AN EVALUATION OF GROUNDWATER CONTAMINATION UTILIZING SELECT UNCERTAINTIES ASSOCIATED WITH AGRICULTURAL CHEMICALS

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TABLE OF CONTENTS

Chapter Page

I. INTRODUCTION 1

Analysis Approach and Results 3
Summary 11

II. AN EVALUATION OF THE INFLUENCE OF IRRIGATION PRACTICES IN CONTROLLING AGRICULTURAL GROUNDWATER CONTAMINATION 12

Introduction 12
Experimental 15
Materials and Methods 19
Results 29
Discussion 49
Summary 55

REFERENCES 58

APPENDIXES 61

APPENDIX A - DATA INPUT 62

APPENDIX B - PRZM MODEL DESCRIPTION 66

APPENDIX C - AT123D MODEL DESCRIPTION 68

APPENDIX D - THREE DIMENSIONAL PLOTS OF PESTICIDE LOADING IN AN AQUIFER 69

APPENDIX E - AQUIFER CHEMICAL LOADING PARAMETERS 91

APPENDIX F - RAW DATA 94

LIST OF TABLES

Table Page

I. Summary of Results: Risk-Based Evaluation of Available Management Practices 9

II. Randomly Chosen Rainfall and Depth to Groundwater Records 22

III. Simulated Water Table Aquifer 25

IV. Annual Leaching Output at 12" [1 KG/HA/YR Applied] 33

V. Leaching Output at Depth to Groundwater [1 KG/HA/YR Applied] 34

VI. Pesticide Runoff for Various Irrigation Management Practices [1 KG/HA/YR Applied] 39

VII. Typical Pesticide Root Zone Model Simulation Output [1 KG/HA/YR Applied] 45

VIII. Typical Loading of Pesticide at Top of Aquifer (KG/HR) 48

LIST OF FIGURES

Figure Page

1. Leaching at 12" Depth Exceedance Probability 7

2. Leaching at Depth To Groundwater Exceedance Probability 7

3. Maximum Concentration at 12/31 Exceedance Probability 10

4. Affected Volume on 12/31 Exceedance Probability 10

5. Study Area 17

6. 75% Probability Plot of Leaching Concentration at 12" versus Total Number of Simulations 30

7. Pesticide Leaching Probability at 12" versus Concentration 32

8. Pesticide Leaching Probability at Depth to Groundwater versus Concentration 32

9. Probability of Peak Pesticide Concentration in an Aquifer 37

10. Probability of Affected Aquifer Volume Due to Leaching 37

11. Typical 3-D Plot of Pesticide Concentration Leached to an Aquifer vs. Time vs. Affected Volume for "No Irrigation" Simulation 41

12. Typical 3-D Plot of Pesticide Concentration Leached to an Aquifer vs. Time vs. Affected Volume for "Scientific Irrigation" Simulation 42

Figure Page

13. Typical 3-D Plot of Pesticide Concentration Leached to an Aquifer vs. Time vs. Affected Volume for "Traditional Irrigation" Simulation 43

CHAPTER I

Introduction *

Pesticide applications onto farm lands in the United States totaled approximately 260,000 tons in 1984 (OTA, 1984). In Oklahoma, these figures equaled almost four million pounds of active ingredients from the 20 most commonly used chemicals (Criswell, 1982). There is growing concern that some of these chemicals could leach to shallow groundwaters and offer significant risks to the ultimate users of these resources. Over 17 pesticides have been found in the groundwaters of 23 different states (USEPA, 1986). Concentrations ranging from 0.1 to 700 ppb of herbicides, insecticides, and nematocides have been identified in groundwaters monitored during these previous efforts. Monitoring for

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these chemicals may prove deficient, however, when attempts to evaluate previously untested alternatives to existing conditions are needed.

As an alternative to monitoring, simulation modeling has proven attractive. Various, previously untried alternatives can be evaluated in a relatively short time at lessened expense. The reported effort utilized a Monte Carlo simulation approach to address some of the uncertainties associated with pesticide transport to and within an aquifer system beneath Caddo County in southwestern Oklahoma. The agricultural base in this county is changing from dry land farming where pasture and winter wheat were the predominant farm types, to one based upon irrigation where a much wider range of crops can be grown. The question under investigation is whether this change to irrigation-based agriculture will increase the probabilities of groundwater contamination from the pesticides used.

The Monte Carlo method utilized in this effort repeatedly input randomly selected input data into a deterministic transport code to generate a series of separate but similar simulation outputs. These outputs were then pooled and arranged into probability density functions to define the probability that a given condition could occur. In this effort, the deterministic code selected for simulating pesticide transport to the top of the water table was the U.S. Environmental Protection Agency's (EPA) Pesticide Root Zone Model (PRZM) (Carsel et al., 1984), with the Oak Ridge National Laboratory's AT123D program used to model transport within the aquifer (Yeh, 1981). The distributions used to develop these series of input values were prepared from data available through various state and federal agencies.

Analysis Approach and Results

Input data describing soil and hydraulic features were randomly selected from distributions structured to address parameter correlations. These included soil organic matter, bulk density, wilting point, field capacity, depth to groundwater, and rainfall year. In addition, fixed variables such as pesticide decay and partitioning, as well as various cropping and tillage options, were also selected for sequential simulation trials. Pesticide selection was modeled using the partition and decay coefficients, Koc and Ks respectively, while cropping and tillage alterations were addressed by modifications to SCS curve numbers which are required by PRZM. These parameters were selected sequentially from a range of values consistent with those either practiced or possible for Caddo County, Oklahoma agriculture. The random parameters represented physical features which could occur anywhere within the study area while these fixed variables included management alternatives which would only vary in response to economic or environmental considerations. In this way, a risk-based, sequential evaluation of the effects of select management practices upon pesticide leaching and transport was attempted for all locations within the study area.

The rainfall record randomly selected for each annual simulation was unaltered for the base or non-irrigated conditions. For the "Traditionally" managed irrigation option, the equivalent of 7.5 acre-inches of additional water was added each month. This amount approximates that needed for corn growth in southwestern Oklahoma and as such represents an extreme value when compared to that needed for other crops (Nelson, 1988). This water was added throughout the growing season with no regard for the existing soil moisture. It often produced conditions of increased surface runoff due to pre-existing high soil water contents.

The "Scientifically" managed irrigation precipitation record was constructed by completing 25 years of daily soil moisture simulations. Whenever the simulated soil moisture decreased to 1.5 times the wilting point within the soil surface layers, additional water was added to bring these values back to field capacity. This data set was intended to approximate the irrigation record which would result if more sophisticated soil moisture monitoring techniques were employed.

Pesticide loads resulting from these simulations were then input into the 3-dimensional transport code to route the delivered chemical through the receiving aquifer. The annual loads to the aquifer previously generated by PRZM were not suitable for this task as a finer resolution of loading rates was needed. The simulations were repeated on a monthly basis to determine the appropriate temporal distributions of these materials at the top of the water table.

Probability density functions describing the mass of pesticide leached below the root zone as well as that delivered to the top of the water table were determined. The probabilities associated with peak pesticide concentrations within the aquifer and the aquifer volumes affected by the contaminant plumes were also determined. All three of these were done on an annual basis on the last day of each simulation year but comparisons to the maximum values simulated throughout the year were also completed.

Figure 1 (page 7) represents the pesticide leaching probabilities for all three irrigation options at twelve inches of soil depth. This was intended to approximate the shallowest root depth of the common crops currently grown within the study area. Any pesticide escaping this depth for shallow rooted crops would represent a waste into the environment and to the farmer who no longer derives economic utility from the chemical. This figure shows that on an annual basis, little difference would be expected in leaching potentials between the "No" irrigation and the "Traditionally" or "Scientifically" managed systems. Further, over 50% of the applied pesticide would be expected to leach to this depth or deeper 25% of the time. The upper portion of these and all subsequent curves results from a relatively minor number of simulations where almost 100% of the applied pesticide leached to the respective depth. These sections of the curves are assumed to be from different populations than those describing the rest of the distributions and result from a combination of low partition potentials, depressed decay properties and high rainfall years/seasons. When viewed in subsequent analysis at different depths or within the receiving aquifer these observations remain separate from the remainder of the data.

Figure 1

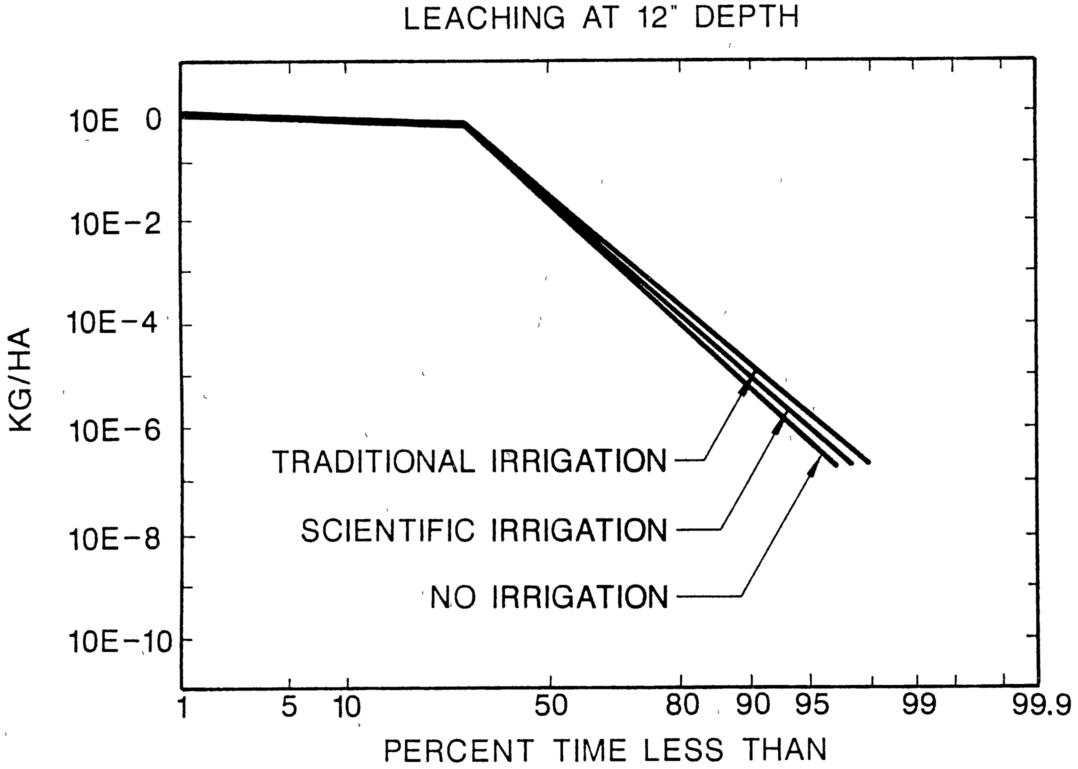


Figure 2

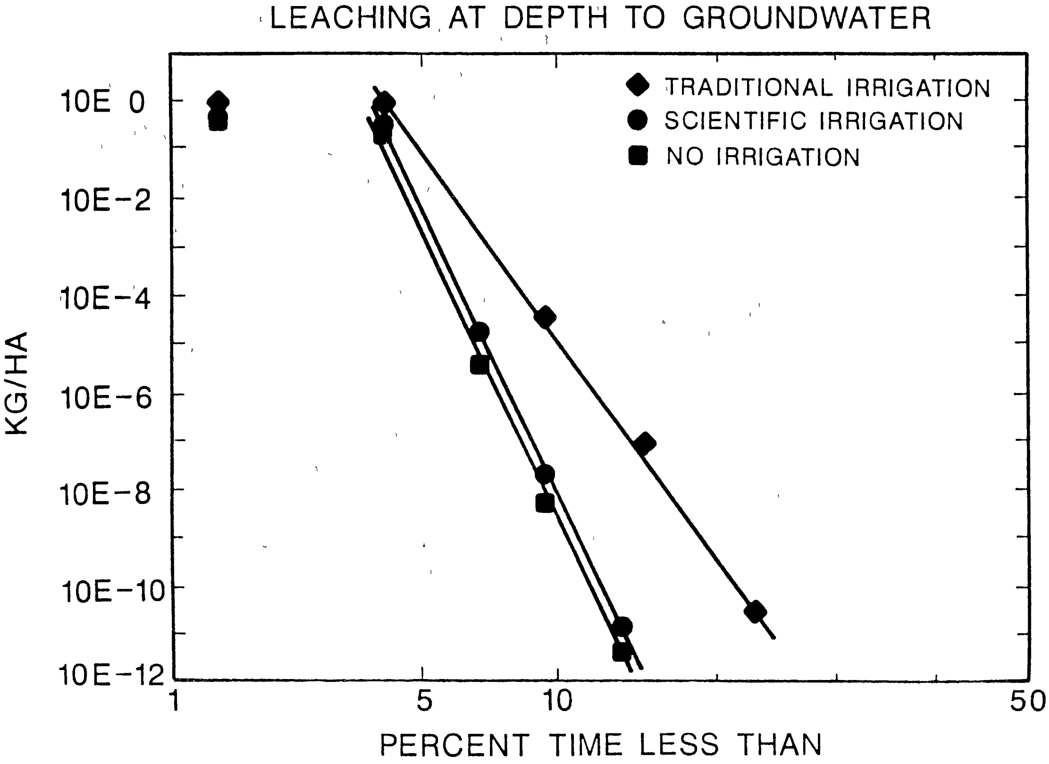


Figure 2 presents the same type of analysis but for the data describing annual leaching to groundwater. The "Traditionally" managed system exhibited a greater leaching potential than did the other systems. Table I (page 9) summarizes the simulations completed for this effort. Special emphasis was placed upon a comparison of the management variables available to control pesticide leaching. The information presented in this table indicated that the land based management options such as alterations in tillage or cropping practices had less effect upon the predicted pesticide leaching than did chemical selection while depth to groundwater, particularly for highly mobile pesticides, was a critical concern. This further implied that those management practices employed to minimize erosion and subsequent runoff based pollution should not prove mutually exclusive to parallel groundwater pollution control efforts.

Figures 3 and 4 (page 10) present the probabilities of peak pesticide concentration and affected aquifer volumes, respectively, for the three water management systems evaluated. These show that the "Traditional" system consistently generated greater contaminant levels than did either of the other two systems.

Table 1. Summary of Results:
Risk-Based Evaluation of Available Management Practices

Management Variable	Model Parameters	Ranges Utilized	Comments	Effects on Simulations
1. Pesticide	Partition Coef:Koc Decay Coef: Ks	0.001-600 0.0023-0.29	Manufacturer supplied	Leaching occurred with low Koc and Ks.
2. Crop and tillage selection	CN	67-91	SCS Handbook supplied	Leaching occurred for all CN's evaluated.
3. Site selection				
A. Depth to groundwater	Soil core	0-65 ft	USGS maps and water supply records	Leaching at detectable levels found no deeper than 26 feet.
B. Sandy soils	CN	67-91	Included in agromomic practice selection	Leaching to 65 feet (total depth).
4. Water Management Approach				
A. Dry land			Base Case	- - - - - - - - -
B. "Traditional" irrigation			Fixed water	Increased concentration peaks and affected areas.
C. "Scientific" irrigation			Soil Moisture driven	Approximately equivalent to dry land farming.

Figure 3

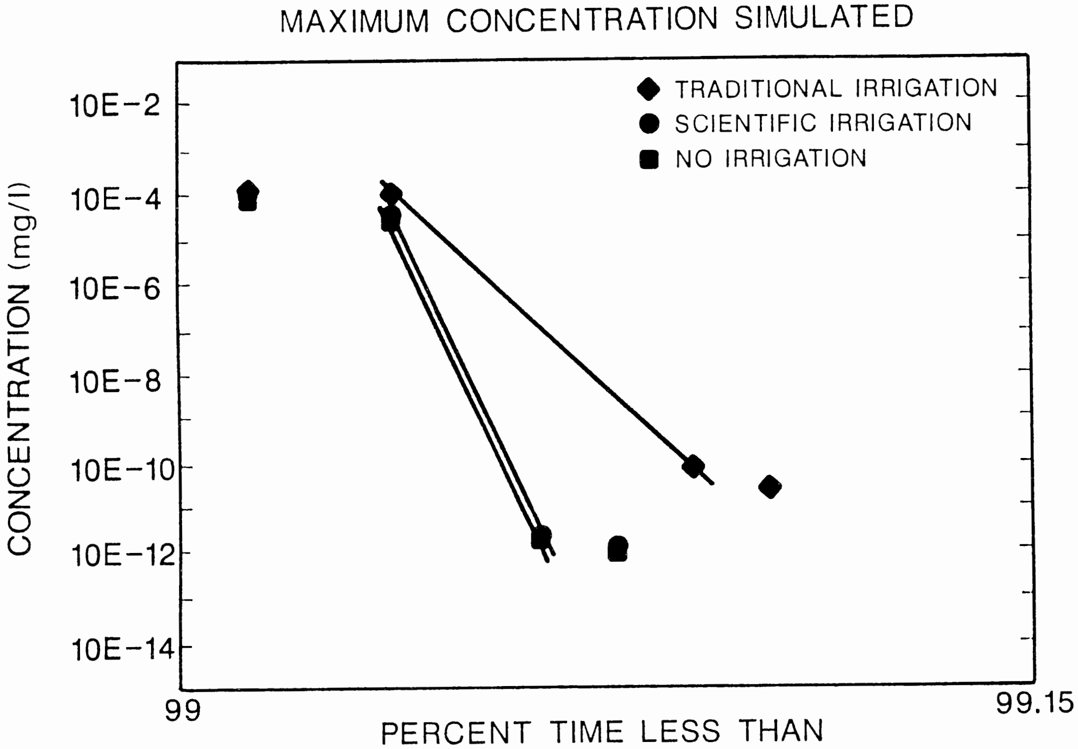
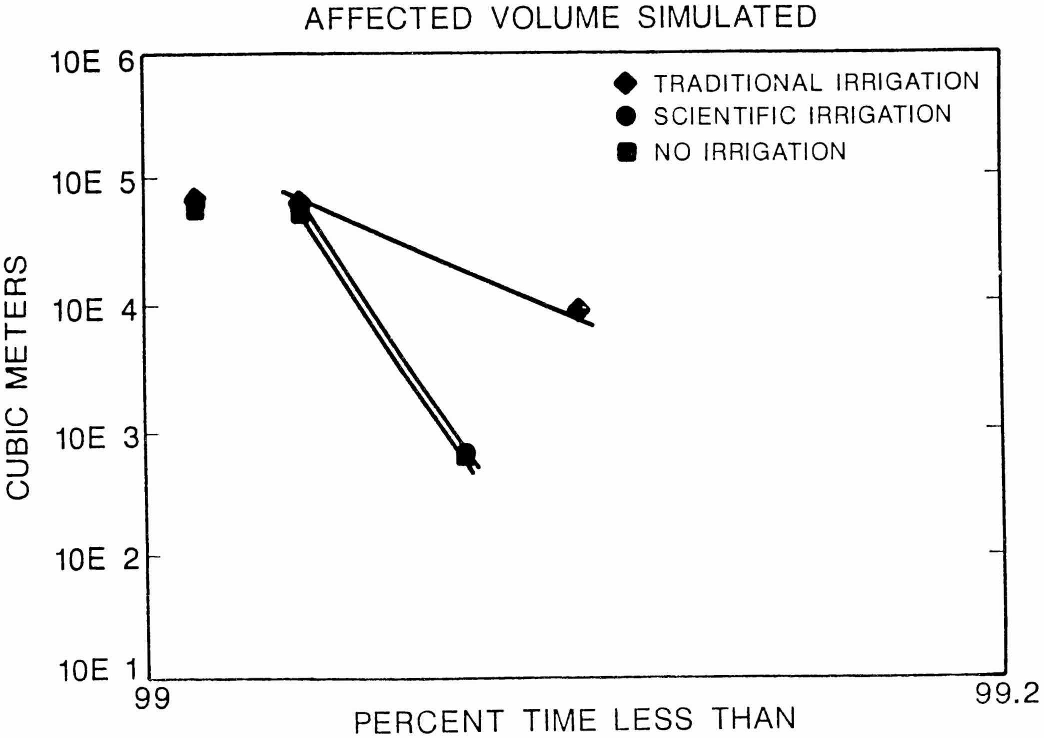


Figure 4



The amount of contamination indicated by this effort would appear best addressed by site specific analysis and regulation. The vast majority of the possible locations addressed by this effort exhibited poor probabilities of contamination.

Summary

A risk based evaluation of select management alternatives potentially available to control agricultural groundwater contamination from pesticides was completed for a single county in Oklahoma. This analysis indicated that pesticide selection as well as imprudent irrigation practices were more critical in allowing pesticides to leach to and transport in water table aquifers than were other alternatives available to the farmer. Not surprisingly, these findings were most severe in areas of extremely shallow water tables.

CHAPTER II

AN EVALUATION OF THE INFLUENCE OF IRRIGATION PRACTICES IN CONTROLLING AGRICULTURAL GROUNDWATER CONTAMINATION **

Introduction

The use of pesticides on agricultural crop land is a widespread practice in the United States resulting in a strong potential for groundwater contamination. In 1984, an estimated total of 260,000 tons of pesticides were used in the United States (OTA, 1984). Pesticide contamination of groundwater due to leaching from agricultural fields has been documented in 26 states and consisted of 46 different pesticides (Groundwater, 1989). In another survey 74 pesticides were found in the groundwaters of 38 states. At the time of this writing, the paths of these 74 contaminating pesticides were under investigation to determine the pollution attributable to agricultural leaching (USEAP, 1986a).

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In some cases, agricultural chemicals applied following World War II have taken over three decades to be detected. The effects of these chemicals on humans are still under investigation (Mott, 1986 and Connell, 1984). The detection of pesticides is due to increased environmental and public health concern and the advancement of technology to quantitatively distinguish specific materials. Many of these chemicals are not routinely monitored, indicating that groundwater contamination from pesticides may be more widespread and causing more damage than presently believed. Concentrations of chemicals in groundwaters which have been monitored have ranged from 0.1 to 700 parts per billion and consist of herbicides, insecticides and nematocides (Mott, 1986 and USEPA, 1986b).

In Oklahoma, according to the most recently available annual survey, almost four million pounds of active ingredients from the 20 most commonly used chemicals were applied (Criswell, 1982). The pollution of Oklahoma's groundwater from these chemicals may be occurring although undetected, due to a lack of monitoring data. Even with proper monitoring the possibility of contamination of aquifers due to future chemical migration through the vadose zone is not routinely evaluated.

Contamination of groundwater by pesticide leaching is influenced by the pesticide characteristics and site specific conditions. Contributing factors include the pesticide's solubility, sorptive properties and soil persistence combined with site specific conditions which include soil properties, climatic conditions, crop type, application method, depth to groundwater and irrigation procedures (USEPA, 1986a and Carsel, 1984).

A chemical may not reach groundwater for months or years, but when it does, it may have the potential to pollute a major drinking water source and subsequently affect a significant population. The leaching of pesticides into water consumed by humans may pose a risk if a toxic or carcinogenic substance is sufficiently mobile to provide long term exposures to a significant number of individuals. An example of this type of incident occurred in California due to contamination from DBCP (Mott, 1986). In 1979, DBCP (Dibromochloropropane), which had been linked to cancer, birth defects and other maladies, was discovered in wells throughout California's Central Valley. Forty wells were known to be contaminated in 1979. In 1986, water from 1,473 wells exceeded the action level and was unsuited for drinking, cooking or bathing. Other nematocides, such as ethylene dibromide (EDB) and 1,2-D have also forced the closure of public water supplies in that state.

Groundwater provides the sole or chief drinking water source for over 95% of the nation's rural residents and 67% of Oklahoma's water uses (Pettyjohn, 1983 and Sun, 1986). Realizing the effects of groundwater pollution, the Oklahoma Water Resources Board recently established a "clear" zone around municipal supply wells in an effort to prevent contamination of potable groundwater and subsequent contamination of the consuming public (EPA, 1986).

The United States Environmental Protection Agency (EPA) has used computer modeling to predict pesticide contamination on a national level by applying Monte Carlo simulation techniques to evaluate the risk of aldecarb leaching. A national ban of the chemical had been suggested and evaluated in this manner as acceptable monitoring data were unavailable (USEPA, 1986a, Carsel, 1988 and Lewis, 1989). A similar effort was undertaken at the regional level in Oklahoma, where it was found that 55% of all agricultural pesticides would leach to six (6) feet or more 4% of the time (Daniels, 1988).

Experimental

The question under investigation by this paper is whether a change to irrigation based agriculture will increase the probabilities of groundwater and surface water contamination from the chemicals used. This effort also employed a Monte Carlo computer simulation technique and evaluated not only the probabilities for agricultural pesticide leaching at a county level, but also the effects of irrigation management on the transport of pesticides through soil. This study resulted in a methodology which was capable of determining the groundwater contamination potential of a pesticide as it relates to various irrigation practices.

The contamination potential of a chemical as it relates to irrigation practices becomes important in such places as the study area, Caddo County, Oklahoma, where, in an effort to make cash crops more profitable, irrigation has often been installed (USDA, 1973 and Saffigna, 1977). Caddo County is located in west-central Oklahoma, has an area of approximately 808,320 acres, and derives the major part of its income from the sale of crops such as peanuts, wheat, cotton, grain sorghum and hay. In a recent survey the study area (shown in Figure 5) contained 1,000 farms with irrigation potential comprising a total of 75,000 acres of land (Kizer, 1985). In 1985, 950 of these farms used irrigation on a total of 62,735 acres. Ninety-nine percent of the farms with irrigation potential located in the study area employed sprinkler systems with 90%

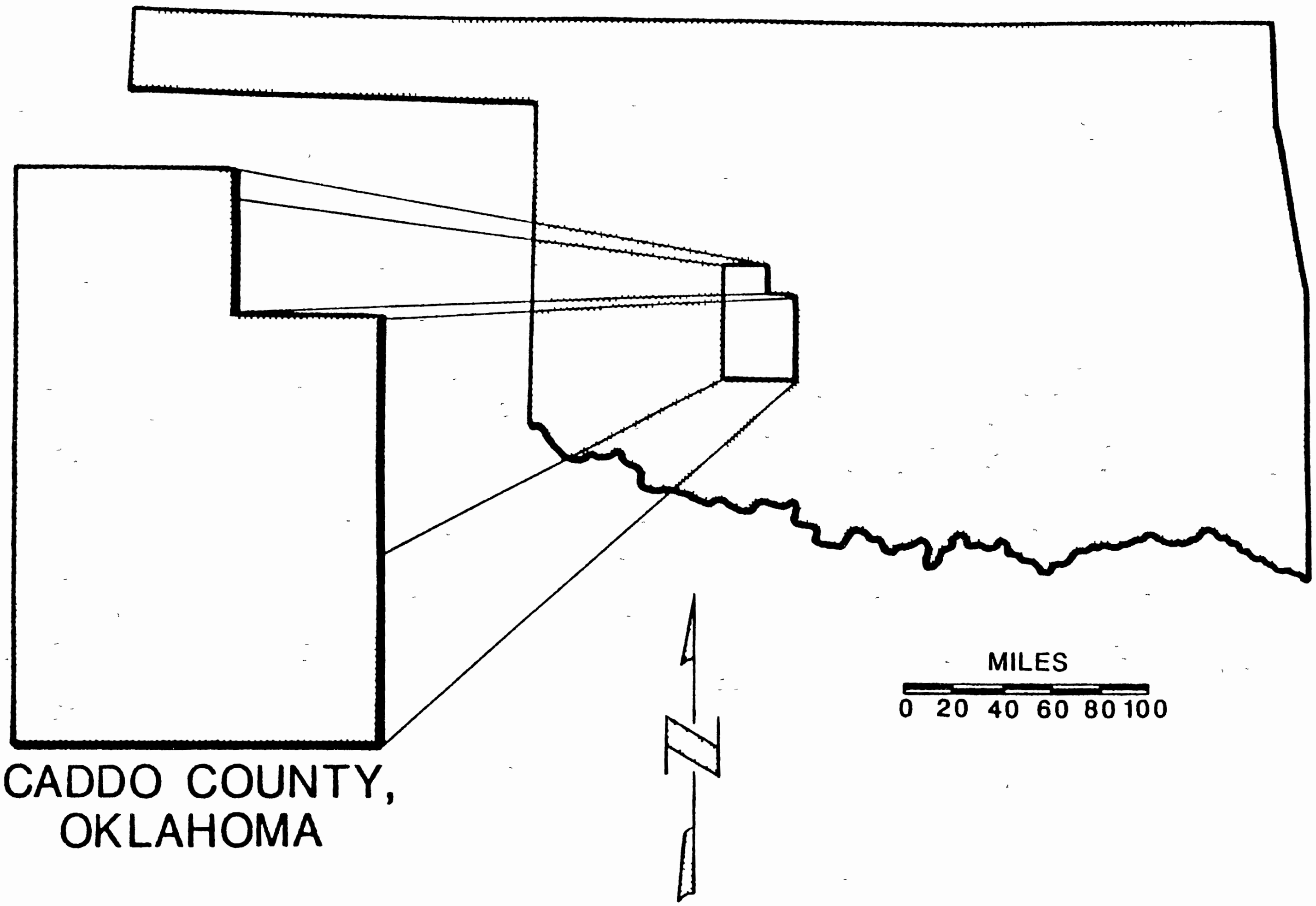


Figure 5 - Base Map of Caddo County, Oklahoma Study Area

of the land irrigated utilizing groundwater. Irrigation in Caddo County, Oklahoma, used an estimated 82,000 acre feet of water in 1979 which constituted 88% of all municipal and irrigation water used in the county (Pettyjohn, 1984).

Simulation of the irrigation systems used in Caddo County included a method where water was regularly added regardless of soil or climatic conditions, as well as a scientific approach that applied water based on soil moisture. The simpler of these approaches is often employed as an irrigation practice and is referred to as "Traditional" in this effort while the evaluations based upon soil moisture condition are called "Scientific". This latter approach parallels a system where soil moisture probes would trigger irrigation demand. As water is the driving force in the leaching of pesticides, it was determined that three distinct sets of conditions should be analyzed in this effort to address the possibility of pesticides leaching in the study area: (1) normal rainfall events, (2) traditional irrigation approaches and (3) scientific irrigation approaches. The simulations completed for the normal rainfall events served as a base case for comparison with the traditional and scientific irrigation approaches.

The use of the Monte Carlo computer simulation techniques coupled with the normal rainfall records and with the subsequent replacement of these rainfall records with data which simulated traditional and scientific irrigation resulted in a methodology which directly indicated the amount of additional contaminant driven into the groundwater due to these changes in management practices (traditional irrigation versus non-irrigation versus scientific irrigation). The effects of these management practices on the amount of contaminant driven into the water table aquifer were shown to be significant when management utilized highly mobile pesticides with low partition and decay coefficients in areas of shallow water tables.

Materials and Methods

To evaluate the effects of irrigation practices on pesticide leaching while keeping within an acceptable time frame, a dynamic computer model capable of simulating chemical movement within and below the root zone was required. A Monte Carlo simulation technique was employed for selection of input data into a model which simulated agricultural infiltration and transport one dimensionally within the vadose zone and subsequently for input into a saturated zone code. The vadose model simulated a one time application of pesticide with leaching depth limited by the random variable, depth to groundwater. Data from these simulations were used in a saturated zone model to provide simulations of pesticide movement/transport within an underlying aquifer.

The input file for the vadose zone model provided random selection of soil organic matter, bulk density, wilting point, field capacity and depth to groundwater, with values randomly selected from distributions constructed to address site specific parameter correlations. Combining these values with selected fixed variables such as pesticide decay, partition coefficients, and various cropping and tillage options allowed sequential simulation. The data were then applied with a randomly selected precipitation record maintained by the nearest Type 1 meterological station of the U.S. Weather Bureau. A single annual rainfall period was selected from a twenty five year record for each individual simulation.

The Monte Carlo simulation resulted in the full range of rainfall records being accessed with the depth to groundwater simulated ranging from approximately 2 feet to almost 66 feet, indicating a wide range of conditions evaluated. These depths were randomly accessed from a normal distribution function used to describe depth to water table in Caddo County, Oklahoma.

The actual depths to water table used to develop this distribution were obtained from U.S. Geological Data.

Soils simulated ranged from free draining (type 'A') with a Curve Number (CN) of 67 to fairly impermeable soils (type 'D') with a Curve Number of 91. The degradation rate constant per day, Ks, was chosen to be either 0.0023 (Benomyl) or 0.2961 (Parathion) thus bracketing the range of chemicals used in the project area. This spectrum of Ks provided for interpolation of almost any given Ks, and thus allowed for a range of chemicals to be evaluated. Likewise, the organic carbon distribution coefficient, Koc, was chosen to be 0.001 (MSMA), 2.0 (Dicamba) or 600.0 (Phorate) to provide upper and lower limits of pesticide solubility to be taken into consideration.

The large number of simulations were grouped into the 12 data sets shown in Table II (page 22) for ease of comparison. These data sets were based on various combinations of similar fixed input parameters consisting of curve numbers, partition and decay properties. The ranges of "Rainfall Year" and "Depth to Groundwater" simulated for each data set are also shown in Table II and are sufficient to provide plausible results (See Appendix A for data input).

Output from the vadose zone simulation using the

TABLE II

RANDOMLY CHOSEN RAINFALL AND DEPTH TO GROUNDWATER RECORDS

DATA SET	DEGRADATION RATE/ DAY KS	ORGANIC CARBON DISTRIBUTION KOC	CN	RAINFALL YEAR		DEPTH TO GROUNDWATER (INCHES)	
				MIN.	MAX.	MIN.	MAX.
1	0.2961	600	91	1955	1977	14	702
2	0.0023	600	91	1954	1969	109	762
3	0.0023	0.001	91	1957	1970	22	698
4	0.0023	2	91	1955	1976	205	740
5	0.2961	2	91	1955	1975	145	705
6	0.2961	0.001	91	1956	1976	22	755
7	0.2961	600	67	1954	1978	41	776
8	0.0023	600	67	1955	1974	35	696
9	0.0023	0.001	67	1960	1978	104	767
10	0.0023	2	67	1954	1977	91	723
11	0.2961	2	67	1957	1973	60	771
12	0.2961	0.001	67	1955	1978	20	770

randomly accessed data was repeated until a plot of the 75% probability value versus the number of simulations asymptoted to a relatively constant value. At that point the exercise had achieved an acceptable level of precision as additional simulations had little or no affect on the asymptoted value.

Subsequently, similar simulations were completed following the editing of the meterological input data file in an effort to simulate a traditional irrigation practice. These simulations were accomplished by providing an additional after planting water volume of 7.5 acre-inches of water per month to the original precipitation data set. This additional water was added at a rate of 2.5 inches every ten days during the growth season and approximates that required for corn (Nelson, 1988). This represented an extreme value when compared to that needed for most other crops (USDA, 1985).

The set was simulated a third time after replacing the meterological input data with scientifically managed irrigation data. The development of the scientifically managed irrigation data entailed an initial 9,000 daily simulations to develop appropriate soil moisture distributions. The amount of moisture added was then coupled with the initial meterological moisture data and recomputed to derive the final 25 year meterological record. Whenever the simulated soil moisture decreased to 1.5 times the wilting point within the surface layer, additional water was added to bring the value back to field capacity (Elliot, 1987). This recomputed meterological record was subsequently used to simulate an irrigation method utilizing a sophisticated soil moisture monitoring system.

In an effort to simulate the extremes of crops which have the potential of being grown within the study area if irrigation was feasible, pesticide leaching simulations at 12 inches were performed. This simulated the amount of pesticide leaching past the shallowest root depth expected for a crop grown within the study area. Root depth simulated by the pesticide root zone model was set at 31 inches (80 cm) which approximated that of corn, a heavy water user. This simulated a maximum uptake of the pesticide by the crop and thus reduced the amounts of pesticides available for leaching to groundwater. Correspondingly, the values of pesticide leached at depth to groundwater were minimum simulated values and were expected to increase with reduced plant uptake. Application of the pesticide was on May 1 with a crop emergence 10 days later and harvest in October. These values were reasonable for a large range of crops (from wheat to corn) and allowed conservative estimates of pesticide leaching to groundwater (Carsel, 1984).

Pesticide leaching at 12 inches also illustrated the potential amount of wasted pesticide due to over application. Pesticide leaching at the random variable, depth to groundwater, simulated the amount of contaminant potentially entering the water table aquifer. Probability density functions describing the mass of pesticide leached below twelve inches as well as that delivered to the top of the water table were determined for each of the three rainfall records. All outputs which indicated leaching to groundwater from these three data sets were then sorted and isolated from the non-leaching output data sets. Information obtained from the output files of the leaching data were subsequently input to a saturated zone code.

The saturated zone model was constructed to simulate a single non-changing water table aquifer within the study area. Parameters for this model were shown in Table III. This model was used to determine the contaminant concentration, transport and subsequent contaminated volume within a simulated water table aquifer with respect to time (Garner, 1988 and Yeh, 1981). These output data were required for the use of comparison against existing standards and criteria.

TABLE III

SIMULATED WATER TABLE AQUIFER

Parameter	Value	
Porosity	15%	
Hydraulic Gradient	0.0034	
Hydraulic Conductivity per hour	0.591 ft	0.18 meters
Longitudinal Dispersion	33 ft	10 meters
Transverse Dispersion	3.3 ft	1 meter
Vertical Dispersion	3.3 ft	1 meter
Thickness	33 ft	10 meters
Width	infinite	
Length	infinite	

Output from the saturated zone code, utilizing the yearly chemical load data from the vadose zone model, indicated that only those simulations leaching from the vadose zone in excess of 1E-12 kilogram per hectare could realistically be detected and therefore be expected to pose a threat if consumed from the simulated underlying water table aquifer. Monthly chemical load data was subsequently developed for all simulations leaching in excess of 1E-12 kilograms per hectare. The probabilities associated with peak pesticide concentrations within the simulated aquifer and the aquifer volumes affected by the contaminant plumes were also determined. All three irrigation simulations were performed on an annual basis on the last day of each simulation year, but comparisons to the maximum values simulated throughout the year were also completed.

Pesticide transport in surface runoff was also evaluated for the three trial practices. A comparison of these three management approaches was necessary to address mass balances for the pesticides. As all simulations used unit application rates of 1 kilogram per hectare (Kg/Ha), a significant difference in the amount of pesticide leached should be accompanied by an equivalent difference in one or more of the pesticide partition compartments available. Special emphasis was placed upon a comparison of the management variables available to control pesticide leaching and transport.

To provide better differentiation of the concentration delivered to the water table, all output files from the vadose zone model which indicated chemical leaching to groundwater in excess of 1E-12 kilogram were rerun utilizing a monthly output step. This entailed reviewing over 220 annual simulations to determine the leaching concentrations exiting the deepest simulation compartment. Of these, 99 indicated leaching to groundwater with 33 having annual concentrations which warranted re-simulation to obtain monthly output data. Contaminant loads were obtained from the 33 simulations by reviewing each simulation on a monthly basis and extracting the leachate concentration exiting the lowest compartment simulated.

Contaminant loads which escaped the bottom compartment of the vadose zone model into the water table were subsequently input as monthly data into the saturated zone code. The saturated zone code simulated the movement/transport of the pesticide three dimensionally with respect to time within the underlying water table and provided monthly spatial, temporal and concentration distributions within the aquifer. Three dimensional graphic representations of these outputs were constructed to allow ready interpretation of the effects of the various water management techniques on the pesticide concentrations found in the example aquifer.

The EPA's Pesticide Root Zone Model (PRZM) (See Appendix B) was chosen as the vadose zone model for this effort as it has been shown to effectively represent the primary processes controlling pesticide movement to groundwater (Carsel, 1984, Melancon, 1986 and Hern, 1986). PRZM has been used on a national and regional scale, and is accepted within industry and EPA. PRZM is a one dimensional model which, when coupled with the Monte Carlo simulation techniques has given satisfactory results while using data which are generally available (Hern, 1986). The Oak Ridge National Laboratory's AT123D was chosen as the saturated zone code model due to its three dimensional infinite reservoir modeling capabilities and its ability to handle pulse contaminant loads (Yeh, 1981) (See Appendix C). Results of the AT123D saturated zone code were graphically displayed using Golden Software's Surfer package (Version 3.00) due to its personal computer applicability and three dimensional graphics capability (Golden, 1987).

Results

The 75% probability plot of leaching concentration at 12" versus the total number of simulations began to asymptote at approximately 40 simulations. This was shown in Figure 6 (page 30) and indicated a sufficient number of simulations had been performed to obtain a representative leaching value with a 75% confidence level. Figure 6 showed that the 75th percentile leaching concentration from 40 to 220 simulations remained relatively constant and never exceeded 0.001 kilogram/hectare (kg/ha). It should be noted that the pesticide root zone model maintained a mass balance of the simulated system, thus ensuring numerical accuracy of the leaching values obtained.

The "Traditional Irrigation" simulations utilized the largest volumes of water as they added 7.5 acre inches of additional water to the base case ("No Irrigation") every month during the growing season (June 1 through mid August). These were followed by "Scientific Irrigation" which added water during the growing season as necessary, based on field capacity and wilting point. "No Irrigation" was established as the base case and had the least amount of water present as it accessed a meterological data file constructed of only natural rainfall amounts measured in the area.

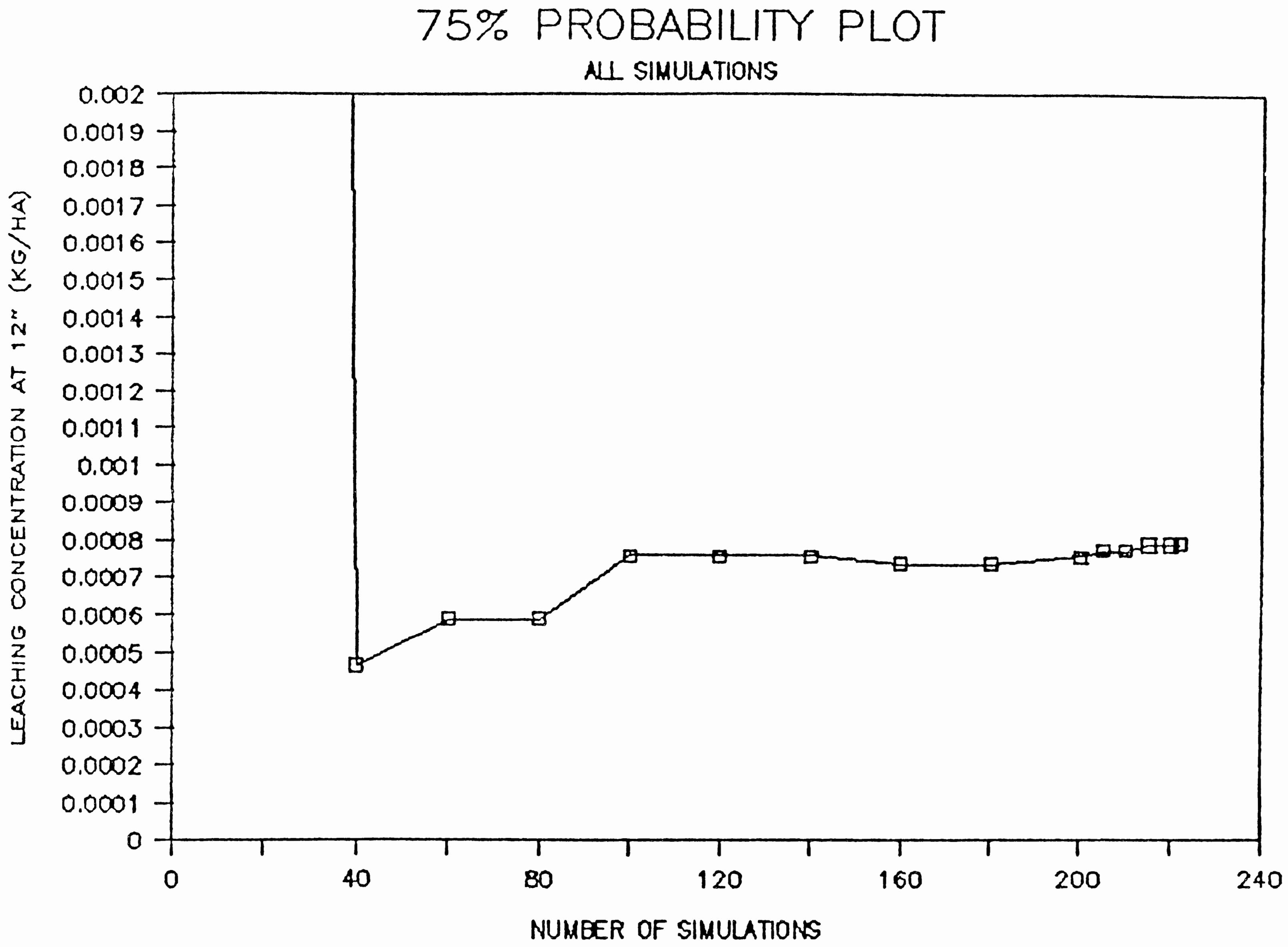


Figure 6 - 75% Probability Plot

These data were compared further in Tables IV-VI for additional analysis.

Pesticide leaching probabilities for all three irrigation options at twelve inches of soil depth are shown in Figure 7 (page 32). As can be observed the "Traditional Irrigation" simulation had a higher probability of pesticide leaching beyond 12 inches than did the "Scientific Irrigation" or "No Irrigation" management practices. The similar slope and close plotting proximity of these data indicate similar leaching characteristics for all three methods at 12 inches of depth. The amount of pesticide leachate observed at the 12 inch depth represented an over application of pesticide for the shallow rooted plants which might be feasibly grown in the study area. Leachate beyond the simulated root zone depth, or below the plant's maximum depth for utilization of pesticide uptake represents a potential contaminant to any underlying aquifers in the area.

Pesticide leaching at a depth of 12 inches for each of the three types of simulations is shown in Table IV (page 33). This Table shows the minimum and maximum leaching output for each of the twelve data sets for each of the three types of water management practices simulated. A general increase in pesticide leaching was observed for the low runoff soils (data sets 7

Figure 7

LEACHING AT 12" DEPTH

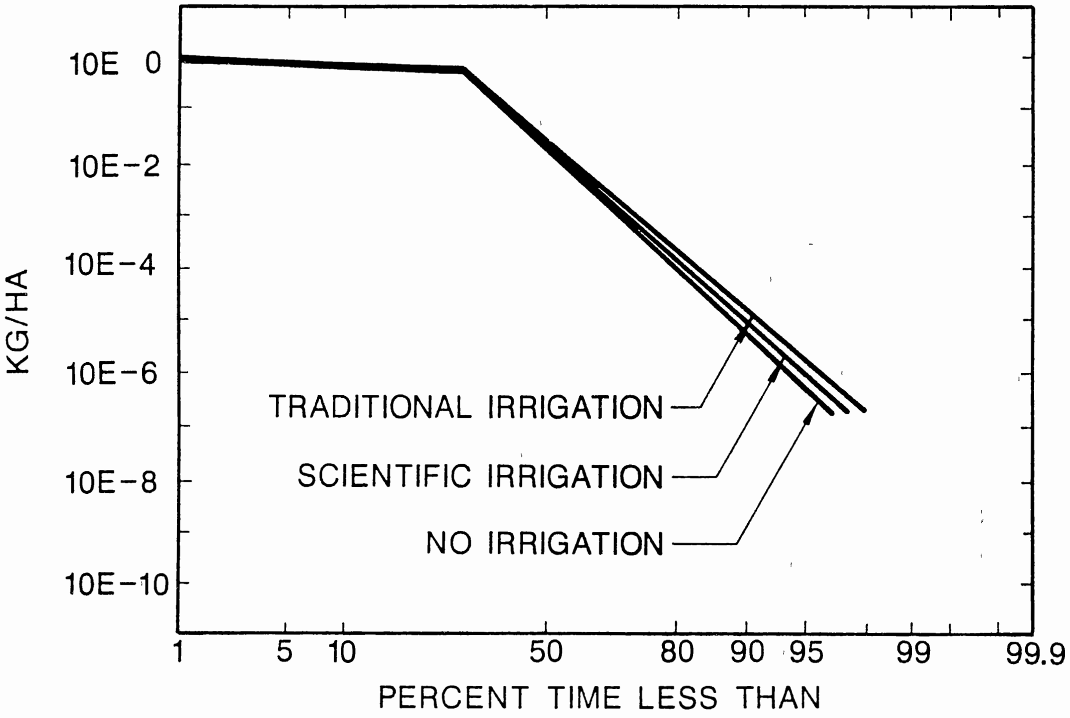


Figure 8

LEACHING AT DEPTH TO GROUNDWATER

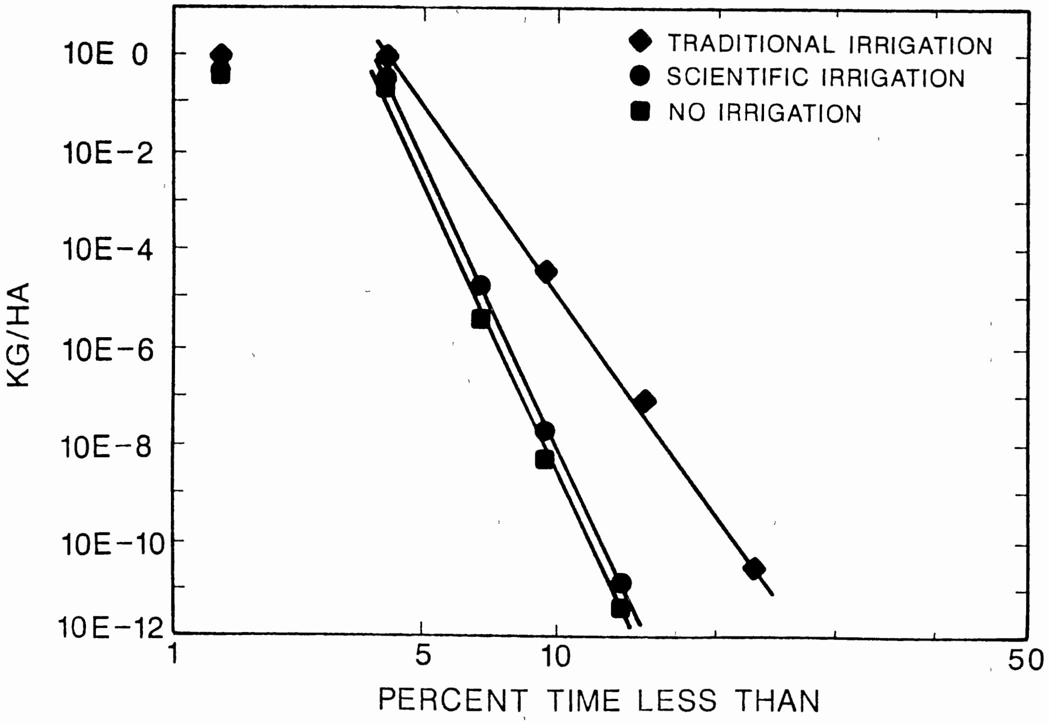


TABLE IV

ANNUAL LEACHING OUTPUT AT 12" [1 KG/HA/YR APPLIED]

DATA	(BASE CASE) NO IRRIGATION LEACHING OUTPUT (KG/HA)		TRADITIONAL IRRIGATION LEACHING OUTPUT (KG/HA)		SCIENTIFIC IRRIGATION LEACHING OUTPUT (KG/HA)	
SET	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.
1	3.8E-10	2.4E-3	1.1E-9	2.4E-3	6.0E-10	4.4E-2
2	2.3E-2	3.9E-1	3.8E-2	3.6E-1	2.7E-2	4.2E-1
3	3.1E-1	8.9E-1	2.8E-1	9.2E-1	3.4E-1	9.1E-1
4	2.7E-1	4.9E-1	2.3E-1	4.7E-1	2.7E-1	4.2E-1
5	0	5.0E-2	6.5E-6	5.0E-2	1.5E-5	5.0E-2
6	3.6E-4	2.1E-2	3.5E-4	2.1E-2	6.5E-4	2.1E-2
7	4.8E-5	3.1E-3	5.0E-5	3.1E-3	4.8E-5	3.1E-3
8	3.6E-7	6.1E-2	6.0E-5	1.1E-1	6.8E-7	6.4E-2
9	6.9E-1	9.0E-1	7.8E-1	8.8E-1	7.1E-1	9.2E-1
10	5.2E-1	8.2E-1	7.4E-1	8.9E-1	7.0E-1	8.4E-1
11	1.1E-3	1.4E-1	1.2E-3	1.4E-1	5.4E-3	1.4E-1
12	5.9E-4	1.3E-1	3.6E-4	1.3E-1	6.9E-4	1.3E-1

through 12) with the addition of more irrigation water. This is shown later in Table VI, and by comparing the values in the middle column of Table IV (Traditional Irrigation Leaching Output) to the other two columns. The exceptions to the trend of increased pesticide leaching with increased water volume for the high runoff soils appeared to be due to the higher percentage of pesticide runoff thus leaving less pesticide on site

TABLE V

LEACHING OUTPUT AT DEPTH TO GROUNDWATER [1 KG/HA/YR APPLIED]

DATA SET	(BASE CASE) NO IRRIGATION LEACHING OUTPUT (KG/HA) MIN.	MAX.	TRADITIONAL IRRIGATION LEACHING OUTPUT (KG/HA) MIN.	MAX.	SCIENTIFIC IRRIGATION LEACHING OUTPUT (KG/HA) MIN.	MAX.
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	5.3E-1	0	8.7E-1	0	7.7E-1
4	0	2.2E-11	0	2.8E-7	0	5.1E-11
5	0	0	0	0	0	0
6	0	6.6E-4	0	1.5E-5	0	6.7E-4
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	2.4E-1	0	8.1E-1	0	4.0E-1
10	0	1.6E-1	0	8.4E-1	0	3.6E-1
11	0	0	0	7.6E-11	0	0
12	0	0	0	5.1E-10	0	0

available for leaching.

The leaching at depth to groundwater, Table V generally increased with the addition of water, in a similar fashion to the 12 inch data set. The exceptions were again accounted for by considering the high runoff of pesticide in the "Traditionally Irrigated" simulations versus the lower runoff experienced with the other two simulations. Of importance also is the fact that pesticides with high partition or decay coefficients were generally not delivered to the depths necessary to intercept the water table aquifers simulated in this effort regardless of the water management approach practiced. This is observed by comparing the data sets from Table V which indicated no leaching, to the corresponding data with their associated simulation criteria shown in Table II (page 22). Of the five data sets (#1,2,5,7,8) from Table V which did not leach utilizing the "Traditional" irrigation simulation data files, four had high Koc's and Ks's. Of the seven data sets (#1,2,5,7,8,11,12) which did not leach utilizing the "No" or "Scientific" irrigation simulation data files, only four had high Koc's, however six of the seven non-leaching data sets simulated pesticides with high degradation constants.

Pesticide leaching probabilities for all three irrigation options at the randomly accessed variable "depth to groundwater" were presented in Figure 8 (page 32). As can be observed from this Figure, most combinations of the fixed and variable input data resulted in conditions which did not leach to groundwater. Only the extreme conditions leached to groundwater. Figure 8 clearly indicates that the "Traditional Irrigation" simulations had higher probabilities of having contaminants reach underlying aquifers than did the other two management practices.

The leaching values from Figure 8 were used as inputs to the saturated zone code model (AT123D) to arrive at Figures 9 and 10 (page 37). Figures 9 and 10 present the probabilities of peak pesticide concentration and affected aquifer volumes, respectively, for the three water management systems simulated. As can be observed from these Figures, "Traditional Irrigation" management techniques had the highest probability of contamination over a larger portion of the receiving aquifer than did the other two management alternatives. Similarly, the contaminant peaks were greater for this case than for the others. Figure 9 shows that a pesticide which might leach at a concentration of 10E-12 parts per million (ppm) utilizing the "No" or "Scientific Irrigation" simulation might exhibit a concentration in the underlying aquifer of 10E-7 ppm if the "Traditional Irrigation" simulation were utilized.

Figure 10 illustrates a dramatic increase in affected aquifer volume when "Traditional Irrigation" is compared with the "Scientific" and "No Irrigation" alternatives. This is further exemplified by observing the difference in slopes between the "Traditional" and other two plots along with the close parallel plots for

Figure 9

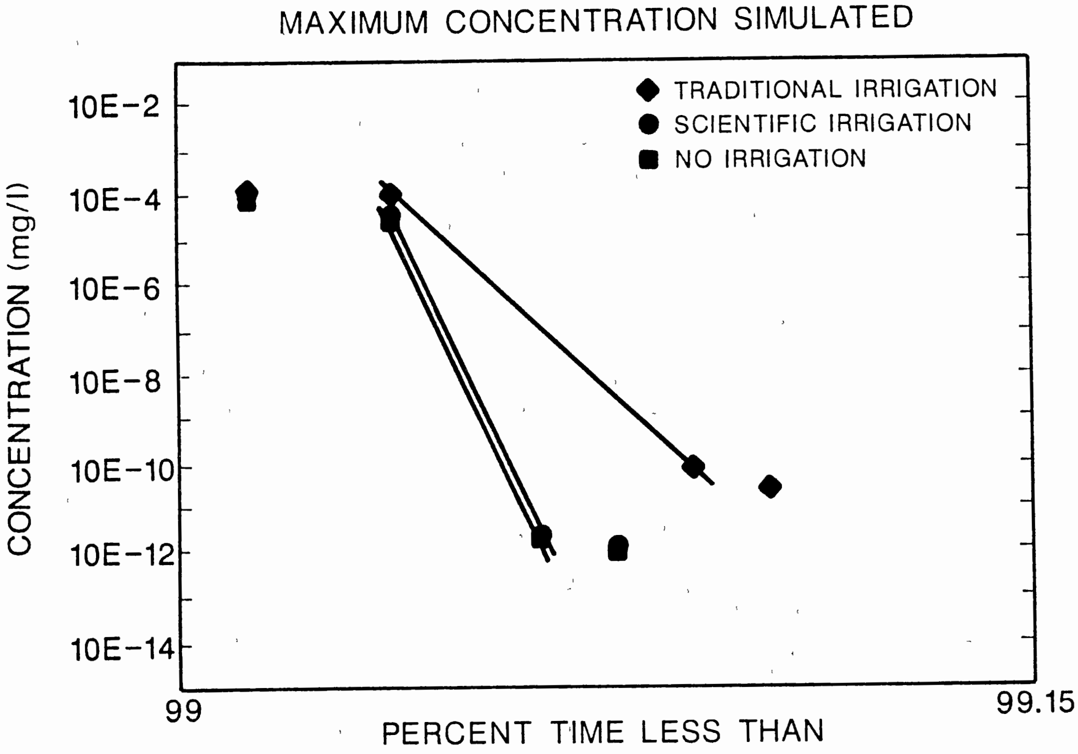
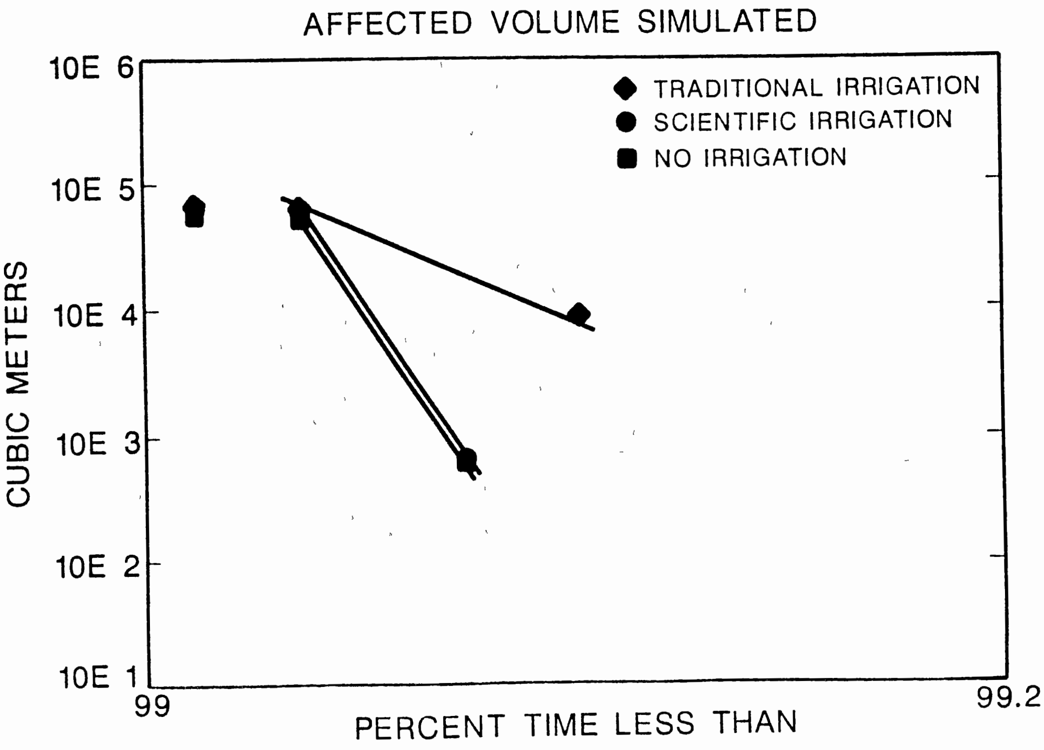


Figure 10



the "No" and "Scientific Irrigation" as compared to the "Traditional" simulation. This Figure indicated that a pesticide which might affect 1000 cubic meters of groundwater utilizing the "Scientific" or "No Irrigation" simulation technique has the potential to affect 10 times that amount if the "Traditional Irrigation" simulation technique were alternatively chosen.

Pesticide not leached to groundwater is potentially available for discharge with surface runoff and offers an equally significant environmental impact. The maximum amount of pesticide carried off site due to runoff is shown for each simulated data set in Table VI (page 39). The highest pesticide runoff observed was 71%. This was from data set 4 while utilizing the simulated "Traditional Irrigation" management practice. The lowest simulated pesticide runoff percentage in Table VI was 0.037% from data set 7.

Table VI showed that for those conditions simulated, pesticides utilizing high decay rates of 0.2961 per day (data sets 1,5,6,7,11 and 12, as opposed to the remaining data sets with degradation rates of 0.0023 per day), the pesticide runoff was essentially the same regardless of the irrigation method practiced. This was observed by reading the table horizontally and comparing the "No Irrigation" output of a given data set

TABLE VI

PESTICIDE RUNOFF FOR VARIOUS IRRIGATION MANAGEMENT PRACTICES [1 KG/HA/YR APPLIED]

DATA SET		MAXIMUM PESTICIDE RUNOFF USING NO IRRIG.	SCIEN. IRRIG.	TRAD. IRRIG.
		(kilograms)		
1	high	7.7E-4	2.9E-2	1.0E-1
2	runoff	4.8E-1	4.6E-1	5.8E-1
3	soils	5.7E-1	5.7E-1	6.7E-1
4	¦	4.9E-1	5.1E-1	7.1E-1
5	¦	8.2E-2	8.2E-2	8.2E-2
6	V	3.2E-2	3.2E-2	3.2E-2
7	low	3.7E-4	3.7E-4	3.7E-4
8	runoff	9.3E-3	2.2E-2	8.4E-2
9	soils	7.2E-2	7.2E-2	1.6E-1
10	¦	9.6E-2	9.3E-2	1.7E-1
11	¦	1.3E-2	1.3E-2	1.3E-2
12	V	1.5E-2	1.5E-2	1.5E-2

to the "Scientific" and "Traditional Irrigation" output of the same data set. Table VI further indicates that approximately five times more pesticide runoff occurred in simulated highly impermeable soils with low decay rate pesticides applied as compared to simulated well drained soils utilizing the same pesticide characteristics. This was observed by comparing data sets 2,3 and 4 of the highly impermeable soils group with data sets 8,9 and 10 of the well drained soils group. These six data sets had a simulated degradation rate constant per day, Ks, of 0.0023. For pesticides having high decay rates, pesticide runoff for the highly impermeable soils was only twice as much, not five times as much, as that simulated for the well drained soils group. It should be noted that the root zone model assumed that pesticide removed by runoff water was unavailable for leaching.

Evaluation of select simulations which showed contamination of the underlying aquifer were performed using three dimensional plots to provide increased interpretation. Plots of typical data for each management practice for a select simulation from the saturated code output are shown as Figures 11 through 13 (See Appendix D for more plots). This particular simulation was chosen as typical as it approximated the average depth of pesticide penetration of the low Ks and Koc trials which leached to groundwater. Figure 11 represents the "No Irrigation" simulation which utilized only natural rainfall in the meterological file while Figures 12 and 13 represent the "Scientific" and "Traditional Irrigation" practices respectively.

When viewing the plots, particular attention should be given to comparing the maximum concentration, maximum affected volume and the shape of the 3-D plots.

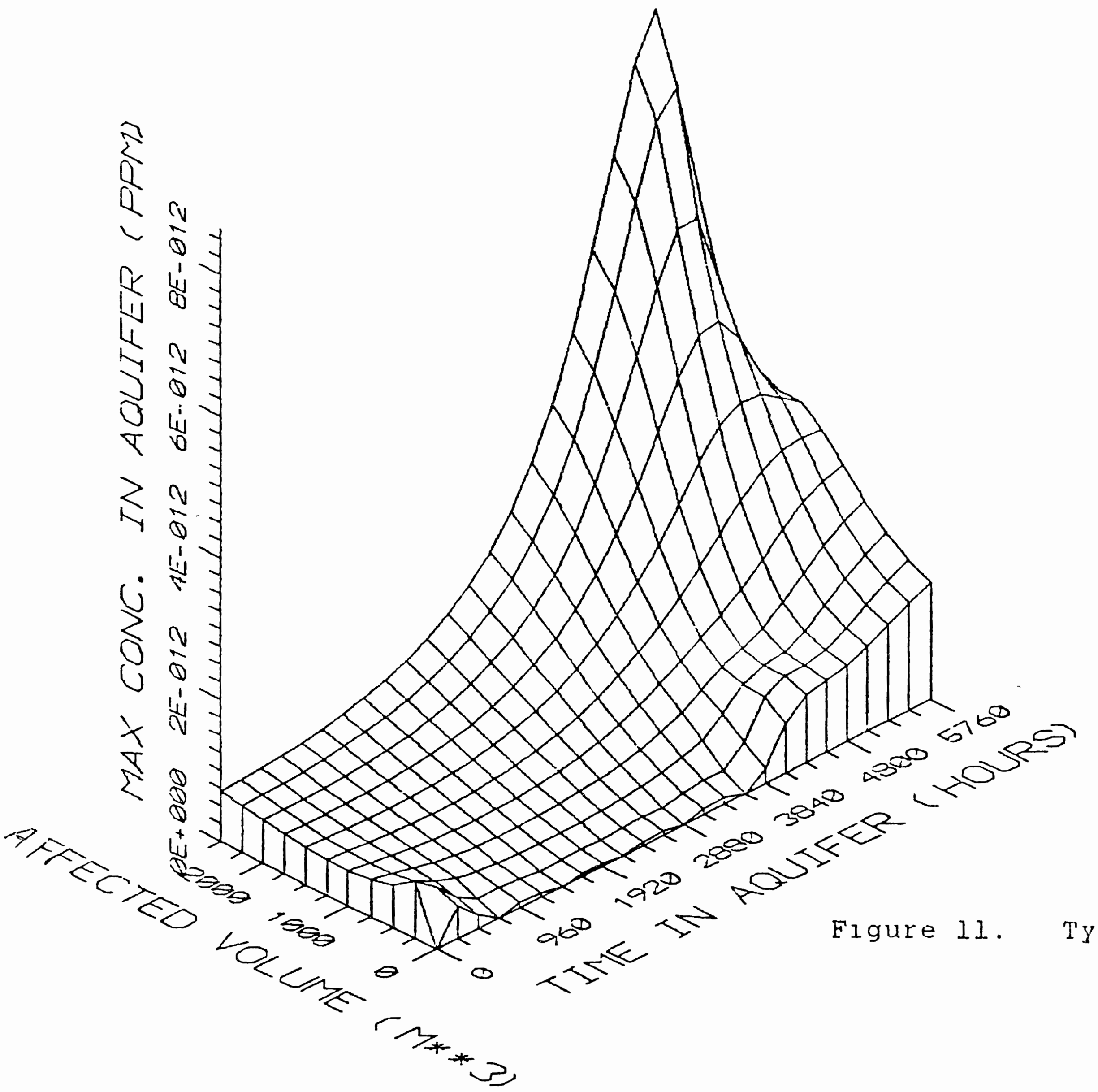


Figure 11. Typical 3-D Plot For "No" Irrigation

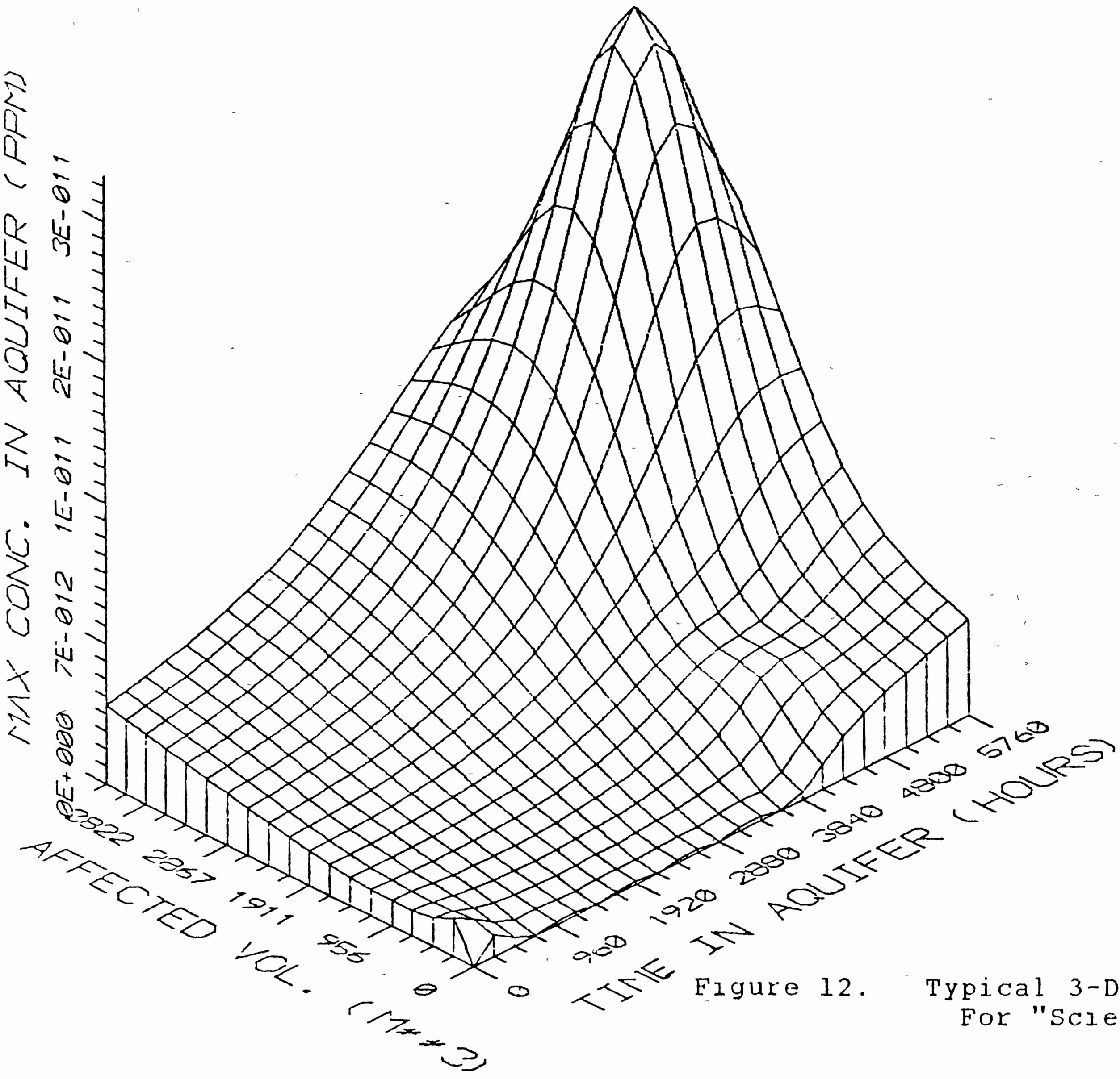


Figure 12. Typical 3-D plot
For "Scientific" Irrigation

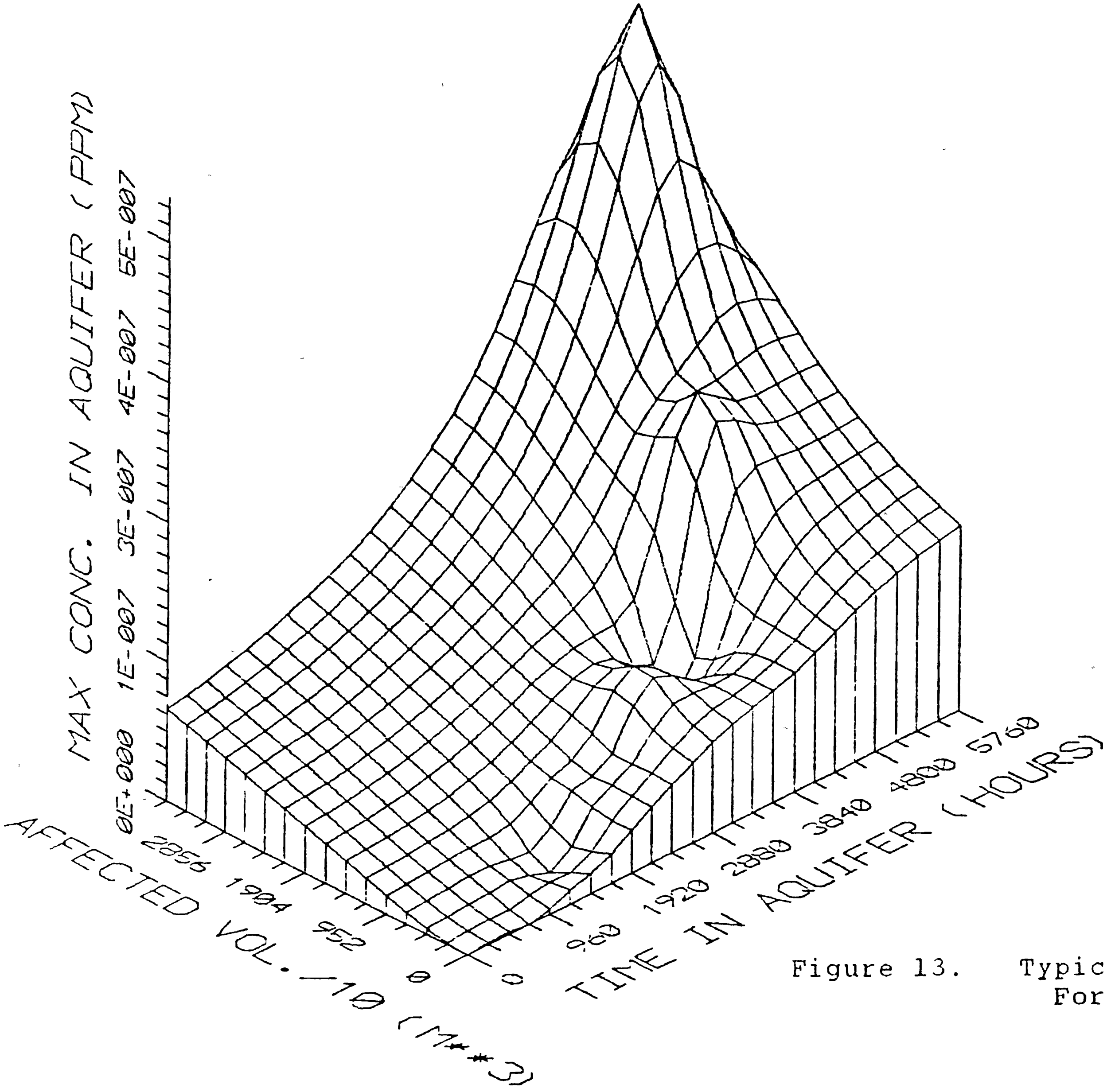


Figure 13. Typical 3-D plot For "Traditional" Irrigation

The "Affected Volume" of the "Traditional Irrigation" plot required a scale change and was approximately 10 times he volume of the "No Irrigation" simulation, while the "Scientific" simulation was only twice that of the "No Irrigation" simulation. The "Maximum Concentration in the Aquifer" was the maximum concentration of the pesticide observed within the simulated groundwater system. It should be noted that the maximum simulated concentration of the "Traditional Irrigation" plot was approximately 5E-7 ppm as compared to the "No Irrigation" concentration of 8E-12. Again, the "Scientific Irrigation" simulation approximated that of the "No Irrigation" simulation with a value of approximately 3E-11. These results were very similar to the overall values observed earlier in Figures 9 and 10.

When utilizing the monthly output data from the vadose model, smoothing of the valleys in the saturated zone plots was observed in the "Scientifically Irrigated" simulations. These smoothing effects were apparently due to the more uniform distribution/transport of the chemical through the vadose zone as irrigation was applied during the growing season only when needed rather than indiscriminately as a function of time.

Table VII (page 45) was constructed from data used to generate the typical 3-D plots and further examines

TABLE VII

TYPICAL PESTICIDE
ROOT ZONE MODEL SIMULATION OUTPUT
[1 KG/HA/YR APPLIED]

SOIL FLUXES & STORAGES		NO IRRIG	TRAD. IRRIG	SCIEN. IRRIG
PLANT UPTAKE OF PEST	:	4.31E-7	6.98E-8	3.34E-7
DECAY OF PESTICIDE	:	6.06E-2	6.01E-2	6.02E-2
EROSION OF PESTICIDE	:	-0-	-0-	-0-
RUNOFF OF PESTICIDE	:	6.66E-2	8.07E-2	6.10E-2
PEST. LEACHED @ 31"	:	.8735	.8604	.8797
ADJUSTED PEST. @ 31"	:	.8791	.8800	.8797
PESTICIDE IN CORE	:	-0-	-0-	-0-
WATER IN JUNE (INCHES)	:	2.4"	9.9"	2.9"

the partitioning of pesticides into various environmental compartments as a function of irrigation practices. This Table indicates that the simulation of pesticide uptake utilizing "Traditional Irrigation" techniques resulted in one tenth the pesticide being taken up by the crop as compared to the simulations from the other two water management schemes. Total decay of the pesticide was reduced with the addition of water to the system as shown in Table VII with the "Traditional" simulation having the least amount of decay while the "No Irrigation" simulation had the largest amount of decay. First order rate functions below twelve inches of depth were lowered according to soil organics as the soil organic matter generally decreased below this depth (Daniels, 1988). The associated low decay amounts experienced in select simulations suggested a quicker flushing of the pesticide to the lower zone when utilizing more water as simulated by the "Traditional" technique.

The increased water volume utilized with the "Traditional" simulation also resulted in a 20% increase in pesticide runoff as compared to the "No Irrigation" simulation. One hypothesis for these differences lies in water applied to the system and its associated runoff. Analysis of the amounts of water simulated for a typical data set for each irrigation system are shown in Table VII for the month of June. As is shown, the "No" irrigation simulation utilized approximately 2.4 inches of precipitation followed by "Scientific" with 2.9 inches and "Traditional" with 9.9 inches of water for the month. It should be remembered that precipitation records were randomly chosen for each of the "No" irrigation simulations while the "Traditional" and "Scientific" precipitation records were chosen to correspond accordingly. As further illustrated by Table VII, the "Scientific Irrigation" simulation had the lowest amount of pesticide runoff even though it simulated more water than did the "No Irrigation" technique. This result was attributable to the timing of the water applications. By adding small amounts of water frequently, the pesticide appeared to migrate downward and not be removed from the area by runoff water. This migration effect is shown in Table VII by comparing the amount of pesticides leached below the deepest root depth simulated (corn at 31 inches) for each of the various management techniques.

Table VII suggests that the "Scientific" simulation had the largest amount of pesticide below this depth, followed by "No Irrigation". The "Traditional" simulation was less than the other two water management practices apparently only because the amount carried off in the runoff. This was observed by adjusting all values of the pesticide leached below simulated root depth (31 inches) to the lowest runoff observed (6.10E-2), thus providing an additional amount of pesticide available for leaching. These adjusted values were shown and labeled 'Adjusted Pesticides @ 31"' in Table VII and suggest that the addition of water directly affected the volume of pesticide leached.

The pesticide leaching effects from additional water were further evidenced by observing the simulated monthly and total annual pesticide loading rates delivered into the underlying aquifer as shown in Table VIII (page 48). Those simulations utilizing large volumes of water indicated high monthly and annual

TABLE VIII

TYPICAL LOADING
OF PESTICIDE AT TOP OF AQUIFER
(KG/HR)

MONTH-->	JUNE	JULY	AUG	SEPT	OCT	NOV	
SIMULATION TYPE		(LOAD - Kg/Hr)					TOTAL
TRAD. IRR :	2E-14	5E-12	7E-12	0	2E-11	5E-11	8E-11
SCIEN. IRR:	1E-17	2E-17	0	0	3E-16	3E-15	3E-15
NO IRRIG. :	7E-18	8E-18	0	0	7E-17	9E-16	1E-15

pesticide loading rates into the aquifer. Note the greater uniformity in the "Scientific" simulation in addition to the relative differences for each of the various techniques simulated. Although the "Scientific" simulation had more pesticide leached below simulated root depth than the "Traditional" simulation, it leached less pesticide at depth to groundwater. This was due to the longer length of time the "Scientifically" managed pesticide remained in the soil horizon above the aquifer prior to entering the groundwater. This increased time was attributable to the smaller water volumes (ie: less driving force) and more uniform additions of water as simulated with the "Scientific" technique as compared to the "Traditional Irrigation" simulation.

Discussion

Figure 7 indicated that on an annual basis, little difference would be expected in leaching potentials between the "No Irrigation" and the "Traditionally" or "Scientifically" managed irrigation systems at 12" of soil depth. Further, over 50% of the normally applied pesticide in this area would be expected to leach 12" or deeper for more than 25% of the time.

In Figure 7, the upper portion of these and all subsequent curves resulted from a relatively minor number of simulations where almost 100% of the applied pesticide leached to the respective depth. These sections of the curves appeared to result from a combination of low pesticide partition potentials, highly permeable soils, depressed decay properties and high rainfall years/seasons. When viewed in subsequent analysis at different depths or within the receiving aquifer, these observations remained separate from the remainder of the data.

Figure 8 indicated that the "Traditionally" managed irrigation system exhibited a greater leaching probability to groundwater than did the other systems. A comparison of Figure 8 to Figure 7 indicated that unlike leaching at 12 inches, the probability of leaching at depth to groundwater occurred only for the extremes of the conditions simulated. The pesticides which leached beyond the 12 inch depth but did not leach to the water table had to decay, be adsorbed or stored within the soil column. Of this group of pesticides, generally, those pesticides with high decay rates (Ks) exhibited in excess of 90% decay within the soil column while those with low decay rates exhibited approximately 50% storage within the soil column, regardless of Koc or water management technique employed. This high percentage of storage by pesticides with low decay rates suggests a potential for future migration and subsequent contamination of the water table by these chemicals. It further suggests that selection of high decay rate pesticides should reduce the potential for contaminating the water table aquifer.

The maximum depth of groundwater contaminated with detectable pesticide was 26 feet. This depth was a result of the randomly selected depth to groundwater and the other variables chosen by the Monte Carlo technique. It did not represent the maximum depth the simulated pesticides will leach to, only the maximum conditions randomly chosen and simulated within this effort. The deepest penetration of pesticide not reaching groundwater was almost 50 feet and was attributable to a low Koc, high sand content soil and high rainfall year. A review of the chemical characteristics, Table II, with those which showed leaching to the water table aquifer, Table V, indicated that those chemicals which were highly mobile were most likely to reach groundwater. This again suggests that pesticide selection was one of the primary controlling factors affecting leaching potential.

Figures 9 and 10 showed that the "Traditional" system consistently generated greater contaminant levels than did either of the other two simulated water management alternatives. Additionally, due to the closeness of the "No" and "Scientific Irrigation" data in these plots, these two figures suggest that the use of "Scientific Irrigation" practices have the potential to increase revenue yet cause a minimal amount of additional groundwater contamination. Furthermore, as observed from Table VI, "Proper", as compared to "Traditional" irrigation generally resulted in less pesticide runoff in surface waters. Results of the pesticide root zone model simulations, shown in Table VII, indicated that in general, excess irrigation water increased the percentage of pesticide runoff. Approximately twenty percent of additional pesticide runoff occurred with the "Traditional" irrigation simulation as compared to either of the other irrigation simulations. This additional percentage of pesticide runoff utilizing "Traditional" irrigation was simulated by using approximately three times the water volume utilized by either the "No" or "Scientific" irrigation data sets. The reduction of pesticide runoff has the potential for increasing profits as less money would be spent on "unused" pesticide in addition to reducing the potential for surface water contamination.

Overall, Figures 7-10 displayed the increase in probability of contamination and the associated increase in the affected volume of an underlying aquifer due to the use of "Traditional Irrigation" practices as compared to "No Irrigation" or "Scientific Irrigation" management schemes. This was further evidenced by reviewing Figures 11 through 13 which were three dimensional plots of typical simulated data sets. These figures showed the maximum concentration of leachate in the aquifer and its associated contaminated volume (with respect to time) for a unique data set employing each of the water management schemes. These figures indicate that the maximum concentration of contaminant in the aquifer and/or the affected volume increased substantially for the "Traditional Irrigation" process versus either the "Scientific" or "No Irrigation" simulations. [It should be noted that the "Affected Volume" scale on the "Traditional Irrigation" plot (Figure 13) is ten times those shown on the "No" or "Scientific" plots (Figures 11 and 12).]

The large volume of water associated with the "Traditional Irrigation" simulation process provided a vehicle for high percentages of pesticides to be flushed through the vadose zone and into the underlying water table aquifer. The large volumes of water associated with the "Traditional Irrigation" simulations maintained a high moisture content and pore velocity within the soil. This in turn allowed efficient transmission of a chemical below the root zone while simultaneously satisfying the evapotranspiration requirements of the upper zone. The pesticide loading rates entering the top of the aquifer shown in Table VIII further support this point.

The three dimensional plots indicate that "Scientific Irrigation" reduces the spikes and valleys of the maximum concentration of contaminant within the aquifer. This smoothing effect was due to the simulation of a more uniform distribution/transportation of the chemical through the vadose zone as it moved toward the top of the reservoir during the drier times of the year. Proper irrigation provided for a lower moisture content and pore velocity resulting in a more uniform contact time between the chemical and soil above the groundwater. The more uniform and longer contact time between the chemical and the soil above the aquifer provided higher chemical reactions which reduced the chemical mass and concentration leached to the aquifer.

A review of the plots representing the simulations which leached to groundwater showed those pesticides originally applied at the surface which simulated high decay constants generally had their peak concentration immediately upon entering the aquifer and subsequently decreased in concentration with respect to time from that point. This was expected due to the high decay rate of the chemical. Consequently, those surface applied pesticides which originally simulated low decay rates generally showed a gradual increase in aquifer concentration with time before reaching a peak and subsequently decreasing. This was true for the entire data set except for those simulations exhibiting very shallow water tables (approximately 2 feet from surface). The very shallow water depths allowed for rapid movement of the chemical into the aquifer while providing a very limited storage and consequently, limited reaction time within the vadose zone. This resulted in a very small percentage of chemical available within the vadose zone to be flushed into the water table aquifer following subsequent water flush cycles.

It should be realized that the vast majority of the possible locations addressed by this effort exhibited poor probabilities of groundwater contamination.

However, it should also be noted that the amount of groundwater contamination indicated by this effort can be severe for select conditions. As such, it is suggested that individual properties be evaluated separately utilizing as much site specific data as possible. Although, for the pesticide application rates simulated, the pesticide doses found in the aquifer will be below the reference doses, this does not mean that all chemicals can be used at all sites in Caddo County. Furthermore, it should be understood that many pesticides will leach if shallow water table conditions exist and that the surrounding aquifer can become highly toxic.

Summary

A risk based evaluation of select management alternatives potentially available to control agricultural groundwater contamination from pesticide leaching was completed for a single county in Oklahoma. The methodology employed in this report utilized existing software and techniques in a manner which provided satisfactory results in determining pesticide leaching while requiring a minimum of site specific data. Furthermore, the interlinking of the Monte Carlo techniques, the Pesticide Root Zone Model and the AT123D saturated zone code provided a detailed evaluation of pesticide leaching in the vadose zone and subsequent movement through an affected water table.

This analysis indicated that pesticide selection as well as imprudent irrigation practices were more critical in allowing pesticides to leach to and be transported in water table aquifers than were other alternatives available to the agricultural community. Not surprisingly, pesticide leaching concentration was most severe in areas of extremely shallow water tables. Additionally, regardless of the water management approach practiced, pesticides with high partition or decay coefficients were generally not delivered to the depths necessary to intercept the aquifers simulated. However, at the extreme conditions of shallow water tables and small partition or decay coefficients, the water management technique employed exhibited dramatic effects on the contaminated volume and the contaminant concentration simulated within the water table aquifer.

This effort has:

* provided a methodology for predicting the probability of additional pesticide leaching due to a change in water management practices.
* provided a methodology for predicting the probability of aquifer pesticide concentration and affected aquifer volume

due to leaching, as associated with various water management practices.

- indicated a general lack of leaching to groundwater of pesticides exhibiting high partition or decay coefficients regardless of the water management techniques employed.
- indicated pesticide selection coupled with irrigation practices affected pesticide leaching to groundwater and subsequently, the concentration of the contaminant within an underlying aquifer and the volume affected within that aquifer.

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APPENDIXES

APPENDIX A

DATA INPUT

Data input selection was based on site specific agricultural conditions presently existing in or near Caddo County, Oklahoma. The weather station providing the meterological data nearest the site was in Chickasha, Oklahoma located approximately ten miles east of Caddo County, Oklahoma. This data was deemed acceptable due to the stochastic nature of weather patterns and the availability of detailed climetological records covering a 25 year period. USGS information (1972) was used to obtain depth to ground water across the county. Tables in the PRZM manual provided the actual daytime hours for Caddo County (latitude 35 north).

Pesticide application was set at 1 Kilogram per Hectare (Kg/Ha). Due to the linear nature of the adsorption isotherm, this application concentration allows direct conversion of pesticide leachate into a percentage. This percentage can then be applied to predict leachate associated with any given application concentration. The type of pesticides modeled were typical of those used in Caddo County. Pesticide application was to a free draining tilled soil (typical for soil types 'A', 'B' and 'C') at a depth of 4 inches (10 cm) on the first day of May. The initial pesticide level of the soil was set at zero.

The random rainfall selection was from twenty five years of historical data collected during the period from 1954 through 1978. The non-scientific, or traditional irrigation simulation was constructed from the no irrigation simulation by adding 2.5 inches of water every 10 days from June 1 through August 15 to each of the 25 years of data, regardless of weather conditions. While this may not at first seem proper, irrigation practices similar to this are presently in operation.

One crop with one harvest was simulated. In an effort to maximize the amount of chemical transferred to the groundwater, the erosion of the soil was neglected. Water runoff was calculated within the program with runoff curve numbers based on Hydrologic Soil Groups where CN1, CN2 and CN3 respectively being 77, 67, 72 represented soil type 'A' and 94, 91, 92 represented soil type 'D'. Group 'A' soil is defined by PRZM as deep sand, deep loess, or aggregated silts with a minimum infiltration of 0.3 to 0.4 inches/hr (0.76 to 1.14 cm/hr). A Group 'D' soil is defined as a soil which swells significantly when wet, heavy plastic clays, and certain saline soils with a minimum infiltration of 0.01 to 0.05 inches/hr (0.03 to 0.13 cm/hr). CN1 is for fallow conditions, CN2 is for cropping conditions and CN3 is the mean of these and is used for the residue part of the growing season. The PRZM manual provided an interception storage for wheat of 0.06 inches (0.15 cm). Plant harvest was chosen as October 10th., a typical harvest date for wheat in this area (Carsel, 1984).

Two soil zones were modeled in the runs. The upper zone consisted of top soil to a depth of 12 inches (30.48 cm) while the bottom zone was modeled to represent the substrata to the top of the water table. The total core depth was chosen by a Monte Carlo simulation technique using the parameter correlations developed from USGS depth to groundwater data. The depth of the bottom zone was modeled to extend from 12 inches (30.48 cm) to the total core depth. Each run was set up to have a total of 35 vertical compartments to allow adequate evaluation of the movement of pesticides through the soil (Carsel, 1984).

The degradation rate constant per day, Ks, was chosen to be either 0.0023 or 0.2961 thus bracketing the range of degradation rate constants for chemicals used in the area and allowing interpolation for any given Ks.

This allowed for a range of chemicals to be modeled, from Benomyl (0.0023) to Parathion (0.2961). The organic carbon distribution coefficient, Koc, was chosen to be 0.001, 2.0, or 600.0. This provided upper and lower limits of pesticide solubility to be taken into consideration.

All combinations of the above Ks, Koc and Curve Numbers along with the bulk densities, organic carbons, wilting points and field capacities were run while randomly accessing rainfall periods and depths to groundwater for the scientific, traditional and no irrigation data sets.

APPENDIX B

PRZM MODEL DESCRIPTION

The EPA's Pesticide Root Zone Model's (PRZM) two major components are hydrology and chemical transport. The Universal Soil Loss Equation and the Soil Conservation Service curve number technique were used in calculating the hydraulic runoff and erosion. Evapotranspiration was comprised of evaporation from plant interception, evaporation from the soil and transpiration from the crop, and was estimated by the model from pan evaporation, empirical formula or a combination of these. Water movement was simulated by empirical formula which considered field capacity, wilting point and saturation. The chemical transport component estimated leaching, decay/transformation, surface runoff, plant uptake, foliar loss, dispersion and retardation using a numerical finite-difference solution technique.

The soil horizon in this model was divided into two layers and had a time step of one day due to its use of daily rainfall records in its calculation of the runoff and infiltration components. Chemical degradation was represented by a first-order equation in which the rate coefficient was specified for each defined soil zone. This model should not be used to evaluate data for volatile chemicals as it does not account for vapor-phase partitioning and transport.

APPENDIX C

AT123D MODEL DESCRIPTION

The Oak Ridge National Laboratory's AT123D aquifer model is an analytical transient one, two or three dimensional model capable of computing the spatio-temporal distribution of chemicals within an aquifer. The solute transport model incorporated calculations to account for the effects of biological decay, retardance, adsorption, advection and dispersion. The model allowed for a choice of three types of source releases. These could be instantaneous, continuous or of a finite duration. The model was designed to handle chemicals, radioactive waste, heat, finite reservoirs and infinite reservoirs (Yeh, 1981). The need to expand this model to allow more than eight source releases appears to be needed to properly simulate a detailed site specific situation if it is to be evaluated on a monthly basis in excess of one year.

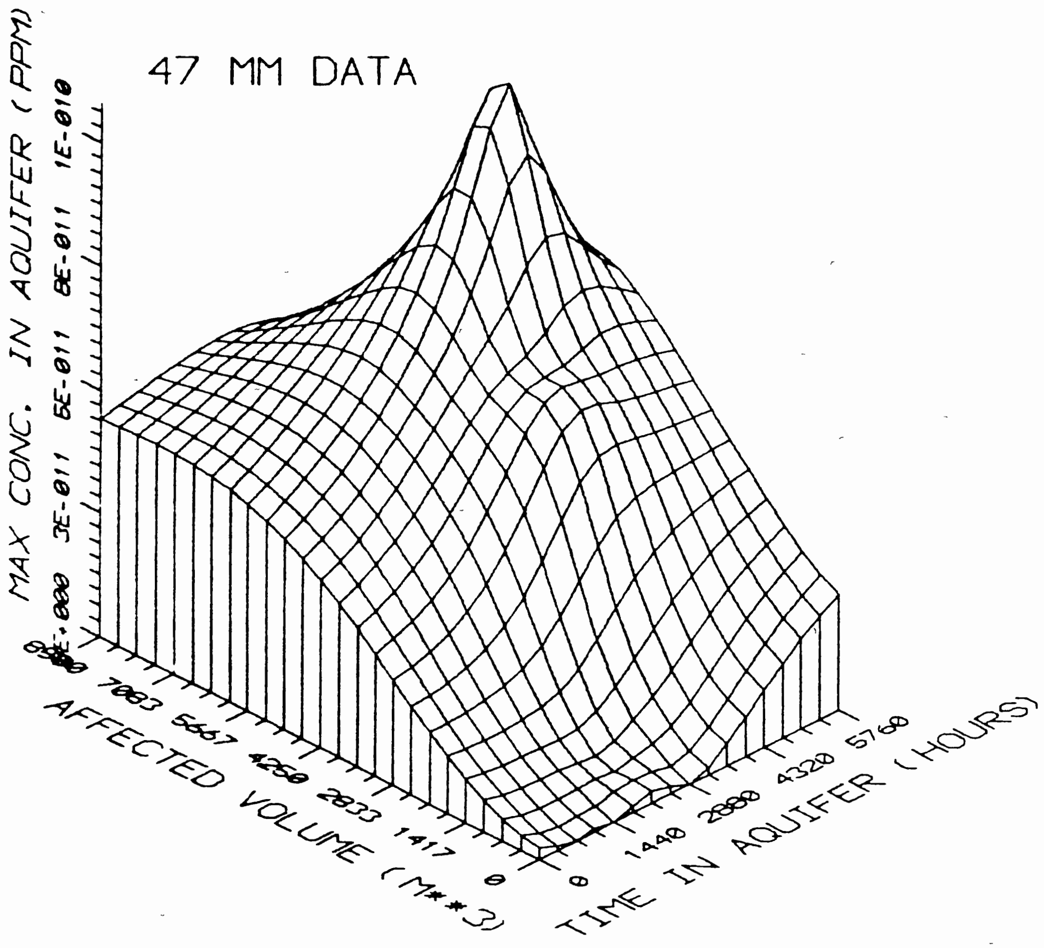
APPENDIX D

THREE DIMENSIONAL PLOTS OF PESTICIDE LOADING IN AN AQUIFER

Three dimensional plots of the pesticide loading, maximum concentration and affected area were presented to provide quick vivid references indicating the effects of leaching as associated with various water management techniques. Each simulation which indicated a concentration in the water table aquifer in excess of 1E-12 part per million was plotted.

The methodology of the construction of the three dimensional plots by the software package was unsatisfactory to a large part. While it did represent the leaching effects easily, quickly and vividly, some of the assumptions within the plotting program appeared to be unsatisfactory to this application. In particular, the plots indicated a chemical concentration with a given volume at a time of which there may have been no leaching. This phenomena was believed to be associated with the methodology of interpolation between the zero boundary and the given data points. In general, this author believed the contamination plume should tend to graph in more of a pie or pyramid shape than those presented in this paper. Since it was not the intention of this study to evaluate plotting procedures, no attempt was made to fully evaluate or correct this apparent problem.

The following plots are coded with the run number followed by MT ("No Irrigation"), PM ("Scientific Irrigation") or MM ("Traditional Irrigation").



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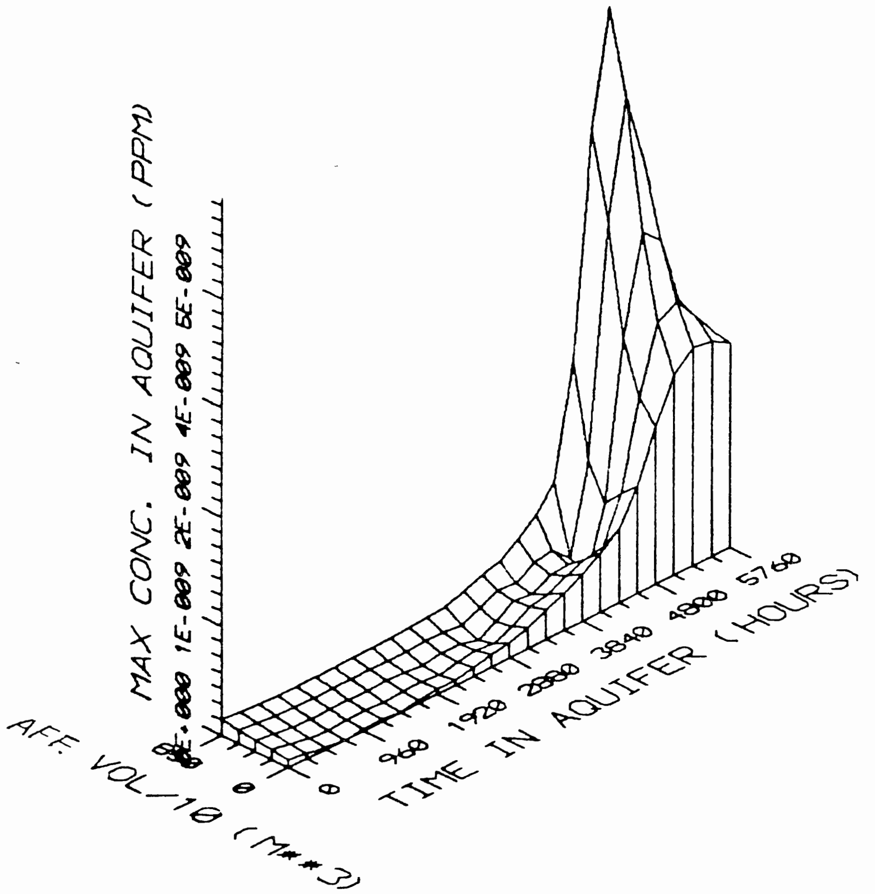
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4E-009
5E-009
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1920
2880
3840
4800
5760
AFF. VOL/10 (M**3)
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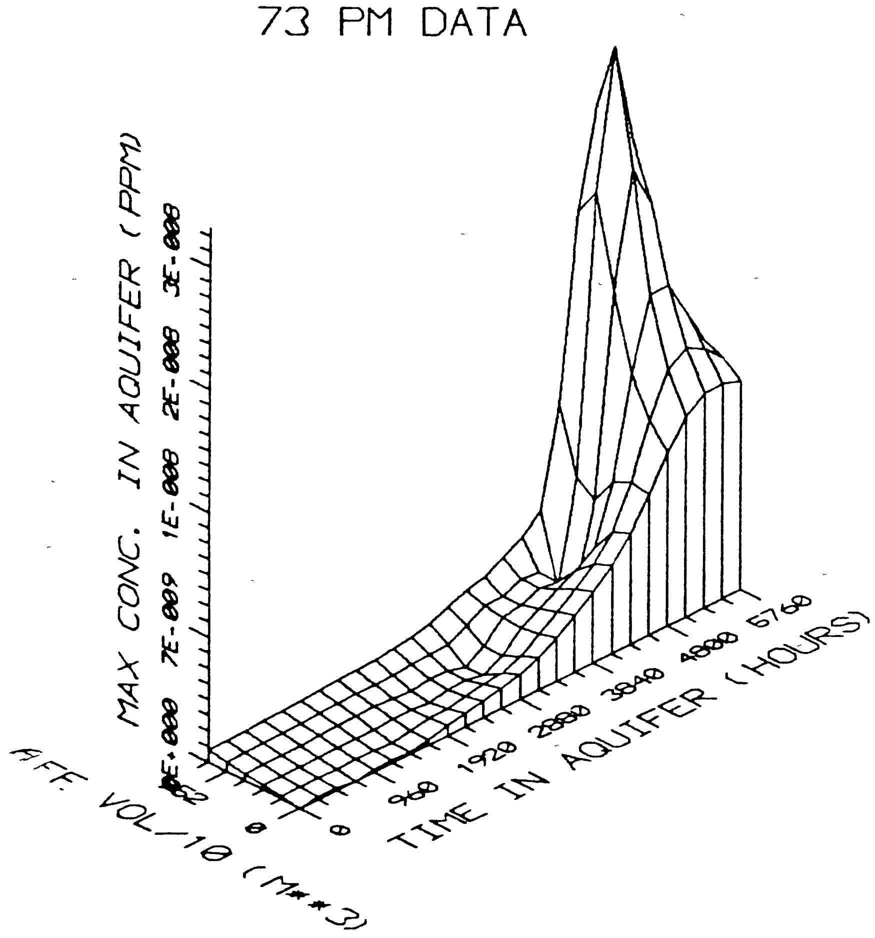
0
0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4800
5760
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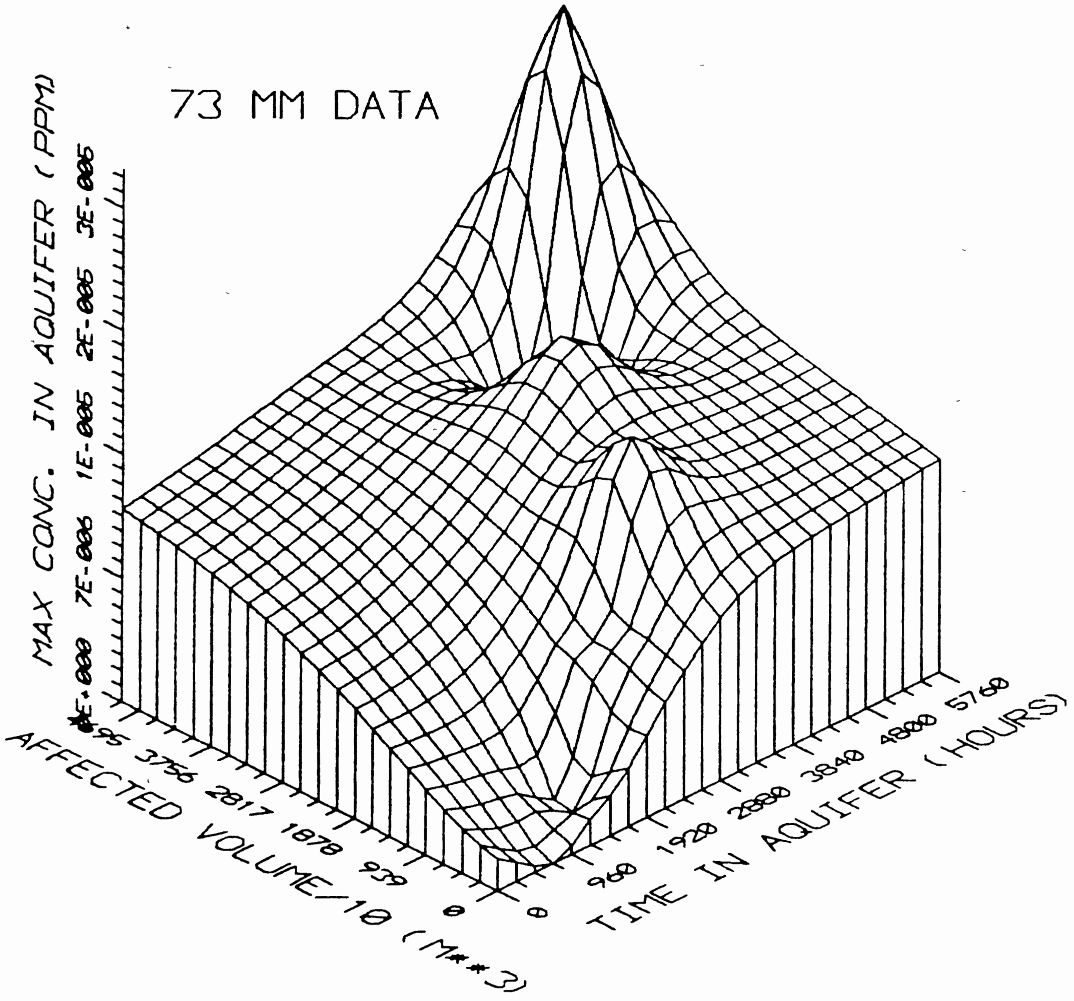
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2817
1878
939
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3840
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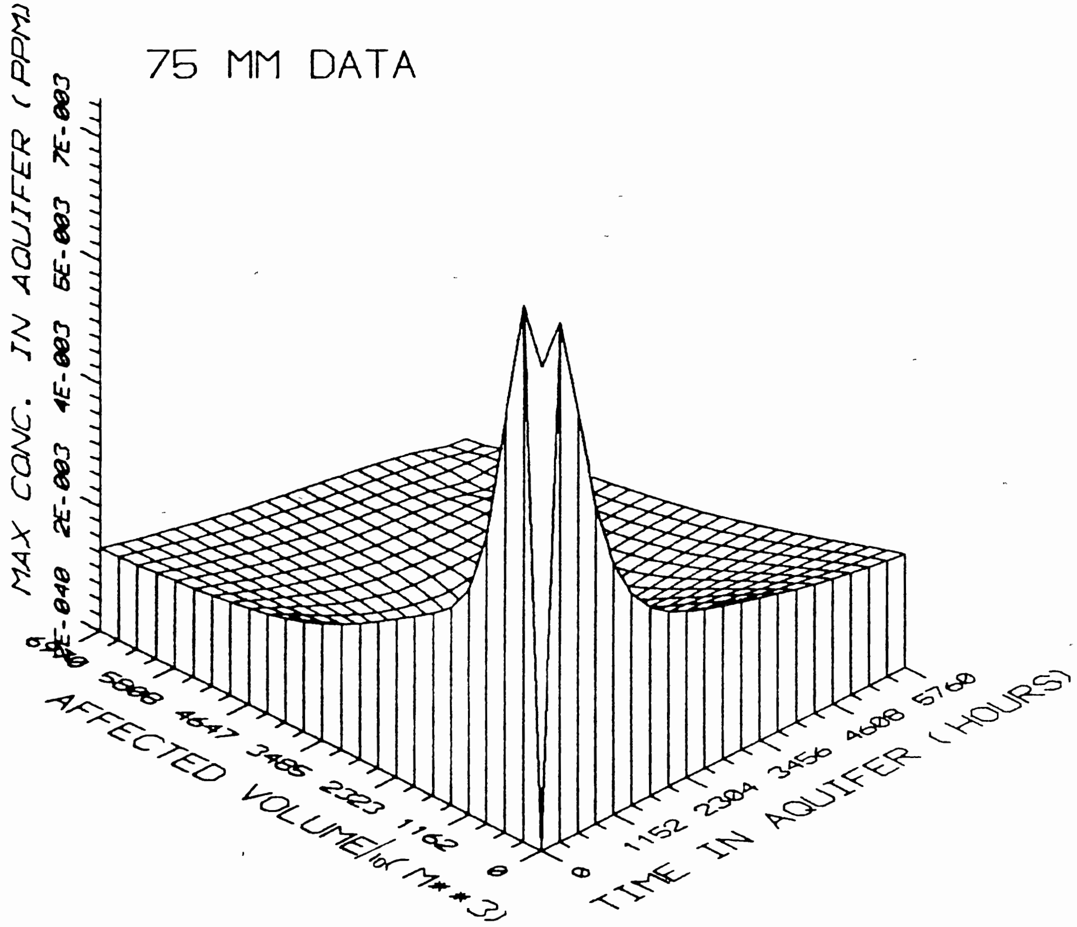
5760
TIME IN AQUIFER (HOURS)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5E-003
7E-003
5808
4647
3485
2323
1162
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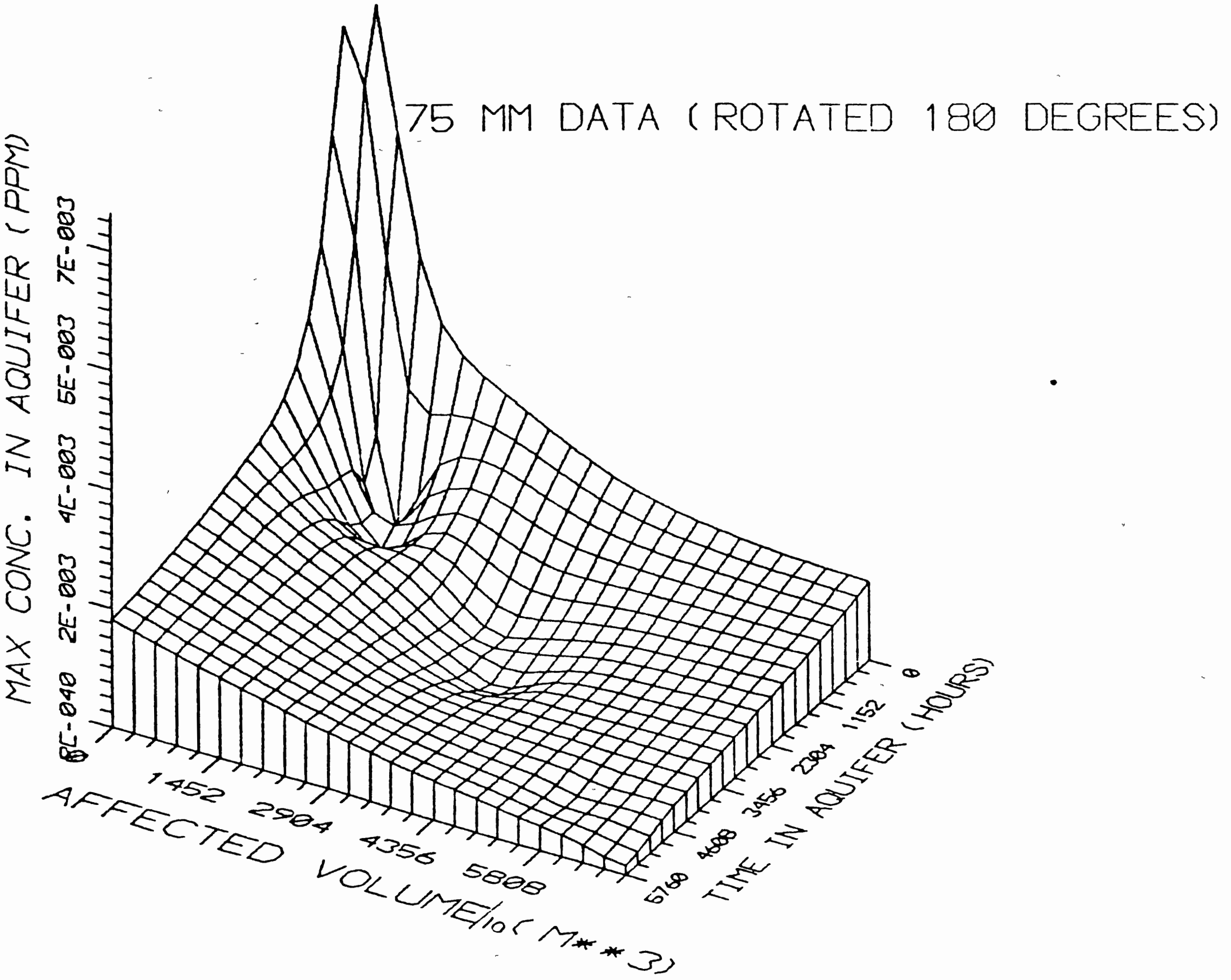
1152
2304
3456
4608
5760
TIME IN AQUIFER (HOURS)



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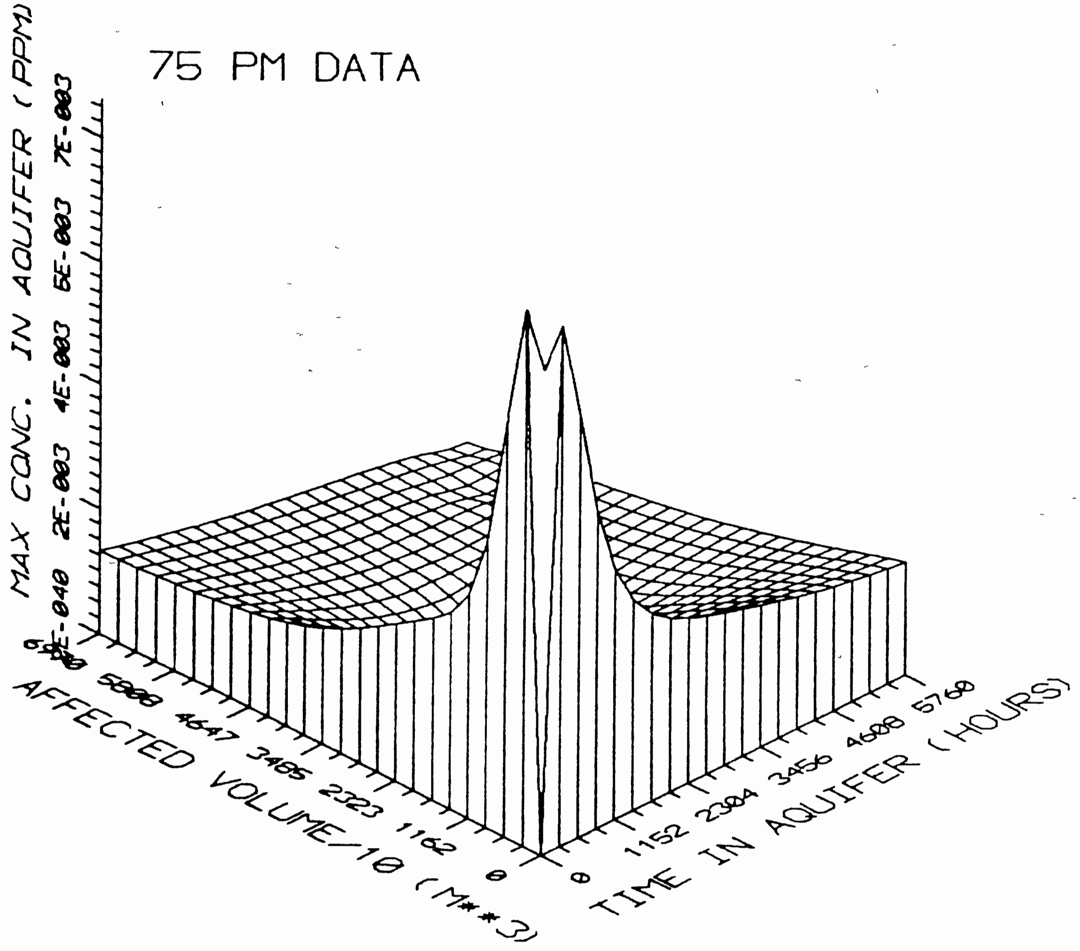
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7E-003
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3485
2323
1162
0
TIME IN AQUIFER (HOURS)
0
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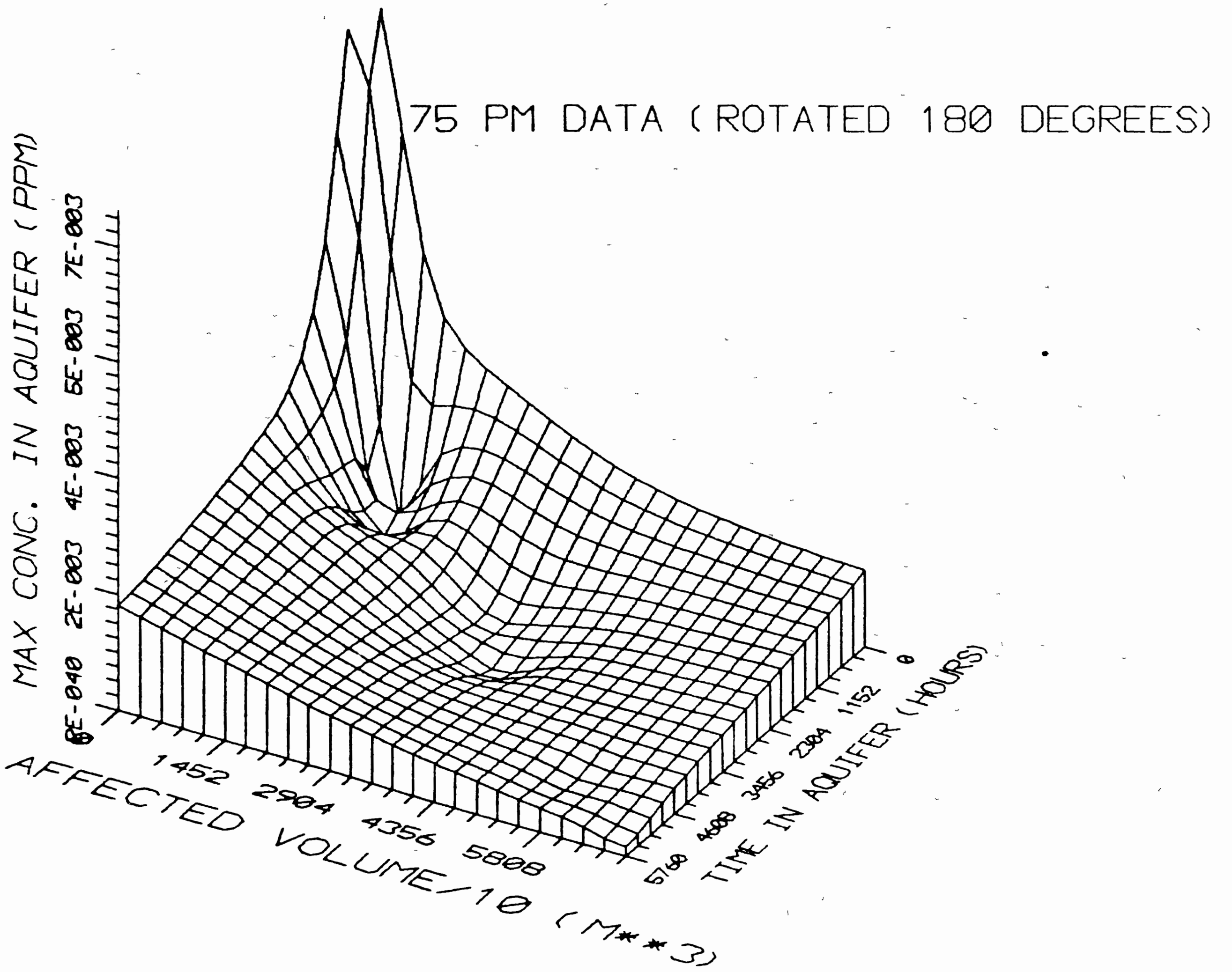
2304
3456
4608
5760

75 PM DATA (ROTATED 180 DEGREES)
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2904
4356
5808
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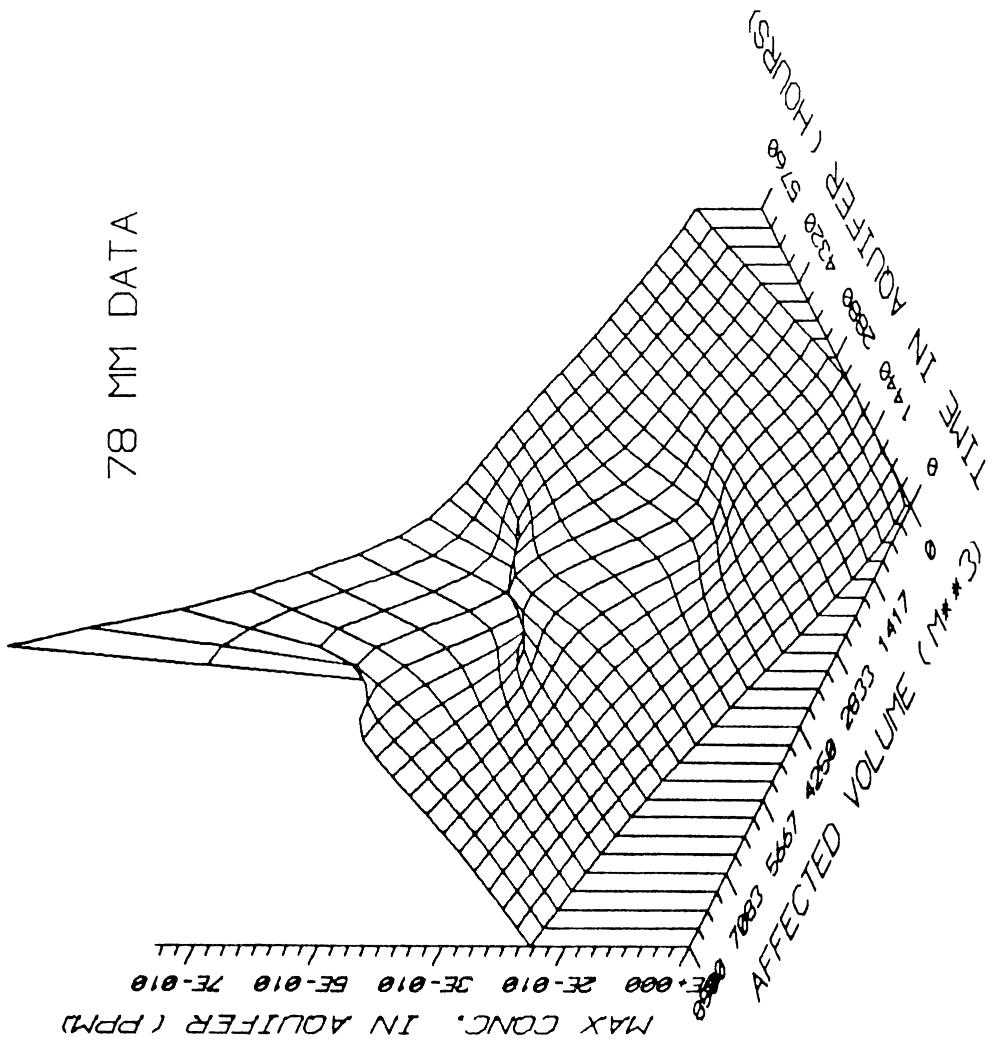
2304
3456
4608
5760
TIME IN AQUIFER (HOURS)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3E-010
5E-010
7E-010
AFFECTED VOLUME (M**3)
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4250
5667
7083
TIME IN AQUIFER (HOURS)
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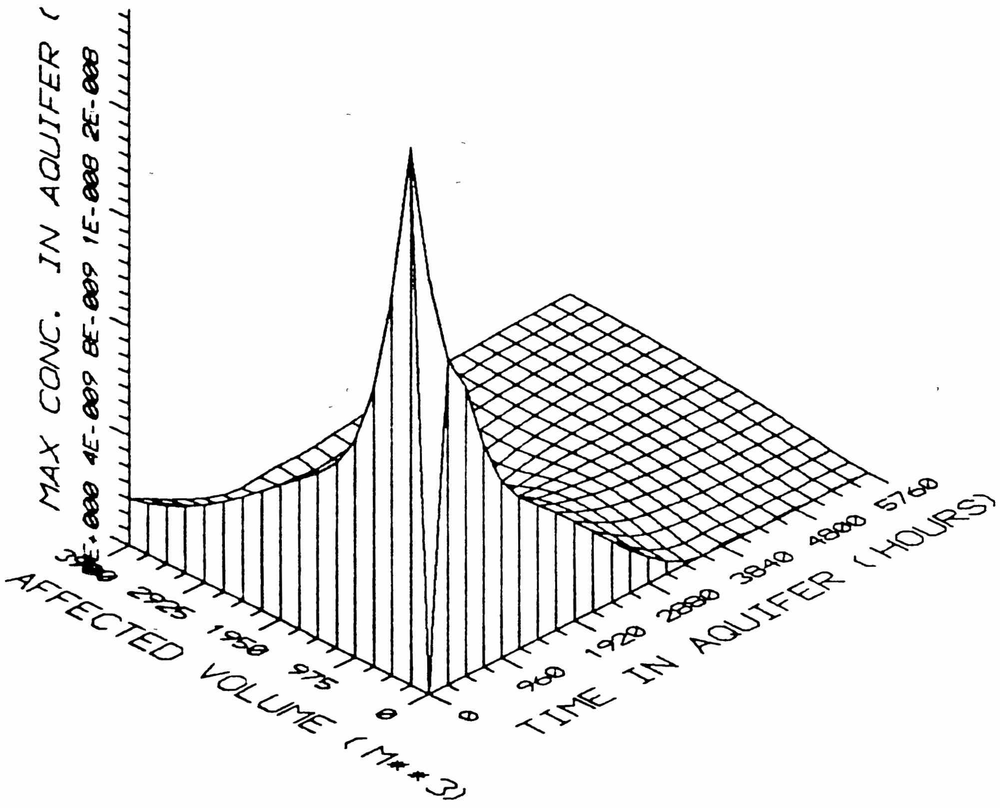
1440
2880
4320
5760

90 MT DATA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8E-009
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975
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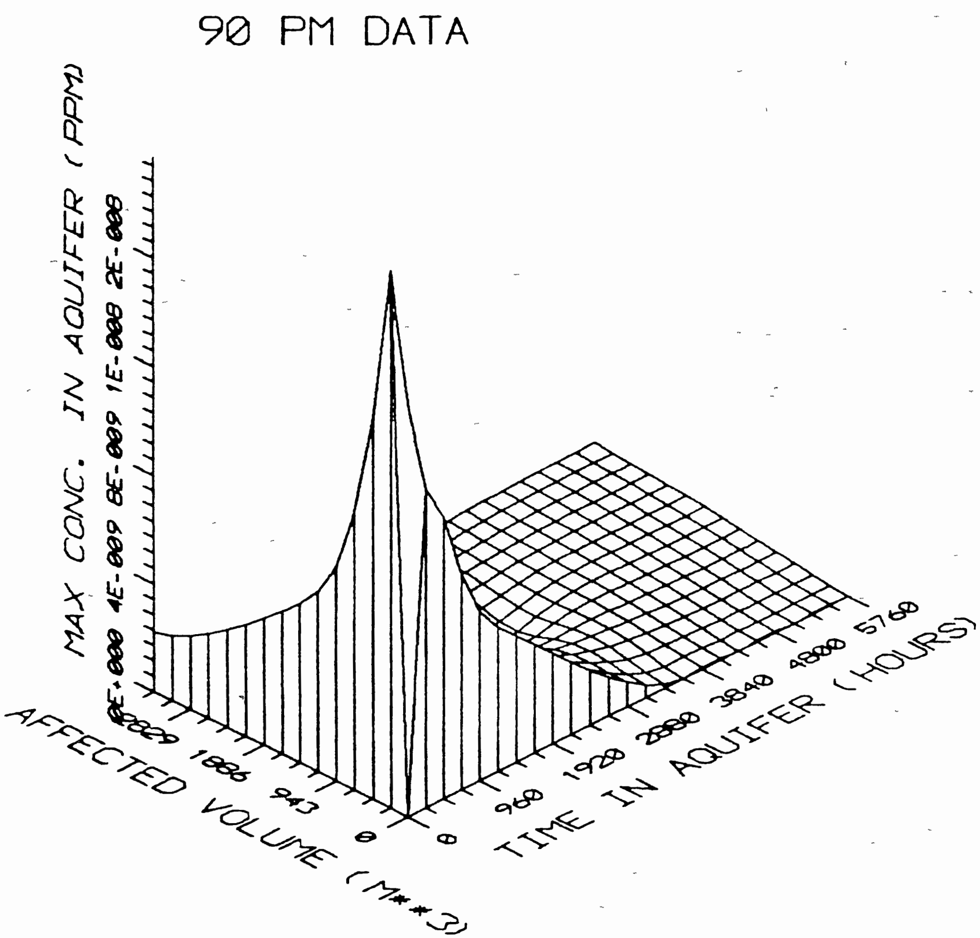
1920
2880
3840
4800
5760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8E-009
1E-008
2E-008
AFFECTED VOLUME (M**3)
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943
0
0
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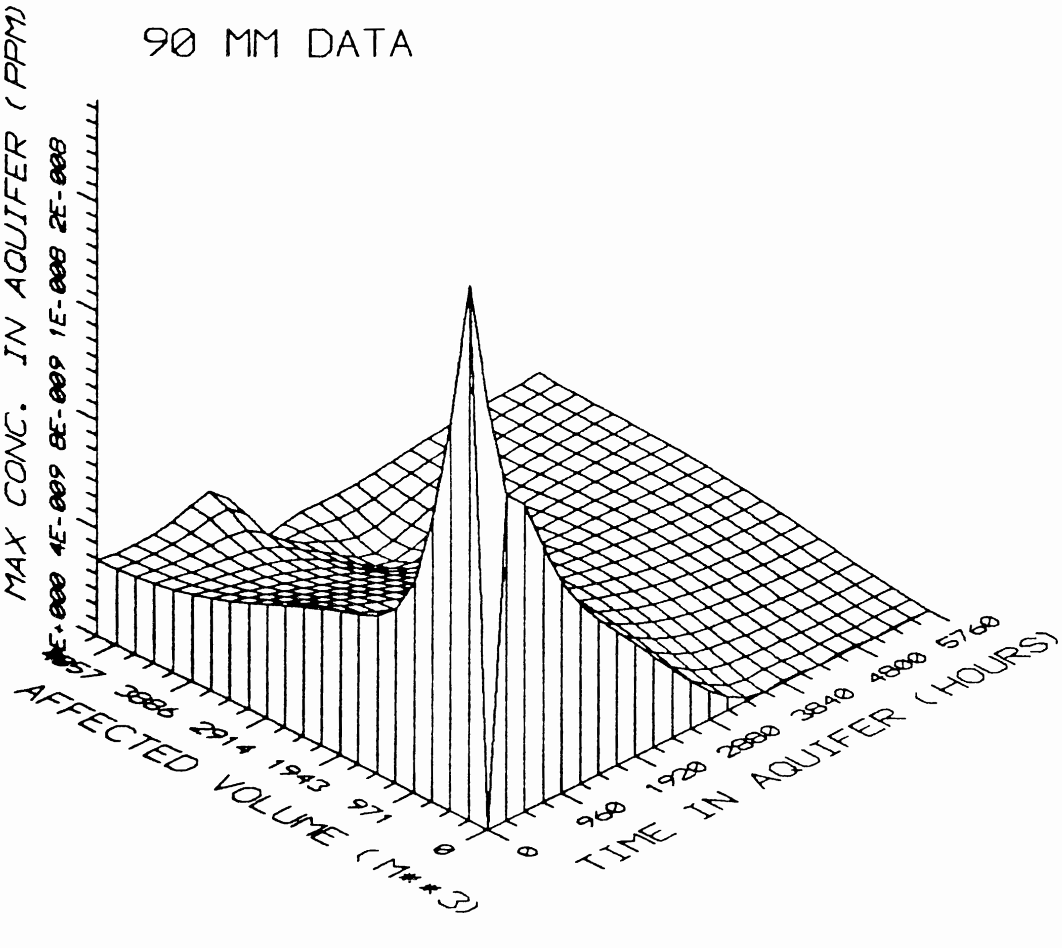
1920
2880
3840
4800
5760
TIME IN AQUIFER (HOURS)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8E-009
1E-008
2E-008
857
3886
2914
1943
971
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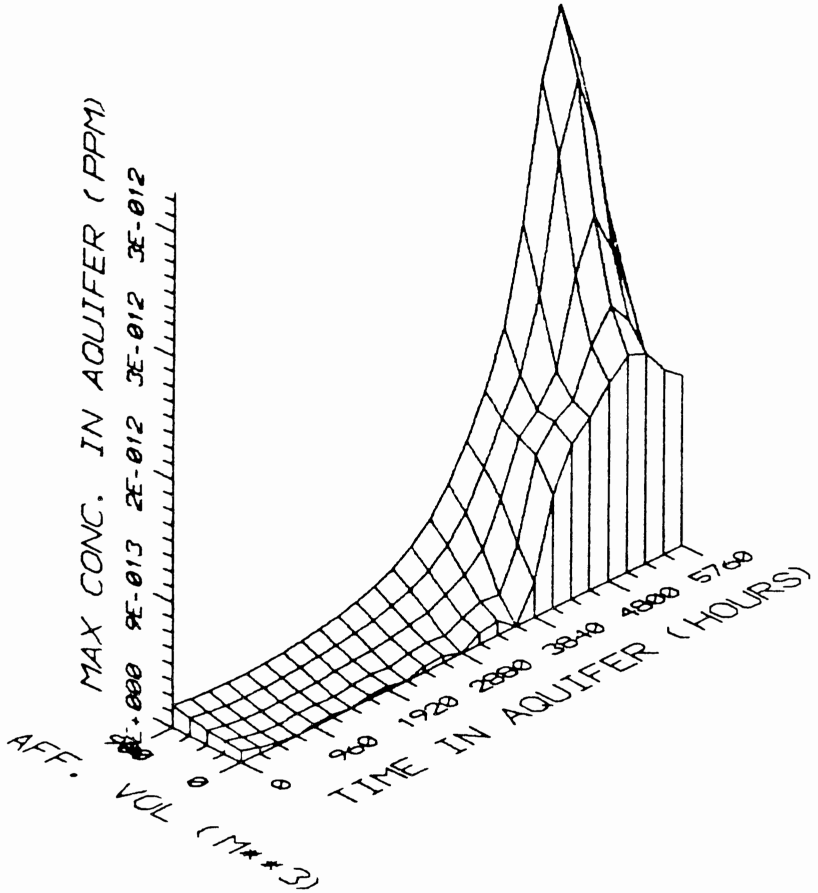
1920
2880
3840
4800
5760
TIME IN AQUIFER (HOURS)

107 MT DATA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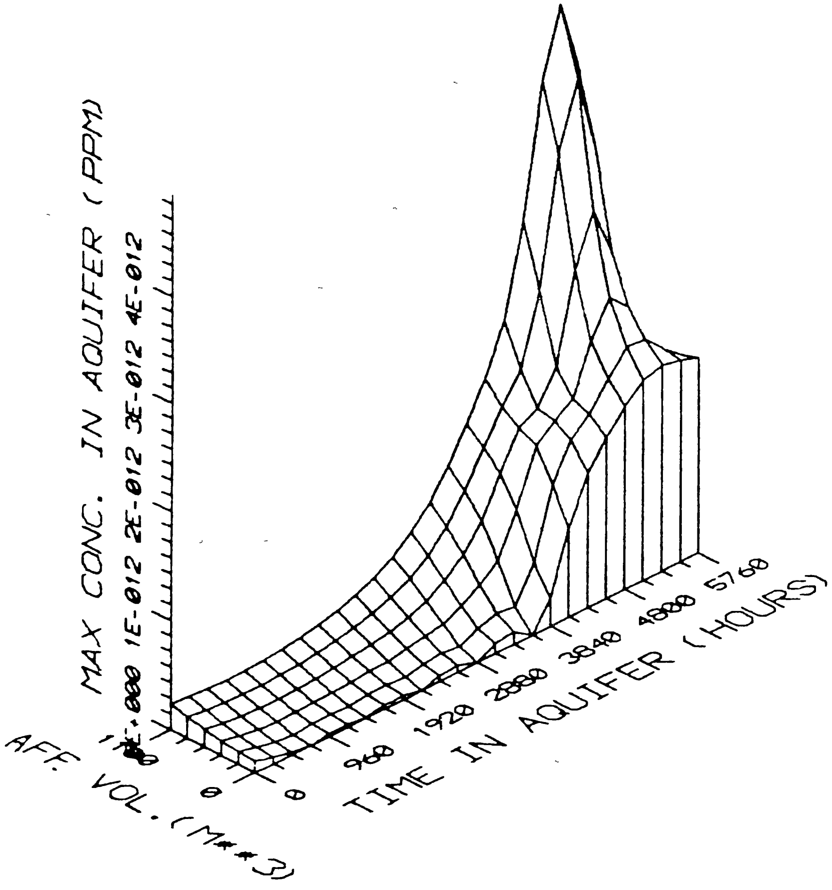
2E-012
3E-012
3E-012
AFF. VOL (M**3)
0
0
TIME IN AQUIFER (HOURS)
960
1920
2880
3840
4800
5760

107 PM DATA


MAX CONC. IN AQUIFER (PPM)
E.000 1E-012 2E-012 3E-012 4E-012
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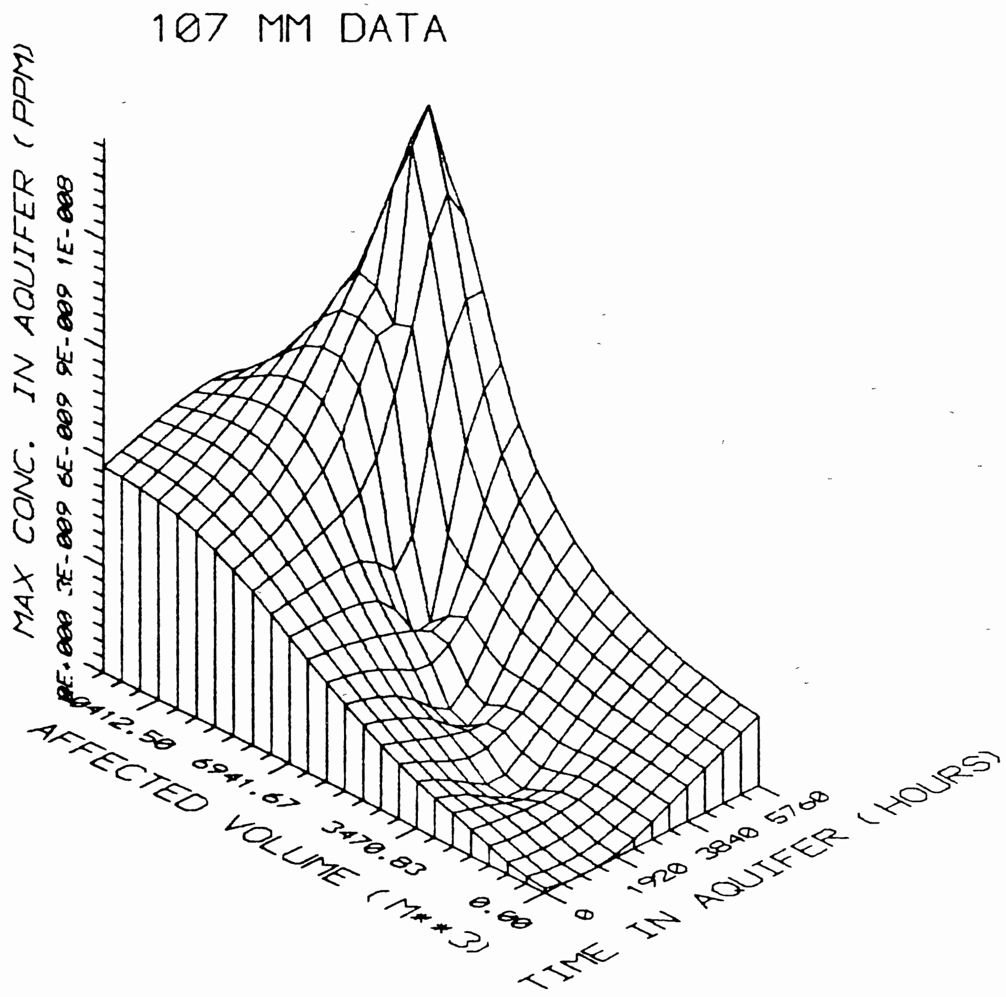
1920
2880
3840
4800
5760
TIME IN AQUIFER (HOURS)


107 MM DATA
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TIME IN AQUIFER (HOURS)
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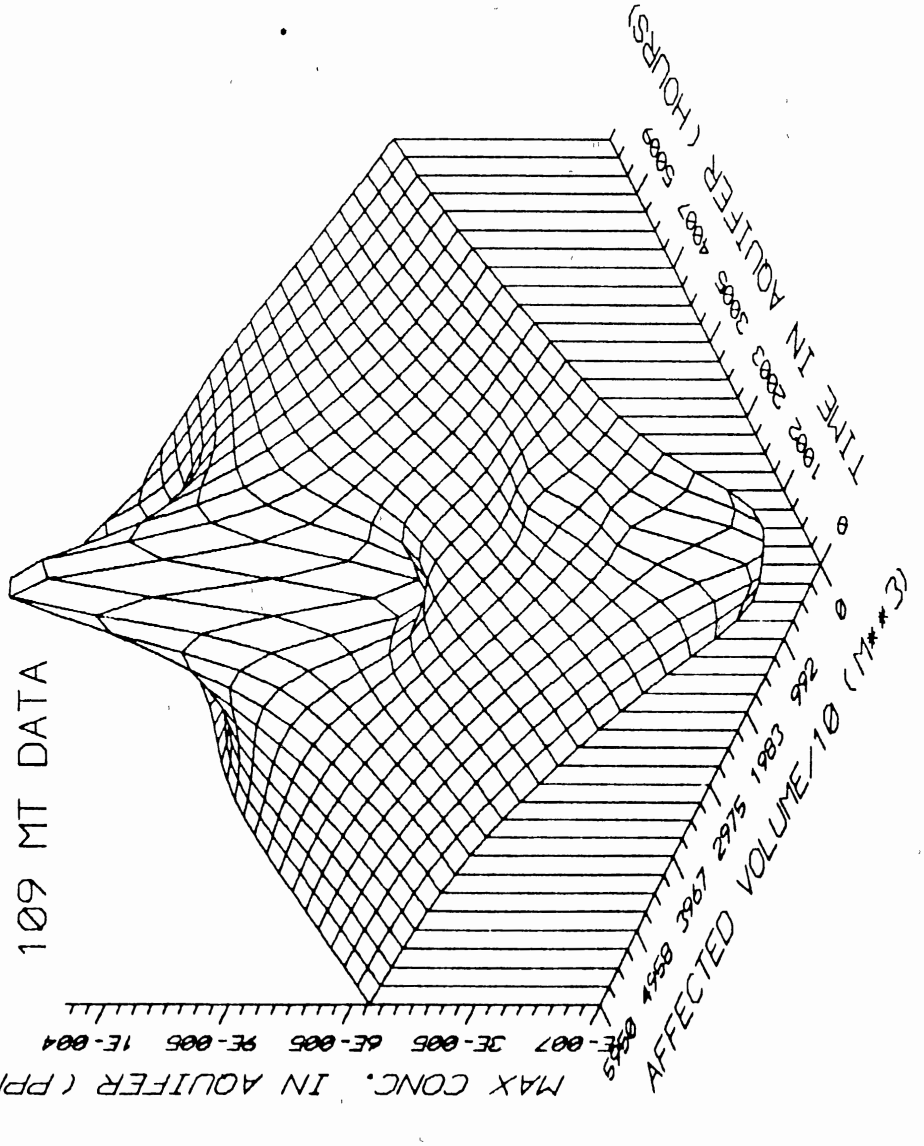109 MT DATA
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6E-005
9E-005
1E-004
AFFECTED VOLUME/10 (M**3)
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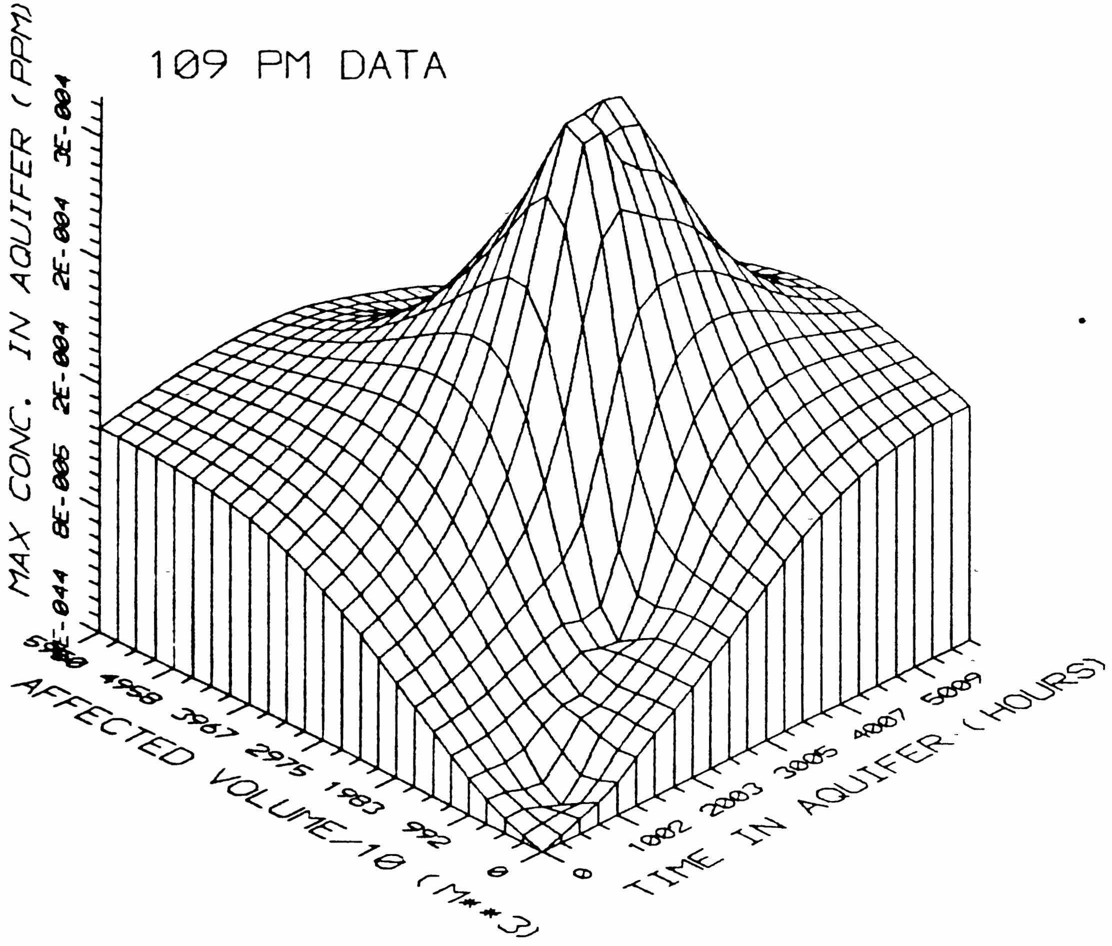
3967
2975
1983
992
0
TIME IN AQUIFER (HOURS)
0
1002
2003
3005
4007
5009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MAX CONC. IN AQUIFER (PPM)
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2E-004
2E-004
3E-004
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4958
3967
2975
1983
992
0
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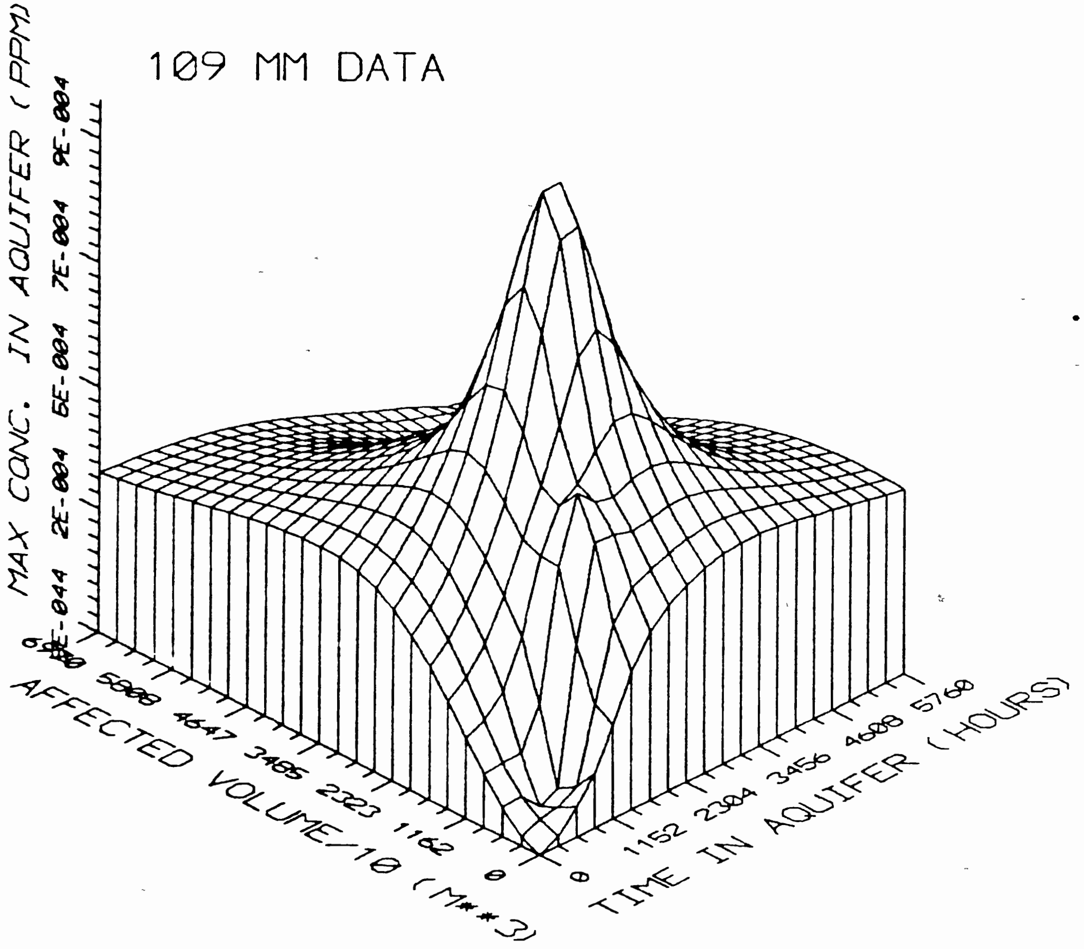
0
1002
2003
3005
4007
5009
TIME IN AQUIFER (HOURS)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5E-004
7E-004
9E-004
AFFECTED VOLUME/10 (M**3)
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1162
2323
3485
4647
5808
69
TIME IN AQUIFER (HOURS)
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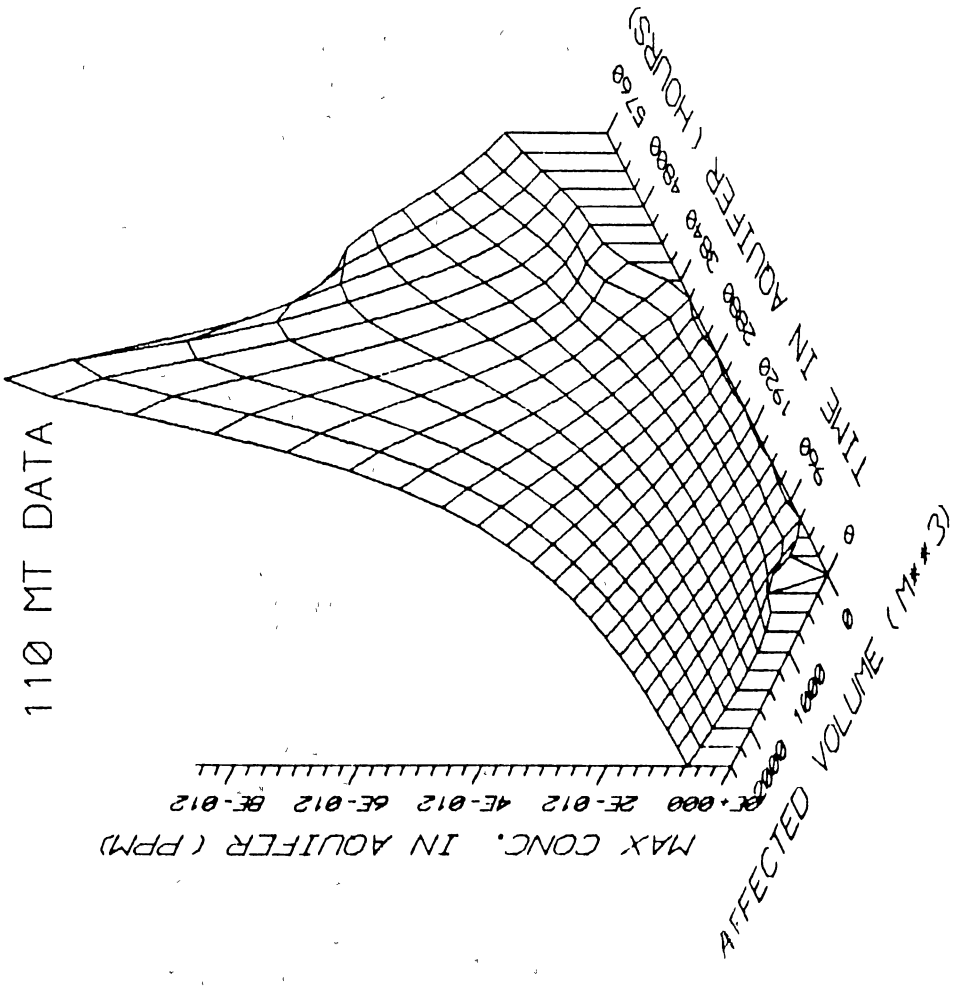
2304
3456
4608
5760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6E-012
8E-012
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TIME IN AQUIFER (HOURS)
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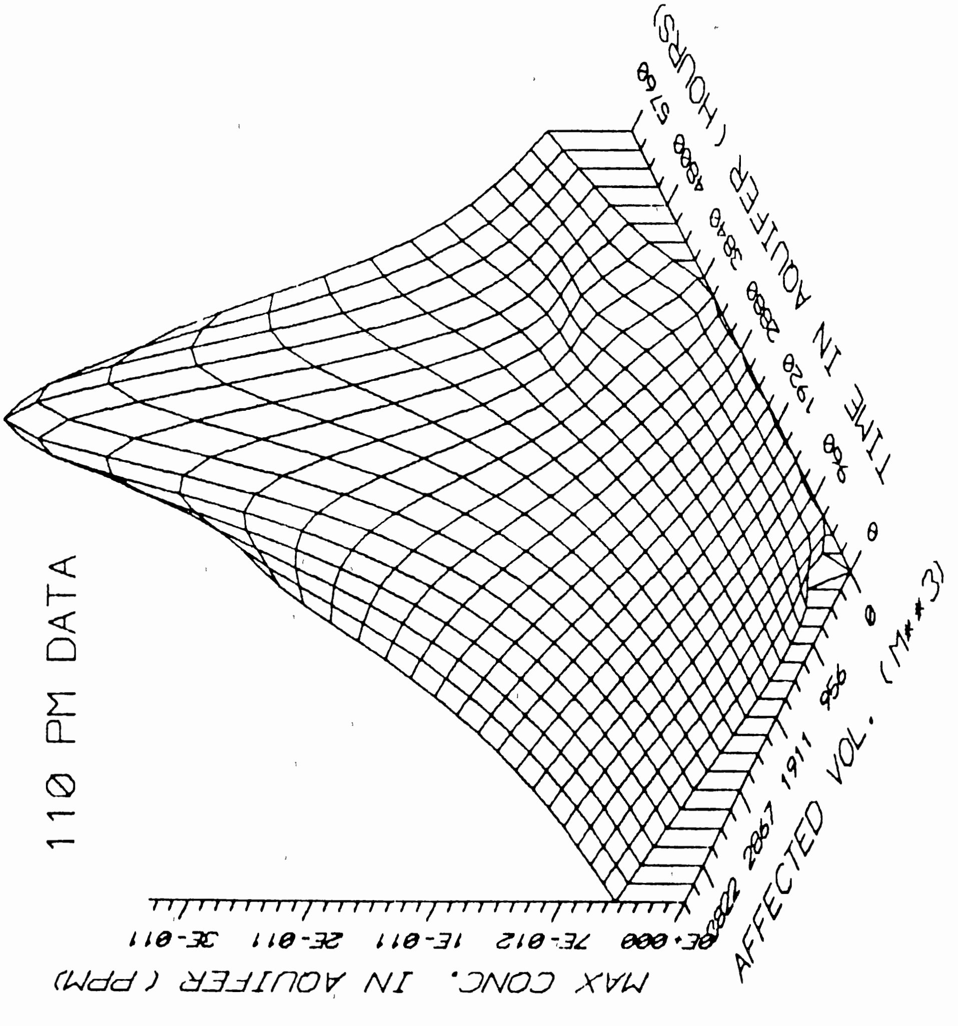
1920
2880
3840
4800
5760

110 PM DATA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1E-011
2E-011
3E-011
TIME IN AQUIFER (HOURS)
0
960
1920
2880
3840
4800
5760
AFFECTED VOL. (M**3)
0
956
1911
2867
3822

APPENDIX E

AQUIFER CHEMICAL LOADING PARAMETERS

The aquifer chemical loading parameters obtained for this evaluation from the pesticide root zone output data required a slight adjustment due to limiting factors within the AT123D aquifer zone code. The limited size of the "infinite" aquifer coupled with the large aerial extent evaluated by the agricultural zone code required the loading at the top of the aquifer be reduced from kilograms per hectare to an equivalent loading covering one square meter. The aquifer zone code could then show the detail required for this study by illustrating the movement of a contaminant with respect to time, toward the model's infinite boundary of 200 meters (approximately 660 feet). The aquifer model would not permit a manual override of its designated 200 meter infinite boundary limit. This resulted in the evaluation being able to look only one direction in the X and Y plane, as leaching surpassed the boundary limits when the source was placed in the center of the 200 meter grid of the model.

The pesticide application rate of 0.5 pounds per acre required adjustment to a per square meter rate for input into the aquifer zone code. The monthly leaching rates at the top of the aquifer obtained from the agricultural zone code simulation runs were converted to meters per hour for input into the aquifer zone code. These were extracted from the CHE.OUT data file of the agricultural zone code for compartment #35 (the deepest compartment simulated). The pesticide decay rate per day required conversion to decay rate per hour. This value was obtained from the HYE.OUT data file of the agricultural zone code as was the bulk density of soil. The organic carbon distribution coefficient (KOC) was obtained from the input while the percent organic carbon (%OC) was obtained from the output of the randomly generated input file for the agricultural zone code.

To enable monthly changes in the chemical loading (Qs) at the top of the aquifer the "continuous" source option in the program had to be chosen. To ensure no carryover of the contaminant beyond its designated time period, the final Qs was set at zero (0). Due to a maximum number of time steps of eight (8) allowed by the software, care had to be used in setting the time steps. The time step used in this report was one month, or 720 hours. This allowed simulation to the end of December as leaching did not begin occurring until May. The discharge time was the total time (sum) of Qs discharging into the aquifer. Output at 720 hours was actually at 719.9 hours as was evidenced by the second loading into the aquifer having to experience a full 720 hours of dilution before an increase in chemical concentration was realized.

Appendix F

Raw Data

FILE NAME (D)	DEPTH TO G.W. (cm)	RAINFALL YEAR (1900)	KS	KOC	CN1	CN2	CN3
2	1782.41	67	0.2961	600	94	91	92
4	1177.90	57	0.2961	600	94	91	92
6	1934.98	67	0.0023	600	94	91	92
7	1744.29	68	0.0023	600	94	91	92
8	1867.58	55	0.0023	600	94	91	92
9	1881.58	67	0.0023	600	94	91	92
10	1542.96	66	0.0023	600	94	91	92
11	1485.36	58	0.0023	600	94	91	92
12	1365.25	60	0.0023	0.001	94	91	92
13	1774.06	69	0.0023	0.001	94	91	92
15	1293.16	68	0.0023	0.001	94	91	92
16	1249.19	71	0.0023	2	94	91	92
17	1879.29	69	0.0023	2	94	91	92
18	1523.28	69	0.0023	2	94	91	92
19	1047.88	76	0.0023	2	94	91	92
21	1148.42	69	0.2961	2	94	91	92
22	1513.41	71	0.2961	2	94	91	92
23	1553.14	75	0.2961	2	94	91	92
25	1791.86	55	0.2961	2	94	91	92
26	1561.41	68	0.2961	0.001	94	91	92
27	1917.89	62	0.2961	0.001	94	91	92
29	1441.29	56	0.2961	0.001	94	91	92
30	1591.09	62	0.2961	0.001	94	91	92
32	1269.09	67	0.2961	600	77	67	72
33	1557.49	73	0.2961	600	77	67	72
34	1972.15	54	0.2961	600	77	67	72
35	959.75	69	0.2961	600	77	67	72
37	1552.12	72	0.0023	600	77	67	72
38	1233.48	71	0.0023	600	77	67	72
40	1766.86	55	0.0023	600	77	67	72
41	988.54	68	0.0023	0.001	77	67	72
42	1946.55	69	0.0023	0.001	77	67	72
43	1913.67	77	0.0023	0.001	77	67	72
45	1403.81	78	0.0023	0.001	77	67	72
46	1836.32	62	0.0023	2	77	67	72
47	926.71	62	0.0023	2	77	67	72
48	1789.54	54	0.0023	2	77	67	72

49	1193.70	77	0.0023	2	77	67	72
50	1504.92	64	0.0023	2	77	67	72
51	1671.81	67	0.2961	2	77	67	72
52	1609.74	69	0.2961	2	77	67	72
53	1509.00	57	0.2961	2	77	67	72
54	1958.26	70	0.2961	2	77	67	72
55	1216.02	70	0.2961	2	77	67	72
56	1956.71	71	0.2961	0.001	77	67	72
57	1785.15	69	0.2961	0.001	77	67	72
60	978.82	77	0.2961	0.001	77	67	72
61	286.11	75	0.2961	600	94	91	92
62	358.50	66	0.2961	600	94	91	92
63	162.61	56	0.2961	600	94	91	92
65	601.59	63	0.2961	600	94	91	92
70	628.81	62	0.0023	600	94	91	92
72	556.12	57	0.0023	0.001	94	91	92
73	125.21	63	0.0023	0.001	94	91	92
75	56.22	57	0.0023	0.001	94	91	92
78	811.05	65	0.0023	2	94	91	92
82	425.94	66	0.2961	2	94	91	92
83	772.47	70	0.2961	2	94	91	92
84	759.26	67	0.2961	2	94	91	92
86	56.76	60	0.2961	0.001	94	91	92
88	502.52	65	0.2961	0.001	94	91	92
90	274.33	76	0.2961	0.001	94	91	92
96	640.61	65	0.0023	600	77	67	72
97	239.34	74	0.0023	600	77	67	72
98	88.63	58	0.0023	600	77	67	72
101	308.42	62	0.0023	0.001	77	67	72
102	811.69	67	0.0023	0.001	77	67	72
107	771.05	71	0.0023	2	77	67	72
109	229.60	58	0.0023	2	77	67	72
110	501.14	56	0.0023	2	77	67	72
112	756.13	64	0.2961	2	77	67	72
115	781.23	73	0.2961	2	77	67	72
117	514.10	71	0.2961	0.001	77	67	72

NO IRRIGATION

	NORMAL		RAINFALL		
FILE NAME (D)	LEACHING OUTPUT @ 12" (decimal)	COMPART. LEACHED TO	DEPTH LEACHED TO (cm)	LEACHING OUTPUT @ DTGW (decimal)	PLANT UPTAKE OF PESTICIDE (decimal)
2	5.88E-04	11	560.19	0.00E+00	0.00E+00
4	2.40E-03	12	403.85	0.00E+00	1.29E-09
6	4.15E-02	14	773.99	0.00E+00	0.00E+00
7	3.21E-02	13	647.88	0.00E+00	0.00E+00
8	2.45E-02	13	693.67	0.00E+00	0.00E+00
9	3.34E-02	14	752.63	0.00E+00	0.00E+00
10	2.28E-02	13	573.10	0.00E+00	0.00E+00
11	3.89E-01	35	1485.36	5.62E-19	0.00E+00
12	3.29E-01	33	1287.24	0.00E+00	8.80E-03
13	3.06E-01	33	1672.69	0.00E+00	0.00E+00
15	6.06E-01	35	1293.16	4.84E-24	2.06E-02
16	3.61E-01	35	1249.19	3.48E-14	1.54E-02
17	2.84E-01	26	1396.04	0.00E+00	0.00E+00
18	3.56E-01	30	1305.67	0.00E+00	0.00E+00
19	2.67E-01	35	1047.88	2.04E-23	2.96E-02
21	5.03E-02	26	853.11	0.00E+00	7.85E-08
22	1.29E-04	31	1340.45	0.00E+00	0.00E+00
23	8.08E-06	20	887.51	0.00E+00	0.00E+00
25	1.78E-02	25	1279.90	0.00E+00	0.00E+00
26	2.05E-02	27	1204.52	0.00E+00	0.00E+00
27	7.90E-04	30	1643.91	0.00E+00	0.00E+00
29	4.82E-04	24	988.31	0.00E+00	0.00E+00
30	3.63E-04	25	1136.49	0.00E+00	0.00E+00
32	4.65E-04	11	398.86	0.00E+00	0.00E+00
33	4.54E-04	14	623.00	0.00E+00	0.00E+00
34	3.05E-03	11	619.82	0.00E+00	0.00E+00
35	4.75E-05	13	356.48	0.00E+00	1.50E-10
37	2.91E-02	14	620.85	0.00E+00	0.00E+00
38	6.13E-02	16	563.88	0.00E+00	8.28E-05
40	5.76E-02	15	757.23	0.00E+00	0.00E+00
41	8.01E-01	35	988.54	1.74E-14	2.72E-02
42	7.66E-01	35	1946.55	6.87E-21	0.00E+00
43	6.90E-01	35	1913.67	2.49E-22	0.00E+00
45	8.60E-01	35	1403.81	2.11E-17	0.00E+00
46	7.08E-01	35	1836.32	3.04E-21	0.00E+00
47	7.52E-01	35	926.71	4.08E-12	6.58E-02
48	5.23E-01	32	1636.15	0.00E+00	0.00E+00

49	7.65E-01	35	1193.70	5.60E-18	1.53E-02
50	7.48E-01	35	1504.92	1.68E-14	0.00E+00
51	2.35E-02	35	1671.81	5.93E-22	0.00E+00
52	1.13E-01	32	1471.76	0.00E+00	0.00E+00
53	1.42E-01	35	1509.00	5.74E-21	0.00E+00
54	6.05E-03	35	1958.26	3.75E-21	0.00E+00
55	2.60E-03	32	1111.79	0.00E+00	5.23E-09
56	5.90E-04	30	1677.18	0.00E+00	0.00E+00
57	1.25E-01	35	1785.15	7.53E-18	0.00E+00
60	2.27E-02	35	978.82	4.54E-19	4.51E-08
61	6.54E-09	16	130.79	0.00E+00	1.35E-07
62	2.13E-07	14	143.40	0.00E+00	3.56E-09
63	3.74E-10	21	97.57	0.00E+00	2.76E-06
65	6.53E-07	12	206.26	0.00E+00	0.00E+00
70	2.56E-02	18	323.39	0.00E+00	8.13E-03
72	5.48E-01	35	556.12	3.97E-17	1.55E-01
73	4.83E-01	35	125.21	3.74E-06	4.14E-01
75	8.94E-01	35	56.22	5.34E-01	2.43E-01
78	4.88E-01	35	811.05	2.17E-11	6.95E-02
82	1.33E-04	35	425.94	4.77E-22	9.76E-08
83	1.00E-13	17	375.20	0.00E+00	1.97E-09
84	4.10E-04	29	629.10	0.00E+00	1.90E-09
86	1.04E-02	35	56.76	6.56E-04	1.59E-05
88	8.06E-04	35	502.52	2.87E-20	5.76E-08
90	3.86E-03	35	274.33	1.12E-06	0.00E+00
96	2.19E-02	21	384.37	0.00E+00	1.84E-03
97	4.78E-03	29	198.31	0.00E+00	5.92E-03
98	3.62E-07	33	83.57	0.00E+00	1.71E-02
101	8.95E-01	35	308.42	2.44E-01	4.64E-02
102	7.52E-01	35	811.69	3.94E-15	5.39E-02
107	8.24E-01	35	771.05	2.45E-09	4.97E-02
109	8.16E-01	35	229.60	1.58E-01	1.51E-01
110	7.94E-01	35	501.14	5.68E-09	1.44E-01
112	1.42E-02	35	756.13	4.37E-16	3.10E-08
115	1.11E-03	35	781.23	1.70E-16	7.59E-09
117	3.41E-04	35	514.10	1.07E-14	3.93E-08

			TRADITIONAL	IRRIGATION	
FILE NAME (D)	PESTICIDE DECAY (decimal)	PESTICIDE RUNOFF (decimal)	LEACHING OUTPUT @ 12" (decimal)	COMPART LEACHED TO	DEPTH LEACHED TO (cm)
2	0.9992	7.68E-04	6.03E-04	12	611.11
4	0.9994	6.00E-04	2.40E-03	12	403.85
6	0.3077	2.91E-02	6.91E-02	15	829.28
7	0.3181	2.69E-02	4.88E-02	14	697.72
8	0.3082	4.12E-02	3.84E-02	13	693.67
9	0.3122	2.12E-02	5.70E-02	15	806.39
10	0.3326	2.26E-02	4.10E-02	14	617.18
11	0.1631	4.81E-01	3.63E-01	35	1485.36
12	0.1358	5.73E-01	2.88E-01	35	1365.25
13	0.1642	4.84E-01	2.87E-01	35	1774.06
15	0.1751	3.31E-01	5.54E-01	35	1293.16
16	0.1603	5.32E-01	2.29E-01	35	1249.19
17	0.1946	3.87E-01	2.88E-01	31	1664.51
18	0.1597	4.85E-01	3.31E-01	35	1523.28
19	0.2295	3.34E-01	3.74E-01	35	1047.88
21	0.9184	8.16E-02	5.03E-02	30	984.36
22	0.9941	5.91E-03	1.19E-04	35	1513.41
23	0.237	7.24E-02	5.83E-05	25	1109.39
25	0.9687	3.13E-02	1.79E-02	27	1382.29
26	0.989	1.10E-02	2.05E-02	31	1382.96
27	0.9989	1.07E-03	7.56E-04	35	1917.89
29	0.9989	1.06E-03	5.31E-04	28	1153.03
30	0.9995	5.18E-04	3.55E-04	30	1363.79
32	1	2.46E-06	4.70E-04	13	471.38
33	0.9999	1.47E-04	4.82E-04	15	667.50
34	0.9998	1.57E-04	3.06E-03	12	676.17
35	0.9996	3.68E-04	5.02E-05	14	383.90
37	0.3358	9.30E-03	8.02E-02	16	709.54
38	0.3596	8.08E-03	1.07E-01	17	599.12
40	0.3181	9.04E-03	9.76E-02	16	807.71
41	0.2395	2.40E-02	8.39E-01	35	988.54
42	0.2346	5.99E-02	8.23E-01	35	1946.55
43	0.237	7.24E-02	7.76E-01	35	1913.67
45	0.2296	5.14E-02	8.84E-01	35	1403.81
46	0.2526	4.82E-02	7.39E-01	35	1836.32
47	0.2477	2.67E-02	7.76E-01	35	926.71
48	0.2695	2.44E-02	7.82E-01	35	1789.54

49	0.235	8.69E-02	7.92E-01	35	1193.70
50	0.2435	9.59E-02	7.86E-01	35	1504.92
51	1	3.44E-05	2.38E-02	35	1671.81
52	0.9872	1.27E-02	1.13E-01	35	1609.74
53	0.9982	1.80E-03	1.42E-01	35	1509.00
54	0.9982	1.77E-03	6.56E-03	35	1958.26
55	0.9992	8.34E-04	2.69E-03	35	1216.02
56	1	2.91E-05	7.92E-04	35	1956.71
57	0.9848	1.52E-02	1.26E-01	35	1785.15
60	0.9993	6.51E-04	2.32E-02	35	978.82
61	0.9918	8.21E-03	1.82E-08	19	155.32
62	0.9998	1.53E-04	2.29E-07	16	163.89
63	0.9999	9.37E-05	1.07E-09	23	106.86
65	1	1.58E-07	7.26E-07	14	240.64
70	0.3322	1.67E-01	5.07E-02	20	359.32
72	0.1409	3.64E-01	5.86E-01	35	556.12
73	0.1975	3.38E-02	7.17E-01	35	125.21
75	0.1367	3.04E-02	9.20E-01	35	56.22
78	0.2008	3.03E-01	4.72E-01	35	811.05
82	0.9985	1.52E-03	1.40E-04	35	425.94
83	0.9944	5.59E-03	6.54E-06	26	573.83
84	0.9868	1.32E-02	4.40E-04	35	759.26
86	0.9674	3.20E-02	1.04E-02	35	56.76
88	0.9962	3.78E-03	8.31E-04	35	502.52
90	1	1.39E-05	3.94E-03	35	274.33
96	0.3769	8.18E-03	7.65E-02	26	475.88
97	0.3795	2.81E-08	2.87E-02	33	225.66
98	0.3808	5.43E-03	6.02E-05	35	88.63
101	0.2147	1.48E-02	8.71E-01	35	308.42
102	0.2601	9.77E-03	8.19E-01	35	811.69
107	0.2396	3.48E-02	7.64E-01	35	771.05
109	0.208	1.54E-02	8.93E-01	35	229.60
110	0.2204	6.80E-02	8.55E-01	35	501.14
112	0.9941	5.86E-03	1.44E-02	35	756.13
115	0.998	1.97E-03	1.20E-03	35	781.23
117	1	9.53E-06	3.60E-04	35	514.10

					SCIENTIFIC
FILE NAME (D)	LEACHING OUTPUT @ DTGW (decimal)	PLANT UPTAKE OF PESTICIDE (decimal)	PESTICIDE DECAY (decimal)	PESTICIDE RUNOFF (decimal)	LEACHING OUTPUT @ 12" (decimal)
2	0.00E+00	0.00E+00	0.9992	8.05E-04	5.88E-04
4	0.00E+00	1.27E-09	0.9994	6.03E-04	2.40E-03
6	0.00E+00				
7	0.00E+00	0.00E+00	0.305	7.26E-02	3.21E-02
8	0.00E+00	0.00E+00	0.2973	8.08E-02	2.89E-02
9	0.00E+00	0.00E+00	0.2966	7.66E-02	3.54E-02
10	0.00E+00	0.00E+00	0.3176	7.27E-02	2.70E-02
11	2.34E-13	0.00E+00	0.1239	5.83E-01	4.23E-01
12	7.08E-23	3.54E-03	0.1005	6.67E-01	3.38E-01
13	2.31E-21	0.00E+00	0.1041	6.60E-01	3.83E-01
15	3.15E-19	6.44E-03	0.1526	4.04E-01	6.06E-01
16	6.27E-11	1.58E-03	0.1069	7.07E-01	3.91E-01
17	0.00E+00	0.00E+00	0.1201	6.25E-01	3.63E-01
18	6.57E-25	0.00E+00	0.1083	6.25E-01	4.23E-01
19	2.33E-17	1.04E-02	0.1596	4.92E-01	2.67E-01
21	0.00E+00	2.79E-08	0.9184	8.16E-02	5.03E-02
22	3.63E-23	0.00E+00	0.9938	6.15E-03	1.63E-04
23	0.00E+00	0.00E+00	0.9719	2.81E-02	1.01E-04
25	0.00E+00				1.99E-02
26	0.00E+00	0.00E+00	0.9888	1.12E-02	2.05E-02
27	2.32E-23	0.00E+00	0.9985	1.53E-03	1.53E-03
29	0.00E+00	0.00E+00	0.9988	1.19E-03	6.50E-04
30	0.00E+00	0.00E+00	0.9992	7.61E-04	7.36E-04
32	0.00E+00	0.00E+00	1	4.14E-06	4.65E-04
33	0.00E+00	0.00E+00	0.9998	1.55E-04	1.13E-03
34	0.00E+00	0.00E+00	0.9998	1.62E-04	3.05E-03
35	0.00E+00	1.45E-10	0.9996	3.68E-04	4.76E-05
37	0.00E+00	0.00E+00	0.3268	2.40E-02	3.47E-02
38	0.00E+00	1.93E-04	0.3473	3.04E-02	6.39E-02
40	0.00E+00	0.00E+00	0.3112	2.32E-02	6.20E-02
41	9.23E-09	2.31E-03	0.2187	9.39E-02	8.01E-01
42	5.14E-13	0.00E+00	0.2036	1.33E-01	8.05E-01
43	1.99E-16	0.00E+00	0.2027	1.59E-01	7.06E-01
45	2.78E-11	0.00E+00	0.2161	7.61E-02	8.64E-01
46	3.01E-16	0.00E+00	0.2073	1.75E-01	7.55E-01
47	9.23E-08	4.62E-03	0.217	1.43E-01	8.02E-01
48	1.80E-18	0.00E+00	0.2158	1.20E-01	7.01E-01

49	2.95E-12	2.36E-03	0.2048	1.57E-01	7.76E-01
50	1.14E-09	0.00E+00	0.21	1.50E-01	7.58E-01
51	3.96E-13	0.00E+00	0.9993	1.22E-04	2.35E-02
52	2.49E-20	0.00E+00	0.9872	1.28E-02	1.13E-01
53	9.23E-18	0.00E+00	0.9982	1.82E-03	1.42E-01
54	1.16E-15	0.00E+00	0.9981	1.93E-03	1.22E-02
55	1.83E-21	6.48E-10	0.9991	8.66E-04	5.44E-03
56	5.68E-22	0.00E+00	0.9997	3.26E-04	6.88E-04
57	2.37E-12	0.00E+00	0.9847	1.52E-02	1.25E-01
60	7.24E-16	5.03E-09	0.9993	6.63E-04	2.27E-02
61	0.00E+00	1.56E-07	0.9918	8.23E-03	2.18E-08
62	0.00E+00	7.44E-09	0.9998	1.75E-04	2.13E-07
63	0.00E+00	2.76E-06	0.9999	1.08E-04	5.99E-10
65	0.00E+00	0.00E+00	1	3.25E-06	7.78E-07
70	0.00E+00	9.78E-03	0.2634	3.61E-01	3.72E-02
72	5.92E-13	5.85E-02	0.1484	3.69E-01	5.70E-01
73	3.21E-02	1.81E-01	0.206	5.41E-02	6.46E-01
75	8.74E-01	1.82E-02	0.076	3.04E-02	9.05E-01
78	2.75E-07	8.63E-03	0.1566	4.48E-01	5.14E-01
82	3.82E-17	1.08E-07	0.9984	1.62E-03	1.33E-04
83	0.00E+00	1.70E-09	0.9943	5.66E-03	1.50E-05
84	4.56E-23	9.75E-10	0.9868	1.32E-02	4.10E-04
86	9.39E-04	1.52E-05	0.9671	3.20E-02	1.04E-02
88	1.71E-15	2.56E-08	0.9962	3.83E-03	8.06E-04
90	3.55E-05	0.00E+00	0.9999	2.49E-05	3.86E-03
96	0.00E+00	3.95E-03	0.3523	5.17E-02	2.33E-02
97	0.00E+00	2.26E-02	0.3544	8.43E-02	1.58E-02
98	1.14E-18	1.79E-02	0.3732	2.85E-02	6.76E-07
101	8.06E-01	5.44E-03	0.1093	6.22E-02	9.16E-01
102	7.83E-08	4.42E-03	0.2249	1.00E-01	7.66E-01
107	1.15E-05	3.47E-03	0.2116	1.63E-01	8.40E-01
109	8.35E-01	1.98E-02	0.103	2.48E-02	8.28E-01
110	4.47E-04	6.12E-03	0.223	8.48E-02	8.25E-01
112	7.63E-11	2.04E-09	0.9941	5.87E-03	1.42E-02
115	2.79E-12	1.07E-09	0.998	1.98E-03	0.003114
117	5.14E-10	6.10E-09	1	3.87E-05	3.99E-04

IRRIGATION

FILE NAME (D)	COMPART. LEACHED TO	DEPTH LEACHED TO (cm)	LEACHING OUTPUT @ DTGW (decimal)	PLANT UPTAKE OF PESTICIDE (decimal)	PESTICIDE DECAY (decimal)
2	11	560.19	0.00E+00	0.00E+00	0.9992
4	12	403.85	0.00E+00	1.18E-10	0.9994
6	35	1934.98	0.00E+00		
7	13	647.88	0.00E+00	0.00E+00	0.3181
8	13	693.67	0.00E+00	0.00E+00	0.3078
9	14	752.63	0.00E+00	0.00E+00	0.3121
10	13	573.10	0.00E+00	0.00E+00	0.3321
11	35	1485.36	9.73E-17	0.00E+00	0.1634
12	33	1287.24	0.00E+00	8.79E-03	0.1359
13	35	1774.06	1.34E-25	0.00E+00	0.1623
15	35	1293.16	4.84E-24	2.06E-02	0.1751
16	35	1249.19	9.69E-14	1.44E-02	0.1623
17	28	1503.43	0.00E+00	0.00E+00	0.1912
18	32	1392.71	0.00E+00	0.00E+00	0.1578
19	35	1047.88	2.04E-23	2.96E-02	0.2295
21	26	853.11	0.00E+00	5.37E-08	0.9184
22	32	1383.69	0.00E+00	0.00E+00	0.9941
23	21	931.88	0.00E+00	0.00E+00	0.9722
25	25	1279.90	0.00E+00	0.00E+00	0.969
26	27	1204.52	0.00E+00	0.00E+00	0.989
27	32	1753.50	0.00E+00	0.00E+00	0.999
29	24	988.31	0.00E+00	0.00E+00	0.999
30	26	1181.95	0.00E+00	0.00E+00	0.9995
32	11	398.86	0.00E+00	0.00E+00	1
33	14	623.00	0.00E+00	0.00E+00	0.9998
34	11	619.82	0.00E+00	0.00E+00	0.9998
35	13	356.48	0.00E+00	1.54E-10	0.9996
37	14	620.85	0.00E+00	0.00E+00	0.3352
38	16	563.88	0.00E+00	8.92E-05	0.3593
40	15	757.23	0.00E+00	0.00E+00	0.3177
41	35	988.54	1.74E-14	2.72E-02	0.2395
42	35	1946.55	1.35E-19	0.00E+00	0.2296
43	35	1913.67	3.66E-22	0.00E+00	0.2357
45	35	1403.81	2.75E-17	0.00E+00	0.2291
46	35	1836.32	1.10E-20	0.00E+00	0.249
47	35	926.71	1.39E-11	4.78E-02	0.2455
48	35	1789.54	0.00E+00	0.00E+00	0.2542

49	35	1193.70	8.29E-18	1.44E-02	0.2335
50	35	1504.92	2.63E-14	0.00E+00	0.2424
51	35	1671.81	1.04E-21	0.00E+00	1
52	33	1517.75	0.00E+00	0.00E+00	0.9872
53	35	1509.00	5.80E-21	0.00E+00	0.9982
54	35	1958.26	1.85E-20	0.00E+00	0.9977
55	33	1146.53	0.00E+00	7.50E-09	0.9989
56	30	1677.18	0.00E+00	0.00E+00	1
57	35	1785.15	1.81E-17	0.00E+00	0.9848
60	35	978.82	4.57E-19	3.83E-08	0.9993
61	17	138.97	0.00E+00	1.50E-07	0.9917
62	15	153.64	0.00E+00	4.76E-09	0.9998
63	21	97.57	0.00E+00	2.80E-06	0.9999
65	13	223.45	0.00E+00	0.00E+00	1
70	19	341.35	0.00E+00	9.55E-03	0.3305
72	35	556.12	6.82E-14	4.33E-02	0.1558
73	35	125.21	2.09E-05	3.25E-01	0.2124
75	35	56.22	7.67E-01	6.55E-02	0.1286
78	35	811.05	5.14E-11	6.31E-02	0.2025
82	35	425.94	6.87E-21	1.27E-07	0.9985
83	23	507.62	0.00E+00	6.71E-09	0.9944
84	30	650.79	0.00E+00	1.71E-09	0.9868
86	35	56.76	6.65E-04	1.57E-05	0.9673
88	35	502.52	7.48E-20	5.59E-08	0.9962
90	35	274.33	1.12E-06	0.00E+00	1
96	21	384.37	0.00E+00	1.89E-03	0.3766
97	31	211.99	0.00E+00	2.11E-02	0.3758
98	35	88.63	0.00E+00	1.24E-02	0.3819
101	35	308.42	3.97E-01	2.55E-02	0.2009
102	35	811.69	6.70E-15	5.10E-02	0.2585
107	35	771.05	3.63E-09	4.28E-02	0.2394
109	35	229.60	3.56E-01	8.75E-02	0.1947
110	35	501.14	1.83E-08	1.20E-01	0.221
112	35	756.13	7.07E-16	2.65E-08	0.9941
115	35	7.5E-16	7.52E-16	7.91E-09	9.98E-01
117	35	514.10	1.67E-14	3.60E-08	1

FILE NAME (D)	PESTICIDE RUNOFF (decimal)
2	7.68E-04
4	6.00E-04
6	
7	2.69E-02
8	4.14E-02
9	2.12E-02
10	2.28E-02
11	4.64E-01
12	5.67E-01
13	4.53E-01
15	3.31E-01
16	5.07E-01
17	3.65E-01
18	4.55E-01
19	3.34E-01
21	8.16E-02
22	5.92E-03
23	2.78E-02
25	3.10E-02
26	1.10E-02
27	1.00E-03
29	1.03E-03
30	4.94E-04
32	2.46E-06
33	1.79E-04
34	1.57E-04
35	3.68E-04
37	9.42E-03
38	8.07E-03
40	9.26E-03
41	2.40E-02
42	6.09E-02
43	7.21E-02
45	5.12E-02
46	4.09E-02
47	2.05E-02
48	2.47E-02

49	8.66E-02
50	9.30E-02
51	3.44E-05
52	1.27E-02
53	1.80E-03
54	2.34E-03
55	1.13E-03
56	2.97E-05
57	1.52E-02
60	6.51E-04
61	8.30E-03
62	1.53E-04
63	9.29E-05
65	1.57E-07
70	1.63E-01
72	3.63E-01
73	6.60E-03
75	3.04E-02
78	2.89E-01
82	1.52E-03
83	5.58E-03
84	1.32E-02
86	3.20E-02
88	3.78E-03
90	1.39E-05
96	8.16E-03
97	2.20E-02
98	5.70E-03
101	7.70E-03
102	9.16E-03
107	3.05E-02
109	1.52E-02
110	6.17E-02
112	5.86E-03
115	0.002379
117	1.22E-05

VITA

Edward David Mize

Candidate for the Degree of

Master of Science

Thesis: AN EVALUATION OF GROUNDWATER CONTAMINATION UTILIZING SELECT UNCERTAINTIES ASSOCIATED WITH AGRICULTURAL CHEMICALS

Major Field: Civil Engineering

Biographical:

Personal Data: Born in Tulsa, Oklahoma, July 13, 1954, the son of William Edward and Nona Catherine Mize.

Education: Graduated from Charles Page High School, Sand Springs, Oklahoma, in June 1972; received Bachelor of Science Degree in Petroleum Engineering from Tulsa University, Tulsa, Oklahoma, in June 1976; completed requirements for the Master of Science degree at Oklahoma State University in December, 1989.

Professional Experience: Registered Professional Engineer in the state of Oklahoma; Member of Tau Beta Pi; Engineer, Gulf Oil Corporation, both domestic and international experience, June 1976 to August 1985; Engineer, Chevron U.S.A., Casper, Wyoming, August 1985 to August 1986; Consultant, Independent, Oklahoma/Wyoming, August 1986 to March 1987; Engineer/Trust Officer, First National Bank and Trust Company of Tulsa, Tulsa, Oklahoma, March 1987 to November 1987; City Engineer, Bixby, Oklahoma, July 1988 to present.