EVALUATING POTENTIAL IMPACT OF A BOLL WEEVIL ERADICATION PROGRAM ON REGIONAL WATER RESOURCES AND THREATENED/ENDANGERED SPECIES IN OKLAHOMA

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CHAPTER I

LITERATURE REVIEW

Cotton is an agricultural crop that has been extensively cultivated in the area with a long growing season, fertile soil, warm temperature, and adequate soil moisture. Oklahoma is a cotton-growing state located on the northern boundary of the U.S. Cotton Belt. Cotton production is primarily concentrated in the southwestern region of the state. During 1992, approximate 149,734 ha was planted and 210,000 bales of cotton valued at $43 million were produced (Oklahoma Department of Agriculture, 1992).

Cotton crops are annually exposed to attacks from various cotton insects. Among them, boll weevil, *Anthonomus grandis*, has been cited by cotton growers as one of the most harmful pests that inflict economic damage (Karner et al., 1993). In years with mild winters, high survival of weevils can occur and widespread economic losses result (Karner and Price, 1992). From 1988 to 1992, a statewide total reduction in cotton yields attributed to weevil infestations was 27,071 bales (Head, 1990, 1991, 1992, 1993, Karner, 1994 unpublished data).

The boll weevil is a migratory pest. To efficiently control the pest, joint actions of cotton producers are needed. The boll weevil eradication program is a cooperative effort for eliminating the established weevil populations in a large cotton-producing region (Carlson and Suguiyama, 1985, Animal and Plant Health Inspection Service, 1991). It is conducted and supervised by the Animal and Plant Health Inspection Service (APHIS) of U.S. Department of Agriculture (USDA), in conjunction with state agencies and cotton producers. Under the eradication program, all the cotton areas infested by weevils would receive insecticide treatments. Several sprays would be applied to the heavily infested fields. Four insecticides which are suggested for use in the program include azinphos-methyl, methyl-parathion, malathion, and diflubenzuron. The treatments will be scheduled for spring, midseason, and fall period of each program year and concentrated in the initial three years. The number of applications varies from field to field, depending on the initial infestation level of the pest. On the average, the application frequency of the insecticides except diflubenzuron is four in the fall of program year one, eight in the full growing season of year two, and four in year three. Diflubenzuron will not be applied in the first year and may be used for the spring treatment in the program year two and three. Completion of the program requires a total of four and half years (APHIS, 1991).

Agricultural Nonpoint Source Pollution

Nonpoint source (NPS) of pollution is a term which has been widely used in water pollution assessment. The term nonpoint source is used by some researchers to indicate the discharge of waste water to water courses without passing through sewers (Duttweiler and Nicholson, 1983). Nonpoint pollution source may be defined as the diffuse discharge of pollutant into a water body that can not be located as to specific source, as with sediment, certain agricultural chemicals, and acid mine drainage (Overcash and Davidson, 1981).

Agricultural use of pesticides in the United States has been recognized as a significant nonpoint source of water pollution (Great Plains Agricultural Council Water Quality Task Force, 1992, Duttweiler and Nicholson, 1983, Gilliland and Baxter-Potter, 1987, Deliman and Wolfe, 1990). Under certain circumstances, large amounts of pesticides applied to agricultural fields can leave their original application sites, reach surface and ground water systems, and result in adverse impacts on aquatic environment. There are several general characteristics that describe agricultural nonpoint source pollution: (1) nonpoint source discharges are diffuse in nature and spread over an extensive area of crop land, (2) nonpoint source pollution is stochastic and essentially determined by natural events and processes, (3) nonpoint source pollution is dynamic in the sense that land uses and configurations change over time making the quantity and type of pollutant vary both spatially and temporally, and (4) control of the pollution is most effectively achieved by best management practices (Bailey and Swank, 1983, Novotny and Chesters, 1981).

Pesticide Transport

Pesticides applied on crops and on the top of soil can be washed off by rainfall and enter surface and ground water. Primary processes and mechanisms of pesticide transport from cropland to surface and ground water have been investigated and described by many researchers (Khaleel, 1981, Onishi et al., 1982, Rao et al., 1983, Cheng and Koskinen, 1986). Pesticide residues reach surface and ground waters through two pathways: runoff and leaching. Runoff is the physical transport of pollutants over the ground surface by rain water. Leaching is a process through which pollutants are flushed through the soil by rain or irrigation water as it moves downward.

The pesticide released to the environment undergoes complex and dynamic interactions of processes which control and affect its fate and movement in the soil environment. Donigian and Rao (1986) and Smith et al. (1989) listed the major processes including sorption, transformation or degradation, volatilization, and plant uptake. When a pesticide enters soil, some of it will be adsorbed onto soil particles, particularly organic matter, through the process called adsorption. The partitioning of a pesticide between dissolved and adsorbed phases determines the mass of a pesticide that is easily available for transport. A detailed discussion of pesticide adsorption onto soil was given by Jury (1986a). The transformation of a pesticide is any change in the structure or composition of the original compound. The degradation is the breakdown of the compound into smaller fragments with inorganic end products such as water and carbon dioxide (Smith et al., 1989). The major processes involved in pesticide transformation and degradation were described in detail by Valentine (1986) and Valentine and Schnoor (1986) and include chemical hydrolysis, photolysis, and micro-biological reactions in soil.

Factors affecting pesticide fate and migration include pesticide properties, soil characteristics, environmental parameters, and agricultural practices (Wauchope, 1978, Weber et al., 1981, Baker, 1981, Willis and McDowell, 1982 Nofziger and Hornsby, 1986). Solubility and adsorption are important properties that determine pesticide mobility with water. Pesticides with high water solubility (low sorption) are more easily moved by runoff or by percolation water in solution form and, therefore, are more likely to reach surface and ground water. Pesticides adsorbed to soil particles will move only if carried off with the eroded soil particles to which they are adsorbed (Rao et al., 1983).

The length of time that a pesticide may be available to enter the water depends on its persistence. Persistence is determined by its degradation. Degradation time is measured in "half-life." Half-life refers to the amount of time it takes for one-half the original amount of a pesticide in soil to be deactivated (Rao et al., 1983). Based on persistence, Rao et al. (1983) grouped pesticides as non-persistent (half-life less than 30 days), moderate-persistent (half-life greater than 30 and less than 100 days), and persistent (half-life greater than 100 days) types.

Soil properties influencing pesticide movement include bulk density, soil water content, permeability, organic matter content, and field capacity (Jury, 1986b). Environmental parameters include temperature, amount and intensity of daily precipitation, evaporation, and watershed characteristics. Agricultural practices affecting pesticide transport with runoff and percolation include: crop characteristics, irrigation activities, rate and method by which a pesticide is applied, and time interval between pesticide application and rainfall. It has been reported by researchers that most losses of pesticides in runoff occur when a heavy rainstorm takes place shortly after pesticides are applied (Wauchope, 1978, Willis and McDowell, 1982).

Water Pollution by Pesticides

Pesticide contamination of surface and ground water has been addressed in numerous studies. Duttweiler and Nicholson (1983) reviewed nation-wide water pollution problems caused by agricultural pesticides. Canter (1986) listed important agricultural pollutants and analyzed their effects on water quality. Cohen et al. (1986) and Leonard (1986) reported the presence of at least 17 pesticides in ground water in a total of 23 states as a result of agricultural practices. In the Great Plains region, ground water contamination by pesticides has been documented in every state except Wyoming, where ground water contamination is suspected, and agricultural runoff is identified as the most extensive source of surface water quality degradation accounting for about 60 to 80% of the impaired water (Great Plains Agricultural Council Water Quality Task Force, 1992).

Pesticides lost from the target areas and reaching surface water may cause water quality degradation and detrimentally impact survival of aquatic species in the water. Presence of agricultural pesticides in ground water may degrade water quality, impair normal uses of ground water for agricultural production, and threaten the health of people who drink the water (Novotny and Chesters, 1981, Canter, 1996).

Model Simulation of Pesticide Leaching and Runoff

In evaluation of agricultural nonpoint source pollution and effectiveness of the management practices, two methods are commonly utilized: actual field testing and computer modeling (Shoemaker, 1990). Determination of pollutant movement through watershed monitoring is very expensive and time consuming (Sweeney and Campbell, 1982), and it is impossible to measure pollutant movement on every field (Leonard and Knisel, 1986). Field testing is limited to the number of locations and scenarios that can be feasibly examined.

Modeling is the most viable alternative for evaluation of NPS pollution from agricultural areas and pollution management (Bailey et al., 1974, Sweeney and Campbell, 1982, Leonard and Knisel, 1986, Shoemaker et al., 1990). Mathematical models integrate many mechanisms controlling transport and fate of pesticides into a framework which allows more accurate assessment of pesticide migration and potential risks (Onishi et al., 1982). Models improve our understanding of factors that dominate pesticide behaviors in a hydrologic system (Barfield et al., 1989). Models assist in examining the behavior of different agricultural chemicals under varying management practices and identifying potential environmental problem areas (Bailey and Swank, 1983, Hann et al., 1993). Although the absolute accuracy of the outputs from the model is limited, a comparison and ranking of outputs for various alternative remedial measures are often reliable (Novotny and Chesters, 1981). Through use of a simulation model, the best management alternative may be selected for reducing the pesticide transport and pollution.

NPS Models and the Model Application

To describe pesticide behaviors and the effect of management alternatives for pesticide movement and pollution control, simulation models must meet certain requirements. These requirements are that: the models should (1) incorporate characteristics of climate, soil, geology, watershed, and topography of the simulated area, (2) be able to simulate management practices, (3) describe the processes relevant to the pollutant movement, such as runoff, erosion, sediment, infiltration, evaporation, adsorption, and chemical behavior, (4) predict multimedia pollutant transport, (5) show spatial and temporal variability, (6) determine impacts on surface and ground water, and (7) operate in a manageable way (Bailey et al., 1974, Bailey and

Swank, 1983, Shoemaker et al., 1990).

The model selected for use must represent the conditions and provide the desired results for the specific problem at hand (Leonard and Knisel, 1986). Some considerations for model selection are summarized as: (1) the modeling purpose and proposed model application, (2) input data requirement and availability, (3) model sensitivity to changes in management practices, (4) calibration requirement, and (5) computational time required for simulation (Sweeney and Campbell, 1982, Leonard and Knisel, 1986).

A large number of mathematical models have been developed for the study of NPS pollution and reported in the literature since 1970s. These models vary greatly in complexity and are structured to answer specific questions at various levels of sophistication (Bailey and Swank, 1983, Smith et al., 1986). Models which have been used include the crop growth/chemical movement model (EPIC-PST), agricultural chemical transport model (ACTMO), agricultural runoff management (ARM), areal nonpoint source watershed environment response simulation (ANSWERS), chemical movement in layered soil (CMIS), Cornell nutrient simulation (CNS) and pesticide model (CPM), chemicals, runoff, and erosion from agricultural management systems (CREAMS), ground water loading effects of agricultural management systems (GLEAMS), hydrological simulation program (HSPF), pesticide root zone model (PRZM), and pesticide transport model (PTR) (Bailey et al., 1974, Sweeney and Campbell, 1982, Leonard and Knisel, 1986, Leonard et al., 1987, Novotny, 1986, Shoemaker et al., 1990).

Model applications for evaluation of NPS pollution have been contributed by many researchers. Donigian and Carsel (1987) described the use of PRZM integrated with a saturated-zone model and surface water module to evaluate the effects of tillage practices for corn and soybeans on ground and surface water pesticide concentrations. Jones et al. (1987) utilized the unsaturated-zone model to identify agricultural fields where the application of leachable pesticides would result in unacceptably high ground water residue concentrations. Leonard (1986) examined how changes in pesticide properties and application scenarios affect pesticide leaching potential from cropland using GLEAMS. Leonard et al. (1992) evaluated pesticide runoff potential based on the GLEAMS simulations of both long-term and single-event pesticide losses. Sabbagh et al. (1992) used EPIC-PST to demonstrate environmental impacts of alternative chemical and irrigation management practices. The PRZM model was applied by Daniels and McTernan (1989) to identify agricultural areas with the potential for pesticide contamination.

GIS Integrated with NPS Modeling

Successful application of pesticide transport models requires that (1) the watershed be spatially divided into homogeneous sub-areas, (2) large amount of input data characterizing soil, topography, and land use of the site be collected, (3) the multiple types of data compiled be manipulated to provide the input information for model simulations, and (4) final modeling results be graphically displayed and represented (Williams et al., 1984, Zhang et al., 1990, Vieux, 1991). A manual approach for data collection and manipulation can be obstructive to the model application. Geographic information systems (GIS), designed to handle spatially referenced information, provide a powerful means by which all the requirements can be met.

There are many different definitions of a GIS. Star and Estes (1990) defined a GIS as a database with capabilities for spatial-referenced data and a set of operations for working with the data. From a comprehensive point of view, GIS may be defined as an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, analyze, and display all forms of geographically referenced information (Environmental Systems Research Institute, Inc., 1990). The concept of a GIS and overview of its primary functions are illustrated in figure 1.

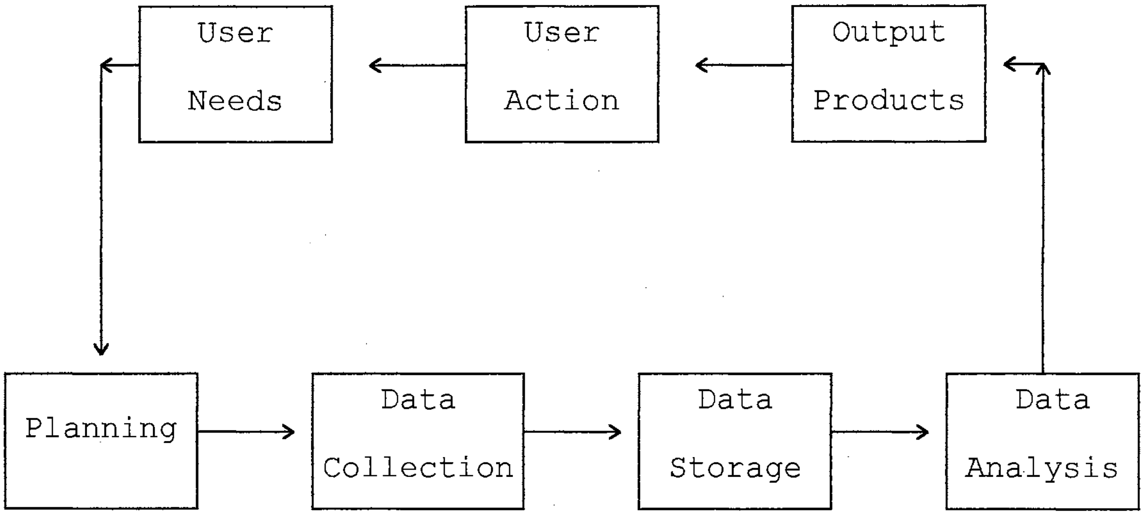

Figure 1. Functions of a geographic information system
Source: Star and Estes. 1990. *Geographic Information System: An Introduction*. Englewood Cliffs, New Jersey: Prentice-Hall, Inc.

Because of its capability and efficiency in data manipulation, GIS has been integrated with mathematical models for evaluating water quality impact of agricultural nonpoint sources. The beneficial aspects and advantages of combining GIS techniques with modeling have been discussed by many researchers and are summarized in the following:

(1) The ability of a GIS to extract and delineate land characteristics and to overlay geographic features which are represented as multiple data layers makes GIS suited to delineation of homogeneous sub-areas in the watershed.

(2) GIS provides an efficient and accurate means for collecting and storing data in a database, which allows the users to utilize highly diverse information sources to characterize the drainage area.

(3) With GIS, the full information content of data can be used to analyze the hydrologic processes, and the data needed for modeling can be provided.

(4) The GIS function of data display is able to convey the desired or intended meaning of model simulation results.

(5) Integration of NPS models with GIS techniques provides a powerful tool for decision making in the management of agricultural impact on water quality (Broten et al., 1987, Fisher, 1989, Zhang et al., 1990, Vieux et al., 1986, Vieux, 1991).

The application of NPS models in combination with GIS has been provided by researchers. A GIS combined with the universal soil loss equation and agricultural pollution index was utilized by Hamlett et al. (1991) to rank statewide watersheds based on their nonpoint pollution potential. Hession and Shanholtz (1988) integrated a geographic information system with the universal soil loss equation and delivery ratio to identify the nonpoint-source pollution potential of agricultural land. A similar method was also applied by Gilliland and Baxter-Potter (1987) and Deliman and Wolfe (1990) to determine agricultural nonpoint pollution sources. Broten et al. (1987) illustrated the application of GIS techniques linked with a numerical ground water model for evaluating ground water pollution by hazardous waste. An approach for estimating pesticide leaching potential through connecting a GIS with a chemical root zone model was also described by Haan et al. (1993).

The general steps developed for the application of pesticide transport models with GIS techniques include: (1) data collection and spatial database construction, (2) integration of spatial model layers (3) creation of the interface between the GIS and model, and (4) graphic display of model outputs (Zhang et al., 1990, Broten et al., 1987).

Effect of Pesticides on Nontarget Species

Although insecticides have proven to be a useful tool for controlling undesirable pests, their movement outside the target area can result in destructive impacts on nontarget animals, including beneficial insects (predators, parasites, and pollinators); soil organisms; birds; amphibians; and aquatic species (Pimentel, 1971, Pimentel and Levitan, 1986, Brown, 1978, Ware, 1980, Metcalf, 1982). The effect of an insecticide will depend on its concentration, persistence, and its toxic properties.

Wildlife species vary in their sensitivity to insecticides. Some organisms can adapt to minimize toxic effects (Onishi et al., 1982). The life stage of an organism also influences toxic effects as insecticides may be harmless to adult members but lethal to embryo and small fry. The overall impacts of insecticides on nontarget species may be evaluated from the following aspects: (1) reduction of the number of individuals in species or the number of species, (2) alteration of wildlife habitat, (3) changes in species behavior, (4) changes in species reproductivity, and (5) biological magnification (the accumulation of an insecticide in a living organism) (APHIS, 1991, Ware, 1980).

Insecticidal effects on beneficial insects. Broad spectrum insecticides are toxic not only to insect pests, but also to many beneficial insects that include natural enemies of the pest and pollinators. The reduction of natural enemies may lead to two undesired consequences: first, rapid resurgence of the target pest population and , second, outbreaks of secondary pests due to the elimination of their natural enemies, or the change in status of minors into the major pest (Metcalf, 1982, Reynolds et al., 1982). Bottrell and Rummel (1978), Brown (1978), and Ware (1980) all reported outbreaks of secondary cotton pests as a result of boll weevil control by using insecticides such as azinphos-methyl, malathion, and methyl-parathion.

Effect on pollinators. The honeybee, Apis mellifera, is an economically important insect in the United States, not only because of honey and beeswax production, but as pollinator of fruits, vegetables, and seed crops (Metcalf, 1982). Organophosphorus insecticides, which were suggested for use in the boll weevil eradication program, are highly toxic to bees (APHIS, 1991). The danger to bees comes either from direct contact poisoning or from the taking of poisoned nectar and transport of poisoned nectar to the hive (Brown, 1978). In addition to the toxic effect on honeybees, their poisoning can inflict serious economic damage to both beekeepers and to growers whose crops depend on bee pollination (Ware, 1980). The economic effect is particularly aggravated if intensive application is made during blooming period. Throughout the cotton areas, pollinators are critical for pollination of alfalfa for seed and melon crops.

Insecticide impact to soil organisms. Insecticides, especially those that are persistent in the soil, may have toxicity to soil organisms such as arthropods and earthworms. It has been reported that some organophosphorus chemicals have selective effect of reducing predaceous mites and the population of Carabid beetles in soil (Brown, 1978).

Potential influence to aquatic species. The greatest potential environmental hazard of pesticides is to aquatic organisms (Willis and McDowell, 1982). Insecticide toxicity to aquatic species is affected by parameters such as temperature, dissolved oxygen, insecticide concentration, and chemical loading of the water (Onishi et al., 1982). Fish susceptibility to insecticides varies greatly, depending on species and type of insecticides it is exposed to (APHIS, 1991, Brown, 1978). The salmonids, for example, are the most susceptible to organophosphorus insecticides. The bluegill sunfish is 250 times more susceptible to malathion than fathead minnow, and 250 times more susceptible to azinphos-methyl than goldfish (Brown, 1978).

Some organophosphorus insecticides were reported to have deleterious effects on aquatic invertebrates (APHIS, 1991). For example, azinphos-methyl is extremely dangerous to crabs, shrimp, and other aquatic invertebrates. stoneflies and caddisflies are most acutely sensitive to malathion.

Species inhabiting small creeks and farm ponds within or near the areas heavily sprayed or in the vicinity of chemical discharge may be at high risk of toxic effects of the insecticides. These potential effects have been documented by numerous complaints and reports of fish kills due to the boll weevil eradication program (APHIS, 1991).

Ecological Application of GIS

The potential of GIS as an ecological research tool has been investigated by numerous researchers. GIS provides a capable means for the study of ecological interactions and for solving ecological problems over large areas (Johnston, 1989, Lillesand et al., 1989). GIS techniques also allow resource planners to evaluate the ecological impact of proposed projects in ways that are creative and systematic (Moreno and Heyerdahl, 1990). The application examples that have been reported include the identification of high quality wildlife habitat (Dicks and Christianson, 1991), determination of how the increase in number of specific species affected the landscape (Johnston, 1989), and impact assessment of large projects on wildlife habitat (Moreno and Heyerdahl, 1990).

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CHAPTER II

EVALUATING POTENTIAL IMPACT OF A BOLL WEEVIL ERADICATION PROGRAM ON REGIONAL WATER RESOURCES IN OKLAHOMA

ABSTRACT

Implementing a boll weevil eradication program would increase the risk of regional water contamination by insecticides. The mathematical model EPIC-PST integrated with geographic information system (GIS) techniques was utilized to evaluate potential leaching and runoff of insecticides from cotton areas proposed for the eradication program in Oklahoma. A spatial database was developed which includes cotton fields and soil mapping units. The GIS was used as a data manipulation tool for preparing the input data file and for generating the graphic display of model outputs. Model simulations of insecticide leaching and runoff were conducted for each soil type using 100 different, but equally likely, weather sequences. The potential of leaching and runoff was examined by checking insecticide losses in each percolation and runoff event and comparing the chemical concentration of events with the EPA heath advisory levels and Oklahoma surface water quality standards, respectively. The variation of insecticide losses to runoff with different rainfall sequences was predicted. The spatial distribution of potential insecticide runoff losses was delineated and the areas potentially contributing high chemical runoff were identified. Modeling results show

that leaching of the insecticides used in the eradication program would not be significant. The insecticides would be lost from cotton fields to runoff, with concentrations higher than Oklahoma surface water quality standards. Proper management of insecticide applications and measures to reduce chemical runoff from cotton fields will be needed during the eradication period.

INTRODUCTION

Cotton is a primary agricultural crop planted in southwestern Oklahoma. In 1992, about 149,734 ha was planted and 210,000 bales of cotton valued at $43 million were produced (Oklahoma Department of Agriculture, 1992). Cotton production annually experiences economic damage from infestations of boll weevil, Anthonomus grandis, a harmful cotton pest. In years with mild winters, high survival of weevils can occur and widespread economic losses result (Karner and Price, 1992). In an attempt to effectively control the pest, Oklahoma cotton producers are now considering implementing a boll weevil eradication program.

The boll weevil eradication program is a cooperative effort for eliminating the established weevil populations in a large cotton-growing region (Carlson and Suguiyama, 1985, Animal and Plant Health Inspection Service, 1991). The program is conducted by Animal and Plant Health Inspection Service (APHIS) of U.S. Department of Agriculture (USDA), in conjunction with state agencies and cotton growers. Under the eradication program, all cotton areas infested by the pest would receive at least one insecticide treatment. More application would be applied to heavily infested fields. Insecticides suggested for use include azinphos-methyl,

methyl-parathion, malathion, and diflubenzuron. Treatments will be scheduled for spring, midseason, and fall in the initial three program years. On average, the application frequency of insecticides, except diflubenzuron, is four in program year one (Treatments start in fall), eight in year two, and four in year three (APHIS, 1991). Diflubenzuron will not be applied in the first year and may be used for the spring and midseason treatment in program years two and three. Completion of the program requires a total of four and one half years.

Agricultural use of insecticides for pest control has been recognized as a major non-point pollution source in the United States (Great Plains Agricultural Council Water Quality Task Force, 1992). Insecticide applications for cotton production are intensive and can contribute to water quality problems (Crutchfield et al., 1992). The insecticide residues may move from cotton fields into groundwater and pose health risks to the ultimate users. They can also reach surface water bodies in either dissolved or particulate form, impairing the water quality and jeopardizing aquatic species.

It is foreseen that the insecticide application to the cotton fields within the program region will be increased during the program period. This area-wide increase of insecticide use will raise the contamination risk of regional water sources by the insecticides. Concern about such adverse effects necessitates the evaluation of the potential impact of the boll weevil eradication program.

Computer modeling has proven to be a capable tool in the study of agricultural nonpoint source pollution. A number of mathematical models have been developed for evaluation of agricultural pollution potential and effectiveness of management practices. It has also been shown that integrating a geographic information system (GIS) with the transport models can enhance and facilitate model applications.

Objectives of the Study

This study is designed with the following objectives:

(1) Evaluate potential leaching and runoff of the insecticides applied in the eradication program from cotton fields using mathematical modeling integrated with GIS techniques.

(2) Identify cotton fields which potentially contribute high insecticide losses in runoff.

MATERIALS AND METHODS

The overall procedure followed consists of several steps illustrated by the flowchart in figure 1. The study began with problem identification and objective definition.

The method, computer modeling integrated with the GIS, was then determined and the mathematical model was selected for use. Information required for model simulation was collected from various sources. Following data collection, the spatial database was developed, and the data were manipulated and input files were prepared. The model was tested by using the actual (observed or field) data to demonstrate its validity. Simulation of insecticide leaching and runoff associated with the eradication program was designed and conducted for the soils within cotton fields. Finally, model output was analyzed, tabulated, and graphically presented.

Study Area

The study area is located in southwest of Oklahoma (fig. 2) and covers a total area of 13,965 km^2. It embraces seven major cotton-producing counties including Beckham, Cotton, Greer, Harmon, Jackson, Kiowa, and Tillman. These counties represent the proposed geographic region for the boll weevil eradication program in Oklahoma.

The study area lies within the central rolling plain of the Red River and gently slopes from northwest to the southeast. The Red River, which borders the region on the south, and its major tributaries: the Salt Folk, North Fork, Cache Creek, and Deep Creek, flow southeastward and drain most of the area. The elevation in the northwest corner of

Beckham County is 688.8 m above mean sea level and declines to 268.2 m at the confluence of Cache Creek with the Red River in southeast of Cotton County.

The climate is continental and relatively dry. The average temperature in Jan. and July is 3.9 and 28.7^0 C, respectively (Oklahoma Department of Agriculture, 1992). The average annual precipitation is about 711.5 mm, with a fluctuation of 26.9 mm in Jan. and 124.2 mm in May.

Most of the soils cultivated for cotton production in the area are formed and distributed on broad plains and uplands, with a deep profile and nearly level to gently sloping. Dominant soil textures are clay loam and silt or sandy loam, with slow or moderate permeability. Soils adjacent to rivers or on rough land are relatively shallow and sloping.

Cotton is a primary crop and is widely planted in the area. In 1992, the seven counties contained 76% of cotton fields and provided 79% of total cotton production (Oklahoma Department of Agriculture, 1992). Planting dates for cotton vary within the region from early May to early June. Harvest starts on dates ranging from Oct. through late Dec.. Jackson and Harmon Counties lead in irrigation and contain 87% of irrigated cotton land in the state. In the normal climate condition, approximate 460 to 610 mm water was supplied annually through furrow irrigation systems with a 7 to 10 day interval.

Modeling System

The modeling system used in this study consists of a database, the crop growth/chemical movement model called EPIC-PST, and a geographic information system. After comparison of widely used mathematical models, the EPIC-PST model was selected for use in the study based on the following reasons: (1) the EPIC-PST model meets the purpose of the study, which requires a model capable of simulating pesticide losses with runoff and leaching below the root zone under various weather conditions, (2) the model is comprehensive, (3) its components have been widely tested and validated, and (4) the structure and execution of the model are well known.

EPIC-PST model. The model EPIC-PST (Sabbagh et al., 1991) is designed to simultaneously simulate the effects of different agricultural management practices on crop yield and pesticide transport with surface runoff, sediment movement, and leaching below the root zone. It is written in FORTRAN 77 language and compiled to run on IBM-compatible personal computers with a math co-processor and 6 MB of hard disk memory. The model was developed by using the EPIC (Erosion Productivity Impact Calculator) model as a building block and incorporating the pesticide-related subroutines of another mathematical model called GLEAMS (Groundwater Loading Effects of Agricultural Management System). The incorporation of the pesticide subroutines was accomplished by using two transition subprograms, which were developed to link the subroutines to the rest of the model. The main functions of the subprograms are to adjust the units and format of parameters that are simulated by the hydrology and erosion submodels of EPIC and are required as input to the pesticide subroutines. A detailed description about the EPIC-PST model was given by Sabbagh et al.(1991).

The drainage area considered by EPIC-PST is small (1 ha) with soils and management practices assumed to be spatially homogeneous. In the vertical direction, the model is capable of working with variation in soil properties by dividing the soil profile into a maximum of 10 layers (Williams et al., 1990). Each layer is assumed to be homogeneous in its characteristics.

Surface runoff volume and peak runoff rates are simulated by the runoff submodel, given daily rainfall amounts. Runoff volume is estimated by using a modification of the Soil Conservation Service (SCS) curve number technique. The technique was selected for use because: (1) it is reliable and has been used for many years, (2) it is computationally efficient, (3) the required inputs are available, and (4) it relates runoff to soil type, land use, and management practices. Peak discharge rate is estimated by using a modification of the Rational Formula. A stochastic element is introduced to the Rational Formula to allow realistic simulation of peak discharge rates, given only daily rainfall and monthly rainfall intensity information (Williams et al., 1990).

The percolation component uses a storage routing technique to simulate flow through soil layers. Flow from a soil layer occurs when soil water content exceeds field capacity. Water drains from the layer until the storage returns to field capacity. The reduction in soil water is simulated with the routing equation. The routing process is applied from the soil surface layer by layer through the deepest layer (Williams et al., 1990).

The precipitation model included in EPIC-PST is a first-order Markov chain model. The model requires the input of monthly probabilities of receiving precipitation for two conditions: (a) precipitation occurred on the previous day, and (b) no precipitation on the previous day. Given the initial wet-dry state, the model determines stochastically if precipitation occurs or not. When a precipitation event occurs, the amount is determined by generating from a skewed normal daily precipitation distribution (Williams et al., 1984).

The components of EPIC-PST have been well tested for the validation (Sabbagh et al., 1991, Williams et al., 1984). For example, the weather component was tested by Nicks et al. (1990) and desired weather data were generated. Reasonable results were obtained by Knisel (1980) from the test of hydrology and water erosion components by using field-observed data. Leonard et al. (1987) reported a general agreement between the simulated and observed pesticide leaching at the bottom of root zone. The crop growth model was found to be satisfactory in simulating the yields for dryland wheat and grain sorghum (Steiner et al., 1987) and for irrigated corn (Bryant et al., 1992).

EPIC model. The EPIC model was developed by the Agricultural Research Service (ARS) of USDA. The model is designed to determine the relationship between erosion and soil productivity for various agricultural management strategies. It uses a daily time step to simulate erosion, plant growth, and related processes for up to 100 years. The physically-based components of EPIC consist of hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage, economics, and plant environment control (Williams et al., 1984).

GLEAMS model. The GLEAMS model is a modification of CREAMS (Chemical, Runoff, and Erosion for Agricultural Management System) incorporating a component for vertical movement of pesticides (Leonard et al., 1987). The model was constructed for evaluating the movement of pesticides with surface and percolation waters on field-size areas under different agricultural practices. The major interactive components of GLEAMS include hydrology, erosion, and pesticides. The model simulates the activities of pesticides in soil by incorporating six processes: degradation, extraction into runoff, percolation, movement with sediment, evaporation, and plant uptake.

Geographic information system. The geographic information system utilized in the study includes a Sun SPARC station, 61 by 91 cm graphic digitizer, Tektronix printer, and the GIS software known as GRASS (Geographic Resources Analysis Support System), all located in the GIS laboratory of Agronomy Department. GRASS is a public domain GIS software package developed by the U.S. Army Construction Engineering Research Laboratory (USA-CERL) in the mid 1980s. The package is well-known in the GIS community and has been widely used by government agencies and universities. GRASS is raster-based GIS which allows for digitizing and graphic overlays in the vector format. Both raster and vector data files can be incorporated for spatial analysis. It is capable of data collection, analysis, and presentation.

Data and Data Collection

To run the EPIC-PST model, the following types of data on the study area were assembled:

(1) daily maximum and minimum temperatures and precipitation,

(2) soil mapping unit data and characteristics of soil layers for each soil type,

(3) spatial location and distribution of cotton fields,

(4) information about cotton production and irrigation,

(5) agricultural management practices utilized, and

(6) insecticide properties and application scenarios to be adopted by the program

Weather data. Weather data were obtained through Oklahoma Climatological Survey in Norman, Oklahoma. The data covered the period of 30 years (1962 to 1991) and were recorded separately by the weather stations located within the area, including Altus Irrigation Research Station (Jackson County), Altus Dam (Kiowa County), Erick 4 E (Beckham County), Hollis (Harmon County), and Frederick (Tillman County). The data collected were in the digital format and with English units.

Soil data. Soil data include the soil mapping units and mapping unit attributes. The soil mapping unit data, showing the spatial distribution of each soil type within the area, had been previously digitized and were available for the study from the GIS laboratory of the Agronomy Department. The data were raster format with each cell representing 4 hectares (9.88 ac). The attribute data include soil slopes, the SCS hydrologic soil groups (HSG), number of layers for each soil, and the characteristics of each soil layer in depth, bulk density, available water content, sand and silt content, soil pH, and organic carbon. The attribute data were obtained from the USDA-SCS state office. High and low values were provided for the most of these parameters.

Location of cotton fields. Spatial location of cotton fields scattered in the seven counties was obtained by interpreting USDA SCS aerial photographs which were taken in Aug. 1991. The photographs are black and white, with a scale of 1:12,000. All cotton fields were identified on the photographs and then recorded on the county maps. The airphoto interpretation was finished with the help of SCS officers and Oklahoma Cooperative Extension Service personnel in 1992.

Crop production and management. Information of cotton production and management practices was assembled through consultation with the cotton agent of each county and cotton research and extension personnel who were familiar with the local conditions. The data described the crop rotation, planting and harvest dates, irrigation activities, and practices used for erosion control on cotton land. According to the data collected, erosion control practices were adopted by very few cotton producers in the area.

Insecticide properties and application. Insecticide application rate, treatment frequency, and application scenario to be used in the eradication program were gathered through contacting USDA-APHIS and consulting the published APHIS program documents. The characteristics of insecticides recommended by APHIS for use in the boll weevil eradication program were taken from the USDA-ARS pesticide database. The major characteristics of these insecticides are listed in table 1.

GIS Database and Input File Development

The GIS database established for the study includes landuse (irrigated and dry cotton fields) and soil mapping unit data. The boundaries of each cotton field recorded previously on the county maps were traced on transparent paper overlaid on the top of the maps. The transparencies were then registered to a UTM coordinate grid and the cotton fields were manually digitized into the GIS database.

Once landuse data were entered into the GIS database, the polygons were labeled and data files in both vector and raster format were created. The landuse and soil coverage, which were saved on the separate data layers in the GIS database, were intersected using GRASS so that soil types within dry and irrigated cotton fields were identified.

Based on the soil types identified, the soil input file was developed. Average values of soil slope, bulk density, pH, and organic matter were calculated and entered into the file. The curve number (CN) was determined for each soil by assuming straight row planting on cotton fields based on the collected information showing that practices for erosion control were rarely used. The soil names, slopes, hydrologic soil groups, and curve numbers are listed for Jackson County in table 2. Soil characteristics by layers for Abilene clay loam (category number one) in Jackson County are shown in table 3. Soil input data for other soil types and counties are provided in the Appendix.

The weather parameters required by EPIC-PST were computed using the collected weather data and the weather parameter calculator written and donated by USDA ARS in Temple, Texas. The parameters for Jackson County are shown in table 4.

The number of insecticide applications and application dates in the input file were determined according to the collected information regarding chemical treatments in the eradication program. The number of applications for each program year was the average number of treatment estimated by APHIS (1991). The application dates used in model simulations were determined by assigning the application frequency for the spring, midseason, and fall treatment and then specifying the application dates within each treatment period. The dates were assumed to be the same for each program year. The application frequency and dates used in model simulations are presented in table 5. The insecticide application rates are listed in table 7.

Model Validation

In model validation, the model should be tested using observed data. For this study, however, observed insecticide losses from cotton fields in the area were not available. Model validity was demonstrated by comparing simulated cotton yields with observed yields by soil types in the study area. The validation of EPIC-PST for simulating chemical losses was successfully tested by Sabbagh et al. (1991).

The annual cotton yields during a ten year period (from 1981 to 1990) on dry and irrigated land were simulated separately by EPIC-PST for each soil type. Then, the 10-year average values of the simulated yields were calculated for each soil and compared with corresponding observed values for the same period. Results are presented in table 6.

Simulated yields on irrigated cotton land show high agreement with observed data for all soil types. Even though the dryland exhibits a little higher percent error rate than the irrigated, the simulated yields for all soil types are in a reasonable range of matching the observed values. The largest difference for dry land is +23% which was shown by soil 21. The general agreement between the simulated and observed values suggests that the EPIC-PST model is adequate for use in this study to simulate the chemical movement from cotton fields

Model Simulations of Chemical Losses

Since pesticide leaching and runoff are functions of interactions between weather, soil, and agricultural practices, change of weather pattern would affect insecticide losses on the site. Haan et al. (1994) reported a considerable variation in predicted pesticide leaching through soil due to different weather sequences. To examine potentials of chemical losses associated with the eradication program, insecticide movement was simulated for each soil type by using 100 different, but equally likely, weather sequences. These weather sequences were generated by the weather generator included in EPIC-PST. The simulation period for a single sequence was five years.

The weather generator provided daily generated values of precipitation, maximum and minimum temperatures, and solar radiation for the years at each given location. Precipitation was generated independent of the other variables. Maximum temperature, minimum temperature, and solar radiation were generated, conditioned on whether the day was wet or dry (Richardson and Wright, 1984, Richardson and Nicks, 1990).

Because insecticides tend to migrate with water, irrigation practices can affect insecticide movement. The impact of irrigation practices was estimated by using rigid and automatic irrigation scenario defined by the EPIC-PST model. The simulations of insecticide losses from irrigated land were conducted using irrigation volume of 650 mm per year and 125 mm per application.

The Oklahoma surface water quality standards and the EPA health advisory levels (HAL) for the insecticides were obtained and utilized respectively as criteria for evaluating insecticide losses in runoff and percolation. For insecticides whose numeral standards and/or advisories were not available, the values of LC_{50} for certain aquatic species and no-observed-effect levels (NOEL) for human health were used. The evaluation criteria are listed in table 7.

Model outputs for each weather sequence were stored in a file with a specific sequence name. All the files for the same soil type were grouped together using the same code number. Chemical concentrations of individual runoff events were computed and then compared with the standards. All the events with concentrations exceeding the standards were identified for each weather sequence. Potential insecticide runoff losses on cotton fields were predicted by analyzing the number of events exceeding the Oklahoma surface water quality standards.

When the model simulation was completed, results of simulated insecticide losses from dry and irrigated cotton areas were edited, saved, and imported into GRASS. Graphic representation of the results was generated by using GRASS module p.map.

RESULTS AND DISCUSSION

After simulations were performed, model outputs were read to identify insecticide losses to each runoff and percolation event. The mass losses of insecticides in runoff and their concentrations in percolation were summarized for each weather sequence.

Insecticide Losses in Percolation

Simulation results show that methyl-parathion and malathion would not move out of the root zone with leaching water. Their short half-lives in soil (five and one days, respectively) and strong adsorbance to soil particles and organic matter limit their downward movement. Insecticides azinphos-methyl and diflubenzuron could leach below the root zone from some soils, with concentrations up to about .3 μg/l. The predicted percolation of these two chemicals is summarized in tables 8 and 9.

Alluvial sand and Lincoln loamy fine sand, located respectively in Harmon and Greer Counties, are only the soils that demonstrated insecticide percolation in model simulations. These soils are classified as HSG A, with loose, well-drained textures and a high rate of water transmission.

The maximum concentration of azinphos-methyl in percolation is .3 μg/l, which is about 900 times lower than the NOEL (table 7). The simulated concentration of diflubenzuron in leaching water is .1 μg/l, representing a .01% of the dose at which no health effects were observed. Comparing the concentrations of leachate with the evaluation criteria indicates that the insecticides would not leach in significant amounts. Their short half-lives (10 days for both) and strong adsorbance to soil minimize their transport in percolation.

Insecticide Losses in Runoff

Model simulations, however, indicate that four insecticides applied to cotton fields would be lost to runoff. To illustrate the insecticides dissolved in runoff, the total number of insecticide losses to runoff events generated by each weather sequence with concentrations exceeding the standards was calculated for 100 sequences under each soil type. The statistical analysis of the calculation results is presented in tables 10 and 11.

Variation with weather sequences. The number of insecticide runoff events for each soil with concentrations exceeding the standards varies with the different weather sequences. The average value (Avg) represents the mean number of loss events produced by a single sequence based on the simulations of 100 different sequences for each soil type. It provides a measurement by which the potential losses of each chemical from different soil types can be compared and evaluated. The maximum (Max) and minimum (Min) are the largest and smallest number of losses to runoff events from a single sequence, respectively, and define a range of varying losses associated with the different weather sequences. Comparing the difference between maximum and minimum values for different soils shows that the effect of changing rainfall sequences on chemical losses varies with soil types. For Jackson County, Vernon clay loam (category number 35) and Treadway clay (category number 34) response with the largest variance in chemical losses, compared with other soils.

To show the variation of insecticides lost in runoff with weather sequences, Vernon clay loam, which showed the highest losses, was selected and the simulated numbers of runoff losses for 100 different sequences were plotted for each insecticide. The plots are presented in figures 3, 4, 5, and 6. The vertical scale on the left shows the number of exceeding events from a single rainfall sequence. The largest and smallest values on the plots correspond to the maximum and minimum numbers, respectively, which are listed in tables 10 and 11 for soil 35. Obviously, the numbers of insecticide loss events on both dry and irrigated land are variously distributed between the range. The variation between the highest and lowest differs with the insecticides. For diflubenzuron, the number for dry cotton land ranges from 28 to 2, indicating 14 times of difference.

The distribution patterns shown by the plots illustrate that the potential insecticide losses from the eradication program are closely related to the rainfall pattern of the area. Each point on the curves responds to one of different but equally likely rainfall sequences utilized in the simulation and, therefore, represents one possible scenario of insecticides moved with runoff from cotton fields. To estimate the potential of the chemical losses and describe the variation, the probability distributions associated to each point on the plots are calculated and shown on the horizontal scale. For azinphos-methyl, the probability of its losses to runoff events from the soil is 0.99 (or 99 percent), based on model simulations.

Spatial variation of insecticide losses. In addition to variation with weather sequences, the modeling results in tables 10 and 11 also indicate that the number of insecticide runoff events varies spatially with soil types within the cotton area. In Jackson County, for example, Vernon clay loam exhibits the largest average number on both dry and irrigated cotton lands. The values range from 22 to 64 for the irrigated and from 13 to 50 for the dryland, depending on the insecticide used. Soils with the smallest average are Enterprise and Alluvial loamy fine sand (category number seven and three, respectively) on dryland and Enterprise loamy fine sand on the irrigated. The difference between the largest and smallest average is about 4 to 8 and 13 to 25 fold, respectively, varying with the insecticides.

The larger average value indicates the higher potential of a soil in contributing the insecticide movement with the runoff in the eradication program. The different potential of soils can be explained by their different properties which significantly affect the insecticide movement from cotton fields. The soils contributing the relatively high chemical losses are characterized by the tight texture of top layer, steep slope, and poor hydrologic condition.

To show the spatial distribution of insecticide runoff potential on the cotton fields, soils were divided into different classes based on the average number of losses.

Soils in Jackson County were grouped into four classes. Cotton fields located on Vernon clay loam were delineated as the most crucial area because of its much higher average values than those shown by other soil types, with the exception of dryland fields treated with diflubenzuron. The other three cotton areas were determined by grouping the remaining soil types within the cotton areas. The spatial distribution of loss potential for each insecticide is shown in figures 7, 8, 9, and 10.

Effects of Irrigation and Chemical Characteristics

Based on model simulations, the four insecticides recommended for use in the eradication program behave differently in their losses to percolation and runoff. Azinphos-methyl and diflubenzuron have longer soil half-lives than the other two insecticides and could percolate out of the root zone in some porous soils. Table 12 re-lists the average and maximum values that are shown in tables 10 and 11 in the ascending order of soil category. The difference of insecticides in their runoff losses can be visualized by comparing the same type of values of insecticides for the same soil category. Azinphos-methyl exhibits the largest average and maximum losses with runoff for most of the soil types. Its high mobility can be attributed to the lowest adsorption coefficient (K_{oc}=1000 ml/g) and longest soil half life among the insecticides evaluated. Methyl-parathion shows smaller corresponding values than azinphos-methyl and acts as the second in potential of movement. Malathion and diflubenzuron have relatively low potential of runoff losses from both irrigated and dry cotton land. The shortest soil half-life of malathion or the largest K_{oc} (10,000 ml/g) and the smallest solubility (.08 mg/l) of azinphos-methyl greatly reduce their losses in runoff.

Irrigation activities have obvious effects on chemical runoff losses. Comparing the average and maximum values in table 12 for dry and irrigated cotton land for the same soil indicates that irrigation practices consistently increase the number of runoff losses for all insecticides. This increase can be attributed to irrigation water which raised soil antecedent moisture content. The irrigation method used in model simulations may also produce the excessive irrigation water which caused the insecticide runoff.

SUMMARY AND CONCLUSION

The potential impact of the boll weevil eradication program on regional water resources was evaluated using a mathematical model integrated with a GIS. The potential leaching and runoff losses of the insecticides recommended for use in the eradication program were simulated by using the EPIC-PST model. The data required for model simulations were collected from various sources and manipulated using GRASS. Simulations were conducted for each soil within cotton fields using 100 different, but equally likely, weather sequences.

The simulation results show that among the insecticides evaluated, azinphos-methyl and diflubenzuron would have minimal leaching from porous soils under some of rainfall sequences. Four insecticides would mainly be lost to runoff resulting from precipitation and irrigation activities. Since insecticide concentrations in runoff from cotton fields are higher than the Oklahoma surface water quality standards, the risks of potential effects exist from these insecticides on surface water quality and on aquatic species living in polluted water resources within the program areas. Management practices to avoid and reduce insecticide runoff from cotton land will be needed during the program period.

The potential of insecticide runoff losses spatially varies within cotton areas and is greatly affected by soils. To show the spatial distribution of the chemical loss potential, soils were divided into groups according to the average number of losses exceeding the standards. Protection strategies should be adopted to target the cotton areas with the high potential and therefore the high risk of contributing the pollutants.

Because of the stochastic nature of weather conditions, the insecticides show substantial variation in their losses to runoff under different rainfall sequences. The potential of chemical losses from the eradication program can be predicted and expressed by the probability associated with the number of runoff losses.

The insecticides behave differently in their movement. Based on model simulations, malathion would not migrate through the root zone. It also demonstrated the least potential of losses to runoff. From an environmental point of view, malathion should be used in the eradication program. Irrigation activities affect the insecticide movement. Compared with dry cotton land, irrigated fields exhibit high potentials of contributing chemical runoff losses.

As a data analysis and manipulation tool, GIS can benefit and facilitate the model application in the way to provide the information required for model simulations and to accept the model output for graphic display. Combining GIS capability in data collection and analysis with the model application helps identify and delineate the intersection between soil and landuse coverage on which model simulations are based. The graphic display of GIS allows users to visualize the spatial distribution of the insecticide pollution potential on the cropland. In this study, GRASS proves to be a powerful and easily-used GIS software. The data into and out of the model are successfully processed and transferred through GRASS.

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Table 1. Properties of the insecticides suggested for use in the boll weevil eradication program

Name	Solubility	Half Life (days)		Koc
	mg/l	Soil	Foliar	ml/g
Azinphos-methyl	29.00	10	2	1000
Diflubenzuron	0.08	10	27	10000
Methyl-parathion	60.00	5	3	5100
Malathion	130.00	1	1	1800

Source: USDA ARS, Tifton, Georgia.

Table 2. Soil types within cotton fields in Jackson County

SN*	Soil Name	HSG†	CN‡	Slope§ (%)	Landuse (cotton)		Area (ha)
1	Abilene clay loam	C	85	0.5	dry	irrigated	2652
2	Abilene clay loam	C	85	2.0	N/A	irrigated	44
3	Alluvial land	A	67	0.5	dry	N/A	112
4	Altus fine sandy loam	B	78	0.5	dry	irrigated	464
5	Dill fine sandy loam	B	78	2.0	dry	N/A	88
6	Dill fine sandy loam	B	78	4.0	dry	N/A	48
7	Enterprise loamy fine sand	A	67	1.5	dry	irrigated	132
8	Enterprise fine sandy loam	B	78	0.5	dry	irrigated	504
9	Enterprise fine sandy loam	B	78	2.0	dry	irrigated	188
10	Enterprise fine sandy loam	B	78	4.0	dry	irrigated	44
14	La Casa clay loam	C	85	2.0	dry	irrigated	100
16	Miles fine sandy loam	B	78	0.5	dry	irrigated	1312
17	Miles fine sandy loam	B	78	2.0	dry	irrigated	236
18	Miles fine sandy loam	B	78	4.0	dry	irrigated	36
19	Miles loamy fine sand	B	78	1.5	dry	irrigated	196
21	Nobscot fine sand	A	67	2.5	dry	irrigated	108
22	Nobscot fine sand	A	67	8.5	dry	irrigated	16
23	Port clay loam	B	78	0.5	dry	irrigated	768
26	Spur clay loam	B	78	0.5	dry	irrigated	172
28	Spur clay loam, Wet	B	78	0.5	dry	irrigated	100
29	Tillman clay loam	C	85	2.0	dry	irrigated	564
30	Hollister clay loam	D	89	0.5	dry	irrigated	12336
31	Tipton loam	B	78	0.5	dry	irrigated	4184
32	Tipton loam	B	78	2.0	dry	irrigated	112
33	Tivoli fine sand	A	67	10.0	dry	N/A	60
34	Treadway clay	D	89	1.0	N/A	irrigated	24
35	Vernon clay loam	D	89	7.5	dry	irrigated	72
37	Weymouth clay loam	B	78	2.0	dry	irrigated	208
38	Yahola fine sandy loam	B	78	0.5	dry	irrigated	388

* Soil category number. † Hydrologic soil group.

‡ Curve number. § Average slope of soils.

Data source: USDA SCS, Stillwater, Oklahoma.

Table 3. Soil characteristics by layers for Abilene clay loam in Jackson County

Parameter	Layer 1	Layer 2	Layer 3	Layer 4
Layer depth (m)	0.01	0.20	0.64	1.37
Bulk density (t/m^3)	1.48	1.48	1.50	1.60
Wilting point (m/m)	0.19	0.19	0.24	0.21
Field capacity (m/m)	0.37	0.37	0.40	0.35
Sand content (%)	22.00	22.00	15.00	22.50
Silt content (%)	46.50	46.50	45.00	44.00
Soil pH	7.50	7.50	7.50	8.15
Organic carbon (%)	1.48	1.48	1.50	1.60

Data source: USDA SCS, Stillwater, Oklahoma.

Table 4. Weather parameters based on the daily data from Altus Irrigation Research Station for 1962-1991 period

Month	TMX*	TMN†	SDTMX‡	SDTMN§	PRE‖	SDR#
	C	C	C	C	mm	mm
January	11.40	-3.68	7.96	5.71	20.9	3.8
February	14.59	-1.25	7.86	5.08	25.5	4.1
March	20.17	3.55	6.87	5.26	37.0	4.6
April	25.55	9.04	5.86	5.12	51.4	5.3
May	29.54	14.20	4.66	4.62	114.8	10.5
June	33.95	19.16	3.90	3.19	94.5	12.1
July	36.69	21.54	3.39	2.69	43.1	5.9
August	35.63	20.64	3.59	2.29	63.7	8.8
September	30.94	16.71	4.94	3.97	88.6	10.7
October	25.83	10.10	5.52	4.86	60.8	9.6
November	18.25	3.67	6.20	5.26	30.2	4.8
December	11.87	-2.33	10.44	7.81	19.7	2.9

* Average monthly maximum temperature.
† Average monthly minimum temperature.
‡ Monthly standard deviation of maximum temperature.
§ Monthly standard deviation of minimum temperature.
|| Average monthly precipitation.
Monthly standard deviation of daily precipitation.
Data source: Oklahoma Climatological Survey, Norman, Oklahoma.

Table 5. Insecticide application frequency and dates utilized in model simulations

Application Date	Azinphos†	Parathion‡	Malathion	Diflubenzuron
Year One*				
11-Sept.	Yes	Yes	Yes	No
18-Sept.	Yes	Yes	Yes	No
25-Sept.	Yes	Yes	Yes	No
1-Oct.	Yes	Yes	Yes	No
Year Two*				
1-June	Yes	Yes	Yes	Yes
8-June	Yes	Yes	Yes	Yes
1-July	Yes	Yes	Yes	Yes
8-July	Yes	Yes	Yes	Yes
11-Nov.	Yes	Yes	Yes	No
18-Nov.	Yes	Yes	Yes	No
25-Nov.	Yes	Yes	Yes	No
1-Dec.	Yes	Yes	Yes	No
Year Three*				
1-June	Yes	Yes	Yes	Yes
1-July	Yes	Yes	Yes	Yes
11-Sept.	Yes	Yes	Yes	No
1-Oct.	Yes	Yes	Yes	No

* Program year one, program year two, and program year three.

† Azinphos-methyl.

‡ Methyl-parathion.

Table 6. EPIC-PST model testing results: observed vs. simulated average cotton yields

SN*	Dryland (kg/ha)		E. Rate† %	Irrigated Land (kg/ha)		E. Rate %
	SA‡	OA§		SA	OA	
1	370	364	1.5	845	869	-2.7
2	327	308	6.2	845	841	0.5
4	429	448	-4.3	797	841	-5.2
5	341	336	1.3	N/A	N/A	N/A
8	395	364	8.3	803	841	-4.5
9	360	336	7.0	791	729	8.6
14	341	308	10.5	881	841	4.8
16	345	336	2.7	743	785	-5.3
17	300	280	7.2	743	729	2.0
19	314	280	12.0	724	729	-0.6
21	276	224	23.0	N/A	N/A	N/A
23	462	504	-8.4	N/A	N/A	N/A
26	397	392	1.1	954	1009	-5.4
29	289	252	14.7	810	785	3.3
30	303	280	8.0	845	841	0.5
31	389	392	-0.9	894	897	-0.3
32	351	336	4.3	824	841	-2.0
37	249	224	11.0	881	841	4.8
38	460	476	-3.5	883	841	5.1

* Soil category number.

† Relative error rate.

‡ Simulated average cotton yields.

§ Observed average cotton yields, which were obtained from USDA SCS, Stillwater, Oklahoma.

Table 7. Evaluation criteria and insecticide application rates used in model simulations

Name	Standard*	HAL‡	Application Rate
	µg/l	mg/l	kg/ha
Azinphos-methyl	0.01	0.29§	0.280
Diflubenzuron	1.40†	1.00§	0.140
Methyl-parathion	0.14†	0.31	0.560
Malathion	0.10	0.23	1.311

* Oklahoma surface water quality standards, which were obtained from Oklahoma Water Resources Board, Oklahoma City, Oklahoma.

† LC_{50} (APHIS, 1991).

‡ Health advisory levels, which were obtained by calling drinking water hot line of EPA.

§ NOEL (APHIS, 1991).

Table 8. Simulation results of azinphos-methyl leaching below the root zone from the boll weevil eradication program

SN*	Soil Name	County	Landuse (cotton)	Concentration (mg/l) Max†	Min‡
33	Alluvial sand	Greer	Dry	0.0001	0.0001
37	Lincoln loamy fine sand	Harmon	Irrigated	0.0003	0.0001
37	Lincoln loamy fine sand	Harmon	Dry	0.0001	0.0001

* Soil category number.

† Maximum concentration in percolation.

‡ Minimum concentration in percolation.

Table 9. Simulation results of diflubenzuron leaching below the root zone from the boll weevil eradication program

SN	Soil Name	County	Landuse (cotton)	Concentration (mg/l)
37	Lincoln loamy fine sand	Harmon	Irrigated	0.0001

Table 10. Number of insecticide runoff events from irrigated fields in Jackson County with concentrations exceeding the Oklahoma surface water quality standards

Azinphos-methyl				Methyl-parathion				Malathion				Diflubenzuron			
SN*	Avg†	Max‡	Min§	SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min
35	64	86	48	35	48	69	37	35	24	38	13	35	22	36	11
34	39	66	22	34	32	53	20	34	15	28	7	34	16	29	5
2	32	54	21	37	25	41	13	2	11	25	4	37	14	26	6
29	31	52	17	2	24	41	15	29	11	25	4	18	11	19	5
14	31	49	17	29	24	40	13	14	11	24	4	10	11	18	5
37	30	52	15	14	23	38	13	37	11	24	4	29	10	20	5
30	29	49	19	30	21	39	14	30	10	24	3	2	10	19	5
1	27	47	15	1	20	35	11	1	9	21	3	30	10	19	5
18	23	39	10	18	19	35	10	22	9	16	4	14	10	18	5
22	22	42	12	22	19	34	10	10	8	18	3	22	10	17	6
10	22	37	11	10	19	33	11	18	8	18	3	1	9	17	5
32	19	29	13	21	15	25	11	21	7	13	3	9	9	17	5
21	18	29	10	17	15	25	8	9	6	15	3	17	9	17	5
17	17	31	9	9	15	24	9	17	6	15	3	21	9	14	7
9	17	28	10	19	14	27	7	32	6	14	2	8	8	15	4
19	16	28	7	32	14	23	9	19	5	13	2	19	8	15	4
31	15	27	8	38	12	21	7	38	5	13	2	32	8	15	5
4	15	26	10	4	12	20	7	4	5	12	1	16	7	17	4
26	15	26	9	16	12	20	7	23	5	11	1	38	7	16	4
28	15	26	9	8	12	20	5	16	4	13	2	4	7	15	3
23	15	26	8	31	11	20	5	8	4	12	1	26	6	15	3
38	14	26	9	26	11	19	7	26	4	12	1	28	6	15	3
8	14	26	7	28	11	19	7	28	4	12	1	31	6	15	3
16	14	25	7	23	11	19	6	31	4	12	1	23	6	14	3
7	10	16	5	7	9	15	5	7	3	8	1	7	6	11	4

* Soil category number. † Average number of events exceeding the standards. ‡ Maximum number of events exceeding the standards. § Minimum number of events exceeding the standards.

Table 11. Number of insecticide runoff events from dry cotton fields in Jackson County with concentrations exceeding the Oklahoma surface water quality standards

Azinphos-methyl				Methyl-parathion				Malathion				Diflubenzuron			
SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min
35	50	74	36	35	37	57	26	35	21	35	11	35	13	28	2
37	19	40	8	37	16	33	5	37	8	23	1	37	6	18	0
29	19	39	8	29	15	33	5	29	8	23	1	29	5	15	0
33	19	37	8	33	15	30	6	14	8	23	1	33	5	14	0
14	18	41	8	14	14	33	5	33	8	19	2	14	5	14	0
30	17	38	8	30	13	31	5	30	7	20	1	30	4	14	0
1	15	36	6	1	12	29	5	1	7	19	0	18	4	14	0
18	13	35	5	18	11	29	4	6	6	17	0	1	4	14	0
6	13	34	5	6	11	28	4	18	6	17	0	6	4	14	0
22	13	31	5	22	11	25	4	10	6	16	0	10	4	13	0
10	12	32	5	10	10	27	4	22	6	16	1	22	4	13	0
17	9	23	1	17	8	20	1	5	4	13	0	5	3	12	0
5	9	22	1	5	8	19	1	9	4	13	0	9	3	12	0
32	8	21	1	9	7	18	1	17	4	13	0	17	3	12	0
9	8	21	1	32	7	18	1	19	4	13	0	32	3	12	0
19	8	21	0	19	7	18	0	32	4	13	0	38	3	12	0
4	7	20	0	16	5	17	0	4	3	11	0	19	3	11	0
21	7	16	0	38	5	17	0	8	3	11	0	4	2	12	0
16	6	20	0	4	5	16	0	16	3	11	0	8	2	12	0
38	6	20	0	8	5	15	0	31	3	11	0	16	2	12	0
8	6	18	0	31	5	15	0	38	3	11	0	23	2	12	0
26	6	18	0	21	5	14	0	23	3	10	0	26	2	12	0
28	6	18	0	23	5	14	0	21	3	9	0	28	2	12	0
31	6	18	0	26	5	14	0	26	2	11	0	31	2	12	0
23	6	17	0	28	5	14	0	28	2	11	0	21	1	6	0
3	2	10	0	3	2	9	0	3	1	5	0	3	1	5	0
7	2	10	0	7	2	9	0	7	1	6	0	7	1	5	0

Table 12. Comparison of mobility of insecticides and their losses from irrigated and dry cotton land in Jackson County

SN*	Azinphos-methyl				Methyl-parathion				Malathion				Diflubenzuron			
	Irrigated		Dry		Irrigated		Dry		Irrigated		Dry		Irrigated		Dry	
	Avg†	Max‡	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max
1	27	47	15	36	20	35	12	29	9	21	7	19	9	17	4	14
2	32	54	N/A		24	41	N/A		11	25	N/A		10	19	N/A	
3	N/A		2	10	N/A		2	9	N/A		1	5	N/A		1	5
4	15	26	7	20	12	20	5	16	5	12	3	11	7	15	2	12
5	N/A		9	22	N/A		8	19	N/A		4	13	N/A		3	12
6	N/A		13	34	N/A		11	28	N/A		6	17	N/A		4	14
7	10	16	2	10	9	15	2	9	3	8	1	6	6	11	1	5
8	14	26	6	18	12	20	5	15	4	12	3	11	8	15	2	12
9	17	28	8	21	15	24	7	18	6	15	4	13	9	17	3	12
10	22	37	12	32	19	33	10	27	8	18	6	16	11	18	4	13
14	31	49	18	41	23	38	14	33	11	24	8	23	10	18	5	14
16	14	25	6	20	12	20	5	17	4	13	3	11	7	17	2	12
17	17	31	9	23	15	25	8	20	6	15	4	13	9	17	3	12
18	23	39	13	35	19	35	11	29	8	18	6	17	11	19	4	14
19	16	28	8	21	14	27	7	18	5	13	4	13	8	15	3	11
21	18	29	7	16	15	25	5	14	7	13	3	9	9	14	1	6
22	22	42	13	31	19	34	11	25	9	16	6	16	10	17	4	13
23	15	26	6	17	11	19	5	14	5	11	3	10	6	14	2	12
26	15	26	6	18	11	19	5	14	4	12	2	11	6	15	2	12
28	15	26	6	18	11	19	5	14	4	12	2	11	6	15	2	12
29	31	52	19	39	24	40	15	33	11	25	8	23	10	20	5	15
30	29	49	17	38	21	39	13	31	10	24	7	20	10	19	4	14
31	15	27	6	18	11	20	5	15	4	12	3	11	6	15	2	12
32	19	29	8	21	14	23	7	18	6	14	4	13	8	15	3	12
33	N/A		19	37	N/A		15	30	N/A		8	19	N/A		5	14
34	39	66	N/A		32	53	N/A		15	28	N/A		16	29	N/A	
35	64	86	50	74	48	69	37	57	24	38	21	35	22	36	13	28
37	30	52	19	40	25	41	16	33	11	24	8	23	14	26	6	18
38	14	26	6	20	12	21	5	17	5	13	3	11	7	16	3	12

* Soil category number.

† Average number of events exceeding the standards.

‡ Maximum number of events exceeding the standards.

Figure 1. Overall procedure of study

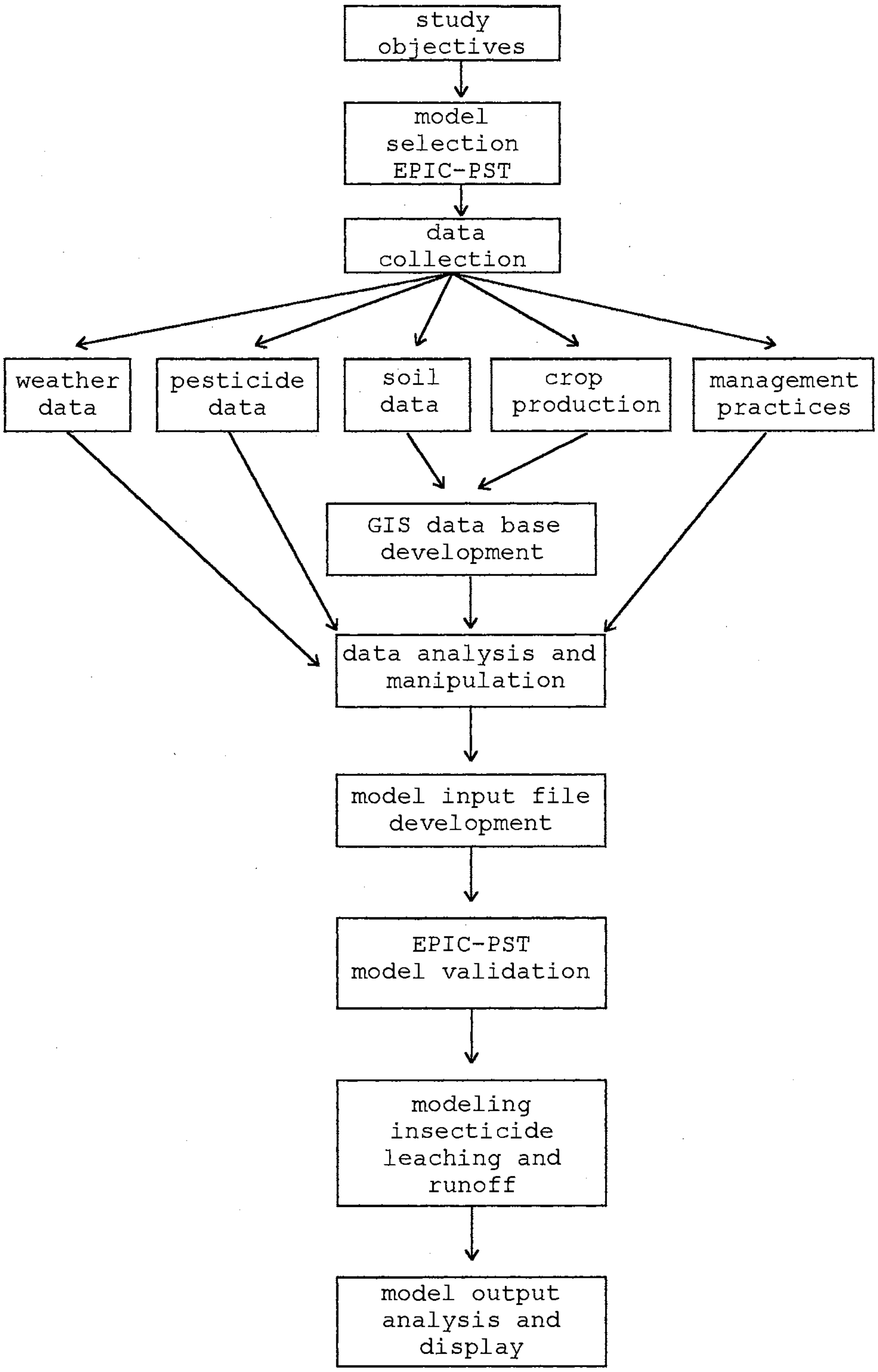

study objectives
model selection EPIC-PST
data collection
weather data
pesticide data
soil data
crop production
management practices
GIS data base development
data analysis and manipulation
model input file development
EPIC-PST model validation
modeling insecticide leaching and runoff
model output analysis and display

Figure 2. Location of study area which includes seven counties in southwest of Oklahoma. Polygons represent individual cotton fields, which were obtained by interpreting SCS aerial photographs.

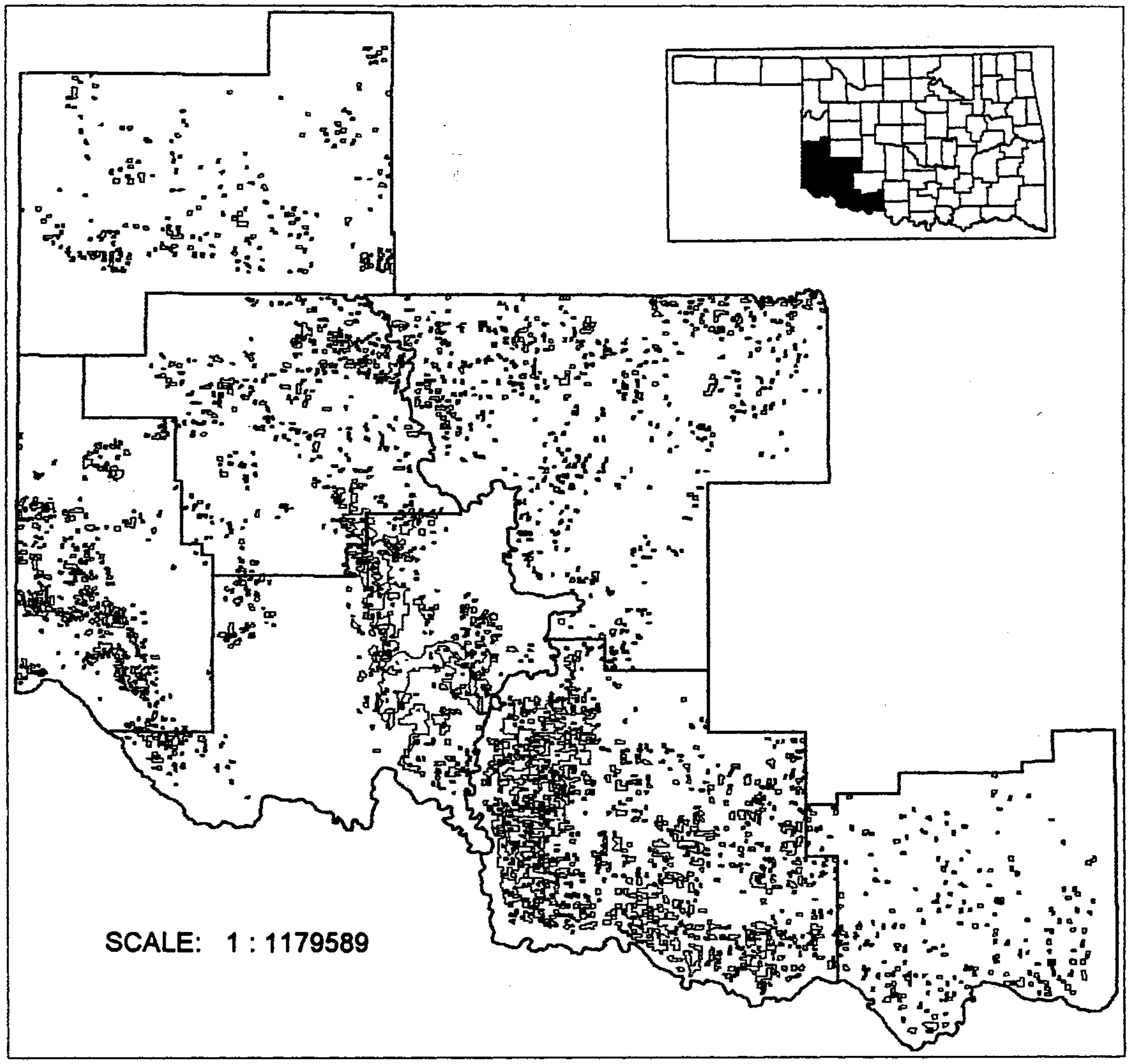

SCALE: 1 : 1179589

Figure 3. Variation of number of azinphos-methyl losses to runoff events with concentrations exceeding the Oklahoma surface water quality standards. ● Indicates the number of losses from irrigated land in Jackson County. ○ Indicates the number of losses from dry land.

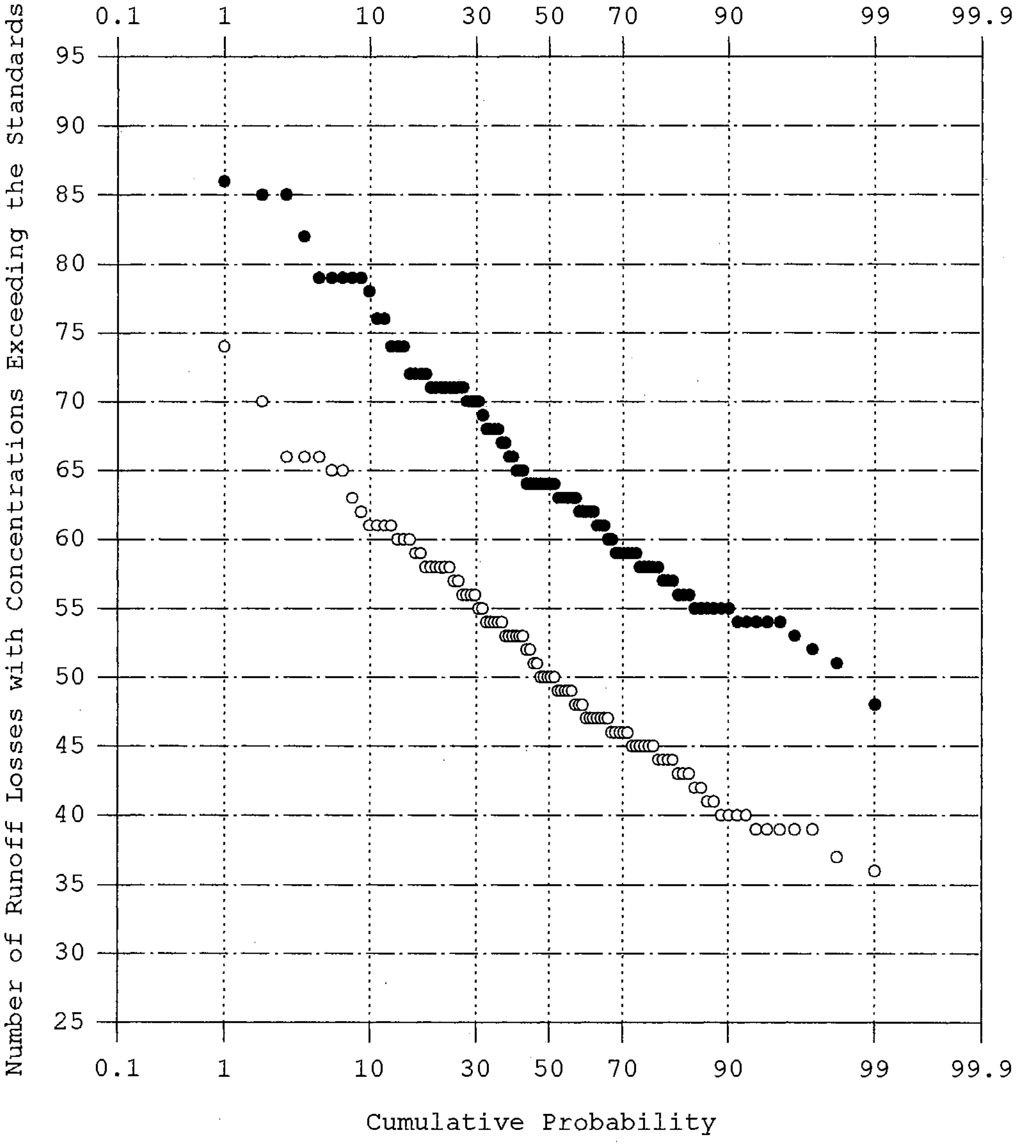

Number of Runoff Losses with Concentrations Exceeding the Standards
Cumulative Probability
0.1
1
10
30
50
70
90
99
99.9
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25

Figure 4. Variation of number of methyl-parathion losses to runoff events with concentrations exceeding the Oklahoma surface water quality standards. ● Indicates the number of losses from irrigated land in Jackson County. ○ Indicates the number of losses from dry land.

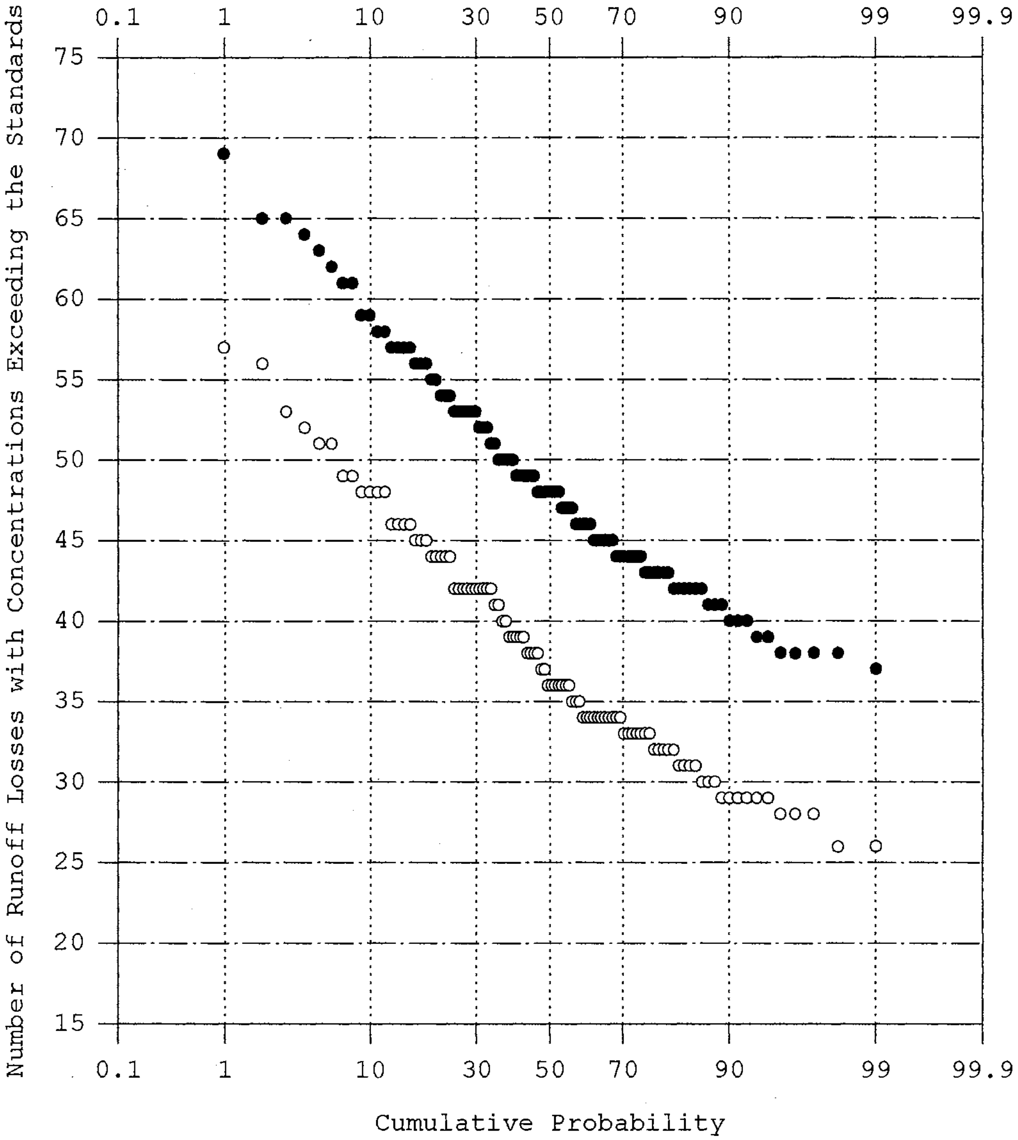

Number of Runoff Losses with Concentrations Exceeding the Standards
Cumulative Probability
0.1
1
10
30
50
70
90
99
99.9
75
70
65
60
55
50
45
40
35
30
25
20
15

Figure 5. Variation of number of malathion losses to runoff events with concentrations exceeding the Oklahoma surface water quality standards. • Indicates the number of losses from irrigated land in Jackson County. o Indicates the number of losses from dry land.

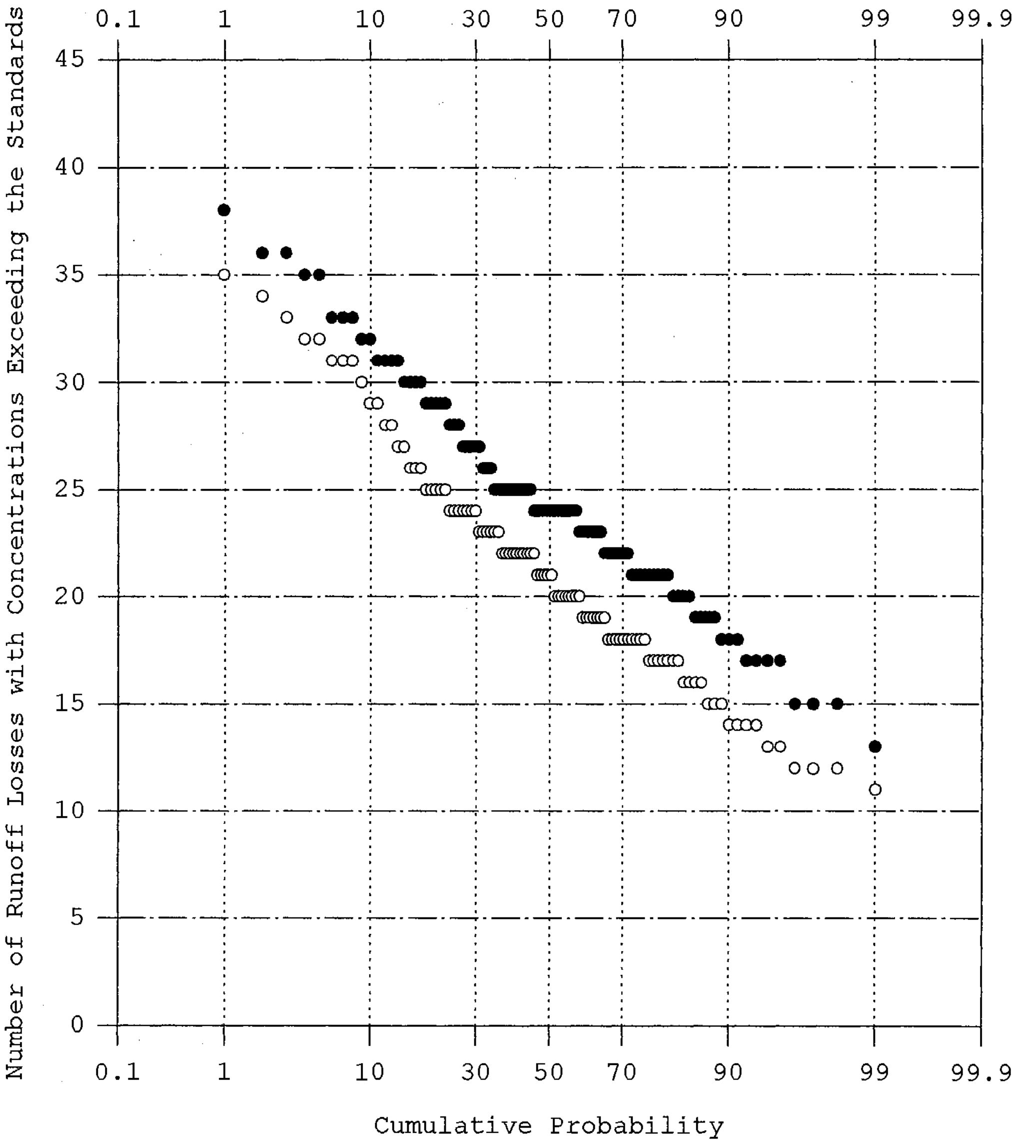

0.1
1
10
30
50
70
90
99
99.9
45
40
35
30
25
20
15
10
5
0
Number of Runoff Losses with Concentrations Exceeding the Standards
Cumulative Probability

Figure 6. Variation of number of diflubenzuron losses to runoff events with concentrations exceeding the Oklahoma surface water quality standards. • Indicates the number of losses from irrigated land in Jackson County. o Indicates the number of losses from dry land.

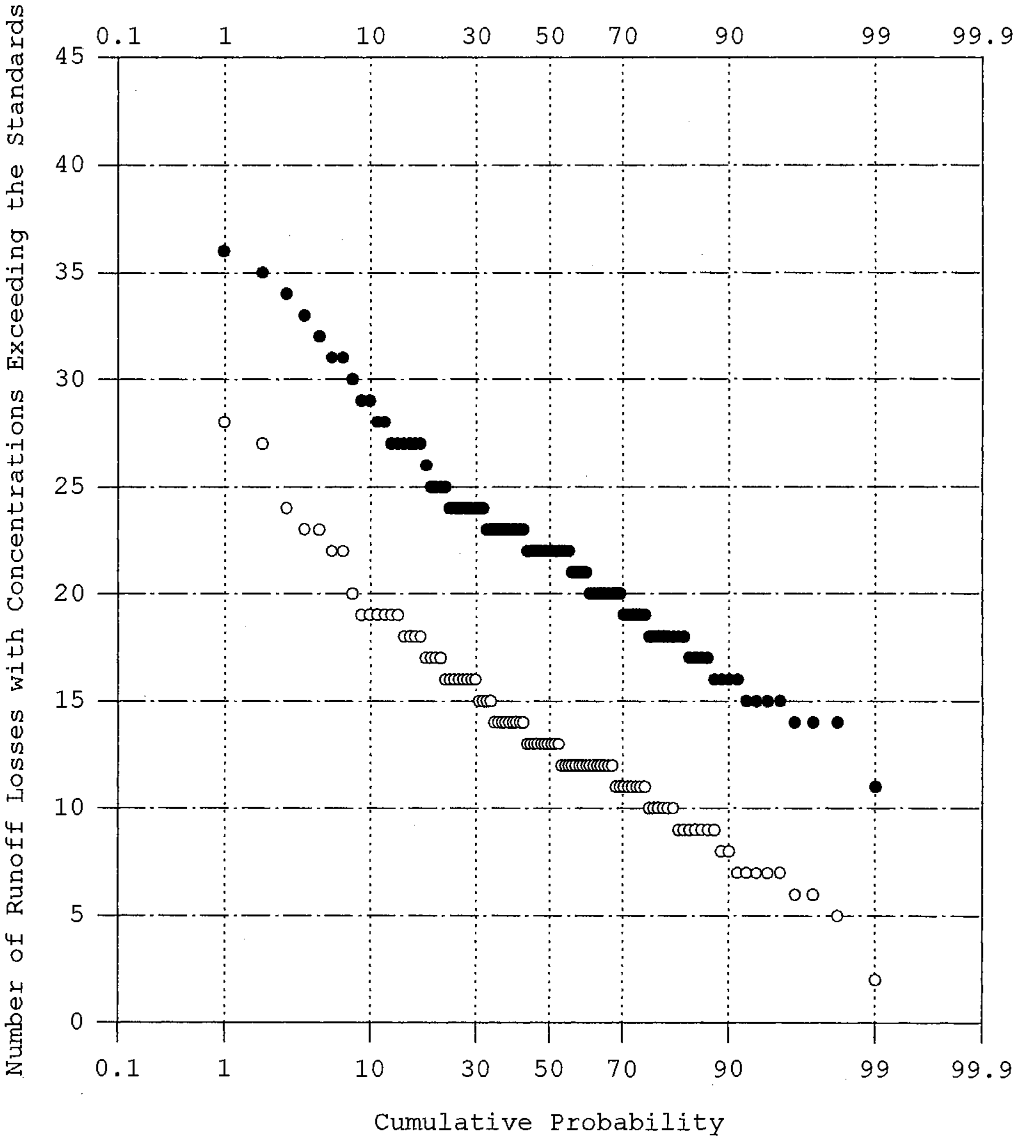

Number of Runoff Losses with Concentrations Exceeding the Standards
0
5
10
15
20
25
30
35
40
45
0.1
1
10
30
50
70
90
99
99.9
Cumulative Probability

Figure 7. Spatial distribution of azinphos-methyl loss potential with runoff from cotton fields in Jackson County. The areas were generated by dividing soils into four groups based on the average number of events shown by each soil.

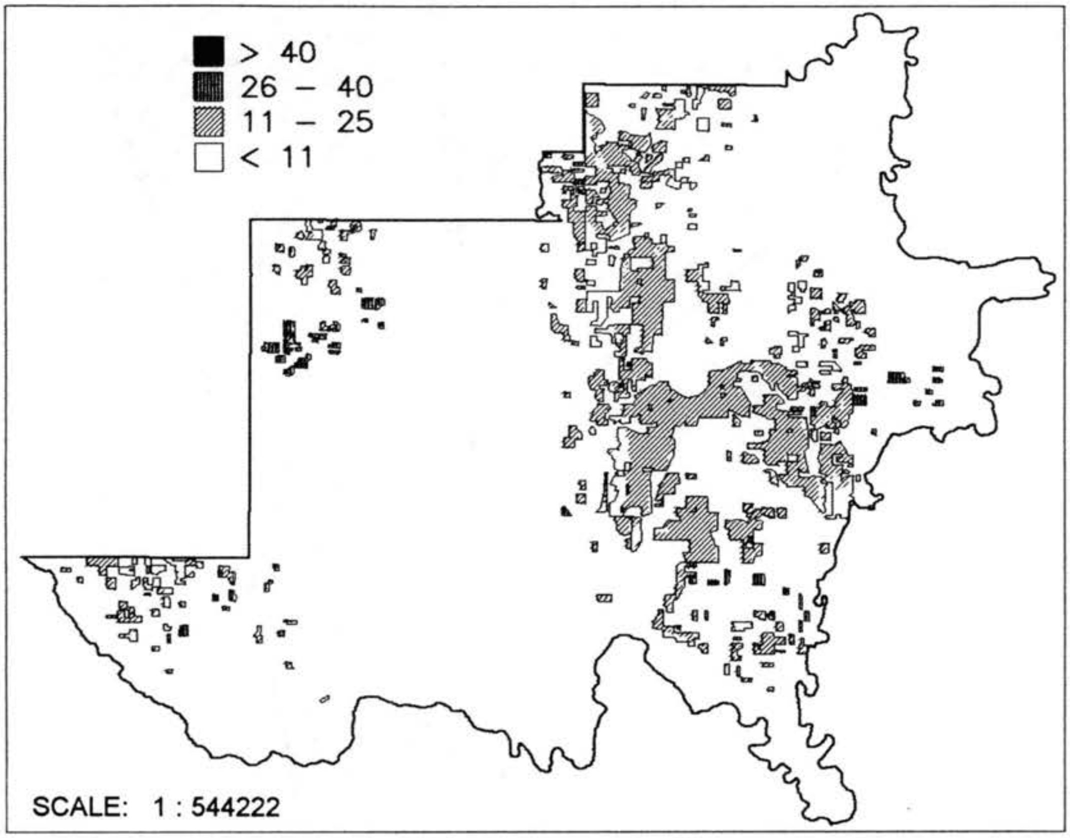

> 40
26 – 40
11 – 25
< 11
SCALE: 1 : 544222

Figure 8. Spatial distribution of methyl-parathion loss potential with runoff from cotton fields in Jackson County. The areas were generated by dividing soils into four groups based on the average number of events shown by each soil.

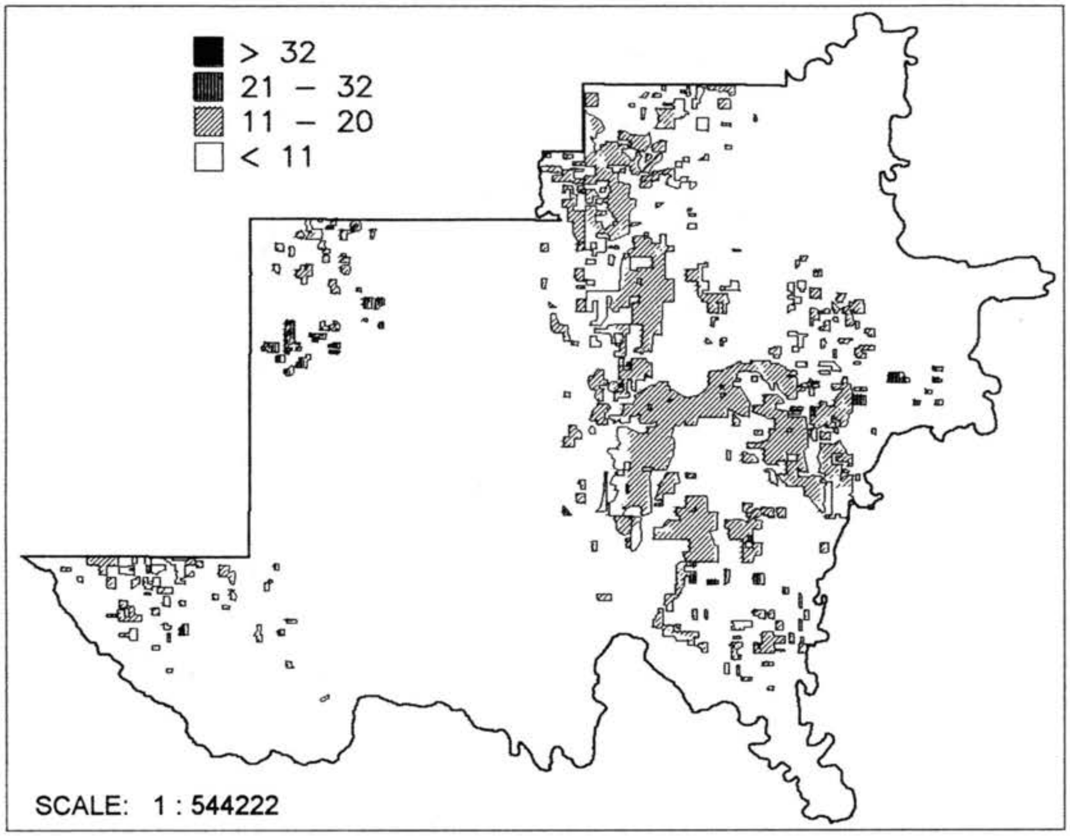

■ > 32
▥ 21 – 32
▨ 11 – 20
☐ < 11
SCALE: 1 : 544222

Figure 9. Spatial distribution of malathion loss potential with runoff from cotton fields in Jackson County. The areas were generated by dividing soils into four groups based on the average number of events shown by each soil.

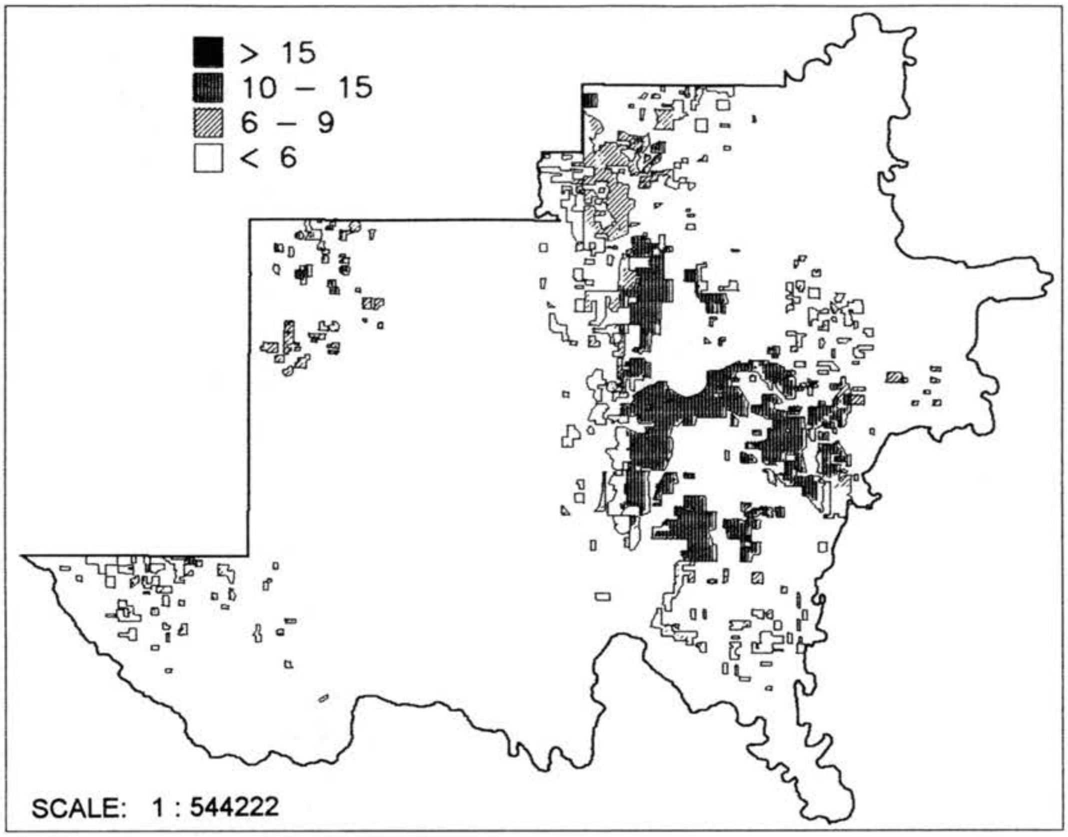
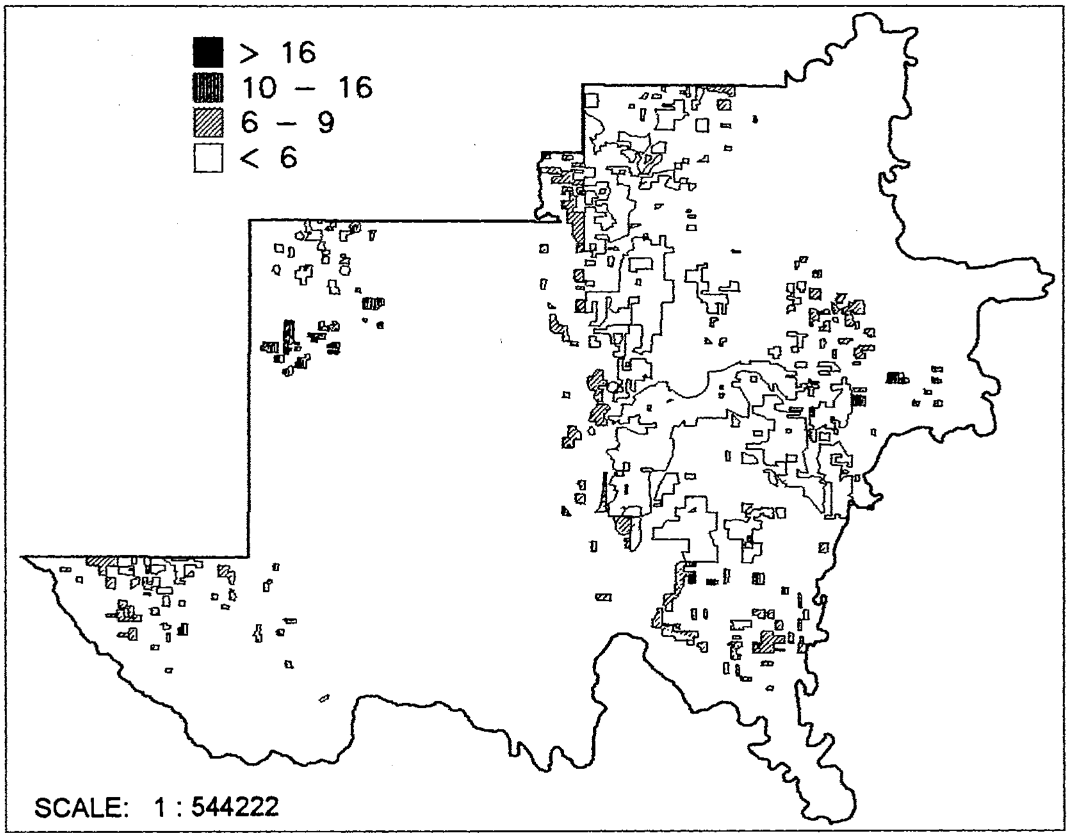

■ > 15
▦ 10 – 15
▨ 6 – 9
☐ < 6
SCALE: 1 : 544222

Figure 10. Spatial distribution of diflubenzuron loss potential with runoff from cotton fields in Jackson County. The areas were generated by dividing soils into four groups based on the average number of events shown by each soil.



> 16
10 – 16
6 – 9
< 6
SCALE: 1 : 544222

CHAPTER III

EVALUATING POTENTIAL IMPACT OF A BOLL WEEVIL ERADICATION PROGRAM ON FEDERALLY LISTED THREATENED AND ENDANGERED SPECIES IN OKLAHOMA

ABSTRACT

The boll weevil eradication program will increase insecticide usage within the program area. Pollution risk to the regional environment will be increased. One concern is the adverse effect of the chemicals on endangered and threatened wildlife species. Based on information collected on breeding distribution, habitat, life history, and diet of these species, this study evaluates the potential impact of the eradication program. The potential exposure of the species to the insecticides used in the program was analyzed and the risk of toxic effects was estimated according to the results of risk analysis provided by APHIS. Results of analyses indicate that all species, except interior least terns, would not be affected by the insecticides within the eradication area. Interio least terns may be indirectly affected if the chemicals are lost in runoff from the sites and reach the roosting areas along the Red River. Further research may be needed to determine the risk to least terns exposed to the insecticides in runoff.

INTRODUCTION

The boll weevil eradication program requires that all infested cotton fields in the program area be treated by the aerial application of the insecticides. The fields with high infestations would receive intensive treatments. The widespread application and intensive usage of insecticides will increase the risk of pollution to the regional environment. One concern about their impact is adverse effects on endangered wildlife species.

Protection of endangered wildlife species is important in maintaining all of the places of the complex ecological web of life that we depend on (U.S. Fish and Wildlife Service, 1989). Pesticides are responsible for more than one million bird deaths each year, including some endangered and threatened birds. They can also stress or delay recovery of endangered or threatened species. The Endangered Species Act requires that the activities undertaken or permitted by federal agencies not jeopardize the continued existence of endangered or threatened species or result in adverse impacts on their critical habitat. The purpose of this study is to evaluate the potential impact of the insecticides used in the eradication program on animals and plants that are listed by U.S. Fish and Wildlife Service as endangered or threatened species within Oklahoma.

MATERIALS AND METHODS

The study area covers seven major cotton-producing counties located in southwest of Oklahoma, including Beckham, Cotton, Greer, Harmon, Jackson, Kiowa, and Tillman. The area represents the core geographic region proposed for the boll weevil eradication program.

Method of Impact Assessment

The study analyzed the possibility of species being exposed to the insecticides used in the program and resultant direct and indirect toxic effects. Information on species distribution, habitat, life history, and diet was utilized to determine whether a species would likely be exposed to the applied insecticides. Results of risk assessment for birds provided by APHIS were utilized to estimate the risks of insecticide toxic effects on the species. These two types of data served as the basis on which the risk assessment was performed.

For each specific species, the current geographical distribution was evaluated to determine if the breeding areas were located in or bordered the proposed program region. Species whose breeding distribution was not spatially related to the proposed program area would not be affected by the eradication program and thus were excluded from the further impact analysis. Habitat, life history, and diet of the species were evaluated to determine the likelihood of their exposure to the insecticides. For species that would potentially be exposed to the insecticides, the risks of direct and indirect exposure to the insecticides were estimated based on the study provided by APHIS (1991) in which the risks to endangered species were evaluated. Indirect exposure comes from contact with vegetation at a drift distance of about 7.6 m from a treated field and from ingestion of contaminated diet items that constitute a percentage of an animal's daily food intake. Direct exposure assumes the species to be directly sprayed and to consume only contaminated food (APHIS, 1991). The assessment procedure is illustrated in figure 1.

Data Collection

A total of twenty plants and animals considered threatened or endangered as of August 4, 1992, within the state were obtained from the Oklahoma Department of Wildlife Conservation. The names and current status of 19 species are listed in table 1. Eskimo curlew, which has not been observed in the state since 1948 (Oklahoma Cooperative Extension Service, 1993), was not included in this analysis. Information on species breeding distribution, habitat, life history, diet, and causes of decline was taken from the documents and publications provided by the U.S. Fish and Wildlife Service (1987), Oklahoma Cooperative Extension Service (1993), APHIS (1991), and other researchers (Armbruster, 1990, Ehrlich et al., 1988, Grzybowski, 1987, 1991, Kuyt, 1992, Kuyt and Goossen, 1987, Ruelle, 1991, Stehn and Johnson, 1987, Whitman, 1988).

Risk assessment was conducted by APHIS for nontarget organisms listed by the U.S. Fish and Wildlife Service as threatened or endangered species that may be affected by the insecticides proposed for use in the program. Based on a group of representative species, the assessment tested the toxic properties of the insecticides in laboratory and field studies, calculated the species exposure to the insecticides, and estimated the risks to species. The results of this assessment for birds were taken from APHIS (1991) and are shown in table 2.

RESULTS AND DISCUSSION

Examining the geographical distributions specifies three endangered species whose current breeding areas are either located within or border the proposed eradication program region. They are black-capped vireo, Vireo atricapillus, interior least tern, Sterna antillarum, and whooping crane, Grus americana. The impact analysis for each of them is presented below. The remaining species would not be affected by the boll weevil eradication program since their nesting locations are distant from the proposed program area.

Black-capped Vireo

General description. The black-capped vireo is a songbird about 12 cm in length (Oklahoma Cooperative Extension Service, 1993). Mature males are olive green above and white below with faint yellow flanks. The females are duller in color than males. Typically, three to four eggs are laid. The birds feed on insects such as beetles and seeds (Ehrlich et al., 1988). Factors causing the decline of the species are cowbird nest parasitism and habitat destruction due to urbanization, domestic overgrazing, and rangland improvements (APHIS, 1991).

Geographical distribution. The breeding areas of black-capped vireo historically extended from south-central Kansas through central Oklahoma and Texas to central Coahuila, Mexico (Oklahoma Cooperative Extension Service, 1993). At present, the range extends from Oklahoma south through the Edwards Plateau and Big Bend National Park, Texas, to at least the Sierra Madera in central Coahuila, Mexico. In Oklahoma, specific localities where the black-capped vireo has been found (since 1985) are the upper reaches of Salt

Creek (north of Watonga) in Blaine County, southwestern Canadian County, the area near Scott in Caddo County, and the Wichita Mountains (including the Wichita Mountains National Wildlife Refuge and Fort Sill Military Reservation) (Grzybowski, 1991). The general breeding distribution of black-capped vireo and spatial location of the proposed eradication areas are shown in figure 2.

Habitat. Black-capped vireo habitat consists of scattered trees and brushy areas (U.S. Fish and Wildlife Service, 1987), where junipers are interlaced with other deciduous species such as oaks, rough leaf dogwood, redbud, etc. (Grzybowski, 1987, 1991). Most nests are 35 to 125 cm from the ground. Vireo territories are sometimes located on steep slopes, where trees are often clumped and intermediate in height and the habitat on level terrain is a mixture of shrubs and smaller trees (Oklahoma Cooperative Extension Service, 1993). Vireos were almost never observed in any but woody vegetations (Grzybowski, 1987).

Analysis and conclusion. The delineated breeding locations and habitat of black-capped vireo are distant from cotton fields within the proposed program areas and the species unlikely roosts in or near the crop fields during the eradication period. Therefore, the insecticides to be used in eradication program would not pose any risks to black-capped vireo, nor would its habitat be disturbed.

Interior Least Tern

General description. Least terns are small birds with a wingspan of about 50 cm (U.S. Fish and Wildlife Service, 1987). They have a black crown, white forehead, black-tipped yellow bill, grayish back, snowy white undersides, and orange legs. Least terns migrate in small, loose flocks and exact wintering locations are unknown (Whitman, 1988). The species arrive at breeding sites from late April to early June and leave the sites after four or five months (Oklahoma Cooperative Extension Service, 1993). Small fish near the nesting area are the major part of their diet. Major causes of nest failure include permanent flooding of the colony, predation, recreational uses of breeding sites by humans, and contaminants in polluted water (Whitman, 1988, Ruelle, 1991).

Geographic distribution. Interior least terns formerly ranged along the major river systems in the midwestern United States, including Colorado, Red, Arkansas, Missouri, Ohio, and Mississippi river systems. Currently, they breed as small remnant colonies within their historical distribution (Oklahoma Cooperative Extension Service, 1993). In Oklahoma, interior least terns nest along most of the large rivers, which are shown in figure 3, and at the Salt Plains National Wildlife Refuge in Alfalfa County.

Habitat. Terns choose salt flats, islands, and sandbars along rivers and lakes for roosting. The roosting sites are well-drained and the sand must be mostly devoid of vegetation (Oklahoma Cooperative Extension Service, 1993, Whitman, 1988). Water levels must be low enough during the nesting season so nests remain dry.

Analysis and conclusion. Interior least terns would not be affected through direct exposure to the insecticides used by the eradication program because their nesting areas along the Red River are not adjacent to the cotton fields located within the proposed program area. Soils along the rivers in the area are usually shallow and steep and would not satisfy the requirement for cotton production. However, the species may be affected by indirect exposure to the insecticides if these chemicals reach the water through runoff and contaminate the water and food fish. According to the risk analysis completed by APHIS for birds (table 2), the risks of toxic effects on birds are low from the indirect exposures to azinphos-methyl, malathion, and diflubenzuron and moderate from the indirect exposure to methyl-parathion. A further study may be needed for evaluating the potential exposure of the insecticides lost in runoff as well as their toxic effects to the species.

Impact Analysis for Whooping Crane

General description. The whooping crane is the tallest

American bird with long neck, white color, and long legs (U.S. Fish and Wildlife Service, 1987, Oklahoma Cooperative Extension Service, 1993). Adults have a red crown and a patch of black feathers below the eye. Whooping cranes eat insects, frogs, small birds, minnows, small grains (corn, wheat, sorghum, barley) and green forage (alfalfa, winter wheat). Factors causing the population decline include destruction of breeding habitat and human disturbance. The losses of migrating whooping cranes are also due to collisions with power lines (Kuyt, 1992).

Geographical distribution. Whooping cranes were originally distributed from the northwest territories of Canada through the prairie provinces and northern prairie states to Illinois (Oklahoma Cooperative Extension Service, 1993). Currently, the main population of wild whooping cranes nests in northeastern Alberta and south-central Northwest Territories of Canada and winters along the Texas Gulf Coast (Kuyt and Goossen, 1987, Stehn and Johnson, 1985). They migrate alone, in pairs, in family groups, and in small flocks and pass through the western part of Oklahoma on their spring (April and May) and fall (Oct. and Nov.) migrations (U.S. Fish and Wildlife Service, 1987). The important stopover area in the state is the Salt Plains National Wildlife Refuge in Alfalfa County. Sightings of cranes during migration have been also reported on other regions. The general locations of the stopover area and regions are shown in figure 4.

Habitat. Migrating whooping cranes usually landed on or near wetlands for overnight roosting and feeding (Armbruster, 1990, Kuyt, 1992). The sites may be located along rivers or near a pond and lake. Whooping cranes sometimes use grain fields near small wetlands for feeding.

Analysis and conclusion. The eradication program would unlikely affects migrating whooping cranes which stopover in Oklahoma during their migration for the following reasons: (1) the species would not use cotton fields for overnight nesting and feeding, and (2) the dates of their arriving and leaving Oklahoma are respectively before and after the dates scheduled for the insecticide application in the eradication program (The treatments start in early June and would largely be finished by late Sept. during each program year).

SUMMARY AND CONCLUSION

The potential impact of boll weevil eradication program on federally listed threatened and endangered species in Oklahoma was evaluated using the information drawn from government publications and reports. Analysis results indicate that all species, except interior least terns, would not be affected by the insecticides to be used within the proposed program area. Interior least terns may be indirectly affected by the insecticides if the chemicals are lost in runoff and reach the roosting areas of the species along Red River. According to the risk assessment reported by APHIS, the toxic effect from indirect exposure can be moderate or low, depending on the insecticides. Further risk assessment for interior least terns is needed to determine the potential exposure of the insecticides in runoff and their toxic effects to the species.

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Whitman, P. L. 1988. Biology and conservation of the endangered interior least tern: a literature review. Biological Report 88(3). Washing, DC: U.S. Fish and Wildlife Service.

Table 1. Threatened and endangered species of Oklahoma

Common Name of Species	Current
American alligator	Threatened*
American burying beetle	Endangered†
American peregrine falcon	Endangered
Arctic peregrine falcon	Threatened
Bald eagle	Endangered
Black-capped vireo	Endangered
Eastern prairie fringed orchid	Threatened
Gray bat	Endangered
Indiana bat	Endangered
Interior least tern	Endangered
Leopard darter	Threatened
Neosho madtom	Threatened
Ouachita rock-pocketbook	Endangered
Ozark big-eared bat	Endangered
Ozark cavefish	Threatened
Piping plover	Endangered
Red-cockaded woodpecker	Endangered
Western prairie fringed orchid	Threatened
Whooping crane	Endangered

* Species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range (APHIS, 1991).

† Species in danger of extinction throughout all or a significant portion of its range (APHIS, 1991).

Data source: Oklahoma Department of Wildlife Conservation. Oklahoma City, Oklahoma.

Table 2. Risks to nontarget terrestrial species from insecticides

Species	Azinphos-methyl		Diflubenzuron		Malathion		Methyl-parathion	
	Indirect*	Direct†	Indirect	Direct	Indirect	Direct	Indirect	Direct
Birds	Low‡	High§	Low	Low	Low	Low	Moderate‖	High

* Indirect exposure of species to the insecticides.

† Direct exposure of species to the insecticides.

‡ Low risk of toxic effects from the insecticides: dose to which the species are exposed is greater than or equal to LD_{50} for the species.

§ High risk of toxic effects from the insecticides: dose to which the species are exposed is less than 1/5 LD_{50} for the species.

‖ Moderate risk of toxic effects from the insecticides: dose to which the species are exposed is greater than or equal to 1/5 LD_{50} but is less than LD_{50} for the species.

Data source: APHIS, 1991.

Figure 1. Method and procedure for assessing potential effects of insecticides from the eradication program on endangered or threatened species in Oklahoma.

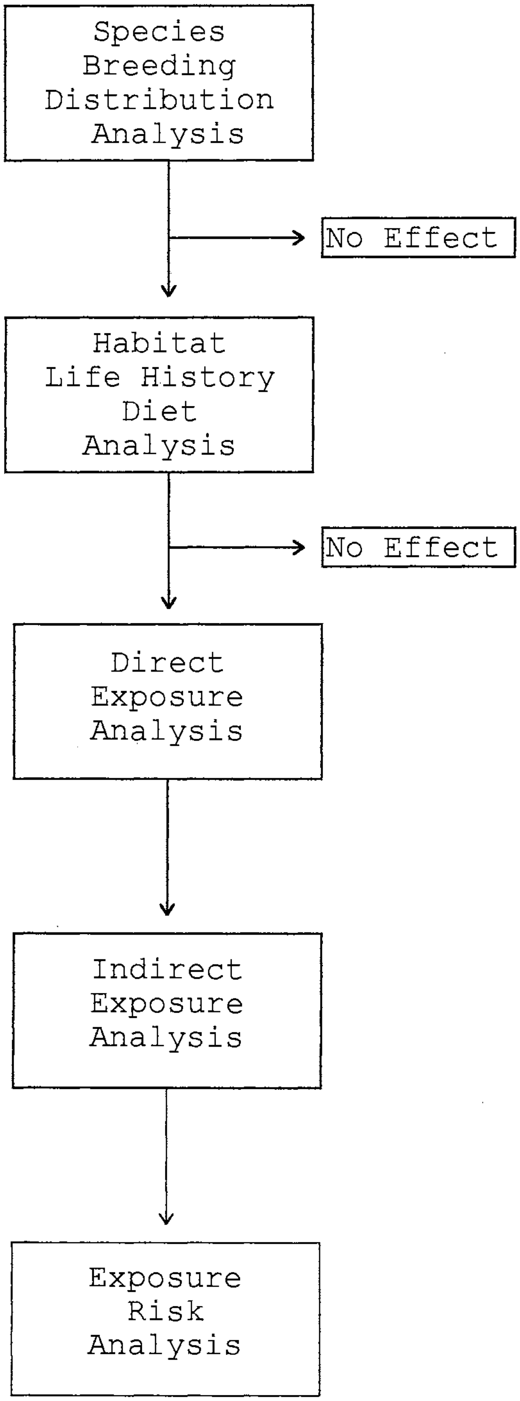

Species Breeding Distribution Analysis
No Effect
Habitat Life History Diet Analysis
No Effect
Direct Exposure Analysis
Indirect Exposure Analysis
Exposure Risk Analysis

Figure 2. Breeding distribution of black-capped vireo in Oklahoma. Data were collected from the Oklahoma Department of Wildlife Conservation, Oklahoma City, Oklahoma.

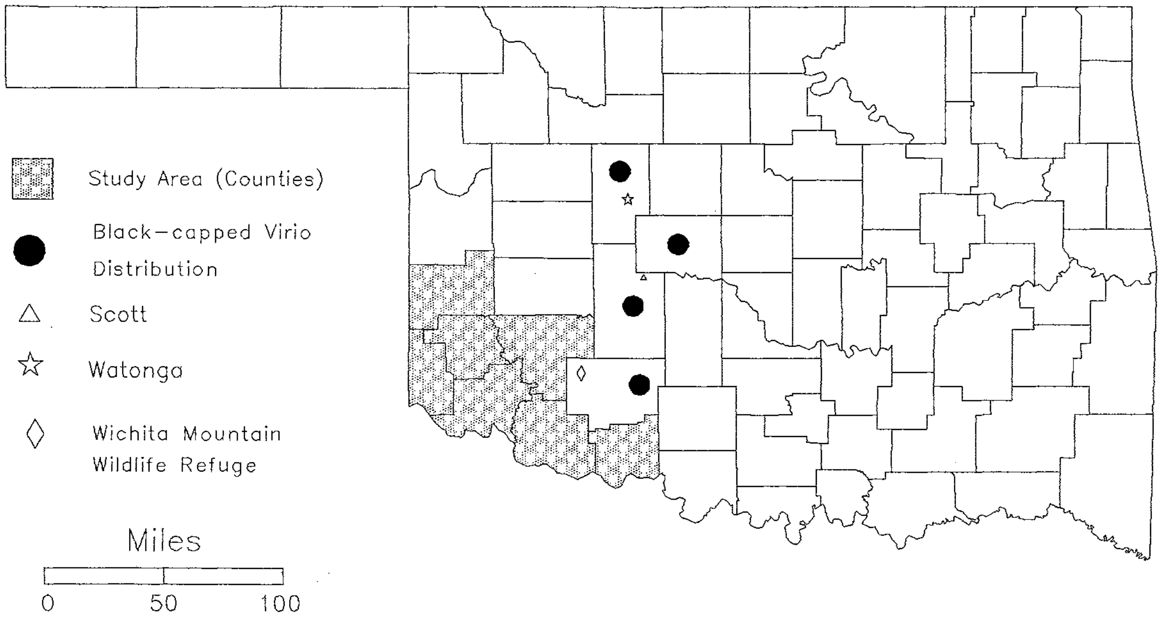

▨ Study Area (Counties)
● Black-capped Virio Distribution
△ Scott
☆ Watonga
◊ Wichita Mountain Wildlife Refuge
Miles
0
50
100

Figure 3. Nesting areas of interior least terns in Oklahoma. Data were collected from the Oklahoma Department of Wildlife Conservation, Oklahoma City, Oklahoma.

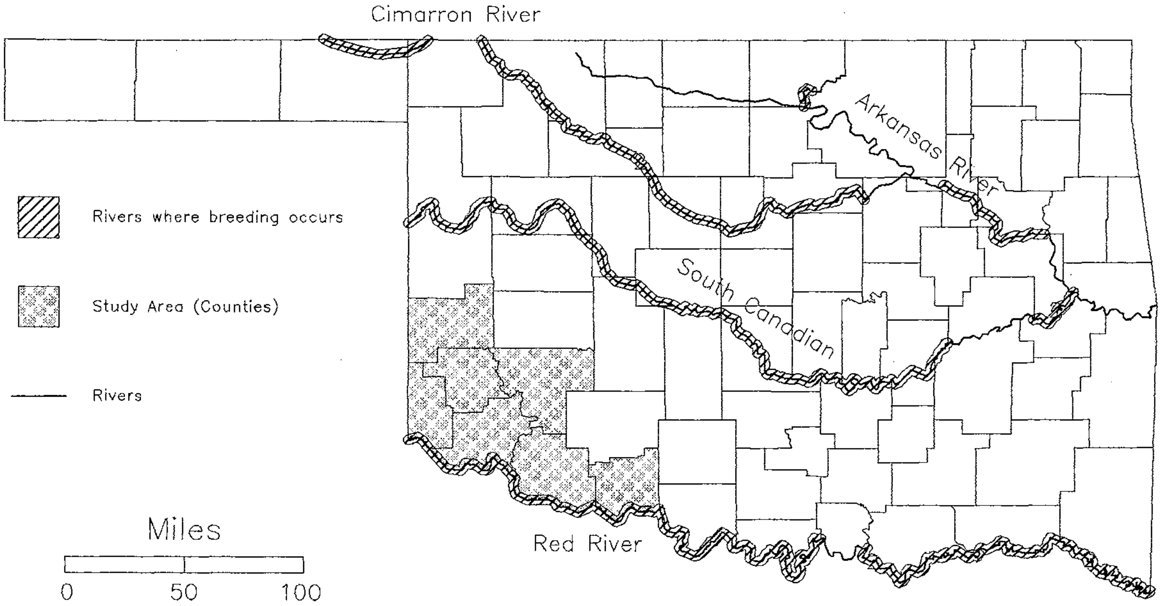
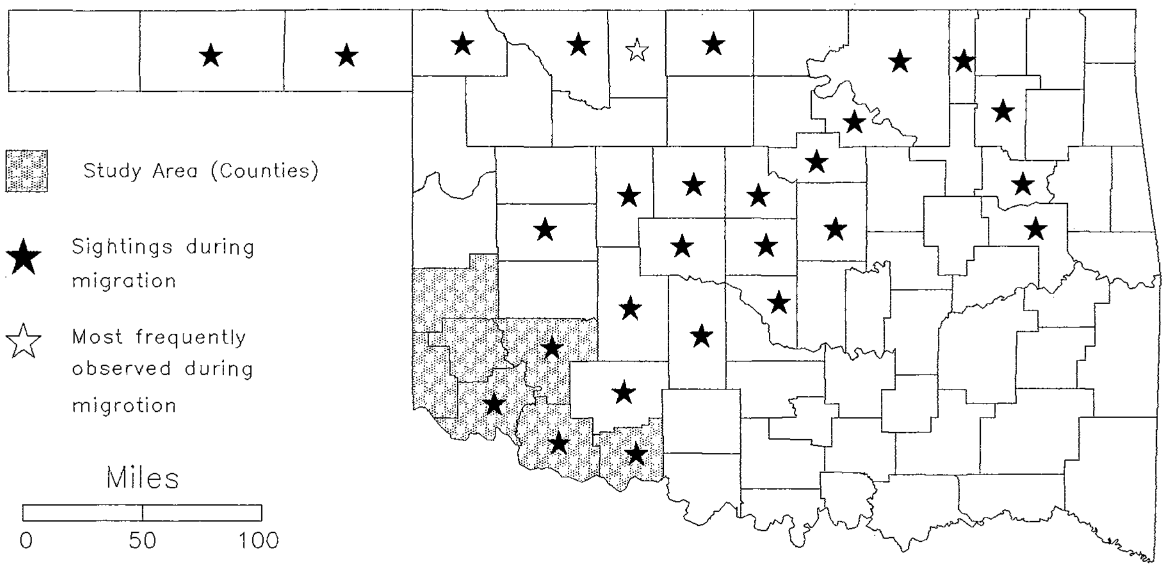

Cimarron River
Arkansas River
South Canadian
Red River
▨ Rivers where breeding occurs
▩ Study Area (Counties)
Rivers
Miles
0
50
100

Figure 4. Sighting areas of whooping cranes in Oklahoma. Data were collected from the Oklahoma Department of Wildlife Conservation, Oklahoma City, Oklahoma.


Study Area (Counties)
Sightings during migration
Most frequently observed during migrotion
Miles
0
50
100

APPENDIX A

SOIL AND WEATHER DATA AND SIMULATING RESULTS FOR BECKHAM COUNTY

Weather parameters based on the daily data from
Erick 4 E Station for 1962-1991 period

Month	TMX*	TMN†	SDTMX‡	SDTMN§	PRE‖	SDR#
	C	C	C	C	mm	mm
January	10.3	-5.3	7.8	5.6	13.9	4.9
February	13.3	-2.7	7.7	5.3	23.5	7.1
March	18.4	1.7	6.8	5.4	41.8	10.9
April	23.8	7.6	5.4	4.9	52.0	13.3
May	27.9	12.5	4.7	4.3	107.6	18.7
June	32.2	17.5	4.0	3.1	91.5	16.4
July	35.4	19.9	3.5	2.5	43.6	11.4
August	34.4	18.9	3.7	2.7	66.3	13.9
September	30.0	14.9	5.2	4.5	84.6	16.1
October	24.5	8.2	5.6	4.8	56.7	21.4
November	16.9	1.8	6.4	5.2	31.9	11.1
December	11.3	-3.4	7.1	5.2	20.5	7.5

* Average monthly maximum temperature.
† Average monthly minimum temperature.
‡ Monthly standard deviation of maximum temperature.
§ Monthly standard deviation of minimum temperature.
‖ Average monthly precipitation.
Monthly standard deviation of daily precipitation.
Data source: Oklahoma Climatological Survey, Norman, Oklahoma.

Soil types within cotton fields in Beckham County

SN*	Soil Name	HSG†	CN‡	Slope§ (%)	Landuse (cotton)	Area (ha)
1	Abilene clay loam	C	85	0.5	dryland	76
2	Altus fine sandy loam	B	78	2.0	dryland	212
3	Aspermont silt loam	B	78	4.0	dryland	76
4	Aspermont silt loam	B	78	3.5	dryland	136
7	Carey loam	B	78	2.0	dryland	780
8	Clairemont silt loam	B	78	0.5	dryland	100
15	Delwin loamy fine sand	A	67	1.5	dryland	584
16	Devol loamy fine sand	B	78	1.5	dryland	128
17	Devol loamy fine sand	B	78	5.5	dryland	140
18	Devol fine sandy loam	B	78	7.5	dryland	16
19	Dill fine sandy loam	B	78	2.0	dryland	376
20	Dill fine sandy loam	B	78	4.0	dryland	72
21	Dill fine sandy loam	B	78	8.5	dryland	16
22	Gracemont clay loam	C	85	0.5	dryland	24
23	Gracemont clay loam, Saline	C	85	0.5	dryland	20
25	Grandfield loamy fine sand	B	78	2.0	dryland	112
26	Grandfield loamy fine sand	B	78	3.5	dryland	24
27	Grandfield fine sandy loam	B	78	2.0	dryland	812
28	Grandfield fine sandy loam	B	78	4.0	dryland	96
29	Grandfield fine sandy loam	B	78	3.5	dryland	44
30	Hardeman fine sandy loam	B	78	2.0	dryland	80
31	Hardeman fine sandy loam	B	78	4.0	dryland	12
36	Nobscot fine sand	A	67	3.5	dryland	624
39	Obaro silt loam	B	78	2.0	dryland	128

Soil types within cotton fields in Beckham County
(continued)

SN	Soil Name	SHG	CN	Slope (%)	Landuse (cotton)	Area (ha)
40	Quinlan silt clay loam	C	85	2.0	dryland	8
41	Quinlan silt loam	C	85	4.0	dryland	48
42	Port silt clay loam	B	78	0.5	dryland	44
44	Talpa loam	D	89	4.0	dryland	40
45	Quinlan silty clay loam	C	85	4.0	dryland	32
47	Quinlan loam	C	85	3.5	dryland	20
48	Quinlan loam	C	85	8.5	dryland	72
49	Quinlan fine sandy loam	C	85	7.0	dryland	36
50	Spur loam	B	78	0.5	dryland	24
52	St. Paul silt loam	B	78	0.5	dryland	216
53	St. Paul silt loam	B	78	2.0	dryland	308
54	Tillman clay loam	C	85	2.0	dryland	28
55	Tipton loam	B	78	0.5	dryland	52
56	Tipton loam	B	78	2.0	dryland	68
57	Tivoli fine sand	A	67	8.5	dryland	24
61	Woodward loam	B	78	2.0	dryland	168
62	Woodward loam	B	78	4.0	dryland	48
63	Quinlan loam	C	85	2.0	dryland	64
64	Quinlan loam	C	85	4.0	dryland	140
66	Yahola fine sandy loam	B	78	0.5	dryland	16

* Soil category number.
† Soil hydrologic group.
‡ Curve number.
§ Average slope of soils.
Data source: USDA SCS, Stillwater, Oklahoma.

Number of insecticide runoff events from dry cotton fields in
Beckham County with concentrations exceeding the
Oklahoma surface water quality standards

Azinphos-methyl				Methyl-parathion				Malathion				Diflubenzuron			
SN*	Avg†	Max‡	Min§	SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min
44	33	54	21	44	24	42	12	44	13	27	5	48	9	23	2
48	30	51	20	48	23	41	14	49	13	25	5	49	9	23	3
49	30	52	18	49	23	41	13	48	12	27	5	41	8	20	1
41	26	46	16	41	20	35	8	41	11	23	3	44	8	19	1
64	24	44	14	64	19	34	7	45	10	23	3	64	8	20	1
45	23	43	14	45	18	34	7	47	10	23	3	21	7	19	0
47	23	43	14	47	18	34	7	64	10	23	3	40	7	18	1
18	21	43	11	18	16	34	5	18	9	24	2	45	7	19	1
40	21	42	12	21	16	34	4	21	9	24	2	47	7	20	1
21	20	43	11	40	16	32	6	40	9	22	2	18	6	18	0
54	19	39	9	63	15	30	4	54	8	19	2	63	6	18	1
63	18	38	8	54	14	30	4	63	8	19	2	17	5	16	0
17	17	35	8	17	13	29	2	17	7	21	1	20	5	15	0
1	15	33	5	22	12	25	3	1	6	17	1	22	5	18	0
22	15	32	6	23	12	25	2	3	6	17	1	23	5	17	0
23	15	32	5	1	11	25	2	20	6	18	1	26	5	14	0
28	14	31	4	20	11	25	2	22	6	17	1	28	5	15	0
31	14	30	4	26	11	23	2	23	6	17	1	29	5	15	0
3	13	29	5	28	11	25	2	26	6	17	1	31	5	16	0
4	13	28	4	31	11	25	2	28	6	18	1	54	5	17	0
20	13	30	4	57	11	21	3	29	6	17	1	1	4	15	0
26	13	29	4	62	11	24	2	31	6	18	1	3	4	14	0
29	13	29	4	3	10	24	2	57	6	15	1	4	4	14	0
57	13	28	5	4	10	22	2	62	6	17	1	19	4	13	0
62	13	29	5	29	10	24	2	2	5	14	1	25	4	12	0
2	11	28	4	2	9	21	2	4	5	15	1	27	4	13	0

Number of insecticide runoff events from dry cotton fields in Beckham County with concentrations exceeding the Oklahoma surface water quality standards (continued)

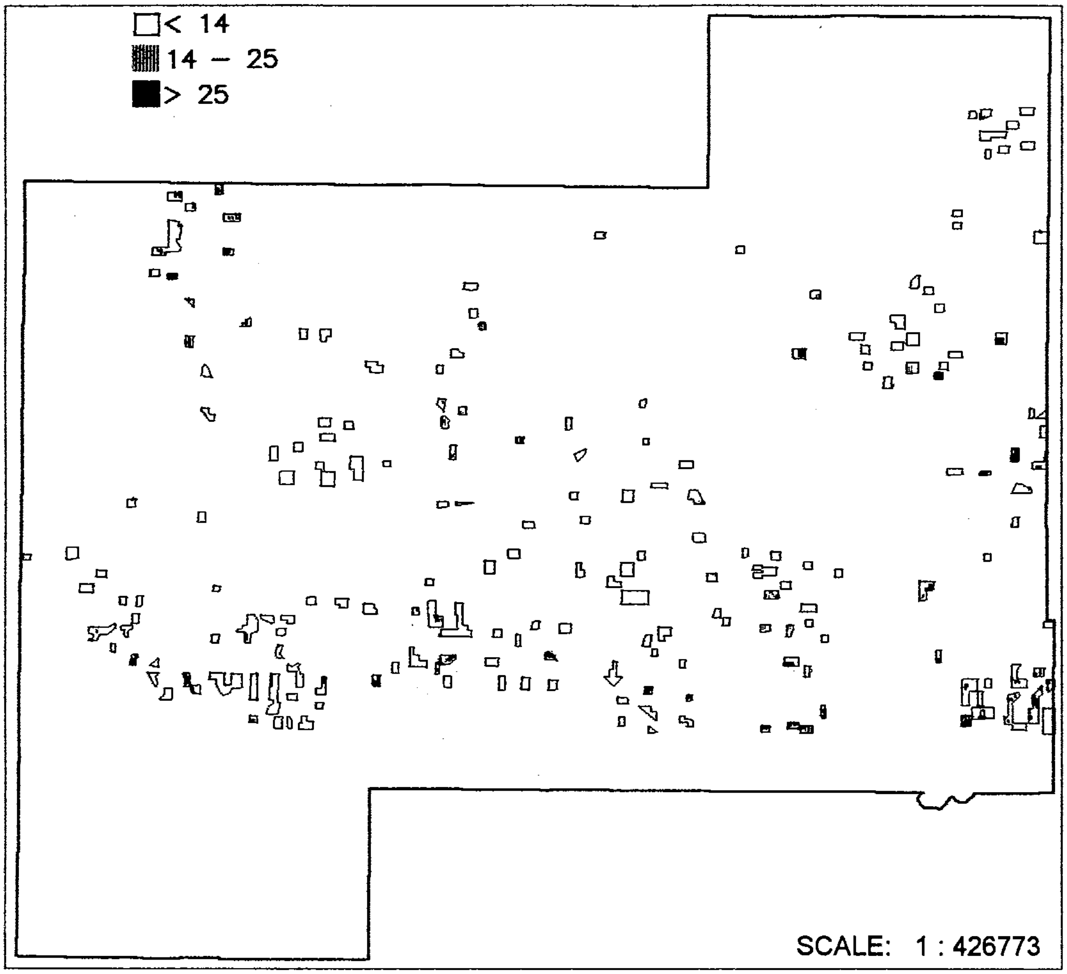
Azinphos-methyl				Methyl-parathion				Malathion				Diflubenzuron			
SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min
25	11	26	4	25	9	20	2	19	5	14	0	30	4	13	0
30	11	28	4	30	9	21	2	25	5	14	0	39	4	14	0
7	10	27	4	39	9	21	2	27	5	14	0	57	4	12	0
16	10	25	4	7	8	20	2	30	5	14	0	62	4	15	0
19	10	27	4	16	8	19	2	39	5	15	0	2	3	13	0
27	10	27	4	19	8	20	2	7	4	13	0	7	3	13	0
39	10	26	4	27	8	20	2	16	4	14	0	16	3	12	0
53	10	27	4	53	8	20	2	53	4	14	0	53	3	13	0
56	10	27	4	56	8	20	2	55	4	13	0	55	3	13	0
61	10	27	4	61	8	20	2	56	4	14	0	56	3	13	0
8	8	19	3	55	7	16	2	61	4	14	0	61	3	13	0
42	8	20	3	66	7	18	2	66	4	13	0	66	3	12	0
50	8	20	3	8	6	15	2	8	3	12	0	8	2	11	0
52	8	20	3	42	6	15	2	42	3	12	0	42	2	11	0
55	8	21	3	50	6	15	2	50	3	13	0	50	2	12	0
66	8	23	3	52	6	16	2	52	3	12	0	52	2	12	0
36	5	14	0	36	4	12	0	36	2	9	0	15	1	5	0
15	4	13	0	15	3	11	0	15	1	7	0	36	1	7	0

* Soil category number.

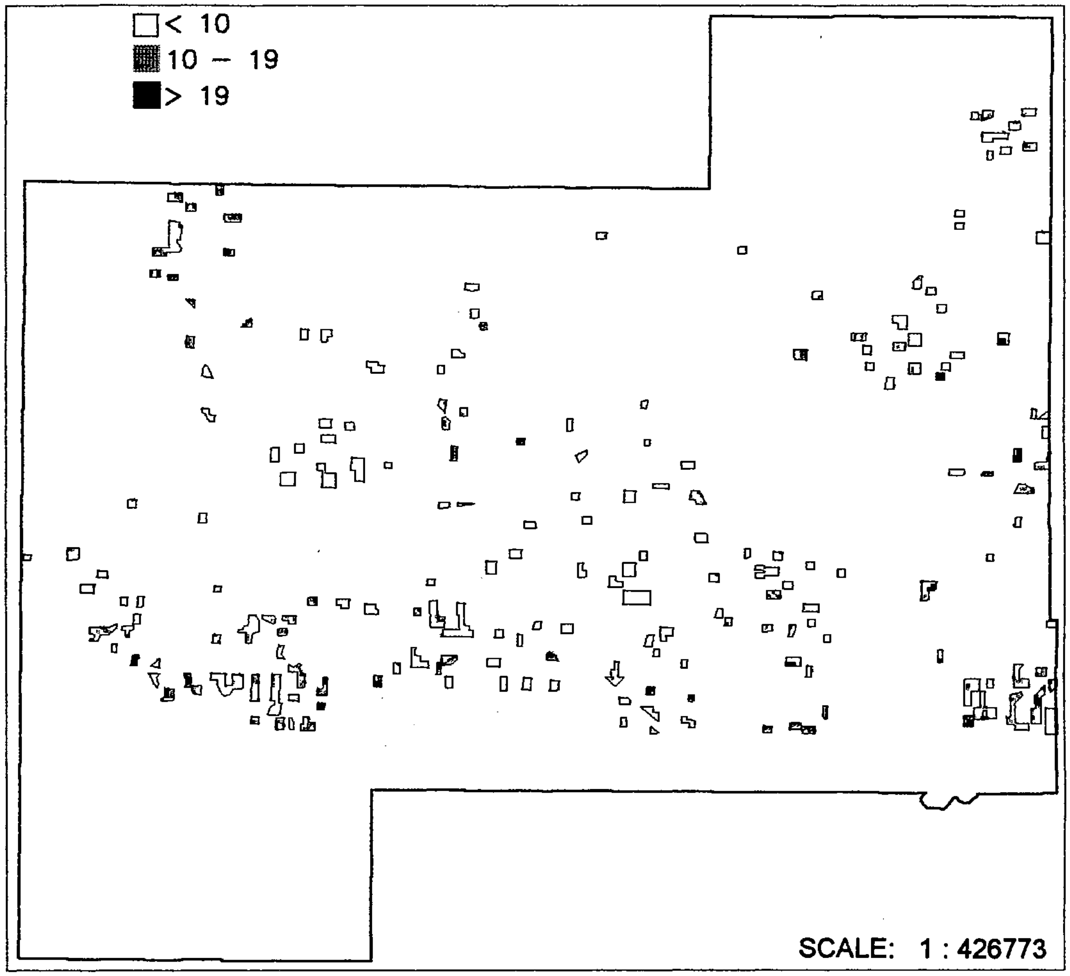
† Average number of events exceeding the standards.

‡ Maximum number of events exceeding the standards.

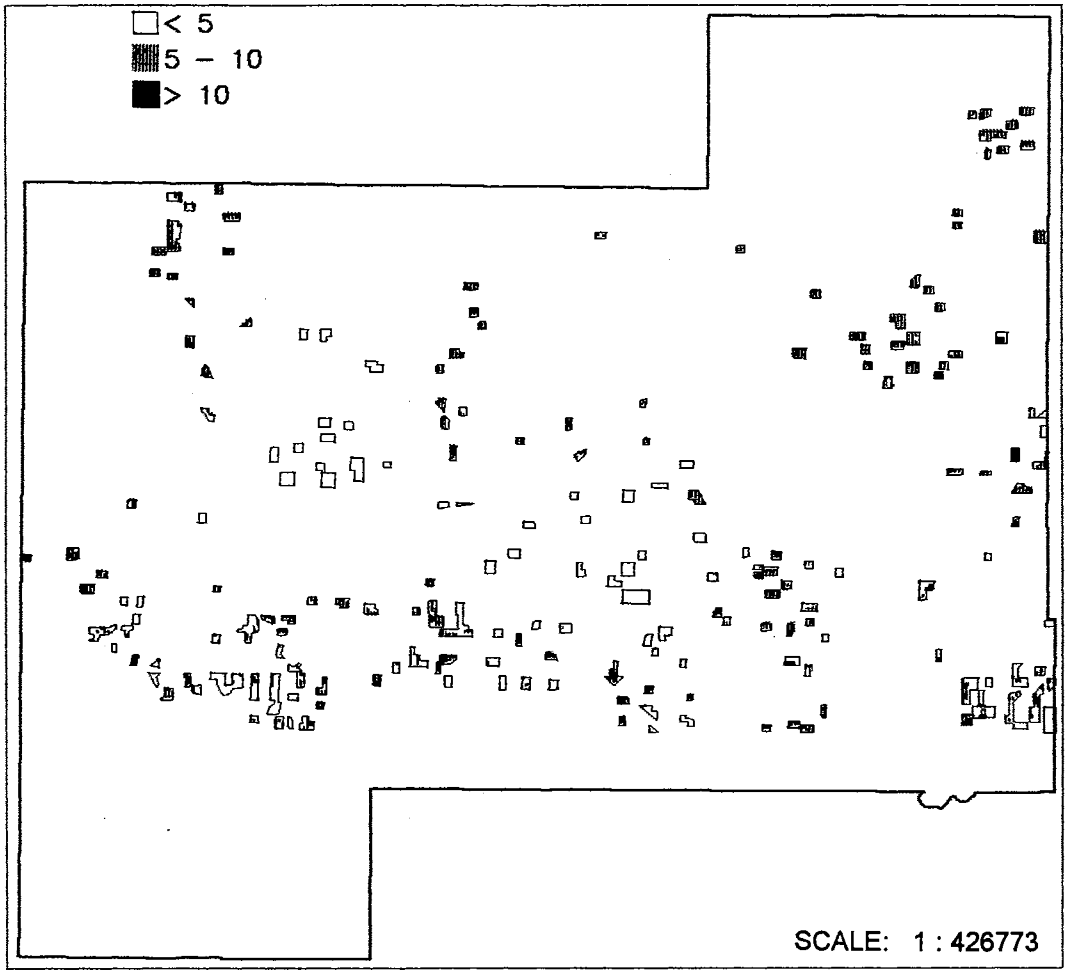
§ Minimum number of events exceeding the standards.



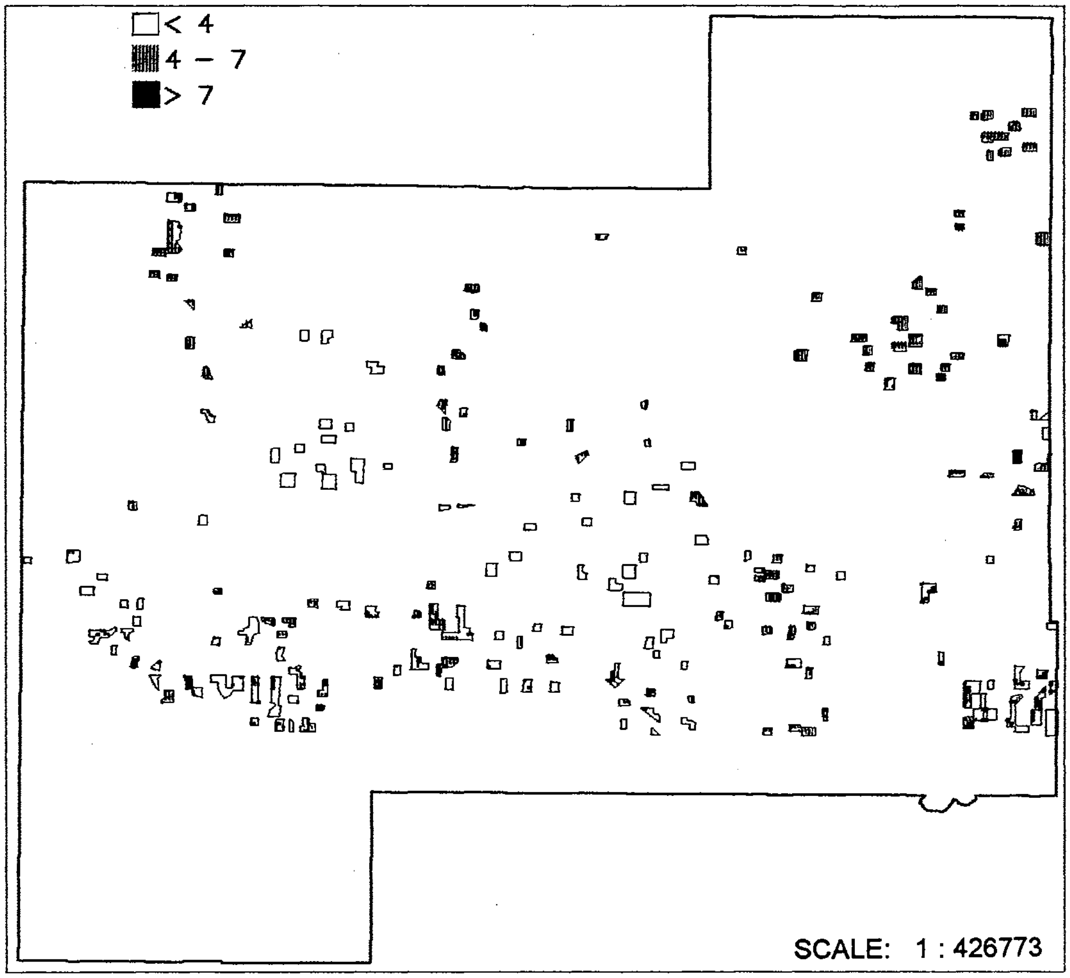
Spatial distribution of azinphos-methyl loss potential with runoff from cotton fields in Beckham County



Spatial distribution of methyl-parathion loss potential with runoff from cotton fields in Beckham County



Spatial distribution of malathion loss potential with runoff from cotton fields in Beckham County



Spatial distribution of diflubenzuron loss potential with runoff from cotton fields in Beckham County

APPENDIX B

SOIL AND WEATHER DATA AND SIMULATING RESULTS FOR COTTON COUNTY

Weather parameters based on the daily data from Frederick Station for 1962-1991 period

Month	TMX*	TMN†	SDTMX‡	SDTMN§	PRE‖	SDR#
	C	C	C	C	mm	mm
January	11.0	-3.1	7.8	5.4	25.8	8.6
February	14.3	-0.8	8.0	5.3	31.5	9.0
March	19.7	4.0	7.1	5.2	50.5	11.2
April	25.1	9.8	5.5	4.6	59.1	12.5
May	29.2	14.5	4.8	4.0	111.9	16.6
June	33.7	19.3	4.1	3.1	89.5	21.4
July	36.8	22.0	3.6	2.2	56.4	14.5
August	36.0	21.1	4.0	2.4	70.5	15.6
September	31.0	16.9	5.4	4.1	92.0	20.1
October	25.4	10.4	5.7	4.6	69.3	18.9
November	17.9	4.0	6.4	5.1	39.1	11.0
December	12.2	-1.4	7.2	5.3	29.9	9.5

* Average monthly maximum temperature.
† Average monthly minimum temperature.
‡ Monthly standard deviation of maximum temperature.
§ Monthly standard deviation of minimum temperature.
‖ Average monthly precipitation.
Monthly standard deviation of daily precipitation.
Data source: Oklahoma Climatological Survey, Norman, Oklahoma.

Soil types within cotton fields in Cotton County

SN*	Soil Name	HSG†	CN‡	Slope§ (%)	Landuse (cotton)	Area (ha)
2	Broken alluvial land	B	78	1.5	dryland	52
4	Enterprise very fine sandy loam	B	78	0.5	dryland	340
5	Enterprise very fine sandy loam	B	78	2.0	dryland	204
6	Enterprise very fine sandy loam	B	78	4.0	dryland	20
7	Enterprise very fine sandy loam	B	78	6.5	dryland	64
9	Foard silt loam	D	89	0.5	dryland	1016
10	Foard silt loam, Complex	D	89	0.5	dryland	112
11	Foard silt loam, Complex	D	89	2.0	dryland	292
12	Foard silt loam, Complex	D	89	2.0	dryland	1388
13	Lawton loam	C	85	0.5	dryland	52
14	Lawton loam	C	85	2.0	dryland	108
15	Lawton loam	C	85	4.0	dryland	40
16	Lawton loam, Eroded	C	85	4.0	dryland	44
19	Miller clay	D	89	0.5	dryland	76
20	Port clay loam	B	78	0.5	dryland	324
21	Port loam	B	78	0.5	dryland	180
22	Port loam, Complex	B	78	0.5	dryland	156
23	Pratt loamy fine sand	A	67	3.0	dryland	88
24	Pratt loamy fine sand, Rolling	A	67	8.5	dryland	32
26	Shellabarger loamy sand	B	78	2.0	dryland	16
27	Tillman silt loam	C	85	2.0	dryland	112
28	Tipton loam	B	78	0.5	dryland	272
29	Tipton loam	B	78	2.0	dryland	256
30	Treadway soils	D	89	1.0	dryland	24
35	Yahola fine sandy loam	B	78	1.0	dryland	24
40	Slickspot clay loam, Complex	B	78	2.0	dryland	280

* Soil category number. † Hydrologic soil group.

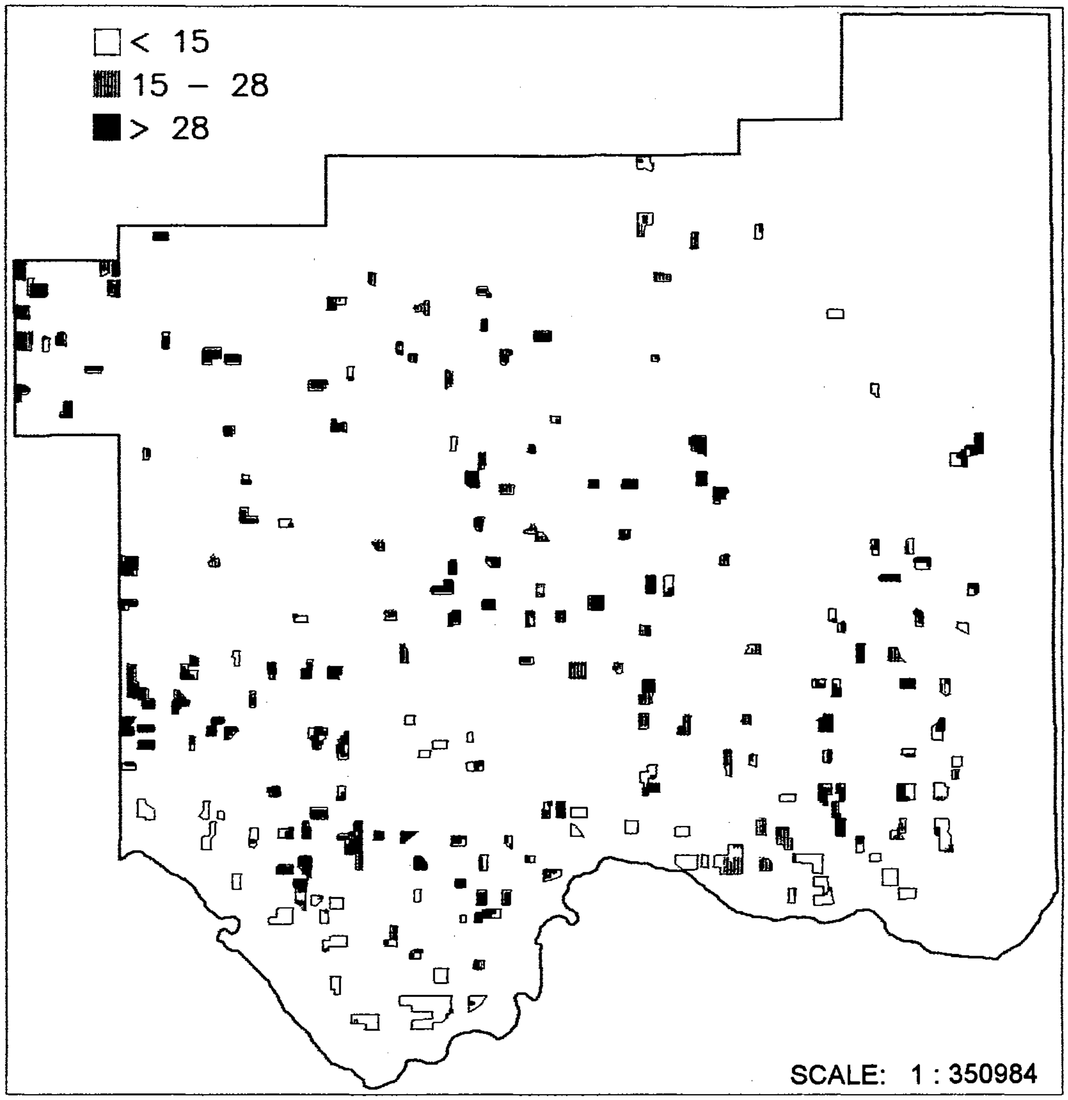
‡ Curve number. § Average slope of soils.

Data source: USDA SCS, Stillwater, Oklahoma.

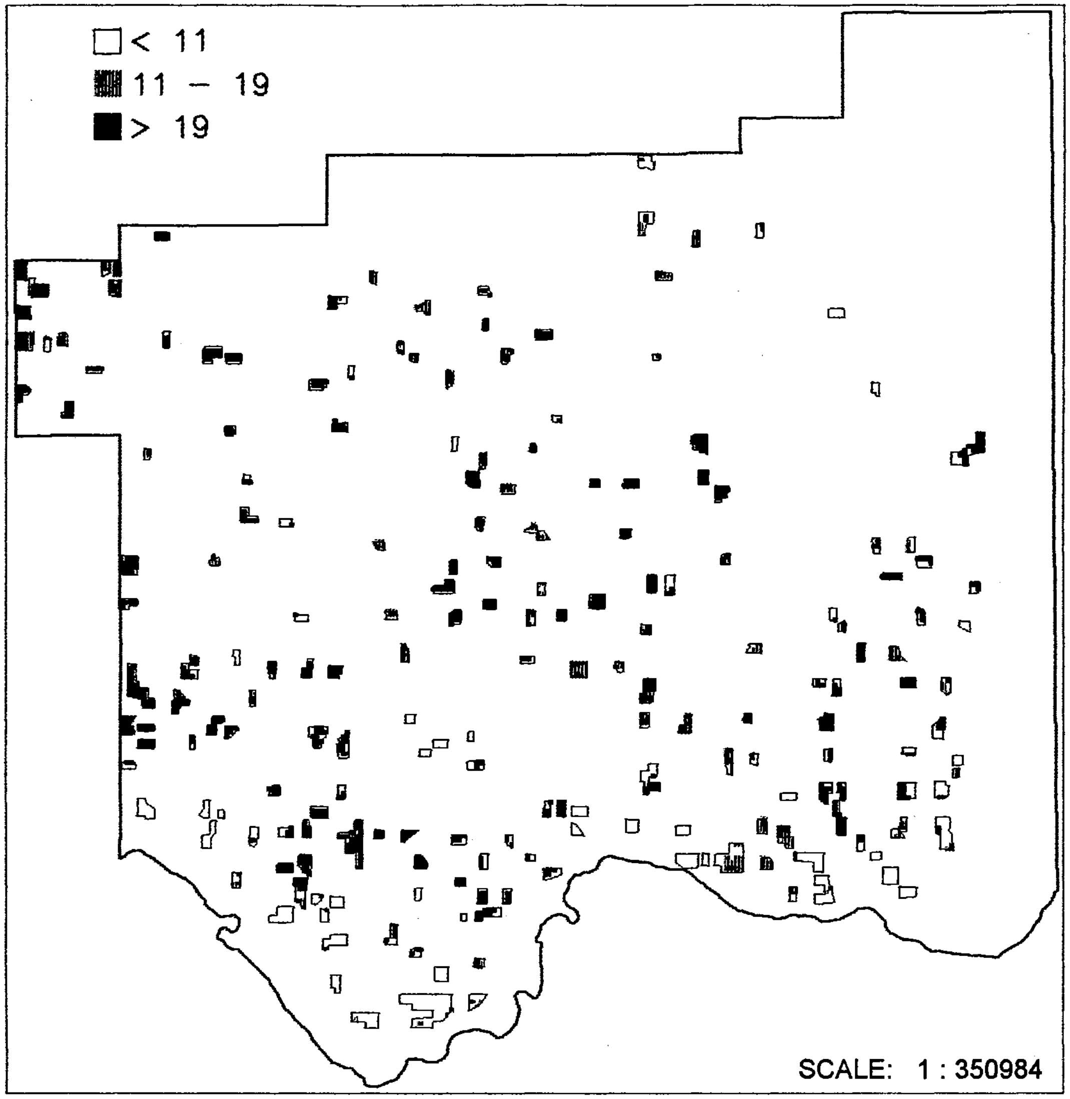
Number of insecticide runoff events from dry cotton fields in Cotton County with concentrations exceeding the Oklahoma surface water quality standards

Azinphos-methyl				Methyl-parathion				Malathion				Diflubenzuron			
SN*	Avg†	Max‡	Min§	SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min
11	31	55	20	30	22	40	10	11	12	26	4	30	9	23	3
12	31	55	20	11	21	40	9	12	12	26	4	9	7	19	0
9	29	53	18	12	21	40	9	9	11	25	4	10	7	19	0
10	29	53	18	9	20	39	9	10	11	25	4	11	7	19	1
30	29	51	18	10	20	39	9	30	11	25	4	12	7	19	1
19	28	51	18	15	19	35	9	15	10	22	4	19	7	19	0
15	27	49	17	16	19	35	9	16	10	22	4	15	6	18	0
16	27	49	17	19	19	37	9	19	10	23	4	16	6	18	0
27	24	44	14	27	17	32	6	14	9	21	2	27	6	18	0
14	23	43	13	14	16	32	6	27	9	21	2	7	5	16	0
7	21	40	11	7	15	30	5	7	8	21	2	14	5	17	0
13	19	36	10	13	13	28	5	6	7	19	1	6	4	15	0
20	19	35	10	20	13	26	5	13	7	19	2	13	4	15	0
21	19	35	10	21	13	27	5	20	7	19	2	20	4	16	0
22	19	35	10	22	13	26	5	21	7	19	2	21	4	15	0
6	17	36	8	6	12	27	3	22	7	19	2	22	4	16	0
26	14	28	5	24	11	23	2	24	6	17	1	24	4	14	0
24	13	30	4	26	10	22	2	40	6	15	1	40	4	13	0
29	13	28	5	29	10	24	2	2	5	14	1	2	3	12	0
40	13	30	5	40	10	25	3	5	5	14	1	4	3	12	0
2	12	27	5	2	9	19	2	26	5	15	1	5	3	13	0
5	12	27	5	5	9	21	2	29	5	15	1	26	3	13	0
4	11	24	3	35	9	20	2	35	5	14	1	28	3	12	0
28	11	24	3	4	8	18	2	4	4	13	1	29	3	13	0
35	11	25	4	28	8	19	2	28	4	13	1	35	3	13	0
23	7	19	1	23	5	16	0	23	3	11	0	23	2	8	0

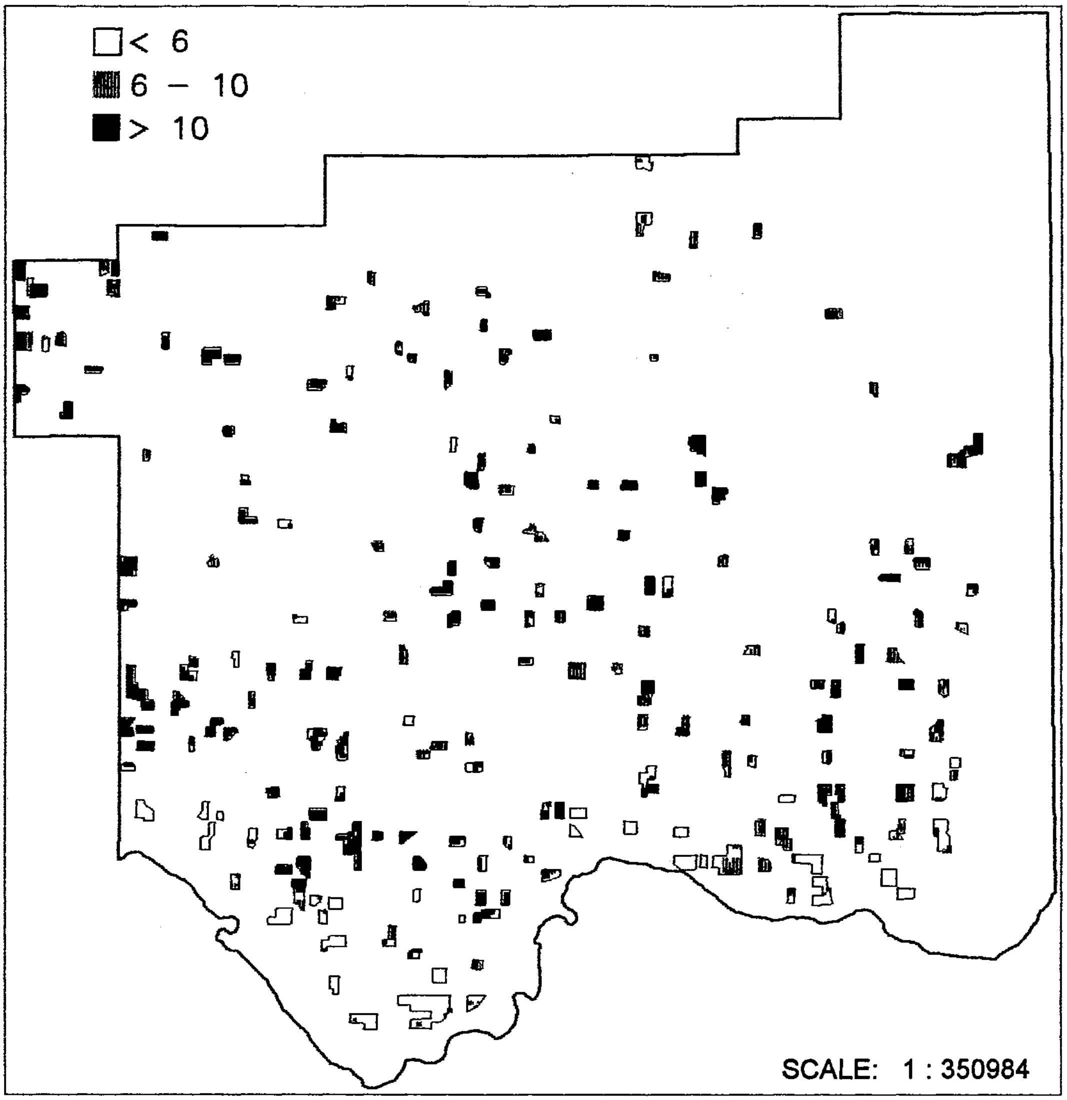
* Soil category number. † Average number of events exceeding the standards. ‡ Maximum number of events exceeding the standards. § Minimum number of events exceeding the standards.



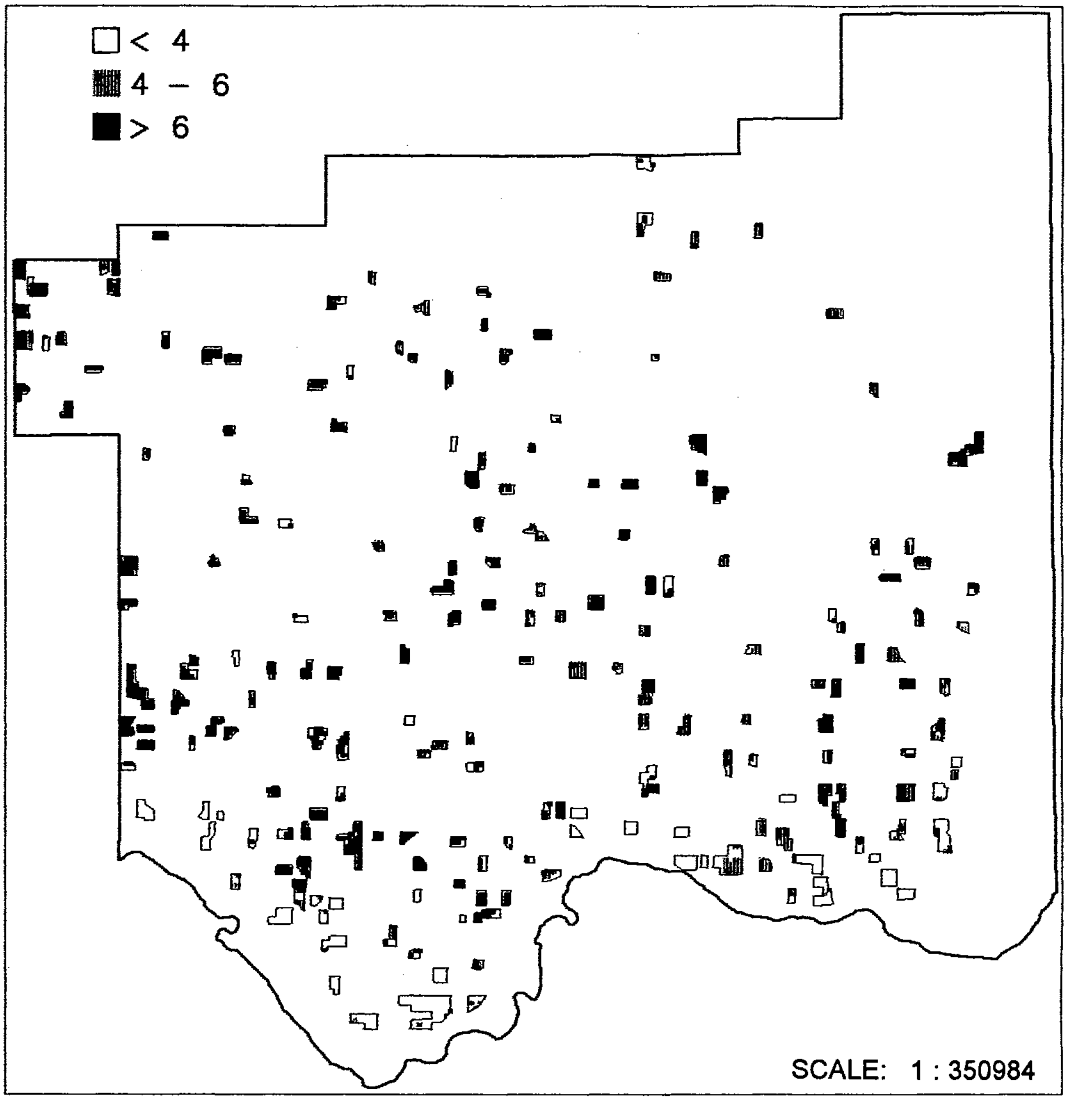
Spatial distribution of azinphos-methyl loss potential with runoff from cotton fields in Cotton County



Spatial distribution of methyl-parathion loss potential with runoff from cotton fields in Cotton County



Spatial distribution of malathion loss potential with runoff from cotton fields in Cotton County



Spatial distribution of diflubenzuron loss potential with runoff from cotton fields in Cotton County

APPENDIX C

SOIL AND WEATHER DATA AND SIMULATING RESULTS FOR GREER COUNTY

Weather parameters based on the daily data from Altus Dam Station for 1966-1991 period

Month	TMX*	TMN†	SDTMX‡	SDTMN§	PRE‖	SDR#
	C	C	C	C	mm	mm
January	9.3	-3.9	7.8	5.4	22.5	8.3
February	12.5	-1.1	8.1	5.4	26.5	7.3
March	18.1	3.8	7.3	5.3	47.0	11.5
April	23.5	9.2	5.7	4.8	52.2	11.0
May	27.9	14.5	4.9	4.1	122.9	19.2
June	32.7	19.7	4.1	3.3	92.4	16.4
July	35.6	22.5	3.5	2.5	45.7	13.0
August	34.5	21.4	3.7	2.7	64.5	14.9
September	29.7	16.9	5.4	4.4	85.2	17.0
October	24.0	9.9	5.7	5.0	71.2	21.2
November	16.6	3.2	6.7	5.3	32.2	8.2
December	11.0	-2.0	7.3	5.3	25.5	8.1

* Average monthly maximum temperature.
† Average monthly minimum temperature.
‡ Monthly standard deviation of maximum temperature.
§ Monthly standard deviation of minimum temperature.
‖ Average monthly precipitation.
Monthly standard deviation of daily precipitation.
Data source: Oklahoma Climatological Survey, Norman, Oklahoma.

Soil types within cotton fields in Greer County

SN*	Soil Name	HSG†	CN‡	Slope§ (%)	Landuse (cotton)	Area (ha)
1	Abilene clay loam	C	85	0.5	dryland	772
3	Altus fine sandy loam	B	78	0.5	dryland	272
4	Badland	D	89	2.0	dryland	28
7	Enterprise very fine dandy loam	B	78	0.5	dryland	80
8	Enterprise very fine dandy loam	B	78	2.0	dryland	40
9	Enterprise very fine dandy loam	B	78	4.0	dryland	32
10	Enterprise very fine dandy loam	B	78	6.5	dryland	36
11	Eroden sandy land	B	78	5.5	dryland	16
12	Hollister clay loam	D	89	0.5	dryland	788
13	La Casa clay loam	C	85	2.0	dryland	56
14	Lawton loam	C	85	0.5	dryland	488
15	Lawton loam	C	85	2.0	dryland	328
16	Lawton loam	C	85	4.0	dryland	32
17	Lawton-Gravelly complex	C	85	5.5	dryland	16
19	Mansic clay loam	B	78	0.5	dryland	92
20	Meno loamy fine sand	C	85	0.5	dryland	424
21	Miles fine sandy loam	B	78	4.0	dryland	96
22	Miles fine dandy loam, Eroded	B	78	4.0	dryland	44
23	Miles and Altus fine sandy loams	B	78	0.5	dryland	524
24	Miles and Altus fine sandy loams	B	78	2.0	dryland	616
25	Miles and Brownfield soils	B	78	1.5	dryland	1276
26	Nobscot fine sand	A	67	2.5	dryland	124
27	Nobscot fine sand	A	67	8.5	dryland	12
29	Quinlan loam	C	85	4.0	dryland	108
30	Quinlan loam	C	85	8.5	dryland	88
33	Sandy alluvial land	A	67	0.5	dryland	36
34	Sandy broken land	B	78	12.5	dryland	84
35	Springer loamy fine sand	B	78	1.5	dryland	540
36	Springer loamy fine sand	B	78	5.5	dryland	328
37	Spur clay loam	B	78	0.5	dryland	212

Soil types within cotton fields in Greer County
(continued)

SN	Soil Name	HSG	CN	Slope (%)	Landuse (cotton)	Area (ha)
38	Spur loam	B	78	0.5	dryland	396
39	Spur soil, Channeled	B	78	0.5	dryland	56
40	St. Paul silt loam	B	78	0.5	dryland	1100
41	St. Paul silt loam	B	78	2.0	dryland	280
42	Tillman clay loam	C	85	0.5	dryland	68
43	Tillman clay loam	C	85	2.0	dryland	44
44	Tipton loam	B	78	0.5	dryland	620
45	Tipton loam	B	78	2.0	dryland	92
46	Tivoli fine sand	A	67	17.5	dryland	16
47	Tivoli loamy fine sand	A	67	8.5	dryland	84
49	Vernon soils	D	89	8.5	dryland	36
51	Wet alluvial land	C	85	1.0	dryland	100
52	Weymouth clay loam	B	78	2.0	dryland	28
53	Weymouth clay loam	B	78	4.0	dryland	44
55	Weymouth clay loam, Complex	B	78	2.5	dryland	20
56	Woodward loam	B	78	2.0	dryland	80
58	Woodward loam	B	78	4.0	dryland	28
59	Yahola fine sandy loam	B	78	0.5	dryland	104

* Soil category number.

† Soil hydrologic group.

‡ Curve number.

§ Average slope of soils.

Data source: USDA SCS, Stillwater, Oklahoma.

Number of insecticide runoff events from dry cotton fields in Greer County with concentrations exceeding the Oklahoma surface water quality standards

Azinphos-methyl				Methyl-parathion				Malathion				Diflubenzuron			
SN*	Avg†	Max‡	Min§	SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min
49	43	61	26	49	31	46	20	49	17	29	7	49	11	24	4
30	33	55	21	30	25	43	15	30	13	26	5	30	10	24	2
20	29	52	18	20	22	41	12	20	12	26	4	20	9	24	2
17	28	52	18	17	20	39	10	17	11	23	4	29	8	19	1
12	26	51	17	29	20	37	9	34	11	24	4	34	8	19	1
29	26	47	15	34	20	39	10	12	10	23	3	12	7	17	0
16	25	49	15	12	19	38	9	16	10	23	3	17	7	16	1
34	25	48	15	4	18	34	9	29	10	23	5	4	6	16	1
4	24	43	15	16	18	36	9	4	9	21	2	10	6	17	0
13	21	44	11	15	16	33	7	46	9	22	2	11	6	17	0
15	21	44	11	46	16	32	7	10	8	21	2	16	6	15	1
43	21	44	11	11	15	32	4	11	8	21	2	46	6	16	0
46	21	41	12	13	15	33	7	13	8	20	2	51	6	17	1
11	19	40	9	43	15	33	6	15	8	20	2	9	5	15	0
36	19	41	9	10	14	32	6	36	8	21	1	13	5	15	0
10	18	40	10	36	14	32	4	43	8	20	2	14	5	14	0
14	18	38	9	51	14	32	6	51	8	20	2	15	5	15	0
42	18	39	9	1	13	29	5	1	7	18	1	21	5	15	0
51	18	40	10	14	13	29	4	9	7	18	1	22	5	15	0
1	17	38	9	42	13	29	5	14	7	18	1	36	5	16	0
19	17	39	8	9	12	27	2	19	7	19	1	42	5	15	0
9	15	33	5	19	12	29	5	21	7	18	1	43	5	15	0
21	15	33	6	21	12	27	3	22	7	19	1	53	5	15	0
22	15	33	6	22	12	27	3	42	7	18	1	1	4	14	0
53	15	36	5	53	12	29	2	53	7	19	1	8	4	15	0
58	15	35	7	58	12	28	3	58	7	19	1	19	4	13	0
27	13	28	3	27	11	23	1	27	6	16	1	24	4	13	0

Number of insecticide runoff events from dry cotton fields in Greer County with concentrations exceeding the Oklahoma surface water quality standards (continued)

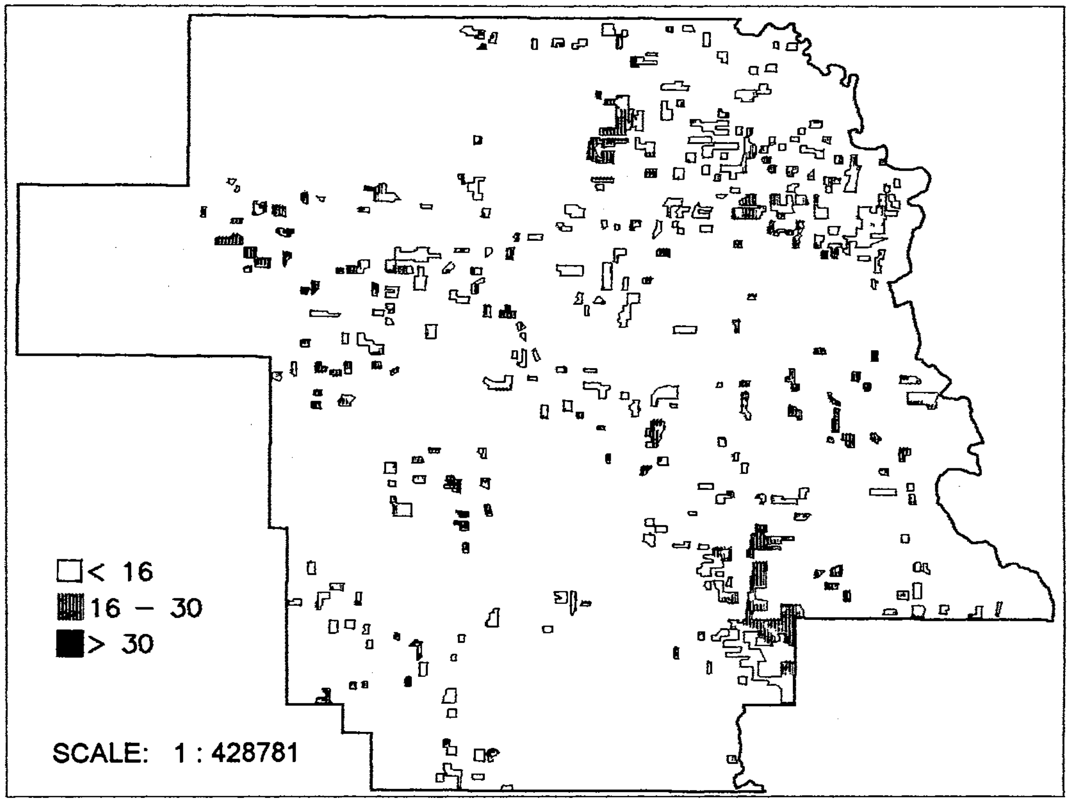
Azinphos-methyl				Methyl-parathion				Malathion				Diflubenzuron			
SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min
47	13	29	5	47	11	24	3	47	6	16	1	27	4	12	0
55	13	31	4	8	10	21	2	55	6	16	0	47	4	12	0
8	12	26	4	24	10	21	2	8	5	15	0	52	4	13	0
24	12	26	4	52	10	22	2	24	5	14	0	55	4	15	0
35	12	25	4	55	10	25	2	25	5	13	0	56	4	14	0
41	12	28	5	56	10	21	2	35	5	13	0	58	4	14	0
45	12	26	4	25	9	20	2	41	5	14	0	3	3	11	0
52	12	28	4	35	9	20	2	45	5	15	0	7	3	13	0
56	12	28	4	41	9	21	2	52	5	14	0	23	3	11	0
25	11	24	4	45	9	20	2	56	5	15	0	25	3	11	0
3	9	20	4	7	8	17	2	3	4	12	0	35	3	12	0
7	9	20	3	23	8	16	2	7	4	12	0	41	3	14	0
23	9	20	3	59	8	16	2	23	4	12	0	44	3	13	0
37	9	21	3	3	7	16	2	37	4	13	0	45	3	14	0
38	9	20	3	37	7	17	2	38	4	13	0	59	3	11	0
39	9	20	3	38	7	16	2	39	4	13	0	37	2	12	0
40	9	20	3	39	7	16	2	40	4	12	0	38	2	12	0
44	9	20	4	40	7	16	2	44	4	13	0	39	2	12	0
59	9	20	3	44	7	16	2	59	4	12	0	40	2	12	0
26	6	18	1	26	5	14	0	26	2	10	0	26	1	7	0
33	3	13	0	33	3	11	0	33	1	7	0	33	1	6	0

* Soil category number.

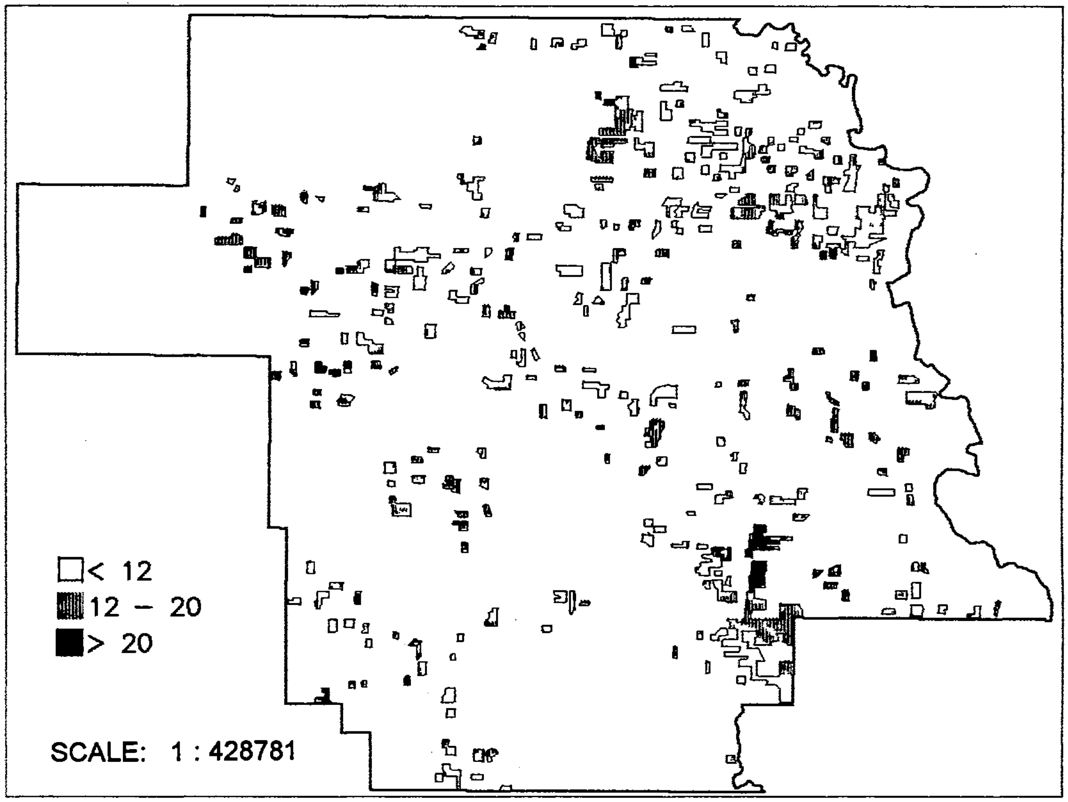
† Average number of events exceeding the standards.

‡ Maximum number of events exceeding the standards.

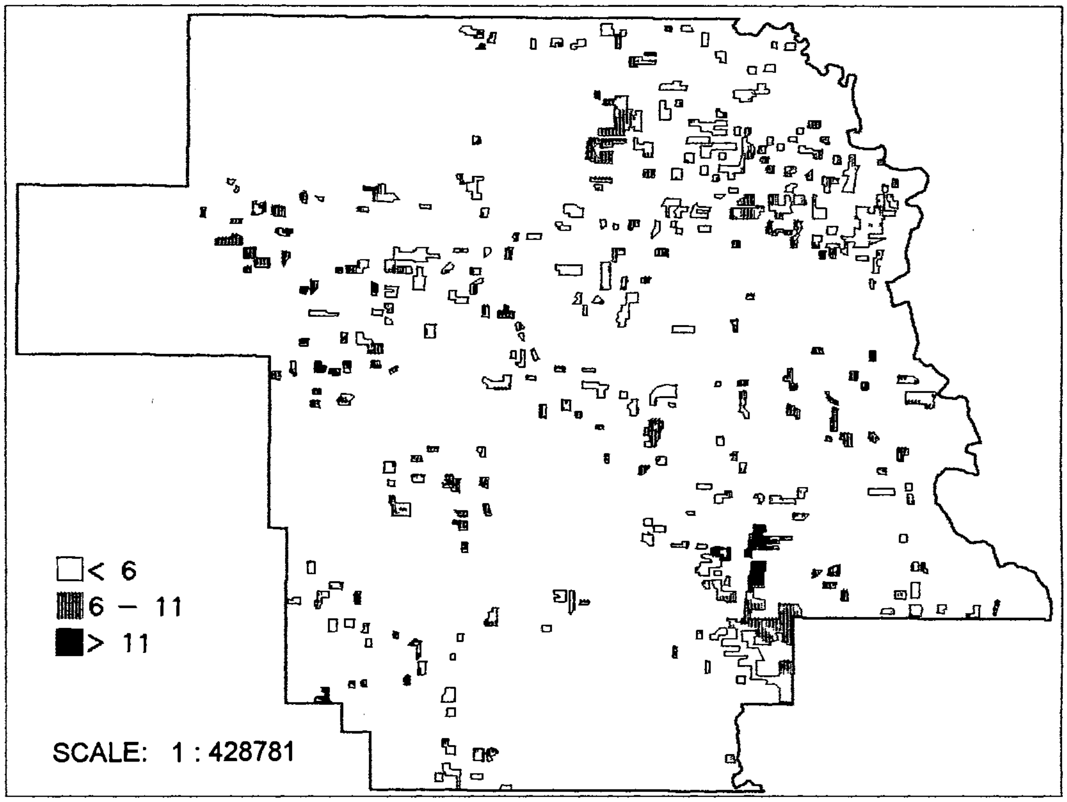
§ Minimum number of events exceeding the standards.



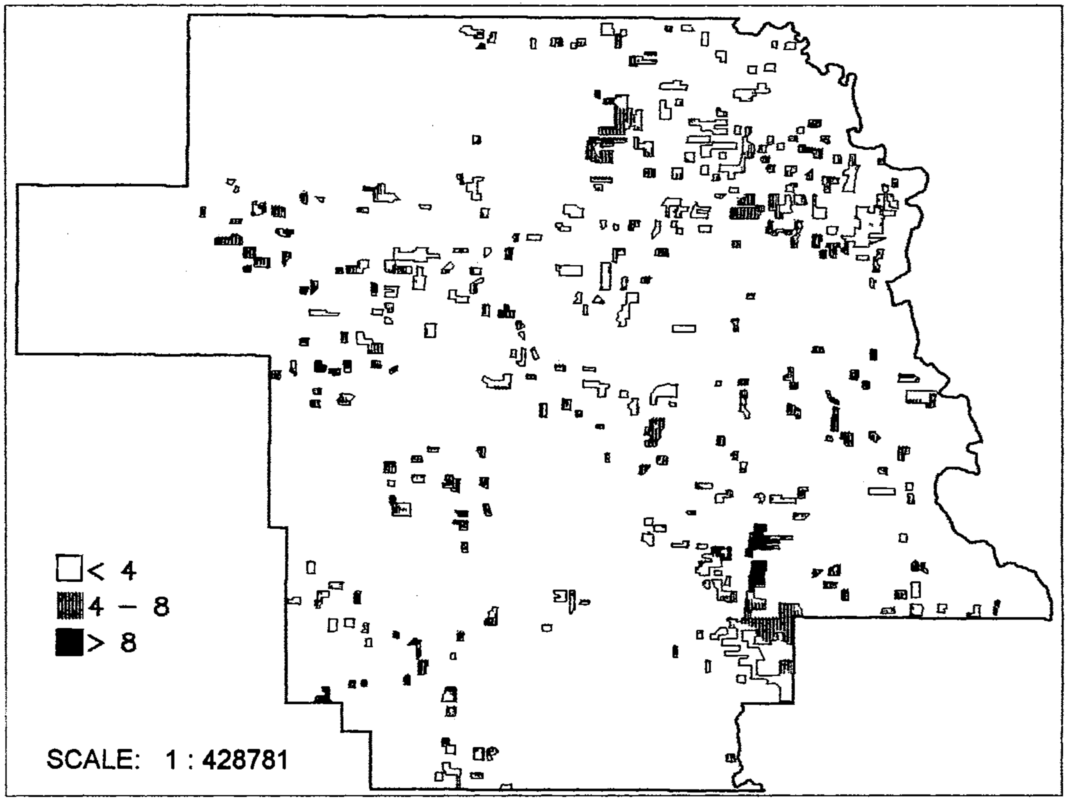
Spatial distribution of azinphos-methyl loss potential with runoff from cotton fields in Greer County



Spatial distribution of methyl-parathion loss potential with runoff from cotton fields in Greer County



Spatial distribution of malathion loss potential with runoff from cotton fields in Greer County



Spatial distribution of diflubenzuron loss potential with runoff from cotton fields in Greer County

APPENDIX D

SOIL AND WEATHER DATA AND SIMULATING RESULTS FOR HARMON COUNTY

Weather parameters based on the daily data from Hollis Station for 1963-1991 period

Month	TMX*	TMN†	SDTMX‡	SDTMN§	PRE‖	SDR#
	C	C	C	C	mm	mm
January	11.5	-4.4	7.6	5.2	16.4	7.0
February	14.6	-1.9	7.9	5.1	26.2	8.4
March	20.4	2.9	6.8	5.3	33.4	9.8
April	25.9	8.6	5.3	5.0	50.7	14.4
May	29.7	13.7	4.8	4.1	95.3	15.7
June	34.3	18.9	3.8	3.1	87.5	17.9
July	36.9	21.2	3.3	2.5	35.3	13.1
August	35.7	20.0	3.5	2.4	65.6	17.1
September	30.9	15.8	5.1	4.4	84.7	18.8
October	25.7	9.0	5.7	4.7	55.2	20.0
November	18.1	2.5	6.4	5.1	27.6	8.2
December	12.6	-2.7	7.0	5.1	21.4	6.9

* Average monthly maximum temperature.

† Average monthly minimum temperature.

‡ Monthly standard deviation of maximum temperature.

§ Monthly standard deviation of minimum temperature.

‖ Average monthly precipitation.

Monthly standard deviation of daily precipitation.

Data source: Oklahoma Climatological Survey, Norman, Oklahoma.

Soil types within cotton fields in Harmon County

SN*	Soil Name	HSG†	CN‡	Slope§ (%)	Landuse (cotton)	Area (ha)
1	Abilene loam	C	85	0.5	dry irrigate	412
2	Abilene loam	C	85	2.0	dry irrigate	40
3	Vinson silt loam, Complex	B	78	0.5	N/A irrigate	68
4	Vinson silt loam, Complex	B	78	2.0	N/A irrigate	64
5	Altus fine sandy loam	B	78	0.5	dry irrigate	488
6	Altus fine sandy loam	B	78	2.0	dry irrigate	80
7	Aspermont silt loam	B	78	2.0	dry irrigate	544
8	Aspermont silt loam	B	78	4.0	N/A irrigate	36
11	Carey loam	B	78	2.0	dry irrigate	24
12	Clairemont silt loam	B	78	0.5	N/A irrigate	28
14	Devol loamy fine sand	B	78	1.5	dry irrigate	468
15	Devol loamy fine sand	B	78	5.5	dry irrigate	296
16	Devol loamy fine sand, Eroded	B	78	5.5	dry irrigate	164
17	Devol fine sandy loam	B	78	2.0	dry irrigate	28
18	Gracemont fine sandy loam, Saline	C	85	0.5	dry irrigate	24
20	Grandfield loamy fine sand	B	78	1.5	dry irrigate	1352
21	Grandfield loamy fine sand,	B	78	3.5	dry irrigate	120
22	Grandfield fine sandy loam	B	78	1.0	dry irrigate	288
24	Grandmore loamy fine sand	B	78	1.5	dry irrigate	284
25	Hardeman fine sandy loam	B	78	2.0	dry irrigate	268
26	Hardeman fine sandy loam	B	78	4.0	dry irrigate	20
30	Devol fine sandy loam, Complex	B	78	11.5	dry N/A	24
31	Hollister silty clay loam	D	89	0.5	N/A irrigate	88
34	Knoco clay, Complex	D	89	11.0	N/A irrigate	48
37	Lincoln loamy fine sand	A	67	0.5	dry irrigate	32
38	Madge loam	B	78	0.5	dry irrigate	400
39	Madge loam	B	78	2.0	dry irrigate	504
42	Mcknight loamy fine sand	B	78	1.5	dry irrigate	364
43	Mcknight loamy fine sand, Eroded	B	78	3.5	dry irrigate	132
44	Mcknight fine sandy loam	B	78	2.0	dry irrigate	152
45	Nobscot fine sand	A	67	3.5	dry irrigate	56

Soil types within cotton fields in Harmon County
(continued)

SN	Soil Name	HSG	CN	Slope (%)	Landuse (cotton)		Area (ha)
46	Nobscot fine sand	A	67	8.5	dry	irrigated	84
47	Talpa loam, Complex	D	89	3.0	N/A	irrigated	192
48	Quinlan fine sandy loam, Complex	C	85	28.5	dry	N/A	28
49	Quinlan loam, Complex	C	85	4.0	dry	N/A	36
51	Shrewder fine sandy loam	B	78	2.0	dry	irrigated	104
53	Spur clay loam	B	78	0.5	N/A	irrigated	84
54	Spur clay loam, Flooded	B	78	0.5	N/A	irrigated	188
55	Tillman clay loam	C	85	0.5	dry	irrigated	208
56	Tillman clay loam	C	85	2.0	dry	irrigated	468
57	Tipton loam	B	78	0.5	dry	irrigated	1048
58	Tipton loam	B	78	2.0	N/A	irrigated	104
62	Vernon clay loam	D	89	2.0	dry	irrigated	532
63	Vernon clay loam	D	89	4.0	dry	irrigated	16
64	Vernon clay loam, Eroded	D	89	3.5	N/A	irrigated	60
65	Vernon clay loam, Complex	D	89	6.5	N/A	irrigated	108
66	Westview silty clay loam	B	78	0.5	N/A	irrigated	640
67	Woodward loam	B	78	2.0	dry	irrigated	52
69	Quinlan loam, Complex	C	85	1.5	dry	N/A	24
70	Quinlan loam, Complex	C	85	4.0	dry	irrigated	92
71	Woodward loam, Complex	B	78	8.5	dry	irrigated	68
73	Yahola fine sandy loam	B	78	0.5	dry	irrigated	72

* Soil category number.

† Hydrologic soil group.

‡ Curve number.

§ Average slope of soils.

Data source: USDA SCS, Stillwater, Oklahoma.

Number of insecticide runoff events from irrigated cotton fields in Harmon County with concentrations exceeding the Oklahoma surface water quality standards

Azinphos-methyl				Methyl-parathion				Malathion				Diflubenzuron			
SN*	Avg†	Max‡	Min§	SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min
34	54	73	42	34	39	57	28	34	20	32	11	34	17	27	9
48	46	67	35	48	35	47	25	48	18	27	10	65	16	27	8
65	46	65	35	65	33	47	23	65	16	26	9	48	16	25	9
47	44	63	32	47	31	45	22	47	15	25	8	64	14	27	7
64	42	60	32	64	31	43	20	64	15	25	6	47	14	23	8
63	40	59	29	63	30	41	20	63	14	24	6	63	14	23	7
62	36	56	24	62	27	39	16	62	13	23	5	62	13	23	7
70	32	52	21	70	24	38	14	70	11	22	5	70	12	21	6
31	32	49	21	49	24	37	14	49	11	22	4	49	12	20	6
49	31	51	21	31	23	35	13	30	10	23	3	71	11	21	6
71	29	50	19	71	22	38	12	71	10	22	4	30	11	20	6
30	28	49	18	30	21	37	13	31	10	21	4	16	10	19	5
56	28	48	17	56	21	35	12	56	10	20	4	18	10	19	6
2	28	47	18	2	20	35	11	16	9	23	3	21	10	19	5
69	26	47	16	16	20	35	12	15	9	21	3	26	10	19	5
16	25	47	17	69	20	35	10	2	9	20	4	15	10	18	5
1	25	46	16	15	19	33	10	69	9	20	3	31	10	18	5
55	25	46	16	18	19	32	10	1	8	20	3	43	10	18	5
15	25	43	16	1	18	34	10	55	8	20	3	56	10	18	5
18	23	41	14	55	18	34	10	8	8	20	2	69	10	18	6
8	23	40	15	8	18	31	9	26	8	20	3	55	9	18	4
43	22	37	14	21	18	29	11	18	8	20	3	2	9	17	6
21	22	36	13	43	18	29	10	21	8	18	3	46	9	17	5
26	22	36	12	26	18	28	10	43	8	18	3	8	9	17	6
7	20	34	14	46	16	25	8	4	7	17	3	24	9	17	5
6	20	33	11	7	15	27	9	7	7	17	2	25	9	17	5
46	20	33	10	4	15	25	8	46	7	17	2	44	9	16	6
11	20	32	14	17	15	25	9	17	7	15	3	7	9	16	4
39	20	32	14	25	15	25	9	25	7	15	3	51	9	15	5

Number of insecticide runoff events from irrigated cotton fields in Harmon County with concentrations exceeding the Oklahoma surface water quality standards (contimued)

Azinphos-methyl				Methyl-parathion				Malathion				Diflubenzuron			
SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min
17	19	35	12	51	15	25	9	67	6	17	3	1	8	17	4
4	19	32	14	67	15	25	9	6	6	15	3	6	8	16	4
67	19	31	13	6	15	24	8	11	6	15	2	17	8	16	5
58	19	30	12	44	15	24	8	51	6	15	2	67	8	16	4
25	18	31	11	58	15	24	9	58	6	15	2	58	8	15	4
14	18	31	11	24	15	23	7	24	6	15	2	42	8	14	5
24	18	29	8	39	14	25	8	39	6	15	2	4	8	14	5
51	18	29	11	14	14	24	8	44	6	14	3	14	8	13	5
44	18	28	12	11	14	24	8	42	6	14	2	20	8	13	5
42	17	31	10	42	14	24	8	14	6	14	2	22	8	13	5
3	17	25	11	20	14	23	8	20	6	13	2	73	8	13	5
20	17	28	10	22	14	22	7	22	6	13	2	39	7	15	4
66	17	28	10	5	13	22	7	3	5	12	0	3	7	15	3
38	17	27	10	12	13	21	7	5	5	12	2	11	7	14	3
12	17	27	9	3	13	20	7	12	5	12	2	57	7	13	4
53	17	27	10	66	13	20	7	38	5	12	1	37	7	12	5
54	17	26	10	73	13	23	7	54	5	12	1	5	7	12	4
57	17	26	10	45	12	22	7	45	5	11	1	12	7	12	4
5	16	29	9	53	12	21	6	53	5	11	0	45	7	12	4
22	16	29	10	38	12	20	7	57	5	11	0	38	6	14	3
73	16	27	9	57	12	20	7	66	5	11	0	53	6	13	3
45	15	25	8	54	12	19	7	73	5	11	1	54	6	13	3
37	11	20	6	37	10	16	7	37	3	7	1	66	6	13	3

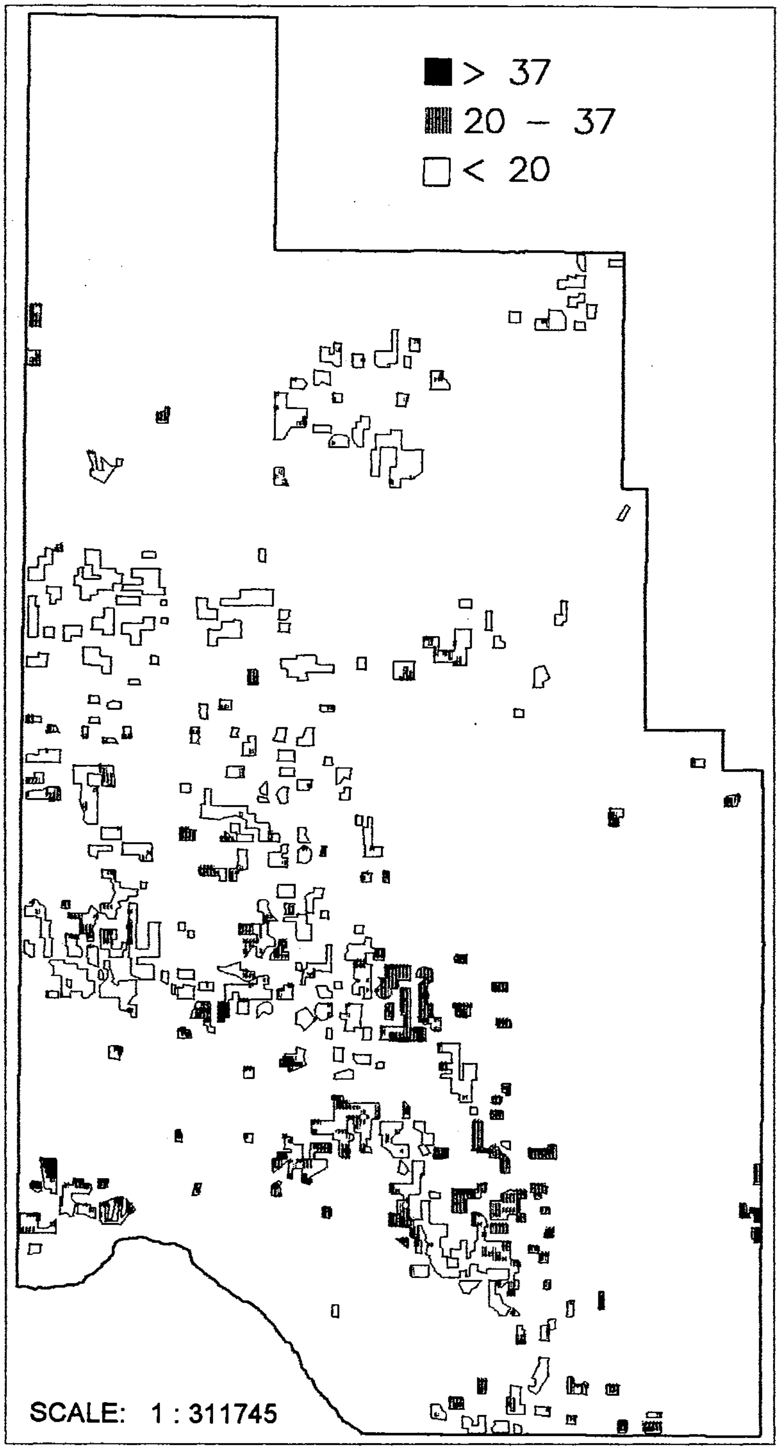
* Soil category number. † Average number of events exceeding the standards. ‡ Maximum number of events exceeding the standards. § Minimum number of events exceeding the standards.

Number of insecticide runoff events from dry cotton fields in Harmon County with concentrations exceeding the Oklahoma surface water quality standards

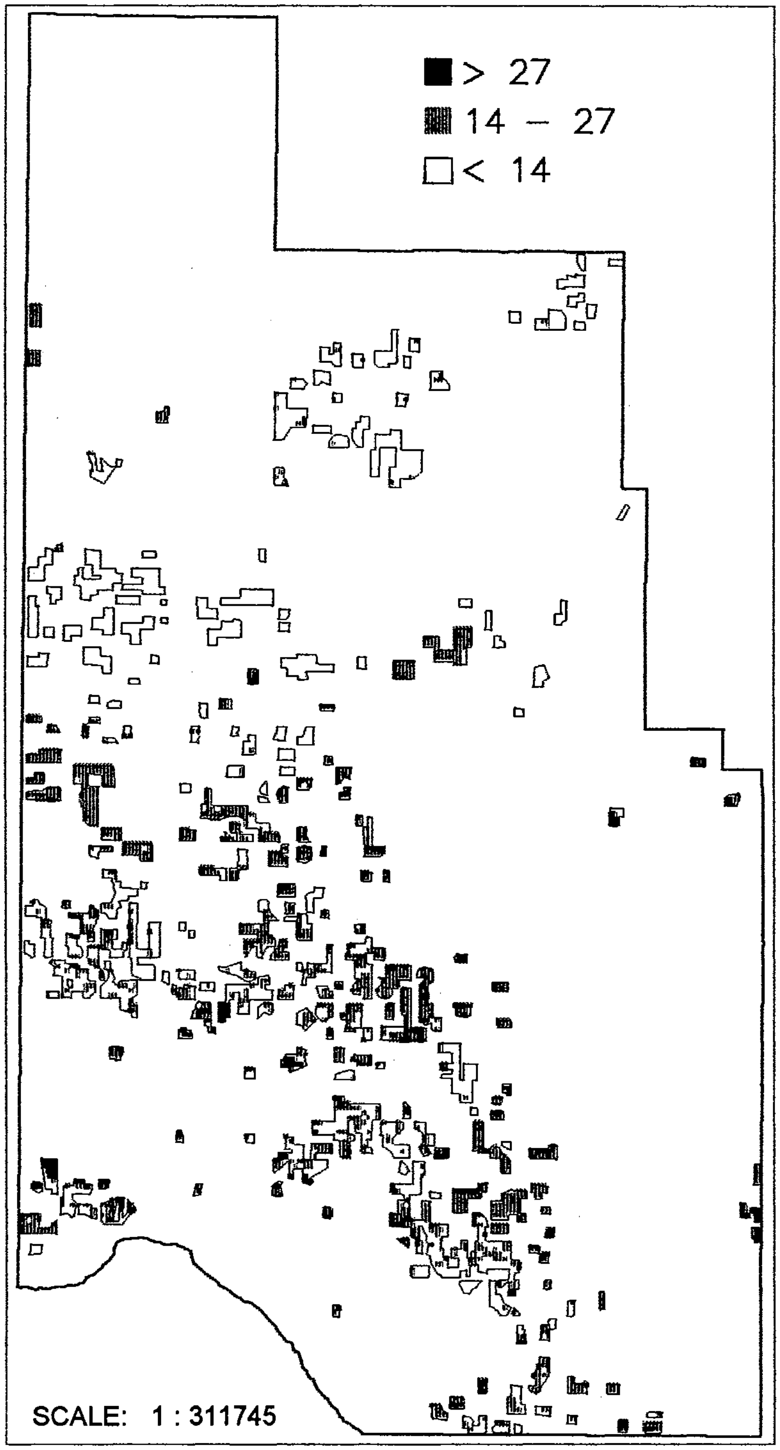
Azinphos-methyl				Methyl-parathion				Malathion				Diflubenzuron			
SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min
34	41	59	26	34	29	46	18	34	16	30	8	34	10	21	2
48	35	53	21	48	25	37	15	48	14	25	7	48	9	20	3
65	34	54	20	65	24	39	15	65	13	25	6	65	8	20	1
47	31	52	19	47	22	38	12	47	12	24	5	47	7	19	1
64	30	51	17	64	21	36	12	64	12	23	4	64	7	19	1
63	28	48	17	63	21	35	12	63	11	23	4	63	7	19	1
62	25	45	15	62	18	33	9	62	10	21	3	62	7	17	1
31	20	39	11	49	16	32	5	49	8	21	2	49	6	17	1
49	20	39	10	70	16	30	5	31	8	20	2	70	6	17	0
70	20	38	10	31	15	30	5	70	8	20	2	30	5	15	0
2	17	38	8	30	13	30	4	30	7	21	1	69	5	15	0
30	17	36	8	2	13	28	4	15	7	20	1	2	5	14	0
56	17	36	7	56	13	28	3	71	7	19	1	71	5	14	0
71	17	34	9	71	13	28	5	2	7	18	1	31	5	14	0
69	16	32	7	15	12	27	2	56	7	18	1	18	4	15	0
16	15	34	6	69	12	27	4	69	7	17	1	1	4	14	0
15	15	33	6	16	11	28	2	16	6	21	1	16	4	14	0
1	14	33	5	18	11	25	2	1	6	17	1	56	4	14	0
18	14	32	6	1	10	26	2	55	6	17	1	55	4	14	0
55	14	31	5	55	10	25	2	18	6	17	1	8	4	13	0
26	12	28	5	26	10	23	2	21	6	16	0	15	4	13	0
43	12	27	4	8	10	22	2	43	6	16	0	26	4	13	0
21	12	27	4	21	10	22	2	26	5	16	1	21	4	12	0
8	12	26	4	43	10	22	2	8	5	16	0	43	4	12	0
46	11	25	3	46	8	19	2	46	5	14	0	17	3	13	0
6	10	24	2	6	8	18	2	6	4	15	0	51	3	12	0
17	10	24	2	17	8	18	2	25	4	15	0	6	3	12	0

Number of insecticide runoff events from dry cotton fields in Harmon County with concentrations exceeding the Oklahoma surface water quality standards (continued)

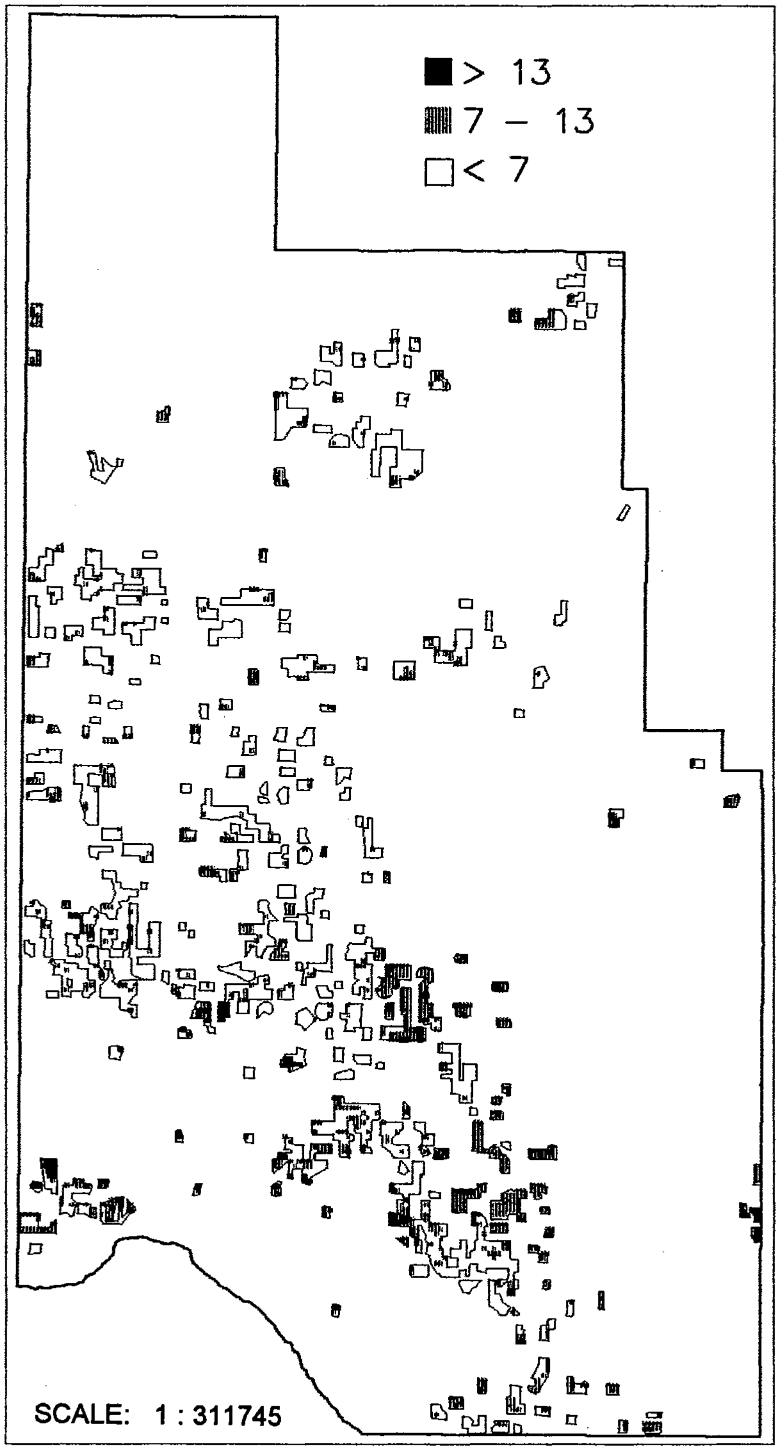
Azinphos-methyl				Methyl-parathion				Malathion				Diflubenzuron			
SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min
25	10	23	3	25	8	18	2	17	4	15	0	7	3	12	0
39	10	23	2	51	8	18	2	51	4	15	0	58	3	12	0
51	10	23	3	67	8	17	2	44	4	14	0	67	3	12	0
58	10	22	3	7	7	18	2	4	4	13	0	25	3	12	0
7	9	23	3	39	7	18	2	7	4	13	0	44	3	11	0
14	9	23	2	42	7	18	2	11	4	13	0	14	3	10	0
42	9	23	3	44	7	18	2	39	4	13	0	46	3	10	0
11	9	22	3	4	7	17	2	58	4	13	0	42	3	10	0
67	9	22	2	11	7	17	2	67	4	13	0	20	3	10	0
44	9	22	2	14	7	17	2	14	4	12	0	24	3	10	0
20	9	22	2	20	7	17	2	20	4	12	0	22	3	10	0
4	9	21	2	58	7	17	2	24	4	12	0	39	2	12	0
24	9	20	2	22	7	16	1	42	4	12	0	11	2	11	0
3	8	20	2	24	7	16	2	22	4	11	0	4	2	11	0
22	8	19	2	5	6	16	1	3	3	11	0	3	2	10	0
5	7	19	2	3	6	15	1	5	3	10	0	54	2	10	0
12	7	19	2	12	6	15	1	12	3	10	0	38	2	10	0
38	7	19	2	38	6	15	1	38	3	10	0	5	2	9	0
53	7	19	2	53	6	15	1	53	3	10	0	12	2	9	0
54	7	19	2	54	6	15	1	54	3	10	0	53	2	9	0
57	7	19	2	57	6	15	1	57	3	10	0	57	2	9	0
66	7	19	2	66	6	15	1	66	3	10	0	66	2	9	0
73	7	18	2	73	6	15	1	73	3	10	0	45	2	8	0
45	6	15	2	45	5	14	1	45	3	9	0	73	2	8	0
37	3	10	0	37	2	9	0	37	1	5	0	37	1	5	0



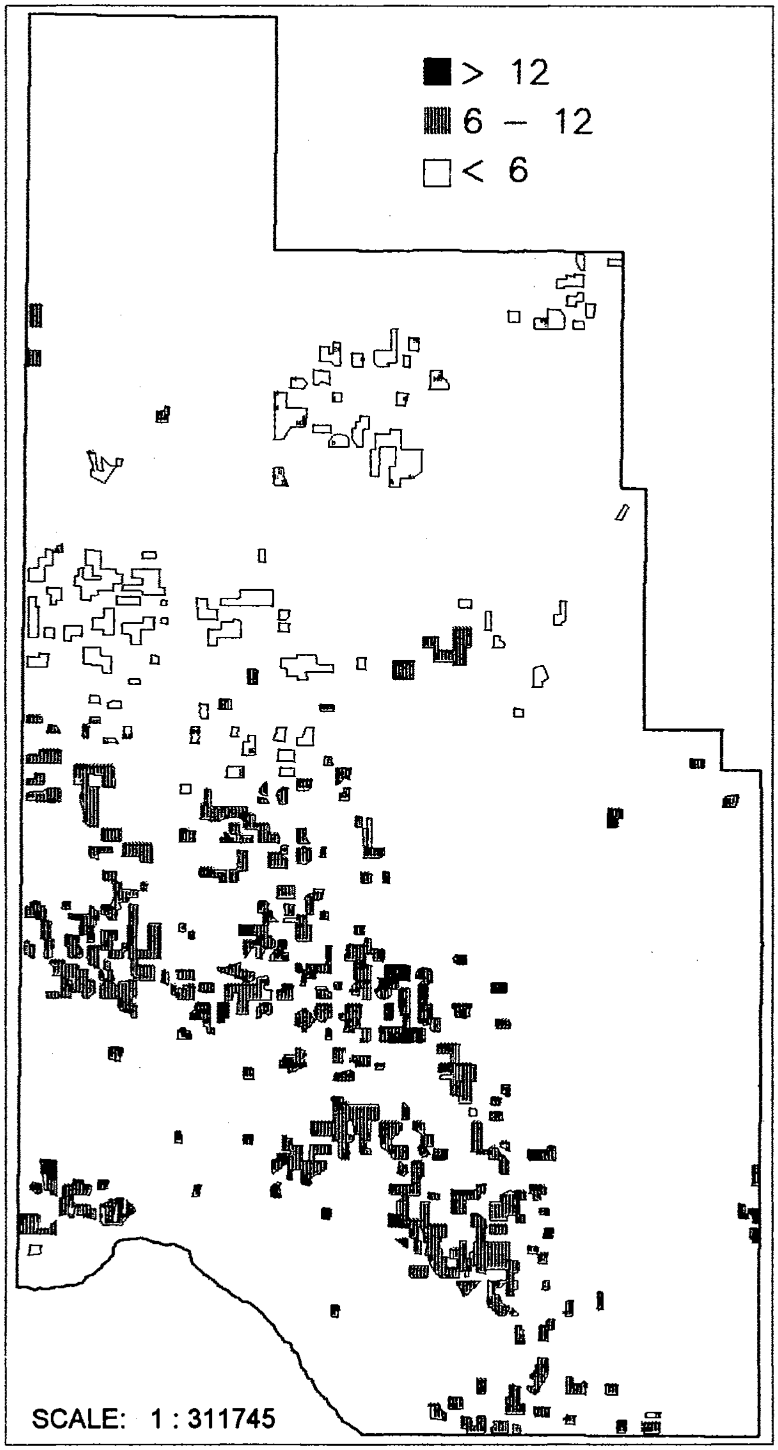
Spatial distribution of azinphos-methyl loss potential with runoff from cotton fields in Harmon County



Spatial distribution of methyl-parathion loss potential with runoff from cotton fields in Harmon County



Spatial distribution of malathion loss potential with runoff from cotton fields in Harmon County



Spatial distribution of diflubenzuron loss potential with runoff from cotton fields in Harmon County

APPENDIX E

SOIL AND WEATHER DATA AND SIMULATING RESULTS FOR KIOWA COUNTY

Weather parameters based on the daily data from Altus Dam Station for 1966-1991 period

Month	TMX*	TMN†	SDTMX‡	SDTMN§	PRE‖	SDR#
	C	C	C	C	mm	mm
January	9.3	-3.9	7.8	5.4	22.5	8.3
February	12.5	-1.1	8.1	5.4	26.5	7.3
March	18.1	3.8	7.3	5.3	47.0	11.5
April	23.5	9.2	5.7	4.8	52.2	11.0
May	27.9	14.5	4.9	4.1	122.9	19.2
June	32.7	19.7	4.1	3.3	92.4	16.4
July	35.6	22.5	3.5	2.5	45.7	13.0
August	34.5	21.4	3.7	2.7	64.5	14.9
September	29.7	16.9	5.4	4.4	85.2	17.0
October	24.0	9.9	5.7	5.0	71.2	21.2
November	16.6	3.2	6.7	5.3	32.2	8.2
December	11.0	-2.0	7.3	5.3	25.5	8.1

* Average monthly maximum temperature.

† Average monthly minimum temperature.

‡ Monthly standard deviation of maximum temperature.

§ Monthly standard deviation of minimum temperature.

‖ Average monthly precipitation.

Monthly standard deviation of daily precipitation.

Data source: Oklahoma Climatological Survey, Norman, Oklahoma.

Soil types within cotton fields in Kiowa County

SN*	Soil Name	HSG†	CN‡	Slope§ (%)	Landuse (cotton)	Area (ha)
2	Altus fine sandy loam	B	78	0.5	dryland	496
3	Altus fine sandy loam	B	78	2.0	dryland	176
5	Carey silt loam	B	78	2.0	dryland	264
6	Carey silt loam	B	78	4.0	dryland	236
7	Carey silt loam, Eroded	B	78	3.5	dryland	236
8	Hinkle silt loam	D	89	3.0	dryland	104
9	Carey soils, Eroded	B	78	5.0	dryland	44
10	Clairemont silt loam	B	78	0.5	dryland	224
11	Cobb fine sandy loam	B	78	2.0	dryland	36
12	Cyril loam	B	78	0.5	dryland	124
13	Devol loamy fine sand	B	78	1.5	dryland	164
14	Dill fine sandy loam, Complex	B	78	7.5	dryland	16
15	Foard silt loam	D	89	0.5	dryland	244
16	Gotebo loam	B	78	8.5	dryland	64
18	Grandfield loamy fine sand	B	78	1.5	dryland	264
19	Grandfield fine sandy loam	B	78	2.0	dryland	32
20	Hardeman fine sandy loam	B	78	2.0	dryland	112
21	Hardeman fine sandy loam	B	78	4.0	dryland	232
22	Hardeman fine sandy loam	B	78	6.5	dryland	168
23	Hollister silty clay loam	D	89	0.5	dryland	4028
24	Hollister silty clay loam	D	89	2.0	dryland	28
25	Hollister silty clay loam, Eroded	D	89	2.0	dryland	192
28	Lawton loam	C	85	2.0	dryland	124
29	Lawton loam	C	85	4.0	dryland	44
30	Lawton loam, Eroded	C	85	3.5	dryland	28
35	Lugert loam	B	78	0.5	dryland	276
36	Mclain silty clay loam	C	85	0.5	dryland	104

Soil types within cotton fields in Kiowa County
(continued)

SN	Soil Name	HSG	CN	Slope (%)	Landuse (cotton)	Area (ha)
37	Meno loamy fine sand	C	85	1.5	dryland	52
38	Miller clay	D	89	0.5	dryland	268
39	Miller soils, Saline	D	89	0.5	dryland	48
40	Natrustalfs	D	89	1.5	dryland	24
41	Port silty clay loam	B	78	0.5	dryland	704
42	Reinach loam	B	78	0.5	dryland	36
45	Roscoe clay	D	89	0.5	dryland	36
46	St. Paul silt loam	B	78	0.5	dryland	952
47	St. Paul silt loam	B	78	2.0	dryland	908
48	St. Paul silt loam, Complex	B	78	0.5	dryland	40
49	Shellabarger fine sandy loam	B	78	4.0	dryland	156
53	Tillman clay loam	C	85	2.0	dryland	1172
55	Hinkle silt loam, Complex	D	89	2.0	dryland	156
56	Tillman clay loam, Complex	C	85	3.5	dryland	108
58	Tobosa clay	D	89	0.5	dryland	360
59	Vernon clay loam	D	89	3.5	dryland	332
60	Vernon clay loam, Complex	D	89	6.0	dryland	24
62	Vernon soils	D	89	8.5	dryland	88

* Soil category number.

† Hydrologic soil group.

‡ Curve number.

§ Average slope of soils.

Data source: USDA SCS, Stillwater, Oklahoma.

Number of insecticide runoff events from dry cotton fields in Kiowa County with concentrations exceeding the Oklahoma surface water quality standards

Azinphos-methyl				Methyl-parathion				Malathion				Diflubenzuron			
SN*	Avg†	Max‡	Min§	SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min
62	40	59	26	62	29	45	18	62	16	29	7	8	10	25	2
60	38	57	24	60	28	44	17	60	15	28	5	60	10	22	2
59	33	55	21	8	24	41	15	8	13	23	5	62	10	22	3
8	32	53	21	59	24	42	15	59	13	25	5	40	9	22	1
24	30	54	19	55	23	40	13	24	12	23	4	55	9	23	1
55	30	53	20	40	22	40	12	25	12	23	4	59	9	21	1
25	29	54	19	24	21	40	12	40	12	23	5	15	7	17	0
40	28	52	18	25	21	40	13	55	12	23	5	24	7	18	1
39	27	52	17	15	19	36	9	39	11	23	3	25	7	18	1
15	26	50	15	23	19	37	9	15	10	22	4	39	7	18	0
23	26	50	15	38	19	36	9	23	10	23	3	58	7	18	1
38	26	49	15	39	19	38	9	29	10	22	3	14	6	17	0
45	26	50	15	58	19	38	9	30	10	21	3	16	6	17	1
58	26	51	16	29	18	35	9	38	10	22	3	22	6	18	0
29	25	48	15	30	18	34	9	45	10	23	3	23	6	17	0
30	24	46	14	45	18	37	8	58	10	23	3	29	6	15	1
56	24	46	14	16	17	34	8	14	9	22	2	30	6	15	0
16	21	43	12	56	17	34	9	16	9	21	3	37	6	16	0
53	21	44	11	14	16	36	6	56	9	21	3	38	6	16	0
14	20	44	10	22	15	35	5	22	8	21	2	45	6	16	1
22	20	43	9	28	15	32	7	28	8	19	2	56	6	15	0
28	20	43	11	37	15	34	4	37	8	21	2	21	5	15	0
37	20	42	8	53	15	33	7	53	8	20	2	28	5	15	0
36	17	37	9	21	13	29	3	9	7	19	1	53	5	15	0
9	16	38	8	36	13	29	5	21	7	19	1	3	4	13	0
21	16	37	6	9	12	29	4	36	7	18	1	6	4	14	0

Number of insecticide runoff events from dry cotton fields in Kiowa County with concentrations exceeding the Oklahoma surface water quality standards (continued)

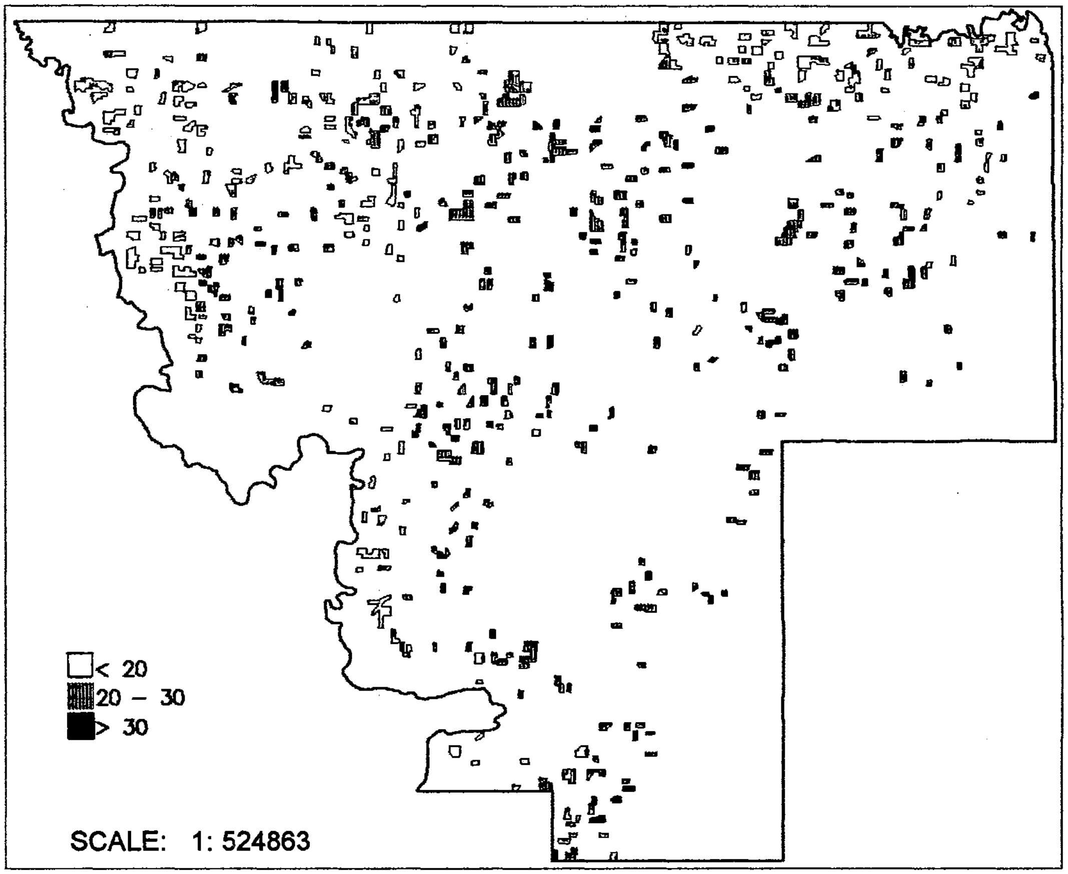
Azinphos-methyl				Methyl-parathion				Malathion				Diflubenzuron			
SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min
6	15	34	7	6	11	27	3	6	6	18	1	7	4	14	0
49	15	34	6	7	11	26	2	7	6	18	0	9	4	13	0
7	14	32	5	49	11	27	2	20	6	15	1	11	4	13	0
3	13	31	5	3	10	24	2	49	6	18	1	19	4	13	0
20	13	30	5	11	10	22	2	3	5	15	1	20	4	13	0
5	12	28	4	19	10	21	2	5	5	14	0	36	4	14	0
11	12	27	4	20	10	24	2	11	5	14	0	49	4	14	0
19	12	27	4	5	9	21	2	13	5	13	0	2	3	11	0
47	12	28	5	13	9	20	2	18	5	13	0	5	3	13	0
13	11	25	4	18	9	20	2	19	5	14	0	10	3	12	0
18	11	24	4	47	9	21	2	47	5	14	0	12	3	13	0
2	10	21	4	2	8	17	2	2	4	12	0	13	3	11	0
35	10	20	4	10	7	16	2	10	4	12	0	18	3	12	0
10	9	20	3	12	7	17	2	12	4	12	0	35	3	12	0
12	9	21	3	35	7	17	2	35	4	12	0	46	3	12	0
41	9	19	3	41	7	16	2	41	4	11	0	47	3	14	0
42	9	20	3	42	7	16	2	42	4	12	0	48	3	12	0
46	9	20	3	46	7	17	2	46	4	12	0	41	2	11	0
48	9	20	3	48	7	17	2	48	4	12	0	42	2	12	0

* Soil category number.

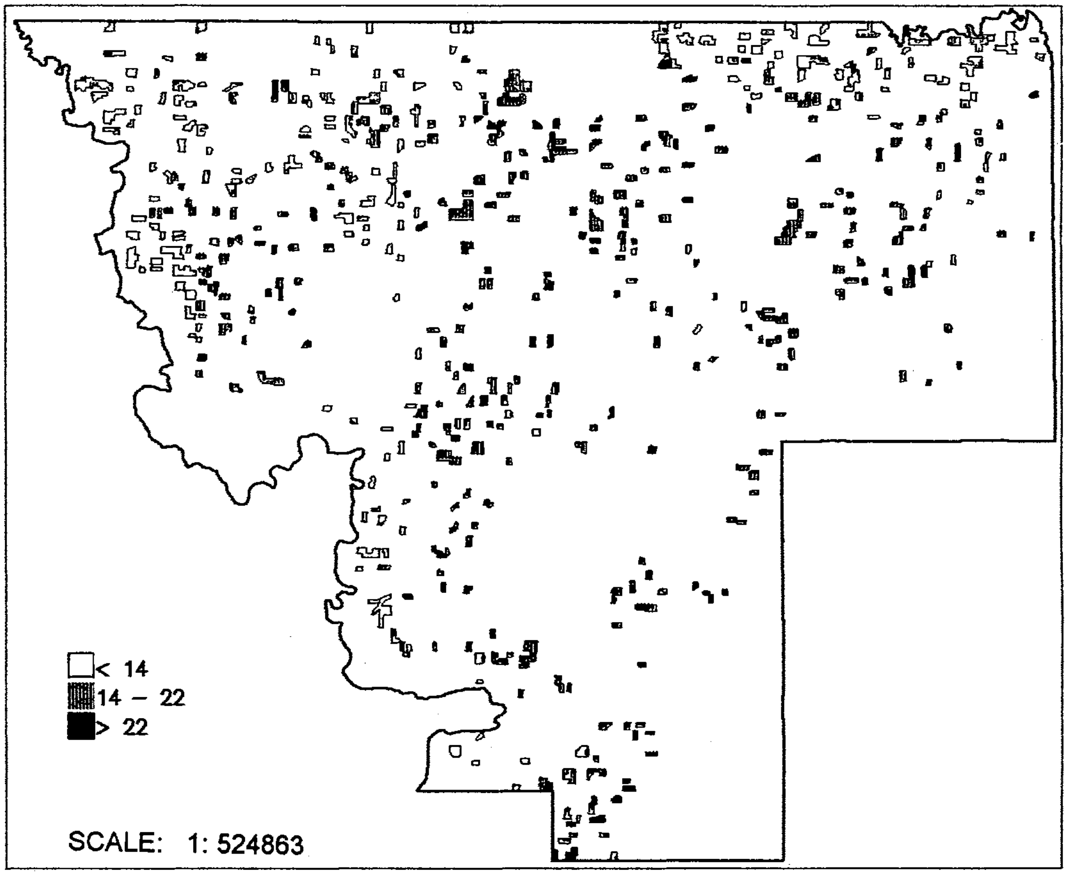
† Average number of events exceeding the standards.

‡ Maximum number of events exceeding the standards.

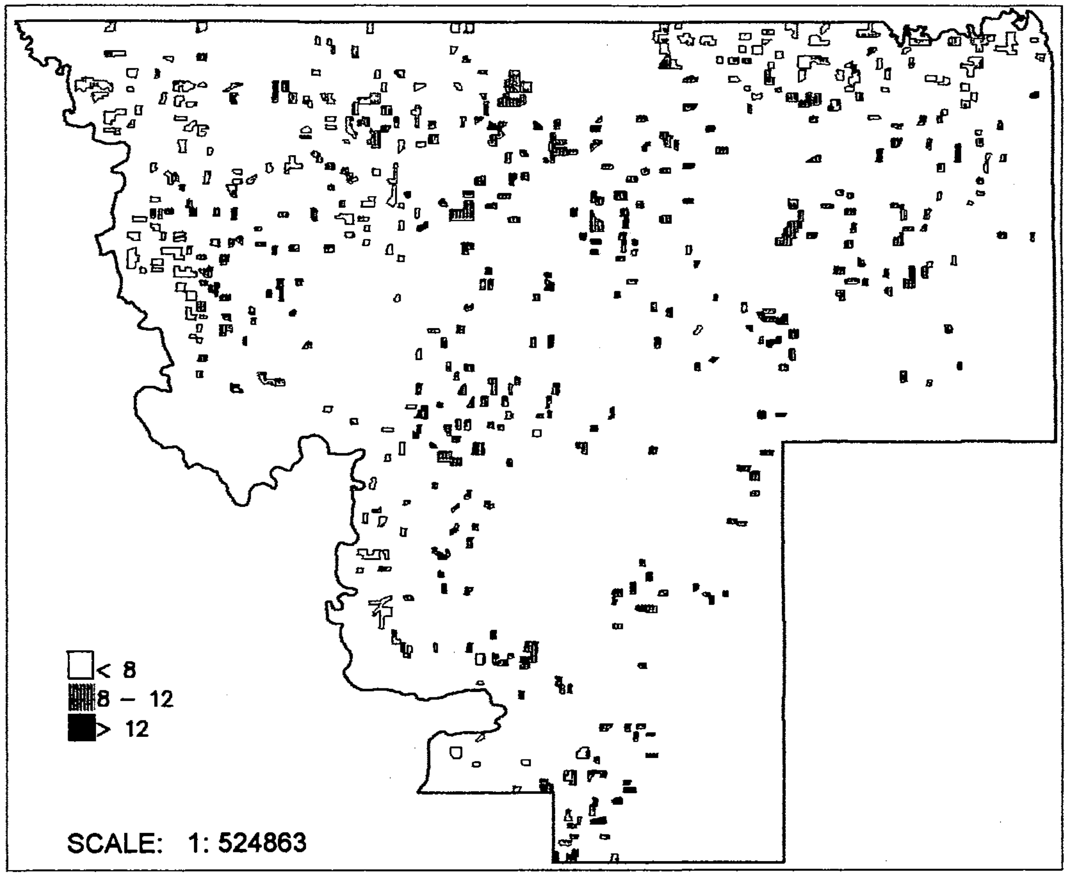
§ Minimum number of events exceeding the standards.



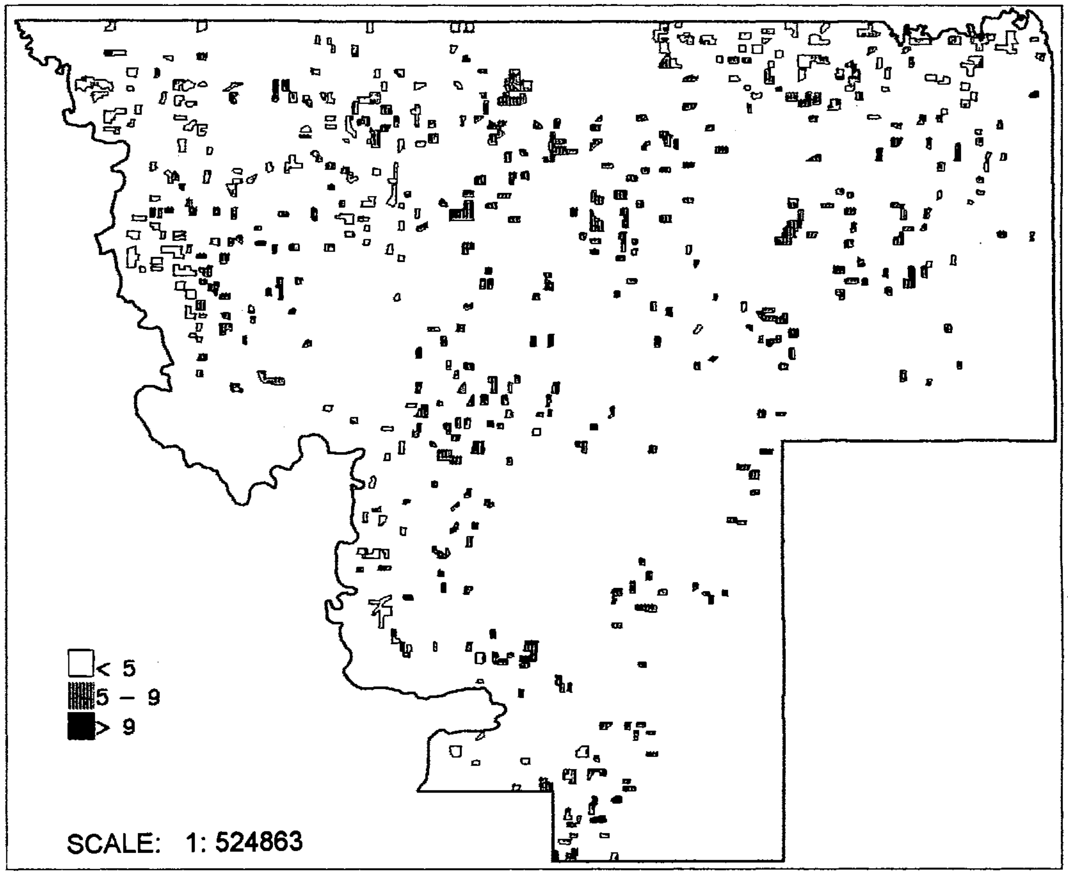
Spatial distribution of azinphos-methyl loss potential with runoff from cotton fields in Kiowa County



Spatial distribution of methyl-parathion loss potential with runoff from cotton fields in Kiowa County



Spatial distribution of malathion loss potential with runoff from cotton fields in Kiowa County



Spatial distribution of diflubenzuron loss potential with runoff from cotton fields in Kiowa County

APPENDIX F

SOIL AND WEATHER DATA AND SIMULATING RESULTS FOR TILLMAN COUNTY

Weather parameters based on the daily data from Frederick Station for 1962-1991 period

Month	TMX*	TMN†	SDTMX‡	SDTMN§	PRE‖	SDR#
	C	C	C	C	mm	mm
January	11.0	-3.1	7.8	5.4	25.8	8.6
February	14.3	-0.8	8.0	5.3	31.5	9.0
March	19.7	4.0	7.1	5.2	50.5	11.2
April	25.1	9.8	5.5	4.6	59.1	12.5
May	29.2	14.5	4.8	4.0	111.9	16.6
June	33.7	19.3	4.1	3.1	89.5	21.4
July	36.8	22.0	3.6	2.2	56.4	14.5
August	36.0	21.1	4.0	2.4	70.5	15.6
September	31.0	16.9	5.4	4.1	92.0	20.1
October	25.4	10.4	5.7	4.6	69.3	18.9
November	17.9	4.0	6.4	5.1	39.1	11.0
December	12.2	-1.4	7.2	5.3	29.9	9.5

* Average monthly maximum temperature.

† Average monthly minimum temperature.

‡ Monthly standard deviation of maximum temperature.

§ Monthly standard deviation of minimum temperature.

‖ Average monthly precipitation.

Monthly standard deviation of daily precipitation.

Data source: Oklahoma Climatological Survey, Norman, Oklahoma.

Soil types within cotton fields in Tillman County

SN*	Soil Name	HSG†	CN‡	Slope§ (%)	Landuse (cotton)	Area (ha)
1	Abilene loam	C	85	0.5	dryland	1552
2	Asa silt loam	B	78	0.5	dryland	512
3	Asa silt loma, Complex	B	78	0.5	dryland	76
6	Clairemont soils	B	78	0.5	dryland	412
7	Clairemont soils, Saline	B	78	0.5	dryland	220
8	Cyril fine sandy loam	B	78	0.5	dryland	36
9	Devol loamy fine sand	B	78	1.5	dryland	1248
10	Devol loamy fine sand	B	78	5.5	dryland	540
11	Devol fine sandy loam	B	78	0.5	dryland	384
12	Foard silt loam	D	89	0.5	dryland	2588
13	Foard silty clay loam, Complex	D	89	0.5	dryland	2648
14	Grandfield loamy fine sand	B	78	0.5	dryland	1108
15	Grandfield loamy fine sand	B	78	1.5	dryland	3728
16	Grandfield fine sandy loam	B	78	0.5	dryland	544
17	Grandfield fine sandy loam	B	78	2.0	dryland	2012
18	Grandfield fine sandy loam	B	78	4.0	dryland	96
19	Hardeman fine sandy loam	B	78	0.5	dryland	2436
20	Hardeman fine sandy loam	B	78	2.0	dryland	1200
21	Hardeman fine sandy loam	B	78	4.0	dryland	116
22	Hardeman fine sandy loam	B	78	14.0	dryland	64
23	Hilgrave gravelly loam	B	78	10.0	dryland	52
24	Hollister silt loam	D	89	0.5	dryland	2108
25	Indiahoma silt clay loam	D	89	2.0	dryland	768
26	Indiahoma silt clay loam	D	89	4.0	dryland	172
27	Likes loamy fine sand	A	67	6.0	dryland	216
31	Miller clay	D	89	0.5	dryland	204
32	Miller clay, Saline	D	89	0.5	dryland	44
33	Minco very fine sandy loam	B	78	0.5	dryland	400

Soil types within cotton fields in Tillman County
(continued)

SN	Soil Name	HSG	CN	Slope (%)	Landuse (cotton)	Area (ha)
34	Minco very fine sandy loam	B	78	2.0	dryland	116
35	Port silty clay loam	B	78	0.5	dryland	196
36	Quanah silt loam	B	78	0.5	dryland	308
38	Roscoe clay	D	89	0.5	dryland	1076
39	Stamford silty clay loam	D	89	4.0	dryland	80
40	St. Paul silt loam	B	78	2.0	dryland	340
41	Hinkle silt loam, Complex	D	89	0.5	dryland	72
42	Hinkle silt loam, Complex	D	89	2.0	dryland	364
43	Tillman silt loam	D	89	4.0	dryland	72
44	Tillman silty clay loam	C	85	2.0	dryland	2228
45	Hinkle silt loam, Complex	D	89	2.0	dryland	1728
46	Tipton fine sandy loam	B	78	0.5	dryland	6408
47	Tipton fine sandy loam	B	78	2.0	dryland	896
48	Tipton loam	B	78	0.5	dryland	6264
49	Tipton loam	B	78	2.0	dryland	572
50	Vernon soils	D	89	2.0	dryland	24
51	Vernon soils	D	89	4.0	dryland	76
52	Vernon soils, Eroded	D	89	4.0	dryland	208
54	Knoco silty clay loam, Complex	D	89	8.5	dryland	212
55	Clairemont silty clay loam, Complex	B	78	0.5	dryland	68
56	Weymouth loam	B	78	4.0	dryland	172

* Soil category number.
† Hydrologic soil group.
‡ Curve number.
§ Average slope of soils.
Data source: USDA SCS, Stillwater, Oklahoma.

Number of insecticide runoff events from dry cotton fields in Tillman County with concentrations exceeding the Oklahoma surface water quality standards

Azinphos-methyl				Methyl-parathion				Malathion				Diflubenzuron			
SN*	Avg†	Max‡	Min§	SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min
54	41	58	28	54	31	49	21	54	17	29	8	54	12	26	5
51	38	56	25	51	27	43	16	51	15	27	8	39	10	23	1
52	38	56	24	52	27	43	16	52	15	26	8	51	10	26	2
26	36	58	24	39	26	41	14	39	14	27	7	52	10	26	2
39	36	56	24	43	25	41	14	43	14	26	7	42	9	25	2
43	36	57	24	26	24	41	13	26	13	26	7	45	9	25	2
50	34	56	23	42	24	41	12	50	13	26	5	50	9	23	1
25	32	56	21	45	24	41	12	25	12	26	4	26	8	19	0
42	32	55	21	50	24	41	13	42	12	25	4	41	8	22	1
45	32	55	21	25	22	40	11	45	12	25	4	43	8	18	1
12	29	52	18	41	21	38	9	12	11	24	4	12	7	18	0
13	29	52	18	12	20	38	9	13	11	24	4	13	7	18	0
32	29	53	18	13	20	38	9	23	11	24	5	22	7	17	1
24	28	50	17	23	20	36	9	32	11	24	4	23	7	17	2
31	28	51	17	32	20	38	9	41	11	24	4	25	7	18	0
38	28	50	17	38	20	37	9	22	10	23	4	31	7	18	0
41	28	52	17	22	19	35	7	24	10	23	4	32	7	19	0
23	27	49	16	24	19	37	9	31	10	23	4	38	7	18	0
22	25	46	13	31	19	37	9	38	10	23	4	24	6	18	0
44	23	45	12	44	16	32	5	44	9	21	2	10	5	16	0
10	21	41	8	10	15	29	4	10	8	21	2	18	5	16	0
1	19	36	10	1	13	27	5	1	7	19	2	21	5	16	0
18	17	36	7	18	13	28	3	18	7	20	1	44	5	18	0
21	17	36	7	21	13	28	3	21	7	20	1	56	5	14	0
56	16	35	7	56	12	27	4	56	7	19	1	1	4	16	0
9	13	27	6	17	10	24	2	17	6	16	1	17	4	14	0
17	13	28	4	20	10	23	2	9	5	14	1	20	4	13	0
20	13	29	5	27	10	21	3	14	5	14	1	2	3	11	0

Number of insecticide runoff events from dry cotton fields in Tillman County with concentrations exceeding the Oklahoma surface water quality standards (continued)

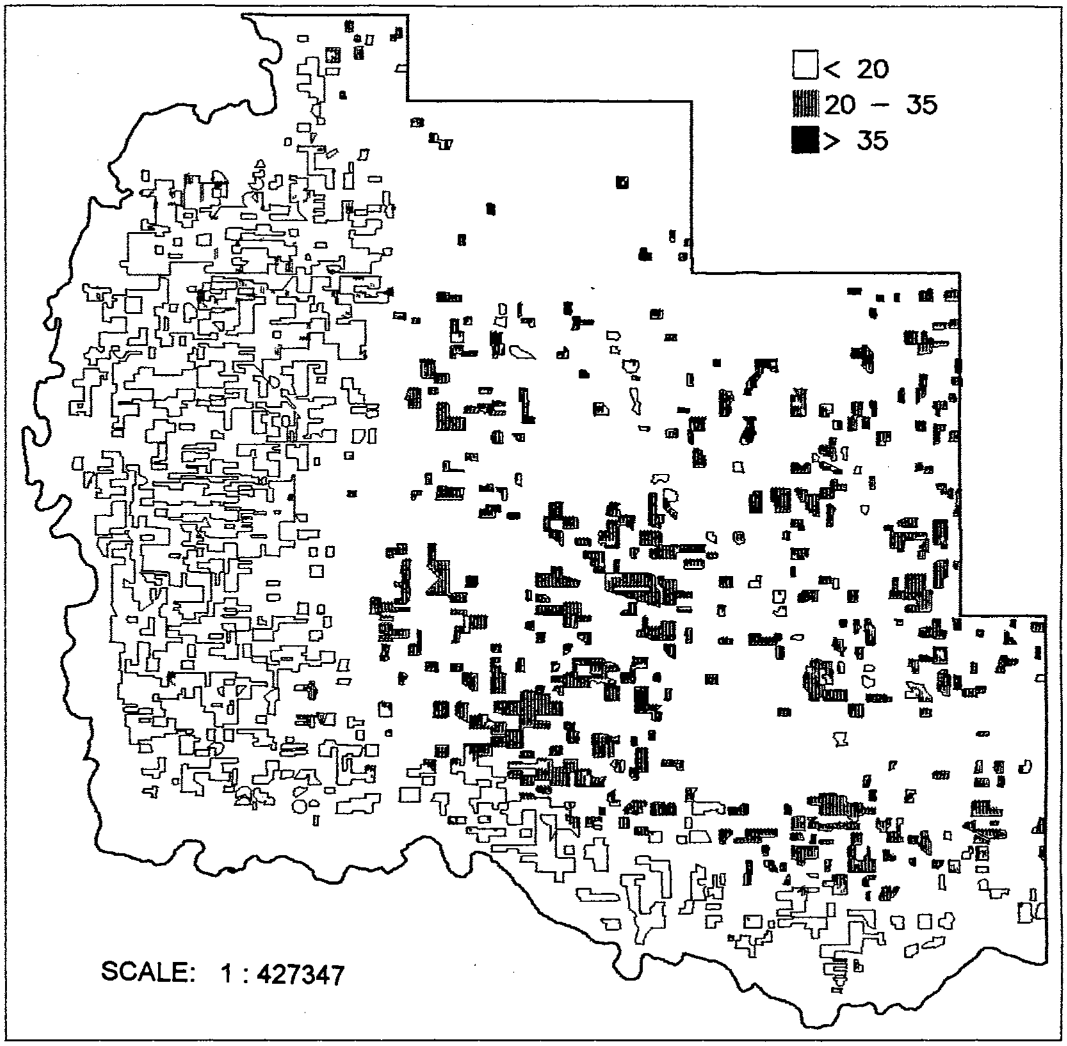
Azinphos-methyl				Methyl-parathion				Malathion				Diflubenzuron			
SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min	SN	Avg	Max	Min
34	13	28	5	47	10	22	2	15	5	14	1	3	3	11	0
40	13	28	5	49	10	23	2	20	5	15	1	6	3	12	0
47	13	29	6	9	9	21	2	27	5	15	1	7	3	11	0
49	13	27	5	14	9	21	2	34	5	15	1	9	3	11	0
14	12	27	5	15	9	21	2	40	5	14	1	11	3	11	0
15	12	27	5	34	9	22	2	47	5	15	1	14	3	11	0
27	12	25	5	40	9	23	2	49	5	15	1	15	3	11	0
6	11	24	3	2	8	18	2	2	4	13	0	16	3	11	0
7	11	26	4	3	8	18	2	3	4	13	0	19	3	11	0
11	11	26	4	6	8	18	2	6	4	13	1	27	3	11	0
33	11	23	3	7	8	19	2	7	4	12	1	34	3	13	0
36	11	24	3	11	8	19	2	8	4	12	0	36	3	12	0
48	11	23	3	16	8	18	2	11	4	12	1	40	3	13	0
2	10	24	3	19	8	19	2	16	4	12	1	46	3	11	0
3	10	24	3	33	8	17	2	19	4	12	1	47	3	13	0
8	10	23	4	36	8	19	2	33	4	13	0	48	3	11	0
16	10	24	4	46	8	19	2	35	4	13	0	49	3	13	0
19	10	25	4	48	8	17	2	36	4	13	1	55	3	12	0
35	10	22	3	55	8	18	2	46	4	12	1	8	2	10	0
46	10	23	4	8	7	16	2	48	4	13	1	33	2	11	0
55	10	23	3	35	7	16	2	55	4	13	1	35	2	11	0

* Soil category number.

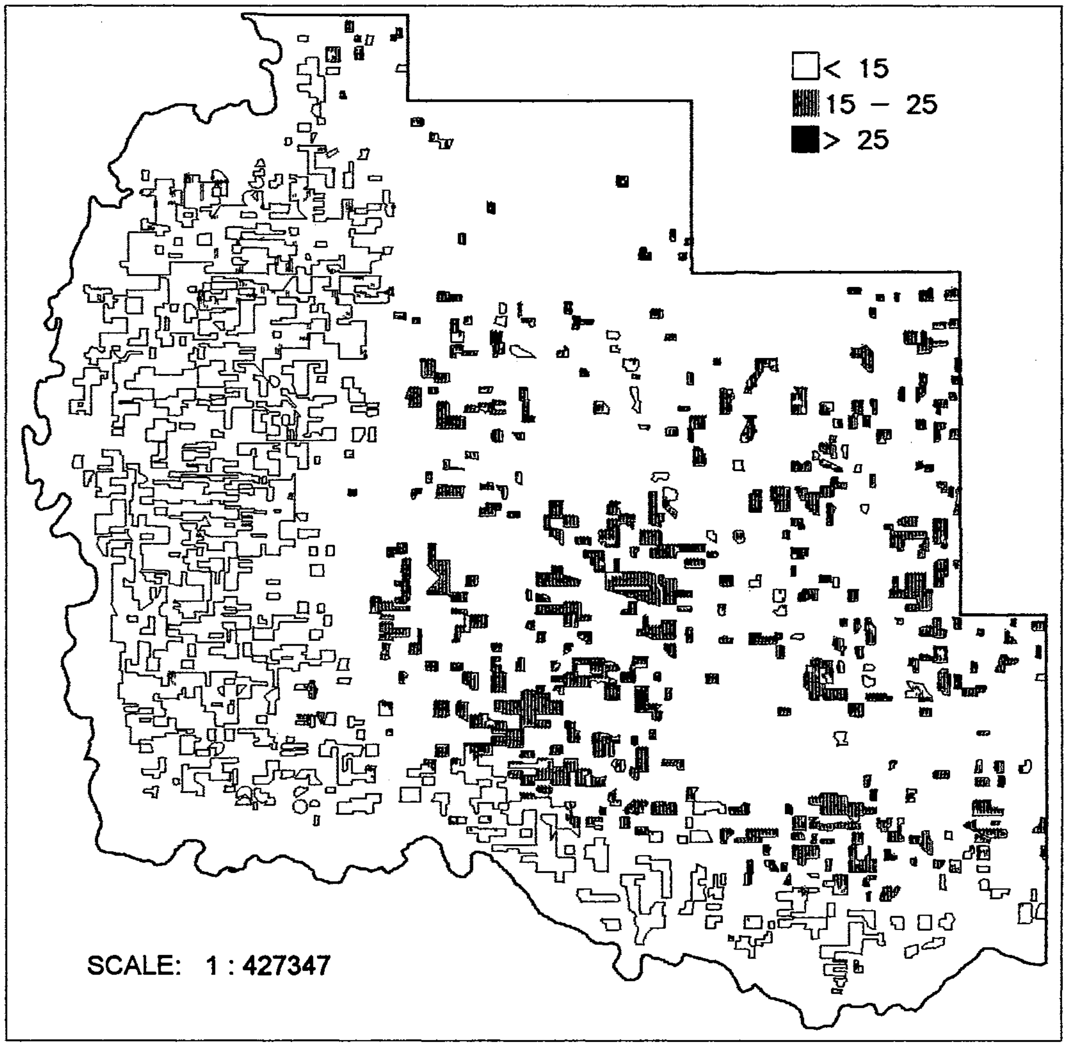
† Average number of events exceeding the standards.

‡ Maximum number of events exceeding the standards.

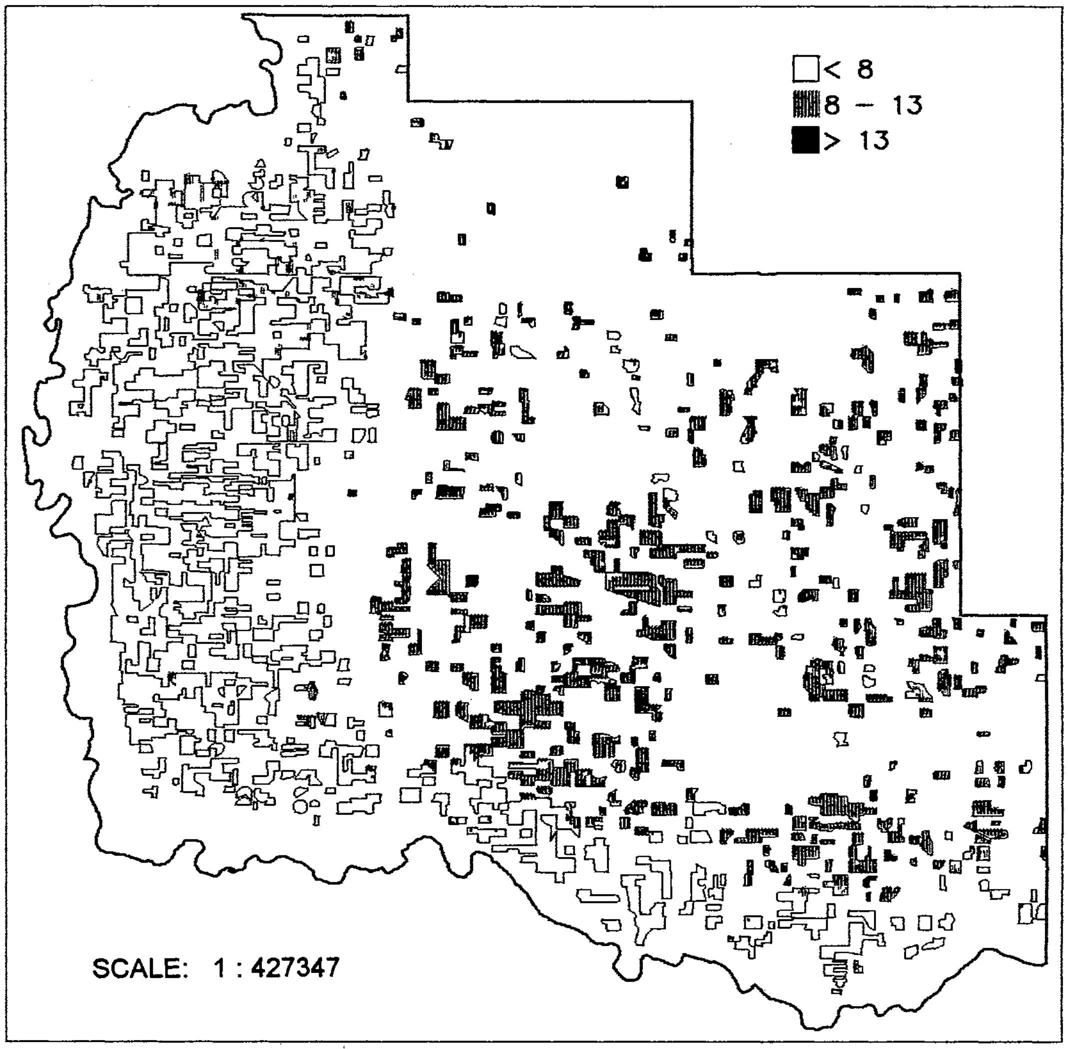
§ Minimum number of events exceeding the standards.



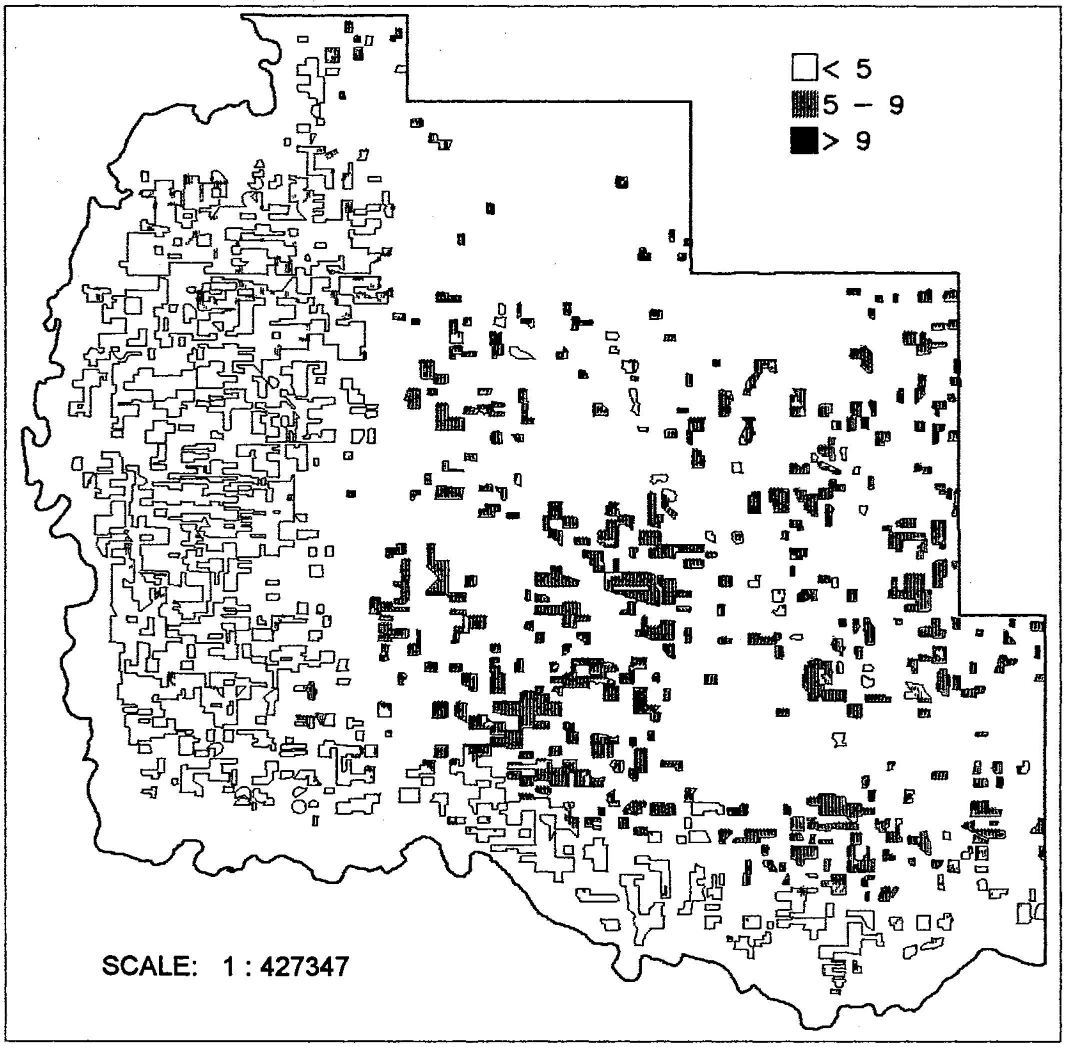
Spatial distribution of azinphos-methyl loss potential with runoff from cotton fields in Tillman County



Spatial distribution of methyl-parathion loss potential with runoff from cotton fields in Tillman County



Spatial distribution of malathion loss potential with runoff from cotton fields in Tillman County



Spatial distribution of diflubenzuron loss potential with runoff from cotton fields in Tillman County

VITA

XIAN TIAN

Candidate for the Degree of

Doctor of Philosophy

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