United States
Environmental Protection
Agency

Environmental Research
Laboratory
Athens, GA 30605-2720

Research and Development

EPA/600/S-93/010 February 1994

EPA

ENVIRONMENTAL RESEARCH BRIEF

PATRIOT–A Methodology and Decision Support System for Evaluating the Leaching Potential of Pesticides

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Abstract

The Pesticide Assessment Tool for Rating Investigations of Transport (PATRIOT) is a methodology for providing rapid analyses of groundwater vulnerability to pesticides on a regional, state, or local level. An appropriate measure of groundwater vulnerability is achieved by quantifying the leaching potential of a pesticide in terms of the mass transported to the top of the water table. The PATRIOT software package integrates, in a personal computer environment, a tool that enables scientifically sound analysis of pesticide leaching potential with the data needed to use the tool for area-specific analyses anywhere in the conterminous United States. PATRIOT is comprised of (i) a chemical fate and transport model (PRZM-2), (ii) a comprehensive database, (iii) an interface that allows the user to explore the database and select the data appropriate to characterize local environmental factors and pesticide application scenarios, (iv) a directed sequence of interaction that guides the user in providing all the necessary information to perform alternative model analyses, and (v) effective, user-selected methods of summarizing and visualizing model results.

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Introduction

One of the most pressing concerns in agrichemical management today, particularly in agricultural areas, is protecting our nation's groundwater supplies from invasion by pesticides. The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) provides state governments with a strong mandate to develop pesticide management plans. In order to make sound decisions, environmental managers at the federal, state, and local levels need to understand the potential for pesticides to leach from application sites through the underlying soil's unsaturated zone and into the groundwater. Pesticide leaching is highly site-specific, and predicting the expected extent of leaching is not a simple task. The tendency to leach to groundwater is determined by the combined factors of climate, pesticide chemodynamics, soil properties, agricultural practices, and depth to groundwater. Accurate estimation of leaching potential requires analysis techniques that consider all of these factors.

The EPA Office of Science, Planning and Regulatory Evaluation has initiated a research program to develop information systems for use in preventing or minimizing groundwater contamination by pesticides. The purpose of this program is to provide practical tools, with a strong scientific base, to state agencies in order to support the development of local pesticide management plans as mandated by FIFRA and implemented by the EPA Office of Pesticide Programs.

PATRIOT integrates existing technologies and hydrogeologic information into a framework for risk assessment and management of agricultural pesticides. The system enables state and local decision makers to rapidly analyze information about pesticides, soils, and other relevant factors in order to make sound recommendations about pesticide use that will protect groundwater quality. Data investigations and model analyses can be evaluated within state, county, U.S. Department of Agriculture Major Land Resource Area, or U.S. Geological Survey Hydrologic Cataloging Unit boundaries.

The primary users of PATRIOT are expected to be state personnel charged with developing local pesticide management plans. An additional user community will reside within EPA Headquarters and Regional Offices, where the tool will aid those involved in evaluating specific pesticides or pesticide management plans. Although data analysis is not the primary function of the software package, it is likely that a broad base of environmental professionals may adopt PATRIOT as a convenient tool to explore the environmental data that support model analyses.

Figure 1 summarizes the PATRIOT groundwater vulnerability assessment software package. The input, process, and output features of PATRIOT illustrated in the figure are described below.

Input. Evaluation of groundwater vulnerability within an area of interest requires data on (i) the influx of water and chemical, (ii) soils properties and distribution, (iii) pesticide chemodynamics, (iv) agricultural practices, and (v) the distance from the soil surface to groundwater.

Stated simply, the concept of PATRIOT is to integrate data for rainfall, soils, pesticides, and cropping practices to rapidly estimate area-specific pesticide leaching potential. These analyses serve as a means of assessing groundwater vulnerability and developing pesticide management strategies. To accomplish these ends, model analyses require data of national scope, but at a scale that allows determination of leaching potential at state and local levels.

Processes. PATRIOT enables its users to investigate available data, select data needed to perform pesticide leaching analyses for scenarios or areas of interest, and assess groundwater vulnerability based on the results of a mathematical model. Data investigation capabilities include extensive searching, ranking, statistical, and display functions that enable users to explore and understand the PATRIOT database prior to, or independent of, model analyses. A directed mode of database interaction dedicated to developing the input to drive one-dimensional unsaturated zone model analysis of flow and chemical transport is included. PATRIOT produces an appropriate estimation of leaching of pesticides to the water table by using scientifically sound methods and area-specific data.

Output. The end point of PATRIOT analyses is the top of the water table. The primary outputs are graphic comparisons of model results of leaching potential for various combinations of pesticide, soil, agricultural practice, and rainfall. Output options allow reporting of either unit- or area-weighted leaching analyses aggregated within various geographic boundaries. For a selected period of analysis, either average annual or total leaching can be reported. In addition, PATRIOT enables the viewing of many intermediate tables, maps, and graphics that support the user and help him or her to understand the impact of decisions in site characterization. A supplemental feature of PATRIOT is the ability to model and report the results of Monte Carlo simulation in order to evaluate the effects of uncertainty in chemical and soil/hydraulic properties (e.g., decay rate, field capacity) on pesticide mass leached to the water table.

Databases

Although many data types are potentially useful for supporting analysis of groundwater vulnerability to pesticides, the data that are required to fuel the PRZM-2 model of chemical fate and transport and allow assessment of pesticide leaching potential with the desired level of detail include:

(a) Long-term daily rainfall records that can be used directly, or with appropriate corrections for evaporation and irrigation, to represent potential infiltration to the unsaturated zone at locations across the conterminous United States.

(b) A comprehensive set of soils properties (e.g., percent sand, percent clay, bulk density, percent organic carbon) that determine pesticide migration through the unsaturated zone.

(c) Data defining the geographic occurrence of soils within appropriate geographic boundaries to support the development of state and local pesticide management plans.

(d) Chemodynamic properties (i.e., half-life, organic carbon partition coefficient) that determine persistence and transport of commonly used agricultural pesticides.

(e) Region-specific cropping practices (i.e., dates for planting, emergence, maturity, and harvest) for agricultural crops commonly grown in the conterminous United States.

(f) Knowledge of, or data that specify, the crops to which specific pesticides may be applied and the likely application dates and rates.

(g) Information about the depth to groundwater for areas that will be evaluated.

The PATRIOT software package provides comprehensive databases that satisfy the needs for information on rainfall, soils properties and occurrence, pesticide properties, and cropping practices. Pesticide-crop relationships and depth-to-water table estimates must be provided by the PATRIOT user. The attributes of the PATRIOT database are:

Rainfall. Ten years of daily rainfall values are included at 184 first-order (primary) National Oceanic and Atmospheric Administration weather stations across the conterminous United States.

Soils. From the NRI/SOILS5 linked database [1], selected properties for 24,000 soils series are included. A single soils series is associated with each of 229,000 sample sites in the conterminous United States that are classified as having agricultural land use; expansion factors in the National Resources Inventory database determine the area represented by each sample site. Data for up to four soil layers within each soil series include U.S. Department of Agriculture texture class and minimum and maximum values for percent sand, percent clay, organic matter, bulk density, and available water. In addition, a Soil Conservation Service hydrologic group designation for each soil series is included in the database.

Cropping. The PATRIOT database includes an EPA cropping practice database [2] compiled from USDA data on the customary planting, emergence, maturation, and harvesting

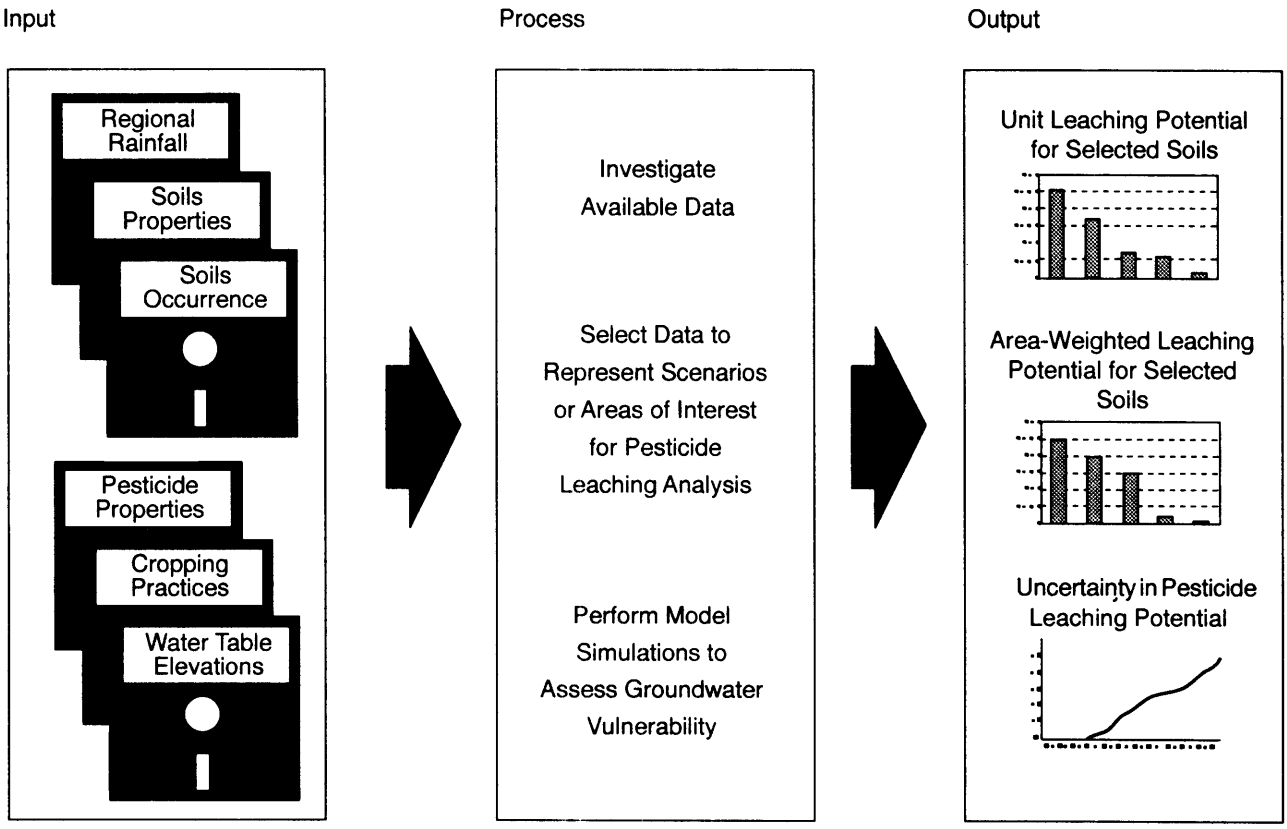


Figure 1. PATRIOT groundwater vulnerability assessment software package.

dates for 32 major agricultural crops. Cropping dates are keyed to all geographic boundary schemes supported for PATRIOT analyses.

Pesticides. Values from the SCS/ARS/CES Pesticide Properties Database [3] for soil sorption coefficient and soil half-life for approximately 125 active ingredients commonly found in agricultural pesticides are included in PATRIOT.

Other Databases. Digital line graph databases are integrated into PATRIOT that allow mapping of the results of database searches within various geographic boundaries (state, county, MLRA, hydrologic unit). A coordinate database for the locations of rainfall records is also included.

Unsaturated Zone Model

PATRIOT integrates the PRZM-2 [4] chemical fate and transport model of the unsaturated zone with supporting databases. The tasks of preparing input for model analyses and interpreting the model's results are supported by analysis and graphics capabilities that are peripheral to the core model and customized to allow efficient analysis of the specific problem that PATRIOT addresses (i.e., leaching potential to the water table).

The use of EPA's PRZM-2 model in PATRIOT enables three general capabilities:

(1) The model evaluates flow and transport through the unsaturated zone using scientifically sound methods. Advection, dispersion, adsorption, and decay are considered.

(2) The model uses formulations that are sensitive to, and can be evaluated by using, readily available environmental and chemical data (soils properties, rainfall, cropping practices, pesticide properties).

(3) The model is capable of comparing mass loadings at the top of the groundwater table for different environmental scenarios; typical run times range from 1 to 60 minutes.

Interaction Framework

PATRIOT is designed specifically for minimal user input and rapid analysis in a PC environment. Interaction with both the model and the databases has been implemented using the interface development tool AIDE [5]. For PATRIOT, AIDE has been used to implement four major categories of user interaction: (i) on-line documentation and assistance, (ii) analysis of databases, (iii) development of model input and execution of the model, and (iv) selection of evaluation options for model output.

Comprehensive on-line documentation and assistance has been provided through the use of two tools: AIDE and Expert Help [6]. AIDE features such as Limits (displays allowable values for user responses to data queries) and Status (displays system status in a window) provide a first level of on-screen assistance to PATRIOT users. Additional assistance is provided through the documentation tool Expert Help. After viewing an initial, context-sensitive help message, Expert Help allows the user to branch out in different directions in the documentation to pursue information on related topics.

Interaction with the databases has been enabled by implementing option menus related to attribute searching, ranking and statistical analysis, and display of products that result from selecting the menu options (i.e., summary displays, graphics, and mapping). In addition to menu selections, two other modes of providing information are used: general data entry fields and "toggled" data fields that only allow selection of "on" or "off" conditions. AIDE has been used to develop a directed mode of database interaction dedicated to developing all the necessary input for a variety of user-selected PRZM-2 analysis options. Finally, menus have been developed that enable the user to select various alternatives for compiling and viewing model results.

PATRIOT provides supportive graphics at every stage (data analysis, model input development, model results evaluation) of the process of analyzing leaching.

The general graphics capabilities of PATRIOT are:

(1) Generation and presentation of tables (Figure 2), maps (Figure 3), and plots (Figure 4) that clarify the impact of decisions in scenario development that are antecedent or ancillary to the model analyses.

(2) Display of a "worksheet" that summarizes the current status of model scenario specification.

(3) Graphical comparison of either unit- or area-weighted leaching analyses (Figure 5) aggregated within various geographic boundaries, as appropriate for regional, state or local investigations.

(4) Plots of "non-exceedance probability" (Figure 6), expressed as a fraction (on the x axis) versus pesticide leached to the top of the water table (on the y axis) to support uncertainty analysis.

The graphics products of PATRIOT, all of which can all be printed on a printer or plotter, are designed to provide much of the information needed for individual hard copy reports on the leaching potential of specific pesticides within specific environmental scenarios.

Discussion of Capabilities

The PATRIOT software is comprised of three branches of code: ANALYSIS, INPUT, and ESTIMATE. A typical application of PATRIOT will require user interaction with all four databases: rainfall, soil properties, pesticide properties, and cropping practices. PATRIOT embodies a "stepping stone" approach to assessing pesticide leaching potential. That is, the results of database search activities performed in the ANALYSIS branch are a prerequisite to specifying model input in the INPUT branch, and the input specification activities in the INPUT branch are prerequisites to performing any of the model analysis alternatives that are executed and summarized in the ESTIMATE branch.

Providing the input needed to perform model analysis requires iterative visits, first to the ANALYSIS branch and then to the INPUT branch, to interact with each of the four databases. The ANALYSIS branch enables the user to investigate each database and to identify the appropriate data to fuel model analyses of area- and pesticide-specific scenarios. These data are stored in a buffer and identified in a "worksheet" to which the INPUT branch refers as a first step in the effort to establish the values for each data type that will be used to execute the model. Within the INPUT branch, two activities are performed. First, for model input that is supplied directly by the databases, the user is allowed to view, refine, and assign to the model the data resident in the buffer after search activity is completed in the ANALYSIS branch. Second, the user is prompted to provide additional input, independent of the databases, that is used to establish model analysis options. A user enters the ESTIMATE branch only after all databases have been investigated and after all information necessary to perform a user-specified model analysis option has been established. If the user attempts to invoke an analysis by selecting an option in the ESTIMATE branch before all the necessary data have been provided, he or she will be returned to the INPUT branch, where an indicator of missing data/decisions is provided.

When dealing with each of the databases, the user performs iterative searches in the ANALYSIS branch, fine-tuning the search criteria until the contents of the buffer satisfy the desired scope of the model analysis (i.e., the proper amount of data with the appropriate characteristics or geographic location).

When a user first enters the INPUT branch, he or she is prompted to define general run information (e.g., number of analysis scenarios, standard or Monte Carlo run). After the basic run characteristics have been defined, the interface grooms its prompts to obtain all the information/decisions from the user and the databases that are required to execute the specified analysis.

After all the databases have been explored in the ANALYSIS branch, and all information required for model execution has been specified in the INPUT branch, the user proceeds to the ESTIMATE branch to specify output products and invoke model execution. In a time span of minutes, the model computes leaching potential and produces output in the user-selected format. The user may view the model results for up to 10 combinations of pesticide/soil/cropping practices/infiltration, then evaluate the results and define new runs, or, when results are acceptable, save them in files or print hard copies.

Availability and System Requirements

PATRIOT model code is available from the Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens GA 30605-2720. Requests, directed to the Laboratory's Center for Exposure Assessment Modeling (CEAM), should include four 3.5-inch diskettes, to which the code will be copied. (Double-sided, high-density, DS/HD 1.44MB, error-free diskettes, B=1 byte, K=1,024, M=1,048,576.) The user also can obtain PATRIOT by dialing the CEAM bulletin board at 706-546-3402 and downloading the model (approximately 1 to 1.5 hours at 9600 baud).

No traditional hard copy users manual is available for PATRIOT. Rather, the model comes with an on-line expert help package that guides the user in analysis of data and in development of input data for the PRZM-2 model and provides detailed documentation on features and characteristics of PATRIOT. The user invokes the on-line help feature by pressing the F1 function key on his or her PC.

PATRIOT was developed to run on a 386/486 IBM-compatible personal computer. The PC must have 7 MB of combined direct access and extended memory for optimal performance, and approximately 20 MB of free disk space. A math coprocessor is required; a VGA monitor that supports a minimum graphics

Soil Series (Name)> Aura Soil Number (Numeric Code)> 12864

Depth (cm)	Class	Percent Sand L	Percent Sand H	Percent Clay L	Percent Clay H	Bulk Dens. L	Bulk Dens. H	Percent Org. Mat. L	Percent Org. Mat. H	cm cm^{-3} Avail H_2O L	cm cm^{-3} Avail H_2O H	HGRP
SUR 20.3	8	30	70	7	20	1.17	1.60	1.0	3.0	0.11	0.17	B
SUB 149.9	8	50	85	15	35	1.50	1.70	0.0	0.0	0.07	0.15	
STR 182.9	5	60	95	3	32	1.45	1.64	0.0	0.0	0.01	0.12	

Potential Crops

26 Peas	13 Cabbage	1 Corn	18 Tomatoes	7 Soybeans	9 Wheat

Figure 2. Example PATRIOT summary table of properties for Aura soil series.

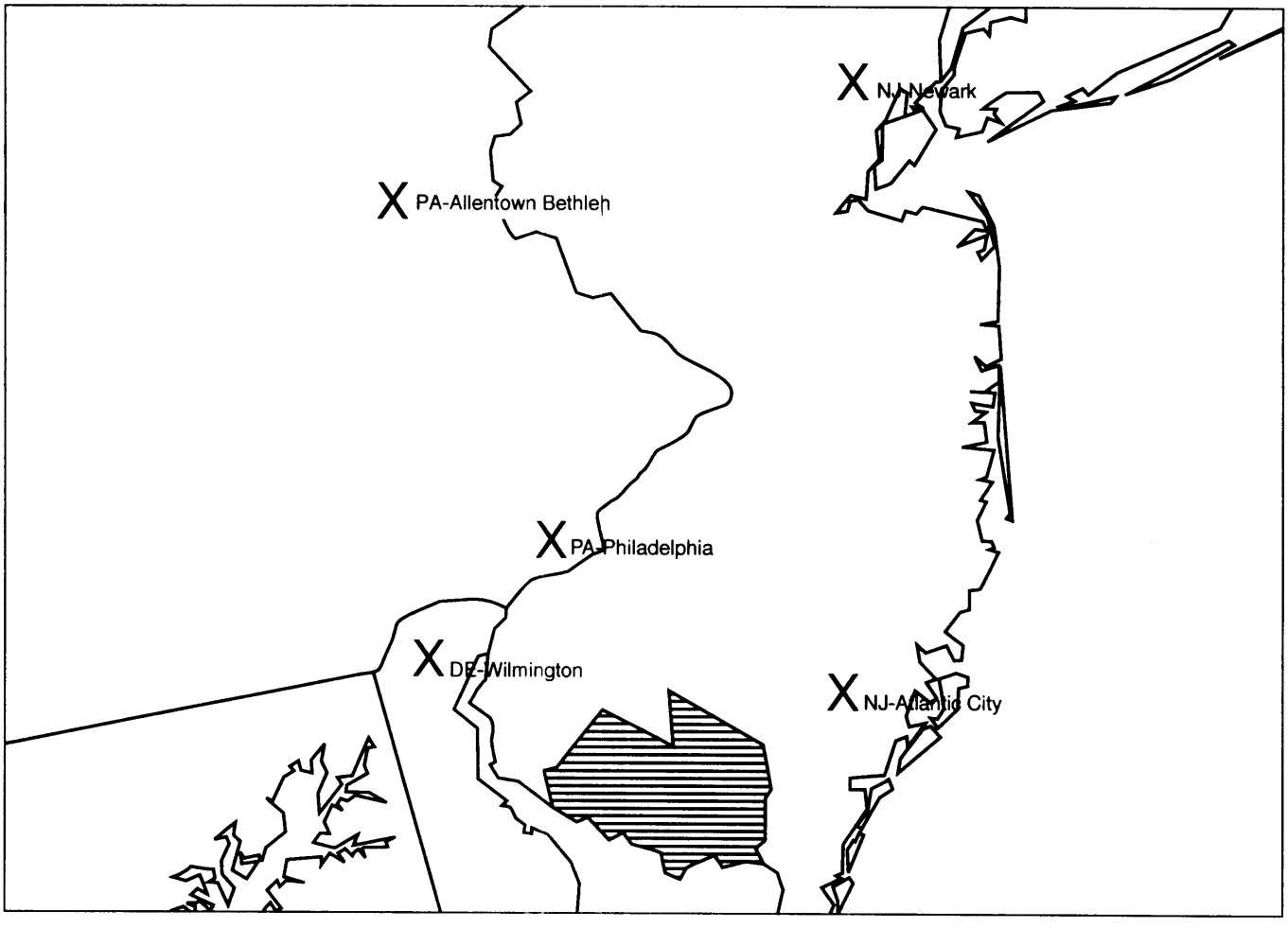


Figure 3. Example PATRIOT map of counties in the New Jersey search area that contain soils satisfying search criteria.

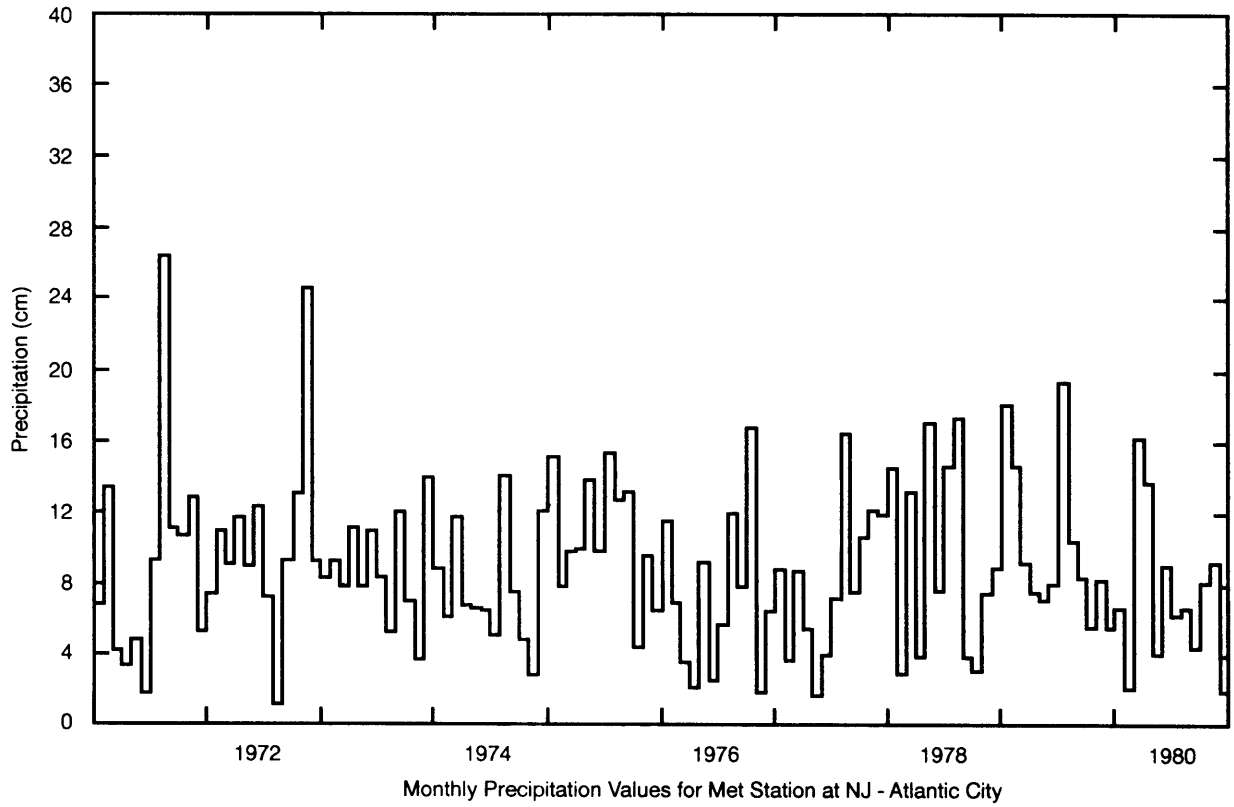
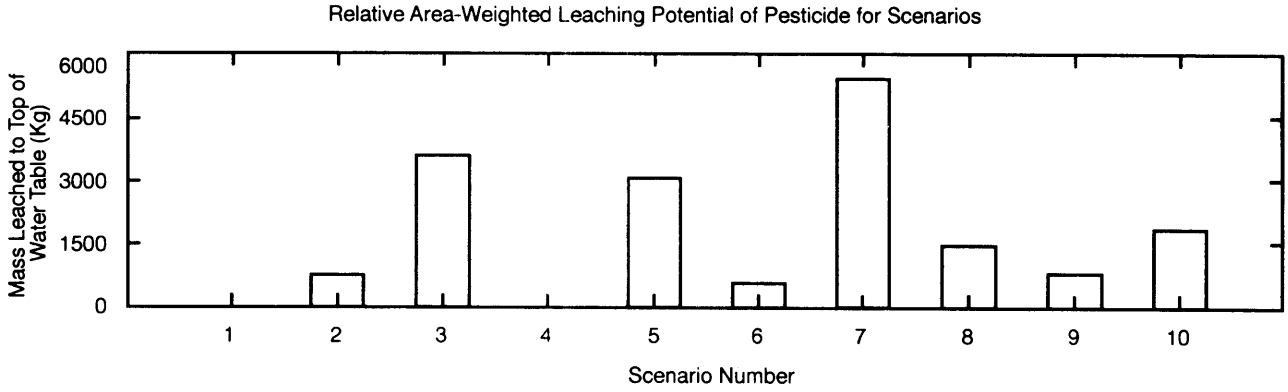


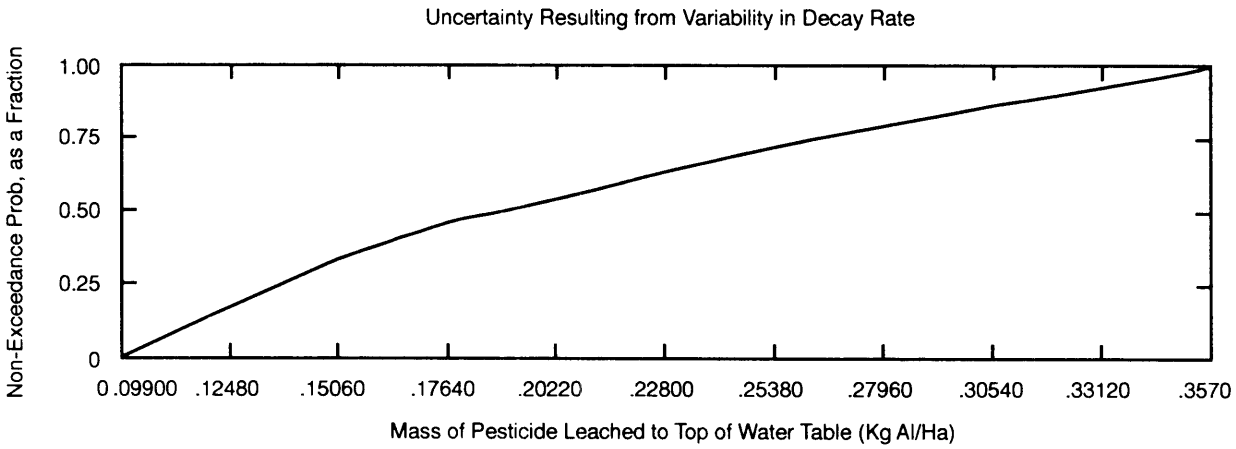
Figure 4. Example PATRIOT summary graphic of monthly rainfall from 1972 to 1980 recorded at the Atlantic City, NJ, weather station.



Scenario Data

Scenario	Soil Number	Soil Name	Unit Leach (Kg/Ha)	Area (Ha)
1	7961	Mattapex	0.021	486.
2	7969	Matapeake	0.132	5751.
3	7973	Sassafras	0.386	9315.
4	7998	Chillum	0.050	446.
5	8030	Klej	0.827	3726.
6	12854	Fort Mott	0.252	2228.
7	12864	Aura	0.303	17901.
8	12867	Hammonton	0.385	3848.
9	12868	Hammonton	0.195	4253.
10	12869	Downer	0.399	4577.

Figure 5. Area-weighted leaching analyses for 10 PATRIOT modeling scenarios.



M. C. Data

Input Variable	LYR	Mean	CV	Dist. Type
Decay Rate	SUR	0.014	7.194	Normal

Figure 6. Plot of "non-exceedance probability" expressed as a fraction (x-axis) versus pesticide leached to the top of the water table (y-axis) to support uncertainty analysis.

display of 640x480 pixels with 16 colors is strongly recommended. Graphics for the PC emulate the ANSI Graphical Kernel System (GKS) using OTG INTERACTER. PATRIOT is written in FORTRAN 77. If compilation of code is necessary, a FORTRAN extended-memory compiler and linker are required. Additional machines that can run PATRIOT include Digital Equipment Corporation VAX computers running the VMS operating system, Prime 50 series computers running PRIMOS, and UNIX workstations.

Summary

PATRIOT provides an easy-to-use, powerful tool for assessing pesticide leaching potential and developing regional and local pesticide management plans. The software package provides access to the most current nationwide databases for soils, rainfall, pesticide properties, and cropping practices for major crops. The use of PATRIOT is supported by an on-line expert help library, and the user is guided in developing the necessary input for running the PRZM-2 model and selecting the desired analysis capabilities. The model operates on widely available PC hardware and is available free-of-charge and without the burden of run-time licenses.

Literature Cited

1. Goebel, J.J. 1991. Agricultural Chemical Use and the Potential for Groundwater Contamination: How Big Is the Problem? Appendix D, Description of the National Resources Inventory. U.S. Department of Agriculture, Washington DC. Draft Report.

2. Bird, S.L., M.J. Cheplick, R.F. Carsel, and M.J. Fendley. 1991. User's Guide for the PRZM Input Collator (PIC Version 1.0). U.S. Environmental Protection Agency, Athens GA. Unpublished Report.

3. Wauchope, R.D., A.G. Hornsby, D.W. Goss, and J.P. Burt. 1990. The SCS/ARS/CES Pesticide Properties Database: I, A Set of Parameter Values for First-Tier Comparative Water Pollution Risk Analysis. IN: Pesticides in the Next Decade: The Challenges Ahead. Virginia Water Resources Research Center, Blacksburg VA.

4. Mullins, J.A., R.F. Carsel, J.G. Scarbrough, and A.M. Ivery. 1993. PRZM-2, A Model for Predicting Pesticide Fate in the Crop Root and Unsaturated Soil Zones: User's Manual for Release 2.0. U.S. Environmental Protection Agency, Athens GA. EPA/600/R-93/046.

5. Kittle, J.L., Jr., P.R. Hummel, and J.C. Imhoff. 1989. ANNIE-IDE, A System for Developing Interactive User Interfaces for Environmental Models (Programmers Guide). U.S. Environmental Protection Agency, Athens GA. EPA/600/3-89/034.

6. SofSolutions, Inc., Omaha NE.

Notice: The information in this document has been funded wholly or in part by the U.S. Environmental Protection Agency under Contract Number 68-C0-0019 to AQUA TERRA Consultants. It has been subject to the Agency's peer and administrative review, and it has been approved for publication as an EPA document.

☆U.S. GOVERNMENT PRINTING OFFICE: 1994 - 550-067/80194

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