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A Model for Managing the Impact of Pesticide on Groundwater at multiple Geographical Scales: Watershed to Soil Profile

By:
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Management Perspective

Watershed management for the protection of groundwater resources requires considerable integration of data, models, and knowledge, to account for a variety of assessments at various geographical scales of investigation. Although several systems have been developed, these are limited in that they rely on only one assessment model or method, and thus, may lead to problems in that the model may be inappropriate for the assessment objectives and/or geographical scale of investigation, or the data required by the model may not be available. Further, the use of only one assessment method, and associated reliance on specific data, may bias the objectives of the assessment or its results. Thus, a decision may be driven by the available information, and not by the goals of the assessment. The multi-level pesticide assessment methodology developed here permits regulatory personnel to undertake a variety of assessments on the potential for groundwater contamination from pesticides in agricultural areas at an increasingly detailed geographical scale of investigation. Our approach accounts for a variety of assessment objectives, scale of the problem, detail required in the assessment, the restrictions on the availability and accuracy of data, the time available to undertake the assessment, and the expertise of the decision maker. The Level 1: regional scale assesses the relative potential for groundwater contamination among several watersheds. The Level 2: local scale assesses the potential for groundwater contamination of soils within a watershed at a soil polygon scale. A Level 3: soil profile scale allows the user to simulate the migration of a pesticide within a specific soil profile, and to determine the extent and timing of leaching of the pesticide. The system developed here integrates environmental modelling, GIS, extensive data bases, data management systems, knowledge-based systems, and pesticide assessment models. Results and information are displayed in graphical, text and geographical forms.

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ABSTRACT

The multi-level pesticide assessment methodology developed here permits regulatory personnel to undertake a variety of assessments on the potential for groundwater contamination from pesticides in agricultural areas at an increasingly detailed geographical scale of investigation. This approach accounts for a variety of assessment objectives, geographical scales, restrictions on the availability and accuracy of data, time available to undertake the assessment, and the expertise of the decision maker. The Level 1: regional scale ranks the relative potential for groundwater contamination among several districts. The Level 2: local scale assesses the potential for groundwater contamination of soils within a district at a soil polygon scale. A Level 3: soil profile scale allows the user to simulate the migration of a pesticide within a specific soil profile, and to determine the extent and timing of leaching of the pesticide. The system developed here integrates, GIS, data bases, data management systems, knowledge-based systems, and pesticide assessment models.

INTRODUCTION

Watershed management for the protection of the quality of water resources requires considerable integration of data, models, and knowledge, to account for a variety of assessments at various geographical scales of investigation. Several projects have combined GIS, the data bases, and simple assessment models to evaluate water quality. However, these assessment methodologies are limited in that they rely on only one assessment model or method, and thus, may lead to problems in that the model may not be appropriate for the assessment objectives and/or geographical scale of investigation, or the data required by the model may not be available. Further, the use of only one assessment method may bias the objectives of the assessment or its results. Thus, a decision may be driven by the available information, and not by the goals of the assessment.

This paper describes a multi-level pesticide assessment methodology that is designed to provide environmental managers and regulatory personnel who may not have expertise in pesticide modelling with a means of undertaking a variety of assessments relating to the potential for groundwater contamination from pesticides in agricultural areas at increasingly detailed geographical scales of investigation. The approach taken here integrates three pesticide assessment models with GIS, extensive data bases, data management systems, and expert systems. Thus, our system can account for the variety of assessment objectives, geographical scale of the problem, restrictions imposed by the availability and accuracy of information needed to meet the objective of an assessment, the time available to undertake the assessment, and the expertise of the decision maker. The reader is referred to Crowe and Booty (1995) for additional information.

Although many GIS/assessment systems use watersheds for their geographic boundary, we use counties here because: (1) soil information is surveyed and reported on by county; (2) pesticide usage is reported on by county; (3) groundwater quality studies are typically reported by county.

METHODS

The system is designed to investigate the susceptibility of groundwater to contamination from pesticides leaching through soils in agricultural areas at three increasingly detailed geographical scales of investigation (Fig. 1), which correspond to a more precise and comprehensive assessment. The framework of the system is comprised of the EXPRES pesticide expert system (Crowe and Mutch 1994) coupled to the RAISON environmental software (Lam et al. 1991). RAISON acts as the basic system for all data storage, management and analysis, as well as integrating all environmental modelling methodologies. It also displays results and information in graphical, tabular and geographical forms. Both the screening assessments and detailed simulations are handled through EXPRES. Results and information are displayed in graphical, text and geographical forms. The multi-level assessment approach is demonstrated with six counties of southwestern Ontario, Canada (Fig. 1). Crowe and Booty (1995) validated the results of the assessment model with a study of the extent of agricultural contaminants in rural wells (WCGR 1992).

Level 1 Assessment: Regional Scale

The objectives of a level 1 evaluation are to (1) compare the likelihood for groundwater contamination from pesticides, based on soil, groundwater and meteorological conditions, among several districts or watershed, and (2) display the results in a manner suitable for a non-technical audience. To do this, we have linked a simple pesticide screening model to a GIS, with the assessment results reported in a qualitative manner, including a relative likelihood ranking and a map.

The AF screening model (Rao et al. 1985) has been selected because it incorporates the principal soil, site, and pesticide characteristics that control the mobility and persistence of a pesticide in the subsurface, and the parameters required by this model are commonly obtained from the literature or soil survey studies. The AF value calculated by this model is used to rank the potential for a pesticide to leach to the water table through a soil profile with respect to other soil profiles or pesticides. A likelihood scale is used to classify the AF values according to the susceptibility of the soils to result in groundwater contamination. Most existing systems that assess the susceptibility of a district to groundwater contamination use a single averaged or representative regional value incorporating all the soil series and soil polygons throughout this district, and use this value to produce a single assessment ranking for this district. Because of the problems with, and meaning of, using a single weighted contamination potential over an entire heterogeneous system, our approach is to display an overall assessment for a large area through a probability distribution of the degree of likelihood for contamination of all soils for each district (Fig. 2). A user can quickly and easily compare the proportion of the soils in each district on which a particular crop is grown to the relative potential for groundwater contamination, and hence determine districts are most susceptible to groundwater contamination.

For each district in the region, the relative ranking of the likelihood for groundwater contamination when the pesticide is applied to the soils is categorized according to the AF contamination potential scale and by the proportion of the total area of the soils on which crop is grown (Fig. 2) through EXPRES. The probability distributions of all of the districts are combined and displayed on a single map through RAISON. This involved the use of the graphics module where the bar graphs were created then, along with the legend, overlaid onto the map.

The level 1 assessment is demonstrated through a comparison on a county by county basis of the relative potential for atrazine to leach to the water table in the corn growing areas of the counties, and which region is most susceptible to contamination. The results of the assessment indicate that atrazine is likely to leach to the water table in all six counties (Fig. 2). When assessing the overall relative susceptibility of various regions to contamination, the advantage of incorporating the area of the county occupied by a soil into the assessment is evident. Although 31.3% of the soils in Elgin county on which corn is grown are categorized as being unlikely to cause groundwater contamination from atrazine, these soils occupy only 7.2% of the area of the corn growing region of Elgin county. Overall, the soils of Elgin, Brant and Haldimand-Norfolk counties were predicted to be most susceptible to contamination from atrazine, and Niagara and Oxford are least susceptible.

Level 2 Assessment: District/Watershed Scale

A level 2 assessment is designed to (1) undertake a relative ranking of the likelihood for groundwater contamination for every soil series and soil polygon within a district (Fig. 3), and (2) map the likelihood for contamination at a soil polygon scale. A level 2 assessment focuses on a smaller scale of investigation than level 1, and specifically, is used to examine one of the individual districts identified during the level 1 to, for example, locate the soils, identified in the level 1 assessment, that have the highest risk for groundwater contamination.

Because the level 2 assessment is required to undertake the assessment quickly and to report the results of the assessment in a qualitative manner (i.e., relative likelihood ranking), the assessment again uses the AF screening model (Rao et al. 1985). However, rather than producing a probability distribution of the likelihood for groundwater contamination representing all soils within the district, the results of the level 2 assessment assigns a likelihood ranking to each soil polygon in the district (Fig. 3). The likelihood categorization of each soil polygon is supplied to the RAISON system from EXPRES as an ACSII file. The digital map of the soil polygons are coloured using the RAISON thermic mapping function as shown by Figure 3.

The following example of the level two assessment shows areas within an enlarged portion of Elgin County that are most susceptible to groundwater contamination from atrazine applied to corn (Fig. 3). Soils on which corn is not grown, or are not suitable for growing corn, are not evaluated. Elgin County is selected here because it was identified in the level 1 assessment of having the highest potential for groundwater contamination from the application of atrazine of all the counties.

Level 3 Assessment: Soil Profile Scale

The objectivess of a level 3 assessment are to (1) identify the processes or factors that have the greatest impact on the leaching of the pesticide in a specific soil identified in level 2, and (2) verify the ranking results obtained from a level 1 or 2 assessment. This involves simulating the migration of a pesticide through the soil profile to the water table, and quantifying the distribution of the pesticide into its dissolved, sorbed and volatilized components, with respect to time and depth. This assessment focuses on one specific soil profile and one pesticide.

Two models are incorporated into the system to simulate the processes involved in the transport and fate of a pesticide in the soil profile, PRZM (Carsel et al. 1984) and LEACHM (Wagenet and Hutson 1987). Both of these models allow the user to quantitatively predict the concentration, distribution and migration rates of a pesticide and its degradation products within the subsurface with respect to both time and depth. The two models differ from each other in the level of detail that is incorporated into the description of the process involved, the number of pesticides and metabolites simulated, the amount and type of data required to undertake a simulation, and the execution time required for a simulation. LEACHM is a research model that attempts to describe the processes involved in full mathematical detail, while PRZM invokes a simplified lumped parameter model that reduces both the amount of input data and the time required to obtain results. The simulation models are accessed through EXPRES. EXPRES guides the user through all the steps required to select the simulation model best suited for the objectives of the study, select the appropriate site, pesticide, and crop data in order to construct an input data set, select the output best suited to the assessment objects, perform integrity checks on user supplied information, execute the model and aid in the assessment and display of the simulation results.

Although the previous assessments indicated that the Fox soil is most susceptible to contamination, field data (WCGR 1992) indicated a greater incidence of pesticide detection in groundwater samples from the Berrien and Muriel soils. The simulation of the fate of atrazine verifies the results of the level 1 and 2 assessments indicating that the Fox soil is more susceptible to contamination. The time series plot of the concentration of dissolved atrazine at the water table shows that the peak concentration of atrazine leaches to the water table through the Fox soil faster that through the Berrien and Muriel soils (Fig. 4) and its peak concentration is higher for the Fox soil than the Berrien and Muriel soils. When accounting for uncertainty and variability of soil parameters by increasing the saturated hydraulic conductivity and decreasing the organic carbon content of the Berrien and Muriel soils, the Fox soil is still less susceptible to contamination.

DISCUSSION

A pesticide assessment model was developed to permit regulatory personnel to undertake a variety of assessments on the potential for pesticide usage in agricultural areas to contaminate the groundwater regime, at three increasing detailed geographical scales of investigation. The level 1 and level 2 assessments are qualitative, and are designed for regulatory guidance purposes, such as prioritizing pesticides or sites for detailed analysis, future monitoring efforts and modelling studies, or evaluating alternative management practices. Because the level 3 assessment is more quantitative, it is designed to both quantify the distribution and leaching rates of pesticides with respect to time and depth, and to validate the risk assessment identified in the level 1 and level 2 assessment.

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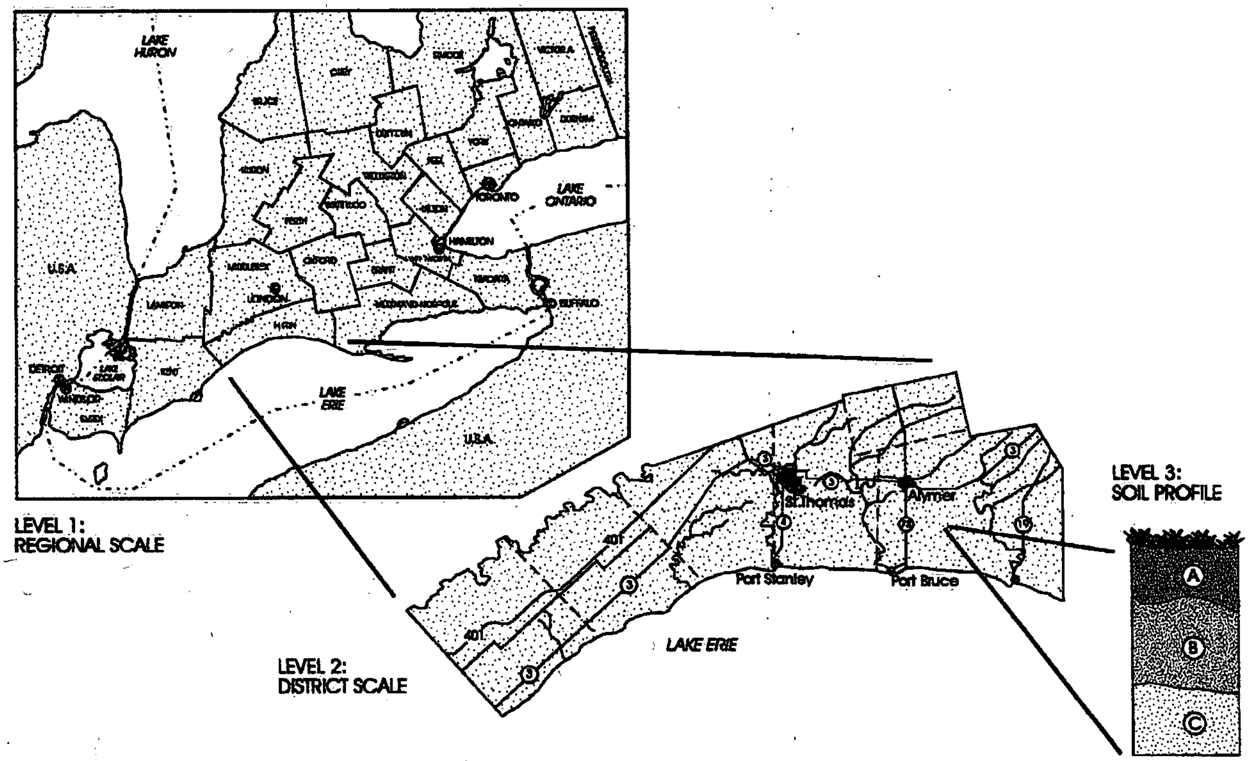

Fig. 1. Illustration of the three geographical scales evaluated with the multi-level pesticide assessment model.

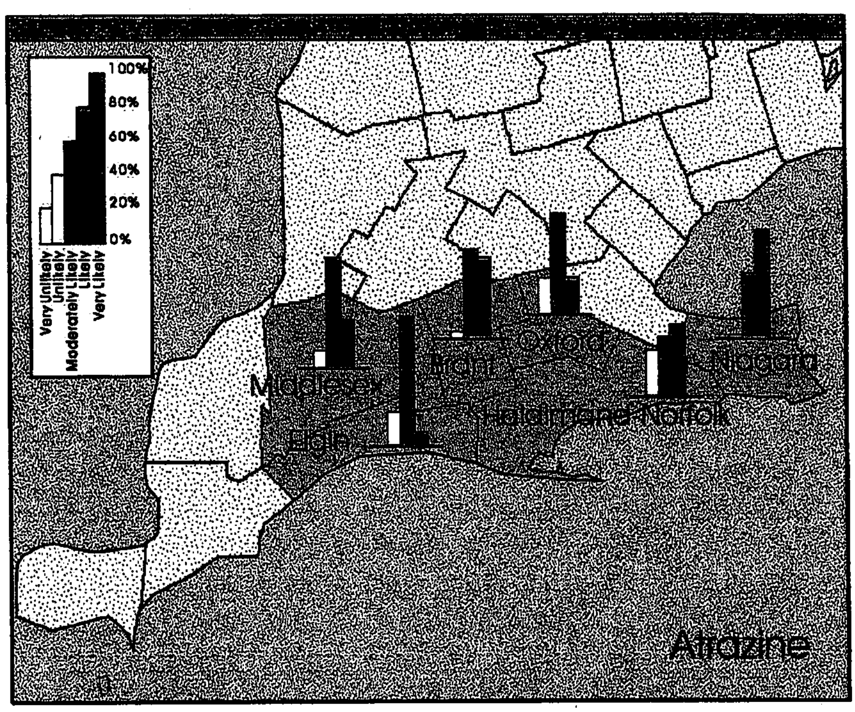

Fig. 2. Level 1 assessment: comparison of six counties showing the percentage of soils on which corn is grown within each likelihood class for groundwater contamination from atrazine.

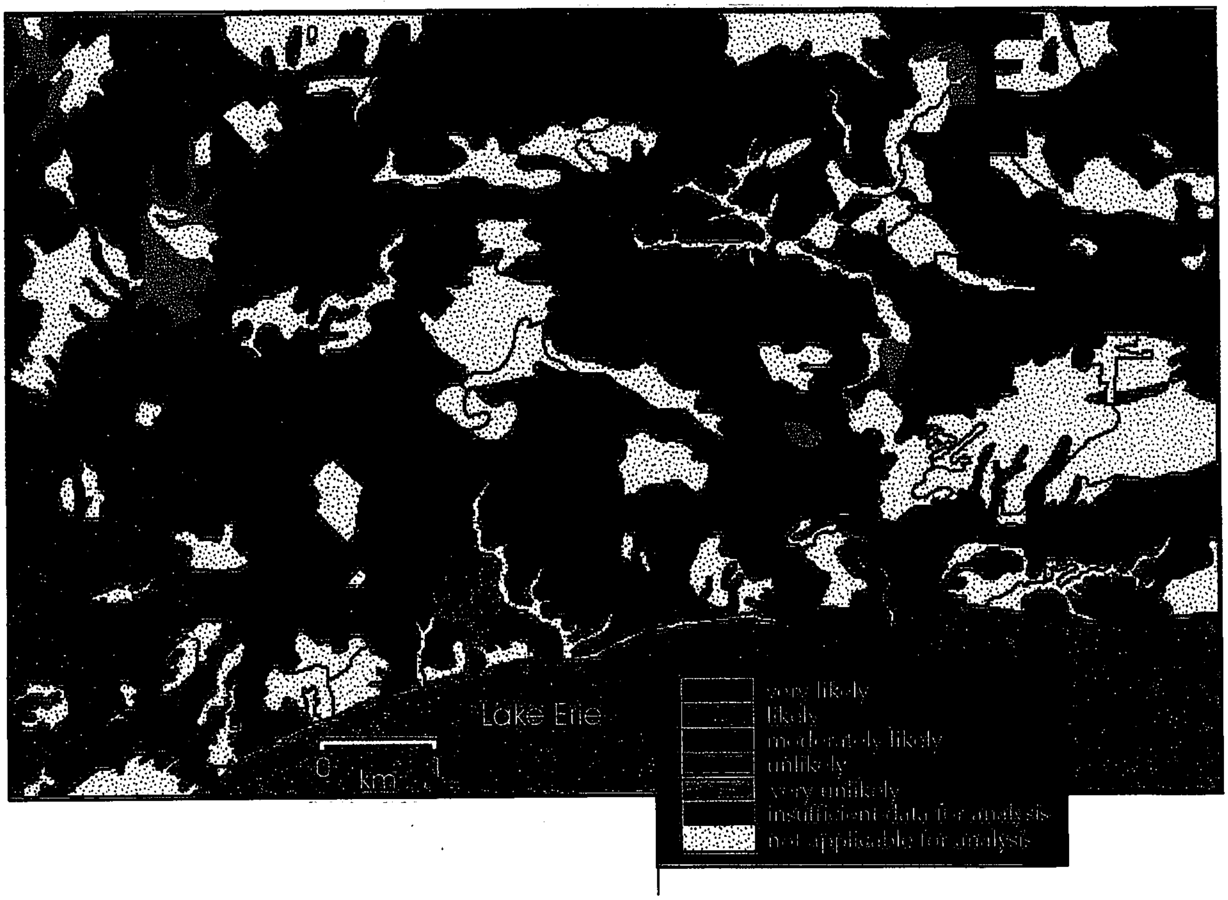

Fig. 3. Results of the level 2 assessment: the likelihood for groundwater contamination from atrazine beneath all soils within Elgin County on which corn is grown.

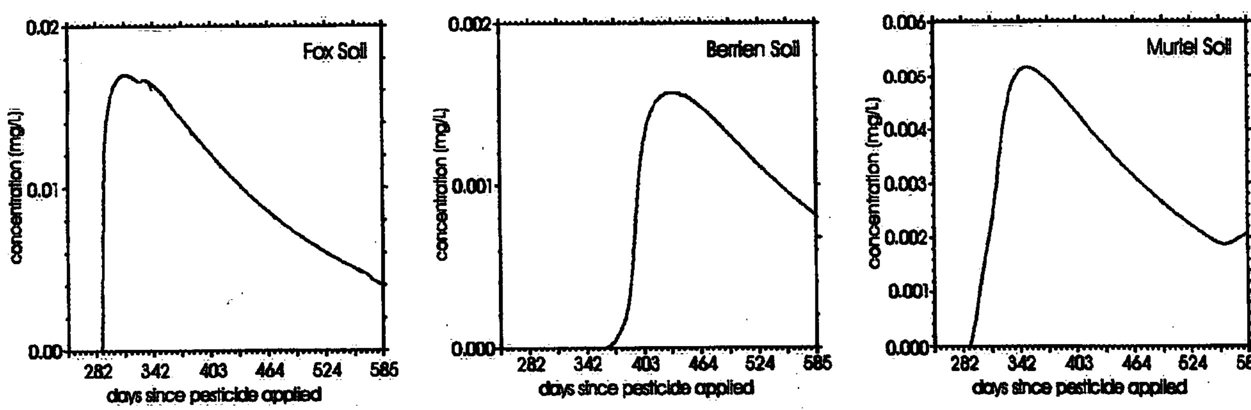

Fig. 4. Results of the level 3 assessment: time series plots showing the peak concentration of dissolved atrazine, and the time to reach the peak concentration, at the water table beneath three soils in Elgin County.

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