Modeling Fate and Transport of Pesticides at Golf Courses

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In this study we examine watershed scale models for their applicability, accuracy, simplicity of use, and cost effectiveness in predicting the behavior of pesticides at golf courses. Watershed scale models were selected for evaluation because most regulatory decisions, or issues raised during public hearings, are associated with pesticide impacts on a large geographical scale like those defined by the boundary of the golf course drainage areas. In these cases, the major interest lies in the concentration of pesticides at potentially large distances from the point of application. For regulatory decisions, a model that has high prediction accuracy is desired.

We refer to these watershed-level models as 'macro-scale' or 'basin level' models. Two 'Macro-scale" models that we are testing are Simulator for Water Resources in Rural Basins-Water Quality (SWRRBWQ) and SWAT, which is combination of SWRRBWQ and a water routing model called ROTO. The objective of the models is to predict the effect of management decisions on water, sediment, nutrient, and pesticide yields at the outlet of a sub-basin or basin.

We purposefully collected data from functioning golf courses, avoiding a total reliance on experimental field trial information. We wanted to test the ability of the models to accurately predict pesticide concentrations under actual field conditions thus reflecting actual management practices. The field data are used to calibrate the models, identify the range of values the model inputs represent, and test the accuracy and precision of the model. Inherent in our modeling approach is the explicit characterization of uncertainties in model structure and model input parameter values. These uncertainties will be carried through model simulations, consistent with EPA's probabilistic framework for ecological risk assessment. Model results will be presented with the appropriate descriptive statistics or as conditional probabilities.

Included in the analysis is an evaluation of model prediction error and whether the actual pesticide measurements fall within the range of model predictions. In addition, we evaluate the macro-scale models (SWRRBWQ and SWAT) for accuracy, ease of use, and information requirements.

The primary challenge presented in this project, to date, has been the assembly of a complete database that has been constructed from data obtained at golf courses operating under typical management practices. We require data from golf courses that tested for pesticides in surface waters on a routine basis, and that had measurable concentrations of the pesticides in the field samples. We found that very few golf courses have a routine monitoring program for detection of pesticides in surface waters. Many of the newer courses are implementing monitoring programs, but data are not yet available. We have however, obtained data from the following locations: two golf courses in Florida, one golf course in British Columbia, and one golf course in Maryland. The British Columbia and Maryland data were recently received, and have not yet been evaluated. The data from the Maryland golf course has three years of data and appears to provide the single best database for the model evaluation study.

Once the databases were established the SWRRBWQ model was run. A multi-tiered approach was taken in the assessment of the model with the Florida golf course data.
The models were run twice, once for a 2-year simulation and again for a 20-year simulation. The 2-year simulation coincided with the time period of the USGS data collection. Actual rainfall

data collected during the period the field measurements were taken was input directly into the model for the 2-year run. For the 20-year simulation, the model's internal weather generator was used. The model outputs were evaluated by comparing predicted concentrations to measured concentrations. Comparisons were made on a daily, monthly, yearly, and multiple year basis. We quickly discovered that the models never predicted a positive pesticide concentration on the exact day a pesticide measurement was recorded in the field. We concluded that establishing model accuracy on a daily time step may be to stringent a requirement for the model given our uncertainty in the rainfall data and other parameters. Therefore, we established other methods for extracting the data from the model outputs as a basis of comparison to the measured values. A summary of these approaches follows:

> *Monthly Comparison*: If the model predicted a positive pesticide concentration in the month a field measurement was taken, we recorded the value and made the comparison between measured and predicted values.
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> *2-Year Comparison*: If the model predicted a positive pesticide concentration within the 2-year run, we recorded the lowest and highest predicted value and determined if the measured field value(s) fell within the range of the model predictions.
>
> *20-Year Comparison*: If the model predicted a positive pesticide concentration within the 20-year run, we recorded the lowest and highest predicted value and determined if the measured field value(s) fell within the range of the model predictions.

Preliminary results from the Florida Golf Course-1 are given in Tables 2 and 3, and for Florida Golf Course-2 in Tables 4 and 5. These results may change as we are better able to define the uncertainty associated with the model inputs. Generally, the models tended to over predict the measured concentrations. The amount of over prediction was a function of the time interval the model was run. The largest over predictions occurred over the 20-year run. This finding is significant because EPA's pesticide office is currently developing risk assessment methods requiring 36 year runs as a basis of assessing pesticide risk. For some pesticides, using the lowest set of input parameters, the model predicted fairly well, within a factor of 2-3.

Cost Summary:

Approved Cost Budget: $30,000; anticipated budget $33,375.

Total costs incurred to date:	Labor = $22,374.00
	Expenses and Travel=$ 2,497.38
Matching contributions from Smart & Associates to date:	Labor = $ 5,602.00
Remaining (anticipated budget):	=$8,503.62

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Annual Progress Report

Prepared for:

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November 1, 1996

Introduction

Golf courses face an increasing number of environmental challenges which are motivated by a growing community awareness of environmental issues, a desire by golf course superintendents to manage environmentally friendly courses, and an associated increase in the number and complexity of environmental regulations. One of the primary environmental concerns for golf courses is the potential contamination or degradation of soil or water resources from associated use of chemical fertilizers and pesticides on golf courses, and the harmful effects of chemicals on non-targeted species. Recently, to obtain the necessary permits, proposed new golf courses have been required to demonstrate that no negative environmental impacts will occur as a result of golf course operations. Models that predict the movement of pesticides in surface water and ground water are often used to address issues associated with the amount of exposure non-targeted organisms will receive from pesticide applications. Models are used by golf course superintendents as a method for managing the risks associated with the use of pesticides and to assess future environmental effects over time within the drainage areas potentially impacted by pesticide applications.

In this study we examine watershed scale models for their applicability, accuracy, simplicity of use, and cost effectiveness in predicting the behavior of pesticides at golf courses. Watershed scale models were selected for evaluation because most regulatory decisions, or issues raised during public hearings, are associated with pesticide impacts on a large geographical scale like those defined by the boundary of the golf course drainage areas. In these cases, the major interest lies in the concentration of pesticides at potentially large distances from the point of application. The pesticide concentrations predicted by the models are the focus of debate, not the details of the chemical structure or the properties of the soil system. For regulatory decisions, a model that has high prediction accuracy is desired. The model may be complicated or simplistic, as long as the model predictions are accurate and fit the geographical scale of the golf course.

We refer to these watershed-level models as 'macro-scale' or 'basin level' models. 'Macro-scale' models (e.g., SWAT, SWRRBWQ) provide answers that golf course managers require to assist in management decisions from obtaining permits to demonstrating compliance with regulations.

The opposite of 'macro-scale' models is a 'micro-scale' model. Micro-scale models focus on specific events in the life of a nutrient or pesticide in the watershed. Although the models are useful in describing 'micro-scale' processes such as turf-specific chemical reactions and leaching rates, they are not as useful as 'macro-scale' models for management decisions (they only apply to small areas), and the accuracy of modeled pesticide concentrations is not necessarily enhanced using a 'micro-scale' model.

Study Objectives

The objectives of this project include the following:

1. Review and Evaluate All Candidate Macro Scale Models

The first step in the project was to develop a list of candidate models that may be appropriate for assessing exposure concentrations of pesticides at golf courses. A survey of functioning golf courses provided information on the types and amounts of important data that are typically collected at a golf course. We compared the model input data requirements against typically available data, and selected the most promising models for detailed statistical evaluation. Parameters of interest included soil characteristics, hydrology, weather information, and the ability to model multiple basins and contour patterns on a watershed scale. Model evaluation was completed in May, 1996 and a report was submitted to USGA. Results of that work suggested that SWAT and SWRRBWQ were appropriate models for use at golf courses. Based on this analysis, these models will be further evaluated in this study.

2. Data Collection

We purposefully collected data from functioning golf courses, avoiding a total reliance on experimental field trial information. We wanted to test the ability of the models to accurately predict pesticide concentrations under actual field conditions thus reflecting actual management practices. The field data are used to calibrate the models, identify the range of values the model inputs represent, and test the accuracy and precision of the model. We did collect field trial information generated by Al Smith for the USGA, we will use this information during the selection of appropriate model inputs for specific pesticides.

Inherent in our modeling approach is the explicit characterization of uncertainties in model structure and model input parameter values. These uncertainties will be carried through model simulations, consistent with EPA's probabilistic framework for ecological risk assessment. Model results will be presented with the appropriate descriptive statistics or as conditional probabilities.

3. Model Evaluation.

Our goal is to evaluate model predictions against actual field measurements of pesticide concentrations on golf course property or nearby areas. We are concentrating on surface water runoff values, but may generalize the analysis to groundwater values if appropriate data are available. We will evaluate the accuracy of model predictions on several time steps, including daily, monthly, yearly, and multiple years. Included in the analysis will be an evaluation of model prediction error and whether the actual pesticide measurements fall within the range of model predictions. In addition, we will evaluate the macro-scale models (SWRRBWQ and SWAT) for accuracy, ease of use, and information requirements.

Overview of the Models

The results of the model evaluation step were documented in the May 1995 report to the USGA, Green Section Research committee. Based on that work, the models that appear to have the greatest potential use at golf courses are SWRRBWQ and SWAT. The models are briefly described below.

SWRRBWQ. Simulator for Water Resources in Rural Basins-Water Quality (SWRRBWQ) was developed for simulating hydrologic and related processes in rural basins (Arnold and Williams 1994; Arnold et al. 1989; Williams et al., 1985). The objective of the model is to predict the effect of management decisions on water, sediment, nutrient, and pesticide yields at the outlet of a sub-basin or basin. SWRRBWQ is a comprehensive, continuous simulation model covering aspects of the hydrologic cycle, pond and reservoir storage, sedimentation, crop growth, nutrient cycling, and pesticide fate.

A basin can be divided into a maximum of 10 sub-basins to account for differences in soils, land use, crops, topography, cover, or weather. SWRRBWQ allows for simultaneous computation on each sub-basin and routes the water, sediment, and chemicals from the sub-basin outlets to the basin outlet. It also has a lake water quality component that tracks the fate of pesticides and phosphorus from their initial application on the land to their final deposition in a lake.

The *UTIL* data assembly system provides for interactive data entry. An internal weather generator can simulate precipitation, air temperature, and solar radiation. One set of data can be generated for the entire basin or for each sub-basin. Long- term simulations (100 years) are possible if the weather generator is used. Parameters from the Soils-5 data base and a pesticide database are housed internally in the model.

SWAT. SWAT is a combination of SWRRBWQ and ROTO. ROTO is a water routing model. The addition of the ROTO model to the SWRRBWQ model greatly enhances the routing capabilities of the model.

SWRRBWQ and SWAT were determined to be suitable candidates for the 'macro-model' for assessment of golf course ecosystems because they : (1)are simple to use, (2) have superior runoff algorithms as compared to the other models, (3) allow measured and point source data to be input to the model and routed with simulated flows, and (4) have internally located soils and weather data. Input of data through the utility "UTIL" is a relatively easy and user-friendly process.

Results

Data Sets

The primary challenge presented in this project has been the assembly of a complete database that has been constructed from data obtained at golf courses operating under typical management practices. We require data from golf courses that tested for pesticides in surface waters on a routine basis, and that had measurable concentrations of the pesticides in the field samples. We found that very few golf courses have a routine monitoring program for detection of pesticides in surface waters. Many of the newer courses are implementing monitoring programs, but data are not yet available. We have however, obtained data from the following locations: two golf courses in Florida (USGS 1996), one golf course in British Columbia, and one golf course in Maryland. We have not included the actual names of these courses in this report. The British Columbia and Maryland data were recently received, and have not yet been evaluated. The data from the Maryland golf course has three years of data and appears to provide the single best database for the model evaluation study. In addition to surface water samples, groundwater and well samples at this course showed measurable quantities of pesticides. Based on this data, we may implement a study of the accuracy of model predictions for groundwater and well samples. If possible, we will incorporate PRISM3 runs into our analysis. The PRISM3 analysis will provide a bridge between this project, and a project under the direction of Stu Cohen.

Data from two golf courses in Florida were obtained from the USGS in 1996. The data were part of a study to determine the effects of irrigation with reclaimed water. Data were collected at each golf course four times over a year and were analyzed for 40 pesticides, 17 heavy metals, nutrients, and ionic constituents. Irrigation amounts were also determined. Application rates and locations of pesticides were obtained from the superintendents at the courses. Methods and materials are given in the USGS report. Additional data requirements for our models included soils information, rainfall and basin characteristics. Data were obtained form the SCS and Regional water quality regulatory offices. Daily rainfall data for the study period were input based on data from the nearest weather station. Information about the golf courses was discussed with each superintendent and their expert judgement was used to fill in data gaps, or augment existing information.

The data from the Florida golf courses were input into the SWRRBWQ model. For each model input parameter there was often a range of appropriate values. This range of values is one type of uncertainty in the data set that can lead to model prediction uncertainty. We attempted to assess the uncertainty by bracketing model runs with the highest, lowest, and best set of possible combinations of input values. For example, in the literature, the solubility of acephate ranges from 650,000 to 818,000. In the model, both these numbers were used. The 'best' set of numbers were based on expert opinion, literature values, or both. Table 1 provides an example of these data for acephate runs at the first Florida golf course.

Model Runs

Once the databases were established the SWRRBWQ model was run. A multi-tiered approach was taken in the assessment of the model with the Florida golf course data.

The models were run twice, once for a 2-year simulation and again for a 20-year simulation. The 2-year simulation coincided with the time period of the USGS data collection. Actual rainfall data collected during the period the field measurements were taken was input directly into the model for the 2-year run. For the 20-year simulation, the model's internal weather generator was used. The model outputs were evaluated by comparing predicted concentrations to measured concentrations. Comparisons were made on a daily, monthly, yearly, and multiple year basis. We quickly discovered that the models never predicted a positive pesticide concentration on the exact day a pesticide measurement was recorded in the field. We concluded that establishing model accuracy on a daily time step may be to stringent a requirement for the model given our uncertainty in the rainfall data and other parameters. Therefore, we established other methods for extracting the data from the model outputs as a basis of comparison to the measured values. A summary of these approaches follows:

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Next Steps

The data from the British Columbia golf course and the Maryland golf course will be evaluated. Because of the quality of the Maryland data, we anticipate that it will provide the best evaluation for golf courses. In addition, we may be able to evaluate groundwater and well samples using PRISM3 models with this data.

<u>Completion time</u>. We anticipate having the project completed by February, 1997.

References

Arnold, J.G. and J.R. Williams. 1994. SWRRB-WQ - A watershed scale model for soil and water resources management. USDA, Agricultural Research Service.

Arnold, J.G. , J.R. Williams, A.D. Nicks, and N.B. Sammons. 1989. SWRRB - A basin scale simulation model for soil and water management. Texas A&M University Press.

USGS. 1996. Water Quality, Pesticide Occurrence, and Effects of Irrigation with Reclaimed Water at Golf Courses in Florida. USGS Water-Resources Investigations Report 95-4250. USGS, Tallahassee, FL

Williams, J.R., A.D. Nicks, and J.G. Arnold. 1985. Simulator for water resources in rural basins. J Hydraulic Eng, ACSE 111:970-986.

Table 1. Examples of input parameters to the model. These data were for Acephate at Florida Golf Course-1 (FGC-1). The terms best, lowest, and highest describe inputs that were varied to reflect and characterize uncertainty in the input data sets. Data are preliminary.

	Lowest	Highest	Best
Soils			
Saturated conductance (mm)	100	330	150
Available water capacity (mm)	0.2	0.25	0.25
Bulk density (t/m^3)	0.25	0.50	0.50
Pesticide Characteristics			
Soil partition coefficient	2	2	2
Wash-off fraction	0.5	1	0.7
Application efficiency	0.5	1	0.75
Solubility (ppm)	650,000	818,000	818,000
Half-life (days)	3	3	3
SCS Runoff Curve Number	71	79	71
USLE erosion control practice factor	0.5	0.6	0.5

Table 2. Comparison of model predictions based on a monthly time-step to measured concentrations in surface water from Florida Golf Course-1. Comparisons were made on a monthly basis. The terms best, lowest, and highest describe inputs that were varied to reflect and characterize uncertainty in the input data sets. See Table 2 for an example. Data are preliminary.

Pesticide	Date	Measured ($\mu g/\ell$)	Predicted ($\mu g/\ell$)		
			Best	Lowest	Highest
Pronamide	7/92	1.0	2.47	1.21	2.94
Ethoprop	7/92	7.7	76	1.49	181.72
	9/92	0.54	0	0	0
Fenamiphos	7/92	0.06	1.21	0	1.19
	9/92	0.33	0	0	0
	12/92	0.77	0	0	0
	3/93	0.30	0	0	0.11
Acephate	9/92	21.1	0	0	15.33
	12/92	1.50	0	0	0
Simazine	7/92	0.48	0	0	0
	9/92	0.25	0	0	0
	12/92	5.70	0	0	0
	3/93	38.0	83.69	30.74	23.92
Oryzalin	12/92	2.20	0	0	0

Table 3. Comparison of model predictions based on a monthly time-step to measured concentrations in surface water from Florida Golf Course-1. Comparisons were made from 2 year and 20 year simulations on a monthly basis. The ranges for all monthly predictions generated in each simulation are given. The terms best, lowest, and highest describe inputs that were varied to reflect and characterize uncertainty in the input data sets. See Table 2 for an example. Data are preliminary.

		Predicted (μg/ℓ) from 2-yr simulations			**Predicted (μg/ℓ) from 20-yr simulation**
Pesticide	**Measured(μg/ℓ)**	**Best**	**Lowest**	**Highest**	**20-year best**
Pronamide	1.0	0.96-94.9	0.08-61.8	1.29-126.8	0.21-508.7
Ethoprop	0.54–7.7	75.9	1.49	181.7	0.203-227
Fenamiphos	0.06–0.77	1.21	0	1.19	0.01-0.8
Acephate	1.5–21.1	0	0	15.3	0.4–81.9
Simazine	0.25–38	83.69	30.74	23.92	2.2–110
Oryzalin	2.20	1.43-97.57	1.4-97.5	1.61-97.13	0.007-314.9

Table 4. Comparison of model predictions based on a monthly time-step to measured concentrations in surface water from Florida Golf Course-2. Comparisons were made on a monthly basis. The terms best, lowest, and highest describe inputs that were varied to reflect and characterize uncertainty in the input data sets. See Table 2 for an example. Data are preliminary.

Pesticide	Date	Measured (µg/ℓ)	Predicted (µg/ℓ)		
			Best	Lowest	Highest
Fenamiphos	3/93	3.69	0	0	0
Fonophos	5/92	0.32	2.35	0	21.5
Simazine	1/93	0.08	0	0	0
	3/93	0.17	0	0	0

Table 5. Comparison of model predictions based on a monthly time-step to measured concentrations in surface water from Florida Golf Course-2. Comparisons were made from 2 year and 20 year simulations on a monthly basis. The ranges for all monthly predictions generated in each simulation are given. The terms best, lowest, and highest describe inputs that were varied to reflect and characterize uncertainty in the input data sets. See Table 2 for an example. Data are preliminary.

		Predicted ($\mu g/\ell$) from 2-yr simulations			**Predicted from 20-yr simulation**
Pesticide	**Measured($\mu g/\ell$)**	**Best**	**Lowest**	**Highest**	**20-year best**
Fenamiphos	3.69	7.69-23.69	0.412	8.49-34.3	6.10-44.7
Fonophos	0.32	2.1-7.55	0	8.6-102.6	0.156-5.3
Simazine	0.08-0.17	0	0	0	0