AN EVALUATION OF METHODS FOR DEFINING THE VARIABILITY IN PESTICIDE CONTAMINATION OF GROUNDWATER IN OKLAHOMA

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VARIABILITY IN PESTICIDE CONTAMINATION
OF GROUNDWATER IN OKLAHOMA

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PREFACE

An investigation into assessment of pesticide contamination of groundwater necessitated utilization of existing techniques along with development of new methods. This work resulted in a spatial indexing method for identification of areas susceptible to contamination, and as a parallel effort, an analysis of variability in parameters affecting transport of pesticides through the unsaturated zone. Identification of pesticide and site combinations which might lead to contaminated groundwater was the goal of this research. It is expected that other research projects will be built upon the information established in this work.

I would like to express my sincere gratitude to all the people who assisted me in this work and during my stay at Oklahoma State University. In particular, I am especially indebted to my major adviser, Dr. William F. McTernan, for his original concepts for this research, and for his constant guidance and encouragement. I am also thankful to the other committee members, Dr. Donald R. Snethen, and Dr. John H. Veenstra for their advisement. The support of Dr. Robert K. Hughes, Head of the School of Civil Engineering, was also greatly appreciated.

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CHAPTER I

INTRODUCTION

Extent of the Problem

The use of pesticides on agricultural crops in the United States is a widespread practice. An estimated total of 260,000 tons of pesticides were used agriculturally in 1984 (1). Pesticides, which are designed to alter the life processes of nuisance insects, plants, and disease producing organisms can subsequently pose a threat to human health (2). Although the potential exists for exposure to pesticides from contaminated air and food, consumption of contaminated groundwater may present a highly significant risk due to the long term nature of the exposure.

Groundwater, which is consumed by one half of the people in the United States, is one of the most valuable natural resources (3). Many of the consumers of groundwater are located in rural areas that may have no readily available alternate water supplies. These rural areas are usually subject to the greatest quantities of applied pesticides making them particularly susceptible to groundwater contamination.

Pesticides that leached from agricultural fields to the groundwater had been discovered in 23 states by 1985 (4). The lack of monitoring for specific pesticide compounds in wells in most areas of the country may mask an even more widespread problem. The contamination of groundwater by pesticides may be attributable to a combination of specific site conditions and certain characteristics of the pesticide. Contributing factors may include the pesticide's solubility, sorptive properties, and soil persistence, and the site specific conditions including soil properties, climatic conditions, crop type, and depth to groundwater (5).

Need for Assessment Tools

The "non-point" nature of pesticide contamination of groundwater makes remediation extremely difficult. Application of pesticides on a vast scale and the low concentrations that are found in contaminated aquifers necessitate a strategy unlike traditional groundwater cleanup methods. In addition, contamination may occur even though no pesticides have been detected in the groundwater since transport to the water table may require several years. Therefore, the prevention of contamination by proper pesticide selection and usage are the best solutions. Failure to reduce the contamination of groundwater by pesticides may lead to restrictions or even total bans on particular compounds. This could result in reduced yields for certain agricultural products. Efficient management of natural resources may provide adequate protection for crops without degradation of groundwater reserves.

Regulatory agencies, that are responsible for environmental contamination, face the difficult task of protecting the quality of groundwater without placing overly restrictive regulations on farmers. The least disruptive policy would not apply restrictions to all localities equally, but would consider the site specific characteristics which partially determine the extent of contamination. A standardized method for the determination of pollution susceptible areas and the consequence of applying specific pesticide compounds to these areas could be a basis for regulatory decisions concerning the trade-off between the public's desire to preserve valuable aquifers for future generations, and the farmer's desire to adequately protect his crops with pesticides.

Research Objectives and Structure

Several methods for assessing groundwater contamination susceptibility have been applied on a national scale or with limited data sets (6 ,7). Application of these methods to the state or regional scale, and with complete data sets, would refine and focus their assessment capabilities. The objectives of this research were to evaluate the efficacy of using the existing assessment methods in the state of Oklahoma, and to adapt or develop entirely new methods where appropriate.

The research approach began with a review of the past and present groundwater contamination assessment techniques. Two alternative techniques that were utilized in this effort, specifically indexing and probablistic methods, were examined in further detail. Information required as input to these techniques was collected from a wide variety of sources. The techniques were then broadened by the inclusion of other relevant data sets and by a more accurate representation of data variability. Finally, the efficacy of the methods and their applicability to the regional scale was evaluated.

The goal of these efforts was to develop easily applied methods, utilizing readily available information, that would identify groundwater pesticide contamination susceptibility. The techniques could be useful in a variety of situations. People involved in long range planning for allocation of land resources could utilize the techniques for identification of areas not suitable for farming activities. Restrictions on pesticides could be based upon the highly susceptible areas delineated by these methods. Lastly, the techniques might be used by developers of groundwater resources to determine aquifer contamination susceptibility.

CHAPTER II

REVIEW OF THE LITERATURE

Groundwater Contaminant Modeling

Due to the unique nature of groundwater being a largely unseen phenomenon, theoretical interpretations are often as important as physical investigations. This has lead to the application of numerous modeling techniques to the problem of groundwater contamination in the search for a better understanding of the hydrologic processes that are involved. Successful modeling can not only describe past events but can also be used to predict future behavior. Therefore, modeling is not restricted to research, but may be utilized in the development of solutions to engineering problems.

Types of Models

Deterministic Models

General. Deterministic models attempt to imitate the behavior of physical systems with mathematical expressions that develop cause and effect relationships. The two major categories of deterministic models are analytical models and numerical models.

Analytical Models. A strict interpretation of the definition of deterministic models is followed by analytical modeling techniques which simulate hydrologic processes with formal algorithms composed of differential equations. Analytical methods, although theoretically rigorous, do not allow input of variable parameters that are often present at field sites. This limits their usefulness to homogeneous systems or to one dimensional modeling.

Numerical Models. Utilizing algorithms that are simplified with empirical relationships, numerical models greatly speed solutions and allow for spatial variability in hydrogeologic parameters. Variability is defined by discreetization at specific nodes establishing a finite number of algebraic equations that are solved with matrix techniques. Finite difference and finite elements, which are the two most common numerical models, differ mainly in their placement of the nodes. Numerical methods have been widely used for modeling specific groundwater contamination incidences due to their flexibility and ease of application.

Stochastic Models

In order to derive a more complete description of poorly understood systems, and to quantify the uncertainty inherent in input data, stochastic analysis was developed. Stochastic analysis assumes that the statistical behavior of the system does not change with time, therefore, the historic records may be used in the construction of synthetic sequences. Thus, the chance properties associated with the sequence of events is preserved. The derived synthetic sequence, which is partially random, is analyzed to determine the probability of specific events occurring during any future period of time. Stochastic techniques may be combined with deterministic models thereby increasing the predictive powers of either single technique. Stochastic methods have been most successfully applied to complex, interactive systems that resist modeling by other techniques.

Relative Ranking Methods

The necessity for selection of a suitable site for waste disposal facilities that have the potential to degrade groundwater has lead to the development of relative ranking methods. These techniques determine risk ratings for different sites on the basis of common criteria. Risks are compared on a relative rather than a quantitative scale. The methodologies are often designed to mimic the logic of experienced scientists and engineers who identify and assign values to those factors considered relevant. Parameters that are normally considered by these techniques include site sensitivity factors and contamination severity factors. Each factor is further subdivided into identifiable units which are assigned values from a scale that is indicative of their overall importance. The values for all factors are summed giving a contamination potential score which may be used for site ranking. The value of these techniques arises from their simplicity of utilization and the ease with which input data may be obtained. The relative ranking methods provide useful tools for preliminary selection of sites based upon their potential for groundwater contamination, however they have not been previously applied to a spatial assessment of the potential for pesticide contamination of groundwater.

Specific Examples

Analytical Models

The Pesticide Analytical Model (PESTAN) is an interactive, one-dimensional analytical model that has been validated by laboratory column experiments (8). PESTAN simulates the transport of pesticides in the vertical dimension only, and at a point that is assumed to be representative of an entire field. Drawbacks of PESTAN that are common with most analytical methods include allowance for only one degradation constant and one retardance coefficient for all soil layers (9). Also, rainfall is calculated as an annual average amount so the flushing action of large storms cannot be simulated.

Numerical Models

Pesticide Root Zone Model (PRZM). PRZM is a one-dimensional, finite difference model developed by the Environmental Protection Agency, that predicts the leaching of pesticides from agricultural fields (10). PRZM has flexibility in the consideration of surface land use practices and specific pesticide properties, however, it requires the input of data which may not be readily available (11). Validation of PRZM at depths of less than three meters has been determined from field data in two states (7).

The developers of PRZM desired only to obtain reasonably accurate solutions for leaching of pesticides (10). This allowed the use of certain empirical approaches to simulate natural processes. Infiltration is simulated by the Soil Conservation Service Curve Number approach which allows greater runoff for fine grained soils.

Erosion of soil and adsorbed pesticides is predicted by using the Universal Soil Loss Equation (12). Percolation is simply defined by the two bulk soil moisture holding characteristics known as field capacity and wilting point. Field capacity is the moisture content that soils attain after excess water has completely drained by gravity. Wilting point is the soil and crop dependent parameter defined as the moisture content below which plants are unable to extract water. PRZM takes soil water in excess of the field capacity in a soil compartment and adds it to the next lower compartment. All of the soil column is assumed to drain in one day. The lower limit of the moisture content allowed is the wilting point. Inside a user designated planting depth, the difference between field capacity and wilting point is made available for evapotranspiration. This drainage scheme may be appropriate for permeable soils but it could be very inaccurate for expansive soils. Leaching of pesticides, however, occurs most often in sandy soils and should therefore be adequately modeled (5).

The Pesticide Root Zone Model was primarily designed to predict the leaching from field size areas (10). Simulation of smaller areas increases the error due to the difficulty in defining the spatial variability in soil parameters. However, PRZM has been successfully tested with field data for aldicarb treated sites in New York, Florida, and Wisconsin (5). These tests have demonstrated that a one-dimensional model using data averaged at the field scale will approximately simulate the actual process.

In contradiction to the implied purposes of the writers of PRZM, the model has been used to evaluate the fate and transport of six pesticides in large soil columns over a 30 day period (8). PRZM closely predicted the measured values of leaching for most pesticides. The use of laboratory determined rate constants substantially reduced the error from those obtained from the literature. It was also concluded that calibration of input parameters would allow a more accurate prediction by PRZM in most site specific cases.

Leaching Evaluation of Agricultural Chemicals Handbook (LEACH). LEACH is a series of addressable matrices for direction to specific frequency distributions that indicate the percentage of time that an applied pesticide will leach beyond the root zone per year (13). LEACH is based upon 49,000 runs from the previously mentioned Pesticide Root Zone Model, however, LEACH simplifies the modeling process accomplished by PRZM. The LEACH methodology is based upon 19 representative sites that typify the major crop growing areas in the United States. The LEACH methodology recognizes specific pesticides through the input of retardance and decay coefficients. These coefficients may lead to significant error, however, due to their nonlinear behavior and dependance upon site specific conditions (7). Another weakness of LEACH is that pesticides are tracked only to the base of the root zone. The method implies that pesticide loadings at this point will reach the water table, however, this ignores the attenuation that will take place throughout the remainder of the unsaturated zone. This simplification is only valid for very shallow, unconfined aquifers.

Groundwater Loading Effects of Agricultural Chemicals Handbook (GLEAMS). GLEAMS is a new model that was devised by incorporating a component for vertical flux of pesticides into the existing model known as Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) (14, 15). CREAMS analyzes pesticide runoff from agricultural fields through several empirical formulas which are also utilized to some degree in PRZM. GLEAMS is more sensitive to erosion losses of pesticide than PRZM but otherwise the two models are quite similar.

Stochastic Models

One of the major drawbacks of analytical and numerical models was that variations in input parameters would substantially alter the results. Calibration and validation methods were often used to improve the reliability of the output but a great deal of uncertainty remained. Stochastic modeling extends a deterministic model by covering the entire range of variations for input parameters.

The evolution of groundwater contamination modeling has generally progressed from one-dimensional models to two-dimensional models. In recent years even three-dimensional transport models have been attempted. This added complexity may not be appropriate to pesticide contaminant modeling. Pesticides are normally uniformly applied to a large area of soil that has been partially homogenized by years of plowing and cultivation. Therefore, the lateral movement of pesticide is not the real concern but rather if it will leach deep enough to contaminate the water table. A one-dimensional model applied to field averaged data may be adequate to address this problem at the field scale. If, on the other hand, the concern is with pesticide contamination from larger areas, such as a county, then neither one, two, nor three-dimensional models are appropriate by themselves. It becomes necessary to address the variability in soils, climate, and agricultural practices. Combining a one-dimensional model with Monte Carlo methods defines the inherent variability in large areas without having to resort to massive data bases.

The Monte Carlo technique is a stochastic process that repeatedly models variables that are randomly selected from statistically defined distributions (16). Carsel et al. (7), and Lia and Vevers (17) utilized distributions from actual data sets to apply to the Monte Carlo technique. This development allowed the resultant statistical inferences to apply to a specific situation rather than a general set of conditions. Analysis of the many simulations necessary with the Monte Carlo approach yields probabilistic determinations. This process expands a site specific model into a general purpose planning or screening tool. PRZM has been incorporated into a Monte Carlo simulation to evaluate aldicarb application to corn in Ohio (7). Simulation of only one pesticide, however, limits the usefulness of this effort to demonstration and research.

Relative Ranking Methods

LeGrand's Method. LeGrand (18) established a technique to evaluate the groundwater pollution potential from waste disposal sites through the use of numerical ranking. This system considered hydrogeology, aquifer sensitivity, contamination severity, natural pollution, and engineering modifications. The utility of this method was the ability to select the "best" site among several available sites for a waste disposal facility. LeGrand's method applied readily available data to a simple, weighted ranking scheme in order to evaluate the trade-offs in site selection.

Olivieri's Method. Recently, LeGrand's method was further refined into a technique that considers toxicology and groundwater use, thereby giving a relative measure of risk. Oliveri (19) expanded LeGrand's site selection method into a risk assessment method for existing hazardous material sites. The new method was appropriate for priority ranking of sites requiring remediation. This method was also notable for its identification of the importance of exposure mechanisms to relative ranking analysis.

DRASTIC. In 1985, a relative ranking method was published by the National Water Well Association in conjunction with the Environmental Protection Agency, which considered point sources and the non-point source of pollution consisting of leachates from agriculturally applied pesticides (6). DRASTIC was a general screening tool utilizing existing information to systematically evaluate the pollution potential of hydrogeologic settings. The title of DRASTIC was an acronym relating to the factors that the technique measures which included:

Depth to Water

Net Recharge

Aquifer Media

Soil Media

Topography

Impact of the Vadose Zone

Hydraulic Conductivity.

The practical utility of DRASTIC resulted from modeling it after the LeGrand system. The DRASTIC methodology consists of mappable hydrogeological factors that are assigned weights according to their relative importance. The sum of these weighted factors yields a value which may be used in the comparison of different areas for their potential for groundwater contamination. A panel of experts performing consensus impact estimation selected the various factors and their relative weights.

DRASTIC is normally used for the assessment of the potential for pollution from sources such as landfills or lagoons, but with the utilization of a special set of weights for the hydrogeological factors, the method is applicable to pollution from agricultural pesticides. The agricultural settings give additional weight to the factors of topography and soil media, and less emphasis is given to the vadose zone and hydraulic conductivity of the aquifer. It was apparently assumed that pesticide contamination is dependent upon surface conditions such as runoff and retardance in the upper soil layers, whereas landfills and lagoons normally place contaminants at a deeper position. The weakness of the DRASTIC methodology was that specific land use practices and differently behaving pesticides cannot be evaluated (11).

CHAPTER III

MATERIALS AND METHODS

Spatial Indexing Methods

Objective of Method

Several of the weaknesses of DRASTIC and LEACH, when used as singular assessment methodologies, can be eliminated by combining them into a joint technique. The strengths of each method will make up for the shortcomings of the other if DRASTIC is used to measure the physical properties of a site, and LEACH is used to predict the mobility of specific pesticides. Consideration of water use patterns and the toxicology of pesticides could complete the analysis of the relative risk for assessments requiring these aspects.

Layout of Index

Due to the different and overlapping spatial distributions of the various necessary data sets, such as soil types, aquifer locations, cropping practices, and groundwater usage, an arbitrarily designated grid was favored. The risk from pesticides at each node of the grid was determined. A grid of lines spaced at twenty miles both horizontally and vertically was used to test the developed methods. This arrangement adequately represented spatial variations with minimal requirements for site specific data.

The grid was overlaid on a map of Oklahoma. Nodal points were used for the aggregation of the different data sets. This nodal system resulted in some loss of precision since all hydrogeological conditions existing between the nodes were neglected, however, it was assumed that as an initial effort a twenty mile grid would be adequate for the delineation of trends on a state-wide scale. The grid resulted in a total of 182 nodal points for the state of Oklahoma. In order to coalesce the divergent data needs at each nodal point, a computer spread sheet was employed (20).

Development of Index

The proper selection of the factors to be considered by an assessment index was of vital importance. Exclusion or duplication of an important parameter could unfairly bias the results. Factors that could be addressed by an index includes hydrogeology, pesticide transport, pesticide usage, toxicology of the pesticides, and groundwater usage patterns. The inclusion of any of all of these factors depends upon what the index was designed to measure.

The two basic assessments which were chosen for index development were groundwater pesticide contamination susceptibility, and the risk associated with consumption of pesticide contaminated groundwater. The assessment of groundwater contamination susceptibility was accomplished by consideration of hydrogeology, pesticide usage, and pesticide transport. By combining these with pesticide toxicology and groundwater usage patterns, the assessment of risk was completed. Since the first basic assessment was a subset of the second, their developments will be described concurrently.

The existence of the DRASTIC and LEACH indices provided a means for the assessment of hydrogeology and pesticide transport respectively. Utilizing DRASTIC and LEACH, which are generally accepted techniques, established a base for the development of this more inclusive assessment. The relationship between DRASTIC, LEACH, and another yet to be defined index, was not determined in this research. It was assumed that they were independent and of equal importance. Efforts were made to remove duplication of parameters inherent in the DRASTIC and LEACH techniques, however, it must be recognized that these methods are not entirely precise, and that judgement should be used in the interpretation of the results.

In assessment of risks, the common convention is that risk is a result of exposure to hazards. Without both hazards and exposure, there is no risk. Hazards in a groundwater contamination scenario is the combination of the availability of contaminants at the ground surface and their transport to the water table. The elements that combine to create a risk are graphically presented in Figure 1, and these elements were used to develop a nomenclature for the indices.

The risk associated with exposure to pesticide contaminated groundwater was derived in the form of a Pesticide Risk Index, which was composed of three equally weighted indices named Physical Index, Pesticide Transport Hazard Index, and Exposure Index. The Physical Index partially determined how readily pesticides leached through the unsaturated zone to the groundwater. The Pesticide Transport Hazard Index was a measure of the actual amount of pesticide leached which was dependent upon pesticide application rates and chemical properties. The potential hazard of the pesticides were also considered by the Pesticide Transport Hazard Index. The degree to which humans are exposed to a pesticide hazard was determined by the Exposure Index. By connecting the potential hazard to exposure, the assessment of risk is derived. Therefore, a combination of the above three indices yielded the Pesticide Risk Index.

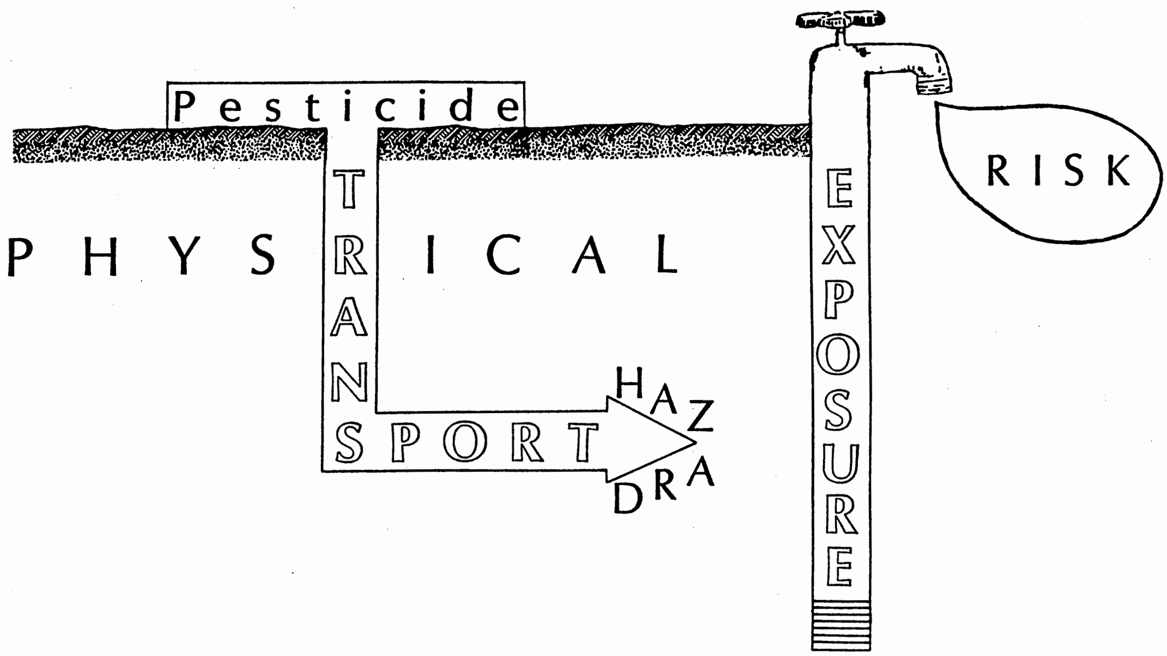


Figure 1. Pesticide Risk

Physical Index

The Physical Index was used to determine the potential for leaching of surface applied chemicals which is dependent on certain hydrogeological factors. The Physical Index was calculated by use of the DRASTIC Agricultural Index. Data for the seven factors were obtained from the following sources: depth to water, and aquifer media was estimated from the Hydrologic Atlas of Oklahoma, which is a series of 27 maps published in 1980 by the U. S. Geological Survey (21); net recharge, and topography were taken from the Water Atlas of Oklahoma (22); vadose zone, and soil media were determined from Benchmark and Key Soils of Oklahoma (23); and representative hydraulic conductivities for the major aquifers in the state were provided by a United States Geological Survey hydrogeologist (24). The major aquifers of the state were the only geologic formations where a hydraulic conductivity was known so all nodes occurring outside of these areas were given the lowest DRASTIC rating for this particular factor since less productive aquifers affect fewer people and a low DRASTIC rank indicates a low pollution hazard potential. Utilizing the DRASTIC methodology, the data obtained at each node was given a rating from one to ten according to its influence upon contamination severity. The rating values were then each multiplied by their respective weights and then summed to estimate the relative pollution potential according to the formula in the DRASTIC users manual:

$$P = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w \quad (1)$$

where

P is the pollution potential

D_r is the rating value for depth to water

D_w is the weight for depth to water

R_r is the rating value for net recharge, etcetera

The weights for the various factors are presented in Table I.

TABLE I

ASSIGNED WEIGHTS FOR AGRICULTURAL DRASTIC INDEX

Feature	Weight
Depth to Water Table	5
Recharge Net	4
Aquifer Media	3
Soil Media	5
Topography	3
Impact of Vadose Zone	4
Conductivity (Hydraulic) Aquifer	2

Source: DRASTIC Manual (1985)

The pollution potential rating derived by the DRASTIC Index was predetermined to be equivalent to the Physical Index, therefore the relative value obtained for the pollution potential at each nodal point was used as the Physical Index value for that node. To illustrate the calculation of the Physical Index, the node in the southwestern corner of Payne County yielded the results shown in Table II. Values obtained for the Physical Index of the state of Oklahoma are presented in Figure 2.

TABLE II

PHYSICAL INDEX AT THE SOUTHWESTERN CORNER OF PAYNE COUNTY

Feature	Value	Rating	Weight	Product
D	25 ft	7	5	35
R	8 in	1	4	4
A	shale	5	3	15
S	silt loam	4	5	20
T	2%	10	3	30
I	shale	2	4	8
C	<100 GPD/ft	1	2	2
			Physical Index	= 114

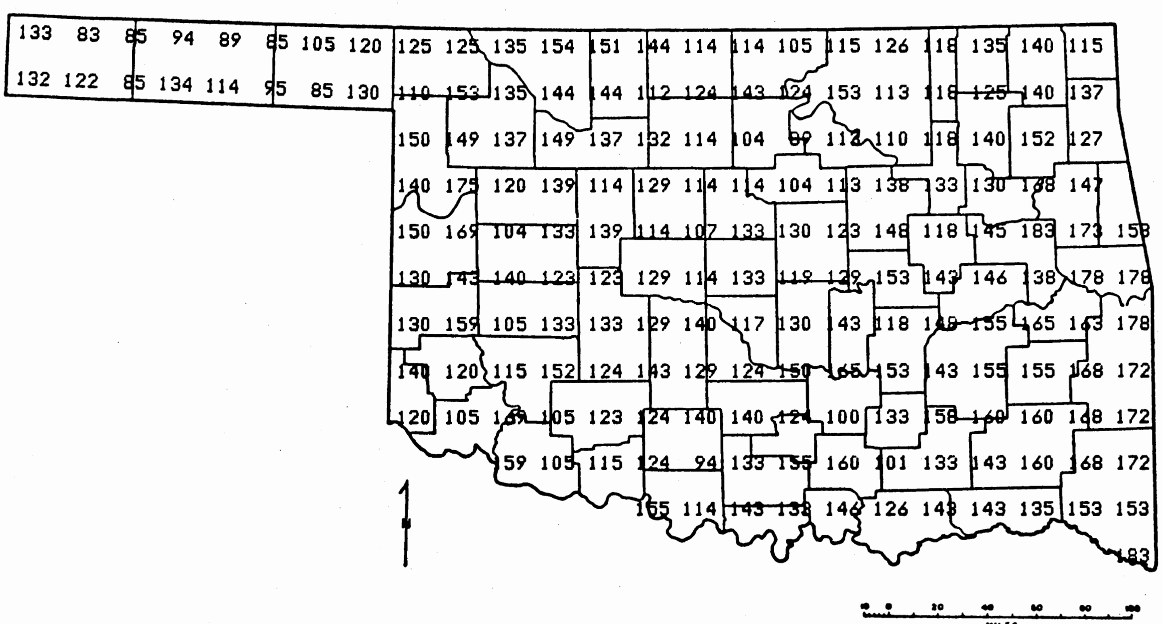


Figure 2. Physical Index Values for Oklahoma

Pesticide Transport Hazard Index

Purpose of Index. The Pesticide Transport Hazard Index was designed to give a relative indication of the amount and toxicity of the pesticides that reach the groundwater. Information that was to be measured by this index included specific pesticide application rates, the ability of the pesticide to leach through the upper soil layers, and the toxicity of the compound.

Pesticide. Due to the lack of specific information on the variability of pesticide usage across the state of Oklahoma, pesticide use for each county was calculated by prorating the total state use according to the amount of each major crop grown in the county. Pesticide use for each of the nine major crops in Oklahoma was recorded in a 1981 survey by the amount of acres treated along with the application rates (25). This survey gave state-wide totals for the major pesticides used on each crop. The exception to this was pesticide totals used on wheat which was further subdivided into the western, central, and eastern thirds of the state. Representative data from this survey are presented in Appendix A.

County cropping information was obtained from Oklahoma Agricultural Statistics for 1981 and representative data showing the total wheat acreage for each county can be seen in Appendix B (26). Pesticides used on wheat were allocated according to the county's crop percentage in the appropriate third of the state. County acres of pesticide treated wheat crops can also be seen in Appendix B. To determine county pesticide usage for all crops other than wheat, the amount of a particular pesticide used on the crop in the entire state was divided among the counties according to the percentage of that crop grown in the county.

In order to determine the amount of pesticide available for leaching at the ground surface, the calculated number of acres treated with a particular pesticide were multiplied by the reported application rate to determine the mass of pesticide used in the county. Pesticides for which no application rates were recorded were given a rounded average rate of 0.5 lbs/acre which was typical for the application of pesticides in the state (25). Calculated pesticide amounts used on all crops are presented in Appendix C.

The method used for determining county totals for all non-wheat crops assumes that pesticides were used uniformly on the crop from one part of the state to another. Climatic differences, time of pesticide applications, regional preferences, and spatially defined infestations may account for variable agricultural practices, however, since the effects of these factors could not be quantitatively determined, and the pesticide use in each county was not directly known, simple proration must suffice.

Pesticide Leaching. Quantifying the amount of applied pesticide that leached through the soil was done with the LEACH methodology. Normally, site specific factors such as soil bulk density and moisture content at field capacity are used in the calculation of the retardance coefficient in the LEACH methodology. Using LEACH in the conventional method, a pesticide applied to one site might be indicated to leach more than the same pesticide applied at another location. This site specific response is typical and it may be attributed to soil properties including texture, organic matter content, mineral fraction, moisture content, and mineral bulk density (27). However, it was desired to manipulate LEACH so that all sites were treated equally since site specific factors had already been taken into account by the Physical Index. In order to prevent duplication of the site specific factors, a constant bulk density was used for all nodes. In this way, LEACH was able to measure the relative mobility of specific pesticides in any soil. A bulk density of 1.2 gm/cm^3 was chosen and this is typical for the range of 1.0 to 1.3 gm/cm^3 for bulk densities of fine grained soils which are predominant in Oklahoma (28). Setting a constant bulk density was not expected to significantly distort the results of the LEACH methodology since a sensitivity analysis performed by the developers indicated that LEACH was most sensitive to K_s, R, and Curve Numbers, with very little sensitivity to bulk density (13).

Determination of the retardance coefficient on a site-independent basis was accomplished by the following set of equations. Retardance was calculated by the formula from the LEACH Handbook:

$$R = 1 + \frac{K_d \cdot P_s}{FC} \qquad (2)$$

where R is the unitless retardance coefficient

K_d is the chemical partition coefficient (cm^3/g of soil)

P_s is the soil bulk density (g/cm^3)

FC is the water content at field capacity (cm^3/cm^3)

Field capacity can be related to bulk density by the regression equation which also is taken from the LEACH Handbook:

$$FC = 1.20 - \left[0.65\ (P_s)\right] \qquad (3)$$

From equations 2 and 3, with the assumed value for bulk density of 1.20 gm/cm^3, retardance can be directly correlated to K_d by

$$R = 1 + \left[2.8571\ (K_d)\right] \qquad (4)$$

Values for K_d and K_s, the decay rate, were obtained from published sources (13, 15, 27). When more than one value was reported for a specific pesticide the value resulting in the worst case of leaching was selected for use in this index (9).

Oklahoma's Pesticides. To adequately address pesticide use in Oklahoma, the twenty most frequently used pesticides were considered. This group of pesticides accounted for 63.2% of the state total in 1981. Of these twenty pesticides, chemical partition coefficients or decay rates could not be found for nine. The remaining eleven pesticides accounted for 55.4% of the total state use, and five of them were the most heavily used pesticides in Oklahoma during 1981 (25). The pesticides significant to Oklahoma are presented in Table III.

LEACH Methodology. LEACH utilizes representative sites classified by major crop types, and climatic and soil characteristics. The site which includes the largest portion of Oklahoma was one of the wheat sites, which covers most of the western half of the state. Since wheat is the major crop in Oklahoma, this site was assumed to adequately represent most agricultural conditions in the state.

Utilizing the LEACH methodology, the address matrix corresponding to the chosen site was entered with the K_s and R values for each of the eleven pesticides. The address matrix identified a cumulative frequency diagram for each pair of K_s and R values.

TABLE III

MAJOR PESTICIDES USED IN OKLAHOMA IN 1981

Trade Name	Common Name	Pounds Applied
1. (Many)	parathion	1,550,440
2. (Many)	methyl parathion	413,193
3. (Many)	2,4-d	409,763
4. Treflan	trifluralin	290,160
5. Cythion	malathion	198,307
6. Prowl	pendimethalin *	153,190
7. Lasso	alachlor * 0.0384	93,441
8. A A trex	atrazine	83,708
9. Furadan	carbofuran	79,029
10. Di-Syston	disulfoton	64,291
11. Banvel	dicamba	60,155
12. Milogard	propazine	59,351
13. Karmex	diuron	55,440
14. Eradicane	R-25788 *	48,158
15. Sencor	metribuzin * 0.0248	47,600
16. Modown	bifenox * 0.142	43,767
17. (Many)	toxaphene * 0.0046 Ks	42,988
18. Roundup	glyphosate *	41,001
19. Terrachlor	quintozene, PCNB *	37,565
20. Cygon	dimethoate * 0.0990	36,869

* Unavailable partition coefficient or decay rate

Source: Pesticide amounts from Criswell (1982)

6- N-(1-ethylpropyl)-3,4-dimethyl-2,6 dinitrobenzenamine.

K_d =

Blank spaces in the address matrix or K_s and R values larger than the given range signified that no predicted potential for leaching below the root zone existed. For pesticides that did have a corresponding cumulative frequency diagram, the median value, which was the percentage of applied pesticide leached that was exceeded 50% of the time, was recorded. For K_s and R values not occurring directly on the values given in the matrix, double interpolation was performed. Table IV shows the matrix with the median leaching values that are representative of Oklahoma. The eleven major pesticides with their respective properties and the percent that they were predicted to leach at the 50^{th} percentile are shown in Table V.

TABLE IV

MEDIAN PERCENTILE LEACHING IN OKLAHOMA

Retardance	Decay Coefficients (K_s)				
Constant (R)	.001	.005	.01	.05	.1
1	85	69	54	13	4
3	73.5	34	16	2	.5
5	72.5	28	9	1	0
20	60	4	1		
50	29	0			

Source: LEACH Handbook (1984)

TABLE V

PESTICIDE PROPERTIES AND LEACHING POTENTIALS

Pesticide	K_s	K_d	R	% Leached
Parathion	0.06	21.9	63.57	0
Methyl Para.	0.2207	12.7	37.29	0
2,4-D	0.07	0.78	3.23	1.31
Treflan	0.004	72.1	207.00	0
Atrazine	0.0063	3.2	10.14	16.26
Banvel	0.0197	0.11	1.31	39.12
Karmex	0.0064	8.9	26.43	0
Milogard	0.0056	3.1	9.86	18.57
Di-Syston	0.1604	32.3	93.29	0
Furadan	0.0079	1.05	4.00	20.27
Malathion	0.4152	34.1	98.43	0

Source: Partition and decay rates from CREAMS Manual (1980)

The cumulative frequency diagrams in LEACH normally have three lines representing three different Soil Conservation Service (SCS) Curve Numbers. This allows the user to tailor the output to his specific site conditions. The cumulative frequency diagrams for the representative site applicable to Oklahoma predicted no differentiation for SCS Curve Numbers as indicated by the overlapping nature of the lines. This allowed continuation of the site-independent application of LEACH. Had the lines not overlapped, it would have been necessary to select one SCS Curve Number to use for all pesticides.

Hazard. The toxicity of pesticides depends on the particular chemical structure, and any assessment of risk related to pesticide exposure should factor in toxic effects (19). The most comprehensive measure of chronic toxicity currently available is the Environmental Protection Agency's Reference Dose (RfD) system. Although they are extrapolated from animal feeding studies and give no indication of oncogenic effects, Reference Doses provide a relative measure of the amount of a chemical that may be assumed to be safely consumed by humans over the long term. Reference Doses were obtained for the significant pesticides (29). Factoring the Reference Doses into the index required that they be transformed to a distribution compatible with the previously described input data. This was necessary because multiplication of the index by the widely distributed Reference Dose values would have overemphasized some of the data. It was desired to maintain the distribution of the Pesticide Transport Hazard Index with that obtained with the DRASTIC Index in order to minimize subsequent interpolation or weighting. Therefore, the Reference Doses were converted to a Transformed Reference Dose (TRfD) by

$$TRfD = (RfD)^{-0.5} \quad (5)$$

Other transform functions were investigated, however, they were not deemed appropriate (7). The selected transform function took the reciprocal of the square root of the Reference Dose. The reciprocal was included because low values of RfD implied a greater degree of toxicity. The square root performed the task of keeping the distribution in the relative range obtained by DRASTIC. The EPA provided Reference Dose of each pesticide that was predicted to leach along with the Transformed Reference Dose values are presented in Table VI.

TABLE VI

PESTICIDE TOXICITY

Pesticide	Reference Dose (mg/Kg/day)	Transformed Reference Dose
Banvel	0.00013	87.70
Furadan	0.005	14.14
Milogard	0.005	14.14
Atrazine	0.00035	53.45
2,4-D	0.01	10.00

Source: Reference Doses from Engler (29)

Calculation of Index. The Pesticide Transport Hazard Index was designed to give a relative indication as to the risk involved in possible exposure to toxic pesticides in the groundwater. Since pesticide usage was not calculated at each node on the state grid, but by counties, the Pesticide Transport Hazard Index must also be determined on a county basis. In order to assign the index value for a county to each node occurring in the county, the land area must be factored into the equation. This provides equal importance to the differently sized counties. The Pesticide Transport Hazard Index (PTHI) for each county was calculated by

$$PTHI = \frac{\Sigma \left[Pest \cdot Tran \cdot TRfD\right]}{A} \cdot (582.247) \qquad (6)$$

where

Pest is the annual amount of a particular pesticide used in a county in pounds of active ingredient

Tran is the fraction of that pesticide that is transported below the root zone as defined by LEACH

TRfD is the hazard of the pesticide as defined by the Transformed Reference Dose toxicity from equation 5

A is the total land area of the county in acres

582.247 is a scalar

All pesticides that were identified by LEACH to be transported past the root zone were used in equation 6. The summation of these pesticide/leaching/toxicity potentials assigned the county's PTHI value. It was predetermined that the Pesticide Transport Hazard Index had an importance equal to that of the Physical Index in the total assessment of risk, so the maximum county value of PTHI was made equal to the maximum nodal value for the Physical Index by use of the scalar in equation 6. The value of this scalar is dependent upon the data and would therefore be different for other circumstances. In order to determine the value of the scalar, the PTHI without the scalar was calculated for each county. The maximum value obtained was divided into the maximum value determined for the Physical Index. This scalar was then multiplied by each PTHI to calculate the final adjusted county values. Appendix D presents the data used to calculate the Pesticide Transport Hazard Index by counties. The PTHI for each county was assigned to all nodes that were inside county lines. Nodes within five miles of county lines were given an average for the adjoining counties. The Pesticide Transport Hazard Index determined from 1981 data for the state of Oklahoma is presented in Figure 3.

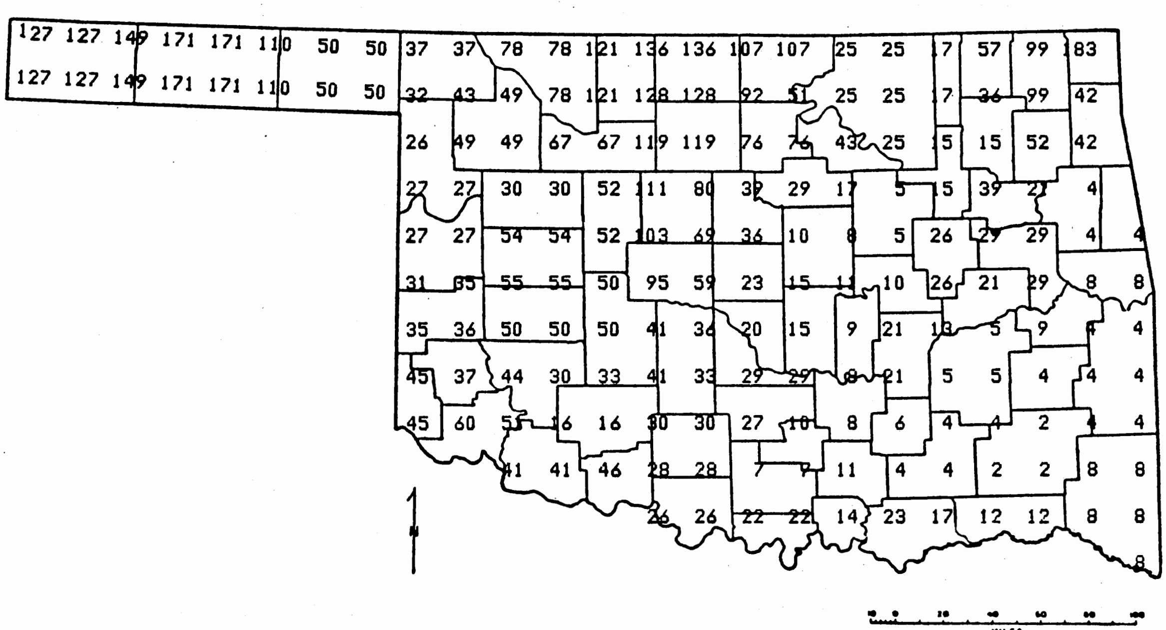


Figure 3. Pesticide Transport Hazard Index Values for Oklahoma

Exposure Index

The third part of the Pesticide Risk Index is the Exposure Index which is a relative measure of the potential for human exposure to pesticide contaminated groundwater. Information that was to be considered by this index included groundwater consumption rates and population totals. The formula used to estimate the Exposure Index was

$$EI = \left[(Pop \cdot 10^{-6}) + 1\right] \cdot GW \cdot 116.6422 \qquad (7)$$

where

EI is the unitless Exposure Index.

Pop is the county's population.

GW is the fraction of municipal water that comes from groundwater sources.

116.6422 is a scalar.

The scalar serves the function of equalizing the Exposure Index's maximum value to that of the Physical Index and Pesticide Transport Hazard Index, allowing equal weight to all three indices. This scalar was calculated similarly to that for the Pesticide Transport Hazard Index. The population total in equation 7 was transformed by multiplication with 10^{-6} and the addition to one. This transformed the county population totals, which ranged from 3,650 to 570,000, to a distribution of 1.0 to 1.6. Therefore, the Exposure Index in the most populated county was 1.6 times higher than that for a sparsely populated county having the same water use patterns. Thus, the population which was at risk became a consideration in the index without dominating the results since it was desired to give more weight to physical factors than to sociological factors. The fraction of municipal water that comes from groundwater was calculated from available sources (22). Data used to calculate the Exposure Index for Oklahoma are shown in Appendix E. Due to the nature of the relevant data, the Exposure Index, like the Pesticide Transport Hazard Index, was also calculated on a county basis and assigned to each node. The Exposure Index for Oklahoma using 1979 water consumption information and 1980 Bureau of Census estimates is presented in Figure 4.

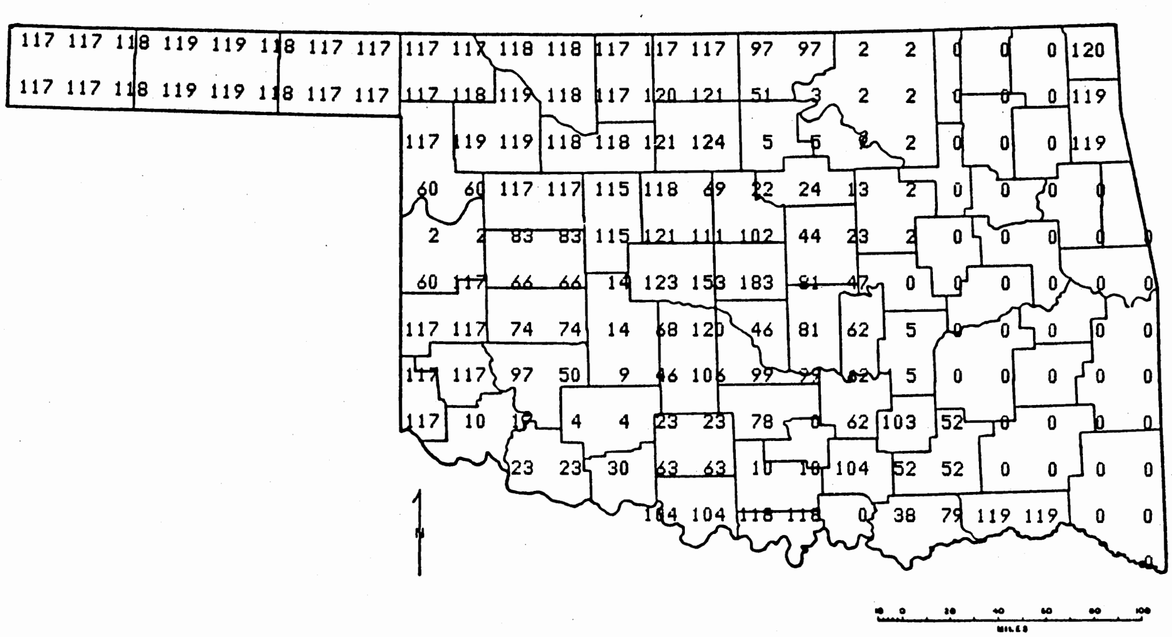


Figure 4. Exposure Index Values for Oklahoma

Summation of Separate Indices

The Pesticide Risk Index which is a relative measure of the risk from human exposure to pesticide contaminated groundwater was calculated by the equation

$$PRI = PI + PTHI + EI \tag{8}$$

where

PRI is the Pesticide Risk Index.

PI is the Physical Index.

Other terms are as previously defined.

The Pesticide Risk Index for the state of Oklahoma is presented in Figure 5.

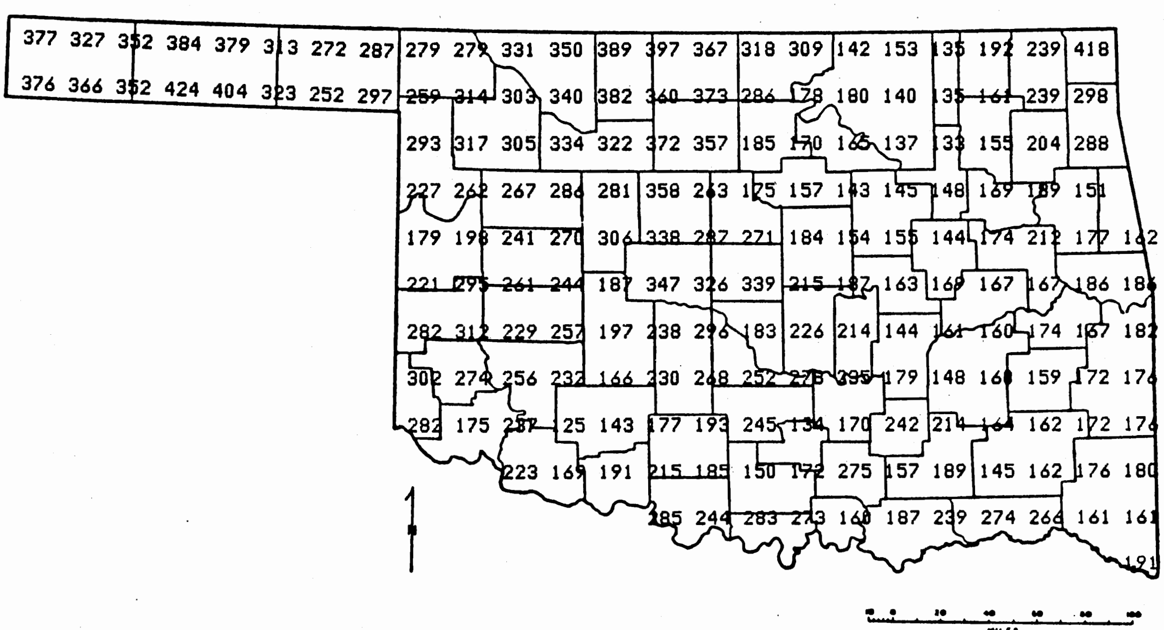


Figure 5. Pesticide Risk Index Values for Oklahoma

<u>Additional Indices</u>

Two other useful observations were obtained by manipulation of the indices. Elimination of sociological and pathological effects, in the form of population density, water use, and toxicology, from the Pesticide Risk Index gave a relative indication of the amount of pesticide that contaminates the groundwater. This partial index, that was entitled Physical Transport Index, consisted of the previous Physical Index, and the Pesticide Transport Hazard Index as calculated by equation 6, but with the toxicity term, TRfD removed. Removal of TRfD from equation 6 necessitated determination of a new scalar so that the index would again be equalized to the Physical Index. The Physical Transport Index (PTI) was determined by

$$PTI = \left\{ \frac{\Sigma \left[Pest \cdot Tran \right]}{A} \cdot (26449.81) \right\} + PI \qquad (9)$$

Data used in the calculations of the PTI for Oklahoma are shown in Appendix F, and the Physical Transport Index is displayed in Figure 6.

A final index, the Physical Transport Hazard Index, provided a measure of the toxicity of pesticides that have leached into the groundwater. It was similar to the Pesticide Risk Index except that no consideration was given to the exposure of contaminated groundwater to humans. The utility of this index would be in the assessment of the present or future value of an aquifer in terms of water quality. The Physical Transport Hazard Index was calculated by a simple addition of the Physical Index and the Pesticide Transport Hazard Index, and the results are displayed in Figure 7.

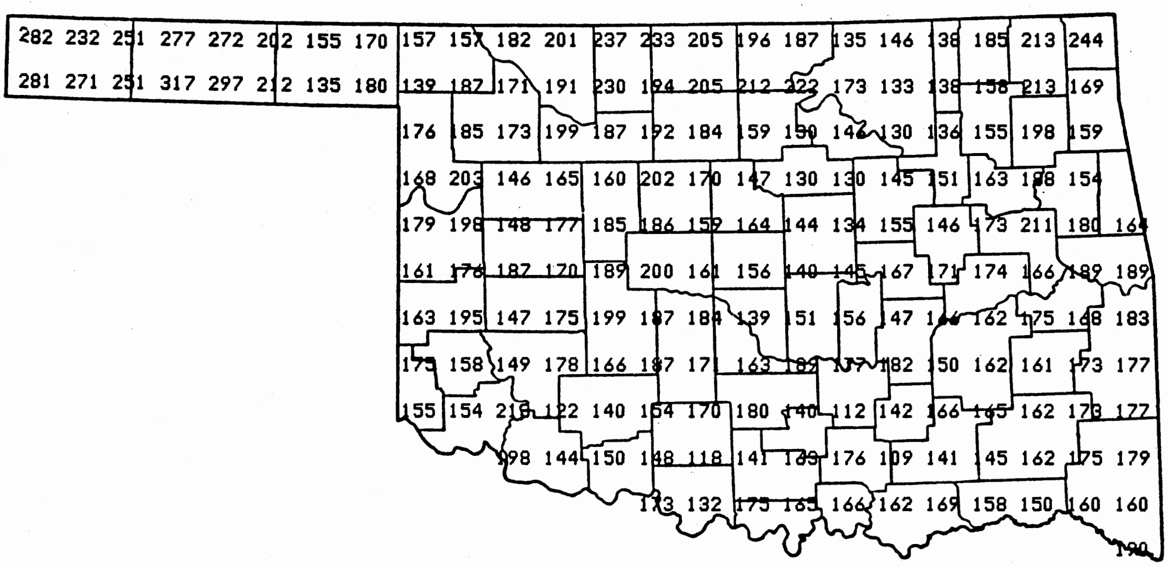


Figure 6. Physical Transport Index Values for Oklahoma

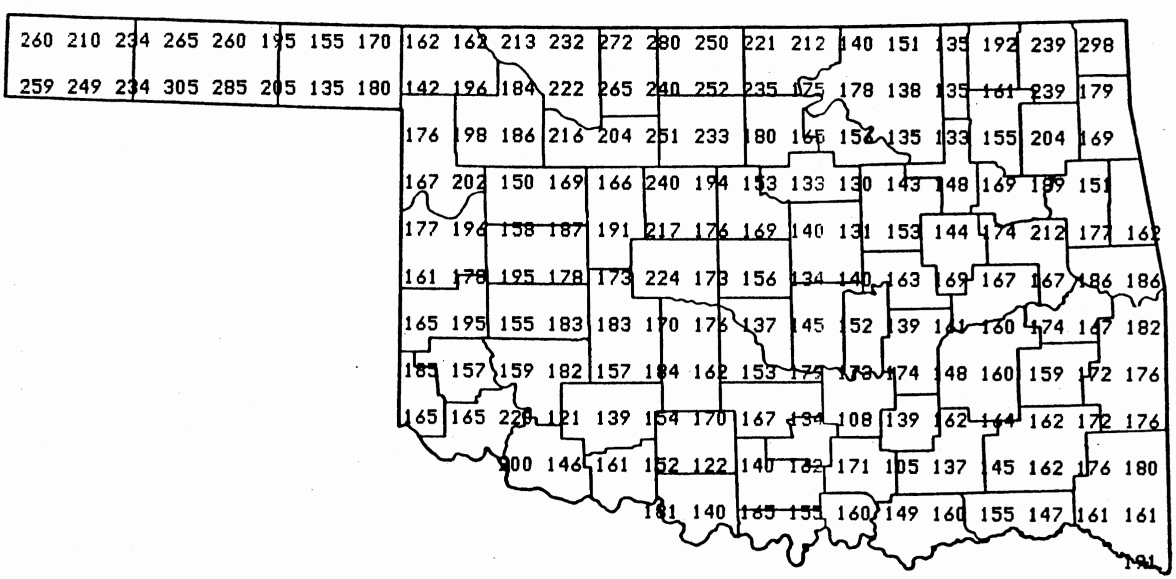


Figure 7. Physical Transport Hazard Index Values for Oklahoma

Summary of Indices

In order to summarize the previously described indices and to give a clear indication of their differences, Table VII presents each index along with its components and assessment capabilities.

TABLE VII

SUMMARY OF INDICES

Index Name	Components	Assessment
Physical Index	DRASTIC Agricultural Index	Aquifer contamination susceptibility from pesticides
Pesticide Transport Hazard Index	Pesticide applications, leachability, and toxicity	Toxicity of pesticides leached to water table
Exposure Index	Groundwater usage patterns and population density	Human exposure to potential groundwater contaminants
Pesticide Risk Index	Physical Index, Pesticide Transport Hazard Index, and Exposure Index	Human risk from pesticide contaminated groundwater
Physical Transport Index	Physical Index, pesticide applications and leachability	Potential for pesticide contamination of groundwater
Physical Transport Hazard Index	Physical Index and Pesticide Transport Hazard Index	Toxicity of pesticide contaminated aquifers

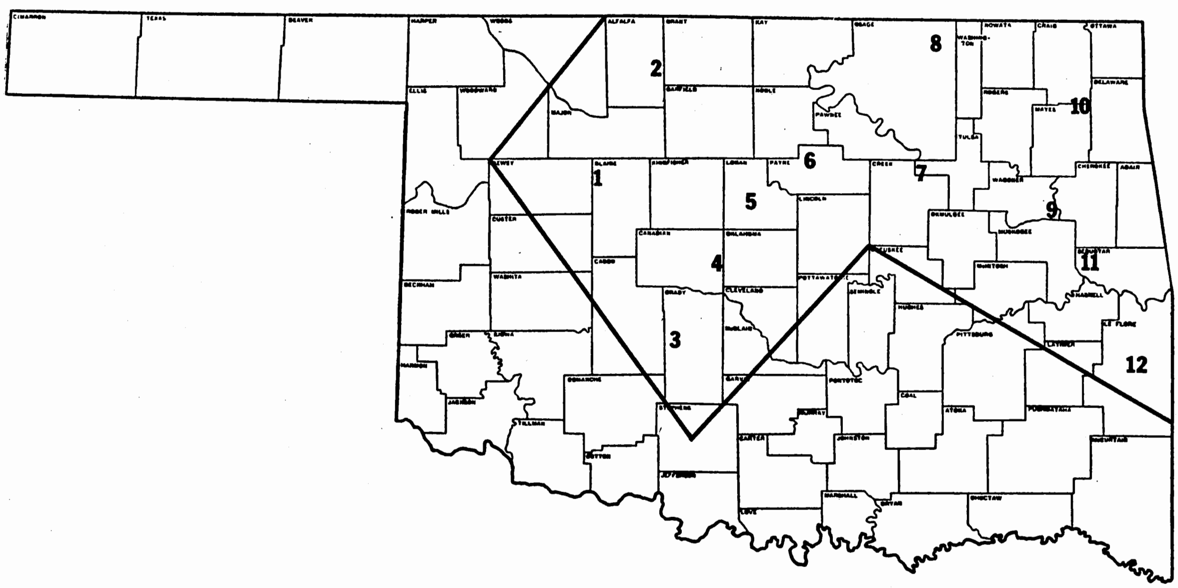
Monte Carlo Analysis

Objective of Method

The second technique used to assess groundwater contamination susceptibility in the state of Oklahoma was the Monte Carlo approach in conjunction with the Pesticide Root Zone Model. This method required specialized information and extensive computer time initially, however, once completed it can be easily applied to a wide variety of situations. Probabilistic analysis of the results permitted prediction of the amount of pesticide that would leach a certain percentage of the time, past a particular depth, for most pesticide and site combinations. This determination could be performed not only on individual field applications of pesticides, but could be extended to predict the results of applying a particular pesticide in any type of soil.

Development of Simulation

Spatial Concerns. Application of the Monte Carlo technique to Oklahoma required that a land area be selected on the basis of availability of data and common agricultural practices. These requirements suggested selection of a relatively small area, however, it was desired to include as much of the state as possible in order to make the results significant. The Oklahoma panhandle and the western edge of the state were eliminated from consideration due to the large amount of irrigation that is applied to crops in that region (22). The southern edge of Oklahoma is an area of little agricultural activity and it had no appropriate climatological reporting stations, so it was also rejected. The remainder of the state, that was used for the Monte Carlo simulation, is shown in Figure 8. PRZM requires the use of daily rainfall, pan evaporation, and average temperature records. Locations of the selected climatological reporting stations are shown in Figure 8. These reporting stations had all of the data required by PRZM, and a period of record of sufficient length.



1. Canton Dam
2. Great Salt Plains Dam
3. Chickasha Experiment Station
4. Lake Overholser
5. Guthrie
6. Stillwater
7. Keystone Dam
8. Hulah Dam
9. Fort Gibson Dam
10. Grand River Dam
11. Tenkiller Ferry Dam
12. Wister Dam

Figure 8. Climatological Reporting Stations in the Simulated Region

<u>Fixed Parameters</u>. Although the Monte Carlo approach is designed to simulate all possible combinations of input parameters, it was possible to fix certain variables in the PRZM input files, without lowering the utility of the approach. This provided a decrease in the number of required simulations. By fixing certain variables, the Monte Carlo technique became a cause and effect simulation which was a novel application for the technique.

Wheat, which is the major crop in Oklahoma, was selected for the simulation. Wheat comprised 62% of all crops in the simulated counties for 1981 (26). The wheat percentage for each county is presented in Figure 9. These values indicated that the predominate agricultural conditions throughout the study area were being adequately addressed.

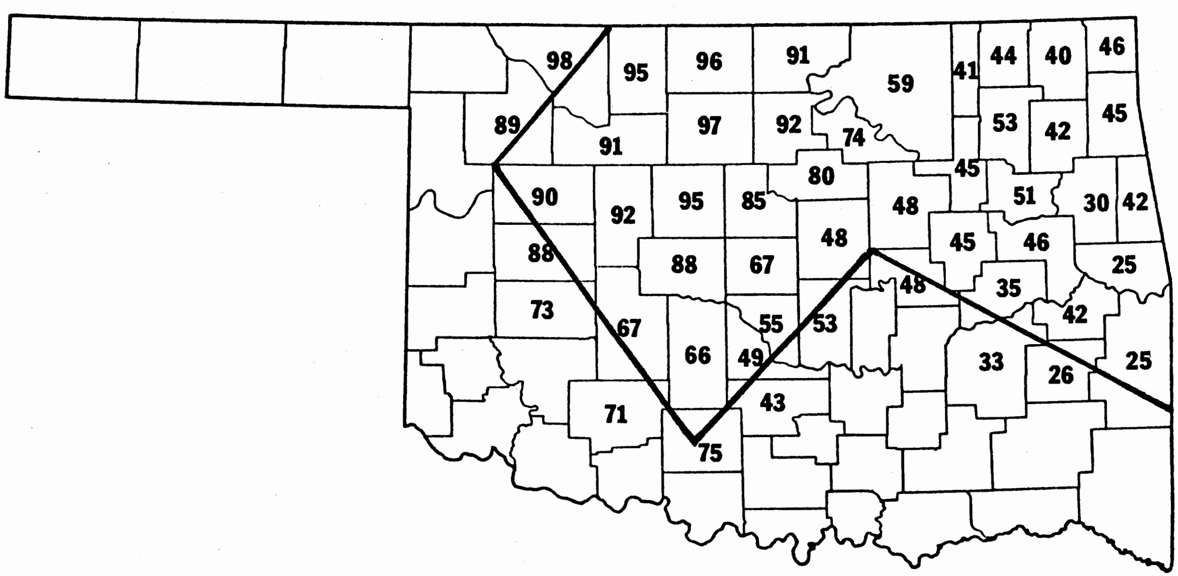


Figure 9. Wheat's Percentage of County's Total Crop Acreage

Wheat is normally planted in the fall and harvested the following summer, and pesticides are applied in either the fall or the spring (30). A comparison of simulations for fall and spring planting showed no significant differences in the results (31). Therefore, for simplification of the simulated period, a spring planting and pesticide application was selected. The planting and pesticide application date that was selected, February 1st, corresponded to the time that wheat revives after winter dormancy (30). The wheat maturation date of April 20th and harvest date of June 15th were taken from published sources (11, 32).

The modeling of erosion losses of adsorbed pesticide by PRZM was not utilized in this simulation. This simplification results in a "worst case" groundwater contamination scenario. The Modified Universal Soil Loss Equation used in PRZM requires determination of several site specific empirical constants that are not consistent with the large scale, non-specific application of the program. To be consistent with the elimination of erosion losses, the pesticide was soil incorporated to a depth of 10 centimeters. This approach was similar to other investigations (7). Other fixed variables, were selected under guidance of the PRZM users manual.

<u>Management Practices</u>. Efficient utilization of the predictive aspects of the Monte Carlo simulation necessitated a simple range of input values that represent possible agricultural practices. It was possible to fairly accurately define an agricultural setting for simulation purposes with three parameters that are among the many required as input to PRZM. The most important site characteristic

was infiltration of rainfall which largely determines the amount of pesticide that will leach into lower soil layers. The Soil Conservation Service classifies soils on the basis of infiltration characteristics with Curve Numbers (CN), and this information is readily available for most soil types. The properties of a pesticide which determines the fate and transport of the compound in the soil are decay and retardance. The rate of decay of the pesticide by chemical and biological processes is described by the decay coefficient (K_s). For simplification, the decay coefficient was assumed to be first ordered and independent of soil type for this simulation.

Retardance of a pesticide by organic and mineral components of the soil could be described by several possible coefficients. The coefficient required by PRZM was K_d, the distribution coefficient, however, this was a soil dependent parameter. It was desired to separate site and pesticide characteristics, so further investigation was necessary.

The organic carbon distribution coefficient (K_{oc}) describes the retardance of a compound in relation to the amount of organic carbon present in the soil. The relationship between K_d and K_{oc} was defined as

$$K_d = (K_{oc}) \cdot (OC) \tag{10}$$

where OC is the percent of organic carbon.

The octanol/water distribution coefficient (K_{ow}), which uses a pesticides absorptive behavior between octanol and water to predict the adsorption to soil, was available for most pesticides. K_{OW} was related to K_{OC} by an equation from the literature (10):

$$\text{Log } (K_{OC}) = [\text{Log } (K_{OW})] - 0.21 \qquad (11)$$

Therefore, K_{OW}, which was a soil independent parameter, was combined with the percent of soil organic carbon to determine a value for K_d.

For simplification, three values each for K_{OC}, K_s, and CN were selected to bracket the range of possible values. Table VIII shows the range of K_{OW} and K_s values that were obtained for the pesticides comprising the twenty most commonly used pesticides in Oklahoma in 1981 for which values were readily obtainable.

As shown in Table VIII the parameter K_{OC} ranged from 34,674 to 1.86, and Ks varied from 0.4152 to 0.0026. Utilizing Table IX, the highest and lowest possible Curve Numbers, 88 and 59 were calculated for the study site. Table X presents the selected values for the three parameters. By comparing Tables VIII and X it can be seen that the selected values for K_s and K_{OC} did not cover the entire range of possible values, however the low end of the range was adequately represented. Values of K_s higher than 0.1, and values of K_{OC} higher than 1200 did not result in significant leaching so these ranges were neglected. The central number of the three values for each of the three parameters represented an approximated median for the high and low numbers. It was assumed that the three parameters had a linear relationship with leaching so that intermediate values of K_s, K_{OC} and CN could be interpolated.

TABLE VIII

PESTICIDE COEFFICIENTS

Pesticide	Log Kow	Koc	Ks
Parathion	3.81	3,981.07	0.0046
Methyl Parathion	3.32	1,288.25	0.0165
2,4-D	2.81	398.11	0.1036
Treflan	4.75	34,673.69	0.0026
Atrazine	2.45	173.78	0.0063
Banvel	0.48	1.86	0.0151
Karmex	2.81	398.11	0.0064
Milogard	2.94	573.03	0.0056
Di-Syston	3.41	1,603.00	0.1604
Furadan	2.44	169.82	0.0040
Malathion	2.89	478.63	0.4152

Source: CREAMS Manual (1980)

TABLE IX

RUNOFF CURVE NUMBERS FOR HYDROLOGIC SOIL-COVER COMPLEXES

Cover			Hydrologic Soil Group			
Land Use	Treatment or Practice	Hydrologic Condition	A	B	C	D
Fallow	Straight Row	-	77	86	91	94
Row Crops	Straight Row	Poor	72	78	85	91
	Straight Row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured and Terraced	Poor	66	74	80	82
	Contoured and Terraced	Good	62	71	78	81
Small grain	Straight Row	Poor	65	76	84	88
	Straight Row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Contoured and Terraced	Poor	61	72	79	82
	Contoured and Terraced	Good	59	70	78	81
Close-seeded legumes or rotation meadow	Straight Row	Poor	66	77	85	89
	Straight Row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured and Terraced	Poor	63	73	80	83
	Contoured and Terraced	Good	51	67	76	80

Source: Soil Conservation Service, USDA. SCS National Engineering Handbook, Section 4, Hydrology (1971).

TABLE X

RANGE OF SELECTED VALUES FOR MANAGEMENT PRACTICES

Item	High	Median	Low
K_{oc}	1200	600	2
K_s	0.1	0.05	0.001
CN	88	73	59

The nine values in Table X formed 27 possible combinations of pesticide and site specific parameters. The range of these combinations was inclusive of all probable conditions to be found in the study site. In an earlier study Carsel determined that 500 years of simulation would achieve a steady state outcome, therefore, it was decided to model 20 years for each combination of fixed parameters resulting in 540 computer runs (7).

Randomized Input Parameters. The basis of most Monte Carlo approaches is to take statistically defined distributions of input parameters and then randomly select values from the distribution for each variable (33). This random selection of variables is performed for every one of a multitude of simulations. Rather than using pre-defined statistical distributions, an alternative was utilized which allowed observed data to define the distribution (17).

Climatological data from 12 reporting stations scattered throughout the area to be simulated were obtained from the Oklahoma Climatological Survey. Gumbel (34) showed that a 25 year data set was sufficient to describe the inherent variability in climatological conditions. Therefore, a 25 year period of record between 1954 and 1978, which was available for most of the selected reporting stations, was obtained. The Keystone Dam reporting station, however, only had a 21 year record. To make Keystone Dam consistent with the other stations, four years of the data were duplicated and added to the file. For these initial efforts the daily data for all 12 stations were averaged to create a single 25 year record that was assumed to be representative of the entire area of simulation. Missing data in individual stations were ignored by an averaging program. Temperature and pan evaporation values should not be appreciably distorted by averaging over a large area, however, rainfall events were noticeably "smoothed" out over a longer time span. Since each year for the period of record was equivalent in significance, they were randomly selected for application to the one year PRZM simulations.

Soil data from two sources were combined, as shown in Figure 10, in order to define Oklahoma's soil distribution in three dimensions (23,35). In order to use the spatial distribution of the soil to define the distribution of the modeling input, the area of each soil in Figure 10 was measured and assigned a percentage of the total area. A file of 100 records for soil properties was created with each soil being represented according to its areal percentage. Records were randomly selected from this file and placed into the

PRZM input files. This selection procedure assumed total correlation of the properties associated with each soil. The randomization of climatic and soil data, and the creation of the input files were combined into the program RANDGEN, which is listed in Appendix G.

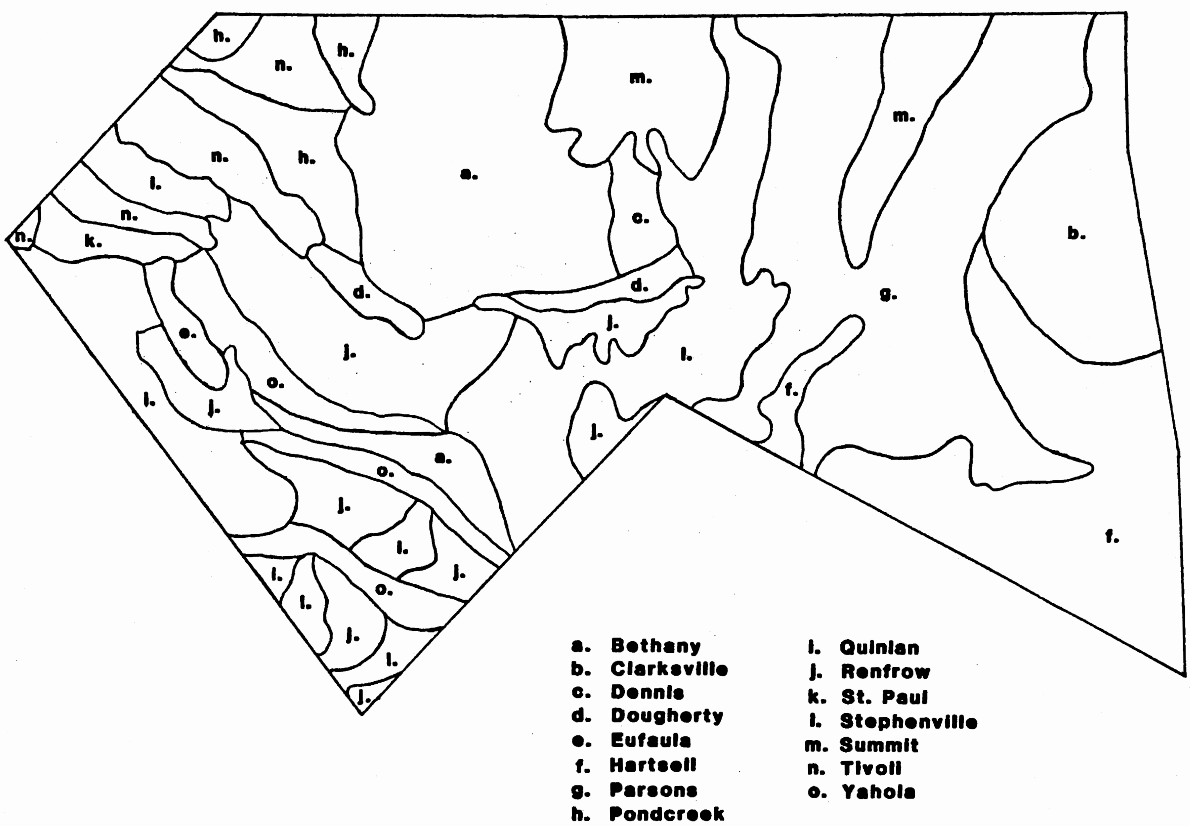
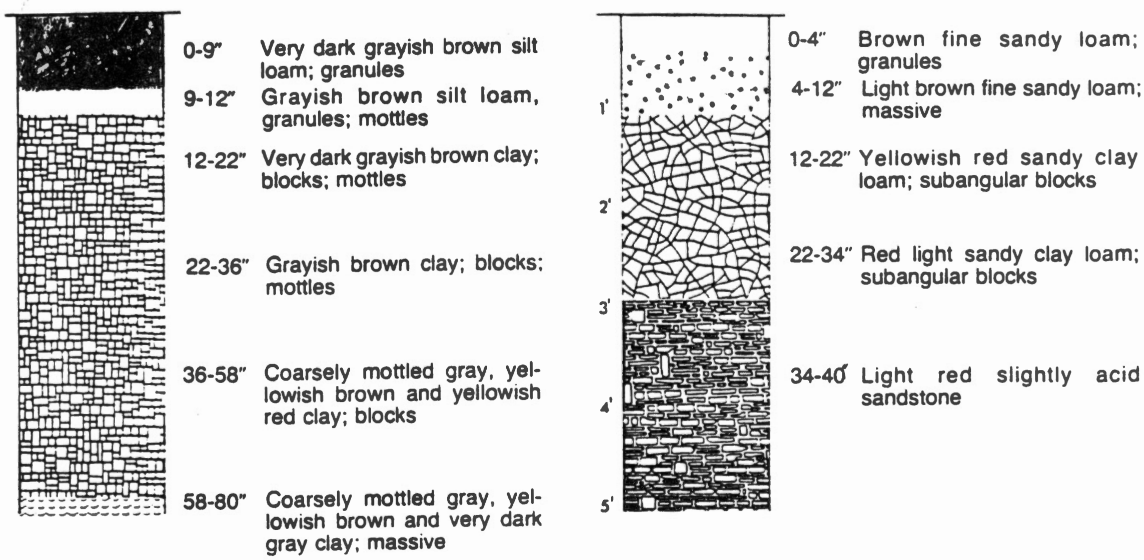


Figure 10. Selected Soils of Oklahoma

PRZM required user defined soil horizons, however, data on subsoil layers varied little throughout the state (23). Schematic soil profiles for soils in Oklahoma typically showed two major soil divisions as in Figure 11. The top horizon was often approximately 12 inches deep with a relatively high organic matter content. Soils extending from the 12 inch depth to six feet, which was the limit for available data, were normally lower in soil organic matter. Therefore, soil properties within the two general horizons were given a weighted average according to the depth of each reported soil layer as shown in Table XI. Properties which were averaged included percent sand and clay, and organic matter content.



Profile of Parsons　　　　Profile of Stephenville

Figure 11. Typical Soil Profiles of Oklahoma

To convert the available data to the required input parameters, the following procedures from the PRZM manual were followed. Bulk density was determined by the following formula:

$$BD = \frac{100}{\frac{OM}{OMBD} + \frac{100 - OM}{MBD}} \tag{12}$$

where

BD is soil bulk density (gm/cm^3)

OM is organic matter content (%)

OMBD is the organic matter bulk density which is a constant 0.224 gm/cm^3

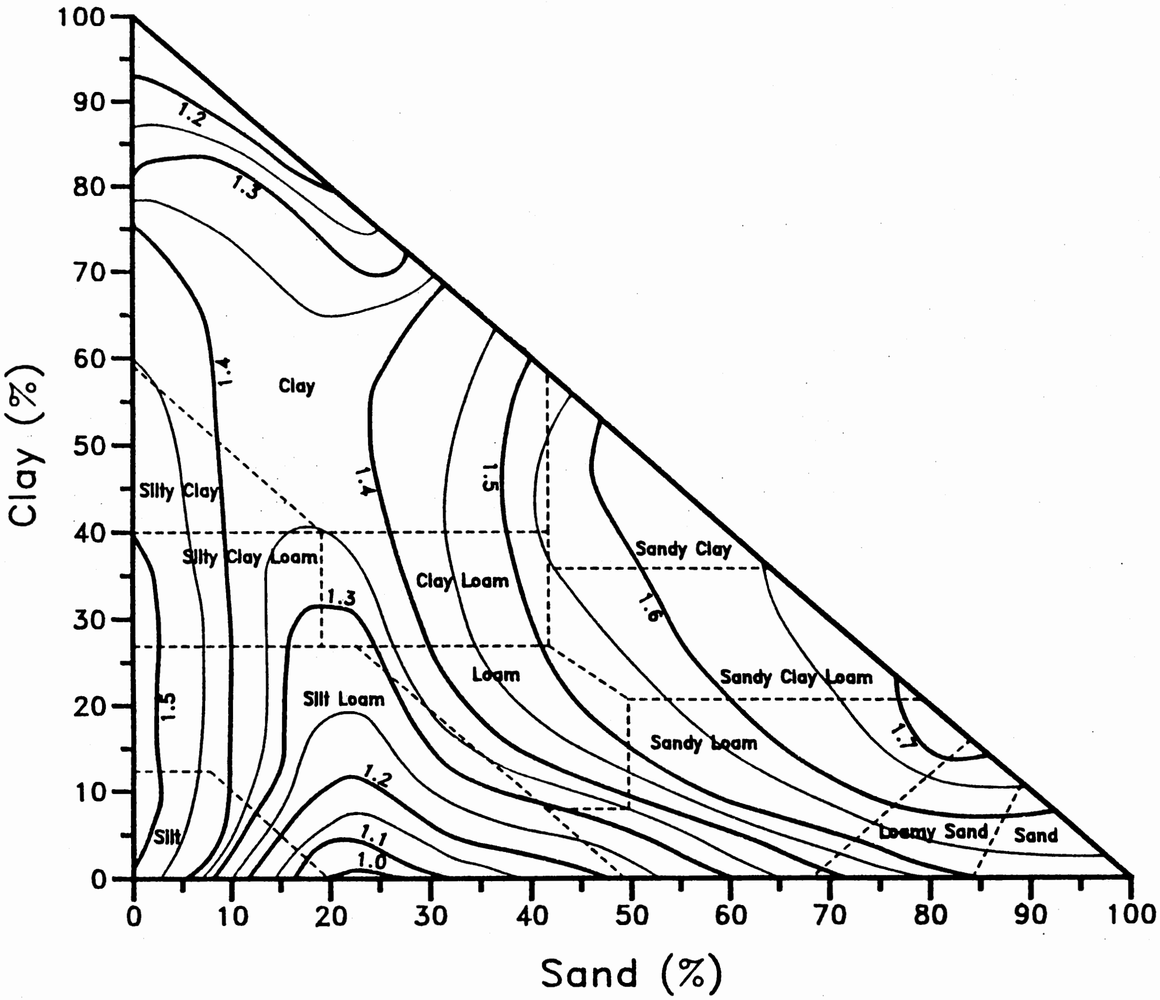
MBD is the mineral bulk density from Figure 12

TABLE XI

TYPICAL SOIL PROPERTIES

Horizon	Depth (inches)	% Sand	% Clay	Organic Matter
		Parsons Silt Loam		
A11	0-6	17.4	12.2	1.98
A12	6-10	18.4	12.4	1.09
A21	10-14	19.5	13.9	0.66
A22	14-16	18.9	25.6	0.86
B21	16-22	7.2	57.8	1.50
B22	22-28	6.6	59.3	1.26
B31	28-37	10.4	49.4	0.55
B32	37-43	14.8	38.5	0.29
C1	43-66	18.2	36.3	0.19
C2	66-84	16.4	40.3	0.10
		Stephenville Fine Sandy Loam		
A1	0-6	82.2	3.7	1.58
A2	6-14	85.4	4.5	0.19
B21T	14-18	68.4	25.5	0.53
B22T	18-27	61.1	34.6	0.53
B3	27-31	70.7	25.6	0.26
R	31-40	79.0	15.7	0.05

Source: F. Gray and M. H. Roozitalab (1974).



Source: Rawls, W.J., U.S. Department of Agriculture, Agricultural Research Service, Beltsville, Maryland

Figure 12. Mineral Bulk Density

Field capacity was derived from the regression formula from the PRZM manual:

$$FC = 0.3486 - (0.0018 \cdot S) + (0.0039 \cdot C) + (0.0228 \cdot OM) - (0.0738 \cdot BD) \quad (13)$$

where

FC is the soil moisture content at field capacity

S is the percent sand

C is the percent clay

Other terms are as previously defined

The wilting point (WP) was calculated by

$$WP = 0.0854 - (0.0004 \cdot S) + (0.0044 \cdot C) + (0.0122 \cdot OM) - (0.0182 \cdot BD) \quad (14)$$

Organic carbon content (OC) was derived from organic matter content by using a conversion constant suggested by the LEACH manual:

$$OC = \frac{OM}{1.7} \quad (15)$$

Bulk density, field capacity, wilting point, organic carbon content, and the area of each of the selected soils is given in Table XII.

The organic carbon content of each of the two soil horizons was multiplied by the K_{oc} of the selected pesticide, as in Equation 11, yielding the K_d for the pesticide and soil combination. This process was performed by the program RANDGEN.

TABLE XII

PROPERTIES OF SELECTED SOILS

Soil Name	Area (%)	Field Capacity	Wilting Point	Bulk Density	Organic Carbon %
Bethany	13	0.32/0.38*	0.14/0.22	1.14/1.33	0.98/0.36
Clarksville	6	0.30/0.40	0.12/0.25	1.37/1.34	0.51/0.24
Dennis	1	0.36/0.39	0.17/0.24	1.13/1.31	1.50/0.39
Dougherty	2	0.12/0.11	0.04/0.06	1.45/1.59	0.38/0.07
Eufaula	1	0.20/0.17	0.11/0.11	1.47/1.62	0.72/0.16
Hartsell	11	0.25/0.24	0.12/0.13	1.35/1.49	0.85/0.23
Parsons	18	0.31/0.40	0.13/0.24	1.26/1.32	0.95/0.32
Pondcreek	4	0.37/0.34	0.18/0.18	1.17/1.29	1.21/0.55
Quinlan	5	0.15/0.15	0.07/0.06	1.49/1.46	0.55/0.29
Renfrow	11	0.37/0.41	0.19/0.25	1.15/1.33	1.54/0.34
St. Paul	1	0.29/0.28	0.14/0.16	1.26/1.41	0.85/0.42
Stephenville	11	0.12/0.21	0.05/0.14	1.48/1.63	0.46/0.19
Summit	7	0.48/0.43	0.26/0.27	1.09/1.35	2.98/0.58
Tivoli	5	0.09/0.08	0.04/0.04	1.51/1.55	0.22/0.07
Yahola	4	0.18/0.21	0.08/0.08	1.41/1.31	0.53/0.27

* Presented data indicates parameter's weighted average for (0 to 12 inches) / (12 to 70) inches of soil depth).

Field capacity is water retained at -0.33 Bar Tension (cm^3/cm^3).

Wilting point is water retained at -15.0 Bar Tension (cm^3/cm^3).

Bulk density in units of g/cm^3.

Sources: F. Gray and M. H. Roozitalab, "Benchmark and Key Soils of Oklahoma", and F. Gray and H. M. Galloway, "Soils of Okla homa".

Since decay properties of pesticides were partially dependent upon soil properties, such as organic matter, it was decided that K_s should be decreased for the second horizon due to the much lower organic matter contents. The mean difference in organic matter content from the first to the second horizon for all of the selected soils was 35%, so the K_s in the lower horizon was reduced by this percentage.

<u>Organization of Computer Simulation</u>. The previously described program RANDGEN combined the selected fixed parameters with a set of randomly selected soil and climatic data. This became the input file for the deterministic PRZM model. Results from the simulations were then analyzed for probability position. The model runs were repeatedly performed so that the predictive capabilities of the simulation would have the required precision. A flow chart of the simulation process is shown in Figure 13.

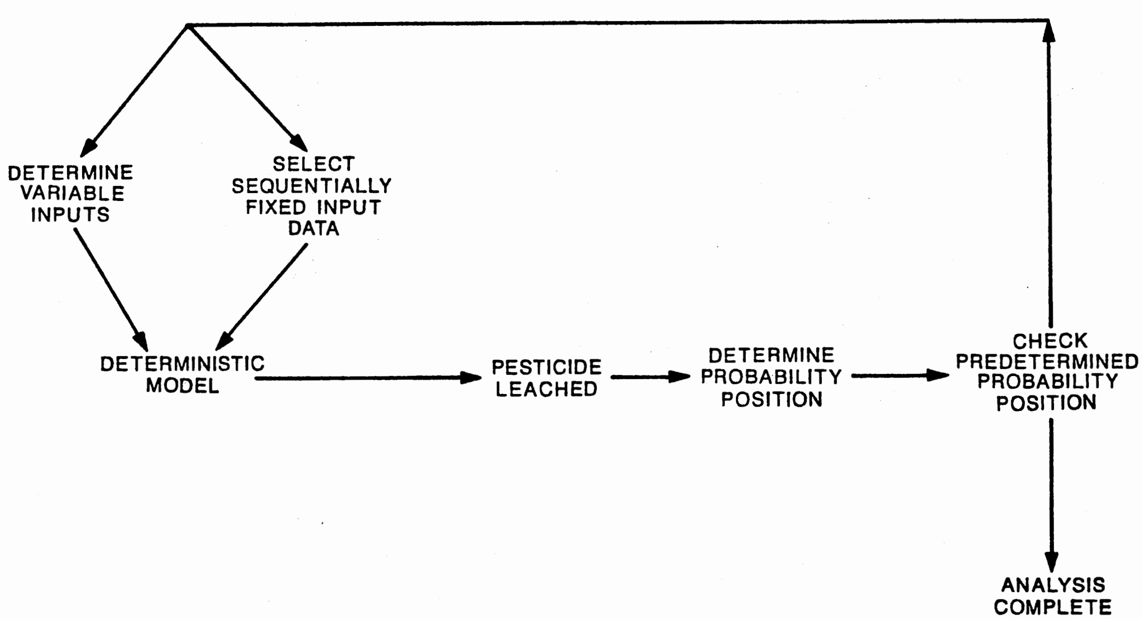


Figure 13. Flow Chart of Monte Carlo Simulation

Design of Output. PRZM calculates water flux in centimeters per day and pesticide flux in grams per centimeter squared per day, for each simulated compartment. Following recommendations from the PRZM manual, 35 compartments were selected for the simulation with each compartment being a node in the one-dimensional finite difference equation. The output most meaningful for assessment of potential leaching was pesticide flux. To be consistent with the chosen soil profiles, pesticide flux past a depth of 12 and 70 inches was recorded for each simulation. A determination of pesticide flux to the water table was not possible in this simulation due to the inability to tie depths of groundwater to other soil parameters, and the possible inappropriateness of PRZM to simulation at greater depths. Therefore, pesticide fluxes at 12 and 70 inches, which are typical depths of topsoils and subsoils in Oklahoma respectively, were used to represent potentials for leaching of pesticides. A pesticide which leaches past 70 inches may or may not contaminate the groundwater, depending upon the depth of the groundwater, the presence of impermeable layers, and other factors. Oklahoma's drinking water aquifers range from the susceptible, extremely shallow water table aquifers to the hundreds of feet deep, highly confined aquifers. Therefore, a pesticide that leaches past 70 inches may be an actual or only a potential threat to the groundwater. A larger pesticide flux at 70 inches was assumed to represent a greater relative threat to the groundwater regardless of its depth.

Analysis of Output. Inferential analysis of unsaturated zone pesticide transport requires a sufficient sample population. Determination of the adequacy of the 540 simulations was provided by probability analysis of successively larger collections of the outputs. The results for the simulations were randomly sorted to disaggregate the initial groupings. The first 27 randomly sorted outputs were sorted in a decreasing order by the amount of pesticide leached. A plotting position (PP) was determined for each output by the formula

$$PP = \frac{100 \cdot m}{n + 1} \tag{16}$$

where

m is the ordered number of the simulation.

n is the sample size.

A 50^{th} and 90^{th} percentile values were recorded for pesticide amounts leached past the 12 inch horizon. The sample size was increased by including the next 27 simulations. The resulting 54 outputs were sorted and percentile values were again determined. At that point, the sample sizes were incrementally increased by 54 simulations until the entire 540 simulations were analyzed.

CHAPTER IV

RESULTS AND DISCUSSION

Pesticide Risk Index

Index Results

The Pesticide Risk Index for Oklahoma ranges from 125 to 424. The value of 125, which is associated with a low risk, occurs in Comanche County which is in southwestern Oklahoma. Conditions present there which lead to the low risk rating include groundwater that is not associated with a major aquifer, a low hydraulic conductivity, very impermeable soils, little municipal water drawn from groundwater supplies, and low pesticide use. The value of 424, which indicates high risk, occurs in Texas County. Factors resulting in this rating include a major aquifer with a high hydraulic conductivity, permeable soils, all municipal water taken from the groundwater, and a very high use of pesticides. This does not mean that the entire county has the potential for serious contamination of groundwater, but that this particular node contained a series of parameters that resulted in a high rating for pollution potential at the nodal point. Other areas of high risk occur in Alfalfa, Grant, Ottawa, Delaware, and Cimarron Counties. Most of these counties are characteristically major agricultural producers, and heavy groundwater consumers. Quite often, factors that make an area favorable for non-irrigated crop production, like a shallow water table and friable soil, also make the area susceptible to groundwater contamination.

To characterize the distribution of the results, several observations were made. For the Pesticide Risk Index values at all 182 nodal points in Oklahoma, the mean was 236, the median was 227, the standard deviation was 76, and the coefficient of variation was 32. Figure 14 presents a frequency histogram of the Pesticide Risk Index which indicates a bimodal distribution.

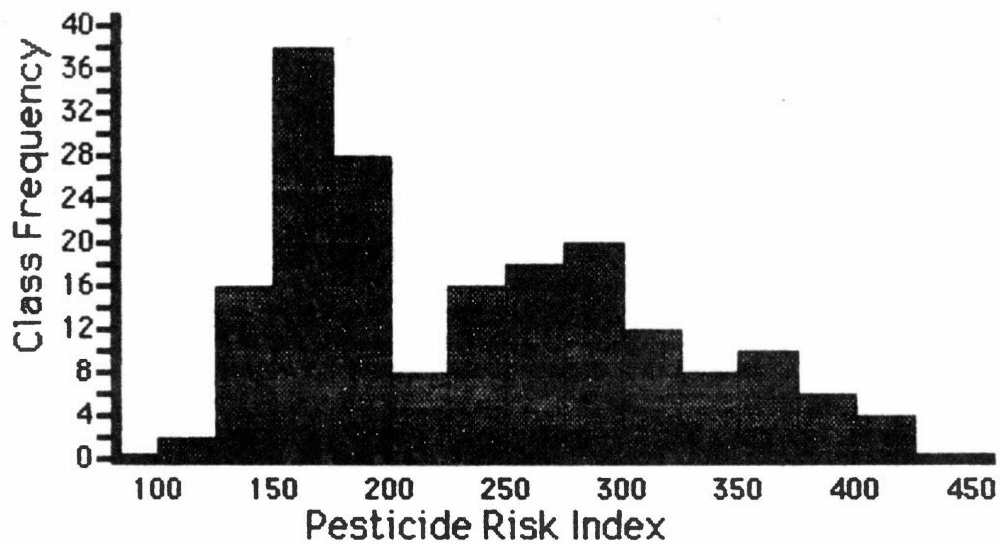


Figure 14. Frequency Histogram of Index

A sensitivity analysis determines how much each factor contributes to the final results. The sensitivity of the Pesticide Risk Index to the contributing sub-indices appears in Table XIII.

The nodes having the ten highest values for the Pesticide Risk Index had relatively equally balanced compositions of the three sub-indices, representing an average of 30%, 32%, and 38% of the total indicies. The lowest ten nodes were predominantly composed of the Physical Index, that is 84% of their total index represents contamination susceptibility, whereas the Exposure Index in the low nodes was very small. This was expected since utilization of groundwater in a particular area is normally either considerable or practically nonexistent. Agricultural activity also tends to have a distribution similar to groundwater usage. Therefore, by generalizing that western Oklahoma has high groundwater consumption and agricultural activity, whereas eastern Oklahoma has little of either, the occurrence of high and low index values in the western and eastern portions of the state respectively was predicted. The Pesticide Risk Index resulted in most nodes having high or low values, and only a few nodes with medium range values due to the above described distributions of agricultural activity and groundwater usage, and this resulted in the bi-modal distribution of the output for the index.

The sensitivity analysis for the ten nodes picked at random shows most sensitivity to the Physical Index, on the order of 66% of the total, however, the Physical Index was not the controlling factor for reasons explained in the following section.

TABLE XIII

SENSITIVITY ANALYSIS FOR PESTICIDE RISK INDEX

Nodes	Physical Index	Pesticide Transport Hazard Index	Exposure Index
Ten Highest	32%	38%	30%
Ten Lowest	84%	14%	2%
Ten Random	66%	14%	20%

Index Interpretation

In order to aid interpretation, the Pesticide Risk Index along with the three indices which form it were shaded to emphasize higher valued areas and are presented in Figures 15 through 18. Examination of these figures shows that the Pesticide Transport Hazard Index, Figure 16, and the Exposure Index, Figure 17, both resemble the Pesticide Risk Index, Figure 18, in areas of emphasis. These three indices all have high values in particular areas of the state including the panhandle, the northeastern and southwestern corners, and a large area in the northern-central region.

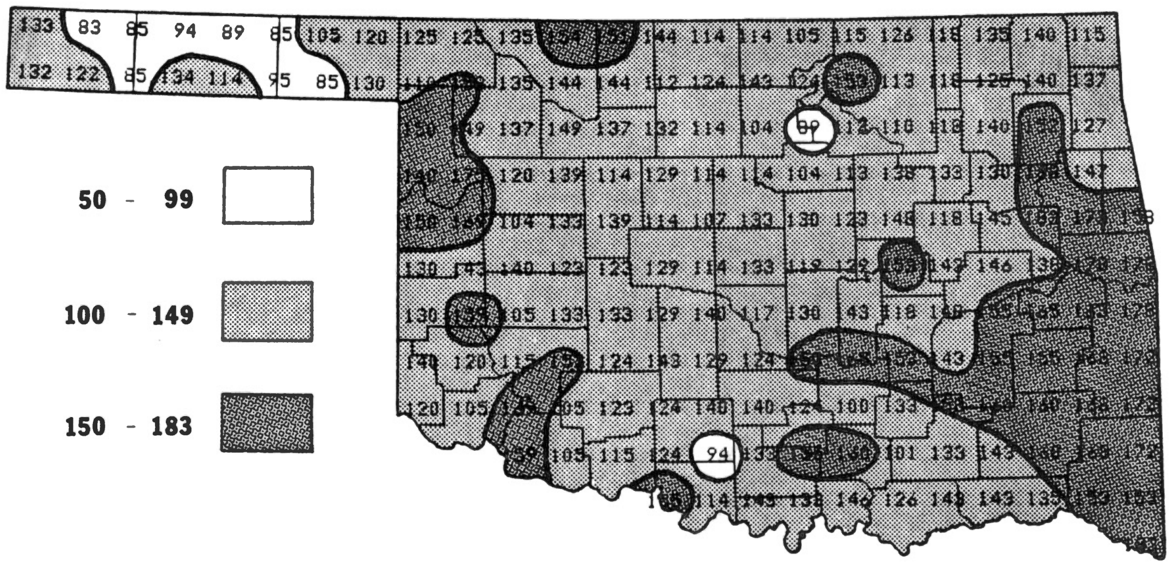


Figure 15. Highlighted Physical Index

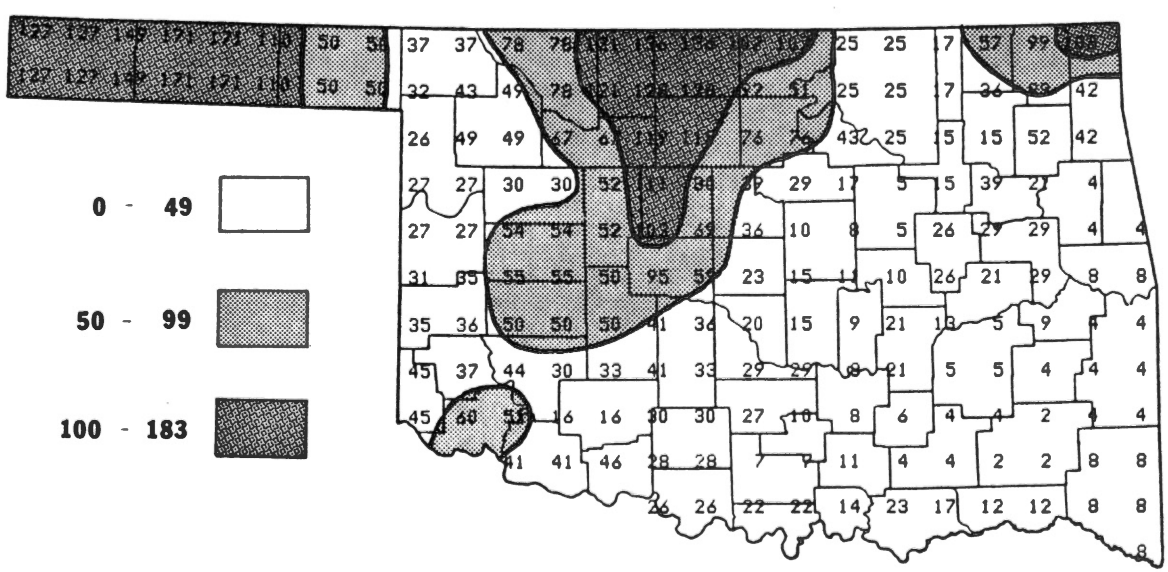


Figure 16. Highlighted Pesticide Transport Hazard Index

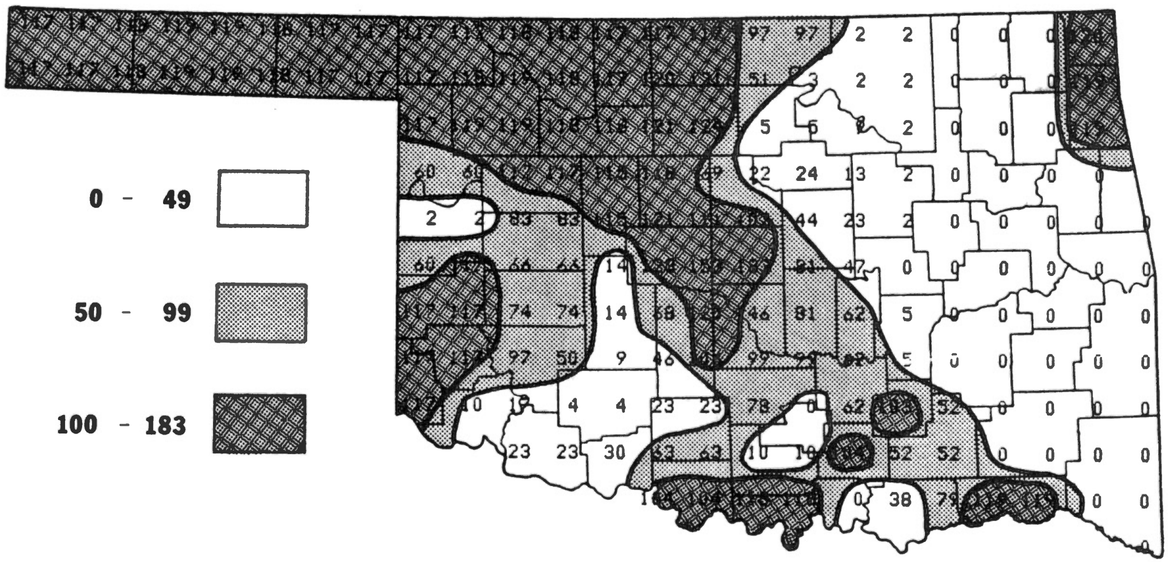


Figure 17. Highlighted Exposure Index

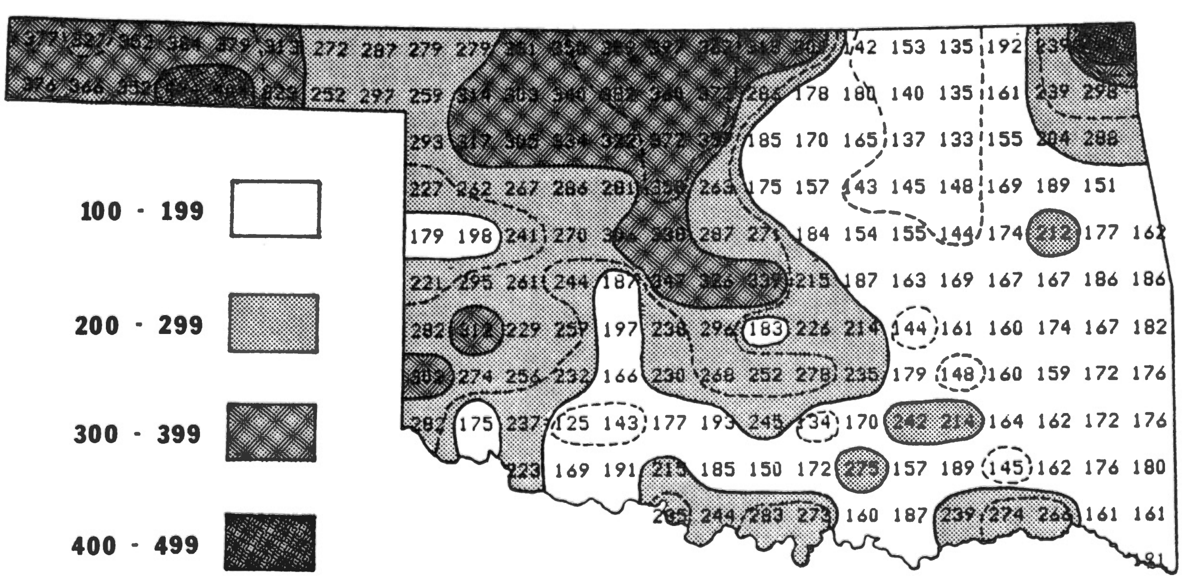


Figure 18. Highlighted Pesticide Risk Index

Examination of the Physical Index, Figure 15, shows a pattern of behavior unlike that of the other indices. A large area of pesticide contamination susceptibility occured in the southeastern corner of the state, but the low pesticide and groundwater usage in this region resulted in a low Pesticide Risk Index. Several other areas of high susceptibility present in the Physical Index did not receive representation in the Pesticide Risk Index. This was partly due to the narrower range of values in the Physical Index as compared to the Exposure Index and the Pesticide Transport Hazard Index. Also, since the Pesticide Transport Hazard Index and the Exposure Index emphasized the same areas, their combined effect overwhelmed that of the Physical Index.

Although the Physical Index was not heavily influencing the final results, certain influences can be seen in the Pesticide Risk Index, such as greater weight to the two nodes in southern Texas County and to the nodes located in the alluvial aquifer between Jackson and Tillman Counties. However, all variations in the Physical Index, the Exposure Index, and the Pesticide Transport Hazard Index must affect the Pesticide Risk Index to some extent since the latter is the simple summation of the former three.

The Pesticide Risk Index for Oklahoma shows four areas of high risk. The largest area was in the northern central part of the state and was the result of high levels of toxic pesticides that were predicted to leach, and the heavy reliance on groundwater in this area. The Physical Index contains only moderate values in most of this region so susceptibility to contamination should not be a widespread concern there. There was, however, two counties in this area, Woods and Alfalfa Counties, that presented a moderately high Physical Index due to the presence of several alluvial aquifers. Therefore, the possibility exists for human exposure to pesticide contaminated groundwater in this region. A specific instance of drinking water extraction from a shallow alluvial aquifer which is near agricultural production in Alfalfa County is cautioned against due to the high risk.

Another area of Oklahoma having a high Pesticide Risk Index was the panhandle. Like the previously described area, this was due to the heavy pesticide and groundwater usage. The panhandle, however, has the lowest Physical Index in Oklahoma as a result of the depth to the aquifer and the impermeable aquifer and soil media. Therefore, contamination was not indicated by the index but may be present. Irrigation, which was not considered by the index complicates the situation further, therefore additional research is necessary before inferences concerning the panhandle can be made.

The next area of concern was the northeastern corner of the state. Ottawa County had the highest Pesticide Transport Index rating in Oklahoma along with a very high Exposure Index. However, as suggested by the Physical Index, this region was not highly susceptible to pesticide contamination since the majority of the water supply originates in deep and confined aquifers. On the other hand, shallow wells in rural areas of Ottawa County may pose a health hazard. Analysis for pesticide compounds in the private wells of this county as well as in the vadose zone, should clarify the hazards.

The final area designated by the Pesticide Risk Index was in the southwestern corner of Oklahoma where alluvial aquifers again increase the contamination susceptibility. Pesticide use in this area was only moderate, however, as before, separate factors might combine to create isolated pockets of high risk along the alluvial aquifers of this region.

The output of the Pesticide Risk Index should reflect the risk of human exposure to pesticides in groundwater. A higher risk would be expected in areas of major aquifers, agricultural activity, or high groundwater consumption. Correlation of risk to major aquifers can be evaluated by comparing Figure 18 with Figure 19 where significant similarities are observed.

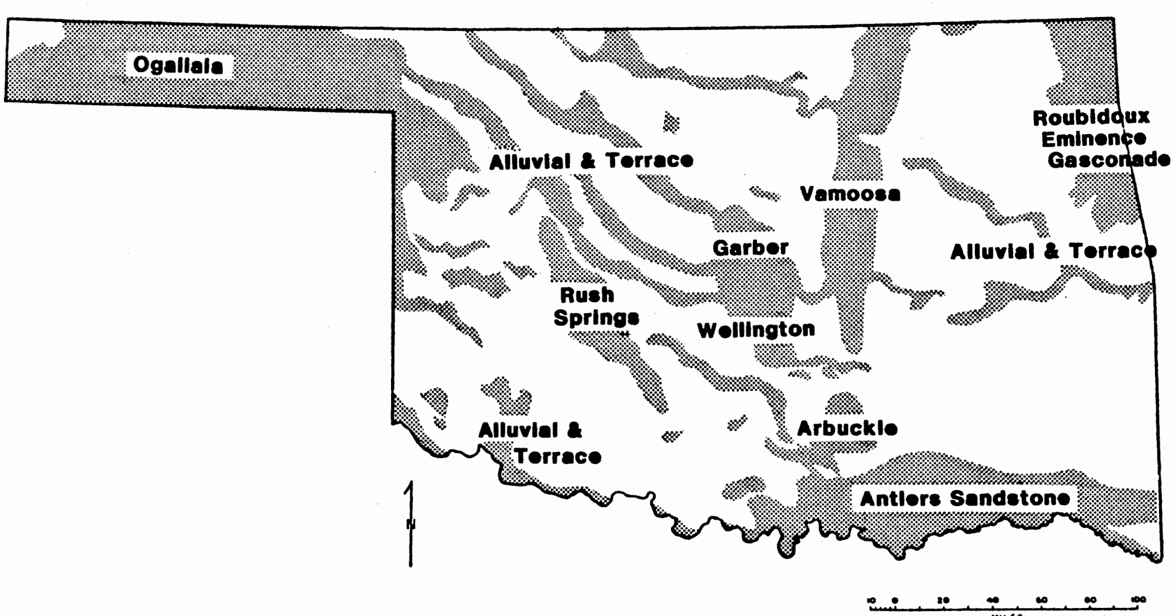


Figure 19. Major Aquifers of Oklahoma

Major aquifers, agricultural activity, and heavy groundwater consumption appears to correlate to high risk fairly consistently. Conversely, areas of dense populations do not necessarily correlate to the index. Tulsa County, which is the most densely populated county in the state, has a very low Pesticide Risk Index due in part to the lack of significant agriculture and the total reliance on surface water for municipal water supplies. However, the second most densely populated county, Oklahoma County, does have a high Pesticide Risk Index attributable to the large amount of groundwater consumed. By comparing Figures 18 and 19, it can be seen that the major aquifers occur in areas of high risk except for the Vamoosa formation which extends from Osage County to Seminole County in the eastern central region of the state. The lack of risk may be explained by the small percentage of water drawn from this large aquifer. Thus, it appears that the Pesticide Risk Index quantitatively measures the relevant factors with their associated importance.

Sources of Error

Sources of error for the Pesticide Risk Index can be grouped into three categories. Arbitrary layout of nodes and the determination of hydrogeological factors at the nodal points may lead to significant distortion of results. This could be rectified by finer discreetization of the grid. Another category for sources of error includes the data. Uncertainty is associated with pesticide use, water consumption, hydraulic conductivity, vadose zone media, depth to water, and other physical factors. Also, the pesticide's descriptive constants, K_d, K_s, and RfD are more potential sources of error. The final category of error is the Pesticide Risk Index itself. Neither DRASTIC nor LEACH are without uncertainty, and the transform functions and weights developed in this research may cause significant error. Calibration of the index through further applications would result in better assessment capabilities.

Additional Indices

Physical Transport Index

The Physical Transport Index as displayed in Figure 20 gave a relative indication of the amount of pesticide that may contaminate the groundwater.

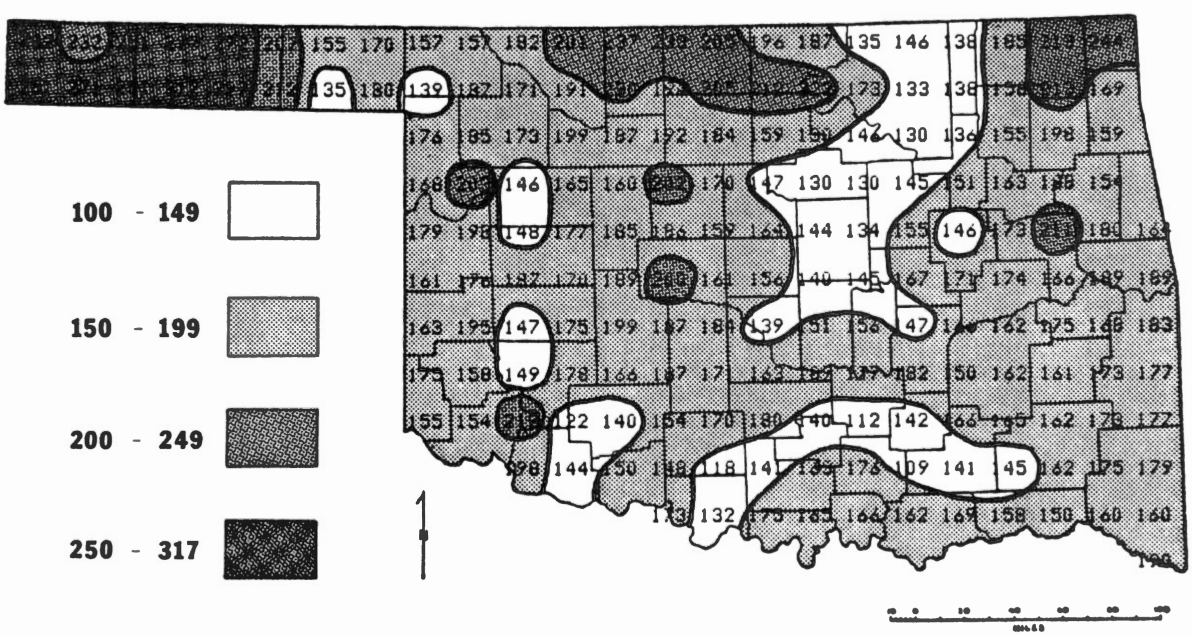


Figure 20. Highlighted Physical Transport Index

Figure 21 shows a frequency histogram of the Physical Transport Index and it can be seen that a slightly skewed distribution was present.

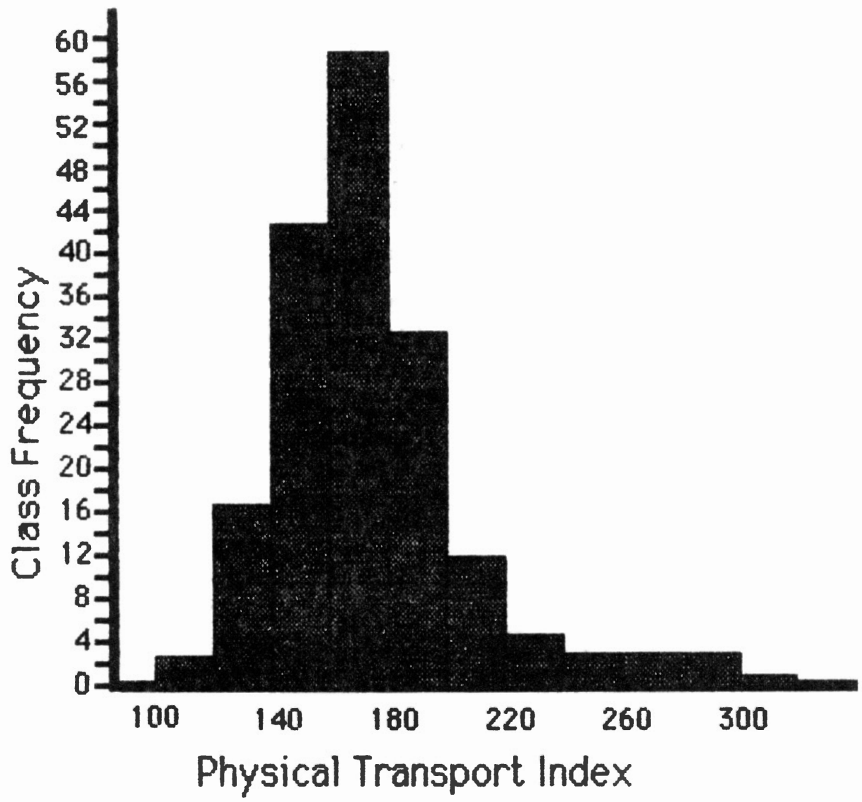


Figure 21. Frequency Histogram of Physical Transport Index

The elimination of exposure mechanisms from this index prevented the bi-modal distribution that was apparent in the Pesticide Risk Index. This suggests that a single population was yielded from the Physical Transport Index, whereas the Pesticide Risk Index may be two separate populations. The Physical Transport Index was derived by a simple addition of the Physical Index, Figure 15, to the Pesticide Transport Index, Figure 22.

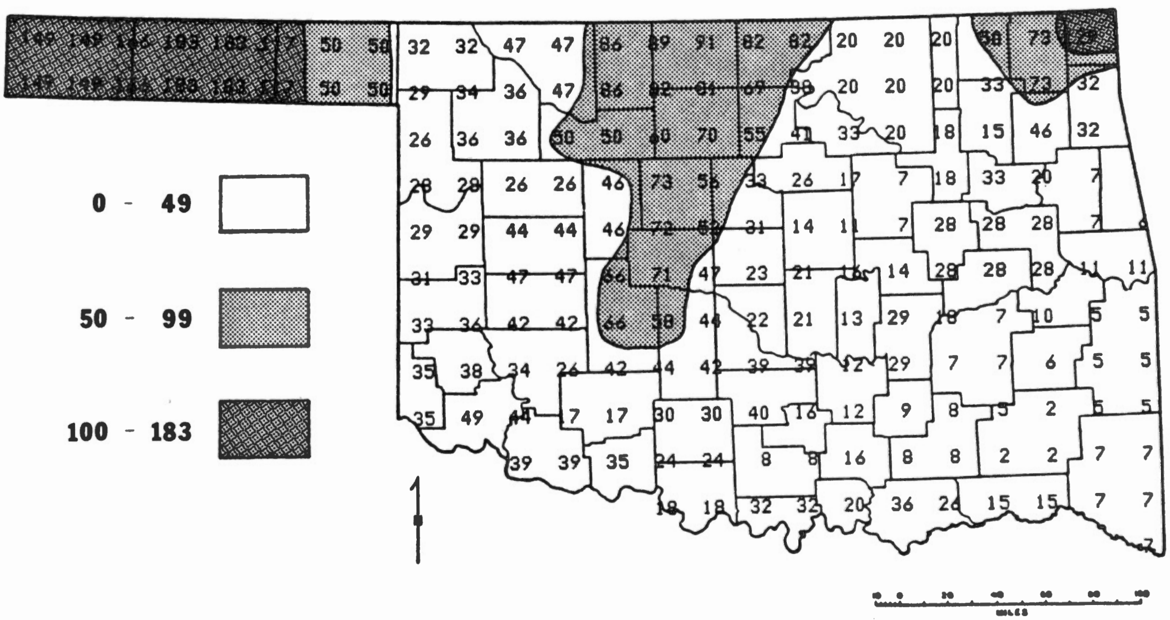


Figure 22. Highlighted Pesticide Transport Index

The Pesticide Transport Index was identical to the Pesticide Transport Hazard Index except that it ignored toxicity, and a comparison of Figures 16 and 22 shows only slight differences due to this exclusion. The greatest difference in the two indices was seen in the northern-central part of the state where a moderate decrease in values occurs after elimination of toxicity consideration. This could indicate that farmers in this area rely on more toxic pesticides than in other parts of the state, however, it must be recalled that only five pesticides were considered for their toxicity. Further analysis would be required to determine toxic pesticide usage patterns and this was beyond the realm of the current efforts.

The Physical Transport Index was the summation of only two preceding indices so it was expected that the Physical Index would have more effect on the outcome than it did in the Pesticide Risk Index. This can be seen in Figure 20 where greater emphasis was given to the southeastern corner of Oklahoma as a result of the high Physical Index values there.

The Physical Transport Index suggests that the greatest potential for pesticide contaminated groundwater in Oklahoma exists first in the panhandle, secondly in Ottawa County, and thirdly along the state line in the northern-central part of the state. However, as with the Pesticide Risk Index, predictions based on these findings should be tempered with knowledge of local conditions and recognition of important, but non-considered factors.

Physical Transport Hazard Index

The Physical Transport Hazard Index, as presented in Figure 23, was the summation of the Physical Index, Figure 15, and the Pesticide Transport Hazard Index, Figure 16. This index was derived similarly to the Physical Transport Index except that the toxicity of leached pesticides was a factor for consideration. Comparison of Figures 20 and 23 indicates the great similarity between the two indices. The only difference, other than slight variations, was the greater weight in the northern central counties for the Physical Transport Hazard Index as expected from the previous comparison of the Pesticide Transport Index and the Pesticide Transport Hazard Index.

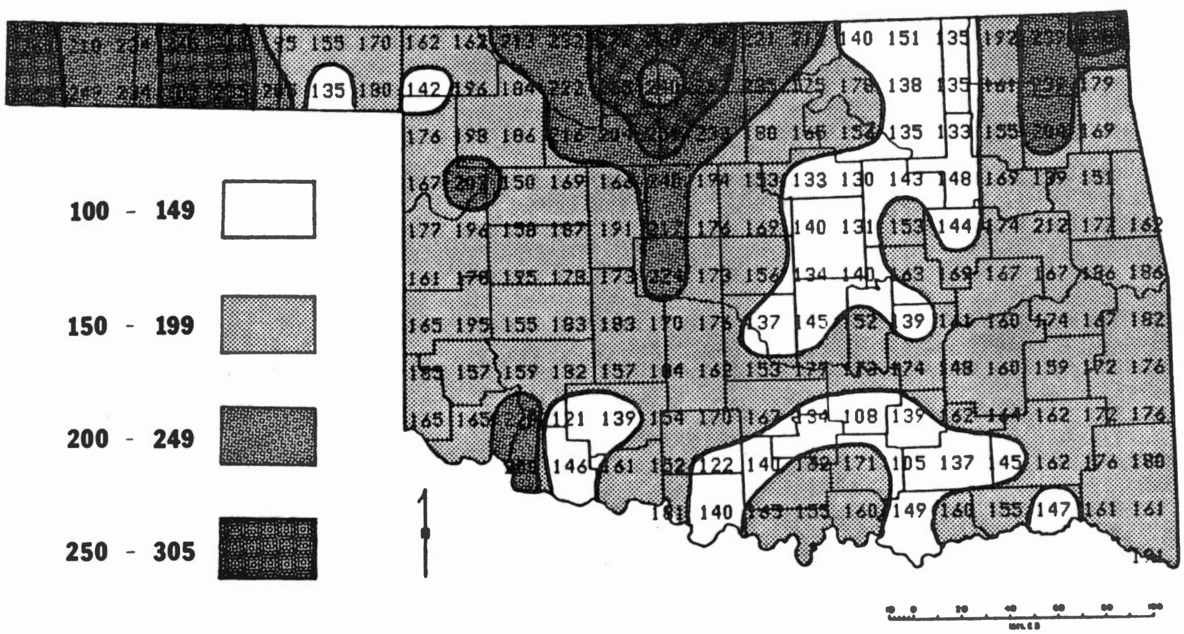


Figure 23. Highlighted Physical Transport Hazard Index

The Physical Transport Hazard Index indicates that the areas of the state possessing the most toxic groundwater due to pesticide contamination were the same areas highlighted by the other indices. More specifically, these areas were the panhandle, the northeastern corner, and the northern-central portion of Oklahoma. Aquifers that might hold the most promise for future unpolluted resources, as predicted by the Physical Transport Hazard Index, are the Vamoosa formation, the Simpson and Arbuckle groups, The Garber Wellington formation, and less importantly, the Rush Springs and Antlers sandstone formations. Aquifers that may be predicted to deteriorate from pesticide contamination include the alluvium and terrace deposits, the Roubidoux, Gasconade, and Eminence formations, and the Ogallala formation.

Monte Carlo Analysis Results

Sample Size

The Monte Carlo analysis was conducted to assess the probability of pesticide leaching in Oklahoma. The amount of pesticide leached past 12 and 70 inches for the 540 cases in the Monte Carlo simulations is presented in Appendix H. Utilizing these results for inferential statements was dependent upon the sample population being of sufficient size so that the distribution of results achieved a steady state. Therefore, any probabilistic analysis would not be biased by an incomplete data set. Plotting of percentile values for increasingly larger populations, as displayed in Appendix I indicated that probabilities achieved a constant value at approximately three hundred simulations with only slight variations thereafter. It can therefore be stated that projections from the complete set of simulations should not be imprecise due to an insufficient sample size.

Inclusive Probabilities

Predictions of the occurrence of pesticide leaching in Oklahoma can be derived from an analysis of all 540 simulations. These simulations were designed to cover the probable range of agricultural activities in the state. The probability of leaching pesticides is presented in Figures 24 and 25. It can be inferred from these graphs that more than 50% of the applied pesticide will leach past 12 inches less than 11% of the time, and that 90% will leach less than 2% of the time. At the 70 inch depth, 50% of the applied pesticide will leach less than 4% of the time. Comparison of Figures 24 and 25 indicate that pesticides will generally leach past 12 inches twice as often as it does past 70 inches. Therefore, on the average, one half of the pesticide moving past a depth of 12 inches will be decayed or retarded before it reaches 70 inches. Correlation of these numbers to pesticide application rates reported for Oklahoma, which approximately average 0.5 pounds per acre and range as high as 2.6 pounds per acre, indicates that there was a 4% possibility of one quarter pound per acre on the average or as much as 1.3 pounds per acre of active ingredient leaching past the 70 inch depth (25).

Separate Probabilities

Prediction of the effect of specific pesticide applications and land management practices was provided by probability assessments of each combination of parameters. These assessments yielded Appendix J which may be addressed from Table XIV. Utilization of Table XIV begins with selection of values for K_s and K_{oc}. Cross referencing of the value for K_s, with the value for K_{oc} indentifies the appropriate cumulative probability figure in Appendix J. A separate plot is presented for each of the two depths.

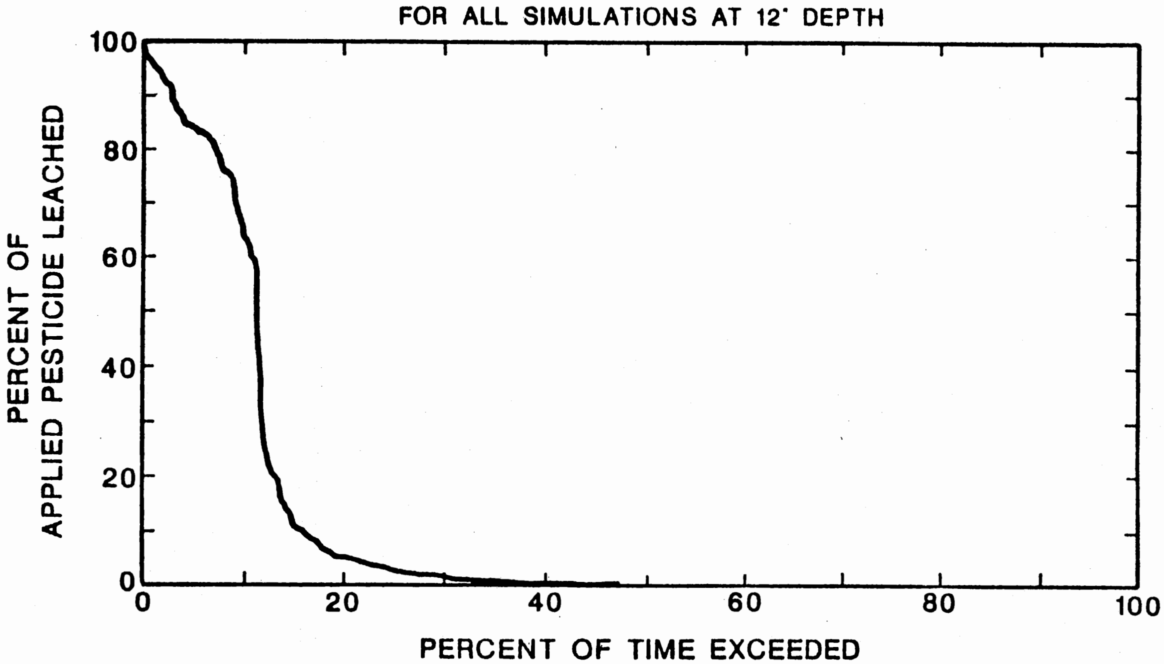


Figure 24. Probability or Leaching at Twelve Inches

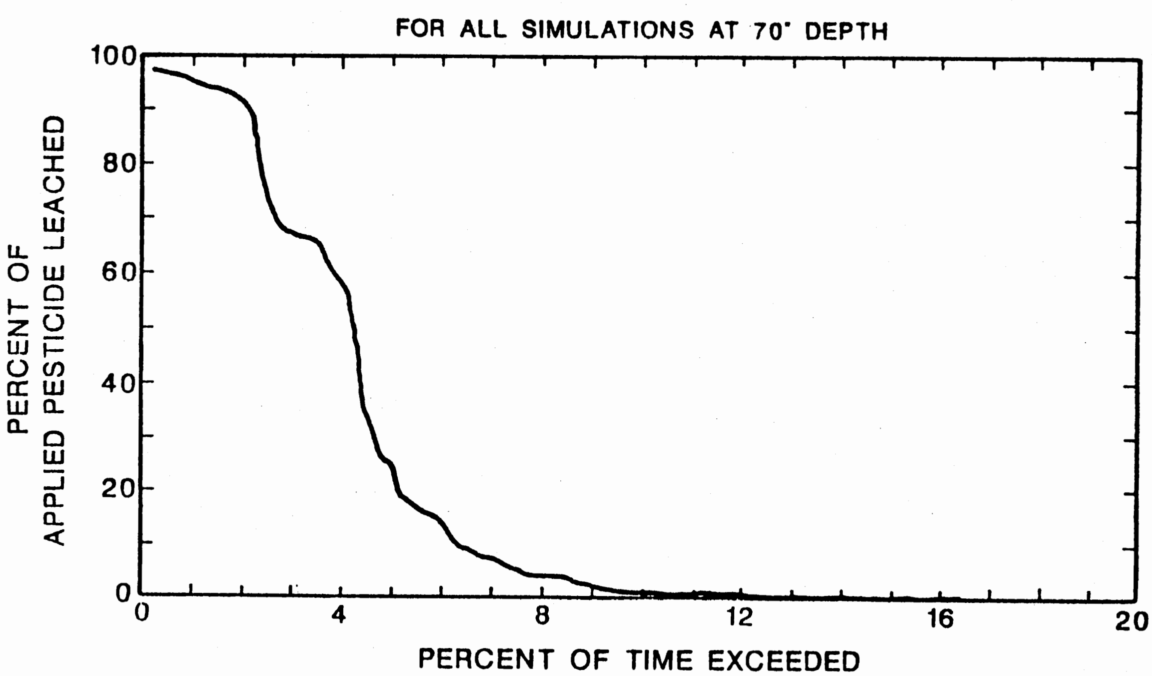


Figure 25. Probability or Leaching at Seventy Inches

TABLE XIV

PROBABILITY FIGURES ADDRESS MATRIX

		K_s		
		0.1	0.05	0.001
K_{oc}	2	28	29✓	✓30
	600	31	32✓	✓33
	1200	34	35	36

Intermediate values of K_s, K_{oc} and CN may be applied to the figures with an interpolation technique, by assuming a linear relationship as in the example which follows. It was desired to determine a 50% probability leaching value at a 12" depth for the pesticide diuron applied to a soil having a SCS Curve Number of 66. Diuron's decay coefficient (K_s) in Table VIII was given as 0.0064 and the Organic Carbon Distribution Coefficient (K_{oc}) was 398.11. The four probability figures which bracket these coefficients are shown in Figures 29, 30, 32, and 33 in Appendix J. The 50% probability leaching values from these figures at a CN of 66, which was assumed to be located half the distance between the CN curves for 59 and 73, were 4, 85, 0, and 2 percent of applied pesticide leached respectively. Double interpolation required an initial interpolation between figures 29 and 30, and 32 and 33 at the K_s of 0.0064 and a depth of 12".

$$X_1 = \left[\frac{4 - 85}{0.05 - 0.001}(0.0064 - 0.001)\right] + 85 \qquad (17)$$

$$= 76.07$$

$$X_2 = \left[\frac{0 - 2}{0.05 - 0.001}(0.0064 - 0.001)\right] + 2 \qquad (18)$$

$$= 1.78$$

The final interpolation between the above two values at the K_{OC} of 398.11 was calculated by

$$X3 = \left[\frac{76.07 - 1.78}{2 - 600}(398.11 - 600)\right] + 1.78 \qquad (19)$$

$$= 26.9$$

Therefore, at the above stated conditions, 26.9% of diuron was predicted to leach less than 50% of the time.

Applying the cumulative probability figures for values outside of the given ranges may not be appropriate, however, K_{OC} values greater than 1200 and K_S greater than 0.1 should result in no significant leaching irrespective of the other parameters. In Appendix J, the probability curves were grouped by holding K_S, K_{OC}, and depth constant while CN was varied. The other possible groupings, where Ks, Koc were used as the variables, are presented in Appendices K and L respectively.

The probability outputs predict significant leaching for the combinations of parameters in Table XV.

TABLE XV

PARAMETERS RESULTING IN SIGNIFICANT LEACHING

K_s	K_{oc}	Depth (inches)	Maximum % of Applied Passing
0.1	2	12	31
0.1	2	70	4
0.05	2	12	40
0.05	2	70	13
0.001	2	12	97
0.001	2	70	97
0.00	600	12	40
0.001	1200	12	9

The last two combinations of K_s and K_{oc} in Table XV indicate the possibility for significant leaching at the 12 inch depth, however, very little was predicted at 70 inches, so these two combinations should not present a significant hazard of groundwater contamination. The greatest potential for leaching was present at a K_{oc} value of two. Appendix L indicates no leaching past 70 inches for K_{oc} values of 600 and 1200, but the possibility for leaching always existed for K_{oc} equal to two. Conversely, Appendix K predicted only a small chance for very minor leaching at 70 inches for K_{oc} greater than two. An increased leaching potential as K_s decreased was present for K_{oc} equal to two, however, K_{oc} was apparently the determinant factor in this simulation. This can be stated since no significant leaching occurred past 70 inches with K_{oc} values other than two. Declaring that K_{oc} was the determinant factor does not negate the importance of K_s. In fact, the retardance of pesticide was significant only because it allowed a longer time span for the decay mechanism to function in the upper soil layers. Soil retardance, by itself, resulted in very little permanent adsorption of the pesticide. Nevertheless, the amount of pesticide leached appeared to be most sensitive to the Organic Carbon Distribution Coefficient.

Common pesticide selections which may present hazards, based on the Monte Carlo analysis, include dicamba, carbofuran, and Atrazine. Dicamba was used primarily on wheat in the central and western parts of the state. This could present a contamination potential for soils exhibiting high infiltration and low runoff characteristics. In particular, wheat fields in the northern-central areas of Oklahoma, located on alluvial or terrace deposits that are sources of drinking water, may be particularly susceptible. Assuming that a soil has a hydrologic classification of "A" and that wheat is grown in a contoured and terraced field gives a SCS curve number of 59. Applying these conditions to the cumulative probability figures yields a 50% probability of occurrence for 34% of the applied dicamba leaching past 70 inches.

Carbofuran is applied to alfalfa and peanut crops in Oklahoma. Many peanut fields are located on alluvial deposits in the western-central part of the state and these may be likely sites for contamination. Using the same SCS Curve Number as in the previous example, 32% of the pesticide carbofuran was predicted to leach at a 50% probability level.

Atrazine, which is used on sorghum and corn fields, would be more likely applied to soils possessing hydrologic classifications of "C" or "D". Assuming the more conservative "C" classification, which results in a Curve Number of 85, gives a 50% probability leaching amount of 6%. The above three examples were worst case scenarios, but they demonstrate that individual conditions may so combine as to cause a serious incident of pesticide leaching. Further simulations with low to intermediate values of K_{oc} are necessary in order to fully quantify the possibility for significant leaching.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Pesticide Risk Index

The Pesticide Risk Index is an easily applied method that provides useful results. Due to the constraint that cleanup of pesticide contaminated groundwater is unfeasible, prevention is the best remedy. In order to prevent groundwater pollution, regulatory agencies must identify the site specific and compound specific parameter combinations that result in serious leaching of pesticides. Recommendations from pesticide manufacturers and agricultural extension agents may decrease the application of mobile pesticides on susceptible areas. Failure of voluntary cooperation could necessitate legislative restrictions or complete bans of particular compounds.

Perhaps the greatest impediment to the solution of pesticide contamination of groundwater is the lack of knowledge about where contamination exists and what particular pesticide compounds are involved. In the recent past, the only sure way to obtain this information was to conduct broad scale sampling programs with analysis for all possible pesticides. Due to the great expense involved in a monumental undertaking of this nature, they were seldom performed. The use of an assessment technique, like the Pesticide Risk Index, to identify areas that have the most potential for harm would be a first step towards the control of pesticide contamination of the groundwater.

Other Indices

The Physical Transport Index and the Physical Transport Hazard Index could be used in place of the Pesticide Risk Index in the assessment of the potential for pollution. These indices provide a narrower focus for investigation of certain aspects of leaching pesticides. Comparison of the Physical Transport Index and the Physical Transport Hazard Index would identify areas of the greatest use of higher toxicity, mobile pesticides. Regardless of which particular index is utilized, the methodology could eliminate the need for costly, blanket, monitoring surveys in the identification of pesticide contaminated groundwater.

Monte Carlo Simulation

After identification of areas susceptible to groundwater contamination by pesticides, a method is necessary to indicate what particular practices may be responsible for the pollution. One such method is the Monte Carlo approach which extends a single site model into a regional model. Although the technique involves a large number of computer simulations, the process can be programmed to automatically generate the necessary input files, initiate the simulations, and analyze the results. Once an area has been simulated, the results of specific practices on pollution of the groundwater can be quickly and easily determined. This technique will also identify pesticides that should be prohibited due to their ability to leach in a large number of soils. Conversely, a particular site may have certain properties which would allow a wide range of pesticides to contaminate the groundwater. Such sites may require utilization by some means other than traditional agriculture. Foresight and planning should significantly decrease the incidences of pesticide contaminated groundwater.

Conclusions

Index

The Pesticide Risk Index for the state of Oklahoma indicated that certain portions of the state had a much higher risk than others. Generally western Oklahoma was high risk and eastern was low. The three sub-indices which comprise the Pesticide Risk Index also displayed this east/west distribution except for the Physical Index which was more evenly distributed. Therefore, it can be concluded that the physical factors affecting the potential for leaching of pesticides were moderately uniform across the state, whereas pesticide use and groundwater consumption were decidedly spatially distributed. This spatial distribution was transferred to the Pesticide Risk Index which became dominated by it. The Physical Transport Index and the Physical Transport Hazard Index closely reflected the distribution of the Pesticide Risk Index due to their similar data requirements. All three indices consider actual data that are recognized as affecting the potential for pollution, and should therefore afford some insight into contamination susceptibility.

Transport Simulation

The majority of the state of Oklahoma was simulated with PRZM in a Monte Carlo approach yielding probability estimates of pesticide leaching. This simulation was designed to consider all possible combinations of input parameters. Several combinations indicated significant leaching particularly when the organic carbon partitioning coefficient was equal to two or less. The only known major pesticide used in Oklahoma which is included in this category is dicamba. Although dicamba has a relatively short soil persistence, there is still the possibility for leaching to moderate soil depths. Caution should be exercised in the application of this herbicide, particularly to soils low in organic matter which would decrease the degradation rate of the compound.

Recommendations

Engineering Alternatives to Lessen Risk

Methods exist which can remove pesticides from groundwater, once it has been pumped to the surface, making it safe to drink (36). However, these techniques are very expensive and often do not remove the sorbed contaminants. Therefore, the prevention of pesticide contamination should ultimately prove to be much less costly. Several avenues are available for protecting this nation's groundwater. Proper instruction for people who use pesticides could prevent improper pesticide selection and over application. These common misuses may be responsible for many of the occurrences of contamination. Best Management Practices, which attempt to maintain protection levels with reductions in chemical applications, should be encouraged among the agricultural industry. Pest resistant crops and non-polluting biological controls may replace chemical pesticides in some situations.

The least desirable alternative, but one which may become increasingly necessary, is legislative restrictions on pesticide use. This could take the form of a total ban on a particular pesticide or a restriction on pesticide application. An example of the latter would be not allowing dicamba to be applied on soils having less than 1% organic matter. Restrictions may become common as more pesticides are found in drinking water sources.

Recommendations for Further Research

More accurate predictions from the Monte Carlo analysis could be achieved by further simulations. Each of the 27 combinations of input parameters should be modeled several hundred times to provide a sufficient sample size. Also, additional values for pesticide properties and run-off curve numbers should be simulated in order to lessen the need for interpolation. This would also decrease the error due to non-linearity. Simulation of other crops and soils along with an examination of the effects of irrigation would broaden the predictive capacity of the Monte Carlo analysis.

The Pesticide Risk Index could be made more applicable to the state of Oklahoma if the results of the Monte Carlo simulation were used to define the transport of pesticides. This would be accomplished by replacing the LEACH Index with the cumulative probability figures in Appendix J.

Another extension of the indices would be linking the Physical Transport Index to a two-dimensional groundwater transport model. This would give an indication of the ultimate fate of any leached pesticides. The potential for contamination of municipal supply wells could be predicted from this effort.

To determine if the Pesticide Risk Index is quantitatively measuring risk, it is necessary to simulate specific sites, identified by the index. The Pesticide Root Zone Model could be used for these simulations. Conclusive results from these simulations would allow calibration of the index, thereby giving a more accurate prediction of the risk from pesticide contaminated groundwater.

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APPENDIXES

APPENDIX A

PESTICIDE SURVEY DATA FOR WHEAT

TABLE XVI

PESTICIDES APPLIED TO WHEAT
IN OKLAHOMA DURING 1981

CHEMICAL & AREA	% OF PLANTED ACRES	TREATED ACRES
Cygon		
Western 1/3	.9	35,900
Central 1/3	1.1	40,300
Eastern 1/3	.1	500
State	1.0	76,700
Malathion		
Western 1/3	2.4	94,000
Central 1/3	2.2	79,000
Eastern 1/3	.8	3,000
State	2.2	176,000
Methyl Parathion		
Western 1/3	2.9	116,000
Central 1/3	3.2	113,200
Eastern 1/3	--	--
State	2.9	229,300
Parathion		
Western 1/3	17.8	707,100
Central 1/3	31.9	1,136,600
Eastern 1/3	8.1	29,800
State	23.7	1,873,500
Parathion 6-3		
Western 1/3	6.1	242,000
Central 1/3	5.1	202,500
Eastern 1/3	.2	900
State	5.6	445,400
Insecticides (Other)		
Western 1/3	.9	35,900
Central 1/3	1.1	40,300
Eastern 1/3	.1	500
State	1.0	76,700
Insecticides (Unknown)		
Western 1/3	1.0	39,700
Central 1/3	2.0	69,800
Eastern 1/3	.1	500
State	1.4	110,000

TABLE XVI (Continued)

CHEMICAL & AREA	% OF PLANTED ACRES	TREATED ACRES
Banvel		
Western 1/3	.9	28,000
Central 1/3	1.4	51,600
Eastern 1/3	2.3	8,500
State	1.1	88,100
2,4-D		
Western 1/3	5.8	232,000
Central 1/3	6.3	222,600
Eastern 1/3	13.3	49,100
State	6.4	503,700
Herbicides (Other)		
Western 1/3	.9	34,000
Central 1/3	5.2	185,500
Eastern 1/3	5.3	19,600
State	3.0	239,100
Herbicides (Unknown)		
Western 1/3	2.4	94,000
Central 1/3	4.6	165,100
Eastern 1/3	8.2	30,500
State	3.7	289,600
Vitavax 200		
Western 1/3	.7	28,000
Central 1/3	1.6	57,000
Eastern 1/3	4.4	16,200
State	1.3	101,200
Vitavax		
Western 1/3	1.2	48,000
Central 1/3	1.8	64,600
Eastern 1/3	1.3	4,700
State	1.5	117,300
Fungicides (Other)		
Western 1/3	2.0	81,000
Central 1/3	1.4	49,700
Eastern 1/3	2.8	10,300
State	1.8	141,000
Fungicides (Unknown)		
Western 1/3	14.6	579,000
Central 1/3	10.2	361,600
Eastern 1/3	3.0	11,200
State	12.0	951,800

Sources: See TABLE XVII

TABLE XVII

APPLICATION RATES FOR WHEAT PESTICIDES

CHEMICAL	RATE[1]	ACRES TREATED	TOTAL[2]
Cygon	.392	76,000	30,066.4
Malathion	.686	176,000	120,736.0
Methyl Parathion	.607	299,300	181,675.1
Parathion	.499	1,873,500	934,876.5
Parathion 6-3 (Methyl Para.)	.780	445,400	355,429.2
Parathion 6-3 (Parathion)	.399	445,400	177,714.6
Insecticide (Unknown)	.872	1,147,400	1,000,532.8
Banvel	.626	88,100	55,150.6
Bromonal	.359	42,600	15,293.4
2,4-D	.545	503,700	274,516.5
Karmex	1.140	45,600	51,984.0
MCPA	.379	69,300	26,264.7
Roundup	1.097	20,300	22,269.1
Sencor	.751	55,500	41,680.5
Herbicides (Unknown)	.421	289,600	121,921.6

[1] Pounds per acre of active ingredient

[2] Total pounds of active ingredient used in Oklahoma, 1981

Source: Criswell, J. T., "Use of Pesticides on Major Crops in Oklahoma, 1981," Research Report P-833, Division of Agriculture, Oklahoma State University, Stillwater, Oklahoma (1982).

APPENDIX B

PESTICIDE TREATED WHEAT AREAS

TABLE XVIII

PESTICIDE TREATED WHEAT AREAS

County	Wheat Acres	Cygon	Mala- thion	Methyl Para.	Para- thion	Para. 6-3	Insecticides Other	/ Unknown
				Western Counties				
Beaver	310000	2868	7510	9276	56495	19335	3172	39309
Beckham	140000	1295	3392	4189	25514	8732	1432	17753
Blaine	255000	2359	6178	7630	46472	15905	2609	32335
Caddo	205000	1897	4966	6134	37360	12786	2098	25995
Cimmarron	200000	1851	4845	5985	36448	12474	2046	25361
Comanche	86000	796	2084	2573	15673	5364	880	10905
Cotton	180000	1665	43261	5386	32804	11227	1842	22825
Custer	275000	2544	6662	8229	50117	17152	2814	34871
Dewey	145000	1342	3513	4339	26425	9044	1484	18387
Ellis	125000	1157	3028	3740	22780	7796	1297	15851
Greer	127000	1175	3077	3800	23145	7921	1299	16104
Harmon	128000	1184	3101	3830	23327	7984	1310	16231
Harper	195000	1084	4724	5835	35537	12162	1995	24727
Jackson	295000	2730	7147	8827	53761	18399	3018	37407
Kiowa	280000	2591	6784	8378	51028	17464	2865	35505
Roger Mills	105000	972	2544	3142	19135	6549	1074	13314
Texas	360000	3331	8722	10772	65607	22454	3684	45649
Tillman	189000	1749	4579	5655	34444	11788	1934	23966
Washita	280000	2591	6784	8378	51028	17464	2865	35505
				Central Counties				
Alfalfa	340000	3820	7488	10730	107735	19194	6616	58009
Atoka	3000	34	66	95	951	169	58	512
Bryan	22000	247	485	694	6971	1242	428	3754
Canadian	250000	2809	5506	7890	79217	14113	4865	42654
Carter	10000	112	220	316	3169	565	195	1706
Cleveland	14000	157	308	442	4436	790	272	2389
Coal	3000	34	66	95	951	169	58	512
Creek	7000	79	154	221	2218	395	136	1194
Garfield	435000	4887	9580	13728	137837	24557	8465	74218
Garvin	23000	258	507	726	7288	1298	448	3924
Grady	100000	1124	2202	3156	31687	5645	1946	17062
Grant	440000	4943	9691	13886	139421	24840	8562	75071
Jefferson	62000	697	1365	1957	19646	3500	1206	10578
Johnston	3000	34	66	95	951	169	58	512
Kay	285000	3202	6277	8994	90307	16089	5546	48626
Kingfisher	332000	3730	7312	10477	105200	18743	6460	56645
Lincoln	17000	191	374	536	5387	960	331	2900
Logan	112000	1258	2467	3535	35489	6323	2179	19109
Love	15000	169	330	473	4753	847	292	2559
Major	190000	2135	4185	5996	60205	10726	3697	32417
Marshall	7000	79	154	221	2218	395	136	1194
McClain	27000	303	595	852	8555	1524	525	4607
Murray	5000	56	110	158	1584	282	97	853
Noble	175000	1966	3854	5523	55452	9879	3405	29858

TABLE XVIII (Continued)

County	Wheat Acres	Cygon	Mala-thion	Methyl Para.	Para-thion	Para. 6-3	Insecticides Other	/ Unknown
				Central Counties (Continued)				
Okfuskee	9000	101	198	284	2852	508	175	1536
Oklahoma	36000	404	793	1136	11407	2032	701	6142
Payne	51000	573	1123	1609	16160	2879	992	8701
Pontotoc	4000	45	88	126	1267	226	78	682
Pottawatomie	18000	202	396	568	5704	1016	350	3071
Seminole	7000	79	154	221	2218	395	136	1194
Stephens	70000	786	1542	2209	22181	3952	1362	11943
Woods	345000	3876	7598	10888	109319	19477	6713	58863
Woodward	170000	1910	3744	5365	53867	9597	3308	29005
				Eastern Counties				
Adair	2000	2	14	0	138	4	2	200
Cherokee	2000	2	14	0	138	4	2	200
Choctaw	9000	10	62	0	619	19	10	902
Craig	31000	36	215	0	2133	64	36	3107
Delaware	13000	15	90	0	895	27	15	1303
Haskell	6000	7	42	0	413	12	7	601
Hughes	16000	18	111	0	1101	33	18	1604
Latimer	2000	2	14	0	138	4	2	200
Le Flore	9500	11	66	0	654	20	11	952
Mayes	20000	23	139	0	1376	42	23	2005
McCurtain	27000	31	187	0	1858	56	31	2706
McIntosh	11000	13	76	0	757	23	13	1103
Muskogee	36000	42	249	0	2478	75	42	3608
Nowata	19000	22	132	0	1308	39	22	1904
Okmulgee	18000	21	125	0	1239	37	21	1804
Osage	41000	47	284	0	2822	85	47	4109
Ottawa	40000	46	277	0	2753	83	46	4009
Pawnee	27000	31	187	0	1858	56	31	2706
Pittsburg	5000	6	35	0	344	10	6	501
Pushmataha	2500	3	17	0	172	5	3	251
Rogers	18000	21	125	0	1239	37	21	1804
Sequoyah	7000	8	48	0	482	15	8	702
Tulsa	15000	17	104	0	1032	31	17	1503
Wagoner	45000	52	312	0	3097	94	52	4510
Washington	11000	13	76	0	757	23	13	1103

TABLE XVIII (Continued)

	Other Pesticides Applied to Wheat							
			Herbicides		Vitavax	Vitavax	Fungicides	
County	Banvel	2,4-D	Other/	Unknown	200	6-3	Other/	Unknown
				Western Counties				
Beaver	2237	18536	2716	7510	2237	3835	6472	46260
Beckham	1010	8371	1227	3392	1010	1732	2923	20892
Blaine	1840	15247	2235	6178	1840	3155	5323	38053
Caddo	1479	12258	1796	4966	1479	2536	4280	30591
Cimmarron	1443	11959	1753	4845	1443	2474	4175	29845
Comanche	621	5142	754	2084	621	1064	1795	12834
Cotton	1299	10763	1577	4361	1299	2227	3758	26861
Custer	1985	16443	2410	6662	1985	3402	5741	41037
Dewey	1046	8670	1271	3513	1046	1794	3027	21638
Ellis	902	7474	1095	3028	902	1546	2610	18653
Greer	916	7594	1113	3077	916	1571	2651	18952
Harmon	924	7654	1122	3101	924	1584	2672	19101
Harper	1407	11660	1709	4724	1407	2412	4071	29099
Jackson	2129	17639	2585	7147	2129	3649	6159	44022
Kiowa	2021	16742	2454	6784	2021	3464	5845	41784
Roger Mills	758	6278	920	2544	758	1299	2192	15669
Texas	2598	21526	3155	8722	2598	4454	7515	53722
Tillman	1364	11301	1656	4579	1364	2338	3946	28204
Washita	2021	16742	2454	6784	2021	3464	5845	41784
				Central Counties				
Alfalfa	4891	21100	17583	15649	5403	6123	4711	34275
Atoka	43	186	155	138	48	54	42	302
Bryan	316	1365	1138	1013	350	396	305	2218
Canadian	3596	15514	12929	11507	3973	4502	3464	25202
Carter	144	621	517	460	159	180	139	1008
Cleveland	201	869	724	644	222	252	194	1411
Coal	43	186	155	138	48	54	42	302
Creek	101	434	362	322	111	126	97	706
Garfield	6258	26995	22496	20022	6912	7834	6027	43852
Garvin	331	1427	1189	1059	365	414	319	2319
Grady	1439	6206	5171	4603	1589	1801	1386	10081
Grant	6330	27305	22754	20252	6992	7924	6096	44356
Jefferson	892	3848	3206	2854	985	1110	859	6250
Johnston	43	186	155	138	48	54	42	302
Kay	4100	17686	14739	13118	4529	5133	3949	28730
Kingfisher	4776	2063	17169	15281	5176	5979	4600	33468
Lincoln	245	1055	879	782	270	306	236	1714
Logan	1611	6905	5792	5155	1780	2017	1552	11291
Love	216	931	776	690	238	270	208	1512
Major	2733	11791	9826	8745	3019	3422	2633	19154
Marshall	101	434	362	322	111	126	97	706
McClain	388	1676	1396	1243	429	486	374	2722
Murray	72	310	259	230	79	90	69	504
Noble	2517	10860	9050	8055	2781	3152	2425	17641
Okfuskee	129	559	465	414	143	162	125	907

TABLE XVIII (Continued)

County	Banvel	2,4-D	Herbicides Other/	Unknown	Vitavax 200	Vitavax 6-3	Fungicides Other/	Unknown
				Central Counties (Continued)				
Oklahoma	518	2234	1862	1657	572	648	499	3629
Payne	734	3165	2637	2347	810	918	707	5141
Pontotoc	58	248	207	184	64	72	55	403
Pottawatomie	259	1117	931	828	286	324	249	1815
Seminole	101	434	362	322	111	126	97	706
Stephens	1007	4344	3620	3222	1112	1261	970	7057
Woods	4963	21410	17842	15879	5482	6213	4780	34779
Woodward	2445	10550	8791	7825	2701	3062	2355	17137
				Eastern Counties				
Adair	39	227	91	141	75	22	48	52
Cherokee	39	227	91	141	75	22	48	52
Choctaw	177	1021	407	634	337	98	214	233
Craig	609	3515	1403	2184	1160	336	737	802
Delaware	255	1474	588	916	486	141	309	336
Haskell	118	680	272	423	224	65	143	155
Hughes	314	1814	724	1127	599	174	381	414
Latimer	39	227	91	141	75	22	48	52
Le Flore	186	1077	430	669	355	103	226	246
Mayes	393	2268	905	1409	748	217	476	517
McCurtain	530	3062	1222	1902	1010	293	642	698
McIntosh	216	1247	498	775	412	119	262	285
Muskogee	707	4082	1630	2536	1347	391	856	931
Nowata	373	2155	860	1338	711	206	452	491
Okmulgee	353	2041	815	1268	673	195	428	466
Osage	805	4649	1856	2888	1534	445	975	1061
Ottawa	785	4536	1811	2818	1497	434	952	1035
Pawnee	530	3062	1222	1902	1010	293	642	698
Pittsburg	98	567	226	352	187	54	119	129
Pushmataha	49	283	113	176	94	27	59	65
Rogers	353	2041	815	1268	673	195	428	466
Sequoyah	137	794	317	493	262	76	167	181
Tulsa	294	1701	679	1057	561	163	357	388
Wagoner	883	5103	2037	3170	1684	488	1070	1164
Washington	216	1247	498	775	412	119	262	285

Sources: Criswell, J. T., "Use of Pesticides on Major Crops in Oklahoma, 1981," Research Report P-833, Division of Agriculture, Oklahoma State University, Stillwater, Oklahoma (1982), and Cochrane, J. E., and Waldrop, J. H., "Oklahoma Agricultural Statistics, 1981," Oklahoma Department of Agriculture, Oklahoma City, Oklahoma.

APPENDIX C

COUNTY PRORATIONS OF PESTICIDE AMOUNTS

TABLE XIX

COUNTY WHEAT PESTICIDE AMOUNTS

	Cygon	Mala- thion	Methyl Para.	Para- thion	Para. 6-3	Insecticides Other/	Unknown	Banvel
Application Rate (Lbs/Ac)	.392	.686	.607	.499	.78	.5	.782	.626
County			Western Counties (Lbs/County)					
Beaver	1124	5152	5631	28191	15081	1586	34278	1400
Beckham	508	2327	2543	12731	6811	716	15480	632
Blaine	925	4238	4632	23189	12406	1305	28196	1152
Caddo	744	3407	3723	18642	9973	1049	22668	926
Cimmarron	725	3324	3633	18188	9730	1023	22115	904
Comanche	312	1429	1562	7821	4184	440	9509	389
Cotton	653	2992	3269	16369	8757	921	19903	813
Custer	997	4570	4995	25008	13379	1407	30408	1242
Dewey	526	2410	2634	16186	7054	742	16033	655
Ellis	453	2077	2270	11367	6081	639	13822	565
Greer	461	2111	2307	11549	6178	650	14043	574
Harmon	464	2127	2325	11640	6227	655	14153	578
Harper	707	3241	3542	17733	9487	998	21562	881
Jackson	1070	4903	5358	26827	14352	1509	32619	1333
Kiowa	1016	4653	5086	25463	13622	1432	30960	1265
Roger Mills	381	1745	1907	9549	5108	537	11610	474
Texas	1306	5983	6539	32738	17514	1842	39806	1626
Tillman	686	3141	3433	17187	9195	967	20898	854
Washita	1016	4653	5086	25463	13622	1432	30960	1265
			Central Counties					
Alfalfa	1497	5137	6513	53760	14972	3308	50584	3062
Atoka	13	45	57	474	132	29	446	27
Bryan	97	332	421	3479	969	214	3273	198
Canadian	1101	3777	4789	39529	11009	2432	37194	2251
Carter	44	151	192	1581	440	97	1488	90
Cleveland	62	212	268	2214	616	136	2083	126
Coal	13	45	57	474	132	29	446	27
Creek	31	106	134	1107	308	68	1041	63
Garfield	1916	6572	8333	68781	19155	4232	64718	3917
Garvin	101	347	441	3637	1013	224	3422	207
Grady	440	1511	1916	15812	4403	973	14878	901
Grant	1938	6648	8429	69571	19375	4281	65462	3962
Jefferson	273	937	1188	9803	2730	603	9224	558
Johnston	13	45	57	474	132	29	446	27
Kay	1255	4306	5459	45063	12550	2773	42402	2566
Kingfisher	1462	5016	6360	52495	14619	3230	49394	2990
Lincoln	75	257	326	2688	749	165	2529	153
Logan	493	1692	2145	17709	4932	1090	16663	1009
Love	66	227	287	2372	661	146	2232	135
Major	837	2871	3640	30042	8366	1849	28268	1711
Marshall	31	106	134	1107	308	68	1041	63

TABLE XIX (Continued)

County	Cygon	Mala-thion	Methyl Para.	Para-thion	Para. 6-3	Insecticides Other/	Unknown	Banvel
				Central Counties (Continued)				
McClain	119	408	517	4269	1189	263	4017	243
Murray	22	76	96	791	220	49	744	45
Noble	771	2644	3352	27670	7706	1703	26036	1576
Okfuskee	40	136	172	1423	396	88	1339	81
Oklahoma	159	544	690	5692	1585	350	5356	324
Payne	225	771	977	8064	2246	496	7588	459
Pontotoc	18	60	77	632	176	39	595	36
Pottawatomie	79	272	345	2846	793	175	2678	162
Seminole	31	106	134	1107	308	68	1041	63
Stephens	308	1058	1341	11068	3082	681	10414	630
Woods	1519	5212	6609	54550	15192	3357	51328	3107
Woodward	749	2568	3257	26880	7486	1654	25292	1531
				Eastern Counties				
Adair	1	10	0	69	3	1	175	25
Cherokee	1	10	0	69	3	1	175	25
Choctaw	4	43	0	309	15	5	787	111
Craig	14	147	0	1065	50	18	2709	381
Delaware	6	62	0	446	21	8	1136	160
Haskell	3	29	0	206	10	3	524	74
Hughes	7	76	0	549	26	9	1398	197
Latimer	1	10	0	69	3	1	175	25
Le Flore	4	45	0	326	15	5	830	117
Mayes	9	95	0	687	32	12	1748	246
McCurtain	12	128	0	927	44	16	2360	332
McIntosh	5	52	0	378	18	6	961	135
Muskogee	16	171	0	1236	58	21	3146	442
Nowata	9	90	0	653	31	11	1661	233
Okmulgee	8	86	0	618	29	10	1573	221
Osage	19	195	0	1408	66	24	3583	504
Ottawa	18	190	0	1374	65	23	3496	492
Pawnee	12	128	0	927	44	16	2360	332
Pittsburg	2	24	0	172	8	3	437	61
Pushmataha	1	12	0	86	4	1	219	31
Rogers	8	86	0	618	29	10	1573	221
Sequoyah	3	33	0	240	11	4	612	86
Tulsa	7	71	0	515	24	9	1311	184
Wagoner	20	214	0	1545	73	26	3933	553
Washington	5	52	0	378	18	6	961	135

TABLE XIX (Continued)

	Other Pesticides						
	2,4-D	Herbicides Other/	Unknown	Vitavax 200	Vitavax	Fungicides Other/	Unknown
Application Rate (Lbs/Ac)	.545	.745	.421	.665	.665	.5	.5
County		Western Counties (Lbs/County)					
Beaver	10102	2042	3162	1488	2550	3236	23130
Beckham	4565	914	1428	672	1152	1461	10446
Blaine	8310	1665	2601	1224	2098	2662	19026
Caddo	6680	1338	2091	984	1686	2140	15296
Cimmarron	6518	1306	2040	960	1645	2088	14923
Comanche	2803	561	877	413	708	898	6417
Cotton	5866	1175	1836	864	1481	1879	13430
Custer	8962	1795	2805	1320	2262	2870	20519
Dewey	4725	947	1479	696	1193	1514	10819
Ellis	4073	816	1275	600	1028	1305	9327
Greer	4139	829	1295	609	1045	1326	9476
Harmon	4171	836	1306	614	1053	1336	9551
Harper	6355	1273	1989	936	1604	2035	14550
Jackson	9613	1926	3009	1416	2427	3079	22011
Kiowa	9125	1828	2856	1344	2304	2923	20892
Roger Mills	3422	685	1071	504	864	1096	7834
Texas	11732	2350	3672	1728	2962	3758	26861
Tillman	6159	1234	1928	907	1555	1973	14102
Washita	9125	1828	2856	1344	2304	2923	20892
		Central Counties					
Alfalfa	11499	13099	6588	3593	4072	2355	17137
Atoka	101	116	58	32	36	21	151
Bryan	744	848	426	232	263	152	1109
Canadian	8455	9632	4844	2642	2994	1732	12601
Carter	338	385	194	106	120	69	504
Cleveland	473	539	271	148	168	97	706
Coal	101	116	58	32	36	21	151
Creek	237	270	136	74	84	48	353
Garfield	14712	16759	8429	4597	5210	3014	21926
Garvin	778	886	446	243	275	159	1159
Grady	3382	3853	1938	1057	1198	693	5040
Grant	14881	16952	8526	4650	5270	3048	22178
Jefferson	2097	2389	1201	655	743	430	3125
Johnston	101	116	58	32	36	21	151
Kay	9639	10980	5523	3012	3413	1974	14365
Kingfisher	11229	12791	6433	3508	3976	2300	16734
Lincoln	575	655	329	180	204	118	857
Logan	3788	4315	2170	1184	1341	776	5645
Love	507	578	291	159	180	104	756
Major	6426	7320	3682	2008	2275	1316	9577
Marshall	237	270	136	74	84	48	353
McClain	913	1040	523	285	323	187	1361

TABLE XIX (Continued)

County	2,4-D	Herbicides Other/	Unknown	Vitavax 200	Vitavax	Fungicides Other/	Unknown
			Central Counties (Continued)				
Murray	169	193	97	53	60	35	252
Noble	5919	6742	3391	1849	2096	1212	8821
Okfuskee	304	347	174	95	108	62	454
Oklahoma	1218	1387	698	380	431	249	1815
Payne	1725	1965	988	539	611	353	2571
Pontotoc	135	154	78	42	48	28	202
Pottawatomie	609	693	349	190	216	125	907
Seminole	237	270	136	74	84	48	353
Stephens	2367	2697	1356	740	838	485	3528
Woods	11668	13292	6685	3646	4132	2390	17389
Woodward	5750	6550	3294	1796	2036	1178	8569
			Eastern Counties				
Adair	124	67	59	50	14	24	26
Cherokee	124	67	59	50	14	24	26
Choctaw	556	304	267	224	65	107	116
Craig	1916	1045	919	771	224	369	401
Delaware	803	438	386	323	94	155	168
Haskell	371	202	178	149	43	71	78
Hughes	989	540	474	398	115	190	207
Latimer	124	67	59	50	14	24	26
Le Flore	587	320	282	236	69	113	123
Mayes	1236	674	593	498	144	238	259
McCurtain	1669	911	801	672	195	321	349
McIntosh	680	371	326	274	79	131	142
Muskogee	2225	1214	1068	896	260	428	466
Nowata	1174	641	563	473	137	226	246
Okmulgee	1112	607	534	448	130	214	233
Osage	2534	1383	1216	1020	296	488	530
Ottawa	2472	1349	1186	995	289	476	517
Pawnee	1669	911	801	672	195	321	349
Pittsburg	309	169	148	124	36	59	65
Pushmataha	155	84	74	62	18	30	32
Rogers	1112	607	534	448	130	214	233
Sequoyah	433	236	208	174	51	83	91
Tulsa	927	506	445	373	108	178	194
Wagoner	2781	1518	1334	1120	325	535	582
Washington	680	371	326	274	79	131	142

TABLE XX

COUNTY SORGHUM PESTICIDE AMOUNTS

	Di-Syston	Mala-thion	Para-thion	Para. 6-3	Insecticides Other/	Unknown	Atra-zine	Banvel
Application Rate (Lbs/Ac)	.5	.5	.501	.5	.5	.5	1.246	.429
County			Pesticide Usage (Lbs/County)					
Adair	1	1	9	2	2	3	7	1
Alfalfa	13	27	207	38	54	65	157	16
Atoka	3	7	52	9	13	16	39	4
Beaver	248	498	3882	707	1006	1219	2949	309
Beckham	50	100	776	141	201	244	590	62
Blaine	35	70	543	99	141	171	413	43
Bryan	38	76	595	108	154	187	452	47
Caddo	77	155	1208	220	313	379	917	96
Canadian	15	31	242	44	63	76	183	19
Carter	5	10	78	14	20	24	59	6
Cherokee	1	1	9	2	2	3	7	1
Choctaw	12	23	181	33	47	57	138	14
Cimmarron	891	1794	13975	2546	3623	4387	10615	1112
Cleveland	15	30	233	42	60	73	177	19
Coal	7	13	104	19	27	32	79	8
Comanche	11	22	173	31	45	54	131	14
Cotton	13	27	207	38	54	65	157	16
Craig	83	166	1294	236	335	406	983	103
Creek	6	11	86	16	22	27	66	7
Custer	50	100	776	141	201	244	590	62
Delaware	32	65	509	93	132	160	387	41
Dewey	37	74	578	105	150	181	439	46
Ellis	61	122	949	173	246	298	721	76
Garfield	10	21	164	30	42	51	124	13
Garvin	32	65	509	93	132	160	387	41
Grady	36	72	561	102	145	176	426	45
Grant	48	96	751	137	195	236	570	60
Greer	9	19	147	27	38	46	111	12
Harmon	13	27	207	38	54	65	157	16
Harper	39	78	604	110	157	190	459	48
Haskell	4	9	69	13	18	22	52	5
Hughes	26	53	414	75	107	130	315	33
Jackson	19	38	293	53	76	92	223	23
Jefferson	7	13	104	19	27	32	79	8
Johnston	17	33	259	47	67	81	197	21
Kay	77	155	1208	220	313	379	917	96
Kingfisher	14	29	224	41	58	70	170	18
Kiowa	9	18	138	25	36	43	105	11
Latimer	1	2	17	3	4	5	13	1
Le Flore	1	2	17	3	4	5	13	1
Lincoln	14	28	216	39	56	68	164	17
Logan	8	16	121	22	31	38	92	10
Love	23	47	362	66	94	114	275	29

TABLE XX (Continued)

County	Di-Syston	Mala-thion	Para-thion	Para. 6-3	Insecticides Other/	Unknown	Atra-zine	Banvel
Major	23	47	362	66	94	114	275	29
Marshall	6	12	95	17	25	30	72	8
Mayes	25	51	397	72	103	125	301	32
McClain	17	34	267	49	69	84	203	21
McCurtain	18	35	276	50	72	87	210	22
McIntosh	24	49	380	69	98	119	288	30
Murray	3	6	43	8	11	14	33	3
Muskogee	31	63	492	90	127	154	373	39
Noble	21	42	328	60	85	103	249	26
Nowata	25	51	397	72	103	125	301	32
Okfuskee	8	17	129	24	34	41	98	10
Oklahoma	10	20	155	28	40	49	118	12
Okmulgee	24	49	380	69	98	119	288	30
Osage	50	100	776	141	201	244	590	62
Ottawa	94	188	1467	267	380	460	1114	117
Pawnee	16	32	250	46	65	79	190	20
Payne	17	34	267	49	69	84	203	21
Pittsburg	14	28	216	39	56	68	164	17
Pontotoc	18	37	285	52	74	89	216	23
Pottawatomie	19	38	293	53	76	92	223	23
Pushmataha	1	2	17	3	4	5	13	1
Roger Mills	77	155	1208	220	313	379	917	96
Rogers	12	24	190	35	49	60	144	15
Seminole	9	18	138	25	36	43	105	11
Sequoyah	1	1	9	2	2	3	7	1
Stephens	12	24	190	35	49	60	144	15
Texas	968	1949	15183	2767	3936	4766	11532	1208
Tillman	36	72	561	102	145	176	426	45
Tulsa	5	10	78	14	20	24	59	6
Wagoner	13	25	198	36	51	62	151	16
Washington	9	18	138	25	36	43	105	11
Washita	66	133	1035	189	268	325	786	82
Woods	6	11	86	16	22	27	66	7
Woodward	66	133	1035	189	268	325	786	82

TABLE XX (Continued)

	Other Pesticides							
	2,4-D	Ingran	Milo-gard	Modown	Ramrod	Other/	Herbicide Unknown	Fungi. Unknown
Application Rate (Lbs/Ac)	.601	1.145	1.566	1.159	.5	.5	.5	.5
County			Pesticide Usage (Lbs/County)					
Adair	10	1	8	6	1	1	4	5
Alfalfa	249	33	204	147	24	30	89	117
Atoka	62	8	51	37	6	8	22	29
Beaver	4676	618	3817	2750	450	563	1662	2190
Beckham	935	124	763	550	90	113	332	438
Blaine	655	87	534	385	63	79	233	307
Bryan	717	95	585	422	69	86	255	336
Caddo	1455	192	1187	856	140	175	517	681
Canadian	291	38	237	171	28	35	103	136
Carter	94	12	76	55	9	11	33	44
Cherokee	10	1	8	6	1	1	4	5
Choctaw	218	29	178	128	21	26	78	102
Cimarron	16835	2227	13740	9900	1620	2026	5984	7882
Cleveland	281	37	229	165	27	34	100	131
Coal	125	16	102	73	12	15	44	58
Comanche	208	27	170	122	20	25	74	97
Cotton	249	33	204	147	24	30	89	117
Craig	1559	206	1272	917	150	188	554	730
Creek	104	14	85	61	10	13	37	49
Custer	935	124	763	550	90	113	332	438
Delaware	613	81	500	361	59	74	218	287
Dewey	696	92	568	409	67	84	247	326
Ellis	1143	151	933	672	110	138	406	535
Garfield	197	26	161	116	19	24	70	92
Garvin	613	81	500	361	59	74	218	287
Grady	675	89	551	397	65	81	240	316
Grant	904	120	738	532	87	109	321	423
Greer	177	23	144	104	17	21	63	83
Harmon	249	33	204	147	24	30	89	117
Harper	727	96	594	428	70	88	259	341
Haskell	83	11	68	49	8	10	30	39
Hughes	499	66	407	293	48	60	177	234
Jackson	353	47	288	208	34	43	126	165
Jefferson	125	16	102	73	12	15	44	58
Johnston	312	41	254	183	30	38	111	146
Kay	1455	192	1187	856	140	175	517	681
Kingfisher	270	36	221	159	26	33	96	127
Kiowa	166	22	136	98	16	20	59	78
Latimer	21	3	17	12	2	3	7	10
Le Flore	21	3	17	12	2	3	7	10
Lincoln	260	34	212	153	25	31	92	122
Logan	145	19	119	86	14	18	52	68
Love	436	58	356	257	42	53	155	204
Major	436	58	356	257	42	53	155	204

TABLE XX (Continued)

County	2,4-D	Ingran	Milo-gard	Modown	Ramrod	Herbicide Other/	Herbicide Unknown	Fungi. Unknown
Marshall	144	15	93	67	11	14	41	54
Mayes	478	63	390	281	46	58	170	224
McClain	322	43	263	189	31	39	115	151
McCurtain	333	44	271	196	32	40	118	156
McIntosh	457	60	373	269	44	55	163	214
Murray	52	7	42	31	5	6	18	24
Muskogee	592	78	483	348	57	71	211	277
Noble	395	52	322	232	38	48	140	185
Nowata	478	63	390	281	46	58	170	224
Okfuskee	156	21	127	92	15	19	55	73
Oklahoma	187	25	153	110	18	23	66	88
Okmulgee	457	60	373	269	44	55	163	214
Osage	935	124	763	550	90	113	332	438
Ottawa	1767	234	1442	1039	170	213	628	827
Pawnee	301	40	246	177	29	36	107	141
Payne	322	43	263	189	31	39	115	151
Pittsburg	260	34	212	153	25	31	92	122
Pontotoc	343	45	280	202	33	41	122	161
Pottawatomie	353	47	288	208	34	43	126	165
Pushmataha	21	3	17	12	2	3	7	10
Roger Mills	1455	192	1187	856	140	175	517	681
Rogers	229	30	187	134	22	28	81	107
Seminole	166	22	136	98	16	20	59	78
Sequoyah	10	1	8	6	1	1	4	5
Stephens	229	30	187	134	22	28	81	107
Texas	18289	2419	14927	10756	1761	2201	6501	8564
Tillman	675	89	551	397	65	81	240	316
Tulsa	94	12	76	55	9	11	33	44
Wagoner	239	32	195	141	23	29	85	112
Washington	166	22	136	98	16	20	59	78
Washita	1247	165	1018	733	120	150	443	584
Woods	104	14	85	61	10	13	37	49
Woodward	1247	165	1018	733	120	150	443	584

TABLE XXI

COUNTY COTTON PESTICIDE AMOUNTS

	Ambush	Di-Syston	Dylox	Para-thion	Insecticide Other	/ Unknown
Application Rate (Lbs/Ac)	.155	.5	.5	.5	.5	.5
County	Pesticide Usage (Lbs/County)					
Adair	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0
Atoka	0	0	0	0	0	0
Beaver	0	0	0	0	0	0
Beckham	162	404	230	259	932	1244
Blaine	6	14	8	9	33	44
Bryan	6	14	8	9	33	44
Caddo	140	349	198	224	805	1074
Canadian	20	50	29	32	116	155
Carter	0	0	0	0	0	0
Cherokee	0	0	0	0	0	0
Choctaw	0	0	0	0	0	0
Cimarron	0	0	0	0	0	0
Cleveland	5	11	6	7	26	35
Coal	2	4	2	3	9	12
Comanche	72	179	102	115	412	550
Cotton	124	309	176	198	713	951
Craig	0	0	0	0	0	0
Creek	0	0	0	0	0	0
Custer	57	143	82	92	331	442
Delaware	0	0	0	0	0	0
Dewey	5	11	6	7	26	35
Ellis	0	0	0	0	0	0
Garfield	0	0	0	0	1	1
Garvin	8	21	12	13	48	64
Grady	40	100	57	64	230	307
Grant	0	0	0	0	0	0
Greer	121	301	171	193	695	928
Harmon	159	396	225	254	915	1221
Harper	0	0	0	0	0	0
Haskell	0	0	0	0	0	0
Hughes	0	0	0	0	1	1
Jackson	277	692	394	444	1597	2131
Jefferson	10	26	15	16	59	79
Johnston	1	3	2	2	7	9
Kay	0	0	0	0	0	0
Kingfisher	0	0	0	0	0	0
Kiowa	283	706	402	453	1630	2175
Latimer	0	0	0	0	0	0
Le Flore	0	0	0	0	0	0
Lincoln	0	0	0	0	1	1
Logan	1	2	1	2	5	7
Love	2	6	3	4	13	17

TABLE XXI (Continued)

County	Ambush	Di-Syston	Dylox	Para-thion	Insecticide Other / Unknown	
Major	0	0	0	0	0	0
Marshall	0	0	0	0	1	1
Mayes	0	0	0	0	0	0
McClain	22	55	31	35	127	170
McCurtain	0	0	0	0	0	0
McIntosh	0	0	0	0	0	0
Murray	0	0	0	0	0	0
Muskogee	0	0	0	0	0	0
Noble	0	1	0	0	2	2
Nowata	0	0	0	0	0	0
Okfuskee	0	1	1	1	3	4
Oklahoma	1	2	1	1	4	6
Okmulgee	0	0	0	0	0	0
Osage	0	0	0	0	0	0
Ottawa	0	0	0	0	0	0
Pawnee	0	0	0	0	0	0
Payne	0	0	0	0	1	1
Pittsburg	2	4	2	3	10	13
Pontotoc	0	0	0	0	1	1
Pottawatomie	0	0	0	0	1	1
Pushmataha	0	0	0	0	0	0
Roger Mills	36	89	51	57	206	275
Rogers	0	0	0	0	0	0
Seminole	0	0	0	0	0	0
Sequoyah	0	0	0	0	0	0
Stephens	14	34	19	22	79	105
Texas	0	0	0	0	0	0
Tillman	602	1501	854	964	3466	4626
Tulsa	0	0	0	0	0	0
Wagoner	0	0	0	0	0	0
Washington	0	0	0	0	0	0
Washita	288	718	409	461	1658	2213
Woods	0	0	0	0	0	0
Woodward	0	0	0	0	0	0

TABLE XXI (Continued)

	Other Pesticides					
	Caparol	Prowl	Roundup	Tolban	Treflan	Herbicide Unknown
Application Rate (Lbs/Ac)	.5	.752	.199	.581	.823	.065
County	Pesticide Usage (Lbs/County)					
Adair	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0
Atoka	0	0	0	0	0	0
Beaver	0	0	0	0	0	0
Beckham	240	8512	129	591	14584	824
Blaine	8	300	5	21	515	29
Bryan	8	300	5	21	515	29
Caddo	207	7350	112	511	12594	711
Canadian	30	1062	16	74	1819	103
Carter	0	0	0	0	0	0
Cherokee	0	0	0	0	0	0
Choctaw	0	0	0	0	0	0
Cimarron	0	0	0	0	0	0
Cleveland	7	240	4	17	412	23
Coal	2	84	1	6	144	8
Comanche	106	3765	57	262	6451	364
Cotton	183	6509	99	452	11153	630
Craig	0	0	0	0	0	0
Creek	0	0	0	0	0	0
Custer	85	3024	46	210	5182	293
Delaware	0	0	0	0	0	0
Dewey	7	240	4	17	412	23
Ellis	0	0	0	0	0	0
Garfield	0	6	0	0	10	1
Garvin	12	441	7	31	755	43
Grady	59	2103	32	146	3603	203
Grant	0	0	0	0	0	0
Greer	179	6349	96	441	10878	614
Harmon	235	8352	127	580	14310	808
Harper	0	0	0	0	0	0
Haskell	0	0	0	0	0	0
Hughes	0	10	0	1	17	1
Jackson	411	14581	222	1013	24982	1411
Jefferson	15	541	8	38	927	52
Johnston	2	60	1	4	103	6
Kay	0	0	0	0	0	0
Kingfisher	0	0	0	0	0	0
Kiowa	419	14881	226	1034	25497	1440
Latimer	0	0	0	0	0	0
Le Flore	0	0	0	0	0	0
Lincoln	0	10	0	1	17	1
Logan	1	50	1	3	86	5
Love	3	118	2	8	202	11
Major	0	0	0	0	0	0

TABLE XXI (Continued)

County	Caparol	Prowl	Roundup	Tolban	Treflan	Herbicide Unknown
Marshall	0	8	0	1	14	1
Mayes	0	0	0	0	0	0
McClain	33	1162	18	81	1990	112
McCurtain	0	0	0	0	0	0
McIntosh	0	0	0	0	0	0
Murray	0	0	0	0	0	0
Muskogee	0	0	0	0	0	0
Noble	0	14	0	1	24	1
Nowata	0	0	0	0	0	0
Okfuskee	1	26	0	2	45	3
Oklahoma	1	40	1	3	69	4
Okmulgee	0	0	0	0	0	0
Osage	0	0	0	0	0	0
Ottawa	0	0	0	0	0	0
Pawnee	0	0	0	0	0	0
Payne	0	8	0	1	14	1
Pittsburg	3	90	1	6	154	9
Pontotoc	0	10	0	1	17	1
Pottawatomie	0	6	0	0	10	1
Pushmataha	0	0	0	0	0	0
Roger Mills	53	1883	29	131	3226	182
Rogers	0	0	0	0	0	0
Seminole	0	0	0	0	0	0
Sequoyah	0	0	0	0	0	0
Stephens	20	721	11	50	1235	70
Texas	0	0	0	0	0	0
Tillman	891	31645	481	2198	54219	3062
Tulsa	0	0	0	0	0	0
Wagoner	0	0	0	0	0	0
Washington	0	0	0	0	0	0
Washita	426	15142	230	1052	25943	1465
Woods	0	0	0	0	0	0
Woodward	0	0	0	0	0	0

TABLE XXII

COUNTY ALFALFA HAY PESTICIDE AMOUNTS

	Cygon	Furadan	Mala-thion	Methyl Para.	Para-thion	Para. 6-3	Penncap -M
Application Rate (Lbs/Ac)	.5	.582	2.587	1.37	.816	.687	.508
County			Pesticide Usage (Lbs/County)				
Adair	11	202	248	40	402	74	9
Alfalfa	97	1770	2173	349	3518	646	78
Atoka	14	253	310	50	503	92	11
Beaver	21	379	466	75	754	138	17
Beckham	30	544	667	107	1081	198	24
Blaine	62	1125	1381	222	2236	411	50
Bryan	20	367	450	72	729	134	16
Caddo	68	1239	1521	244	2463	452	55
Canadian	81	1479	1816	292	2940	540	66
Carter	15	278	341	55	553	102	12
Cherokee	22	404	497	80	804	148	18
Choctaw	30	556	683	110	1106	203	25
Cimarron	64	1163	1428	229	2312	425	52
Cleveland	21	392	481	77	779	143	17
Coal	11	202	248	40	402	74	9
Comanche	41	746	916	147	1483	272	33
Cotton	16	291	357	57	578	106	13
Craig	19	354	435	70	704	129	16
Creek	19	341	419	67	678	125	15
Custer	24	442	543	87	880	162	20
Delaware	18	329	404	65	653	120	15
Dewey	19	354	435	70	704	129	16
Ellis	37	670	823	132	1332	245	30
Garfield	26	468	574	92	930	171	21
Garvin	100	1833	2251	362	3644	669	81
Grady	156	2844	3492	561	5654	1038	126
Grant	48	885	1087	175	1759	323	39
Greer	62	1138	1397	224	2262	415	50
Harmon	11	202	248	40	402	74	9
Harper	36	657	807	130	1307	240	29
Haskell	15	265	326	52	528	97	12
Hughes	26	480	590	95	955	175	21
Jackson	47	860	1055	170	1709	314	38
Jefferson	7	126	155	25	251	46	6
Johnston	10	190	233	37	377	69	8
Kay	66	1213	1490	239	2412	443	54
Kingfisher	46	847	1040	167	1684	309	38
Kiowa	44	796	978	157	1583	291	35
Latimer	13	240	295	47	477	88	11
Le Flore	21	379	466	75	754	138	17
Lincoln	40	733	900	145	1457	268	32
Logan	51	923	1133	182	1834	337	41
Love	21	379	466	75	754	138	17

TABLE XXII (Continued)

County	Cygon	Furadan	Mala-thion	Methyl Para.	Para-thion	Para. 6-3	Penncap -M
Major	54	986	1211	195	1960	360	44
Marshall	8	139	171	27	276	51	6
Mayes	48	885	1087	175	1759	323	39
McClain	58	1062	1304	210	2111	388	47
McCurtain	5	88	109	17	176	32	4
McIntosh	42	758	931	150	1508	277	34
Murray	28	506	621	100	1005	185	22
Muskogee	37	683	838	135	1357	249	30
Noble	43	784	962	155	1558	286	35
Nowata	43	784	962	155	1558	286	35
Okfuskee	17	303	373	60	603	111	13
Oklahoma	36	657	807	130	1307	240	29
Okmulgee	15	278	341	55	553	102	12
Osage	52	948	1164	187	1885	346	42
Ottawa	9	164	202	32	327	60	7
Pawnee	20	367	450	72	729	134	16
Payne	33	594	730	117	1181	217	26
Pittsburg	8	139	171	27	276	51	6
Pontotoc	17	316	388	62	628	115	14
Pottawatomie	39	720	885	142	1432	263	32
Pushmataha	7	126	155	25	251	46	6
Roger Mills	25	455	559	90	905	166	20
Rogers	17	303	373	60	603	111	13
Seminole	26	480	590	95	955	175	21
Sequoyah	32	581	714	115	1156	212	26
Stephens	60	1100	1350	217	2186	402	49
Texas	78	1428	1754	282	2840	522	63
Tillman	57	1049	1288	207	2086	383	46
Tulsa	33	594	730	117	1181	217	26
Wagoner	30	556	683	110	1106	203	25
Washington	22	404	497	80	804	148	18
Washita	48	872	1071	172	1734	318	39
Woods	15	265	326	52	528	97	12
Woodward	32	581	714	115	1156	212	26

TABLE XXII (Continued)

	Other Pesticides						
	Insecticide Other/	Unknown	Sencor	Sinbar	Tolban	Herbicide Other/	Unknown
Application Rate (Lbs/Ac)	.5	1.417	.693	.5	1.333	.5	.5
County	Pesticide Usage (Lbs/County)						
Adair	16	600	12	9	48	10	17
Alfalfa	144	5249	107	77	416	92	149
Atoka	21	750	15	11	59	13	21
Beaver	31	1125	23	17	89	20	32
Beckham	44	1612	33	24	128	28	46
Blaine	91	3337	68	49	365	58	95
Bryan	30	1087	22	16	86	19	31
Caddo	101	3675	75	54	291	64	104
Canadian	120	4387	89	65	348	77	125
Carter	23	825	17	12	65	14	23
Cherokee	33	1200	24	18	95	21	34
Choctaw	45	1650	34	24	131	29	47
Cimarron	94	3450	70	51	274	60	98
Cleveland	32	1162	24	17	92	20	33
Coal	16	600	12	9	48	10	17
Comanche	61	2212	45	33	175	39	63
Cotton	24	862	18	13	68	15	24
Craig	29	1050	21	15	83	18	30
Creek	28	1012	21	15	80	18	29
Custer	36	1312	27	19	104	23	37
Delaware	27	975	20	14	77	17	28
Dewey	29	1050	21	15	83	18	30
Ellis	54	1987	40	29	158	35	56
Garfield	38	1387	28	20	110	24	39
Garvin	149	5437	111	80	431	95	154
Grady	231	8437	172	124	669	147	239
Grant	72	3625	53	39	208	46	74
Greer	92	3375	69	50	268	59	96
Harmon	16	600	12	9	48	10	17
Harper	53	1950	40	29	155	34	55
Haskell	22	787	16	12	62	14	22
Hughes	39	1425	29	21	113	25	40
Jackson	70	2550	52	37	202	44	72
Jefferson	10	375	8	6	30	7	11
Johnston	15	562	11	8	45	10	16
Kay	98	3600	73	53	285	63	102
Kingfisher	69	2512	51	37	199	44	71
Kiowa	65	2362	48	35	187	41	67
Latimer	19	712	15	10	56	12	20
Le Flore	31	1125	23	17	89	20	32
Lincoln	59	2175	44	32	172	38	62
Logan	75	2737	56	40	217	48	78
Love	31	1125	23	17	89	20	32
Major	80	2925	60	43	232	51	83

TABLE XXII (Continued)

County	Insecticide Other/	Unknown	Sencor	Sinbar	Tolban	Herbicide Other/	Unknown
Marshall	11	412	8	6	33	7	12
Mayes	72	2625	53	39	208	46	74
McClain	86	3150	64	46	250	55	89
McCurtain	7	262	5	4	21	5	7
McIntosh	62	2250	46	33	178	39	64
Murray	41	1500	31	22	119	26	43
Muskogee	55	2025	41	30	161	35	57
Noble	64	2325	47	34	184	41	66
Nowata	64	2325	47	34	184	41	66
Okfuskee	25	900	18	13	71	16	26
Oklahoma	53	1950	40	29	155	34	55
Okmulgee	23	825	17	12	65	14	23
Osage	77	2812	57	41	223	49	80
Ottawa	13	487	10	7	39	8	14
Pawnee	30	1087	22	16	86	19	31
Payne	48	1762	36	26	140	31	50
Pittsburg	11	412	8	6	33	7	12
Pontotoc	26	937	19	14	74	16	27
Pottawatomie	58	2137	44	31	169	37	61
Pushmataha	10	375	8	6	30	7	11
Roger Mills	37	1350	28	20	107	24	38
Rogers	25	900	18	13	71	16	26
Seminole	39	1425	29	21	113	25	40
Sequoyah	47	1725	35	25	137	30	49
Stephens	89	3262	66	48	259	57	93
Texas	116	4237	86	62	336	74	120
Tillman	85	3112	63	46	247	54	88
Tulsa	48	1762	36	26	140	31	50
Wagoner	45	1650	34	24	131	29	47
Washington	33	1200	24	18	95	21	34
Washita	71	2587	53	38	205	45	73
Woods	22	787	16	12	62	14	22
Woodward	47	1725	35	25	137	30	49

TABLE XXIII

COUNTY SOYBEAN PESTICIDE AMOUNTS

	Insecticide	Other/Unknown	Basagran	Blazer	Dual	Lasso	Lorox	Prowl	Roundup
Application Rate (Lbs/Ac)	.5	.5	.497	.23	.998	2.0	.431	.951	.608
County	Pesticide Usage (Lbs/County)								
Adair	1	3	11	2	12	39	5	18	8
Alfalfa	1	3	11	2	12	39	5	18	8
Atoka	7	13	55	11	59	192	24	89	37
Beaver	2	3	13	3	13	44	5	20	9
Beckham	1	2	7	2	8	26	3	12	5
Blaine	1	2	7	2	8	26	3	12	5
Bryan	29	59	246	50	263	860	107	398	167
Caddo	1	3	11	2	12	39	5	18	8
Canadian	7	14	60	12	64	210	26	97	41
Carter	7	13	55	11	59	192	24	89	37
Cherokee	1	3	11	2	12	39	5	18	8
Choctaw	6	11	48	10	51	167	21	77	32
Cimarron	2	3	13	3	13	44	5	20	9
Cleveland	7	14	60	12	64	210	26	97	41
Coal	7	13	55	11	59	192	24	89	37
Comanche	1	3	11	2	12	39	5	18	8
Cotton	1	3	11	2	12	39	5	18	8
Craig	129	257	1074	217	1146	3754	465	1736	730
Creek	7	14	60	12	64	210	26	97	41
Custer	1	2	7	2	8	26	3	12	5
Delaware	27	54	224	45	239	782	97	362	152
Dewey	1	2	7	2	8	26	3	12	5
Ellis	2	3	13	3	13	44	5	20	9
Garfield	1	3	11	2	12	39	5	18	8
Garvin	7	13	55	11	59	192	24	89	37
Grady	7	14	60	12	64	210	26	97	41
Grant	1	3	11	2	12	39	5	18	8
Greer	1	3	11	2	12	39	5	18	8
Harmon	1	3	11	2	12	39	5	18	8
Harper	2	3	13	3	13	44	5	20	9
Haskell	21	43	179	36	191	626	78	289	122
Hughes	27	54	224	45	239	782	97	362	152
Jackson	1	3	11	2	12	39	5	18	8
Jefferson	7	13	55	11	59	192	24	89	37
Johnston	7	13	55	11	59	192	24	89	37
Kay	1	3	11	2	12	39	5	18	8
Kingfisher	7	14	60	12	64	210	26	97	41
Kiowa	1	3	11	2	12	39	5	18	8
Latimer	6	11	48	10	51	167	21	77	32
Le Flore	80	161	671	136	716	2346	291	1085	456
Lincoln	7	14	60	12	64	210	26	97	41
Logan	7	14	60	12	64	210	26	97	41
Love	7	13	55	11	59	192	24	89	37

TABLE XXIII (Contintued)

County	Insecticide		Basa-gran	Blaz-er	Dual	Lasso	Lorox	Prowl	Round-up
	Other/	Unknown							
Major	1	3	11	2	12	39	5	18	8
Marshall	7	13	55	11	59	192	24	89	37
Mayes	48	96	403	81	430	1408	175	651	274
McClain	19	38	157	32	167	548	68	253	106
McCurtain	90	180	751	152	802	2628	326	1215	511
McIntosh	38	75	313	63	334	1095	136	506	213
Murray	7	13	55	11	59	192	24	89	37
Muskogee	145	289	1208	244	1290	4224	524	1953	821
Noble	1	3	11	2	12	39	5	18	8
Nowata	43	87	362	73	387	1267	157	586	246
Okfuskee	7	14	60	12	64	210	26	97	41
Oklahoma	7	14	60	12	64	210	26	97	41
Okmulgee	33	65	273	55	291	954	118	441	185
Osage	40	79	331	67	353	1158	144	535	225
Ottawa	134	268	1118	226	1194	3911	485	1809	760
Pawnee	5	11	45	9	48	156	19	72	30
Payne	7	14	60	12	64	210	26	97	41
Pittsburg	8	15	63	13	67	219	27	101	43
Pontotoc	7	13	55	11	59	192	24	89	37
Pottawatomie	7	14	60	12	64	210	26	97	41
Pushmataha	6	11	48	10	51	167	21	77	32
Roger Mills	1	2	7	2	8	26	3	12	5
Rogers	38	75	313	63	334	1095	136	506	213
Seminole	7	14	60	12	64	210	26	97	41
Sequoyah	48	96	403	81	430	1408	175	651	274
Stephens	7	13	55	11	59	192	24	89	37
Texas	2	3	13	3	13	44	5	20	9
Tillman	1	3	11	2	12	39	5	18	8
Tulsa	56	113	470	95	501	1643	204	760	319
Wagoner	188	375	1566	316	1672	5475	679	2532	1064
Washington	43	86	358	72	382	1251	155	579	243
Washita	1	2	7	2	8	26	3	12	5
Woods	1	3	11	2	12	39	5	18	8
Woodward	1	3	11	2	12	39	5	18	8

TABLE XXIII (Continued)

	Other Pesticides							
	Sencor	Surflan	Tolban	Treflan	Herbicide Other/	Unknown	Fungicide Other	/Unknown
Application Rate (Lbs/Ac)	.7	.5	.885	.886	.5	.537	.5	.5
County	Pesticide Usage (Lbs/County)							
Adair	3	3	4	36	9	37	3	5
Alfalfa	3	3	4	36	9	37	3	5
Atoka	13	14	20	175	46	182	15	23
Beaver	3	3	5	40	11	42	3	6
Beckham	2	2	3	24	6	25	2	3
Blaine	2	2	3	24	6	25	2	3
Bryan	58	62	89	783	208	815	67	104
Caddo	3	3	4	36	9	37	3	5
Canadian	14	15	22	191	51	199	16	26
Carter	13	14	20	175	46	182	15	23
Cherokee	3	3	4	36	9	37	3	5
Choctaw	11	12	17	152	40	158	13	20
Cimarron	3	3	5	40	11	42	3	6
Cleveland	14	15	22	191	51	199	16	26
Coal	13	14	20	175	46	182	15	23
Comanche	3	3	4	36	9	37	3	5
Cotton	3	3	4	36	9	37	3	5
Craig	252	270	387	3417	909	3558	291	455
Creek	14	15	22	191	51	199	16	26
Custer	2	2	3	24	6	25	2	3
Delaware	52	56	81	712	189	741	61	95
Dewey	2	2	3	24	6	25	2	3
Ellis	3	3	5	40	11	42	3	6
Garfield	3	3	4	36	9	37	3	5
Garvin	13	14	20	175	46	182	15	23
Grady	14	15	22	191	51	199	16	26
Grant	3	3	4	36	9	37	3	5
Greer	3	3	4	36	9	37	3	5
Harmon	3	3	4	36	9	37	3	5
Harper	3	3	5	40	11	42	3	6
Haskell	42	45	64	570	151	593	49	76
Hughes	52	56	81	712	189	741	61	95
Jackson	3	3	4	36	9	37	3	5
Jefferson	13	14	20	175	46	182	15	23
Johnston	13	14	20	175	46	182	15	23
Kay	3	3	4	36	9	37	3	5
Kingfisher	14	15	22	191	51	199	16	26
Kiowa	3	3	4	36	9	37	3	5
Latimer	11	12	17	152	40	158	13	20
Le Flore	158	169	242	2136	568	2224	182	284
Lincoln	14	15	22	191	51	199	16	26
Logan	14	15	22	191	51	199	16	26
Love	13	14	20	175	46	182	15	23
Major	3	3	4	36	9	37	3	5

TABLE XXIII (Continued)

County	Sencor	Surflan	Tolban	Treflan	Herbicide Other/	Unknown	Fungicide Other	/Unknown
Marshall	13	14	20	175	46	182	15	23
Mayes	95	101	145	1282	341	1334	109	171
McClain	37	39	56	498	133	519	43	67
McCurtain	176	189	271	2392	636	2491	204	318
McIntosh	74	79	113	997	265	1038	85	133
Murray	13	14	20	175	46	182	15	23
Muskogee	284	304	435	3845	1022	4003	328	511
Noble	3	3	4	36	9	37	3	5
Nowata	85	91	131	1153	307	1201	98	154
Okfuskee	14	15	22	191	51	199	16	26
Oklahoma	14	15	22	191	51	199	16	26
Okmulgee	64	69	98	869	231	904	74	116
Osage	78	83	119	1054	280	1097	90	140
Ottawa	263	281	403	3560	946	3706	304	473
Pawnee	11	11	16	142	38	148	12	19
Payne	14	15	22	191	51	199	16	26
Pittsburg	15	16	23	199	53	208	17	27
Pontotoc	13	14	20	175	46	182	15	23
Pottawatomie	14	15	22	191	51	199	16	26
Pushmataha	11	12	17	152	40	158	13	20
Roger Mills	2	2	3	24	6	25	2	3
Rogers	74	79	113	997	265	1038	85	133
Seminole	14	15	22	191	51	199	16	26
Sequoyah	95	101	145	1282	341	1334	109	171
Stephens	13	14	20	175	46	182	15	23
Texas	3	3	5	40	11	42	3	6
Tillman	3	3	4	36	9	37	3	5
Tulsa	110	118	169	1495	398	1557	128	199
Wagoner	368	394	564	4984	1325	5189	425	663
Washington	84	90	129	1139	303	1186	97	152
Washita	2	2	3	24	6	25	2	3
Woods	3	3	4	36	9	37	3	5
Woodward	3	3	4	36	9	37	3	5

TABLE XXIV

COUNTY OAT PESTICIDE AMOUNTS

	Para-thion	Para. 6-3	Insecticide Other/	Unknown	2,4-D	MCPA	Herb. Unknown	Fungi. Unknown
Application Rate (Lbs/Ac)	.41	.5	.5	.5	1.022	.5	.5	.5
<u>County</u>		<u>Pesticide Usage (Lbs/County)</u>						
Adair	12	3	3	17	39	6	8	3
Alfalfa	75	15	17	100	233	38	47	19
Atoka	96	19	22	129	301	48	60	25
Beaver	50	10	11	67	155	25	31	13
Beckham	84	17	19	113	262	42	52	21
Blaine	103	21	23	138	320	52	64	26
Bryan	249	50	57	333	777	125	155	63
Caddo	155	31	35	208	485	78	97	40
Canadian	137	27	31	183	427	69	85	35
Carter	165	33	38	221	515	83	103	42
Cherokee	19	4	4	25	58	9	12	5
Choctaw	50	10	11	67	155	25	31	13
Cimarron	34	7	8	46	107	17	21	9
Cleveland	62	13	14	83	194	31	39	16
Coal	62	13	14	83	194	31	39	16
Comanche	187	38	43	250	583	94	116	48
Cotton	62	13	14	83	194	31	39	16
Craig	103	21	23	138	320	52	64	26
Creek	62	13	14	83	194	31	39	16
Custer	106	21	24	142	330	53	66	27
Delaware	62	13	14	83	194	31	39	16
Dewey	143	29	33	192	447	72	89	36
Ellis	72	14	16	96	223	36	45	18
Garfield	90	18	21	121	282	45	56	23
Garvin	124	25	28	167	388	62	77	32
Grady	187	38	43	250	583	94	116	48
Grant	50	10	11	67	155	25	31	13
Greer	37	8	9	50	117	19	23	10
Harmon	25	5	6	33	78	13	16	6
Harper	78	16	18	104	243	39	48	20
Haskell	25	5	6	33	78	13	16	6
Hughes	62	13	14	83	194	31	39	16
Jackson	109	22	25	146	340	55	68	28
Jefferson	187	38	43	250	583	94	116	48
Johnston	127	26	29	171	398	64	79	32
Kay	37	8	9	50	117	19	23	10
Kingfisher	124	25	28	167	388	62	77	32
Kiowa	62	13	14	83	194	31	39	16
Latimer	7	1	2	10	23	4	5	2
Le Flore	22	4	5	29	68	11	14	6
Lincoln	249	50	57	333	777	125	155	63
Logan	208	42	47	279	651	105	130	53
Love	155	31	35	208	485	78	97	40

TABLE XXIV (Continued)

County	Para-thion	Para. 6-3	Insecticide Other/	Unknown	2,4-D	MCPA	Herb. Unknown	Fungi. Unknown
Major	124	25	28	167	388	62	77	32
Marshall	81	16	18	108	252	41	50	21
Mayes	140	28	32	188	437	70	87	36
McClain	155	31	35	208	485	78	97	40
McCurtain	7	1	2	10	23	4	5	2
McIntosh	37	8	9	50	117	19	23	10
Murray	47	9	11	63	146	23	29	12
Muskogee	124	25	28	167	388	62	77	32
Noble	72	14	16	96	223	36	45	18
Nowata	109	22	25	146	340	55	68	28
Okfuskee	75	15	17	100	233	38	47	19
Oklahoma	230	46	52	308	718	116	143	59
Okmulgee	143	29	33	192	447	72	89	36
Osage	109	22	25	146	340	55	68	28
Ottawa	78	16	18	104	243	39	48	20
Pawnee	78	16	18	104	243	39	48	20
Payne	47	9	11	63	146	23	29	12
Pittsburg	62	13	14	83	194	31	39	16
Pontotoc	106	21	24	142	330	53	66	27
Pottawatomie	93	19	21	125	291	47	58	24
Pushmataha	7	1	2	10	23	4	5	2
Roger Mills	165	33	38	221	515	83	103	42
Rogers	124	25	28	167	388	62	77	32
Seminole	50	10	11	67	155	25	31	13
Sequoyah	12	3	3	17	39	6	8	3
Stephens	155	31	35	208	485	78	97	40
Texas	202	41	46	271	631	102	126	51
Tillman	202	41	46	271	631	102	126	51
Tulsa	53	11	12	71	165	27	33	13
Wagoner	31	6	7	42	97	16	19	8
Washington	78	16	18	104	243	39	48	20
Washita	177	36	40	238	553	89	110	45
Woods	37	8	9	50	117	19	23	10
Woodward	137	27	31	183	427	69	85	35

TABLE XXV

COUNTY CORN PESTICIDE AMOUNTS

	Insecticide Other	Atra-zine	Bladex	2,4-D	Dual	Herbicide Other/	Herbicide Unknown	Fungi. Unknown
Application Rate (Lbs/Ac)	.5	1.319	1.085	.5	.5	.5	.5	.5
<u>County</u>			Pesticide Usage (Lbs/County)					
Adair	63	131	79	7	6	32	22	31
Alfalfa	38	79	47	4	3	19	13	19
Atoka	46	96	58	5	4	23	16	23
Beaver	110	229	138	12	10	56	39	55
Beckham	89	186	112	10	8	45	32	44
Blaine	89	186	112	10	8	45	32	44
Bryan	165	344	207	19	15	84	59	82
Caddo	461	964	580	52	41	235	164	229
Canadian	477	998	601	54	42	244	170	237
Carter	46	96	58	5	4	23	16	23
Cherokee	63	131	79	7	6	32	22	31
Choctaw	99	206	124	11	9	50	35	49
Cimarron	2962	6195	3728	335	262	1514	1055	1473
Cleveland	181	379	228	21	16	93	65	90
Coal	46	96	58	5	4	23	16	23
Comanche	47	98	59	5	4	24	17	23
Cotton	47	98	59	5	4	24	17	23
Craig	181	379	228	21	16	93	65	90
Creek	43	90	54	5	4	22	15	21
Custer	214	447	269	24	19	109	76	106
Delaware	30	63	38	3	3	15	11	15
Dewey	89	186	112	10	8	45	32	44
Ellis	110	229	138	12	10	56	39	55
Garfield	38	79	47	4	3	19	13	19
Garvin	296	619	373	34	26	151	106	147
Grady	148	310	186	17	13	76	53	74
Grant	38	79	47	4	3	19	13	19
Greer	47	98	59	5	4	24	17	23
Harmon	165	344	207	19	15	84	59	82
Harper	110	229	138	12	10	56	39	55
Haskell	63	131	79	7	6	32	22	31
Hughes	181	379	228	21	16	93	65	90
Jackson	47	98	59	5	4	24	17	23
Jefferson	46	96	58	5	4	23	16	23
Johnston	115	241	145	13	10	59	41	57
Kay	38	79	47	4	3	19	13	19
Kingfisher	43	90	54	5	4	22	15	21
Kiowa	47	98	59	5	4	24	17	23
Latimer	99	206	124	11	9	50	35	49
Le Flore	99	206	124	11	9	50	35	49
Lincoln	43	90	54	5	4	22	15	21
Logan	43	90	54	5	4	22	15	21
Love	46	96	58	5	4	23	16	23

TABLE XXV (Continued)

County	Insecticide Other	Atra-zine	Bladex	2,4-D	Dual	Herbicide Other/	Unknown	Fungi. Unknown
Major	230	482	290	26	20	118	82	115
Marshall	46	96	58	5	4	23	16	23
Mayes	313	654	394	35	28	160	111	155
McClain	263	551	331	30	23	135	94	131
McCurtain	99	206	124	11	9	50	35	49
McIntosh	115	241	145	13	10	59	41	57
Murray	46	96	58	5	4	23	16	23
Muskogee	115	241	145	13	10	59	41	57
Noble	38	79	47	4	3	19	13	19
Nowata	197	413	249	22	17	101	70	98
Okfuskee	43	90	54	5	4	22	15	21
Oklahoma	148	310	186	17	13	76	53	74
Okmulgee	346	723	435	39	31	177	123	172
Osage	115	241	145	13	10	59	41	57
Ottawa	82	172	104	9	7	42	29	41
Pawnee	30	63	38	3	3	15	11	15
Payne	43	90	54	5	4	22	15	21
Pittsburg	63	131	79	7	6	32	22	31
Pontotoc	46	96	58	5	4	23	16	23
Pottawatomie	43	90	54	5	4	22	15	21
Pushmataha	99	206	124	11	9	50	35	49
Roger Mills	89	186	112	10	8	45	32	44
Rogers	30	63	38	3	3	15	11	15
Seminole	43	90	54	5	4	22	15	21
Sequoyah	63	131	79	7	6	32	22	31
Stephens	46	96	58	5	4	23	16	23
Texas	7569	15860	9528	857	669	3868	2697	3764
Tillman	47	98	59	5	4	24	17	23
Tulsa	30	63	38	3	3	15	11	15
Wagoner	30	63	38	3	3	15	11	15
Washington	30	63	38	3	3	15	11	15
Washita	89	186	112	10	8	45	32	44
Woods	38	79	47	4	3	19	13	19
Woodward	38	79	47	4	3	19	13	19

TABLE XXVI

COUNTY PEANUT PESTICIDE AMOUNTS

	Di-Syston	Fur-adan	Sevin	Insecticide Other/Unknown	Balan	2,4-D	Dynap	Lasso	Prowl
Application Rate (Lbs/Ac)	.816	1.185	.5	.5	.5	.5	.5	2.183	.5	.5
County			Pesticide Usage (Lbs/County)						
Adair	8	14	3	2	8	2	9	7	55	3
Alfalfa	0	0	0	0	0	0	0	0	0	0
Atoka	237	397	74	63	221	66	276	195	1592	101
Beaver	0	0	0	0	0	0	0	0	0	0
Beckham	11	18	3	3	10	3	13	9	73	5
Blaine	11	18	3	3	10	3	13	9	73	5
Bryan	970	1623	301	256	903	271	1129	798	6506	414
Caddo	2185	3655	678	576	2034	610	2542	1796	14650	932
Canadian	14	24	4	4	13	4	17	12	97	6
Carter	61	102	19	16	57	17	71	50	409	26
Cherokee	8	14	3	2	8	2	9	7	55	3
Choctaw	41	68	13	11	38	11	47	33	273	17
Cimarron	0	0	0	0	0	0	0	0	0	0
Cleveland	14	24	4	4	13	4	17	12	997	6
Coal	15	26	5	4	14	4	18	13	102	7
Comanche	75	125	23	20	69	21	87	61	500	32
Cotton	5	9	2	1	5	2	6	4	36	2
Craig	0	0	0	0	0	0	0	0	0	0
Creek	14	24	4	4	13	4	17	12	97	6
Custer	11	18	3	3	10	3	13	9	73	5
Delaware	0	0	0	0	0	0	0	0	0	0
Dewey	11	18	3	3	10	3	13	9	73	5
Ellis	0	0	0	0	0	0	0	0	0	0
Garfield	0	0	0	0	0	0	0	0	0	0
Garvin	81	136	25	21	76	23	95	67	546	35
Grady	210	352	65	55	196	59	245	173	1410	90
Grant	0	0	0	0	0	0	0	0	0	0
Greer	5	9	2	1	5	2	6	4	36	2
Harmon	5	9	2	1	5	2	6	4	36	2
Harper	0	0	0	0	0	0	0	0	0	0
Haskell	8	14	3	2	8	2	9	7	55	3
Hughes	489	817	152	129	455	136	568	402	3276	208
Jackson	61	102	19	16	57	17	71	50	409	26
Jefferson	15	26	5	4	14	4	18	13	102	7
Johnston	163	272	51	43	152	45	189	134	1092	69
Kay	0	0	0	0	0	0	0	0	0	0
Kingfisher	14	24	4	4	13	4	17	12	97	6
Kiowa	5	9	2	1	5	2	6	4	36	2
Latimer	7	11	2	2	6	2	8	6	45	3
Le Flore	7	11	2	2	6	2	8	6	45	3
Lincoln	14	24	4	4	13	4	17	12	97	6
Logan	14	24	4	4	13	4	17	12	97	6
Love	339	568	105	89	316	95	395	279	2275	145

TABLE XXVI (Continued)

County	Di-Syston	Fur-adan	Sevin	Insecticide Other/Unknown		Balan	2,4-D	Dynap	Lasso	Prowl
Major	0	0	0	0	0	0	0	0	0	0
Marshall	204	341	63	54	189	57	237	167	1365	87
Mayes	0	0	0	0	0	0	0	0	0	0
McClain	47	79	15	13	44	13	55	39	318	20
McCurtain	7	11	2	2	6	2	8	6	45	3
McIntosh	54	91	17	14	51	15	63	45	364	23
Murray	15	26	5	4	14	4	18	13	102	7
Muskogee	8	14	3	2	8	2	9	7	55	3
Noble	0	0	0	0	0	0	0	0	0	0
Nowata	0	0	0	0	0	0	0	0	0	0
Okfuskee	129	216	40	34	120	36	150	106	864	55
Oklahoma	14	24	4	4	13	4	17	12	97	6
Okmulgee	170	284	53	45	158	47	197	139	1137	72
Osage	0	0	0	0	0	0	0	0	0	0
Ottawa	0	0	0	0	0	0	0	0	0	0
Pawnee	0	0	0	0	0	0	0	0	0	0
Payne	14	24	4	4	13	4	17	12	97	6
Pittsburg	156	261	48	41	145	44	182	128	1046	67
Pontotoc	15	26	5	4	14	4	18	13	102	7
Pottawatomie	170	284	53	45	158	47	197	139	1137	72
Pushmataha	7	11	2	2	6	2	8	6	45	3
Roger Mills	11	18	3	3	10	3	13	9	73	5
Rogers	0	0	0	0	0	0	0	0	0	0
Seminole	47	79	15	13	44	13	55	39	318	20
Sequoyah	8	14	3	2	8	2	9	7	55	3
Stephens	156	261	48	41	145	44	182	128	1046	67
Texas	0	0	0	0	0	0	0	0	0	0
Tillman	5	9	2	1	5	2	6	4	36	2
Tulsa	0	0	0	0	0	0	0	0	0	0
Wagoner	0	0	0	0	0	0	0	0	0	0
Washington	0	0	0	0	0	0	0	0	0	0
Washita	75	125	23	20	69	21	87	61	500	32
Woods	0	0	0	0	0	0	0	0	0	0
Woodward	0	0	0	0	0	0	0	0	0	0

TABLE XXVI (Continued)

	Other Pesticides								
	Round-up	Tolban	Treflan	Herbicide Other/Unknown		Bravo	Terra-chlor	Fungicide Other/Unknown	
Application Rate (Lbs/Ac)	.437	.5	.565	.5	.939	.5	.5	.5	.5
County	Pesticide Usage (Lbs/County)								
Adair	3	4	28	3	30	10	7	7	11
Alfalfa	0	0	0	0	0	0	0	0	0
Atoka	98	122	822	87	872	280	192	197	315
Beaver	0	0	0	0	0	0	0	0	0
Beckham	4	6	38	4	40	13	9	9	14
Blaine	4	6	38	4	40	13	9	9	14
Bryan	401	497	3359	354	3562	1144	783	805	1287
Caddo	904	119	7564	797	8020	2576	1763	1813	2898
Canadian	6	7	50	5	53	17	12	12	19
Carter	25	31	211	22	224	72	49	51	81
Cherokee	3	4	28	3	30	10	7	7	11
Choctaw	17	21	141	15	149	48	33	34	54
Cimarron	0	0	0	0	0	0	0	0	0
Cleveland	6	7	50	5	53	17	12	12	19
Coal	6	8	53	6	56	18	12	13	20
Comanche	31	38	258	27	274	88	60	62	99
Cotton	2	3	19	2	20	6	4	5	7
Craig	0	0	0	0	0	0	0	0	0
Creek	6	7	50	5	53	17	12	12	19
Custer	4	6	38	4	40	13	9	9	14
Delaware	0	0	0	0	0	0	0	0	0
Dewey	4	6	38	4	40	13	9	9	14
Ellis	0	0	0	0	0	0	0	0	0
Garfield	0	0	0	0	0	0	0	0	0
Garvin	34	42	282	30	299	96	66	68	108
Grady	87	108	728	77	772	248	170	175	279
Grant	0	0	0	0	0	0	0	0	0
Greer	2	3	19	2	20	6	4	5	7
Harmon	2	3	19	2	20	6	4	5	7
Harper	0	0	0	0	0	0	0	0	0
Haskell	3	4	28	3	30	10	7	7	11
Hughes	202	250	1691	178	1793	576	394	405	648
Jackson	25	31	211	22	224	72	49	51	81
Jefferson	6	8	53	6	56	18	12	13	20
Johnston	67	83	564	59	598	192	131	135	216
Kay	0	0	0	0	0	0	0	0	0
Kingfisher	6	7	50	5	53	17	12	12	19
Kiowa	2	3	19	2	20	6	4	5	7
Latimer	3	3	23	2	25	8	5	6	9
Le Flore	3	3	23	2	25	8	5	6	9
Lincoln	6	7	50	5	53	17	12	12	19
Logan	6	7	50	5	53	17	12	12	19
Love	140	174	1175	124	1245	400	274	282	450
Major	0	0	0	0	0	0	0	0	0

TABLE XXVI (Continued)

County	Round-up	Tolban	Treflan	Herbicide Other/	Unknown	Bravo	Terra-chlor	Fungicide Other/	Unknown
Marshall	84	104	705	74	747	240	164	169	270
Mayes	0	0	0	0	0	0	0	0	0
McClain	20	24	164	17	174	56	38	39	63
McCurtain	3	3	23	2	25	8	5	6	9
McIntosh	22	28	188	20	199	64	44	45	72
Murray	6	8	53	6	56	18	12	13	20
Muskogee	3	4	28	3	30	10	7	7	11
Noble	0	0	0	0	0	0	0	0	0
Nowata	0	0	0	0	0	0	0	0	0
Okfuskee	53	66	446	47	473	152	104	107	171
Oklahoma	6	7	50	5	53	17	12	12	19
Okmulgee	70	87	587	62	623	200	137	141	225
Osage	0	0	0	0	0	0	0	0	0
Ottawa	0	0	0	0	0	0	0	0	0
Pawnee	0	0	0	0	0	0	0	0	0
Payne	6	7	50	5	53	17	12	12	19
Pittsburg	65	80	540	57	573	184	126	130	207
Pontotoc	6	8	53	6	56	18	12	13	20
Pottawatomie	70	87	587	62	623	200	137	141	225
Pushmataha	3	3	23	2	25	8	5	6	9
Roger Mills	4	6	38	4	40	13	9	9	14
Rogers	0	0	0	0	0	0	0	0	0
Seminole	20	24	164	17	174	56	38	39	63
Sequoyah	3	4	28	3	30	10	7	7	11
Stephens	65	80	540	57	573	184	126	130	207
Texas	0	0	0	0	0	0	0	0	0
Tillman	2	3	19	2	20	6	4	5	7
Tulsa	0	0	0	0	0	0	0	0	0
Wagoner	0	0	0	0	0	0	0	0	0
Washington	0	0	0	0	0	0	0	0	0
Washita	31	38	258	27	274	88	60	62	99
Woods	0	0	0	0	0	0	0	0	0
Woodward	0	0	0	0	0	0	0	0	0

TABLE XXVII

COUNTY BARLEY PESTICIDE AMOUNTS

	Para-thion	Insecticide Other/	Unknown	2,4-D	Herbicide Other	Fungicide Other/	Unknown
Application Rate (Lbs/Ac)	.5	.5	.5	.5	.5	.5	.5
County		Pesticide Usage (Lbs/County)					
Adair	5	2	2	3	3	4	5
Alfalfa	56	27	17	34	31	49	55
Atoka	13	6	4	8	7	11	13
Beaver	124	58	37	74	69	107	120
Beckham	135	64	41	81	75	117	131
Blaine	303	143	91	183	168	264	295
Bryan	13	6	4	8	7	11	13
Caddo	157	74	47	95	87	137	153
Canadian	640	303	193	386	355	557	623
Carter	13	6	4	8	7	11	13
Cherokee	5	2	2	3	3	4	5
Choctaw	0	0	0	0	0	0	0
Cimarron	225	106	68	135	125	195	218
Cleveland	22	11	7	14	12	20	22
Coal	13	6	4	8	7	11	13
Comanche	180	85	54	108	100	156	175
Cotton	202	96	61	122	112	176	197
Craig	22	11	7	14	12	20	22
Creek	22	11	7	14	12	20	22
Custer	359	170	108	217	199	313	350
Delaware	22	11	7	14	12	20	22
Dewey	135	64	41	81	75	117	131
Ellis	112	53	34	68	62	98	109
Garfield	270	127	81	162	150	234	262
Garvin	13	6	4	8	7	11	13
Grady	135	64	41	81	75	117	131
Grant	202	96	61	122	112	176	197
Greer	135	64	41	81	75	117	131
Harmon	62	29	19	37	34	54	60
Harper	180	85	54	108	100	156	175
Haskell	5	2	2	3	3	4	5
Hughes	5	2	2	3	3	4	5
Jackson	135	64	41	81	75	117	131
Jefferson	13	6	4	8	7	11	13
Johnston	13	6	4	8	7	11	13
Kay	359	170	108	217	199	313	350
Kingfisher	393	186	118	237	218	342	382
Kiowa	62	29	19	37	34	54	60
Latimer	0	0	0	0	0	0	0
Le Flore	0	0	0	0	0	0	0
Lincoln	22	11	7	14	12	20	22
Logan	247	117	74	149	137	215	240
Love	13	6	4	8	7	11	13

TABLE XXVII (Continued)

County	Para-thion	Insecticide Other/	Unknown	2,4-D	Herbicide Other	Fungicide Other/	Unknown
Major	247	117	74	149	137	215	240
Marshall	13	6	4	8	7	11	13
Mayes	22	11	7	14	12	20	22
McClain	22	11	7	14	12	20	22
McCurtain	0	0	0	0	0	0	0
McIntosh	5	2	2	3	3	4	5
Murray	13	6	4	8	7	11	13
Muskogee	5	2	2	3	3	4	5
Noble	314	149	95	190	174	274	306
Nowata	22	11	7	14	12	20	22
Okfuskee	22	11	7	14	12	20	22
Oklahoma	112	53	34	68	62	98	109
Okmulgee	5	2	2	3	3	4	5
Osage	22	11	7	14	12	20	22
Ottawa	22	11	7	14	12	20	22
Pawnee	22	11	7	14	12	20	22
Payne	168	80	51	102	93	147	164
Pittsburg	5	2	2	3	3	4	5
Pontotoc	13	6	4	8	7	11	13
Pottawatomie	22	11	7	14	12	20	22
Pushmataha	0	0	0	0	0	0	0
Roger Mills	236	111	71	142	131	205	229
Rogers	22	11	7	14	12	20	22
Seminole	22	11	7	14	12	20	22
Sequoyah	5	2	2	3	3	4	5
Stephens	13	6	4	8	7	11	13
Texas	202	96	61	122	112	176	197
Tillman	247	117	74	149	137	215	240
Tulsa	22	11	7	14	12	20	22
Wagoner	22	11	7	14	12	20	22
Washington	22	11	7	14	12	20	22
Washita	236	111	71	142	131	205	229
Woods	67	32	20	41	37	59	66
Woodward	56	27	17	34	31	49	55

APPENDIX D

DETERMINATION OF PESTICIDE TRANSPORT HAZARD INDEX

TABLE XXVIII

PESTICIDE TRANSPORT HAZARD INDEX

County	Banvel (Pounds)	Fur-adan	Milo-gard	Atra-zine	2,4-D	Total Pest.	County Area	Final Index
Adair	892	619	21	1199	25	2757	369062	4.35
Alfalfa	105601	5073	536	2051	1574	114835	553075	120.89
Atoka	1064	1863	134	1173	99	4332	627193	4.02
Beaver	58633	1086	10023	27620	1967	99329	1156812	49.99
Beckham	23810	1611	2003	6744	768	34936	578412	35.17
Blaine	40998	3276	1402	5206	1243	52126	589030	51.53
Bryan	8406	5704	1536	6918	445	23008	577580	23.19
Caddo	35063	14027	3117	16348	1481	70036	822796	49.56
Canadian	77880	4308	622	10264	1262	94335	576908	95.21
Carter	3294	1089	200	1347	135	6064	529600	6.67
Cherokee	892	1198	21	1199	28	3338	478995	4.06
Choctaw	4289	1788	467	2990	129	9663	487936	11.53
Cimarron	69165	3333	36078	146095	3135	257807	1178585	127.36
Cleveland	4975	1192	601	4832	131	11732	338636	20.17
Coal	1201	653	268	1521	59	3702	333081	6.47
Comanche	13826	2496	446	1990	497	19256	688492	16.28
Cotton	28442	860	536	2216	844	32897	419558	45.65
Craig	66558	1015	3340	11837	502	83251	488147	99.30
Creek	2402	1046	223	1356	75	5102	594982	4.99
Custer	44738	1318	2003	9013	1373	58445	628121	54.18
Delaware	26520	943	1313	3911	213	32900	460992	41.55
Dewey	24050	1066	1491	5432	782	32822	644582	29.65
Ellis	21995	1920	2450	8256	723	35341	788761	26.09
Garfield	134831	42	423	1764	2012	139073	678451	119.35
Garvin	8508	5644	1313	8743	251	24459	520268	27.37
Grady	32456	9160	1447	6397	653	50112	708025	41.21
Grant	137988	2537	1938	5640	2105	150207	642739	136.07
Greer	20105	3288	378	1816	593	26179	408505	37.31
Harmon	20379	605	536	4354	597	26471	343526	44.87
Harper	31872	1883	1560	5979	975	42270	664665	37.03
Haskell	2710	800	179	1590	72	5351	364704	8.54
Hughes	7891	3717	1069	6032	298	19006	515552	21.47
Jackson	46522	2757	756	2790	1371	54196	522905	60.35
Jefferson	19418	436	268	1521	372	22014	492102	26.05
Johnston	1647	1324	667	3807	134	7578	409088	10.79
Kay	91329	3477	3117	8656	1498	108076	589465	106.75
Kingfisher	103199	2496	580	2260	1591	110127	579692	110.61
Kiowa	43777	2307	357	1764	1249	49455	652096	44.16
Latimer	892	719	45	1903	24	3584	465958	4.48
Le Flore	4048	1118	45	1903	91	7205	1014265	4.14
Lincoln	5832	2170	557	2208	216	10982	617081	10.36
Logan	34960	2714	312	1582	623	40191	478777	48.88
Love	5627	2714	935	3224	241	12740	332294	22.32
Major	59696	2826	935	6579	973	71009	612806	67.47
Marshall	2436	1376	244	1460	112	5628	238073	13.76
Mayes	24839	2537	1024	8300	288	36988	411878	52.29
McClain	9057	3270	691	6553	238	19810	372179	30.99
McCurtain	12145	284	712	3615	268	17024	1168876	8.48

TABLE XXVIII (Continued)

County	Banvel (Pounds)	Fur-adan	Milo-gard	Atra-zine	2,4-D	Total Pest.	County Area	Final Index
McIntosh	5661	2433	979	4598	175	13846	383526	21.02
Murray	1647	1525	110	1121	52	4455	268883	9.65
Muskogee	16502	1998	1268	5336	423	25528	521331	28.51
Noble	54962	2247	846	2851	882	61787	471072	76.37
Nowata	24393	2247	1024	6205	266	34135	345868	57.46
Okfuskee	3122	1488	333	1634	113	6690	402003	9.69
Oklahoma	11528	1952	402	3720	291	17892	453401	22.98
Okmulgee	8611	1611	979	8787	295	20284	446425	26.45
Osage	49370	2717	2003	7222	503	61815	1449286	24.83
Ottawa	77502	470	3786	11177	590	93526	297568	183.00
Pawnee	21717	1052	646	2199	292	25906	352947	42.74
Payne	16468	1771	691	2546	304	21780	441990	28.69
Pittsburg	2676	1146	557	2564	125	7068	800352	5.14
Pontotoc	2024	980	735	2712	110	6561	458841	8.33
Pottawatomie	6347	2878	756	2720	192	12894	501318	14.98
Pushmataha	1098	393	45	1903	29	3467	906617	2.23
Roger Mills	19556	1356	3117	9586	782	34342	733395	27.26
Rogers	8097	868	491	1799	229	11484	436876	15.31
Seminole	2539	1602	357	1695	83	6276	408646	8.94
Sequoyah	2985	1705	21	1199	66	5976	433875	8.02
Stephens	22129	3901	491	2086	429	29036	566028	29.87
Texas	97230	4093	39195	237802	4144	382464	1305580	170.57
Tillman	30843	3032	1447	4554	999	40875	578470	41.14
Tulsa	6519	1703	200	1060	158	9639	365811	15.34
Wagoner	19521	1594	512	1860	411	23897	357977	38.87
Washington	5009	1158	357	1460	145	8129	270828	17.48
Washita	46213	2858	2673	8448	1462	61654	643852	55.75
Woods	106836	760	223	1260	1563	110642	826316	77.96
Woodward	55339	1665	2673	7518	30	67225	794848	49.24

APPENDIX E

DETERMINATION OF EXPOSURE INDEX

TABLE XXIX

EXPOSURE INDEX

County	Ground Water (Acre-Ft)	Surface Water (Acre-Ft)	Total Water (Acre-Ft)	Percent Ground Water	Population (1000's)	Final Index
Adair	0	3613	3613	0	18.575	0.00
Alfalfa	1230	0	1230	100	7.077	117.47
Atoka	116	150	266	44	12.748	51.51
Beaver	124	0	124	100	6.806	117.44
Beckham	60	1	61	98	19.243	116.94
Blaine	886	24	910	97	13.443	115.09
Bryan	1357	2881	4238	32	30.535	38.49
Caddo	1268	9403	10671	12	30.905	14.29
Canadian	3316	0	3316	100	56.452	123.23
Carter	807	9082	9889	8	43.610	9.93
Cherokee	0	6147	6147	0	30.684	0.00
Choctaw	32	0	32	100	17.203	118.65
Cimarron	1	0	1	100	3.648	117.07
Cleveland	8665	15969	24634	35	133.173	46.49
Coal	104	15	119	87	6.041	102.56
Comanche	678	20458	21136	3	12.456	3.79
Cotton	143	415	558	26	7.338	30.11
Craig	6	1543	1549	0	15.014	0.46
Creek	110	6062	6172	2	59.210	2.20
Custer	2542	1130	3672	69	25.995	82.85
Delaware	55	0	55	100	23.946	119.44
Dewey	70	0	70	100	5.922	117.33
Ellis	404	0	404	100	5.696	117.29
Garfield	6402	0	6402	100	62.820	123.97
Garvin	1086	583	1669	65	27.856	78.01
Grady	701	0	701	100	39.490	121.25
Grant	836	0	836	100	6.518	117.40
Greer	1785	0	1785	100	6.877	117.44
Harmon	263	0	263	100	4.519	117.17
Harper	474	0	474	100	4.715	117.19
Haskell	0	1094	1094	0	11.010	0.00
Hughes	94	1992	2086	5	14.338	5.33
Jackson	276	2984	3260	8	30.356	10.18
Jefferson	471	64	535	88	8.183	103.53
Johnston	250	32	282	89	10.356	104.48
Kay	11140	2910	14050	79	49.852	97.09
Kingfisher	8378	0	8378	100	14.187	118.30
Kiowa	830	278	1108	75	112.711	97.22
Latimer	0	2369	2369	0	9.840	0.00
Le Flore	0	4836	4836	0	40.698	0.00
Lincoln	261	457	718	36	26.601	43.53
Logan	476	2320	2796	17	26.881	20.39
Love	283	0	283	100	7.469	117.51
Major	4136	0	4136	100	8.772	117.67
Marshall	0	798	798	0	10.550	0.00
Mayes	0	1750	1750	0	32.261	0.00
McClain	531	0	531	100	20.291	119.01

TABLE XXIX (Continued)

County	Ground Water (Acre-Ft)	Surface Water (Acre-Ft)	Total Water (Acre-Ft)	Percent Ground Water	Population (1000'S)	Final Index
McCurtain	0	3483	3483	0	36.151	0.00
McIntosh	0	2822	2822	0	15.495	0.00
Murray	0	4892	4892	0	12.147	0.00
Muskogee	0	393	393	0	66.939	0.00
Noble	63	1578	1641	4	11.573	4.53
Nowata	0	200	200	0	11.486	0.00
Okfuskee	0	981	981	0	11.125	0.00
Oklahoma	12761	0	12761	100	568.933	183.00
Okmulgee	0	8658	8658	0	39.169	0.00
Osage	141	10393	10534	1	39.327	1.62
Ottawa	3524	0	3524	100	32.870	120.48
Pawnee	107	1311	1418	8	15.310	8.94
Payne	562	2372	2934	19	62.435	23.74
Pittsburg	0	615	615	0	40.524	0.00
Pontotoc	4511	4244	8755	52	32.598	62.06
Pottawatomie	913	473	1386	66	55.239	81.08
Pushmataha	0	721	721	0	11.773	0.00
Roger Mills	4	192	196	2	4.799	2.39
Rogers	0	1642	1642	0	46.436	0.00
Seminole	5432	5010	10442	52	27.473	62.35
Sequoyah	0	3043	3043	0	30.749	0.00
Stephens	1379	5836	7215	19	43.419	23.26
Texas	4384	0	4384	100	17.727	118.71
Tillman	515	2082	2597	20	12.398	23.42
Tulsa	0	112635	112635	0	470.593	0.00
Wagoner	0	1236	1236	0	41.801	0.00
Washington	0	5049	5049	0	48.113	0.00
Washita	1932	2643	4575	42	13.798	49.94
Woods	256	0	256	100	10.923	117.92
Woodward	5584	0	5584	100	21.172	119.11

APPENDIX F

DETERMINATION OF PHYSICAL TRANSPORT INDEX

TABLE XXX

PHYSICAL TRANSPORT INDEX

County	Banvel (Pounds)	Fur-adan	Milo-gard	Atra-zine	2,4-D	Total Pest.	Final Index
Adair	10.17	43.78	1.49	22.44	2.52	80	5.73
Alfalfa	1204.11	358.78	37.88	38.37	157.45	1797	85.94
Atoka	12.13	131.76	9.47	21.95	9.86	185	7.80
Beaver	668.56	76.82	708.82	516.74	196.75	2168	49.57
Beckham	271.49	113.92	141.69	126.18	76.81	730	33.38
Blaine	467.48	231.69	99.16	97.40	124.33	1020	45.80
Bryan	95.84	403.37	108.63	129.43	44.46	782	35.81
Caddo	399.81	992.01	220.43	305.85	148.15	2066	66.41
Canadian	888.02	304.66	44.01	192.03	126.15	1555	71.29
Carter	37.56	77.03	14.11	25.20	13.51	167	8.34
Cherokee	10.17	84.73	1.49	22.44	2.76	122	6.74
Choctaw	48.90	126.48	33.05	55.93	12.93	277	15.02
Cimarron	788.66	235.74	2551.52	2733.31	313.48	6623	148.63
Cleveland	56.72	84.32	42.53	90.41	13.10	287	22.42
Coal	13.69	46.22	18.94	28.46	5.91	113	8.97
Comanche	157.65	176.55	31.57	37.24	49.70	453	17.40
Cotton	324.30	60.81	37.88	41.46	84.39	549	34.61
Craig	758.93	71.76	236.21	221.46	50.17	1339	72.55
Creek	27.38	73.99	15.78	25.37	7.48	150	6.67
Custer	510.12	93.24	141.69	168.62	137.30	1051	44.26
Delaware	302.40	669.69	92.85	73.17	21.31	556	31.90
Dewey	274.23	75.40	105.48	101.63	78.23	635	26.06
Ellis	250.76	135.81	173.26	154.47	72.30	787	26.39
Garfield	1537.42	3.00	29.90	33.01	201.18	1804	70.33
Garvin	97.02	399.12	92.85	163.58	25.10	778	39.55
Grady	370.08	647.83	102.32	119.67	65.28	1305	48.75
Grant	1573.41	179.39	137.05	105.53	210.46	2206	90.78
Greer	229.24	232.50	26.74	33.98	59.28	582	37.68
Harmon	232.37	42.77	37.88	81.46	59.74	454	34.96
Harper	363.42	133.17	110.31	111.87	97.53	816	32.47
Haskell	30.90	56.55	12.63	29.76	7.22	137	9.94
Hughes	89.98	262.90	75.58	112.84	29.79	571	29.29
Jackson	530.47	195.00	53.48	52.19	137.07	968	48.96
Jefferson	221.42	30.81	18.94	28.46	37.15	337	18.11
Johnston	18.78	93.65	47.17	71.22	13.38	244	15.78
Kay	1041.37	245.88	220.43	161.95	149.76	1819	81.62
Kingfisher	1176.73	176.55	41.04	42.28	159.11	1596	72.82
Kiowa	499.17	163.17	25.26	33.01	124.88	845	34.27
Latimer	10.17	50.88	3.16	35.61	2.45	102	5.79
Le Flore	46.16	79.05	3.16	35.61	9.10	173	4.51
Lincoln	66.50	153.44	39.37	41.30	21.59	322	13.80
Logan	398.63	191.96	22.10	29.59	62.29	705	38.95
Love	64.16	191.96	66.11	60.32	24.05	407	32.40
Major	680.69	199.86	66.11	123.09	97.27	1167	50.37
Marshall	27.78	97.30	19.27	27.32	11.17	181	20.11
Mayes	283.23	179.39	72.42	155.28	28.82	719	46.17
McClain	103.28	231.28	48.84	122.60	23.83	530	37.67
McCurtain	138.48	20.07	50.32	67.64	26.78	303	6.86

TABLE XXX (Continued)

County	Banvel (Pounds)	Fur-adan	Milo-gard	Atra-zine	2,4-D	Total Pest.	Final Index
McIntosh	64.55	172.09	69.27	86.02	17.46	409	28.21
Murray	18.78	107.84	7.80	20.98	5.21	161	15.84
Muskogee	188.17	141.28	89.69	99.84	42.31	561	28.46
Noble	626.70	158.92	59.80	53.33	88.18	987	55.42
Nowata	278.14	158.92	72.42	116.10	26.57	652	49.86
Okfuskee	35.60	105.20	23.58	30.57	11.29	206	13.55
Oklahoma	131.44	138.04	28.41	69359	29.15	397	23.16
Okmulgee	98.19	113.92	69.27	164.39	29.54	475	28.14
Osage	562.94	192.16	141.69	135.12	50.25	1082	19.75
Ottawa	883.72	33.24	267.78	209.10	59.02	1453	129.15
Pawnee	247.63	74.39	45.68	41.14	29.21	438	32.82
Payne	187.78	125.27	48.84	47.64	30.35	440	26.33
Pittsburg	30.51	81.08	39.37	47.97	12.51	211	6.97
Pontotoc	23.08	69.32	52.00	50.73	10.99	206	11.87
Pottawatomie	72.37	203.51	53.48	50.89	19.24	400	21.10
Pushmataha	12.52	27.77	3.16	35.61	2.86	82	2.39
Roger Mills	222.98	95.88	220.43	179.35	72.80	791	28.53
Rogers	92.32	61.42	34.73	33.66	22.87	245	14.83
Seminole	28.95	113.31	25.26	31.71	8.28	207	13.40
Sequoyah	34.03	120.61	1.49	22.44	6.56	185	11.28
Stephens	252.32	275.87	34.73	39.02	42.92	645	30.14
Texas	1108.66	289.46	2771.94	4449.06	414.37	9033	183.00
Tillman	351.69	214.46	102.32	85.20	99.89	854	39.04
Tulsa	74.33	120.40	14.11	19.84	15.76	244	17.64
Wagoner	222.59	112.70	36.21	34.80	41.06	447	33.03
Washington	57.12	81.89	25.26	27.32	14.49	206	20.12
Washita	526.95	202.09	189.04	158.05	146.25	1222	50.20
Woods	1218.20	53.72	15.78	23.58	156.34	1468	46.99
Woodward	631.01	117.77	189.04	140.65	3.00	1081	35.97

APPENDIX G

LISTING OF RANDGEN

TABLE XXXI

RANDGEN

```
1000'*****************************************************************
1010'Random number generator program to be used with PRZM
1020'
1030'For Dr. McTernan                                 By: Albert Aguilar
1040'*****************************************************************
1050'
1060 DIM INN(100,8) : CHK=0 : NUM=3
1070 CLS
1080 LOCATE 1,1,0: PRINT "Dr McTernan":LOCATE 1,25,0:PRINT "OKLAHOMA
     STATE UNIVERSITY"
1090 LOCATE 1,69,0 :PRINT "Al Aguilar"
1100 LOCATE 5,1,0 : PRINT "The current default values are..."
1100 LOCATE 6,1,0 : PRINT "KS =";:PRINT USING "#.###;KS1
1120 LOCATE 7,1,0 : PRINT "KOC=";:PRINT USING "#.###;KOC
1130 LOCATE 8,1,0 : PRINT "CN1=";:PRINT USING "###";CN1
1135 LOCATE 9,1,0 : PRINT "CN2=";:PRINT USING "###";CN2
1140 LOCATE 10,1,0: PRINT "CN3=";:PRINT USING "###";CN3
1145 COLOR 0,7,0   :LOCATE 23,1,0:PRINT "PRESS [RETURN} To Continue
     [E] To Edit  [X] To Exit":COLOR 7,0,0
1150 GOSUB 10000                       'KEYBOARD INPUT ROUTINE
1155 IF (E=0) AND (KB=120) OR (KB=88) GOTO 1999
1160 IF (E=0) AND (KB=101) OR (KB=69) GOTO 1190
1170 IF (E=0) AND (KB=13) GOTO 1300
1180 BEEP : GOTO 1150
1190 LOCATE 15,1,0 : PRINT "Please enter the new values for KS, KOC,
     & CN."
1200 LOCATE 17,1,1 : INPUT "KS=";KS1
1210 LOCATE 18,1,1 : INPUT "KOC=;KOC
1220 LOCATE 19,1,1 : INPUT "CN1=";CN1
1225 LOCATE 20,1,1 : INPUT "CN2=";CN2
1230 LOCATE 21,1,1 : INPUT "CN3=";CN3
1235 CLS : GOTO 1070
1300 IF (CHK=0) THEN GOSUB 2000 ELSE GOTO 1310  'INPUT ROUTINE
1310 GOSUB 3000                                 'RANDOMIZING ROUTINE
1320 GOSUB 4000                                 'FORMULA ROUTINE
1330 GOSUB 6000                                 'RANDOM YR ROUTINE
1340 GOSUB 7000                                'PRINT FILE TO SCREEN
1350 COLOR 0,7,0 : INPUT "Enter the new 8-character filemane (Type
     QUIT to scratch file)";FILNME$
1355 COLOR 7,0,0 : CLS
1360 IF (FILNME$ = "QUIT") GOTO 1070
1370 FILNME$="B:"+FILNME$+".DAT"
1390 GOSUB 5000                                'WRITE FILE ROUTINE
1400 GOTO 1070
1999 CLS : END
```

TABLE XXXI (Continued)

```
2000'*******************************************************************
2010'READ IN DATA ROUTINE
2020'*******************************************************************
2030 OPEN "A:VARIABL.DAT" FOR INPUT AS #1 :N1=1
2040 IF EOF(1) THEN GOTO 2900
2050 INPUT #1, AREA,OC1,FC1,WP1,BD1,OC2,FC2,WP2,BD2
2060 N2=AREA+N1-1
2070 FOR I=N1 TO N2
2080 INN(I,1)=OC1 : INN(I,2)=FC1 : INN(I,3)=WP1 : INN(I,4)=BD1
2090 INN(I,5)=OC2 : INN(I,6)=FC2 : INN(I,7)=WP2 : INN(I,8)=BD2
2110 NEXT I
2120 N1=N2+1 : GOTO 2040
2900 CLOSE : CHK=1
2999 RETURN
3000'*******************************************************************
3010'RANDOMIZING ROUTINE FOR VARIABLE DATA
3020'*******************************************************************
3030 RANDOMIZE TIMER
3040 FOR I=1 TO NUM : NUM=INT(RND*101) : NEXT I
3050 IF NUM > 100 GOTO 3030
3060 IF NUM < 1 GOTO 3030
3999 RETURN
4000'*******************************************************************
4010'FORMULA ROUTINE
4020'*******************************************************************
4030 KD=INN(NUM,1)/100*KOC : KD2=INN(NUM,5)/100*KOC
4040 KS2=KS1*.35
4050 OC1=INN(NUM,1) :FC1=INN(NUM,2) :WP1=INN(NUM,3) :BD1=INN(NUM,4)
4060 OC2=INN(NUM,5) :FC2=INN(NUM,6) :WP2=INN(NUM,7) :BD2=INN(NUM,8)
4999 RETURN
5000'*******************************************************************
5010'WRITE MODIN FILE ROUTINE
5020'*******************************************************************
5030 OPEN FILNME$ FOR OUTPUT AS #1
5040 PRINT #1,USING "&" ;"***PRZM DATA SET FOR OKLAHOMA***"
5050 PRINT #1,USING "\   \";" 0101";:PRINT #1,USING "##;YR;:PRINT
     #1,USING "\         \";"        3112";:PRINT #1,USING "##";YR
5060 PRINT #1,USING "&" ;"***HYDROLOGY PARAMETERS FOR OKLAHOMA***"
5070 PRINT #1,USING "&" ;"   0.710    0.457      0  20.000     1    3"
5080 PRINT #1,USING "&" ;"        0"
5090 PRINT #1,USING "&" ;"        1"
5100 PRINT #1,USING "&" ;"        1    0.15   22.50    0.000     3";
5110 PRINT #1,USING "####"; CN1;CN2;CN3
5120 PRINT #1,USING "&" ;"        1"
5130 PRINT #1,USING "\    \";" 0102";:PRINT #1,USING "##";YR;:PRINT
     #1,USING "\    \";" 2004";:PRINT #1,USING "##";YR;
5140 PRINT #1,USING "\    \";" 1506";:PRINT #1,USING "##";YR;:PRINT
     #1,USING "\    \";"    1"
5150 PRINT #1,USING "&" ;"***PESTICIDE APPLICATION***"
```

TABLE XXXI (Continued)

```
5160 PRINT #1,USING "&" ;"      1"
5170 PRINT #1,USING "\    \";" 0102";:PRINT #1,USING "##";YR;:PRINT
     #1,USING "&";"  1.000  10.000"
5180 PRINT #1,USING "&" ;"      1"
5190 PRINT #1,USING "&" ;"***SOIL AND PESTICIDE PARAMETERS***"
5200 PRINT #1,USING "&" ;" 177.800   1.000   35    0    0    0    0"
5210 PRINT #1,USING "&" ;"      2"
5220 PRINT #1,USING "&" ;"      1  30.480";:PRINT #1,USING
     "####.###";BD1;:PRINT #1,USING "&" ;"  0.000";:PRINT
     #1,USING"####.###"; KS1;FC1
5230 PRINT #1,USING "\    \";:    ";:PRINT #1,USING
     "####.###";FC1;WP1;KD1;OC1
5240 PRINT #1,USING "&" ;"      2 147.320";:PRINT #1,USING
     "####.###";BD2;:PRINT #1,USING "&" ;"  0.000";:PRINT #1,USING
     "####.###"; KS2;FC2
5250 PRINT #1,USING "\    \";"    ";:PRINT #1,USING "####.###";
     FC2;WP2;KD2;OC2
5260 PRINT #1,USING "&" ;"      0"
5270 PRINT #1,USING "&" ;"  WATR   YEAR    1   PEST   YEAR    1
     CONC   YEAR    1"
5280 PRINT #1,USING "&" ;"    0"
5290 PRINT #1,USING "&" ;"   RZFX   TCUM    0  1.0"
5300 CLOSE
5999 RETURN
6000'**************************************************************
6010'RANDOMIZING THE YEAR ROUTINE
6020'**************************************************************
6030 RANDIMIZE TIMER
6040 FOR I = 1 TO NUM : NUM=INT(RND * 26) : NEXT I
6050 IF NUM > 25 GOTO 6030
6060 IF NUM < 1  GOTO 6030
6070 YR=NUM+53
6999 RETURN
7000'**************************************************************
7010'PRINT MODIN FILE TO SCREEN ROUTINE
7020'**************************************************************
7030 CLS : LOCATE 1,1,0
7040 PRINT USING "&" ;"***PRZM DATA SET FOR OKLAHOMA***"
7050 PRINT USING "\    \";" 0101";:PRINT USING "##";YR;:PRINT USING
     "\    \";"    3112;:PRINT USING "##";YR
7060 PRINT USING "&" ;"***HYDROLOGY PARAMETERS FOR OKLAHOMA***"
7070 PRINT USING "&" ;"    0.710   0.457    0  20.000    1     3"
7080 PRINT USING "&" ;"      0"
7090 PRINT USING "&" ;"      1"
7100 PRINT USING "&" ;"      1    0.15  22.50   0.000    3";
7110 PRINT USING "####"; CN1;CN2;CN3
7120 PRINT USING "&" ;"      1"
7130 PRINT USING "\    \";" 0102";:PRINT USING "##";YR;:PRINT USING
     "\    \";" 2004";:PRINT USING "##";YR;
```

TABLE XXXI (Continued)

```
7140 PRINT USING "\     \";" 1506";:PRINT USING "##";YR;:PRINT USING
"\    \";"    1"
7150 PRINT USING "&" ;"***PESTICIDE APPLICATION***"
7160 PRINT USING "&" ;"       1"
7170 PRINT USING "\     \";" 0102";:PRINT USING "##";YR;:PRINT USING
     "&";"  1.000  10.000"
7180 PRINT USING "&" ;"       1"
7190 PRINT USING "&" ;"***SOIL AND PESTICIDE PARAMETERS***"
7200 PRINT USING "&" ;" 177.800   1.000   35    0    0    0    0"
7210 PRINT USING "&" ;"       2"
7220 PRINT USING "&" ;"       1  30.480";:PRINT USING
     "####.###";BD1;:PRINT USING "&" ;"  0.000";:PRINT
     USING"####.###"; KS1;FC1
7230 PRINT USING "\     \";:    ";:PRINT USING "####.###";
     FC1;WP1;KD1;OC1
7240 PRINT USING "&" ;"       2 147.320";:PRINT USING
     "####.###";BD2;:PRINT USING "&" ;"  0.000";:PRINT USING
     "####.###"; KS2;FC2
7250 PRINT USING "\     \";"    ";:PRINT USING "####.###";
     FC2;WP2;KD2;OC2
7260 PRINT USING "&" ;"       0"
7270 PRINT USING "&" ;" WATR   YEAR    1   PEST   YEAR    1   CONC
     YEAR    1"
7280 PRINT USING "&" ;"    0"
7290 PRINT USING "&" ;"   RZFX   TCUM    0  1.0"
7999 RETURN
10000'***************************************************************
10010'KEYBOARD INPUT ROUTINE
10020'***************************************************************
10030 KB$=INKEY$ : IF KB$ = ""GOTO 10030
10040 IF LEFT$(KB$,1) = CHR$(0) THEN KB = ASC(MID$(KB$,2)) : E=1
     ELSE KB=ASC(KB$) : E=0
10999 RETURN
```

APPENDIX H

RESULTS OF MONTE CARLO SIMULATIONS

TABLE XXXII

RESULTS OF MONTE CARLO SIMULATIONS

#	K_s	K_{oc}	CN	Pesticide Leached 12"	70"
1	0.1	2	59	0.002342	0.000006
2	0.1	2	59	0.005515	0.000001
3	0.1	2	59	0.001895	0.000002
4	0.1	2	59	0.1743	0.04291
5	0.1	2	59	0.0514	0.000002
6	0.1	2	59	0.01102	0.000018
7	0.1	2	59	0.02786	0.000025
8	0.1	2	59	0.003937	0.000081
9	0.1	2	59	0.001239	0.000044
10	0.1	2	59	0.133	0.01059
11	0.1	2	59	0.0012	0.000000
12	0.1	2	59	0.06373	0.000808
13	0.1	2	59	0.01046	0.000005
14	0.1	2	59	0.005099	0.000001
15	0.1	2	59	0.001627	0.000013
16	0.1	2	59	0.06491	0.001191
17	0.1	2	59	0.00522	0.000025
18	0.1	2	59	0.005099	0.000001
19	0.1	2	59	0.02258	0.000030
20	0.1	2	59	0.000997	0.000021
21	0.1	2	73	0.005659	0.000002
22	0.1	2	73	0.008639	0.000000
23	0.1	2	73	0.1047	0.000312
24	0.1	2	73	0.002131	0.000005
25	0.1	2	73	0.000091	0.000000
26	0.1	2	73	0.003125	0.000135
27	0.1	2	73	0.01068	0.000104
28	0.1	2	73	0.001219	0.000036
29	0.1	2	73	0.02729	0.000013
30	0.1	2	73	0.004803	0.000207
31	0.1	2	73	0.05455	0.000194
32	0.1	2	73	0.02019	0.000014
33	0.1	2	73	0.000138	0.000000
34	0.1	2	73	0.000356	0.000000
35	0.1	2	73	0.3101	0.001456
36	0.1	2	73	0.000658	0.000000
37	0.1	2	73	0.000167	0.000000
38	0.1	2	73	0.1008	0.003934
39	0.1	2	73	0.000167	0.000000
40	0.1	2	73	0.03972	0.000018
41	0.1	2	88	0.000659	0.000000
42	0.1	2	88	0.006998	0.000024
43	0.1	2	88	0.000133	0.000000

TABLE XXXII (Continued)

#	K_s	K_{oc}	CN	Pesticide Leached 12"	70"
44	0.1	2	88	0.01967	0.000058
45	0.1	2	88	0.00299	0.000475
46	0.1	2	88	0.01109	0.000000
47	0.1	2	88	0.000088	0.000000
48	0.1	2	88	0.000961	0.000000
49	0.1	2	88	0.1046	0.00658
50	0.1	2	88	0.01588	0.000000
51	0.1	2	88	0.000461	0.000000
52	0.1	2	88	0.000034	1.5E-12
53	0.1	2	88	0.1106	0.006532
54	0.1	2	88	0.09461	0.000025
55	0.1	2	88	0.01349	0.000000
56	0.1	2	88	0.05824	0.000252
57	0.1	2	88	0.08028	0.001584
58	0.1	2	88	0.007289	0.000071
59	0.1	2	88	0.03278	0.000000
60	0.1	2	88	0.03091	0.000014
61	0.05	2	59	0.187	0.001514
62	0.05	2	59	0.08133	0.000478
63	0.05	2	59	0.02394	0.000242
64	0.05	2	59	0.04918	0.000531
65	0.05	2	59	0.009909	0.000027
66	0.05	2	59	0.006438	0.000000
67	0.05	2	59	0.1461	0.008078
68	0.05	2	59	0.09786	0.001606
69	0.05	2	59	0.2414	0.02892
70	0.05	2	59	0.01398	0.000046
71	0.05	2	59	0.2188	0.0761
72	0.05	2	59	0.02026	0.000000
73	0.05	2	59	0.1345	0.003887
74	0.05	2	59	0.0338	0.000037
75	0.05	2	59	0.3928	0.1314
76	0.05	2	59	0.008866	0.000951
77	0.05	2	59	0.05013	0.001764
78	0.05	2	59	0.09187	0.00939
79	0.05	2	59	0.02062	0.000498
80	0.05	2	59	0.006927	0.000103
81	0.05	2	73	0.008389	0.000039
82	0.05	2	73	0.03152	0.002093
83	0.05	2	73	0.03191	0.000067
84	0.05	2	73	0.02041	0.000742
85	0.05	2	73	0.04173	0.0000026
86	0.05	2	73	0.04479	0.004128
87	0.05	2	73	0.07175	0.007296
88	0.05	2	73	0.01288	0.001055

TABLE XXXII (Continued)

#	K_s	K_{oc}	CN	Pesticide Leached 12"	Pesticide Leached 70"
89	0.05	2	73	0.03149	0.007623
90	0.05	2	73	0.01939	0.000715
91	0.05	2	73	0.1294	0.001072
92	0.05	2	73	0.05998	0.007628
93	0.05	2	73	0.005484	0.000004
94	0.05	2	73	0.1519	0.05745
95	0.05	2	73	0.1493	0.003171
96	0.05	2	73	0.005006	0.000013
97	0.05	2	73	0.0534	0.000103
98	0.05	2	73	0.05706	0.008219
99	0.05	2	73	0.05696	0.000771
100	0.05	2	73	0.2818	0.02129
101	0.05	2	88	0.04783	0.000008
102	0.05	2	88	0.05088	0.000891
103	0.05	2	88	0.2649	0.05256
104	0.05	2	88	0.03999	0.000843
105	0.05	2	88	0.02065	0.000001
106	0.05	2	88	0.03375	0.000056
107	0.05	2	88	0.007313	0.000287
108	0.05	2	88	0.07967	0.000132
109	0.05	2	88	0.01118	0.000018
110	0.05	2	88	0.01217	0.000000
111	0.05	2	88	0.01024	0.000001
112	0.05	2	88	0.02011	0.000132
113	0.05	2	88	0.02381	0.000018
114	0.05	2	88	0.01936	0.000177
115	0.05	2	88	0.001534	0.000000
116	0.05	2	88	0.02615	0.000014
117	0.05	2	88	0.04815	0.000196
118	0.05	2	88	0.01575	0.000035
119	0.05	2	88	0.2218	0.04337
120	0.05	2	88	0.02233	0.000007
121	0.001	2	59	0.8289	0.08531
122	0.001	2	59	0.9729	0.9729
123	0.001	2	59	0.8832	0.6855
124	0.001	2	59	0.8384	0.1895
125	0.001	2	59	0.9184	0.5946
126	0.001	2	59	0.8402	0.1566
127	0.001	2	59	0.9292	0.9106
128	0.001	2	59	0.8138	0.06715
129	0.001	2	59	0.9166	0.2539
130	0.001	2	59	0.6558	0.000072
131	0.001	2	59	0.8562	0.3475
132	0.001	2	59	0.9617	0.9614
133	0.001	2	59	0.8288	0.7164

TABLE XXXII (Continued)

#	K_s	K_{oc}	CN	Pesticide Leached 12"	70"
134	0.001	2	59	0.7902	0.01613
135	0.001	2	59	0.6921	0.000249
136	0.001	2	59	0.9449	0.9394
137	0.001	2	59	0.7926	0.01135
138	0.001	2	59	0.9481	0.948
139	0.001	2	59	0.97	0.9697
140	0.001	2	59	0.9668	0.9668
141	0.001	2	73	0.7082	0.04174
142	0.001	2	73	0.8596	0.3091
143	0.001	2	73	0.7571	0.09932
144	0.001	2	73	0.8428	0.6643
145	0.001	2	73	0.8746	0.09334
146	0.001	2	73	0.7606	0.0261
147	0.001	2	73	0.8414	0.1805
148	0.001	2	73	0.8273	0.6571
149	0.001	2	73	0.7701	0.7667
150	0.001	2	73	0.8582	0.6735
151	0.001	2	73	0.9431	0.9426
152	0.001	2	73	0.6274	0.000128
153	0.001	2	73	0.8283	0.6134
154	0.001	2	73	0.9338	0.9336
155	0.001	2	73	0.8702	0.6666
156	0.001	2	73	0.5811	0.4944
157	0.001	2	73	0.8206	0.5646
158	0.001	2	73	0.9131	0.8849
159	0.001	2	73	0.7585	0.1534
160	0.001	2	73	0.6278	0.000146
161	0.001	2	88	0.8773	0.2582
162	0.001	2	88	0.8379	0.001299
163	0.001	2	88	0.8162	0.1659
164	0.001	2	88	0.7531	0.04231
165	0.001	2	88	0.5942	0.00274
166	0.001	2	88	0.678	0.002994
167	0.001	2	88	0.8379	0.001299
168	0.001	2	88	0.9255	0.9255
169	0.001	2	88	0.6729	0.01191
170	0.001	2	88	0.7554	0.01481
171	0.001	2	88	0.839	0.006722
172	0.001	2	88	0.738	0.000229
173	0.001	2	88	0.592	0.001703
174	0.001	2	88	0.7823	0.006234
175	0.001	2	88	0.6226	0.007522
176	0.001	2	88	0..8214	0.03797
177	0.001	2	88	0.592	0.001703
178	0.001	2	88	0.6207	0.004725

TABLE XXXII (Continued)

#	K_s	K_{oc}	CN	Pesticide Leached 12"	70"
179	0.001	2	88	0.9597	0.9587
180	0.001	2	88	0.8332	0.07558
181	0.1	600	59	0.000000	1.6E-22
182	0.1	600	59	0.000000	5.1E-23
183	0.1	600	59	0.000000	0
184	0.1	600	59	0.000000	3.8E-23
185	0.1	600	59	0.000000	0
186	0.1	600	59	0.000000	0
187	0.1	600	59	0.000000	5.6E-23
188	0.1	600	59	0.000000	5.4E-18
189	0.1	600	59	0.000000	0
190	0.1	600	59	0.000000	6.2E-24
191	0.1	600	59	0.000000	0
192	0.1	600	59	0.000020	1.1E-16
193	0.1	600	59	0.000000	0
194	0.1	600	59	0.000000	4.8E.22
195	0.1	600	59	0.000000	1.9E-22
196	0.1	600	59	0.000000	3.4E-23
197	0.1	600	59	0.000000	6.1E-23
198	0.1	600	59	0.000002	1.1E-23
199	0.1	600	59	0.000001	6.0E-21
200	0.1	600	59	0.000000	6.8E-23
201	0.1	600	73	0.000000	8.0E-22
202	0.1	600	73	0.000000	0
203	0.1	600	73	0.000000	8.5E-24
204	0.1	600	73	0.000000	0
205	0.1	600	73	0.000115	0.000000
206	0.1	600	73	0.000003	1.5E-17
207	0.1	600	73	0.000000	1.6E-18
208	0.1	600	73	0.000000	0
209	0.1	600	73	0.000000	6.3E-24
210	0.1	600	73	0.000000	0
211	0.1	600	73	0.000000	0
212	0.1	600	73	0.000000	0
213	0.1	600	73	0.000000	1.3E-20
214	0.1	600	73	0.000016	8.6E-12
215	0.1	600	73	0.000010	8.1E-21
216	0.1	600	73	0.000001	9.1E-23
217	0.1	600	73	0.000000	0
218	0.1	600	73	0.000000	0
219	0.1	600	73	0.000000	0
220	0.1	600	73	0.000000	0
221	0.1	600	88	0.000000	0
222	0.1	600	88	0.000000	0
223	0.1	600	88	0.000001	4.5E-24

TABLE XXXII (Continued)

#	K_s	K_{oc}	CN	Pesticide Leached 12"	70"
224	0.1	600	88	0.000000	2.2E-24
225	0.1	600	88	0.000000	0
226	0.1	600	88	0.000000	0
227	0.1	600	88	0.000000	0
228	0.1	600	88	0.000000	7.9E-24
229	0.1	600	88	0.000000	0
230	0.1	600	88	0.000000	0
231	0.1	600	88	0.000000	1.2E-22
232	0.1	600	88	0.000000	0
233	0.1	600	88	0.000000	0
234	0.1	600	88	0.000000	0
235	0.1	600	88	0.000000	1.2E-23
236	0.1	600	88	0.000000	0
237	0.1	600	88	0.000000	0
238	0.1	600	88	1.1E-10	0
239	0.1	600	88	7.2E-11	0
240	0.1	600	88	0.000001	4.5E-24
241	0.05	600	59	0.000000	0
242	0.05	600	59	0.000009	6.8E-20
243	0.05	600	59	0.000003	7.6E-23
244	0.05	600	59	0.000003	2.5E-20
245	0.05	600	59	0.000088	1.2E-15
246	0.05	600	59	0.000002	2.8E-22
247	0.05	600	59	0.000007	9.4E-23
248	0.05	600	59	0.000001	1.6E-22
249	0.05	600	59	0.000000	2.6E-22
250	0.05	600	59	0.000008	1.0E-19
251	0.05	600	59	0.000000	5.6E-22
252	0.05	600	59	0.000000	0
253	0.05	600	59	0.000005	3.1E-17
254	0.05	600	59	0.00090.	0.000000
255	0.05	600	59	0.000008	4.4E-20
256	0.05	600	59	0.000000	2.5E-22
257	0.05	600	59	0.000004	4.9E-19
258	0.05	600	59	0.000004	1.5E-18
259	0.05	600	59	0.000001	2.0E-21
260	0.05	600	59	0.000003	1.6E-19
261	0.05	600	73	0.000008	3.9E-20
262	0.05	600	73	0.000013	9.6E-21
263	0.05	600	73	0.00142	0.000000
264	0.05	600	73	0.000003	1.2E-22
265	0.05	600	73	0.000000	3.6E-22
266	0.05	600	73	0.000001	1.3E-22
267	0.05	600	73	0.000000	3.3E-23
268	0.05	600	73	0.000005	7.5E-22

TABLE XXXII (Continued)

#	K_s	K_{oc}	CN	Pesticide Leached 12"	70"
269	0.05	600	73	0.000000	0
270	0.05	600	73	0.000000	0
271	0.05	600	73	0.000000	0
272	0.05	600	73	0.000006	7.7E-21
273	0.05	600	73	0.000001	1.1E-20
274	0.05	600	73	0.000010	6.0E-20
275	0.05	600	73	0.000031	4.1E-19
276	0.05	600	73	0.000015	1.1E-21
277	0.05	600	73	0.000004	5.8E-19
278	0.05	600	73	0.000001	2.0E-23
279	0.05	600	73	0.000062	5.2E-11
280	0.05	600	73	0.000000	0
281	0.05	600	88	0.000001	1.7E-23
282	0.05	600	88	0.000080	6.2E-13
283	0.05	600	88	0.000002	0
284	0.05	600	88	0.000003	4.7E-24
285	0.05	600	88	0.000001	1.8E-24
286	0.05	600	88	0.000000	0
287	0.05	600	88	0.000000	0
288	0.05	600	88	0.000000	0
289	0.05	600	88	0.000003	2.2E-24
290	0.05	600	88	0.000000	0
291	0.05	600	88	0.000001	1.2E-23
292	0.05	600	88	0.000001	1.6E-22
293	0.05	600	88	0.000053	1.1E-19
294	0.05	600	88	0.000000	0
295	0.05	600	88	0.000000	0
296	0.05	600	88	0.000020	3.8E-21
297	0.05	600	88	0.000000	0
298	0.05	600	88	0.000000	9.7E-25
299	0.05	600	88	0.000000	0
300	0.05	600	88	0.000007	4.7E-23
301	0.001	600	59	0.01319	1.0E-18
302	0.001	600	59	0.01214	2.0E-16
303	0.001	600	59	0.001927	2.6E-19
304	0.001	600	59	0.02103	1.6E-16
305	0.001	600	59	0.1968	1.0E-10
306	0.001	600	59	0.000032	0
307	0.001	600	59	0.01336	6.0E-16
308	0.001	600	59	0.004421	3.4E-23
309	0.001	600	59	0.0507	5.8E-15
310	0.001	600	59	0.01841	1.8E-14
311	0.001	600	59	0.07077	5.2E-13
312	0.001	600	59	0.004421	3.4E-23
313	0.001	600	59	0.0927	1.0E-13

TABLE XXXII (Continued)

#	K_s	K_{oc}	CN	Pesticide Leached 12"	70"
314	0.001	600	59	0.00739	2.7E-20
315	0.001	600	59	0.4047	0.000033
316	0.001	600	59	0.000746	0
317	0.001	600	59	0.04992	7.4E-16
318	0.001	600	59	0.01832	1.6E-18
319	0.001	600	59	0.002398	1.06-19
320	0.001	600	59	0.01429	2.9E-19
321	0.001	600	73	0.009314	8.9E-20
322	0.001	600	73	0.002802	3.8E-24
323	0.001	600	73	0.000076	0
324	0.001	600	73	0.03815	2.0E-18
325	0.001	600	73	0.2001	0.000006
326	0.001	600	73	0.008844	2.2E-19
327	0.001	600	73	0.007037	3.3E-19
328	0.001	600	73	0.00891	6.6E-18
329	0.001	600	73	0.006741	2.3E-17
330	0.001	600	73	0.021	4.3E-15
331	0.001	600	73	0.04857	2.3E-16
332	0.001	600	73	0.0171	1.3E-17
333	0.001	600	73	0.0415	3.0E-15
334	0.001	600	73	0.04786	5.1E-16
335	0.001	600	73	0.009314	8.9E-20
336	0.001	600	73	0.01124	2.2E-15
337	0.001	600	73	0.004037	1.1E-23
338	0.001	600	73	0.04674	1.8E-15
339	0.001	600	73	0.01546	6.6E-18
340	0.001	600	73	0.2001	0.000006
341	0.001	600	88	0.001934	6.1E-22
342	0.001	600	88	0.001278	0
343	0.001	600	88	0.001421	0
344	0.001	600	88	0.001012	0
345	0.001	600	88	0.001934	6.1E-22
346	0.001	600	88	0.008572	1.2E-20
347	0.001	600	88	0.01594	2.5E-21
348	0.001	600	88	0.01121	9.2E-18
349	0.001	600	88	0.02828	1.0E-18
350	0.001	600	88	0.01003	1.1E-21
351	0.001	600	88	0.002699	1.5E-25
352	0.001	600	88	0.001995	0
353	0.001	600	88	0.01229	2.6E-17
354	0.001	600	88	0.000625	0
355	0.001	600	88	0.002301	0
356	0.001	600	88	0.01662	6.2E-21
357	0.001	600	88	0.01161	8.6E-20
358	0.001	600	88	0.000330	0

TABLE XXXII (Continued)

#	K_s	K_{oc}	CN	Pesticide Leached 12"	70"
359	0.001	600	88	0.000241	0
360	0.001	600	88	0.000046	0
361	0.1	1200	59	9.E-11	0
362	0.1	1200	59	0.000000	0
363	0.1	1200	59	0.000000	0
364	0.1	1200	59	0.000000	0
365	0.1	1200	59	0.000000	0
366	0.1	1200	59	0.000000	0
367	0.1	1200	59	0.000000	0
368	0.1	1200	59	7.9E-11	0
369	0.1	1200	59	0.000000	0
370	0.1	1200	59	0.000000	0
371	0.1	1200	59	0.000000	0
372	0.1	1200	59	0.000010	7.2-15
373	0.1	1200	59	0.000000	0
374	0.1	1200	59	0.000000	2.6E-18
375	0.1	1200	59	0.000000	0
376	0.1	1200	59	5.5E-11	0
377	0.1	1200	59	0.000000	0
378	0.1	1200	59	0.000010	7.2E-15
379	0.1	1200	59	0.000000	0
380	0.1	1200	59	0.000000	0
381	0.1	1200	73	0.000000	0
382	0.1	1200	73	0.000000	0
383	0.1	1200	73	6.6E-12	0
384	0.1	1200	73	0.000000	0
385	0.1	1200	73	0.000000	6.4E-18
386	0.1	1200	73	0.000000	0
387	0.1	1200	73	4.2E-12	0
388	0.1	1200	73	0.000000	0
389	0.1	1200	73	0.000000	0
390	0.1	1200	73	0.000000	0
391	0.1	1200	73	0.000000	0
392	0.1	1200	73	0.000000	0
393	0.1	1200	73	0.000000	5.2E-23
394	0.1	1200	73	0.000000	0
395	0.1	1200	73	0.000000	0
396	0.1	1200	73	0.000000	0
397	0.1	1200	73	1.6E-10	0
398	0.1	1200	73	2.8E-11	0
399	0.1	1200	73	0.000000	0
400	0.1	1200	73	1.4E-10	0
401	0.1	1200	88	0.000000	0
402	0.1	1200	88	1.0E-10	0
403	0.1	1200	88	2.3E-10	0

TABLE XXXII (Continued)

#	K_s	K_{oc}	CN	Pesticide Leached 12"	70"
404	0.1	1200	88	0.000000	0
405	0.1	1200	88	0.000002	4.9E-16
406	0.1	1200	88	0.000000	0
407	0.1	1200	88	0.000000	0
408	0.1	1200	88	6.5E-11	0
409	0.1	1200	88	9.8E-11	0
410	0.1	1200	88	0.000000	
411	0.1	1200	88	1.2E-11	0
412	0.1	1200	88	2.1E-10	0
413	0.1	1200	88	0.000000	0
414	0.1	1200	88	0.000000	0
415	0.1	1200	88	3.3E-11	0
416	0.1	1200	88	0.000000	0
417	0.1	1200	88	0.000000	0
418	0.1	1200	88	0.000000	0
419	0.1	1200	88	0.000000	0
420	0.1	1200	8	0.000000	0
421	0.05	1200	59	0.000000	0
422	0.05	1200	59	0.000001	0
423	0.05	1200	59	0.000000	0
424	0.05	1200	59	0.000059	3.8E-12
425	0.05	1200	59	0.000003	1.6E-23
426	0.05	1200	59	0.000001	0
427	0.05	1200	59	0.000001	1.8E-15
428	0.05	1200	59	0.000000	0
429	0.05	1200	59	0.000003	4.0E-24
430	0.05	1200	59	0.000000	0
431	0.05	1200	59	0.000000	0
432	0.05	1200	59	0.000005	0
433	0.05	1200	59	0.000000	0
434	0.05	1200	59	0.000000	0
435	0.05	1200	59	0.000000	0
436	0.05	1200	59	0.000002	1.9E-21
437	0.05	1200	59	0.000000	0
438	0.05	1200	59	0.000000	0
439	0.05	1200	59	0.000003	4.8E-20
440	0.05	1200	59	0.000000	0
441	0.05	1200	73	0.000000	0
442	0.05	1200	73	0.000000	0
443	0.05	1200	73	0.000000	0
444	0.05	1200	73	0.000005	1.1E-15
445	0.05	1200	73	0.000004	0
446	0.05	1200	73	0.000000	0
447	0.05	1200	73	0.000000	0
448	0.05	1200	73	0.000000	0

TABLE XXXII (Continued)

#	K_s	K_{oc}	CN	Pesticide Leached 12"	70"
449	0.05	1200	73	0.000000	0
450	0.05	1200	73	0.000000	0
451	0.05	1200	73	0.000000	0
452	0.05	1200	73	0.000000	0
453	0.05	1200	73	0.000001	0
454	0.05	1200	73	0.000000	0
455	0.05	1200	73	0.000138	7.2E-13
456	0.05	1200	73	0.000002	5.5E-23
457	0.05	1200	73	0.000000	0
458	0.05	1200	73	0.000000	0
459	0.05	1200	73	0.000004	0
460	0.05	1200	73	0.000000	0
461	0.05	1200	88	0.000024	4.8E-17
462	0.05	1200	88	0.000002	0
463	0.05	1200	88	0.000000	0
464	0.05	1200	88	0.000000	0
465	0.05	1200	88	0.000000	0
466	0.05	1200	88	0.000020	1.9E-19
467	0.05	1200	88	0.000000	0
468	0.05	1200	88	0.000000	0
469	0.05	1200	88	0.000000	0
470	0.05	1200	88	0.000000	0
471	0.05	1200	88	0.000000	0
472	0.05	1200	88	0.000000	0
473	0.05	1200	88	0.000000	0
474	0.05	1200	88	0.000000	0
475	0.05	1200	88	0.000000	0
476	0.05	1200	88	0.000000	0
477	0.05	1200	88	0.000000	0
478	0.05	1200	88	0.000000	0
479	0.05	1200	88	0.000000	0
480	0.05	1200	88	0.000161	3.3E-14
481	0.001	1200	59	0.007458	1.3E-21
482	0.001	1200	59	0.08122	0.000000
483	0.001	1200	59	0.001174	5.5E-22
484	0.001	1200	59	0.08868	0.000000
485	0.001	1200	59	0.000008	0
486	0.001	1200	59	0.001728	1.3E-21
487	0.001	1200	59	0.01984	2.6E-19
488	0.001	1200	59	0.000734	0
489	0.001	1200	59	0.02574	1.8E-17
490	0.001	1200	59	0.004307	1.1E-20
491	0.001	1200	59	0.01021	1.6E-14
492	0.001	1200	59	0.001051	0
493	0.001	1200	59	0.000003	0

TABLE XXXII (Continued)

#	K_s	K_{oc}	CN	Pesticide Leached 12"	70"
494	0.001	1200	59	0.00331	6.5E-23
495	0.001	1200	59	0.003533	0
496	0.001	1200	59	0.000105	0
497	0.001	1200	59	0.001715	7.6E-22
498	0.001	1200	59	0.000683	0
499	0.001	1200	59	0.001308	0
500	0.001	1200	59	0.000755	3.5E-24
501	0.001	1200	73	0.000449	0
502	0.001	1200	73	0.01258	1.3E-20
503	0.001	1200	73	0.000098	0
504	0.001	1200	73	0.003757	3.0E-23
505	0.001	1200	73	0.000218	0
506	0.001	1200	73	0.00174	5.8E-24
507	0.001	1200	73	0.000343	0
508	0.001	1200	73	0.000730	0
509	0.001	1200	73	0.002655	7.7E-23
510	0.001	1200	73	0.08456	2.5E-11
511	0.001	1200	73	0.000050	0
512	0.001	1200	73	0.000685	0
513	0.001	1200	73	0.005428	3.8E-23
514	0.001	1200	73	0.000001	0
515	0.001	1200	73	0.000299	0
516	0.001	1200	73	0.000730	0
517	0.001	1200	73	0.00174	5.8E-24
518	0.001	1200	73	0.01187	1.0E-20
519	0.001	1200	73	0.000533	1.6E-24
520	0.001	1200	73	0.001256	3.9E-23
521	0.001	1200	88	0.000097	0
522	0.001	1200	88	0.000001	0
523	0.001	1200	88	0.000142	0
524	0.001	1200	88	0.03779	6.7E-14
525	0.001	1200	88	0.001431	0
526	0.001	1200	88	0.000021	0
527	0.001	1200	88	0.000182	0
528	0.001	1200	88	0.001214	0
529	0.001	1200	88	0.000769	0
530	0.001	1200	88	0.000083	0
531	0.001	1200	88	0.000353	0
532	0.001	1200	88	0.002148	0
533	0.001	1200	88	0.002563	0
534	0.001	1200	88	0.000486	0
535	0.001	1200	88	0.001177	0
536	0.001	1200	88	0.000024	0
537	0.001	1200	88	0.000056	0
538	0.001	1200	88	0.03607	3.5E-14

TABLE XXXII (Continued)

#	K_s	K_{oc}	CN	Pesticide Leached 12"	70"
539	0.001	1200	88	0.000131	0
540	0.001	1200	88	0.000184	0

APPENDIX I

SAMPLE SIZE ANALYSIS

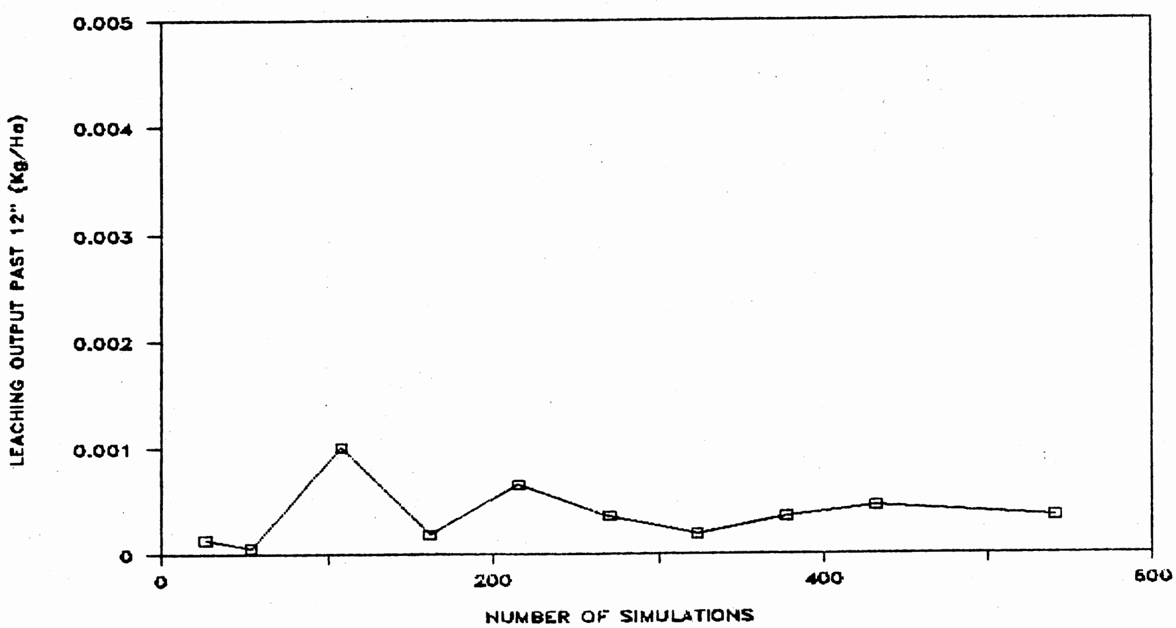


Figure 26. Sample Size Analysis at 50^{th} Percentile Probability

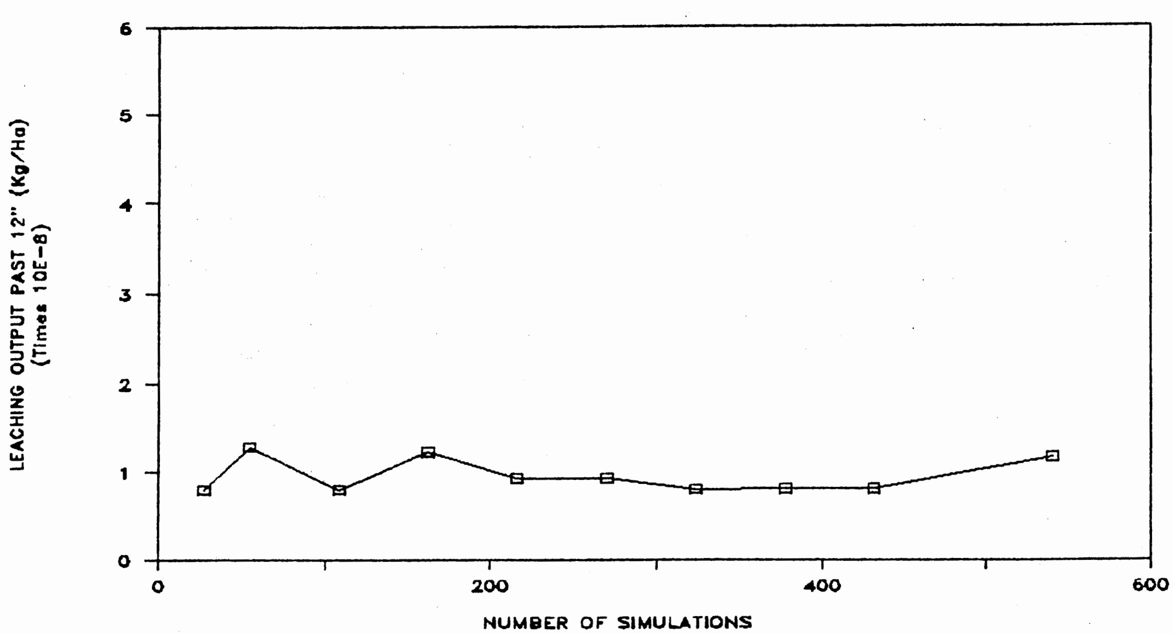


Figure 27. Sample Size Analysis at 90^{th} Percentile Probability

APPENDIX J

CUMULATIVE PROBABILITY GRAPHS WITH VARIED CURVE NUMBERS

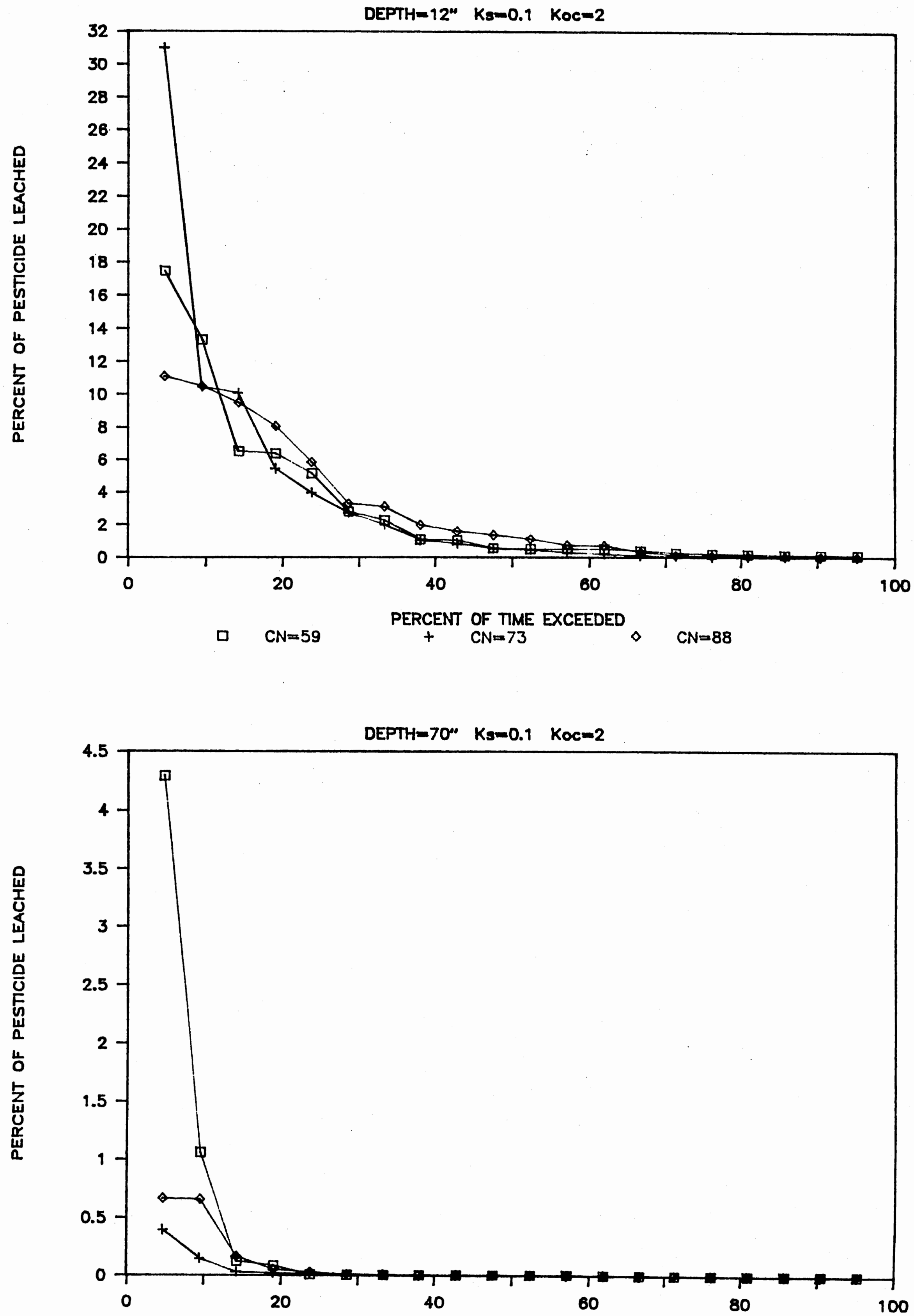


Figure 28. Probability of Leaching: K_s=0.1, K_{oc}=2

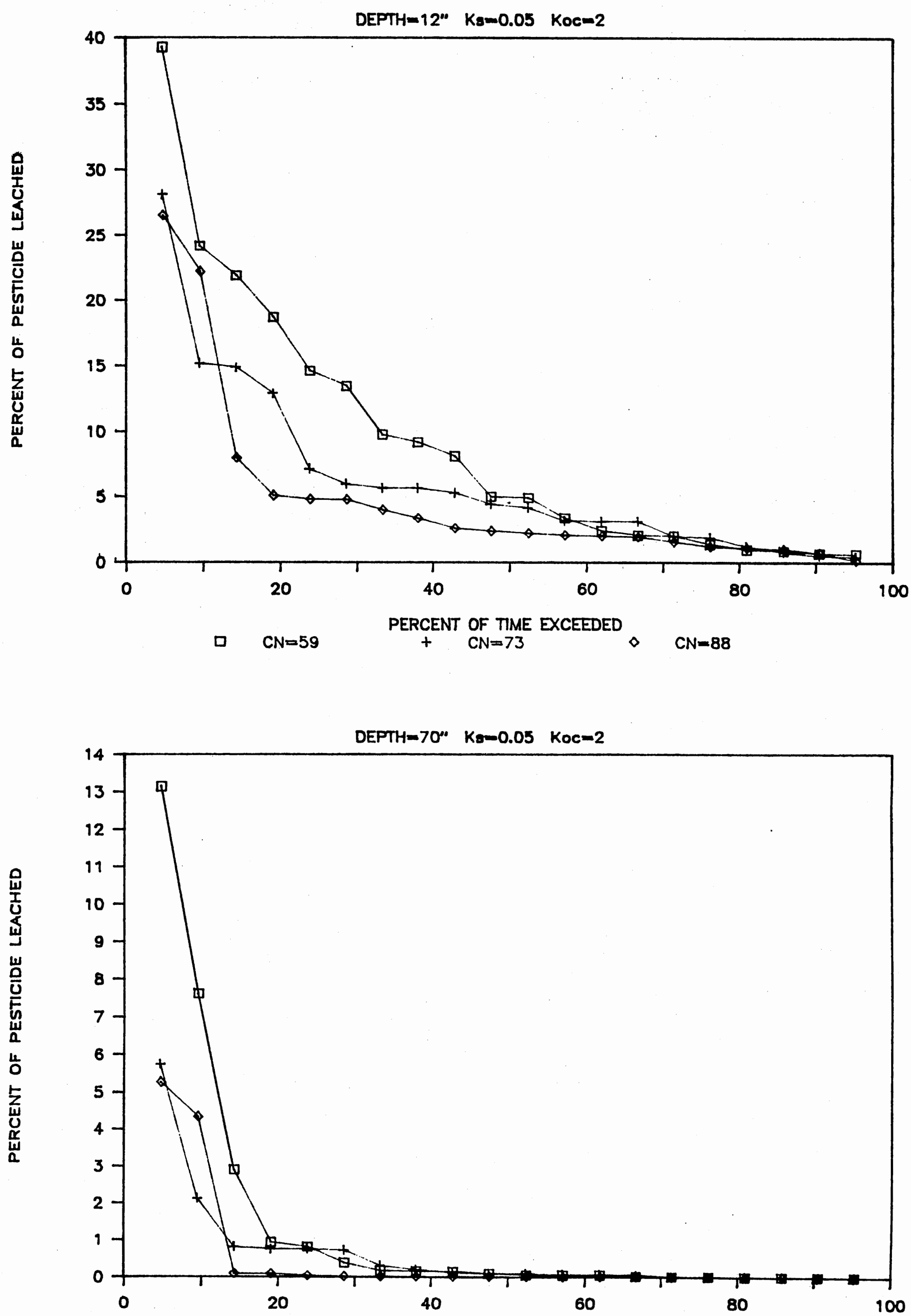
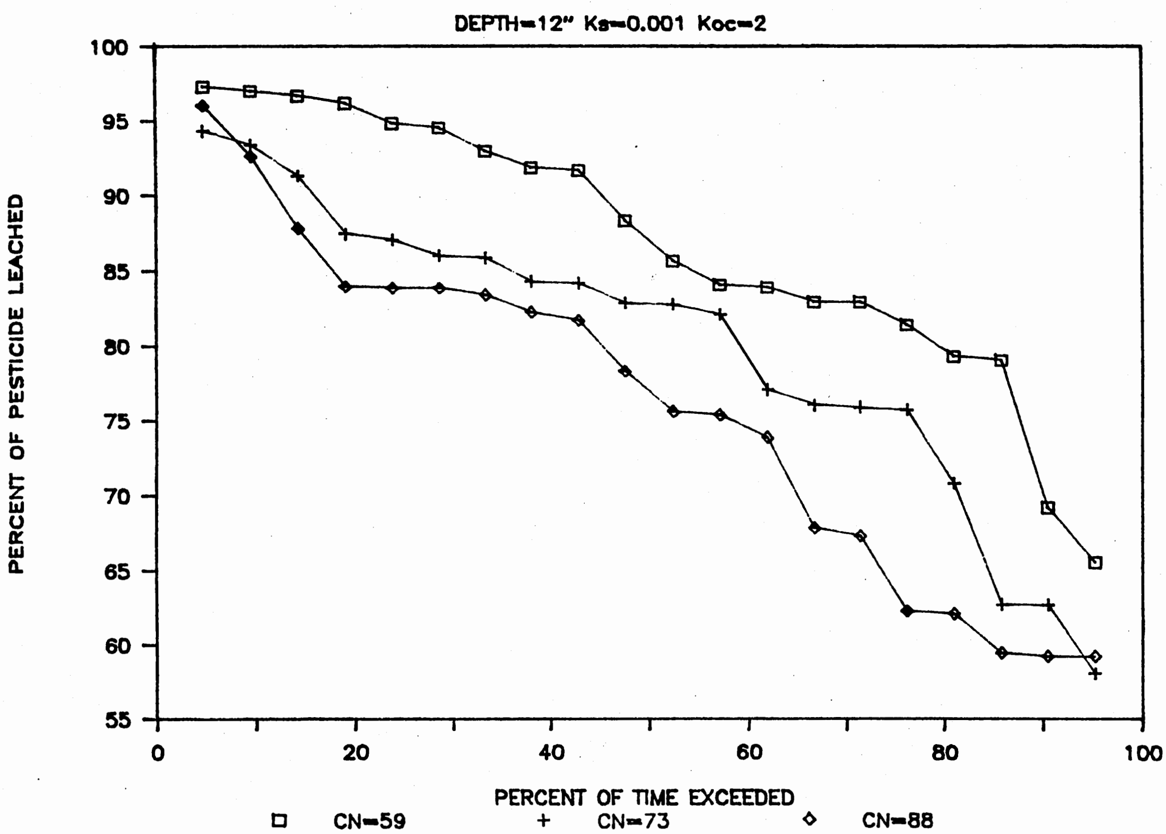


Figure 29. Probability of Leaching K_s=0.05, K_{oc}=2



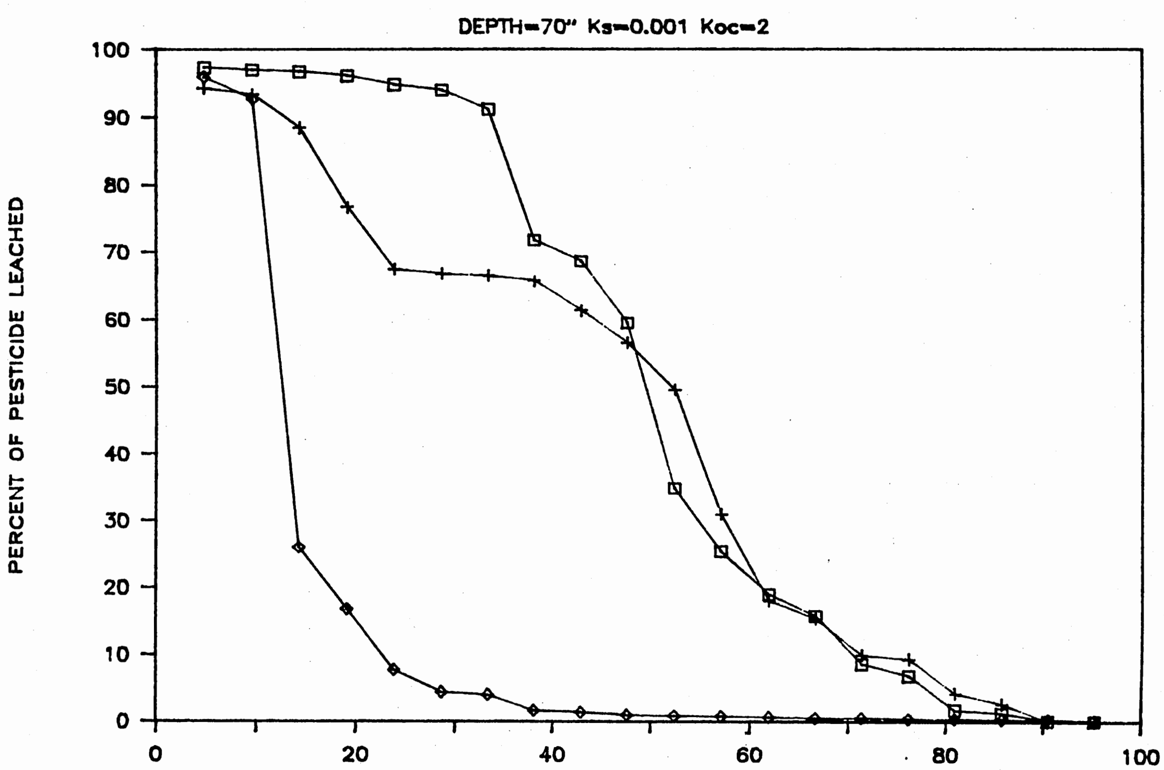
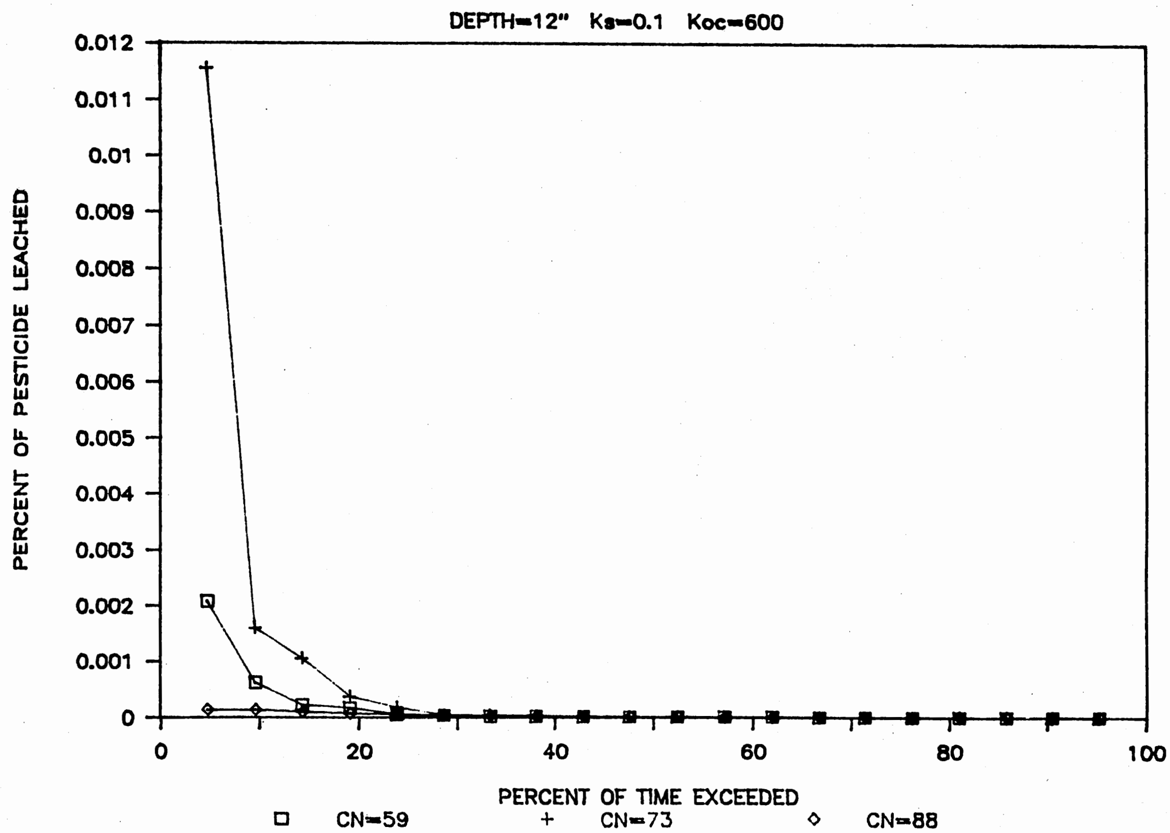


Figure 30. Probability of Leaching K_s=0.001, K_{oc}=2



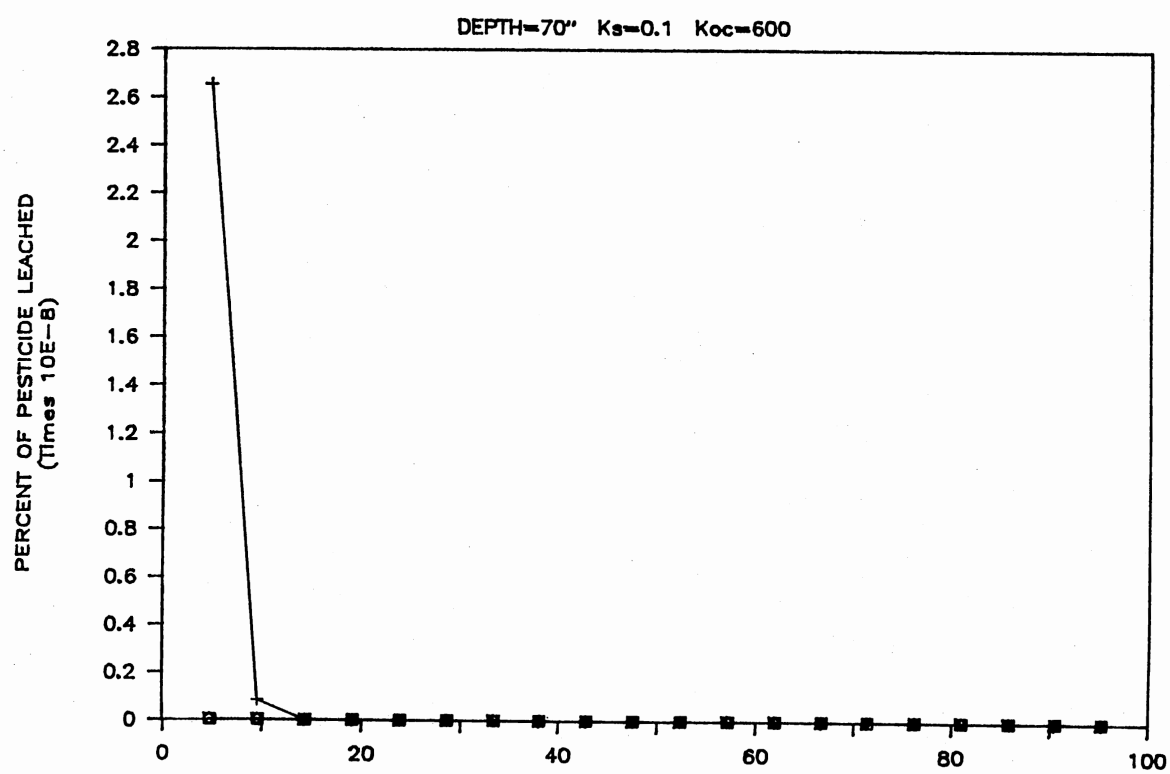
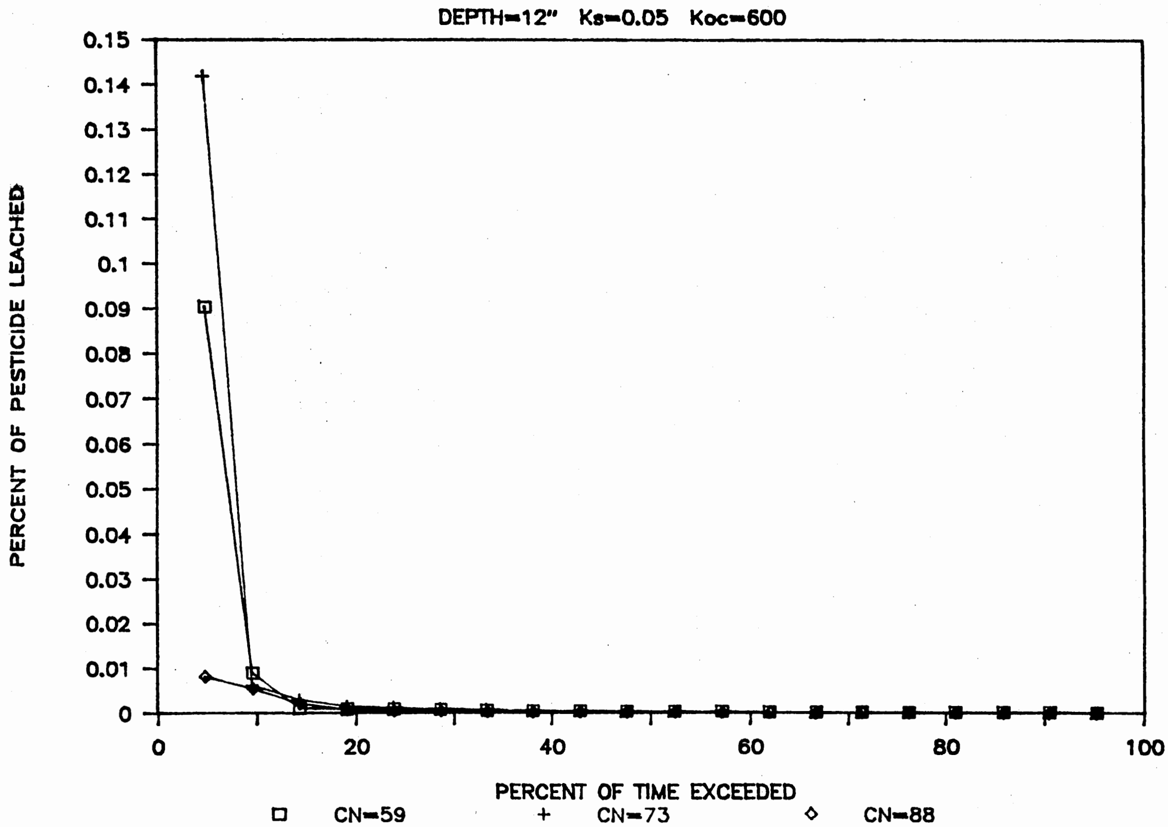


Figure 31. Probability of Leaching: K_s=0.1 K_{oc}=600



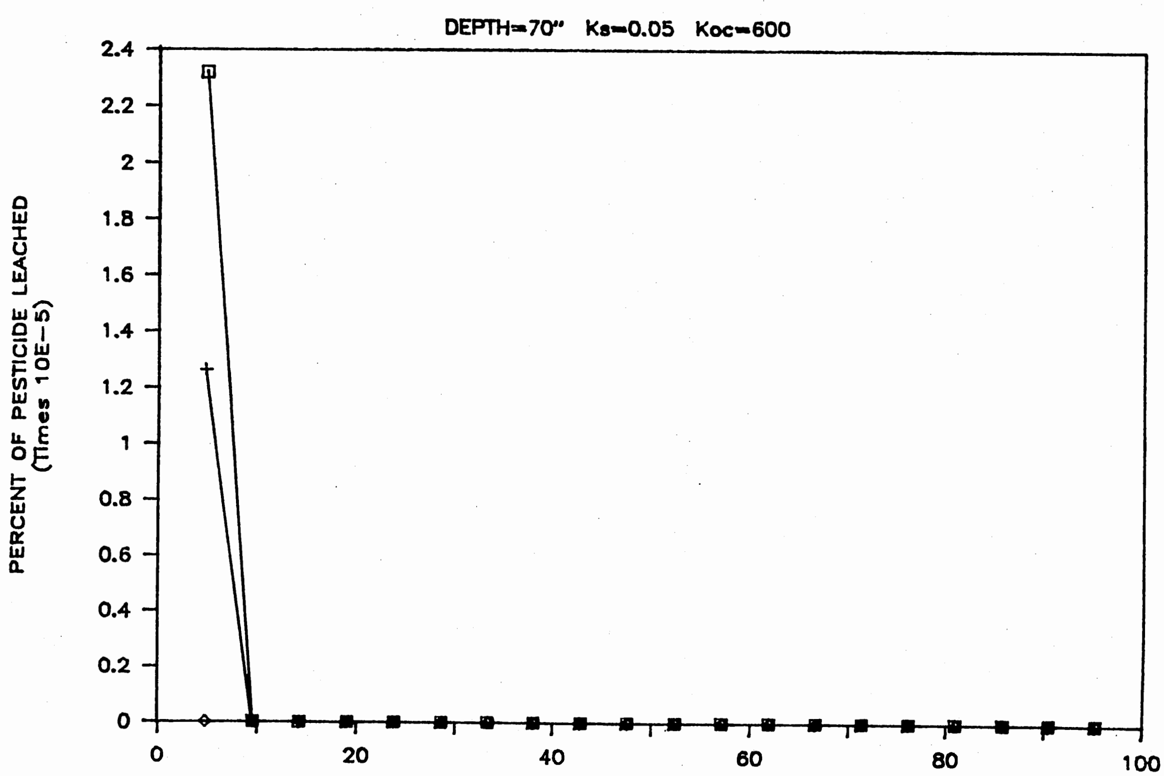
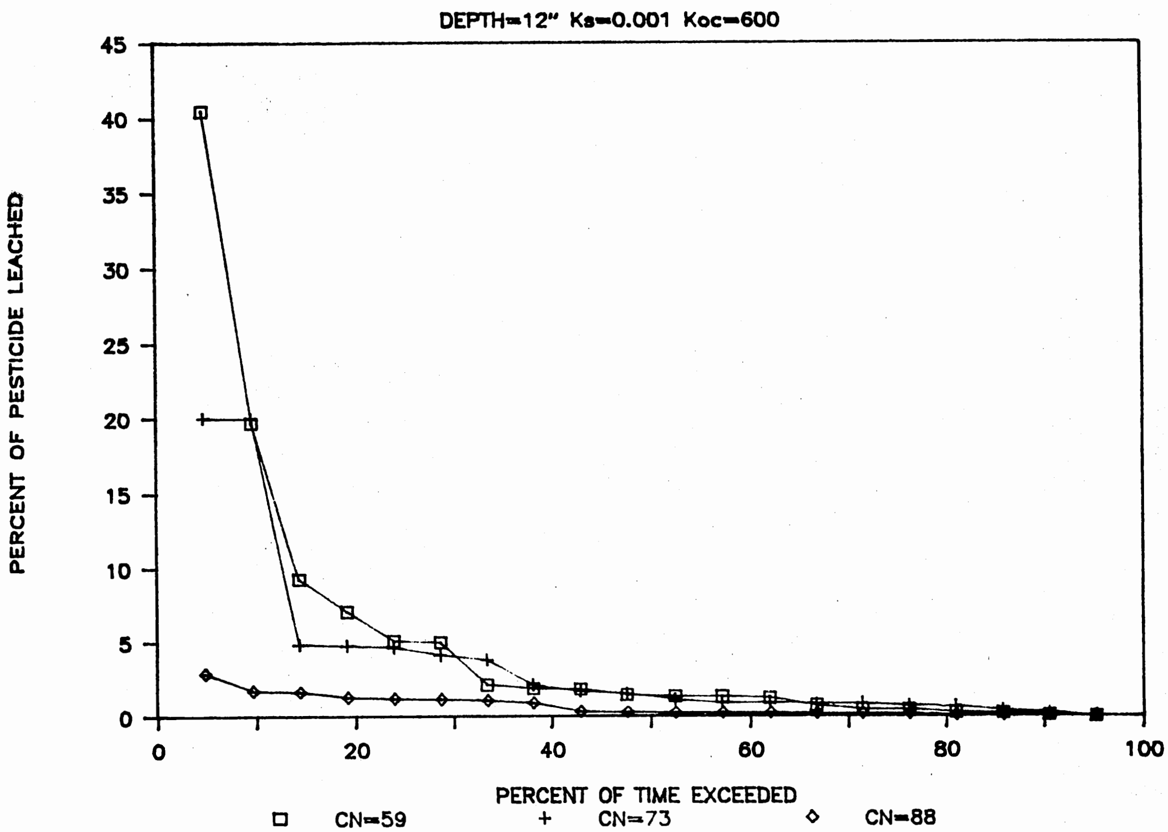


Figure 32. Probability of Leaching K_s=0.05, K_{oc}=600



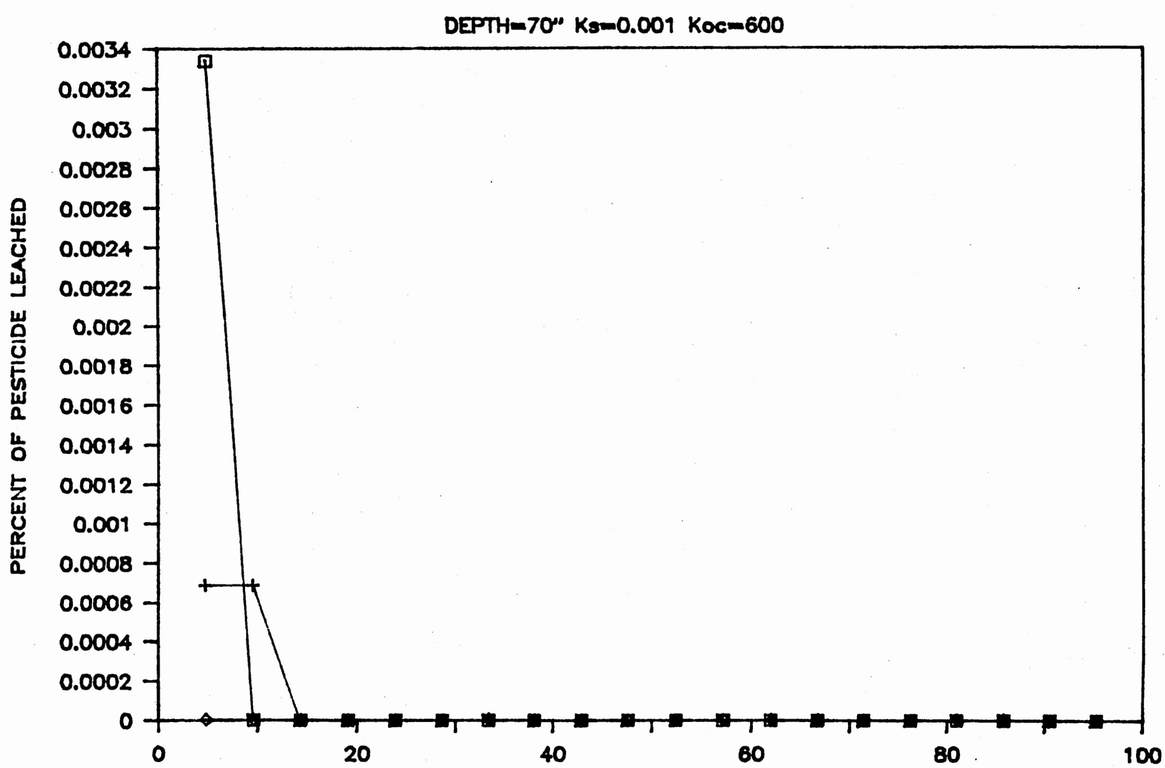
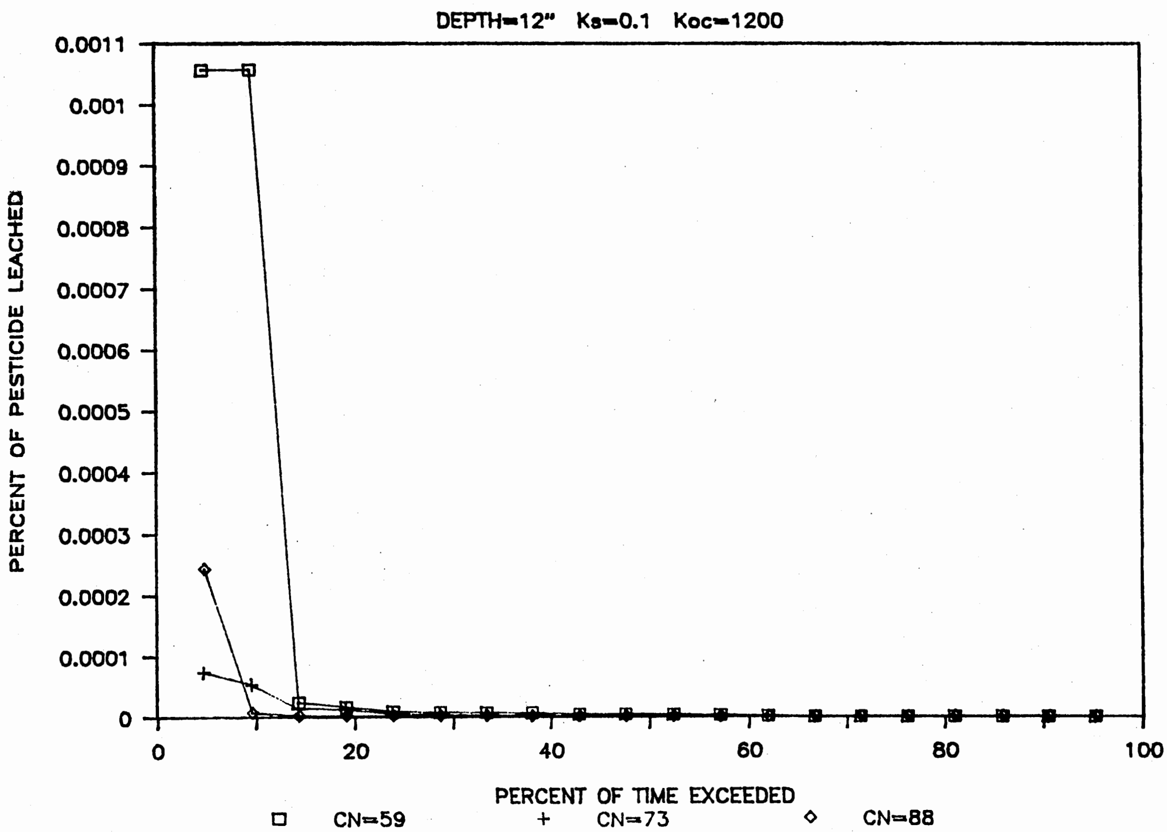


Figure 33. Probability of Leaching: K_S=0.001, K_{OC}=600



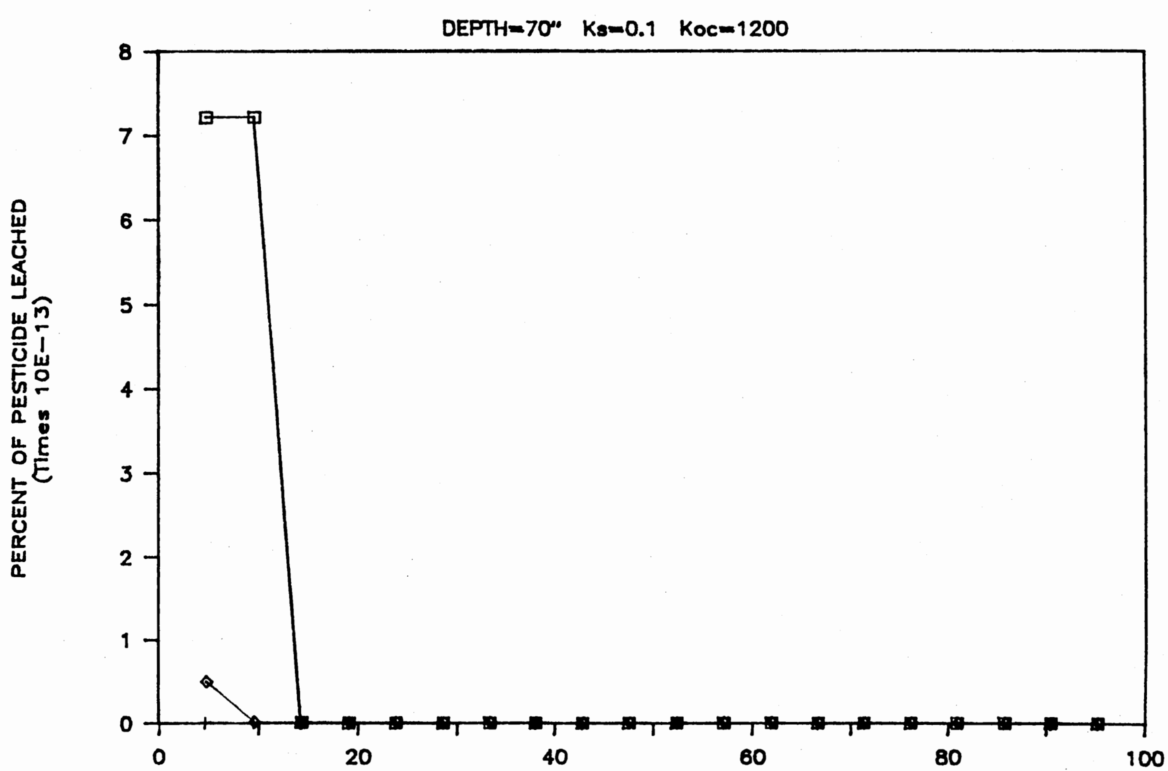


Figure 34 Probability of Leaching K_s=0.1, K_{oc}=1200

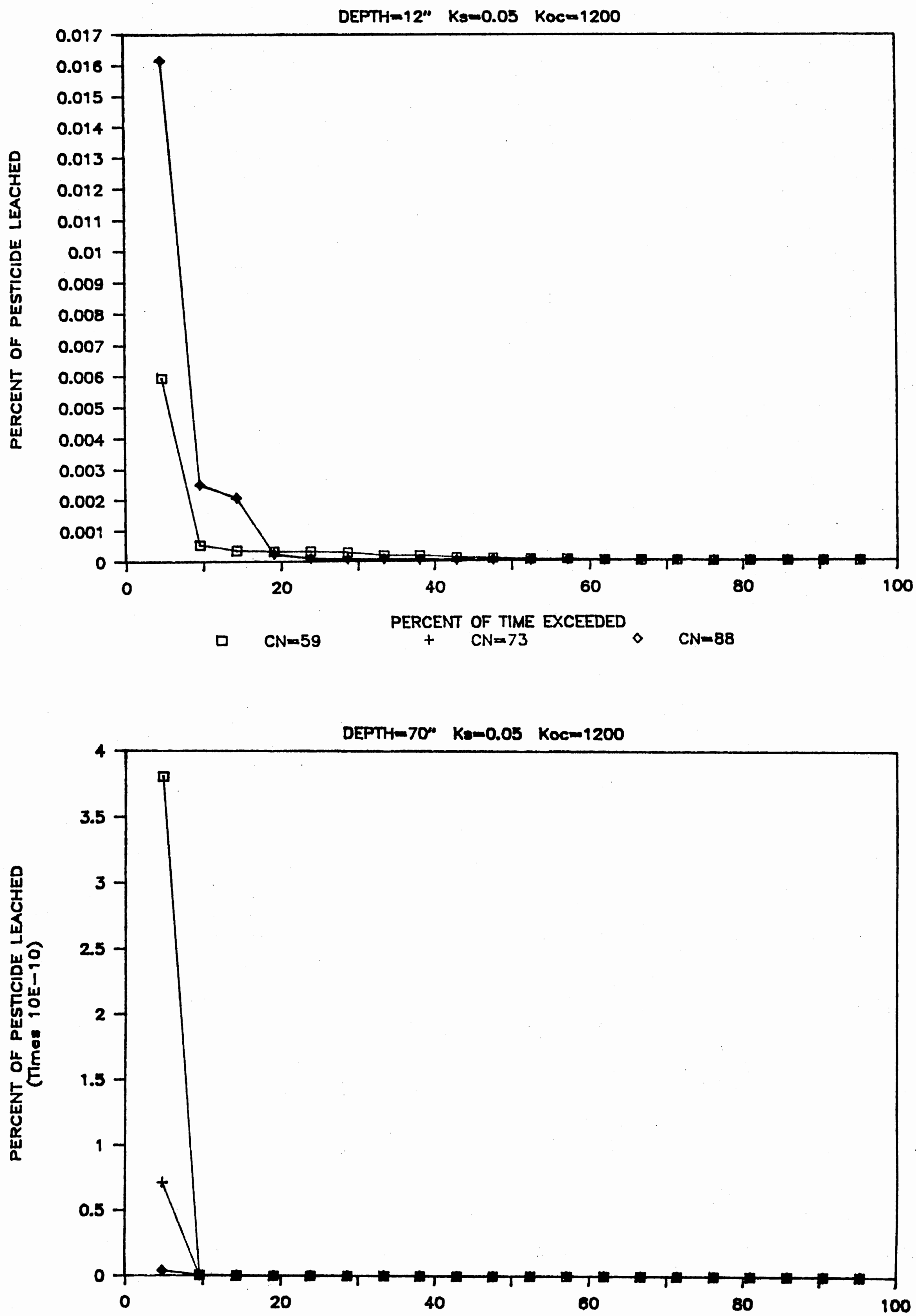


Figure 35. Probability of Leaching: K_s=0.05, K_{oc}=1200

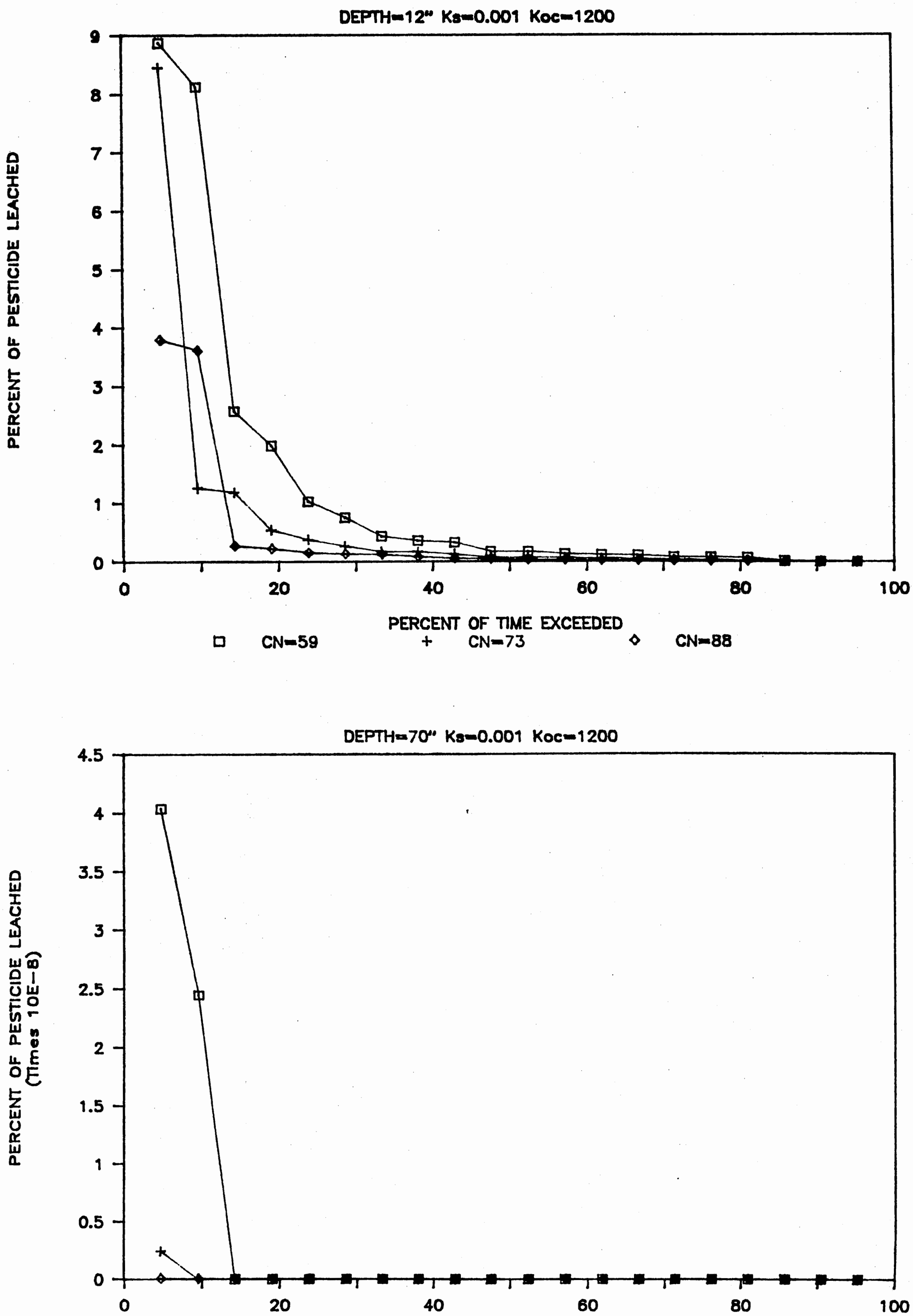
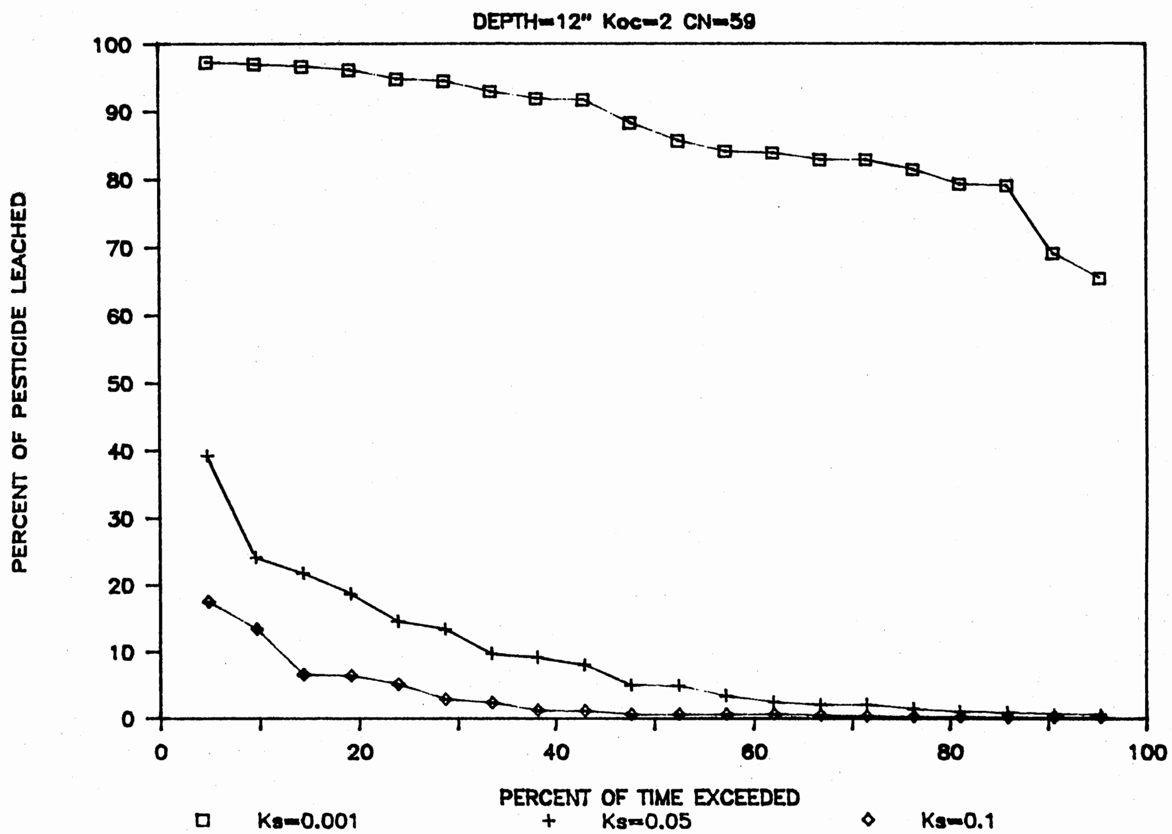


Figure 36. Probability of Leaching: K_s=0.001, K_{oc}=1200

APPENDIX K

CUMULATIVE PROBABILITY GRAPHS WITH VARIED DECAY COEFFICIENTS



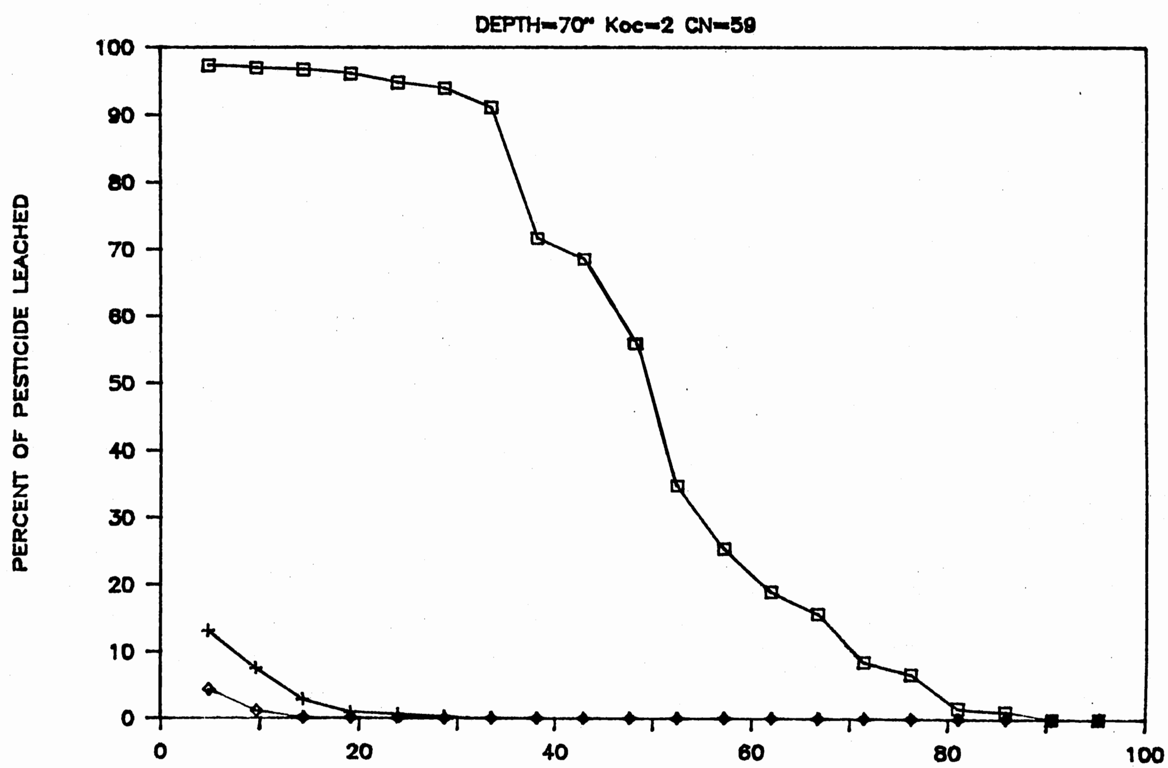


Figure 37. Probability of Leaching K_{oc}=2, CN=59

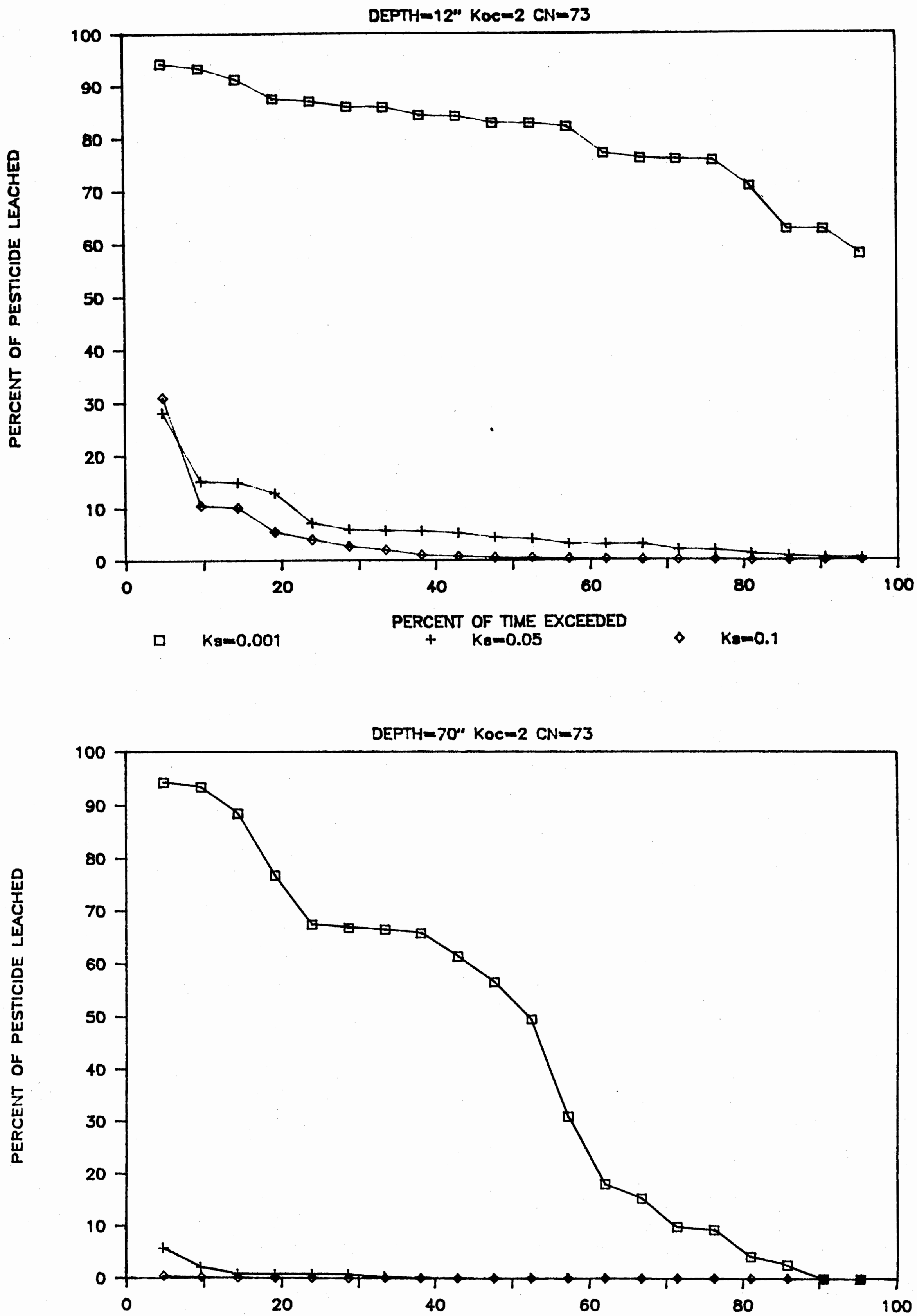
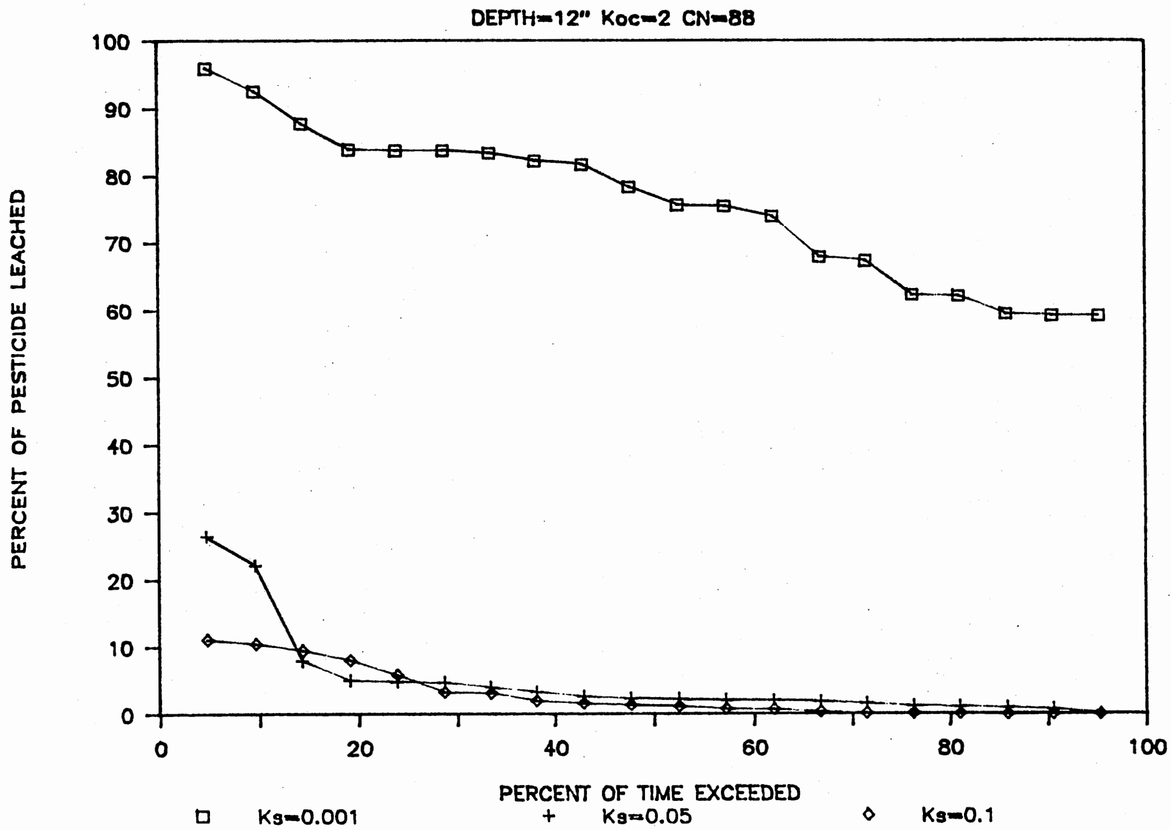


Figure 38. Probability of Leaching K_{OC}=2, CN=73



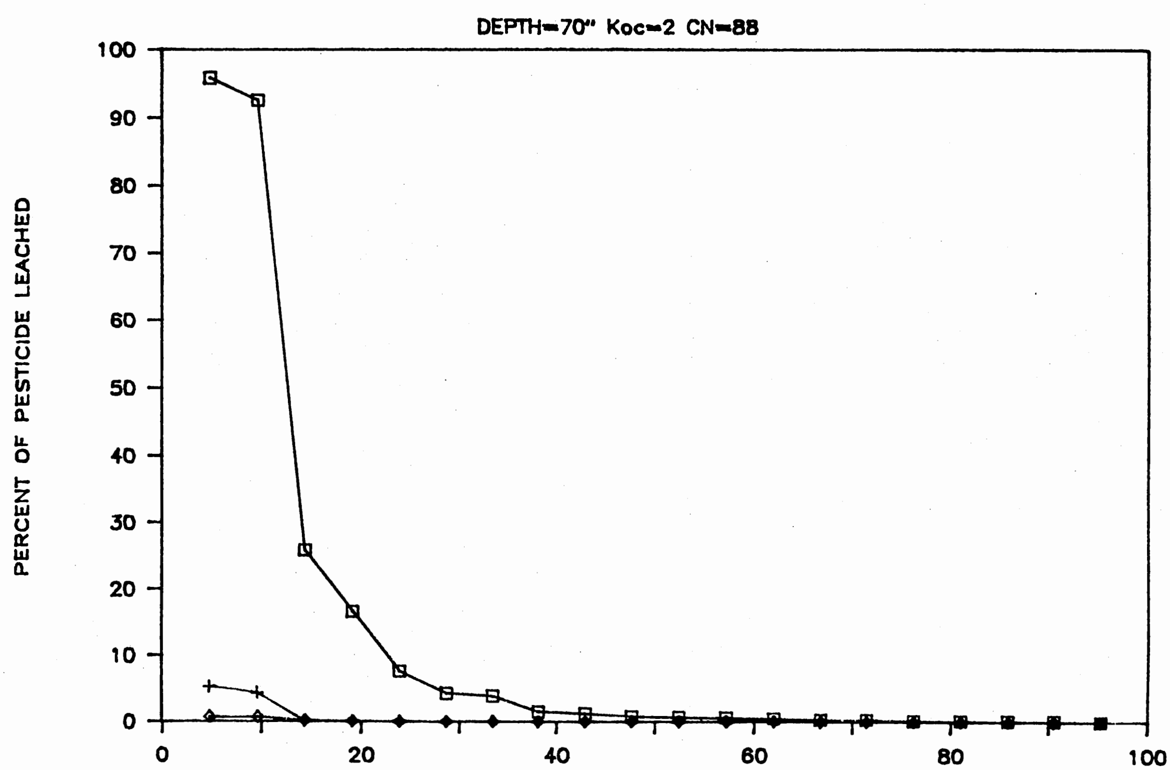
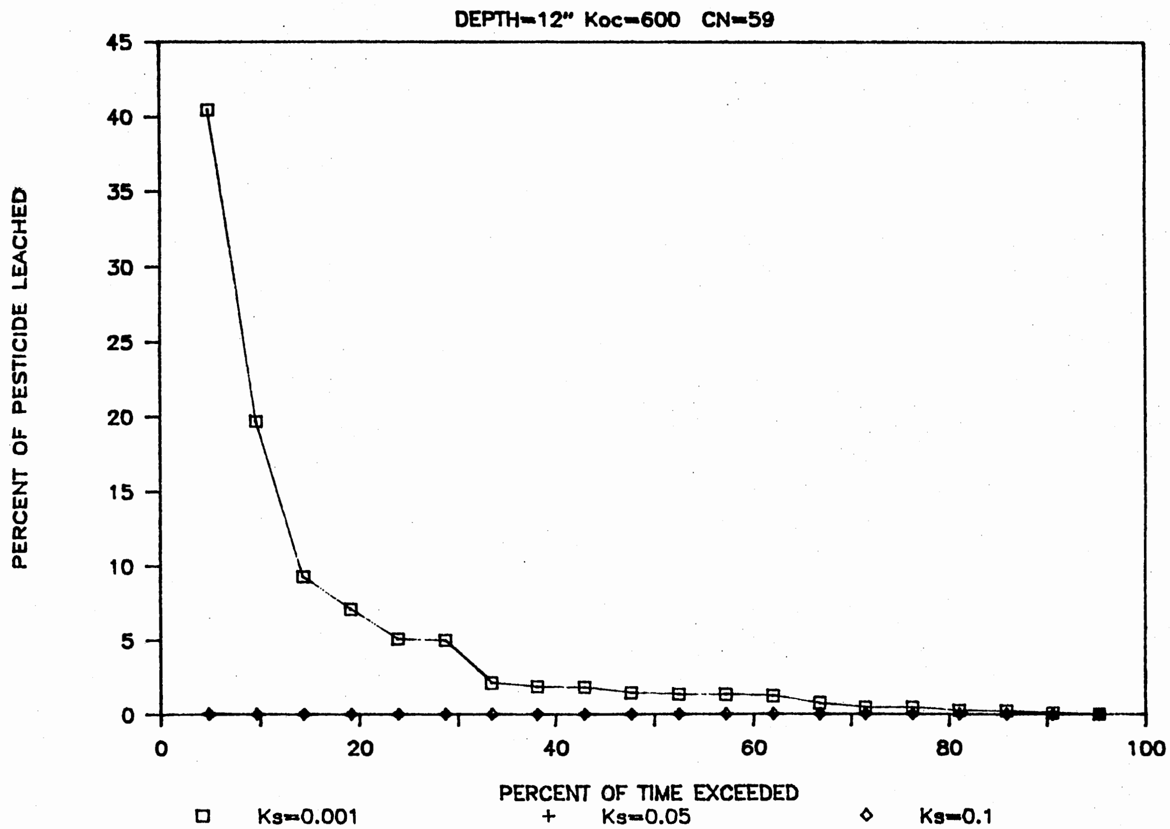


Figure 39. Probability of Leaching K_{oc}=2, CN=88



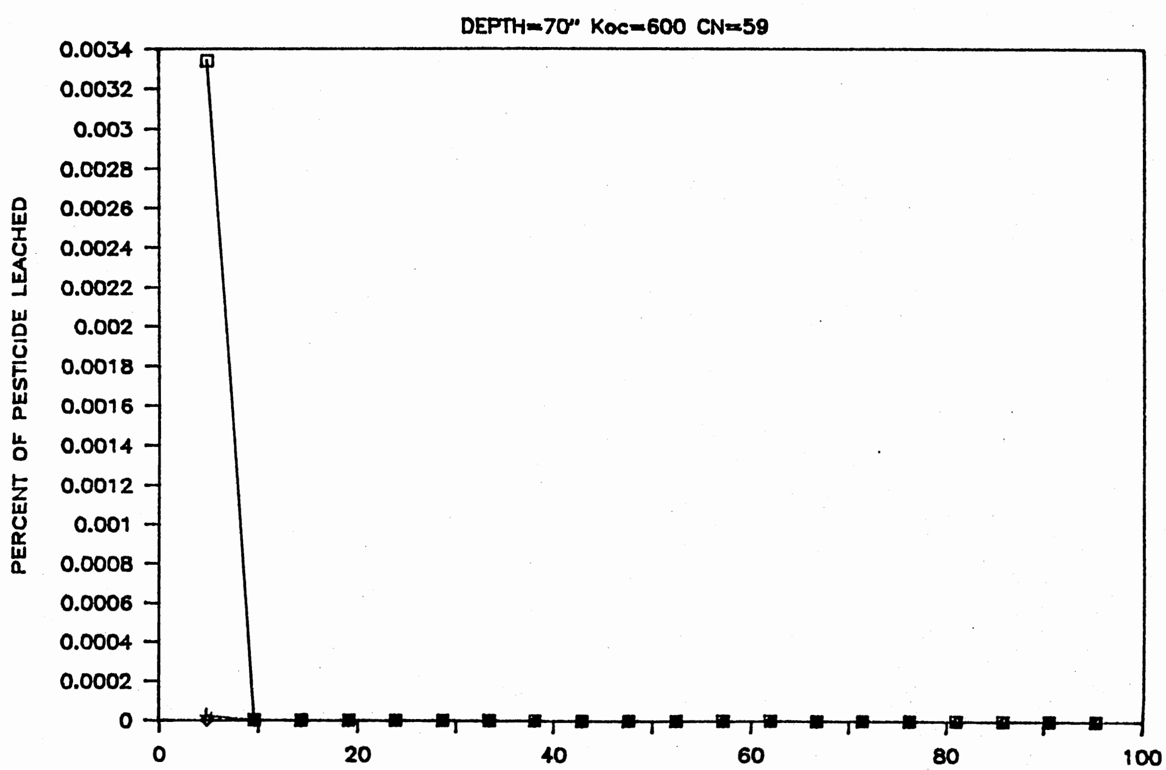
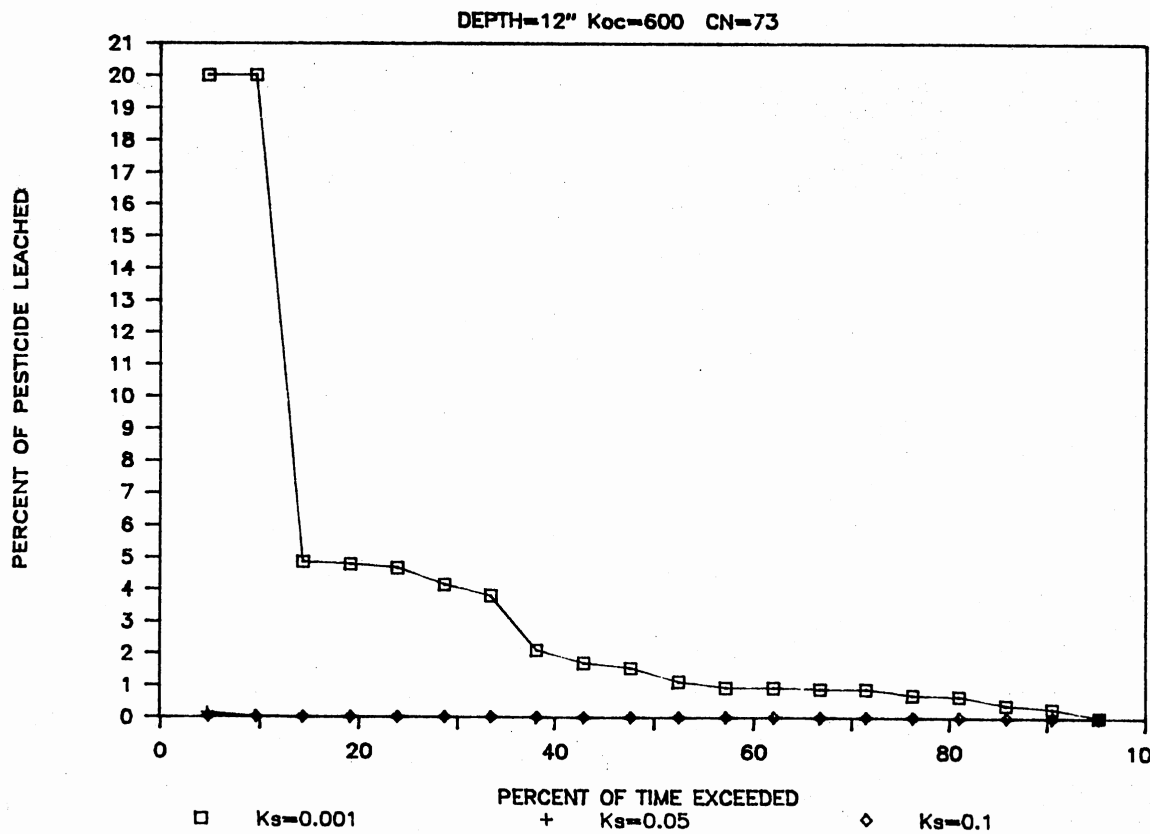


Figure 40. Probability of Leaching K_{oc}=600, CN=59



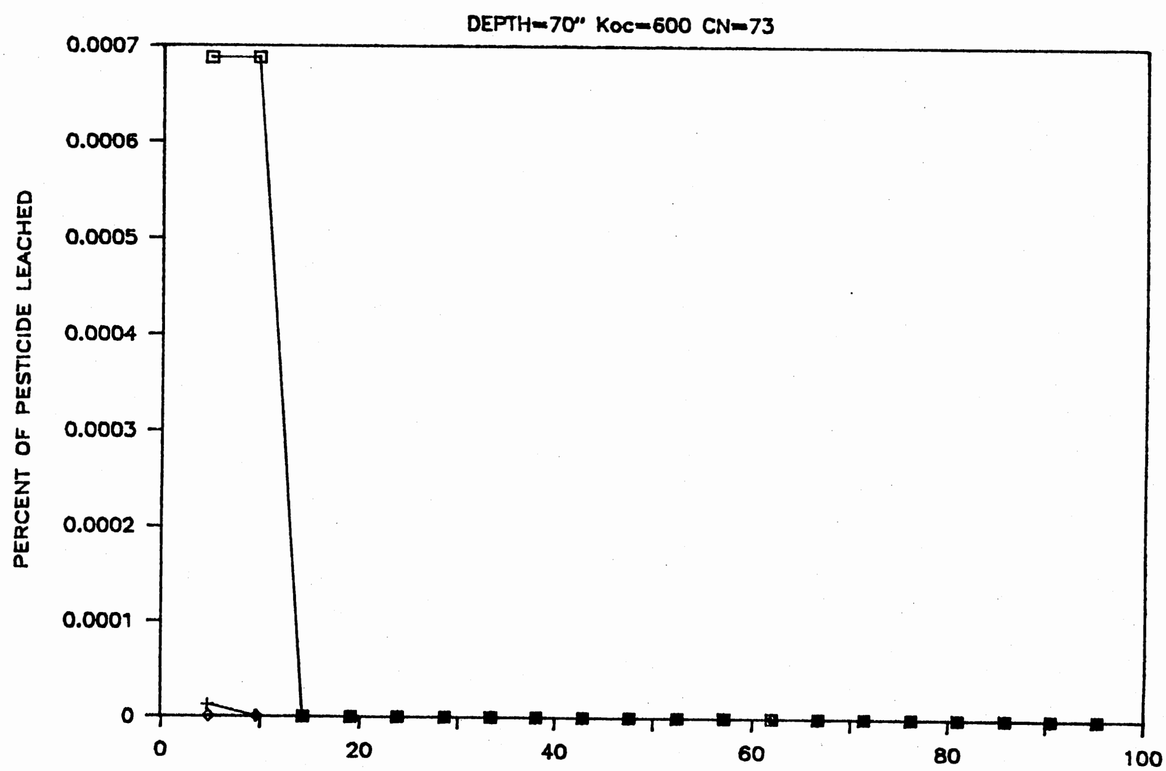
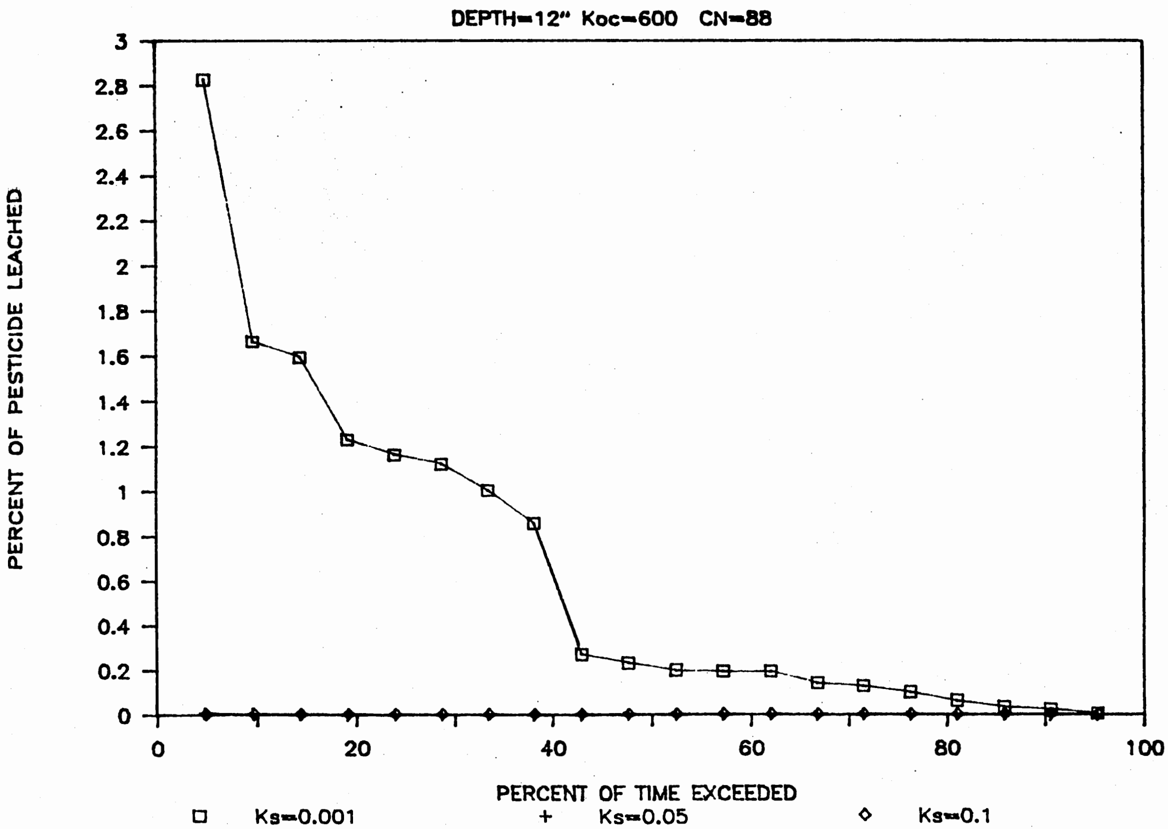


Figure 41. Probability of Leaching K_{oc}=600, CN=73



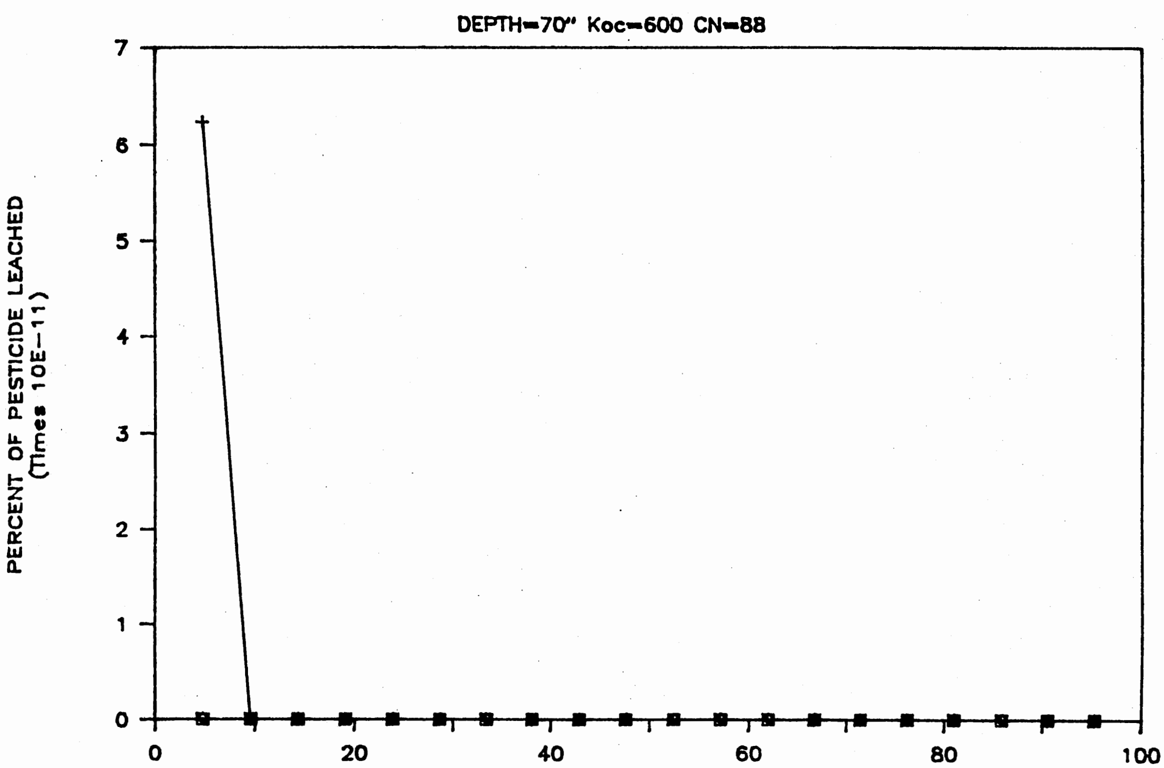


Figure 42. Probability of Leaching: K_{oc}=600, CN=88

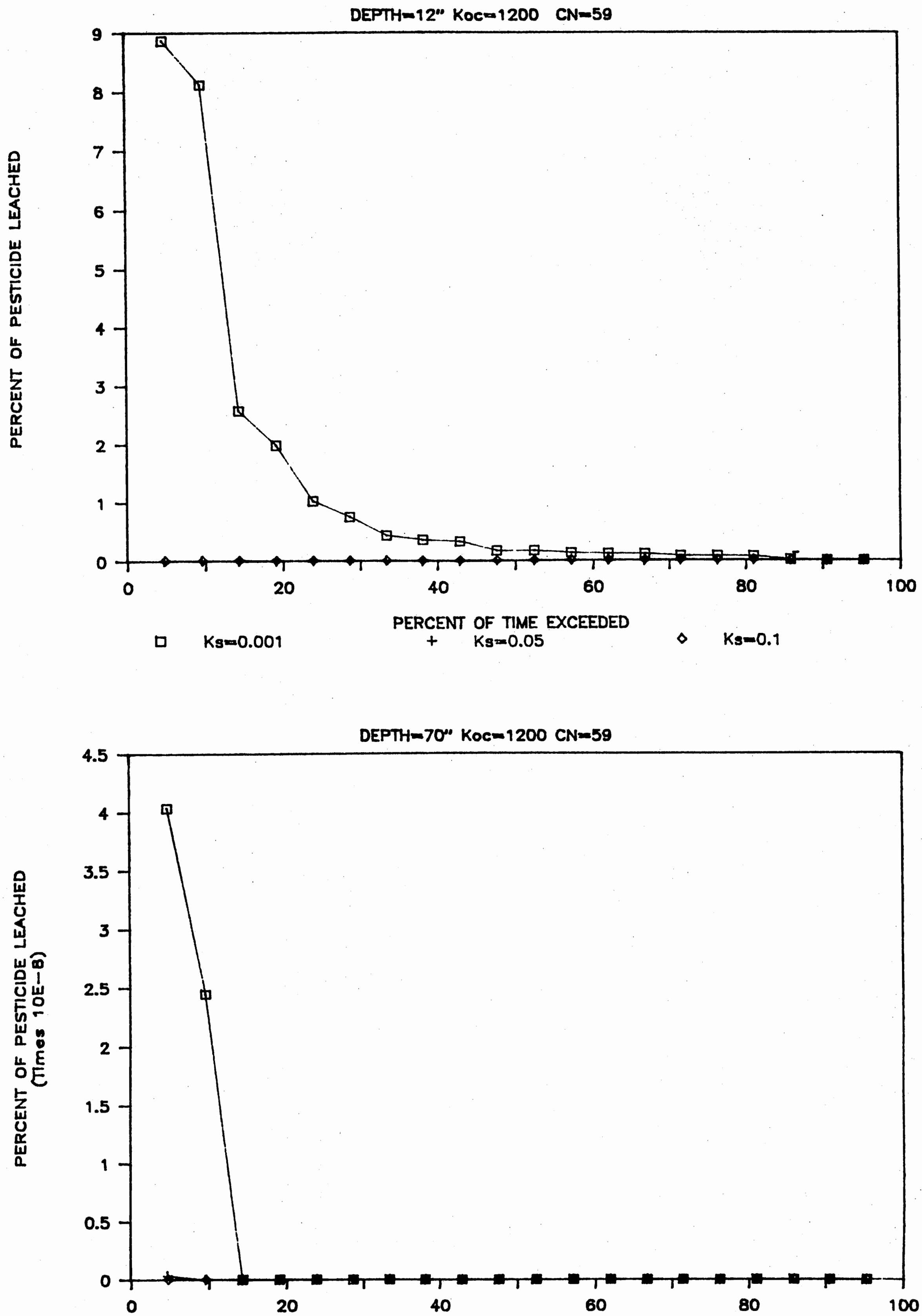


Figure 43. Probability of Leaching K_{oc}=1200, CN=59

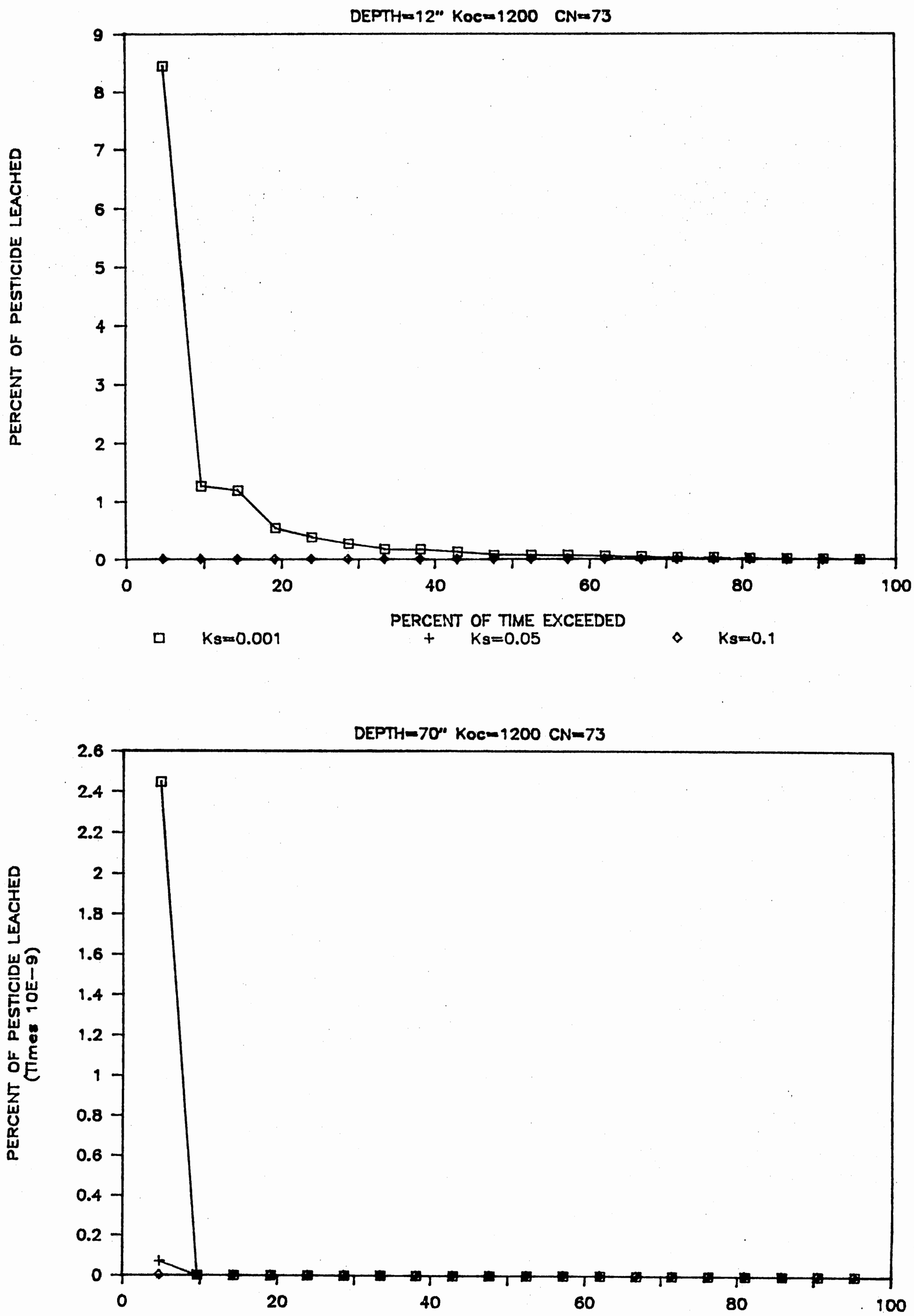
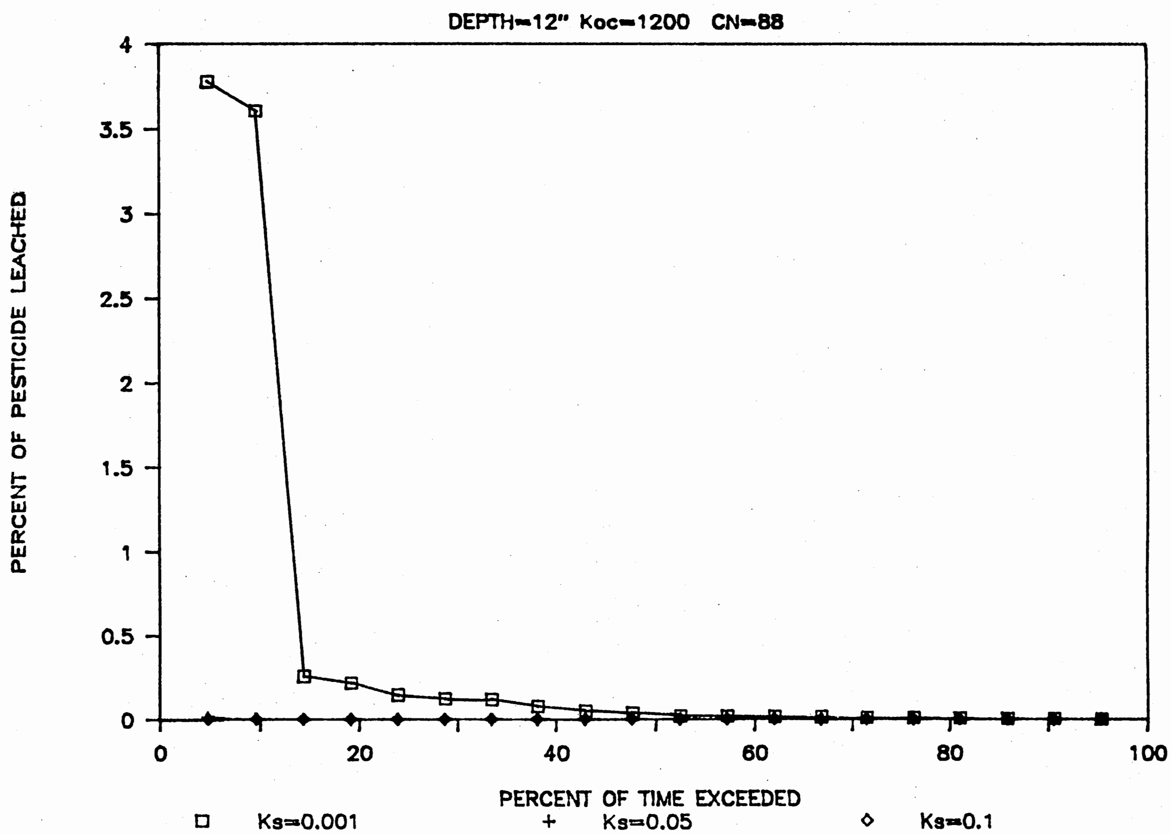


Figure 44. Probability of Leaching: K_{oc}=1200, CN=73



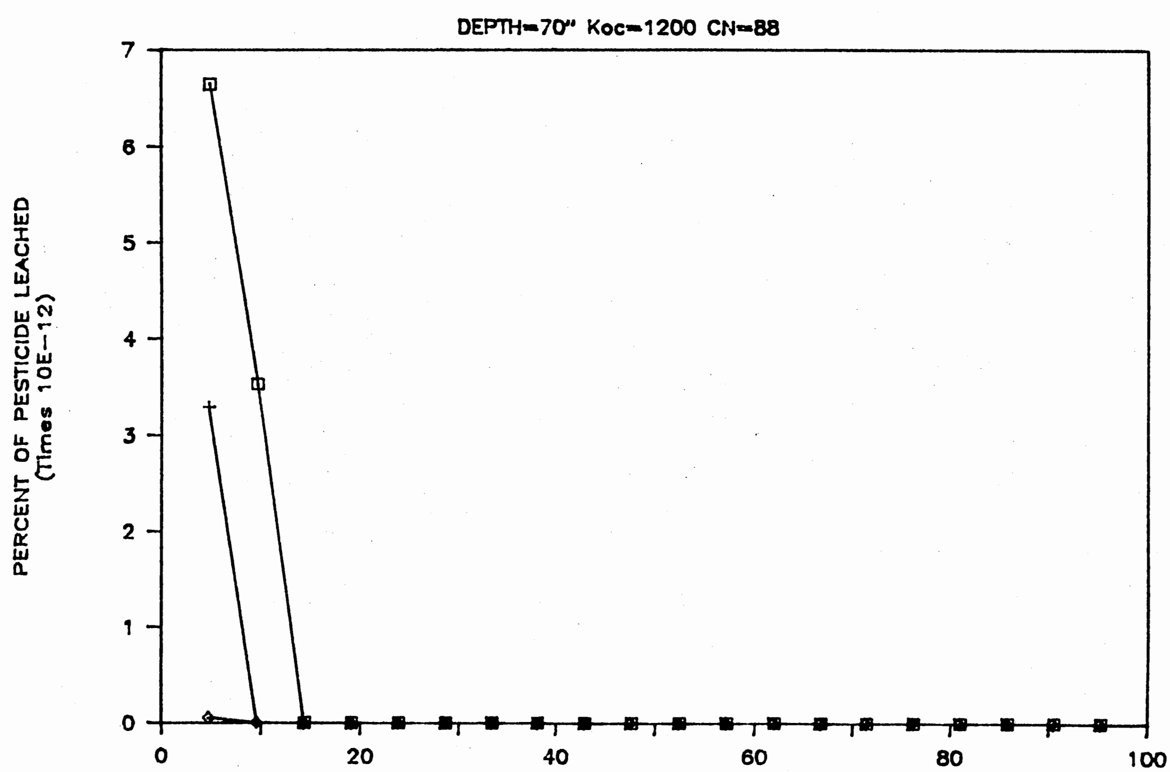
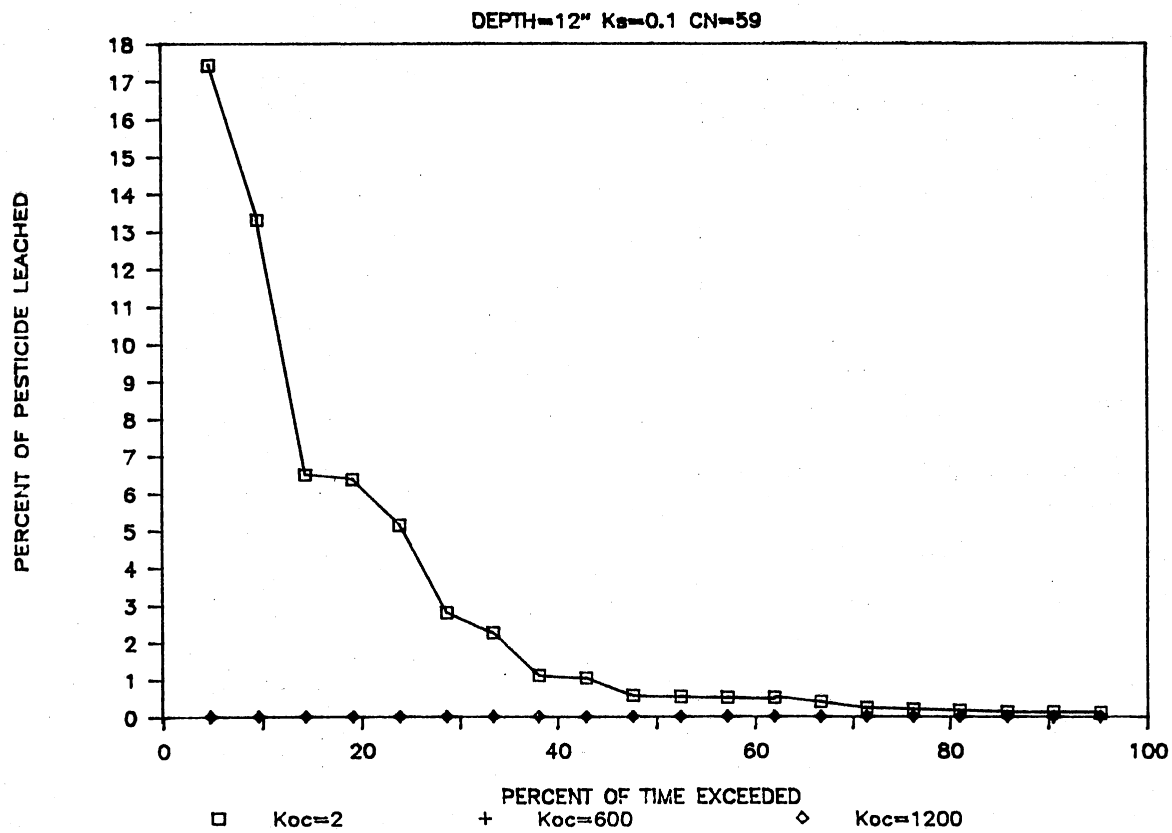


Figure 45. Probability of Leaching K_{oc}=1200, CN=88

APPENDIX L

CUMULATIVE PROBABILITY GRAPHS WITH VARIED RETARDANCE COEFFICIENTS



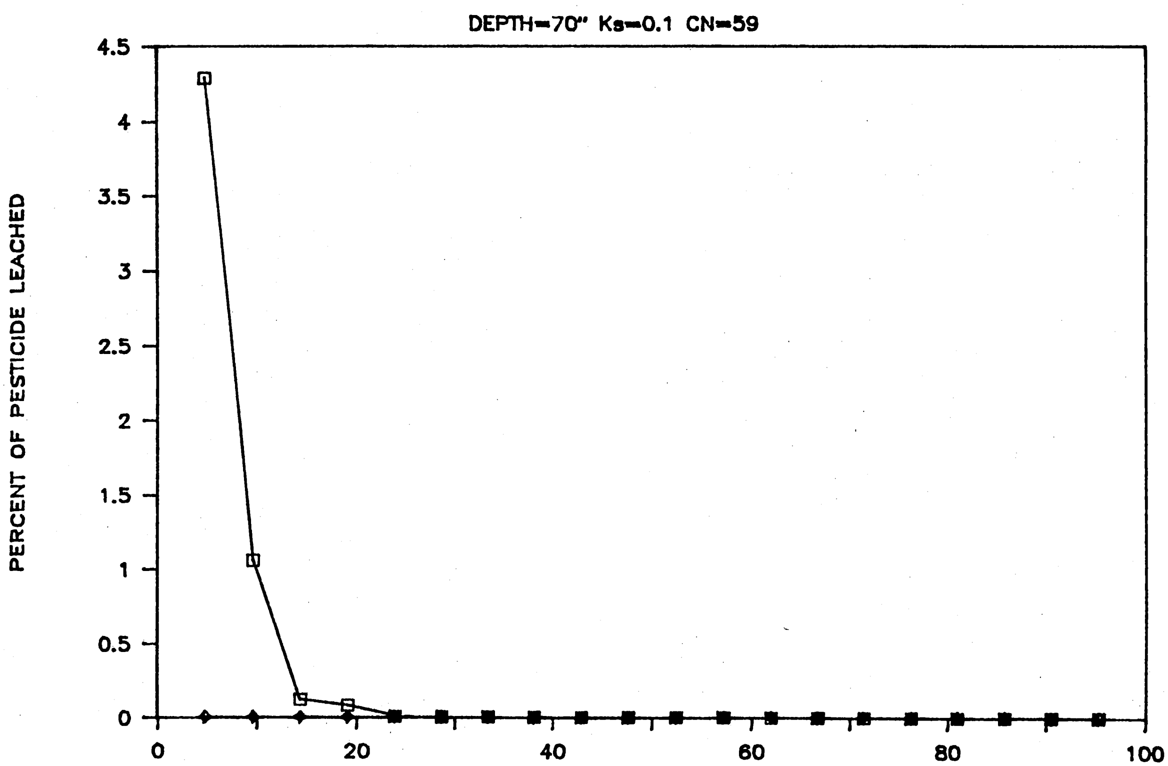
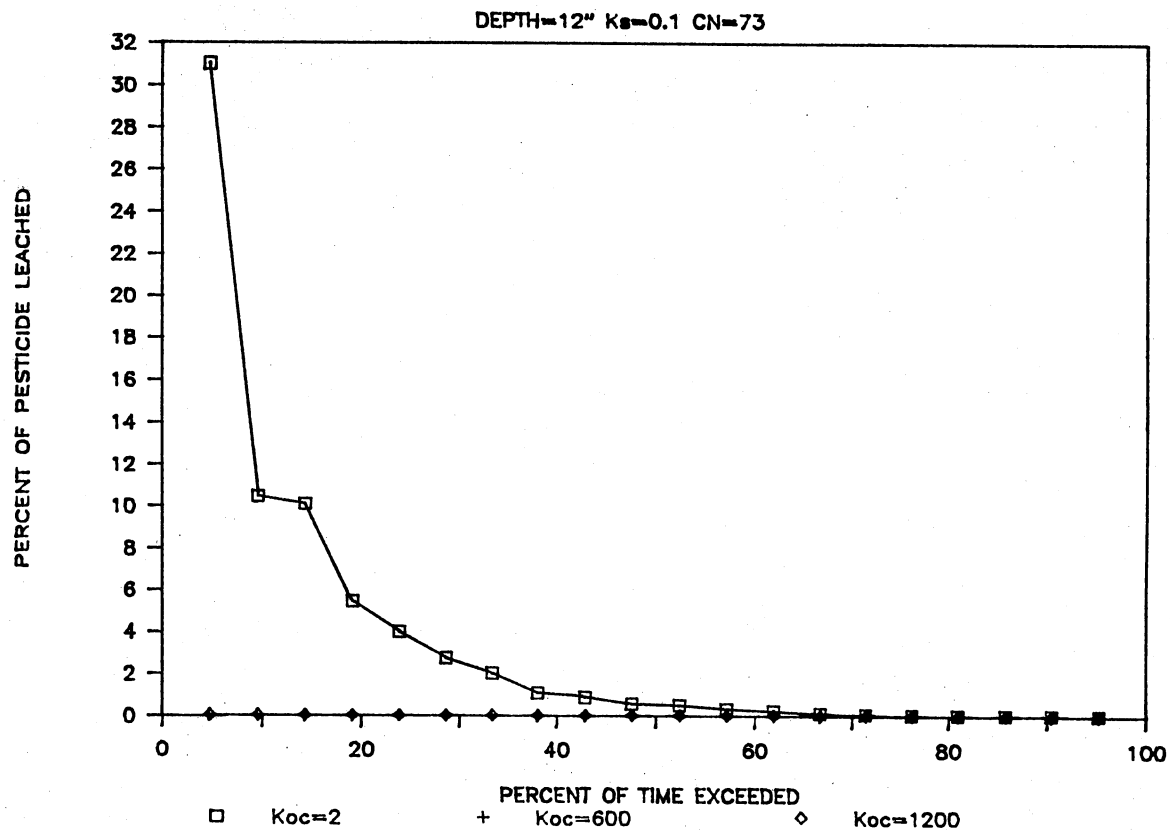


Figure 46. Probability of Leaching K_s=0.1, CN=59



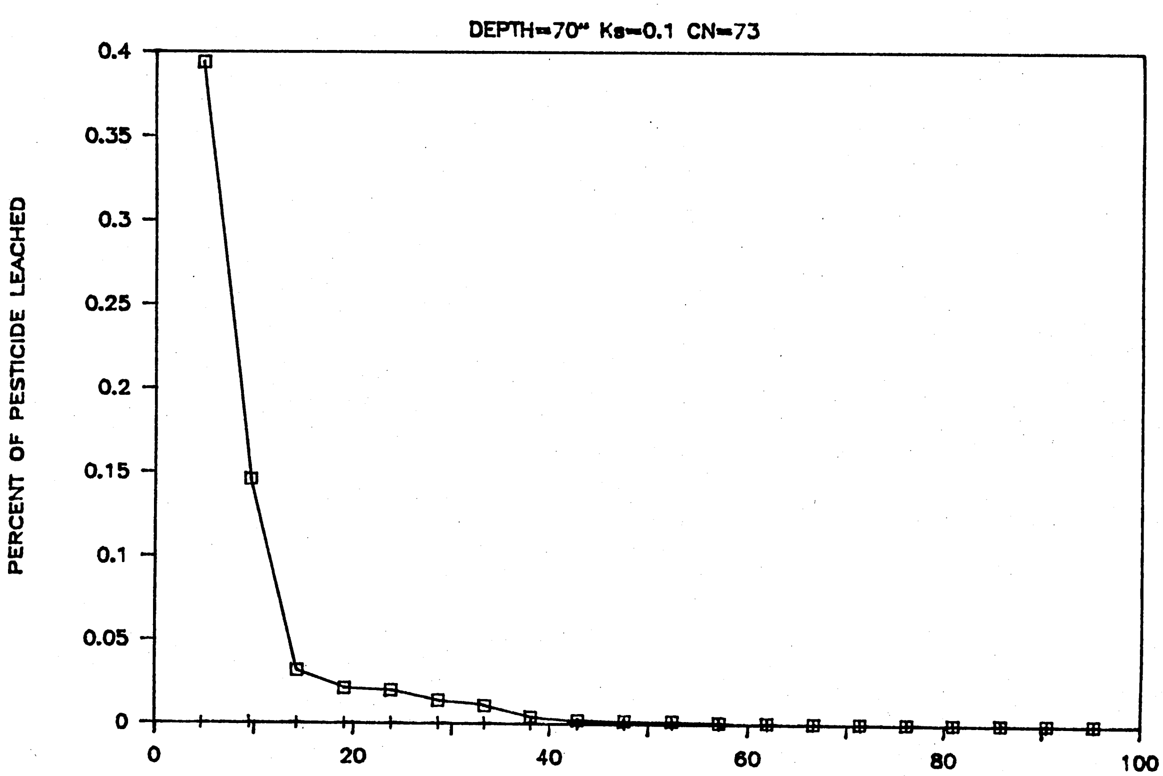
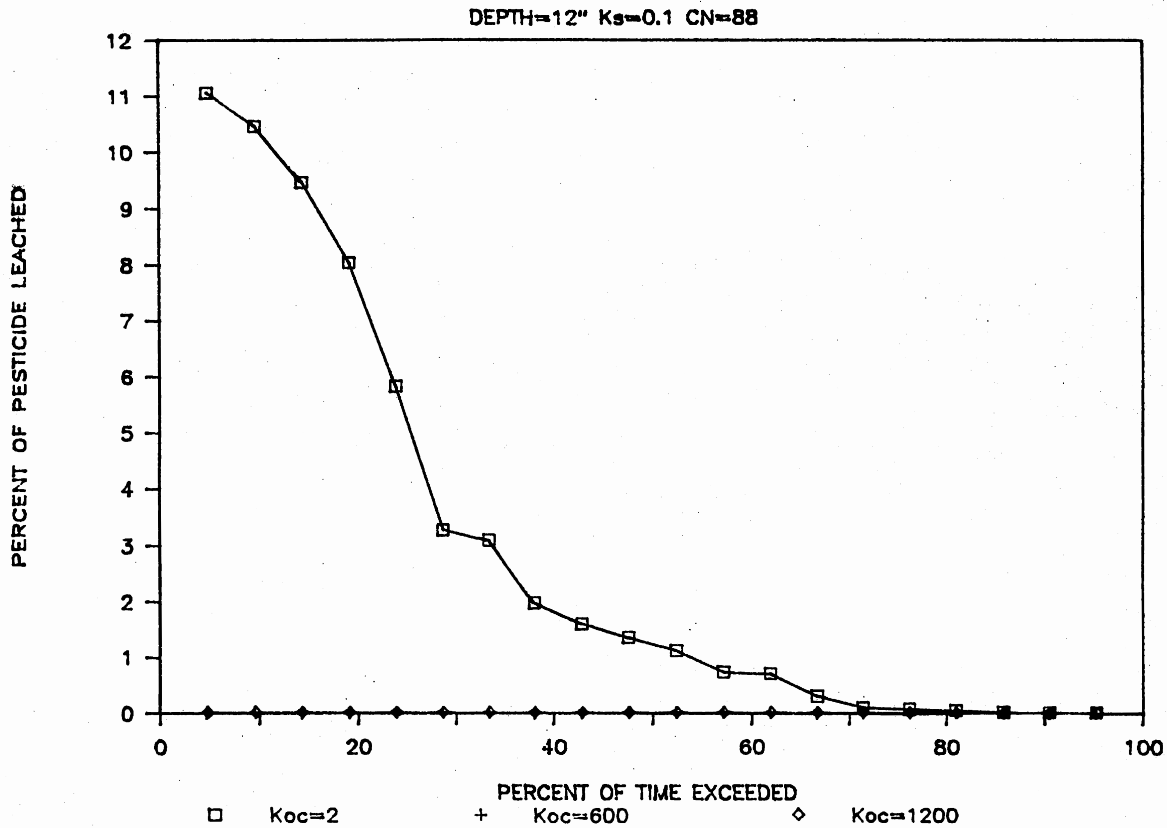


Figure 47. Probability of Leaching K_s=0.1, CN=73



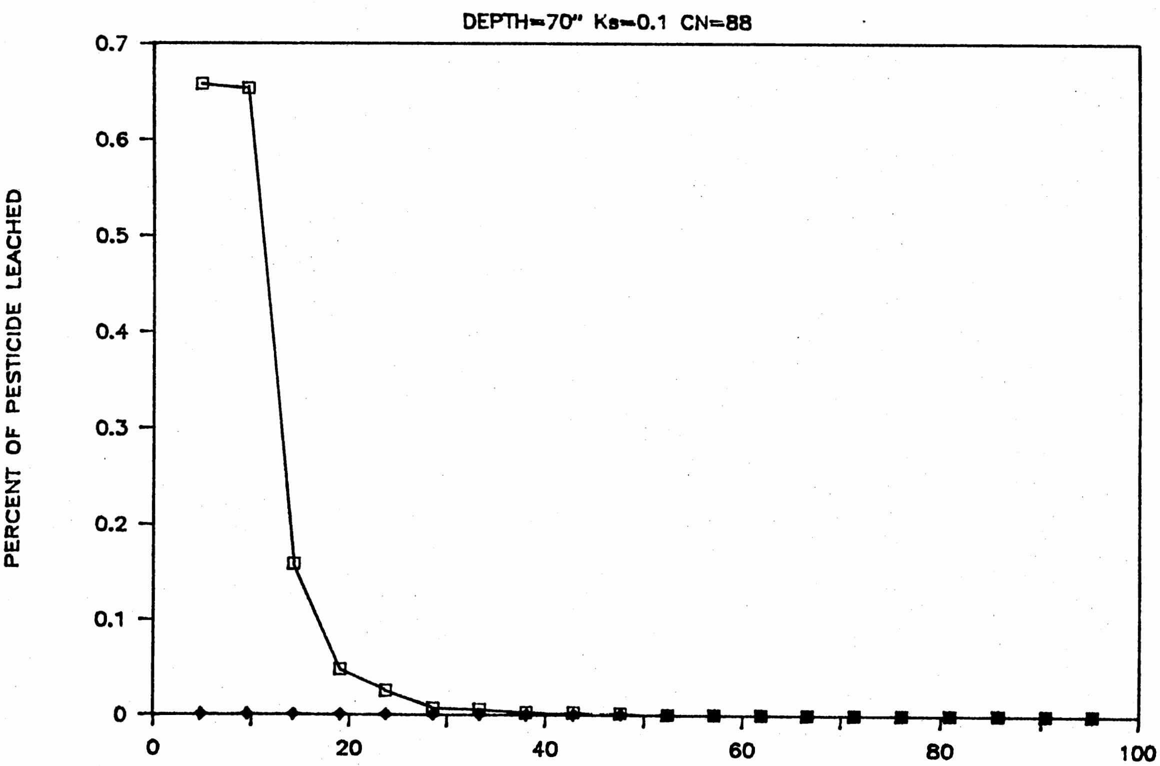


Figure 48. Probability of Leaching: K_s=0.1, CN=88

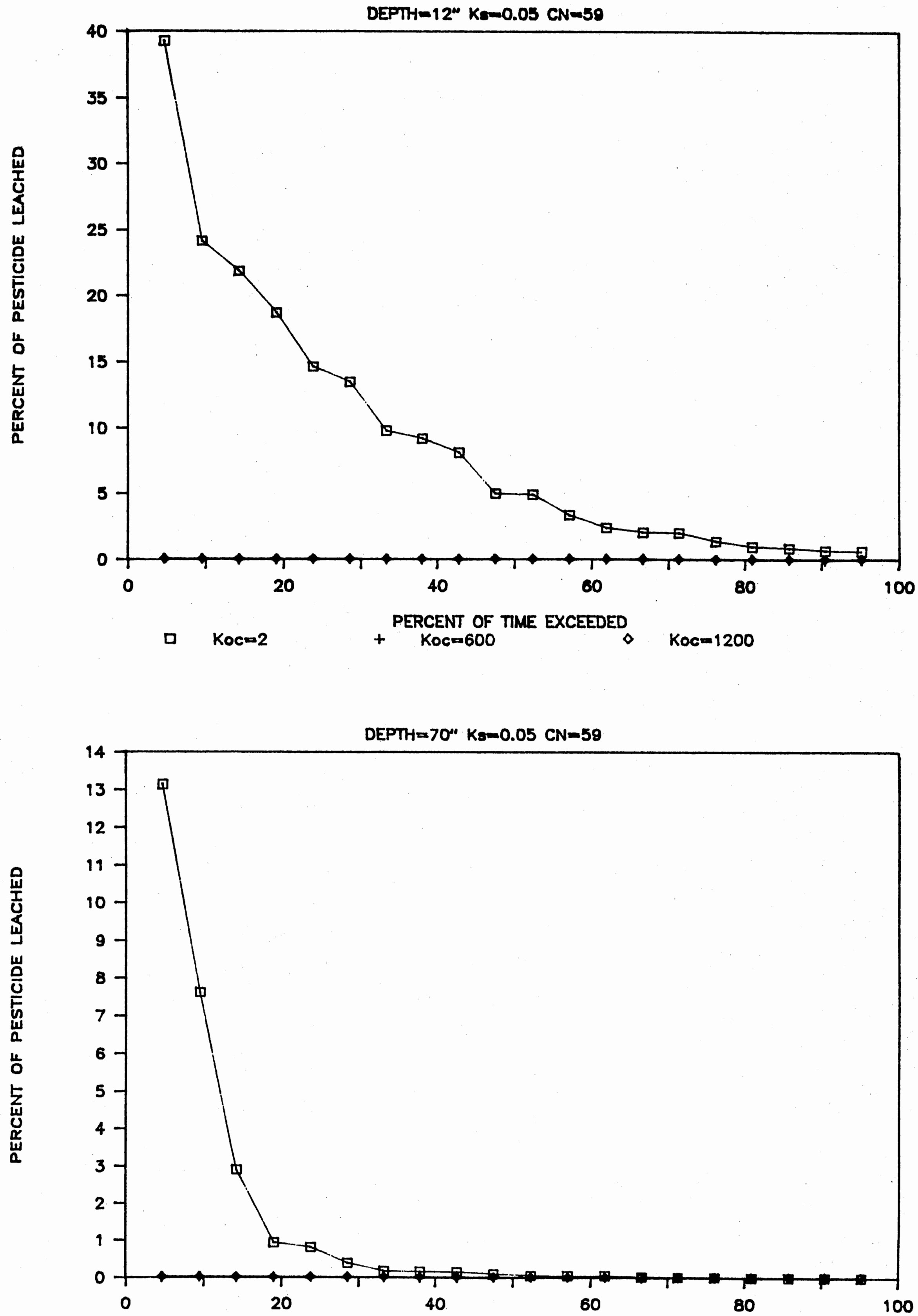


Figure 49. Probability of Leaching K_s=0.05, CN=59

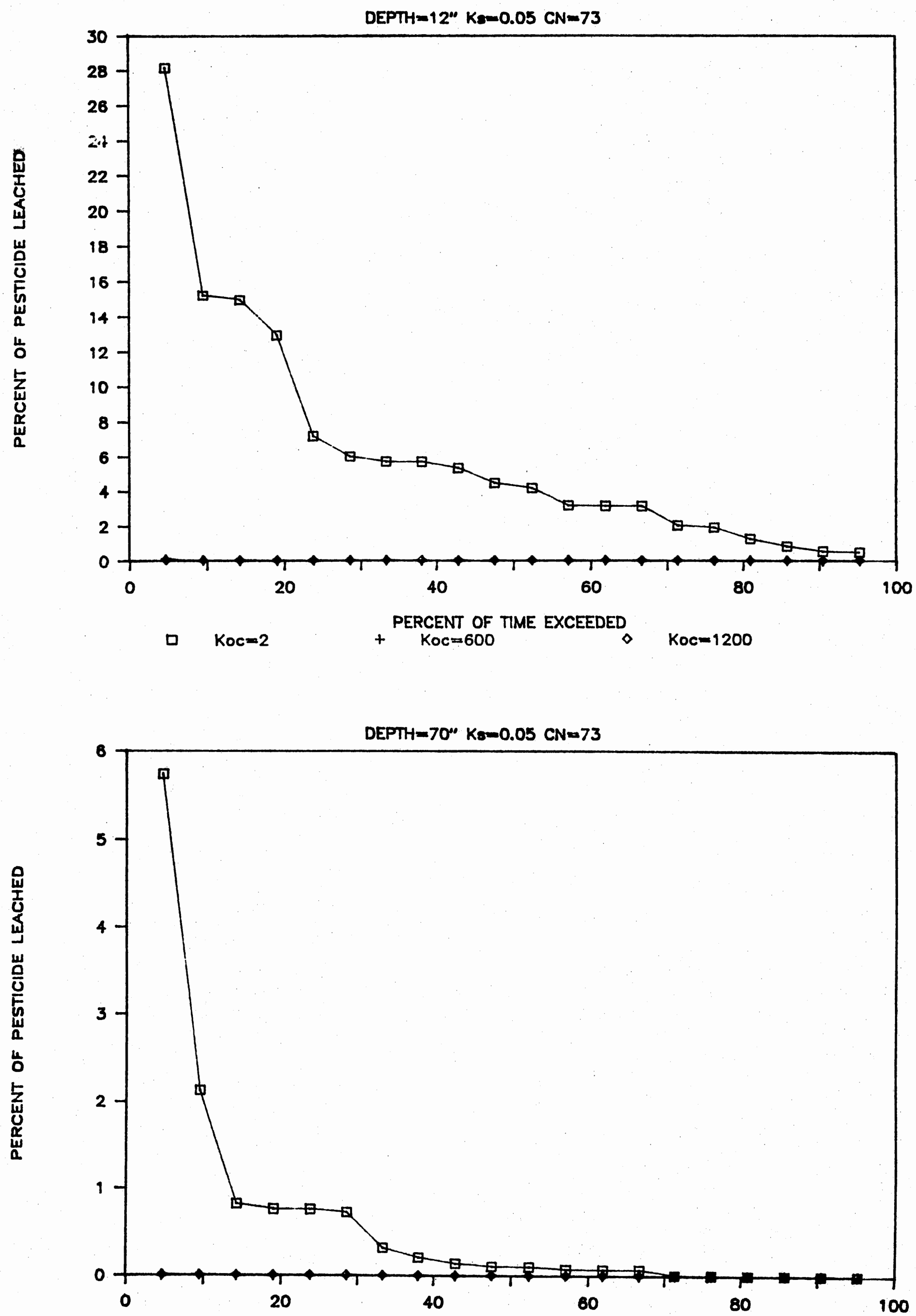
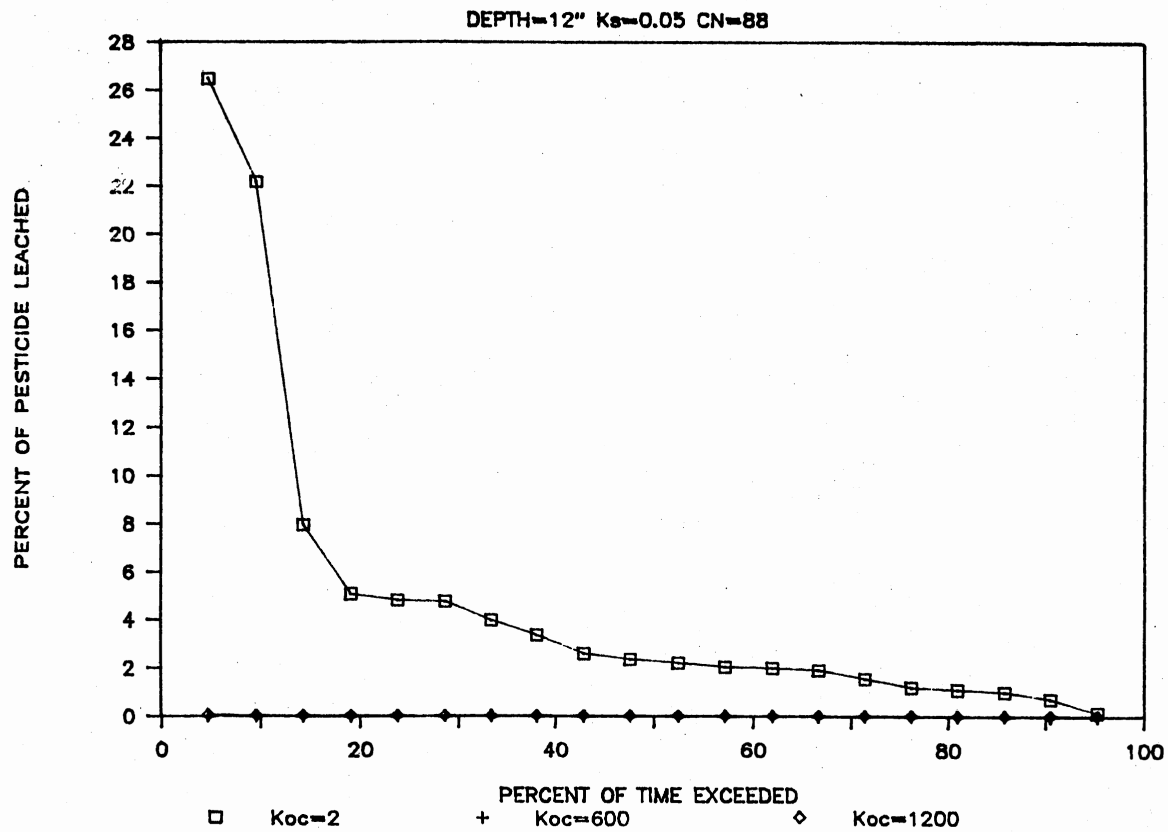


Figure 50 Probability of Leaching K_s=0.05, CN=73



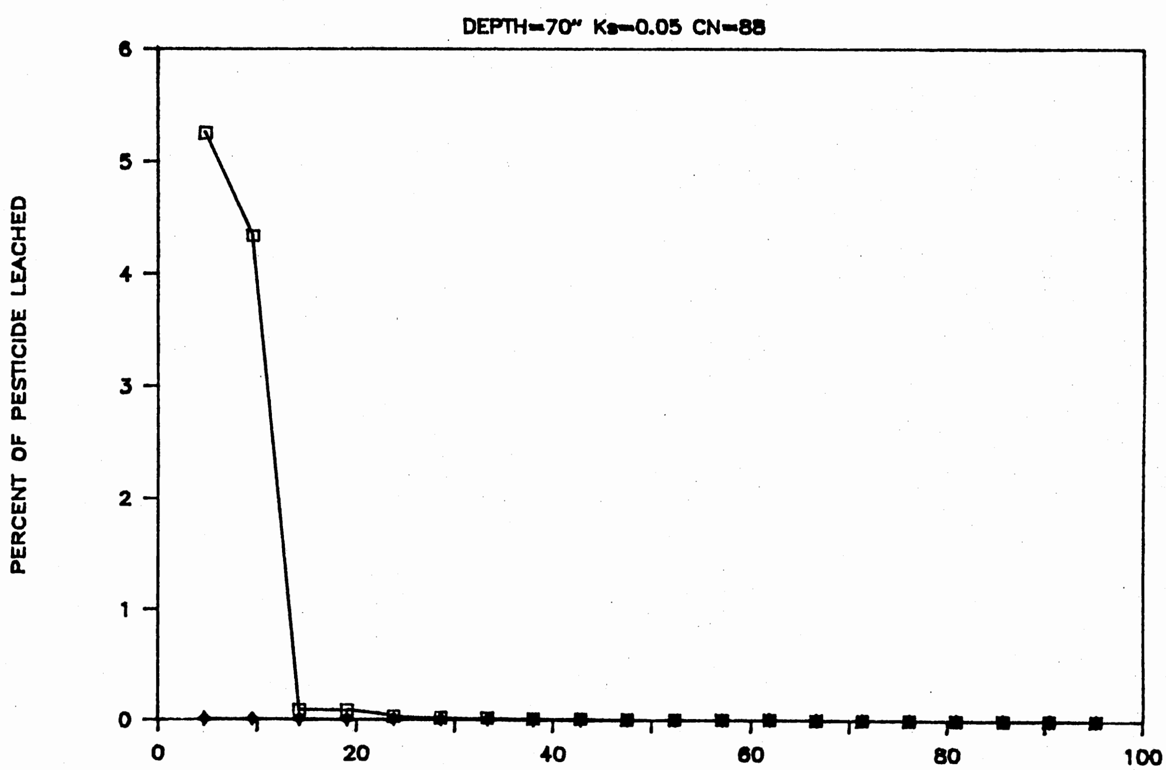
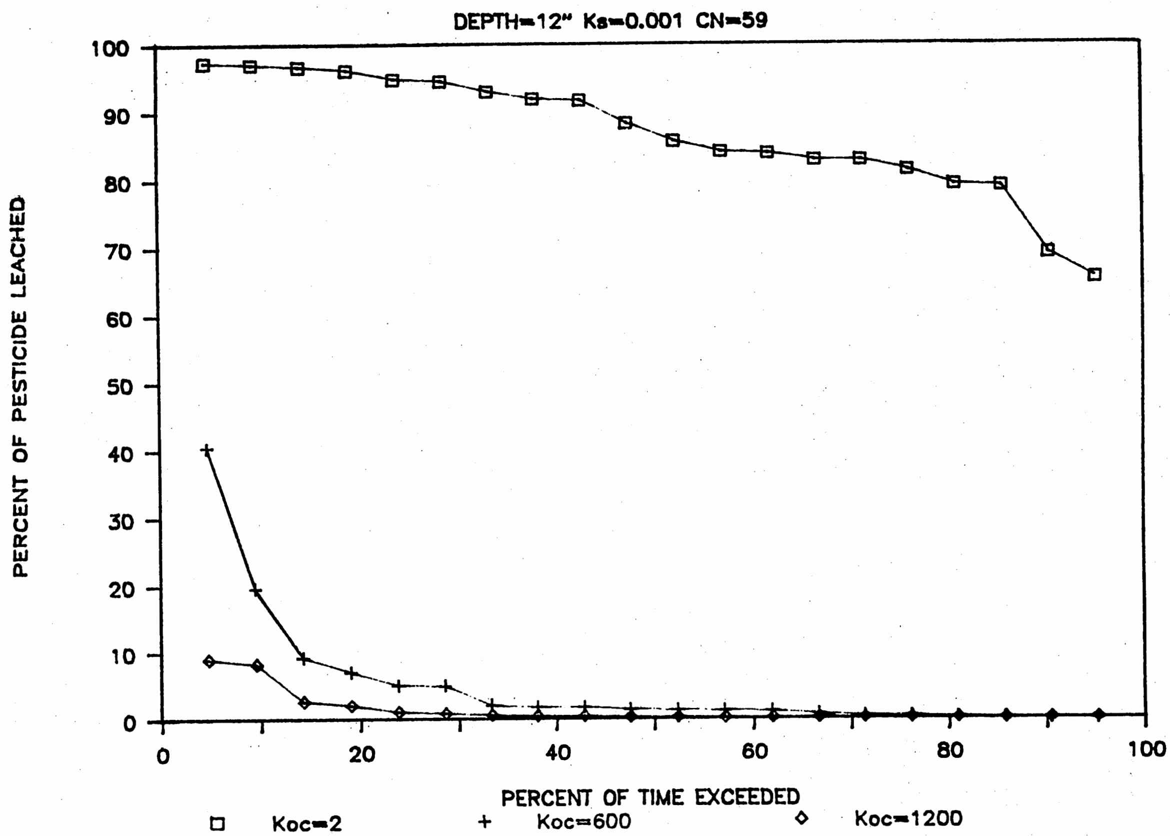


Figure 51. Probability of Leaching K_s=0.05, CN=88



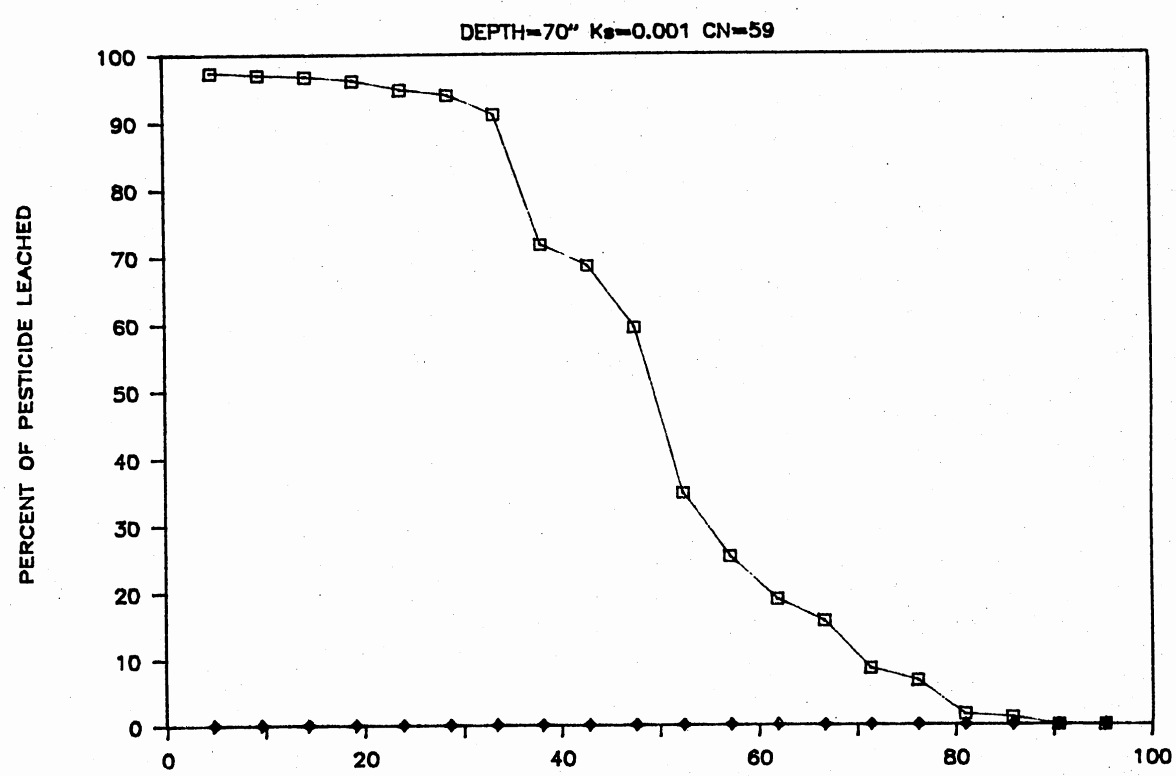
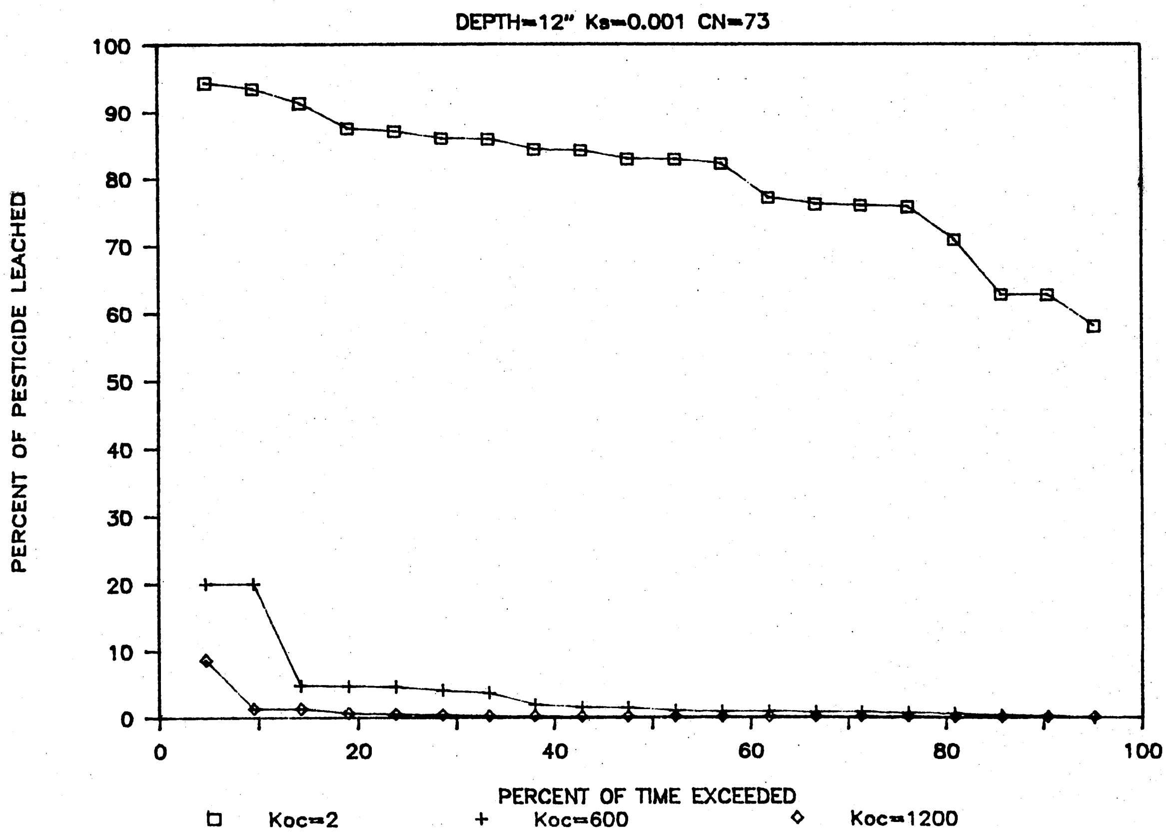


Figure 52. Probability of Leaching K_3=0.001, CN=59



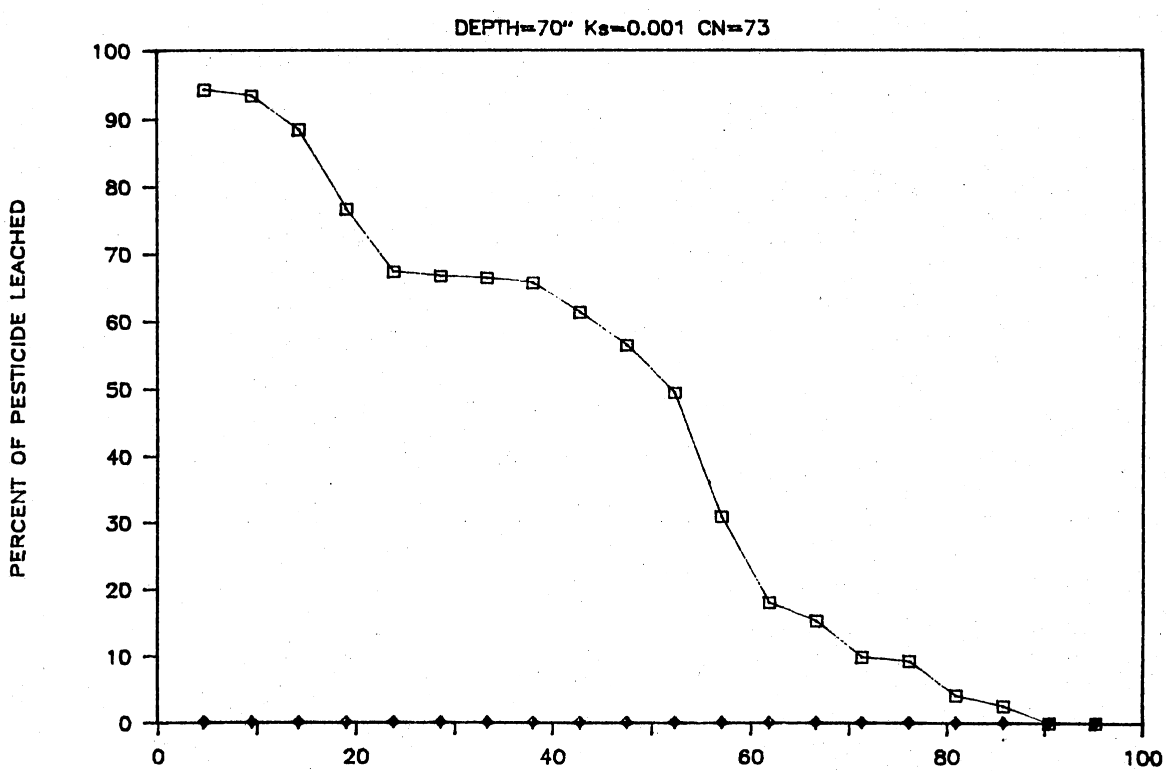
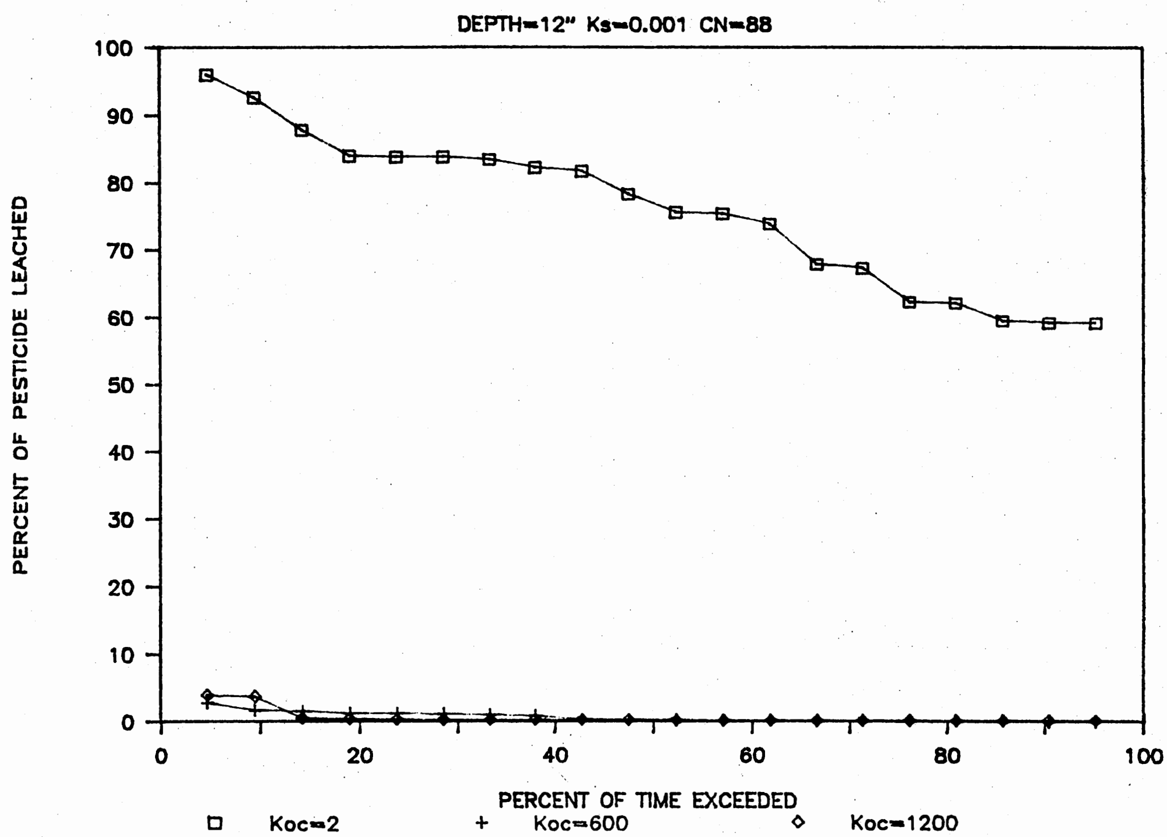


Figure 53. Probability of Leaching K_S=0.001, CN=73



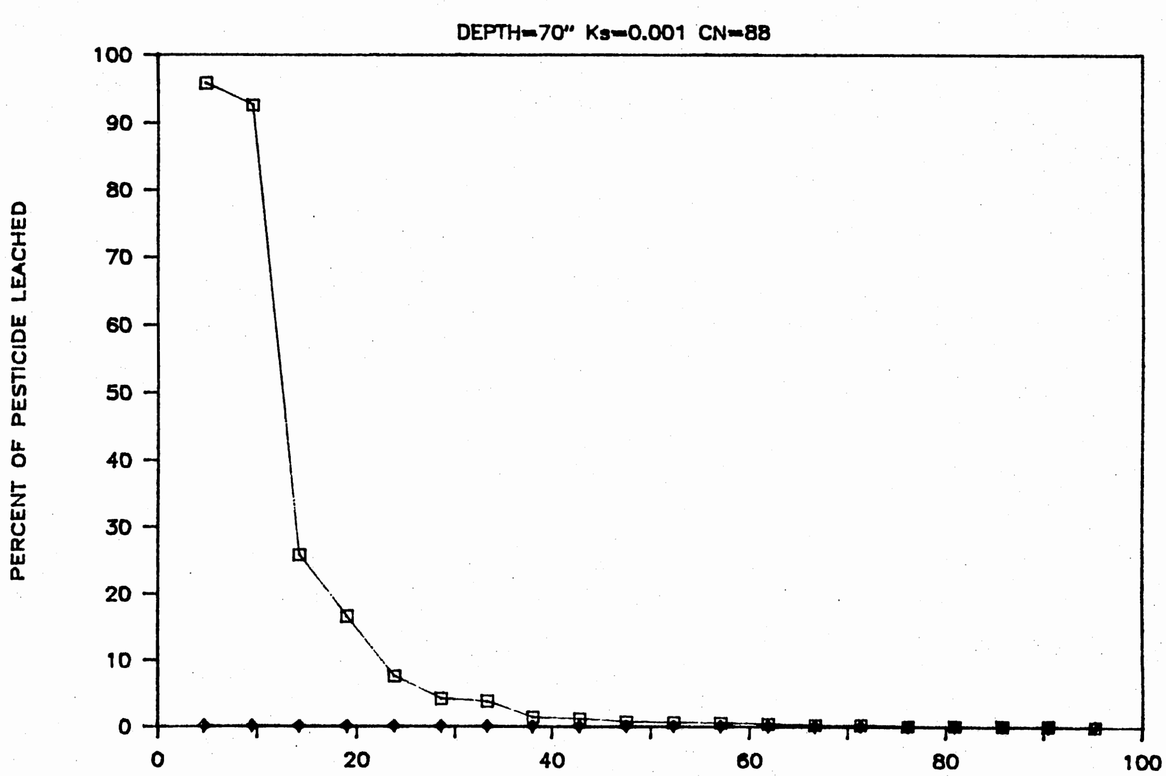


Figure 54. Probability of Leaching: K_s=0.001, CN=88

VITA 2

Barry Thomas Daniels

Candidate for the Degree of

Master of Science

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