminar of Agricultural Economists on Economic Aspects of Environmental Regulations, Copenhagen, Denmark. November 1-4.