AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

*The World's Largest Open Access Agricultural & Applied Economics Digital Library*

**This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.**

**Help ensure our sustainability.**

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

*Journal of Agricultural and Applied Economics,* 29,1(July 1997):77–86
© 1997 Southern Agricultural Economics Association

# Development of Environmental Indicators for Use in Macroeconomic Models

**Robert L. Kellogg and Don W. Goss**

ABSTRACT

In the fields of agriculture and resource economics, good economics is predicated by good science. By partnering more with physical scientists, economists will be better able to provide the broad policy-making community with practical recommendations for addressing resource issues. An example of collaboration is presented for the development of environmental indicators of the potential risk to the environment of the loss of pesticides from farm fields, which will be used by economists to adjust conventionally measured agricultural output for water quality impacts associated with agricultural production.

**Key Words:** environmental indicators, multidisciplinary research, pesticide leaching, pesticide runoff.

We are interested today in discussing how to conduct research on economic issues that are inherently multidisciplinary in nature. The persistent demand for multidisciplinary research and analysis comes directly from the policy-making community. Every day, policy decisions are made at the local, state, and national levels that affect our natural resources and, *at the same time,* have an impact on some segment of our economy. This broad policy-making community is looking for pragmatic advice on actions to take—and actions not to take—when addressing issues. These decision makers work in the real world where details in both science and economics are critical. Whether or not a private landowner's activity should be regulated depends critically on the extent to which those activities produce undesirable externalities, *and* the extent to which the regulation has an adverse economic impact on producers, which ultimately is a cost also borne by the consumer. Decision makers are aware that solving an environmental problem can sometimes create a more serious economic problem. Their challenge is to promulgate policies that balance environmental protection with economic activity to improve the overall well-being of local communities and society as a whole.

Consequently, physical and biological scientists and economists need to collaborate on most, if not all, empirical applications of models to support the broad policy-making community on natural resource issues. If the scientific component is too generalized, the economic implications of the research likely will not be correct. In these real-world applications, good economics is predicated by good

---

Robert L. Kellogg is a natural resource policy analyst with the Natural Resources Conservation Service, U.S. Department of Agriculture, Washington, DC. Don W. Goss is senior scientist, Texas Agricultural Experiment Station, Temple, Texas.

Colleagues who assisted with the analysis include Richard Nehring, Economic Research Service, USDA; Art Grube, Environmental Protection Agency; Susan Wallace and Steve Plotkin, Natural Resources Conservation Service, USDA; and Joaquin Sanabria, Texas Agricultural Experiment Station. The authors thank Mary Ahearn, Economic Research Service, USDA, for the opportunity to write this paper.

science. Economists pursuing multidisciplinary research, however, frequently find that the readily available (off-the-shelf) knowledge base needed for their applications is inadequate in important ways. The limits of science are often reached very quickly in multidisciplinary research.

The scientist and the economist need to collaborate at the beginning of the research and continue the collaboration through to the end. Economists working in isolation with off-the-shelf information on natural resources not only run the risk of misusing the information, but also miss the opportunity to stimulate scientists to creatively adapt and interpret scientific findings to meet the objectives of the economic research. Working together, the economist and the scientist devise an analytical structure at the appropriate scale, and factor into the models those data and relationships that are critical to simulating or measuring important environmental and economic outcomes. In most cases, both the scientist and the economist face inadequate data, inadequate model development, and inadequate process description. If time and resources permit, additional studies can be carried out to fill the gaps. A critical aspect is defining carefully the limitations imposed on the results by the use of existing information. As a result of involvement throughout the process, the scientist gains perspective on the kinds of additional research that would advance multidisciplinary analysis. In the longer run, the limits of science are pushed back as scientists respond to these information needs.

Our example of collaboration between economist and scientist is in the macroeconomic field. Macroeconomists are interested in expanding their accounting of economic activity to include the production of externalities. Economic Research Service economists recently reported that U.S. agricultural productivity increased at an average annual rate of 1.8% during 1948–93, accounting for virtually all of output growth (Ball and Nehring). However, this measure of productivity does not account for the externality costs associated with agricultural production. It is conceivable that productivity adjusted for externalities for this time period would be lower.

We are working with economists at the Economic Research Service (ERS) and the Environmental Protection Agency (EPA) on a project to measure agricultural productivity nationally and regionally for the period 1960 through 1993. An important aspect of the study is to adjust conventionally measured agricultural output for water quality impacts associated with agricultural production. Environmental indexes are being derived that measure the potential risk to the environment of the loss of pesticides from farm fields through leaching and runoff. Taking our cues from the field of macroeconomics, we devised a measure of environmental indexes that is consistent with the approaches used to measure aggregate economic indexes.

The techniques used in this study on pesticides can be extended to the development of environmental indicators for other agricultural production externalities, such as soil loss, nutrient loss, animal wastes, and even particulate matter in air. To achieve these extensions, scientists need to adapt existing models and, in some cases, national databases will need to be augmented. Economists have a role to play in this process to ensure that the resulting indexes are appropriate for use in economic models.

Although these environmental indicators were tailored for use in a macroeconomic model of agricultural productivity, they have utility for other applications as well. Policy makers can use the indicators to see whether or not agricultural externalities are increasing or decreasing over time, and use that information to judge the performance of past policies and the need for new policies. Economists investigating other questions involving externalities at the macroeconomic level may also find the indicators useful.

## Challenges

In addition to the incorporation of externality costs in the measure of productivity, the ERS is generating output, input, and productivity growth measures by individual states or collections of states. The structure of the economic model thus requires times-series data for environmental indicators at the state level. This requirement created three challenges in deriving suitable environmental indicators.

The first challenge was how to handle the diversity of factors that are important determinants of pesticide losses from farm fields. Pesticide loss depends critically on soil characteristics, climate, and management practices. Soils and climate in some areas allow very little pesticide loss from farm fields, while losses are much larger in other areas. A watershed often will contain a variety of soils, so that losses from farm fields will vary considerably within the watershed. Consequently, the majority of the water quality-related externalities result from production activities in a small portion of the watershed. Science provides an abundance of information about fate and transport of pesticides at the field level and sometimes at the small watershed level, but very little empirical data for large regions because of the diversity of conditions within a region. For example, scientists may have conducted studies on the leaching potential of atrazine on a particular soil and for a particular climate and farm management practice, but sufficient information is not available to make detailed assessments for a broad region where a wide variety of soils and climates exist—which in this case is the domain of interest to the economist. The challenge is made even tougher by the diversity of farm management practices in the region.

The second challenge was how to estimate the indexes using consistent data for all states and years. The index must capture land use changes and chemical use changes. The economic model is very sensitive to changes in the indexes over time and space. It is therefore more important that the indexes be spatially and temporally relative than absolutely correct. To estimate a suitable index, it is necessary to use national-level data collected consistently for all states and years.

The third challenge was to measure externalities in terms of economic value. Ideally, the economic model would weigh the benefits to society of agricultural production (goods) against the costs incurred to society from the polluting outcomes (bads) of those production activities. It is not yet possible to place economic values on the loss of pesticides from farm fields, largely because the human and environmental health impacts are not well known. Moreover, regulations have been in place since the early 1970s that have reduced the worst risks associated with agricultural chemical use. While there may still be environmental and human health impacts associated with today's agricultural pesticide use, they are diffuse and difficult to detect and measure. This challenge was partially met, however, by estimating concentrations of pesticides leaving the farm fields and relating those concentrations to water quality standards set by states and the EPA (or estimates of similar thresholds).

## Analytical Approach

The analytical approach we adopted consisted of a combination of (*a*) field-level assessments of the potential for pesticide loss, and (*b*) national-level databases on soils, land use, chemical use, and climate.

The spatial analytical framework consists of 427 resource polygons formed by the intersection of 204 major land resource areas (MLRAs) and 48 states. MLRAs were defined in 1984 by the Soil Conservation Service to represent areas where climate and soil characteristics are relatively homogeneous for purposes of crop production. Essentially, they are a collection of agro-ecosystems. The boundaries of these MLRAs were adjusted so as to coincide with county boundaries prior to defining the 427 resource polygons. This was necessary to allow county-level data to be included in the estimates.

Not all crops are included in the estimate because of workload constraints. At present, seven crops are considered—corn, soybeans, wheat, cotton, sorghum, barley, and rice. Each crop is additionally defined as either irrigated or nonirrigated. Pesticide losses for irrigated crops can differ significantly from pesticide losses for dryland production. The seven crops used provide a fair representation of pesticide use on cultivated cropland, but exclude pesticide use on fruits, nuts, and vegetables, which can be important in some regions.

### *Field-Level Assessment of Pesticide Loss*

Pesticide losses were estimated for a variety of soils and climates using the chemical fate and transport model GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) (Knisel). GLEAMS is a process model that estimates pesticide leaching and runoff losses using as inputs soil parameters, field characteristics (such as slope and slope length), management practices, pesticide properties, and climate.

GLEAMS leaching and runoff estimates were generated for 243 pesticides applied to 120 specific soils for 20 years of daily weather from each of 55 climate stations distributed throughout the United States. This resulted in 1,603,800 runs of 20 years each, or 32,076,000 years of data. Pesticide runoff was denoted as movement beyond the edge of the field, including both pesticides in solution and pesticides adsorbed to soil material and organic matter. Pesticide leaching was characterized as movement beyond the bottom of the root zone. Separate GLEAMS estimates were made for irrigated and nonirrigated conditions.

For each set of variables, the concentration of the chemical at the bottom of the root zone and at the edge of the field was calculated as the total mass of pesticide loss per year divided by the associated water volume per year, and so represents an "annual" concentration. For runoff, only the dissolved fraction of the pesticide loss was included in the calculation of the concentration. The highest annual concentration obtained over the 20-year simulation was used to calculate the index. Pesticide loss concentrations obtained from the GLEAMS model were normalized so that, when multiplied by the actual application rate (which varies over space and time), the actual pesticide loss concentration could be obtained.

Separate estimates of pesticide loss were made for row crops and close-grown crops. Estimates for row crops were used for corn, cotton, sorghum, and soybeans. Estimates for close-grown crops were used for wheat, rice, and barley.

### *Soils Data*

Soils information was obtained from the National Resources Inventory (NRI). The NRI is a national survey of private land use that is based on about 800,000 sample points, 300,000 of which are on cropland (Kellogg, TeSelle, and Goebel). At each NRI sample point, information is collected on nearly 200 attributes, including land use and cover, cropping history, conservation practices, potential cropland, highly eroding land, water and wind erosion estimates, wetlands, wildlife habitat, vegetative cover conditions, and irrigation. The NRI is linked to a national soils database that includes information on soil texture and organic matter content, which were the soil characteristics used to define the 120 soil groups for which pesticide loss estimates were simulated using GLEAMS. Percentage composition of soil types in each resource polygon was calculated by crop for the two full-inventory time periods—1982 and 1992. The percentage composition for 1982 was applied to 1960–86, and the percentage composition for 1992 was applied to 1987–93.

### *Land Use Time Series*

County data on acres planted for the seven crops are available from the USDA's National Agricultural Statistics Service (NASS) for 1972 to the present, and from the U.S. Department of Commerce's *U.S. Census of Agriculture* data and other sources for earlier years. These data are aggregated to the 427 resource polygons, which are combinations of counties. The percentage of each crop that is irrigated in each resource polygon is derived from the NRI.

### *Pesticide Use Time Series*

The Doane Pesticide Profile Study provided a database of application rates and percentage of acres treated by chemical, crop, and year for 1987–93 for the U.S. as a whole and broken down into seven agricultural production regions. For 1960–86, the Doane pesticide use data and NASS chemical use surveys for selected years were used to generate similar estimates. Approximately 250 pesticides were included. Because of the lack of data for some years and crops, interpolation procedures were used to fill gaps in the 1960–86 series. Pesticide use parameters for all years are established for each of seven Doane reporting regions. Values for these seven regions are imputed to the 427 resource polygons according to the share of acres planted in each resource polygon.

### *Estimation of Environmental Risk*

Environmental risk was estimated using threshold exceedance units (TEUs). Threshold concentrations used for each chemical correspond to the maximum safe level for human chronic exposure in drinking water. Where available, water quality standards were used. For other pesticides, estimates of the maximum safe level were made from published toxicity data. For each chemical used on each crop and soil type in each resource polygon, the per acre pesticide loss concentration was calculated and then divided by the threshold concentration. Where the threshold concentration was exceeded, the ratio was multiplied by the acres represented by the crop to obtain estimates of TEUs. TEUs per state were obtained by summing TEUs over chemicals, crops, soil type, and resource polygons in each state. This procedure was repeated for each year in the time series to produce a spatial-temporal environmental indicator. Separate indicators were constructed for pesticides in leachate and pesticides dissolved in runoff.

### *Model for Estimating Indicators*

The following algorithm was used to derive TEUs for each crop (*C*) in each resource polygon (*R*) for each year (*Y*).

$$TEU_{Y,R,C} = \Sigma_{S=soils}\,\Sigma_{P=pesticides}\,[Exceedance\ per\ Acre\ Treated_{Y,R,C,S,P} \times Acres\ Treated_{Y,R,C,S,P}];$$

$$Exceedance\ per\ Acre\ Treated = [(RELCONC \times APPRATE \div THRESHCONC)] - 1,$$

negative values discarded;

$$Acres\ Treated = ACRES \times PCTTREATED \times PCTSOIL,$$

where *RELCONC* is the relative concentration of maximum potential pesticide loss per acre for a specific chemical on a specific soil type; *APPRATE* is the application rate for a specific chemical; *THRESHCONC* is the threshold concentration above which the pesticide loss concentration is defined to be "unsafe" for chronic exposure to humans, specific to each chemical; *ACRES* denotes the acres of crop in the resource polygon; *PCTTREATED* is the percentage of acres treated with a specific chemical; and *PCTSOIL* is the percentage of resource polygon with a specific soil type.

## A Preliminary Look at the Indexes

This work is still in progress, and so final results are not yet available. Results from preliminary analyses will be presented to demonstrate the nature and utility of the forthcoming environmental indicators.

### *Spatial Distribution*

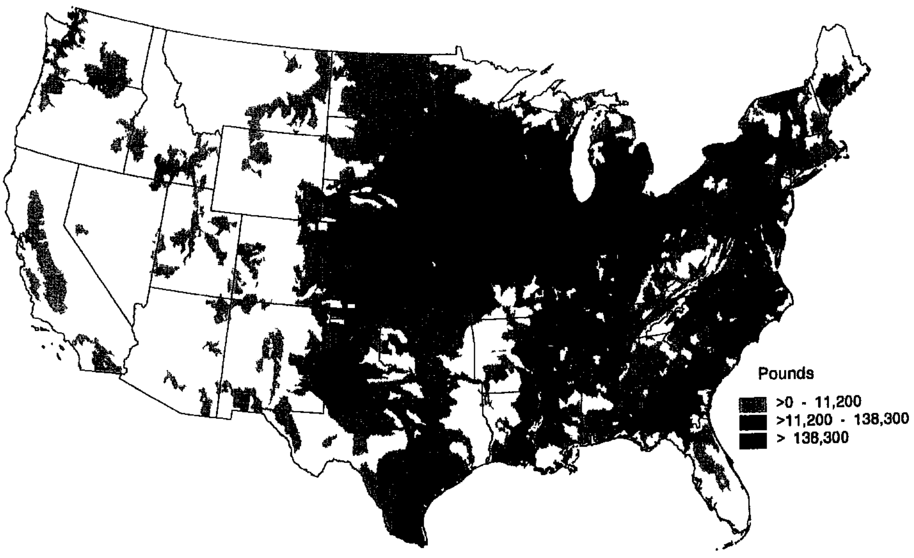
The spatial distribution embodied in the environmental indicators is illustrated by estimating threshold exceedance units (TEUs) for two pesticides—atrazine and metolachlor—by watershed using the NRI as a modeling framework. For this simulation, each NRI sample point is treated as a "representative field." The statistical weights associated with the NRI sample points are used as a measure of how many acres each "representative field" represents. Estimates of percentage of acres treated and application rate made by Gianessi and Anderson are imputed onto the NRI sample points by crop and state. Pesticide loss estimates from GLEAMS were imputed onto NRI sample points according to soil type, geographic location, and chemical. At each sample point, the pesticide concentration was divided by the EPA's maximum contaminant level (MCL) for atrazine (3 ppb), and the EPA's health advisory (HA) for metolachlor (70 ppb). TEUs per watershed were calculated by multiplying the concentration-threshold ratio by the number of acres represented by the sample point (expansion factors), and then summing over the sample points in the watershed. Only sample points where the threshold was exceeded were included in the summation. Prior to the calculation, the acres represented by the sample point were multiplied by the percentage of acres treated for that chemical, using data from Gianessi and Anderson. (This procedure is applicable only for a single point in time—1992—and so cannot be used to generate time-series estimates.)

The spatial distribution of atrazine risk to water quality is illustrated in figures 1 and 2. Figure 1 shows the pounds of atrazine applied per watershed to provide a perspective on where atrazine is used. Figure 2 shows how the watersheds rank according to the *potential* for pesticide concentrations leaving the bottom of the root zone to exceed the EPA's contamination threshold, weighted by the number of acres in the watershed where the potential for exceedance might occur. Watersheds in the highest category are more likely than other watersheds to have contaminated groundwater from pesticide residues originating from farm fields. Watersheds in the second highest category have less likelihood of contamination than watersheds in the highest category, but more likelihood than watersheds in lower categories, and so on. The atrazine leaching map (figure 2) shows, for example, that watersheds in Nebraska and Illinois generally have a greater likelihood of atrazine contamination of water leaching from the field than most of the watersheds in Iowa.

Figures 3 and 4 show similar results for metolachlor. Comparing atrazine TEUs to metolachlor TEUs shows that, although the spatial distribution of quantities used is similar, the potential for atrazine to cause unacceptable contamination is much greater. This finding closely corresponds to water quality monitoring results. This is an important feature of the environmental indicators under development. Current methods based on pounds used would measure externalities associated with atrazine and metolachlor about the same. It is clear from these graphics that externalities associated with metolachlor use are far less than those associated with atrazine use. The environmental indicators under development are adjusted for these differences in risk among all the pesticides used.

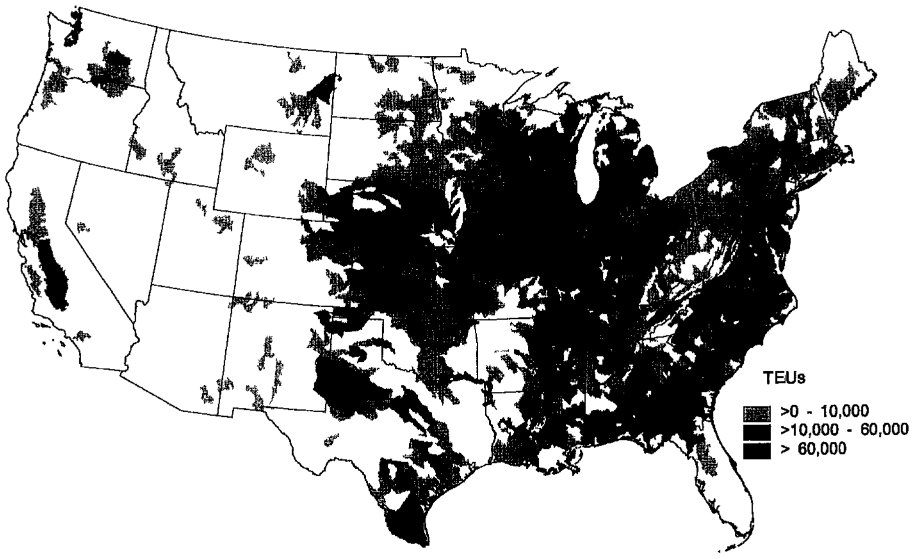
These maps do not show which watersheds are likely to have contaminated drinking water. Other factors need to be taken into account to assess the potential for contamination of drinking water, such as the depth to groundwater, characteristics of the vadose zone, microbial activity after leaving the field, and the amount of groundwater originating from portions of the watershed where no chemicals are applied. For example, aquifers in some of the areas in the highest category for leaching could be protected by impervious layers between the root zone and the aquifer. In other areas, concentrations in water originating from farm fields are diluted by uncontaminated water originating from noncropland areas. Data on these additional factors do not exist for all areas of the country at this time, and so it is not possible to include these factors in the index.

The environmental indicators presently under development will produce spatial distributions of risk similar to those shown here for atrazine and metolachlor. Separate indexes are being developed for surface runoff and for leaching. The basis for the calculation is 427 resource polygons, rather than NRI sample points, and results are aggregated over all the pesticides used. The indexes are thus constructed to facilitate comparisons from one region of the country to another.



*Source:* USDA, Natural Resources Conservation Service, Washington DC, December 1996.

**Figure 1.** Pounds of atrazine applied to corn and sorghum by watershed



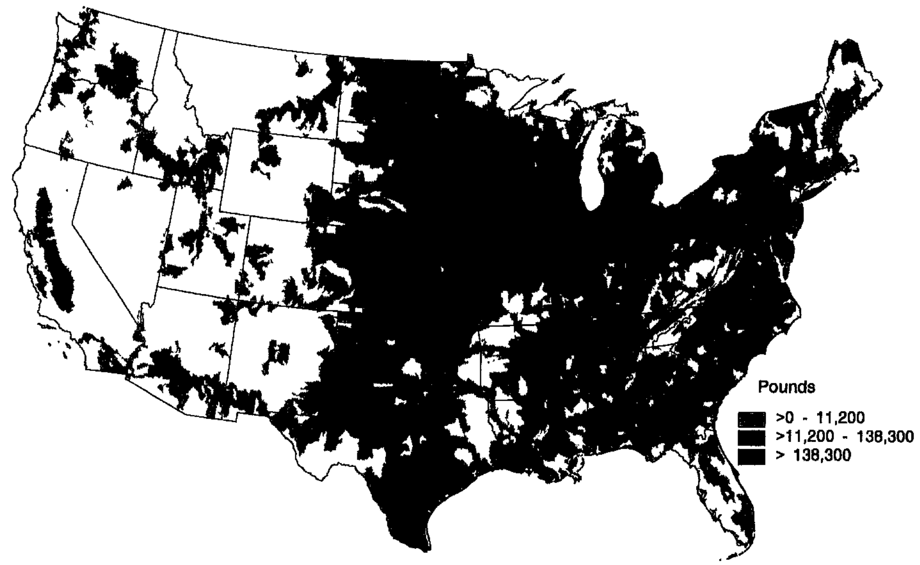
*Source:* USDA, Natural Resources Conservation Service, Washington DC, December 1996.

**Figure 2.** Potential for concentration of atrazine leaching below the root zone to exceed EPA's MCL (3 ppb) (based on atrazine use on corn and sorghum)

### *Temporal Distribution*

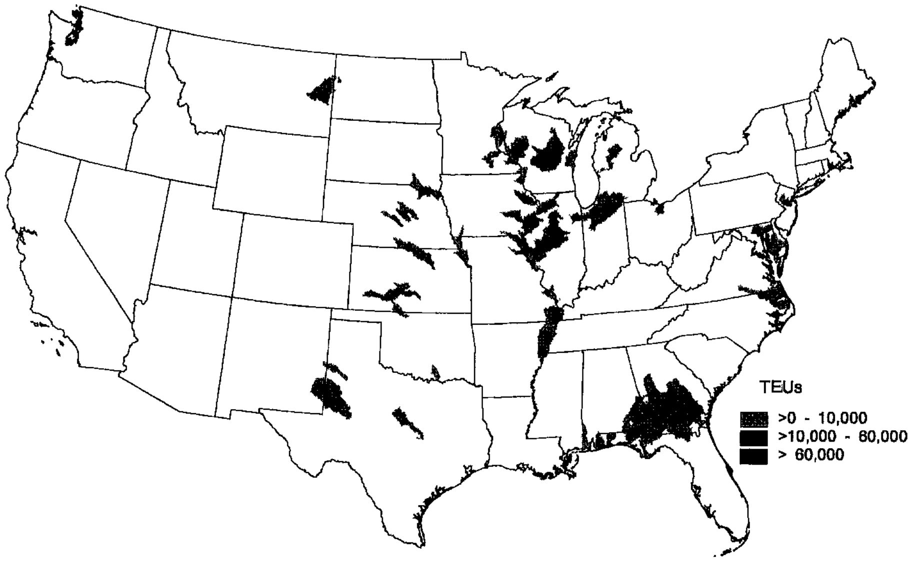
The temporal distribution embodied in the environmental indicators can be illustrated using preliminary results from an ongoing study by Kellogg, Nehring, and Grube. Environmental indexes similar to those described above were generated for 1972–94, except that they were based on the quantity of pesticides used, measured by acre-treatments, rather than on TEUs.

Figure 5 shows the temporal trends in the pesticide leaching index. The potential for pes-



*Source:* USDA, Natural Resources Conservation Service, Washington DC, December 1996.

**Figure 3.** Pounds of metolachlor applied to corn, cotton, peanuts, potatoes, sorghum, and soybeans by watershed



*Source:* USDA, Natural Resources Conservation Service, Washington DC, December 1996.

**Figure 4.** Potential for concentration of metolachlor leaching below the root zone to exceed EPA's HA level (70 ppb) (based on metolachlor use on corn, cotton, peanuts, potatoes, sorghum, and soybeans)

ticide leaching losses from farm fields increases through the 1970s, but levels off and actually decreases somewhat throughout the 1980s, and then increases again in the early 1990s. Figure 6 shows the temporal trends in the pesticide runoff index. The potential for pesticide runoff losses generally increased throughout the 23-year period, except for a

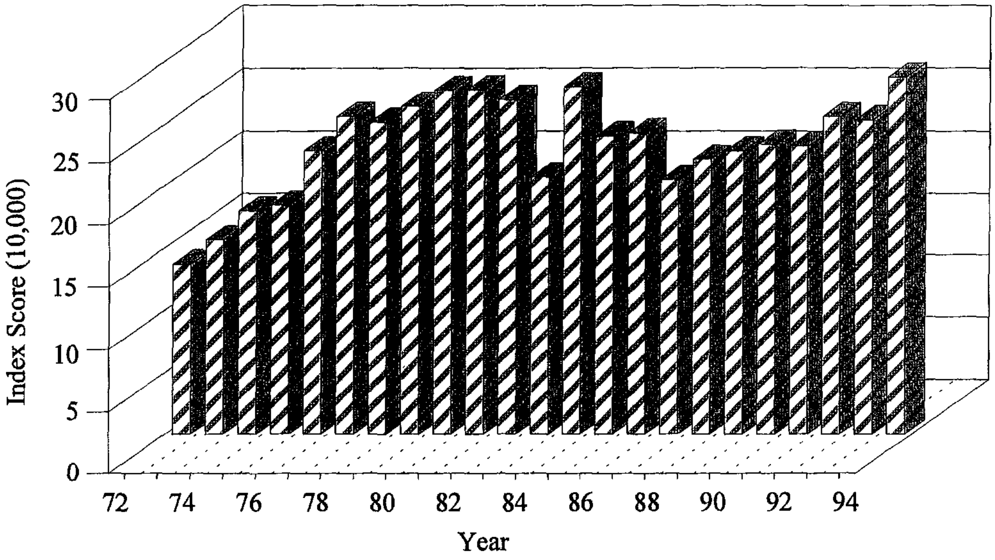


**Figure 5.** Pesticide leaching index for U.S., 1972–94

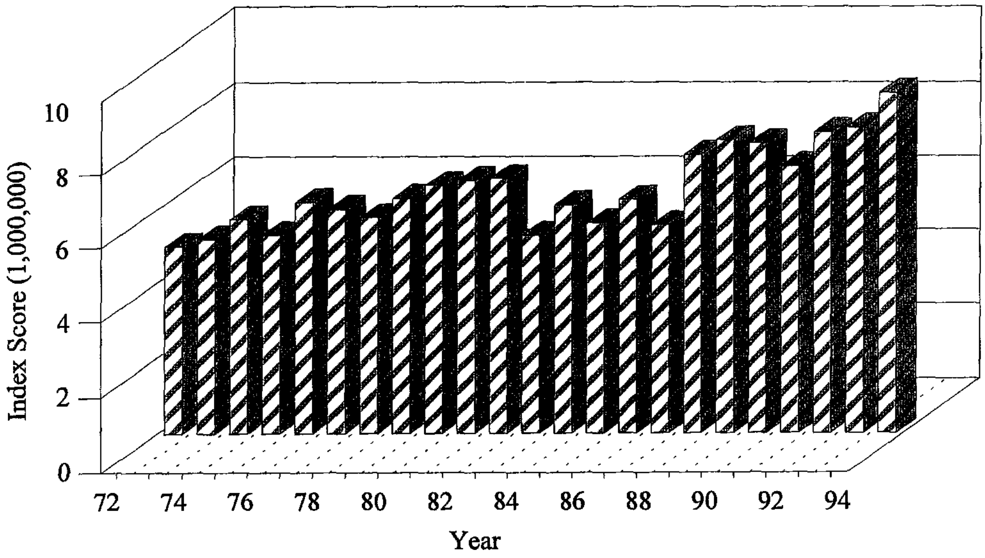


**Figure 6.** Pesticide runoff index for U.S., 1972–94

five-year period from 1983 through 1987, when index scores were markedly lower.

Trends shown here are for the entire nation. We have shown in other work that these trends can be quite different for specific regions of the country. The indexes being prepared for use in the economic model are for individual states, which will capture the regional differences in trends over time.

## Concluding Remarks

To successfully conduct multidisciplinary research, a teamwork approach is required where both scientists and economists work together to make the best use of existing information. Typically, the economist formulates the question by proposing a model to address a natural resource issue that is of concern to decision makers. The interaction usually begins with the scientist telling the economist that sufficient information does not exist to appropriately characterize the natural resource components of the model. Through discussion, the scientist gains perspective on the degree of accuracy required to obtain useful results from the model. The economist gains perspective on what is known and not known about the noneconomic features of the model, and makes the necessary adjustments to the model structure. At the end of the process, the results can be presented with a list of caveats so that the policy recommendations stemming from the research are reasonable and soundly based on what is known.

The collaborative effort we engaged in evolved in this manner, although the basic requirements of the economic model were, for the most part, previously set by accepted procedures for estimating productivity. The following recommendations for conducting successful multidisciplinary research stem from our experience:

- Develop full partnerships between economists and scientists who are interested in multidisciplinary research.
- Engage scientists as early in the study as possible.
- Conduct brainstorming sessions with both economists and scientists present so that scientists can better understand the information requirements of the model and how the results will be used, and so economists can better understand where the limits of science constrain economic models.
- Allow time for the scientists to adapt existing information/models or develop new information/models that are tailored to the specific objectives of the economic model.
- Keep track of the caveats that are identified as the analysis is developed so that the limitations in the application of the results to policy issues are well understood.

## References

Ball, E., and R. Nehring. "Productivity: Agriculture's Engine of Growth." In *Agricultural Outlook,* pp. 25–28. USDA, Economic Research Service, Washington DC, May 1996.

Gianessi, L.P., and J.E. Anderson. "Pesticide Use in U.S. Crop Production: National Data Report." National Center for Food and Agricultural Policy, Washington DC, February 1995.

Kellogg, R.L., R. Nehring, and A. Grube. "Spatial and Temporal Trends in the Potential for Agrichemicals to Leach." Poster presented at the 50th annual meeting of the Soil and Water Conservation Society, Des Moines IA, 6–9 August 1995.

Kellogg, R.L., G.W. TeSelle, and J.J. Goebel. "Highlights from the 1992 National Resources Inventory." *J. Soil and Water Conserv.* 49(1994):521–27.

Knisel, W.G., ed. *GLEAMS: Groundwater Loading Effects of Agricultural Management Systems,* Version 2.10. Pub. No. 5, Biological and Agr. Engineering Dept., University of Georgia/Coastal Plain Exp. Sta., Tifton, 1993.