Using Computer Simulations to Predict the Fate and Environmental Impact of Applied Pesticides

An Aid to Developing Environmentally Sound Integrated Pest Management Plans for Golf Courses and Other Turf Areas

by **KEVIN J. FRANKE**
Environmental Scientist, The LA Group, Saratoga Springs, New York

IN THESE TIMES of increased environmental awareness and uncertain economic future, many turf managers must answer questions regarding the safety and economy of their chemical pest control practices. These questions may be raised by golfers, the general public, and even government regulatory agencies. Are pesticides being applied only when and where they are needed? Are the right pesticides being applied? What are the potential side effects of pesticide use? Are there threats to humans, fish, wildlife, or water resources? Are there safer alternatives which will accomplish the job? Oftentimes, answers are hard to come by.

While it is the goal of every turf manager to use chemical controls in the safest and most efficient manner, there is always uncertainty involved in applying pesticides to a highly variable and often uncontrollable environment. Variability in factors such as soils, weather, and past management practices can all influence the occurrence of pests as well as the effectiveness and fate of applied pesticides.

Without extensive and expensive field studies, it is impossible to accurately predict the fate of applied products on a site-specific basis. Or is it? Recently, the use of computer simulation has significantly reduced the work necessary to answer questions which previously could be addressed only by more time- and labor-intensive means. Today, computer simulations can help determine the fate of a particular pesticide or fertilizer applied at a given rate, on a given schedule, and on a site-specific basis. Currently, The LA Group, a landscape architecture, engineering, and environmental consulting firm in Saratoga Springs, New York, uses computer simulations to aid in the preparation of Integrated Pest Management (IPM) plans for proposed and existing golf courses.

Modeling as a Predictive Tool

Mathematical modeling is an accepted scientific process by which systems can be analyzed in a comprehensive manner based upon documented observations of quantifiable phenomena. Models have been developed to simulate specific processes, often quite complex, and describe these processes beyond what could be accomplished using simple predictions. The effectiveness and reliability of any such predictive tool is dependent on the accuracy of the data used to formulate the model. Development of a model is a process whereby scientifically established values are used in a series of interrelated equations to best fit conditions which have been observed to occur naturally. The relationships of variables and equations are arranged and rearranged in the model development process until they best describe real occurrences over a range of measured conditions.

Models vary in their complexity and in the amount of data that must be supplied by the user (input data). Generally, the more complex the model, the more precise the information it generates (output data). A number of models have been developed to describe the movement of pesticides in soil. These models range from simple, one-equation predictions to the data-intensive computer simulations. The simpler evaluations of leaching or runoff potential deal with the physical properties of a product (i.e., solubility in water, half-life, etc.), regardless of the environment in which they are applied. The more complex models integrate the properties of a product with specific environmental data such as soil type and temperature, rainfall, soil water, evaporation, and the amount and type of crop present. More data-intense models provide more site-specific results.

Models developed to predict the movement of pesticides include the USEPA's "Pesticide Root Zone Model" (PRZM), USDA's "Chemicals, Runoff, and Erosion from Agricultural Management Systems" (CREAMS), Jury et al's "Chemical Transport Screening Model" (CTSM), and Wagenet and Hutson's "Leaching Estimation and Chemistry Model" (LEACHM). All of these models were intended for simulation of field agriculture scenarios.

Table 1: Characteristics of Four Selected Pesticide Models

	PRZM	GLEAMS/ CREAMS	CTSM	LEACHM
Predicts vertical movement	X	X	X	X
Predicts horizontal movement	X	X		
Simulates pesticides	X	X	X	X
Simulates nutrients		X		X
Site specific	X	X		X
Software available	X	X	Not Needed	X

Characteristics and capabilities of each of the four models are presented in Table 1.

The choice of which model to use depends on the precision required to determine the potential for and magnitude of negative environmental impacts associated with turfgrass management practices. Regardless of which model is selected, however, users of the data should be aware of their limitations. Models are predictive tools whose accuracies reflect the quality of the data used to develop them and, just as importantly, the data used to operate them. Data generated from modeling should be used to guide management decisions rather than define them.

(Editor's Note: Pesticide and nutrient fate studies being conducted on turf at several universities suggest that most current computer models tend to overestimate the amount of these potential pollutants that reach groundwater.)

Computer Simulations Using LEACHM

The Leaching Estimation And Chemistry Model, or LEACHM, was developed by Drs. J. L. Hutson and R. J. Wagenet of Cornell University to predict the movement of water, salts, fertilizers, and pesticides through specific soil profiles. Originally developed for use in agricultural situations, the model was modified to more accurately simulate proposed pesticide program options for golf courses from Lake Placid, New York, to Lanai, Hawaii. Results of simulations have aided in the selection of products which will pose the least potential for negative impacts on groundwater, surface waters, and non-target insect, fish, and wildlife species, while still effectively controlling anticipated target pests.

Realistic results are ensured by inputting information specific to the area being simulated. Parameters such as local rainfall, snowfall, temperatures (air and soil), and pan evaporation are taken from published meteorological data. Irrigation events can be tailored to simulate any schedule, and schedules can be modified based on weather conditions. For model soils, the percentages of sand, silt, clay, and organic matter, as well as bulk density for any number of segments within the soil profile can be specified. The thickness of the soil profile can be modified to simulate the depth-to-groundwater or a seasonally high water table. Soil data are obtained from USDA Soil Conservation Service Reports, USGA specifications, or, if desired, on-site sampling. For any product simulated, a specific water solubility, soil half-life, organic carbon partition coefficient, and vapor density are input from published literature values and manufacturers' information. Simulations up to three years in duration have been run to date.

Simulation Results

Execution of the model will provide the information necessary to assess the environmental mobility and safety of the simulated chemical control program. Output data include the amount of product and water which leach through the simulated soil profile, the amount of product which still remains in the profile, and the amount of undissolved surface residues. Mass balances, which account for all of the applied pesticide, also will show how much product has been volatilized, taken up by the turf (if it is a systemic product), and chemically or biologically degraded, and how much has been transformed to specified breakdown products. Output can be obtained for any time interval within the specified simulation period.

Based on these mass balances, it is possible to predict, and thus avoid, adverse environmental impacts of a hypothetical or currently implemented chemical pest control program. For example, simulations have indicated that certain products, even when applied at assumed safe, label-recommended rates, have the potential for reaching groundwater or surface water, or posing unnecessary risks to non-target organisms which may use or occur in a treated turf area. Comparing the values produced in the mass balances of the LEACHM simulations with established water quality standards and published toxicity values for a number of representative potential non-target organisms, ultimately yields the hazard potential. This risk assessment procedure, when applied to a number of pesticides, will result in a relative safety factor being assigned to each product, upon which recommendations for use will be made.

Examples of Simulation Scenarios

For example, if a particular snow mold product applied in late fall or early winter were shown to produce surface residues well past spring snow melt, and if this product were applied to an area where Canada geese might forage, the potential impact to the geese could be quantified. Similarly, if a curative white grub insecticide application were made in late August and an unexpected intense thunderstorm occurred the next day, the potential for leaching to groundwater and runoff to nearby surface water could be predicted.

Figures 1-4, "Sample LEACHM Output," is a portion of an output file generated from the execution of the LEACHM model. In this particular execution, the application of four preemergence crabgrass products was simulated. The results are shown for one of these products, Dacthal. (Note: Trade names appear in the output files for convenience only. All data are inputted and simulations performed for active ingredients. Appearance of trade names does not imply endorsement of any particular product.) Day 210 of the simulation, which began on April 1, is presented here. Both the day number and the date appear in the upper left-hand corner of Figure 1.

The uppermost table, Figure 1, is the Mass Balance Table, which gives an account of the whereabouts of all of an applied product, including the mechanisms of removal from the soil profile. For risk assessment, "undissolved on soil surface" and "losses in drainage" are particularly important parameters. In this instance, Dacthal has not leached through the simulated soil (a green built to USGA specifications). However, elevated surface residue does exist for the product.

The distribution of Dacthal within the soil profile, described in Figures 2 and 3, also is used in the risk analysis process. Potential problems which may arise as a result of persistence can be ascertained by following trends in soil concentrations over time. Results in this section can be used to make adjustments to multi-year plans or seasonal rotation strategies.

Information from Figure 4, Plant Growth, Transpiration, and Product Absorption, does not play an important role in pesticide risk analysis, but is quite useful when analyzing simulated fertilizer programs. Used in conjunction with the other tables, it is possible to determine the efficiency of a fertilizer program. With multiple executions of the model, each simulating a slightly different fertilizer program, it is possible to derive a program that maximizes turf nitrogen uptake while minimizing losses to drainage or other routes.

All simulations will produce a similar output format. The total length of a simulation and report intervals are specified in the input table. Thus, it is possible to evaluate scenarios ranging from the behavior of a single product over a single day to a full chemical management plan for a multiple-year period, and anything in between.

The LEACHM model has been used to make recommendations regarding the timing, amounts, and particular products being applied to specific areas. For every potential pest, there is a window of opportunity in which effective treatments can occur. LEACHM simulations can provide an interval within this window when treatments will be effective and, potentially, produce the least or no negative environmental impact. In conjunction with timing, amounts of products applied, especially for those which are applied more than once (e.g., a preventative *Pythium* program), also can be adjusted to produce the desired effect and safety. Eliminating from consideration any product that provides an unnecessary risk due to its overall toxicity or mobility also will result in a more environmentally sound integrated pest management program.

Integrated Pest Management Programs and LEACHM

LEACHM, by itself, however, will not produce an integrated pest management (IPM) plan. What LEACHM will provide is a determination of what, where, and when products can be expected to work efficiently and safely. This is only one aspect of a comprehensive IPM plan, which also contains regulatory, genetic, cultural, biological, and physical tactics integrated with chemical tactics. The misconception that integrated pest management is synonymous with eliminating pesticide use is slowly being replaced. In reality, reductions in reliance on pesticides are often desirable economic and environmental benefits of a properly implemented IPM plan and not a true goal. By properly implementing other practices, the need for chemical treatments is naturally decreased.

IPM, by definition, is the implementation of a combination of compatible tactics in a manner that maintains pests below injurious levels, while at the same time eliminating threats to humans, animals, and other non-target organisms.

Sample LEACHM Output

Figure 1

Time Elapsed 210.000 Days
Date 10/27/89

		Cumulative Totals and Mass Balance Dacthal (mg/m^2)
Initial total		.0
Currently in profile		124.8
Undissolved on soil surface		3123.6
Simulated change		3248.4
Additions:	i) in rain or irrigation	.0
	ii) as amendment	4200.0
Losses:	i) in drainage	.0
	ii) by evaporation/volatilization/conversion	632.9
	iii) by transformation	318.9
	iv) by degradation	.0
	v) by plant uptake	-.2

Figure 2

	Water			Dacthal		
Depth (mm)	Theta	Potnl (kPa)	Flux (mm)	Total ug/kg	Solution mg/l	Gas ug/l
25.	.089	-199.5	106.7	.203E+04	.324E-02	.295E-03
76.	.066	-202.0	97.8	.168E+02	.112E-03	.102E-04
127.	.066	-196.2	86.4	.394E+00	.272E-05	.247E-06
178.	.069	-156.5	74.1	.732E-02	.522E-07	.474E-08
229.	.074	-120.3	69.1	.111E-03	.822E-09	.746E-10
279.	.077	- 96.5	65.5	.142E-05	.109E-10	.991E-12
330.	.079	- 84.8	67.4	.636E-08	.509E-13	.462E-14
381.	.066	- 79.6	69.2	.000E+00	.000E+00	.000E+00
423.	.066	- 78.9	70.9	.000E+00	.000E+00	.000E+00

Drainage flux: 72.5mm

Figure 3

The following distribution is calculated ignoring undissolved chemical on the soil surface and that lost from the profile by leaching, plant uptake, and volatilization.

Depth and concentration of 1st %ile	0mm	.12E+03
Depth and concentration of 5th %ile	2mm	.12E+03
Depth and concentration of 16th %ile	8mm	.12E+03
Depth and concentration of 50th %ile	25mm	.12E+03
Depth and concentration of 84th %ile	43mm	.12E+03
Depth and concentration of 95th %ile	48mm	.12E+03
Depth and concentration of 99th %ile	50mm	.12E+03

Figure 4

Plant Growth, Transpiration, and Pesticide Absorption (if calculated)

Time: 210.000 Days   Crop Cover: .900   Root Potential: -.2190E+03 kPa

Depth (mm)	RDF	Temp °C	Transpiration (mm) Incr.	Cum.	Uptake by Plants (mg/m^2) Dacthal Incr.	Cum.
25.	.200	3.8	12.2	114.0	.000E+00	.000E+00
76.	.300	5.4	14.0	127.6	.000E+00	.000E+00
127.	.350	6.9	14.8	127.4	.000E+00	.000E+00
178.	.100	8.2	7.5	63.8	.000E+00	.000E+00
229.	.050	9.3	5.8	63.7	.000E+00	.000E+00
279.	.000	10.2	.0	.0	.000E+00	.000E+00
330.	.000	10.9	.0	.0	.000E+00	.000E+00
381.	.000	11.3	.0	.0	.000E+00	.000E+00
432.	.000	11.5	.0	.0	.000E+00	.000E+00
Total: 500.0			54.3	496.4	.000E+00	.000E+00

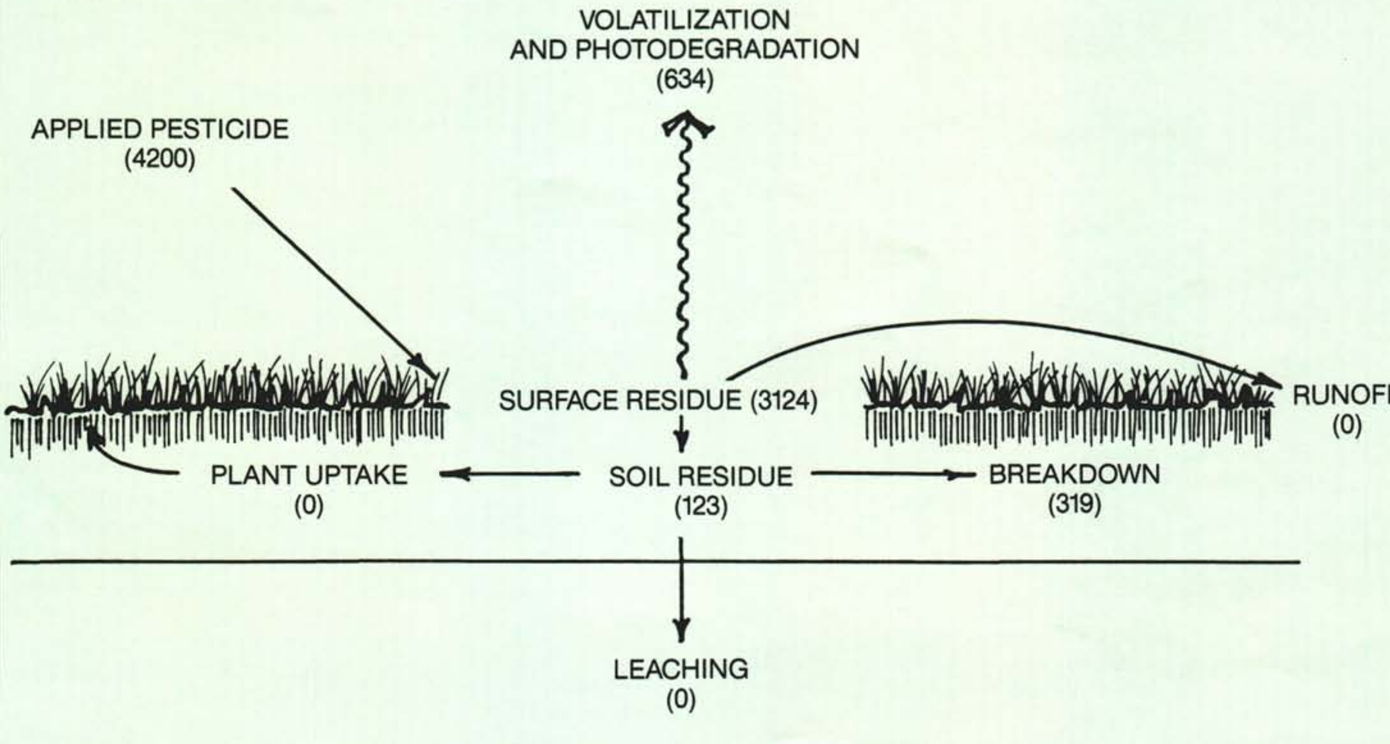
Like the previously discussed LEACHM simulations, IPM programs should be site specific. Practices which prove successful in a particular location may not produce the same effects in other areas due to variations in soils, topography, climate, pest pressure, and past management practices. Therefore, it is essential that an IPM plan contain all practices which can be performed successfully within the limitations imposed by the site and the resources available to those implementing the program.

An increased ability to control the factors which influence turf pest occurrence will decrease the probability of pests exceeding established thresholds and the need for subsequent remedial actions. For this reason, formulating an IPM plan during the design phase for a site will allow preventive measures to be implemented that will reduce the need for future curative actions. This does not mean that comprehensive IPM plans cannot be formulated for, and successfully implemented on, existing turf areas. Rather, less opportunity exists to provide a negative environment for the turf pests at a relatively reasonable cost on established turf. Examples of some IPM tactics which are easier and less expensive to implement prior to turf establishment include proper species and cultivar selection, establishment of high-, medium-, and low-intensity management areas, topographic alteration (grading), planning and installing surface and subsurface drainage and irrigation systems, and introduction of biological control agents. These, and other tactics, all can be considered in the context of existing environmental constraints, such as on-site wetlands, surface waters, and other potentially sensitive areas, and implemented in a way to minimize the potential for negative impacts.

Regardless of the content and extent of a proposed IPM plant, the program must remain flexible to realize its full potential. Since the program is being applied to a variable environment, which, in turn, influences pest occurrence, new situations will arise constantly for the turf manager. Preventative measures and curative actions will be undertaken in response to this variable environment. From a regulatory standpoint, it is important that an IPM plan not limit itself to the tools the turf manager may or may not use to prevent or correct a problem. In designing the IPM plan, it is imperative that a preparer consider all available options for a particular site. This includes consideration of recent advances in techniques, equipment, and products.

Prescreening potential pesticide products and defining what, where, when, and how much of a particular

Figure 5. Schematic of a Prediction of the Environmental Fate of an Applied Pesticide as Simulated by the LEACHM Model (Data Taken from Figure 1)



product can be safely applied can greatly aid the IPM plan formulation process. Information obtained from computer simulations of chemical treatments such as LEACHM can provide estimates which otherwise could not be obtained unless expensive on-site studies were completed. More and more, this type of information is being requested by regulatory or other groups which influence how areas may be managed in the future. In order to insure that a turf manager continues to have all necessary tools to combat a potential or existing problem, it is essential that pertinent questions receive the proper attention and be satisfactorily addressed.

Modeling Today and Tomorrow

Considerable time and effort are currently being devoted to developing more sophisticated and comprehensive modeling systems with yet unrealized precision. The development of modeling systems is an evolutionary process which is always giving rise to superior products. This is not to say that the models we have today are inefficient or inaccurate. In reality, today's models are "state of the art" and are representative of the best technologies currently available.

As stated in Table 1, the software for each of the three more complex models is readily available. The CREAMS/GLEAMS model is available at no cost from USDA Research Labs in Tifton, Georgia. Similarly, the PRZM model is available from the USEPA. LEACHM, however, must be purchased from its authors at Cornell University (contact person: Dr. John Hutson, (607) 755-7631).

All three models can be used by anyone with an IBM-compatible PC, available site-specific input data, the time necessary to formulate accurate input files, and a general working knowledge of computer operation. The models are generally user-friendly and are accompanied by detailed explanatory literature. In order to assure accurate results, however, significant time must be invested by the user during the familiarization process. It is this initial time investment that limits the usefulness to today's turf managers for stimulating their own site-specific program. However, once the initial time investment is made, and after the user becomes accustomed to using a particular model, modification of input data allows for the simulation of an infinite number of management practices as long as the user has confidence in the data he is using.

ON COURSE WITH NATURE
Working Within the Quagmire of Wetland Regulation!

by NANCY P. SADLON
Environmental Specialist, USGA Green Section

HISTORICALLY, wetlands have been considered wastelands, but now they are recognized for providing environmental and economic benefits, including wildlife and fish habitat, shoreline and erosion control, flood protection, improved water quality, storm water management, aquifer recharge, and valuable recreation areas. Wetlands are protected by law, and golf courses are required more frequently than ever to file wetland permit applications. Though the wetland regulatory process is complicated, a few basics can introduce you to the process.

How to Recognize Wetlands on the Golf Course

When analyzing the golf course to determine if a wetland environment exists, there are three basic things to look for:

1. **Water** at or near the surface.
2. **Saturated soils** that often (but not always) display gray-green colors.
3. **Plants** that are typically water tolerant.

These three simple indicators represent the basics for the layman to identify areas of wetland concern on the golf course. It is important to recognize that when analyzing these parameters, it is often necessary to look below the surface (at an average depth of 0-18″) to determine the presence or absence of water or saturated soils. Wetlands *do not* have to exhibit all three parameters to meet the regulatory regulations (as is the case with many drained farm lands), nor are all three indicators always present throughout the year. These basics to wetland identification are not sufficient guidelines for do-it-yourself wetland delineation. They are presented to help the golf course superintendent recognize the potential for wetland existence on the golf course and the need to consult a local expert.

Complete delineation of wetlands to meet regulatory requirements has become a detailed, scientific process that requires the expertise of an experienced wetland consultant.

Why Are Wetlands Such a Big Issue on Golf Courses?

Many golf courses deal with wetland regulations. By their very nature, many