Use of Runoff and Leaching Analysis in Human Health Risk Assessment for USDA Forest Service Nurseries[1]

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Abstract.--Residues from pesticides used at the USDA Forest Service nurseries have the potential to leach into ground water or runoff into surface water resources. The GLEAMS model was used to determine the runoff and leaching potential of the pesticides. The results of the GLEAMS analysis were then used to estimate potential impacts to members of the public from drinking water which may contain pesticide residues.

INTRODUCTION

LABAT-ANDERSON Inc. was contracted by the USDA Forest Service to provide risk assessments to examine the human health impacts of pesticide use at USDA Forest Service nurseries. These risk assessments are included as appendices to the Environmental Impact Statements (EIS's) on nursery pest management practices in each USDA Forest Service region. In addition, LABAT-ANDERSON is providing summary discussions of human health impacts for inclusion in the text of the EIS's.

Risk Assessment

The human health risk assessments that LABAT-ANDERSON completed consisted of three components: hazard analysis, exposure analysis, and risk analysis. These components are explained briefly below.

The hazard analysis provided an overview of the hazard associated with each pesticide to be used in the nursery pest management program. This information was compiled from extensive literature reviews, including all relevant data submitted to the Environmental Protection Agency in support of pesticide registration. This background information was used to obtain the following toxicity reference levels: LD_{50}'s (the amount of pesticide that would kill 50 percent of the test population), systemic and reproductive NOEL's (no-observed-effect levels or the highest dose given during a laboratory study at which no adverse effects were observed), and data about carcinogenicity and mutagenicity.

The exposure analysis identifies potential levels of pesticide exposure that may occur as a result of pesticide use at each nursery. Two human populations may be affected by nursery pesticide use. The first group at risk includes members of the public who live or work near the nursery or who may be present near the nursery during recreational activities. The second group at risk consists of the nursery workers who apply the pesticides and the nursery personnel whose tasks bring them into direct contact with the treated seedlings and soil. In the exposure analysis, potential exposures and resultant doses were estimated for typical and extreme operations. Potential doses from accidents were also estimated. Accidental doses were determined by examining scenarios such as workers spilling or spraying pesticides on their bodies or prematurely entering a treated area.

In the risk analysis portion of the risk assessment, human health risks were evaluated by comparing the estimated doses from pesticide use determined in the exposure analysis section to the laboratory-determined toxicity levels compiled in the hazard analysis section. The risks of threshold effects were calculated in terms of a margin of safety (MOS), which is the ratio of the no-observed-effect level (NOEL) to the dose estimated in the exposure analysis. Risk increases as the MOS becomes smaller, indicating the estimated dose is approaching the laboratory toxicity level. The risks of carcinogenic effects were calculated based on the cancer potency of potentially

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carcinogenic pesticides. The cancer potency represents the increase in likelihood of getting cancer over a lifetime from an increase of 1 mg/kg/day in the dose of the pesticide. Cumulative risks of cancer were calculated by determining exposure to the pesticide over a person's lifetime.

Exposures to Contaminated Water Resources

A variety of scenarios were used in the risk assessment to represent possible ways in which members of the public might be exposed to pesticides used at the USDA Forest Service nurseries. The following represent some of the scenarios: eating garden vegetables contaminated with pesticide drift residues; eating rabbit or grouse which had been dermally exposed to pesticides in a treated seedling bed; direct dermal exposure from pesticide drift; petting a dog or cat which had received dermal exposure to pesticides; and drinking water which had received pesticide drift.

In addition, scenarios were developed in which members of the public may drink water from a stream or local well which contains pesticide residues. The assumption was made that a person may drink two liters of water from one of these sources in a single day. In order to determine the concentration of pesticide residues in the consumed water, a methodology employing the GLEAMS model was developed. The following questions needed to be answered in order to determine the maximum potential pesticide residues concentrations in water:

- What are the pathways for pesticide losses from treated fields and how much pesticide is lost by each pathway?
- Is there a potential for pesticide residues to build-up in soils such that concentrations in water resources increase over time?
- What would be the maximum concentration of pesticide residues in water resources adjacent to the nursery?

The answers to these questions were obtained with the use of the GLEAMS model.

THE GLEAMS MODEL

Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) is a mathematical model developed to evaluate the effects of agricultural management practices on the movement of agricultural chemicals in surface runoff and in the plant root zone (Leonard et al. 1987). The outputs needed from the GLEAMS model for this analysis were: estimates of the mass of pesticide leaving the field in runoff water or adsorbed to sediments; the pesticide mass that would potentially leach below the root zone; and the concentrations of pesticide in each soil layer throughout the observation period. By analyzing these outputs, all the questions posed above could be answered.

The GLEAMS model is made up of three components-the hydrology component, the erosion component, and the pesticides component. The model requires an input file for each component, along with input files for daily rainfall and daily average temperature.

The hydrology component of the GLEAMS model simulates all major processes that occur during a rainstorm including infiltration, soil-water movement, surface-water flow, and evapotranspiration between storms. Applied irrigation water may also be included in the model input, as well as water derived from snow melt. Water balance calculations are done using a storage routing technique that divides the plant root zone into seven layers. Characteristics of the soil profile such as porosity, water retention, and organic matter content are assigned to each soil layer by the model. Upward movement of water from evaporation and plant uptake due to transpiration are also determined layer by layer.

The erosion component of GLEAMS calculates erosion, sediment yield, and particle composition of the sediment. Both the Universal Soil Loss Equation (USLE) and the Williams-modified USLE are used to describe soil detachment and sediment transport separately (Foster et al. 1980. as cited in Knisel 1980). A combination of overland flow, channel flow, and impoundment elements may be selected by the user to characterize the field site. The model also calculates sediment characteristics so that the mass of pesticides that is sorbed to sediments can be predicted by the pesticide component.

The pesticide component of GLEAMS considers mode of application, foliar interception, degradation on plant surfaces and in soils, foliar wash-off, and adsorption and desorption processes. Lumped parameters are used to describe the dissipation of pesticides from soil and plant surfaces. Although degradation rates vary with soil properties (including soil moisture, temperature, pH, organic matter content, and soil type), these relationships are not well enough defined to allow more physically-based equations to be included in the model. Enrichment ratios and partition coefficients are used to calculate the pesticide mass sorbed to the sediment and dissolved in water. A functional relationship is developed between the partition coefficient (K_d) and the soil mass per unit volume of overland flow to better estimate pesticide concentration in the soil phase.

Figure 1 diagrams the physical system and the processes represented in the GLEAMS model. The hydrology and erosion components of GLEAMS are largely unchanged from those of the model on which it is based--Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS-which has been extensively validated (Knisel 1980). The pesticide component of GLEAMS has also been validated for a relatively wide range of climatic conditions and soils, and output was determined to be logical and to reproduce field data within an acceptable range of variability (Leonard et al. 1987; Leonard and Knisel 1988).

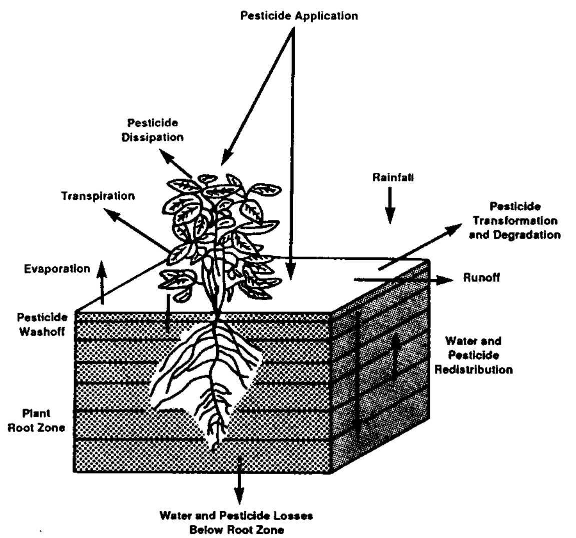

Figure 1.--Physical system and processes represented in the GLEAMS model (Source: Leonard et al. 1987).

Because of the complexity of modeling the many processes involved in determining the fate of pesticides applied to agricultural or forest lands, no models have been developed yet that are absolute predictors of non-point pollutant loads. However, the GLEAMS model has been useful in judging the relative effects of different management practices (Leonard et al. 1987; Leonard and Knisel 1988).

RUNOFF AND LEACHING ANALYSIS AT THE W.W. ASHE NURSERY

The W.W. Ashe Nursery is a USDA Forest Service nursery located near Brooklyn, Mississippi. The nursery has 128 acres dedicated to seedbeds. Of this acreage, only 75 acres are utilized at any time for seedling growth. The nursery grows longleaf, loblolly, shortleaf, and slash pine seedlings which are lifted after approximately one year of growth. The nursery may grow two consecutive seedling crops on a single field prior to planting that field in cover crop for a season or more.

The W.W. Ashe Nursery uses several pesticides to control pest problems in their seedbeds and in other areas of the nursery. The risk assessment completed for the EIS analyzed the use of the following pesticides at the nursery-benomyl, captan, chloropicrin, chlorothalonil, diazinon, glyphosate, methyl bromide, oxyfluorfen, sethoxydim, thiram, and triadimefon. All pesticides, with the exception of thiram, are applied directly to seedling beds; thiram is applied indirectly to the seedbeds since it is applied to seeds prior to sowing. Therefore, all pesticides used at the W.W. Ashe Nursery have the potential to enter the water system and were analyzed using the GLEAMS model. In this paper, the results of the analysis for the fumigants methyl bromide and chloropicrin are not discussed. Due to the volatile nature of these pesticides, he risk assessment was conducted slightly differently.

Methodology

The W.W. Ashe Nursery is adjacent to several water bodies. North of the seedbed area on the nursery property is a small lake used for recreational activities by area residents. No surface drainage from the treated fields enters the lake. To the east and west of the nursery, there are intermittent streams following the nursery boundary. Approximately half of the runoff from the nursery seedbeds drains to each of these streams. Potential impacts to both subsurface and surface water resources were assessed on a storm-by-storm basis from the application of all of the pesticides used at the W.W. Ashe Nursery.

A typical pesticide application schedule provided by the nursery was used in the simulation, and the fall-spring and spring-spring planting schedules were modeled. A fall-spring planting schedule assumed a field was sown in the fall, harvested the following winter, and sown again in the spring. Likewise, a spring-spring planting schedule assumed a field was sown in the spring, harvested in the winter, and sown again in the spring. These schedules indicated the worst-case scenarios for pesticide build-up in the soil. Pesticide application rates are similar for seedlings sown in the fall and in the spring, but the months of application of the pesticides may differ.

The nursery soil is predominantly a McLaurin loamy sand, with Benndale loamy sand and McLaurin-Benndale association soils also present. For modeling purposes, soil characteristics were assumed to be a uniform McLaurin loamy sand throughout the site. The soil has an infiltration rate of approximately 1.45 inches per hour in the root zone, decreasing to 1.1 inches per hour at a depth of 1 to 3 feet (Boyer 1990). The average organic matter content of the soil was determined to be 1.9 percent. Pesticides that leach into soils will have a greater tendency to sorb to soil particles as organic matter increases. Depending on the pesticide's chemical partition coefficient (K_d) and the degradation rate of the pesticide, this will limit the potential for groundwater contamination.

Nursery beds slope about 3 percent and were assigned a Soil Conservation Service runoff curve number of 78, which represents straight row crops and good hydrologic conditions. Runoff from the nursery beds was assumed to drain to the furrows between the beds, and to flow off the field in these furrows.

Daily rainfall and daily average temperature data were obtained from the National Climatic Data Center for Hattiesburg, Mississippi. Data for the years 1985 to 1989 were input into the model. In addition to seasonal precipitation, approximately 20 to 30 inches of water are applied annually to the W.W. Ashe Nursery beds by irrigation. Irrigation was added to the model, based on information about the irrigation schedule during 1988.

The cumulative concentration of each pesticide from all treated areas were estimated immediately downstream of all runoff inputs to each tributary, using mass balance calculations. From topographic mapping, it was determined that a maximum of one-third of the drainage area to either tributary came from the nursery. It was further assumed that two-thirds of the drainage that came from the nursery contained pesticide residuals, if the entire stock is treated with the pesticide at once, and one-third of the drainage that came from the nursery contained pesticide residuals if half of the nursery stock were treated with the pesticide at a time. These assumptions are very conservative, since large portions of the nursery are not treated with any pesticides and at any given time, portions of the seedbeds are in cover crop.

Results of Exposure. Analysis

The GLEAMS model was used to analyze losses of the pesticides from the field and the routes of loss. The results of this analysis are presented in Table 1. The results were based on both a fall and a spring planting schedule. Between 0 and 15.3 percent of each pesticide applied to nursery beds annually is lost in a combination of surface runoff, eroded sediment, and in water that percolates below the root zone. Triadimefon and diazinon exhibited the most total loss, with up to 15.3 percent of the triadimefon applied to a field and up to 3.2 percent of diazinon applied to a field lost in a single growing season. Losses in surface runoff are the major pathway of removal of glyphosate, sethoxydim, benomyl, chlorothalonil, and diazinon from the field. A significant pathway for oxyfluorfen and chlorothalonil loss was through adsorption to eroded sediments. A major pathway of removal of glyphosate, captan, triadimefon, and diazinon was in water that leaches below the plant root zone. Thiram exhibited negligible losses via all pathways during both the fall and spring planting cycles.

Although this analysis indicates the potential for significant portions of several pesticides to leach below the root zone, the contamination of ground water supplies is unlikely for many reasons. First, the ground water table is approximately 100 feet below the surface. It is unlikely that large quantities of the leached pesticides will be

Table l.--Estimated percent of applied pesticide leaving the field with runoff, sediment, and leachate.

	Percent Pesticide Leaving the Field With:		
Pesticide	Runoff	Sediment	Leachate
Fall Planting Schedule			
Benomyl	0.41	0.10	0.09
Captan	0.00[a]	0.00[a]	0.00[a]
Chlorothalonil	0.64	0.37	0.00[a]
Diazinon	1.34	0.05	1.85
Glyphosate	0.46	0.04	0.43
Oxyfluorfen	0.31	0.76	0.00[a]
Sethoxydim	0.39	0.03	0.01
Thiram	0.00[a]	0.00[a]	0.01
Triadimefon	0.85	0.03	14.39
Spring Planting Schedule			
Benomyl	0.07	0.02	0.05
Captan	0.00[a]	0.00[a]	0.54
Chlorothalonil	0.12	0.17	0.00[a]
Diazinon	0.28	0.02	1.48
Glyphosate	0.05	0.01	0.33
Oxyfluorfen	0.06	0.33	0.00[a]
Sethoxydim	0.00[a]	0.00[a]	0.02
Thiram	0.00[a]	0.00[a]	0.00[a]
Triadimefon	0.04	0.00[a]	9.94

[a]Insignificant (less than 0.01 percent).

present at this level. Second, this ground water is actually a perched aquifer, and it is uncertain whether it is hydrologically connected to other aquifers or stream systems. Third, the main drinking water aquifer is 600 to 700 feet below the surface. It is unlikely that a leached pesticide would ever reach this depth, especially since it would most probably be intercepted by the perched aquifer first. Finally, by the time the leachate reaches the groundwater table, additional degradation of the pesticides will have taken place. For these reasons, it was assumed that negligible pesticide residues, attributed by nursery pesticide use, would be found in local well water.

The analysis also examined the potential for pesticide residuals to build up in soil over the years of use at the W.W. Ashe Nursery. For most pesticides, a fall crop cycle, followed by a spring crop cycle on the same field, represented the worst case for residual build up after two crops are grown on a single field. If a third crop (on a spring crop cycle) were planted on the field the following April, just 3 to 4 months after the last crop was lifted, residuals of glyphosate, oxyfluorfen, triadimefon, and diazinon would still be present. If a third crop (on a fall crop cycle) were planted on the field the October following the lifting of the second cycle crop, only residuals of oxyfluorfen and triadimefon would potentially remain. By the time the second crop cycle is lifted, residues of sethoxydim, and captan have already completely disappeared, due in part to the short persistence times in the soil.

In the case of thiram the worst-case conditions were determined to occur after a fall crop/fall crop cycle. However, thiram residues disappear from the soil less than one month after the second crop cycle is lifted.

The analysis of soil residues showed that no pesticide build-up problems would be encountered at the nursery if two seedling crops planted on a single field are followed by a season or more of cover crop in that field. If the field was left in cover crop until the following April (approximately 16 months after the second crop cycle was lifted), no residuals of any pesticide would remain in the soil. That field could then be planted with a spring seedling crop with a negligible chance of pesticide build-up in the soil.

The results of the stream concentration analysis are presented in Table 2. Pesticides were assumed to not degrade after being transported from the edge of the field into the stream, and thus are given as initial concentrations. In reality, pesticides will degrade over time and the concentrations will be further diluted following mixture with additional runoff. Therefore, the values in Table 2 are representative of surface water quality at the most extreme level and these conditions would only be present for a very short time. These concentrations were used in the exposure analysis as the concentrations of pesticide residues in water that might be consumed by a member of the public.

Table 2.--Maximum initial pesticide concentrations in tributaries adjacent to the W.W. Ashe Nursery.

Pesticide	Concentration (ppm)
Benomyl	0.0222
Captan	0.0000
Chlorothalonil	0.0266
Diazinon	0.0889
Glyphosate	0.0086
Oxyfluorfen	0.0068
Sethoxydim	0.0299
Thiram	0.0069
Triadimefon	0.0584

Results of Human Health Risk Analysis

In the risk analysis section of the risk assessment, the dose received by a member of the public from drinking two liters of water was compared to the laboratory-determined NOEL to compute an MOS. In all cases, with one exception, the MOS was computed to be greater than 1,000, indicating the dose received would be at least 1,000 times less than the amount needed to show an effect in laboratory test animals. In the case of diazinon, the MOS computed was 3.6, indicated that the dose received in an extreme situation might be only 3.6 times less than the dose needed to show an effect in laboratory test animals. This indicates a significant risk of health effects associated with drinking two liters of stream water containing diazinon residues. However, the conditions of the analysis were very conservative, making this magnitude of dose highly unlikely. A storm of significant volume (to generate runoff) would have to occur just after a diazinon application and the person would have to drink two liters of water from a point just downstream of the field drainage right after the storm occurred.

An analysis of cancer risk from consuming contaminated stream water was conducted for the pesticides benomyl, captan, chlorothalonil, glyphosate, and oxyfluorfen, which were considered potential carcinogens in this risk assessment. The analysis assumed that over a person's lifetime, that person may receive 30 doses of a single pesticide of the magnitude determined in the exposure analysis. This is very conservative, since the concentrations determined in the exp osure analysis represent a worst-case situation. For all pesticides examined, the cancer risk from this extreme scenario was less than 1 in 1 million.

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