ECONOMIC AND ENVIRONMENTAL IMPACTS OF GROUND WATER QUALITY MANAGEMENT

By

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ECONOMIC AND ENVIRONMENTAL IMPACTS
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INTRODUCTION

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Importance of Ground Water

Ground water is one of Oklahoma's most valuable and widely used natural resources. Over 600 towns and cities in the State derive their drinking water from deposits below the surface (Norris and Anderson, 1991). Sixty percent of the water used for all purposes within Oklahoma comes from wells or naturally occurring springs. Agriculture is also a heavy user of ground water deposits; eighty percent of irrigation water is from alluvial or confined aquifers. The State's 23 major ground water aquifers contain an estimated 320 millon acre feet in storage with approximately one-half of it recoverable given current technology and economic forces (Oklahoma Water Resources Board, 1990).

Nationwide, seventy-five percent of all cities derive drinking water in part or exclusively from ground water. Dependence on ground water is particularly high in rural areas. Almost 95% of the rural U.S. population relies on ground water as their source for drinking water, emphasizing the importance of managing ground water in rural areas

(Batie, Cox and Diebel; 1989).

Pesticide Use

Chemical use by agricultural producers has been characterized as rational behavior for the profit maximizer (Daberkow and Reichelderfer, 1988). Farm chemical use has been widely researched and accepted as a tool for increasing production. When chemicals are eliminated from production options, farmers experience lower net cash income and falling net worth (Richardson et al., 1991). Chemical inputs are important, economically efficient factors of production, substituting for machinery, land or labor as determined by their relative prices.

Data suggest that the pattern of pesticide use is changing. Pesticide use increased rapidly from the 1950's through the 1980's (Osteen and Szmedra, 1989). The share of cotton, corn and wheat treated with a herbicide went from about 10% in 1952 to over 90% by 1980. Osteen and Szmedra report producer use of pesticides has stabilized or declined since 1980. Within Oklahoma peak expenditures for pesticides occurred in 1985 when producers spent $36 million (Oklahoma Department of Commerce, 1990). The earlier increase in use could be attributed to the falling prices of chemical inputs relative to land, labor or machinery. Table 1 shows the price indices of labor, machinery, pesticides and fertilizer from 1948 through 1987. Recently economic thresholds and alternative pest control methods have been incorporated into studies trying to determine the profit

TABLE 1

INDEX OF PRICES PAID BY FARMERS
1965=100

Years	Agricultural Chemicals	Fertilizer	Wages	Tractors	Fuel
1965-68[a]	102	96	113	107	101
1969-72	102	87	152	130	107
1973-76	170	163	214	194	162
1977-80[b]	157	193	297	303	272
1981-84	194	249	381	435	424
1985-88	202	222	427	458	356
1989-92[c]	232	233	516	529	403
Increase	127%	142%	357%	494%	299%

[a]Index data for years 1965-1976 are from USDA 1977.
[b]Index data for years 1976-1991 are from USDA 1991.
[c]Index data for the year 1992 is preliminary data from USDA, ERS 1993a.

maximizing level of chemical input use rather than the biological maximum. Generally, the level of chemical inputs that yields the biological maximum is not the most profitable level of input use (Hall, 1983). Under two circumstances the producer may use a greater level of chemical inputs than the economic optimum. Either the producer is attempting to maximize production for a given land area, or the producer is risk averse and views the use of chemical inputs at elevated rates as a risk management tool (Antle, 1990).

Conflicting Goals

Production processes that create externalities often lead to conflicts (Pearce and Turner, 1990). The producer uses pesticides to maximize his net profits, but the private producer generally does not consider the negative impacts that pesticide use may have on the rest of society. When pesticides contaminate ground water, pesticides have been over applied, from society's point of view, as producers ignore the costs of contamination (Antle, 1990).

Society has expressed a growing concern over agricultural chemical use. In Pennsylvania a 1991 state-wide survey on environmental issues, targeting urban and rural populations, found increasing concern over agricultural chemical use. Nearly 70 percent of the respondents thought that attention to agricultural chemical use should be given greater priority in the 1990's than the topic had received in the 1980's (Scott and Willits, 1991).

Agricultural chemicals have contaminated ground water used by industry, municipalities and agricultural producers. EPA reports pesticides are a widespread pollutant with 46 various formulations being found in 26 states in a preliminary study (US EPA, 1991). The final survey detected only 12 pesticides, when higher concentration levels were used as the minimum detection levels (US EPA, 1990b). Still, most detections in this survey were under their health advisory levels or maximum contaminant levels[1]. It is important to remember the pesticides that are known to have contaminated ground water are a small fraction of the enormous array of pesticides currently available (Stewart, 1988). The large selection of pesticides allows producers to easily switch active ingredients when harmful formulations are removed from the market. However, the fact that so few contaminants have been documented may be the reason some producers refuse to seriously consider low ground water quality a problem. Even so, agricultural producers have a vested interest in protecting the quality of ground water underlying their farms as they themselves are consumers of the water for irrigation, livestock and household use (Stewart, 1988).

Future research will enable chemical selection based on a combination of environmental impacts and target pest efficacy. Trade-offs between drinking water safety and farm

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[1] MCLs and HALs are safety levels defined by the EPA. MCLs and HALs are discussed and defined in the following chapter in more detail.

income may be necessary to make progress in the area of water quality without severely damaging the agricultural economy. Even with changes in farm management practices, zero degradation of ground water quality will not be a realistic goal. State policy makers must decide which agricultural management strategies best meet society's water quality and farmers' income goals.

Administrative Problems

The federal regulations that are in place to address water pollution do not adequately address every issue involved in protecting ground water resources. Attempts to further regulate chemical and land use patterns at the federal level probably would not be as efficient as more localized legislation due to the site specific nature of ground water contamination.

The EPA has suggested that it will begin urging states to adopt their own water quality strategies (US EPA, 1991). Each state will retain primary responsibility for its ground water. As states begin to design ground water policies, they discover pollution from agricultural chemicals is a complex problem. Agricultural chemical pollution is difficult to manage for at least five reasons (Batie, Cox and Diebel, 1989):

1. Non-point pollution leads to widespread contamination which is difficult to trace back to the polluter;
2. Environmental damage potential and target pest

effectiveness are generally site specific;

3. Monitoring and testing are technical and costly;
4. Resistance exists to "polluter pays" regulations;
5. Health and safety implications of contaminated ground water are not well documented.

In addition to the difficulties states encounter with chemical properties, states must weigh the socially desired optimal use of agricultural chemicals against private profits. States that are primarily agricultural may be inclined to pass more lax pesticide restrictions. Even so, states must implement management plans for pesticides in ground water which meet EPA criteria or risk losing the labeled use of chemicals for their state. If management plans do not adequately address the threat to ground water, EPA may revoke the chemical's label on a state-by-state basis (US EPA, 1991).

Some rural communities have reacted to environmental concerns by passing local ordinances. The U.S. Supreme Court has upheld an ordinance from Casey, Wisconsin which requires permits for pesticide applications, thereby granting the town the power to regulate nearby use of pesticides. The Court ruled that Casey's ordinance was not preempted by any Federal legislation (Fawcett, 1992).

Officials from largely agricultural states now are attempting to establish broad-based policies that preempt local governments from passing such laws. One concern is that such policies might be established without the benefit of economic impact studies. Oklahoma has recently passed legislation that preempts local ordinances. The Oklahoma law prohibits restricting sale or use of any agricultural chemical unless the restriction is needed to meet a federal mandate (State of Oklahoma, 1992; Derichsweiler and Sanford, 1992).

Causes of the Problem and Potential Solutions

Contaminant Movement

Movement of pesticides to ground water is influenced by many environmental factors as well as the chemical properties of the pesticides applied (Hornsby, 1991). The local environmental factors make ground water quality management a site-specific problem (Hornsby, 1991). It was once believed that the soil could remove any potential contaminants moving with water through the soil, so that only clean water would reach ground water deposits (Hornsby, 1991; US EPA, 1991). Scientists now know that the soil between the root zone and ground water has limited capabilities for removing contaminants, so that pesticides traveling below the root zone may reach ground water (Hornsby, 1991). Once pesticides reach the ground water, it may be technically or economically impossible to remove the contaminants (US EPA, 1991).

When pesticide contamination of ground water occurs, it may be traceable to chemicals applied according to the label directions (Batie, Cox and Diebel; 1989). Environmental factors for all locations and every possible management practice may not have been considered when the label was first obtained. Unforeseen rainfall can drive pesticides below the root zone before the chemicals can be taken up by the target pests or crops. Pesticides are often driven downward more quickly under irrigation than in rainfed areas. Tillage systems can impact the rate of pesticide movement (Isensee, Nash and Helling, 1990). Different soils have different abilities to retard movement of pesticides toward ground water. Application rates should be adjusted to reflect the soil conditions where the chemical is being applied. Even when application rates are adjusted for soil properties, interactions between weather factors and soil properties are difficult to predict.

A final potential problem is a gap in available technology's ability to accurately predict or track chemical movement throughout the entire soil profile. Many models are available to estimate the movement of various chemicals and pesticides within the root zone (Hornsby et al., 1988; Canter, Knox and Fairchild, 1987). Models are also becoming available to predict water flow within the aquifers. However, knowledge of how the chemicals get from the root zone to the aquifer is limited.

Hornsby discusses several factors and their effects on movement of pesticides in the environment (1991):

1. Properties of contaminants that determine their movement and potential threat to water quality include

water solubility, tendency to adhere to soil materials, persistency and toxicity.

2. Properties of soil, the intermediate vadose zone and the aquifer that affect the rate of contaminant movement include infiltration characteristics, pore size distribution, microbial population density and diversity, organic matter content, total porosity, ion exchange capacity, hydraulic properties, pH and oxygen status.
3. Climatic factors include frequency, intensity and duration of rainfall; temperature; wind speed; and solar radiation.
4. Vegetation may act as a sink for contaminants by uptake or assimilation, thus reducing the amount of contaminant available for transport to ground water.

Available Solutions

Understanding the soil's properties can aid a farmer in managing ground water quality. Soil texture influences water flow through the root zone of the soil. Producers have the opportunity to abate a portion of pesticide leaching by moving chemical-intensive crops to finer textured clay soils that are better able to slow pesticide leaching.

Crop variety selection can aid in reducing the level of pesticides required. Studies matching crop varieties more closely to their environment and any pests present have shown the potential to increase returns for crops grown with formerly high levels of chemical inputs (Ward et al., 1990). Peanut producers in Oklahoma also have this option, as plant breeders have developed peanut varieties that are resistant to some common pests and diseases (Sholar and Kirby, 1989).

Careful pesticide selection and precision placement can be helpful in reducing leaching. By applying a narrow band of the pesticide directly over the row, the quantity applied is reduced. The leaching process may also be slowed by application to plant foliage rather than the soil surface. Foliar application may allow chemical degradation to occur before the chemical reaches the soil and becomes subject to leaching.

Careful irrigation management can greatly reduce pesticide leaching. Sites which have sandy soils and shallow ground water are more susceptible to pesticide leaching. These sites can obtain substantial environmental benefits and increased economic benefits from careful irrigation management. Excessive water applications may hasten the leaching of pesticides below the root zone where little possibility exists of halting the downward movement.

Objectives of this Study

The primary objective of this study is to evaluate trade-offs associated with reducing the risk of pesticide contamination of ground water in Oklahoma. Underlying the primary objective of the research are several secondary objectives:

1. Determine a profit maximizing set of production

practices, crop rotations and pesticide applications for a representative Oklahoma farm.

2. Evaluate impact on farm income of restrictions on pesticide leaching.
3. Evaluate environmental and economic trade-offs associated with alternative risk levels for ground water protection.

Summary of Methods

A three part procedure using physical simulation and math programming models was used. Figure 1 outlines the research procedures. Combined information was used to construct a six-year linear programming model for a representative Oklahoma farm. The farm model was used to determine the baseline discounted net returns without any environmental constraints. Profit maximization was the assumed objective function.

The CMLS (Chemical Movement Through Layered Soil) model was used to predict pesticide leaching parameters. CMLS estimated the relative amount of active ingredient leaching below the root zone. The relative amount remaining is multiplied by the amount applied to estimate the quantity leached. The means and standard deviations of the leaching were used to construct chance-constraints.

Chance-constrained programming (CCP) was used to incorporate the stochastic aspects of environmental constraints into the representative farm model. CCP was used to evaluate alternative safety goals for potential

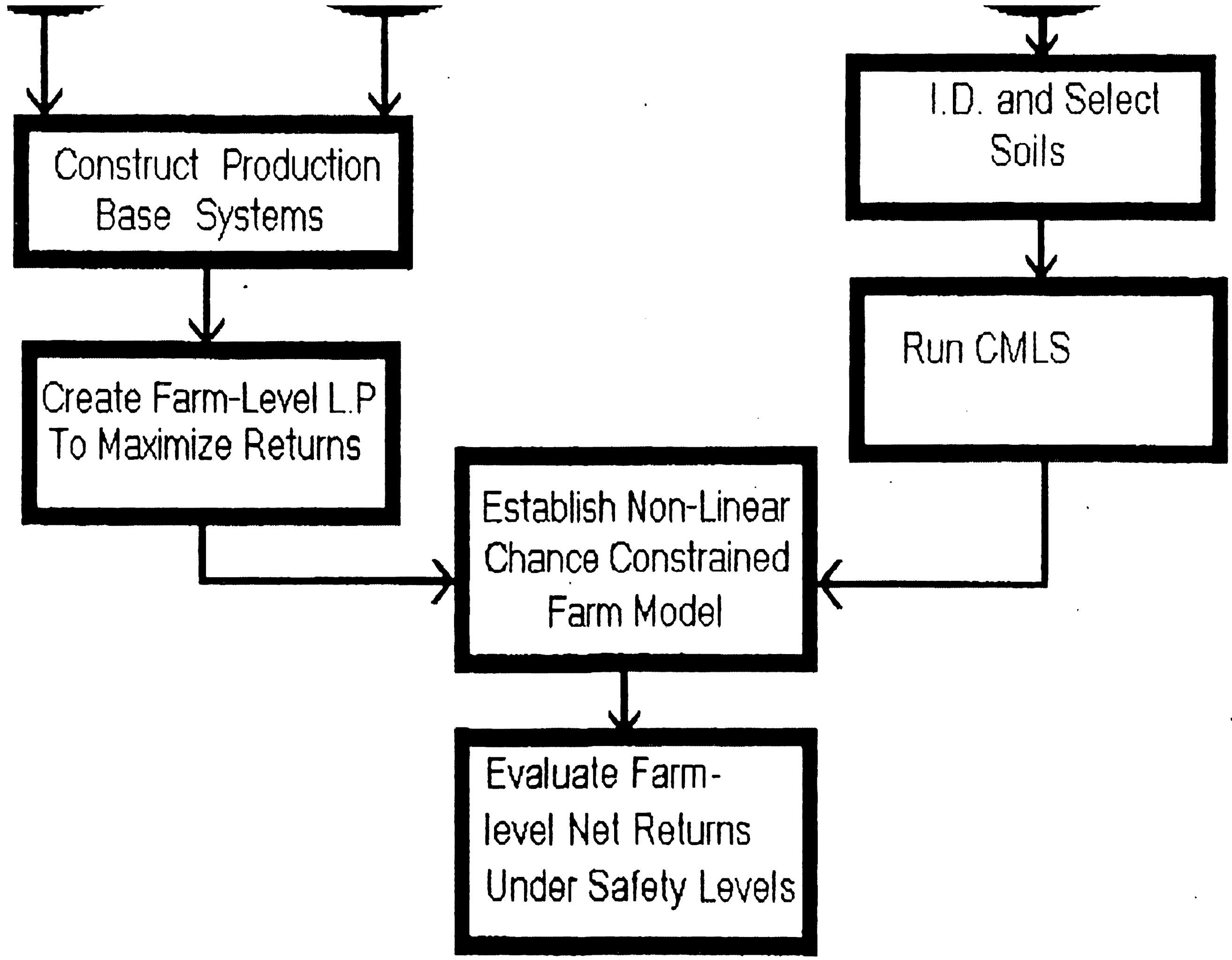

Figure 1. Flow Chart of Research Procedure

state policy. Changes in discounted net returns for the representative farm were evaluated under alterative safety goals.

The Study Area

General Description of the Region

Caddo County is a large agricultural county in west-central Oklahoma. In 1987, the county had the highest value of crops produced in the state (Oklahoma Department of Commerce, 1990). Of the 808,320 acres within the county, about 574,250 acres (71%) have the potential to be cultivated (USDA, SCS, 1973). In 1987, land in the county actually classified as cropland totaled 420,809 acres (US Dept. of Commerce, 1989). There are an estimated 1,530 farms in the county with an average size of 469 acres (US Dept. of Commerce, 1989). The product of the number of farms and average farm size places 717,570 acres (89%) in all agricultural uses within the county, including pasture, woodland and cropland. Elevation in the county ranges from 1,130 feet to 1,718 feet above sea level. Regional freeze-free growing season is normally more than 200 days. Annual rainfall varies from 27 inches in the northern end to 33 inches in the south-eastern corner (USDA, SCS, 1973). County population is estimated at 32,100 (Oklahoma Department of Commerce, 1990).

Soils of the County

There are 61 soil mapping units within the county (USDA, SCS, 1973). The land in the county is used for growing crops, pasture, commercial development and towns. The soils devoted to production agriculture are diverse. Characteristics that vary between the soil groups contribute to different potentials to leach nutrients or agricultural chemicals below the root zone. Grouping the soils by leaching potentials may allow policy makers to target specific practices on certain soil groups that are more likely to contribute to the leaching problem.

Of the soils considered tillable by the Soil Conservation Service, 40% have a high leaching potential. Approximately another 35% are classified as intermediate and less than 25% of the county's farmland is listed as having nominal leaching potential (USDA, SCS, 1973; USDA, SCS, 1988). Figure 2 shows the distribution of all county soils by leaching potential in Caddo County. The breakdown of soils for all uses is similar, with a slightly higher percentage in the high leaching potential and less in the low leaching potential group[2] (AgChems Project, undated).

The Dougherty-Eufaula series is representative of the coarse-textured soils found in the county with the largest potential to leach. These soils are used to grow peanuts

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[2]The percentages for all county soils are 43.68, 36.08 and 19.29 respectively for high, intermediate and nominal leaching potentials. Water covers .96% of the county's surface. The Figure 2 reflects these percentages.

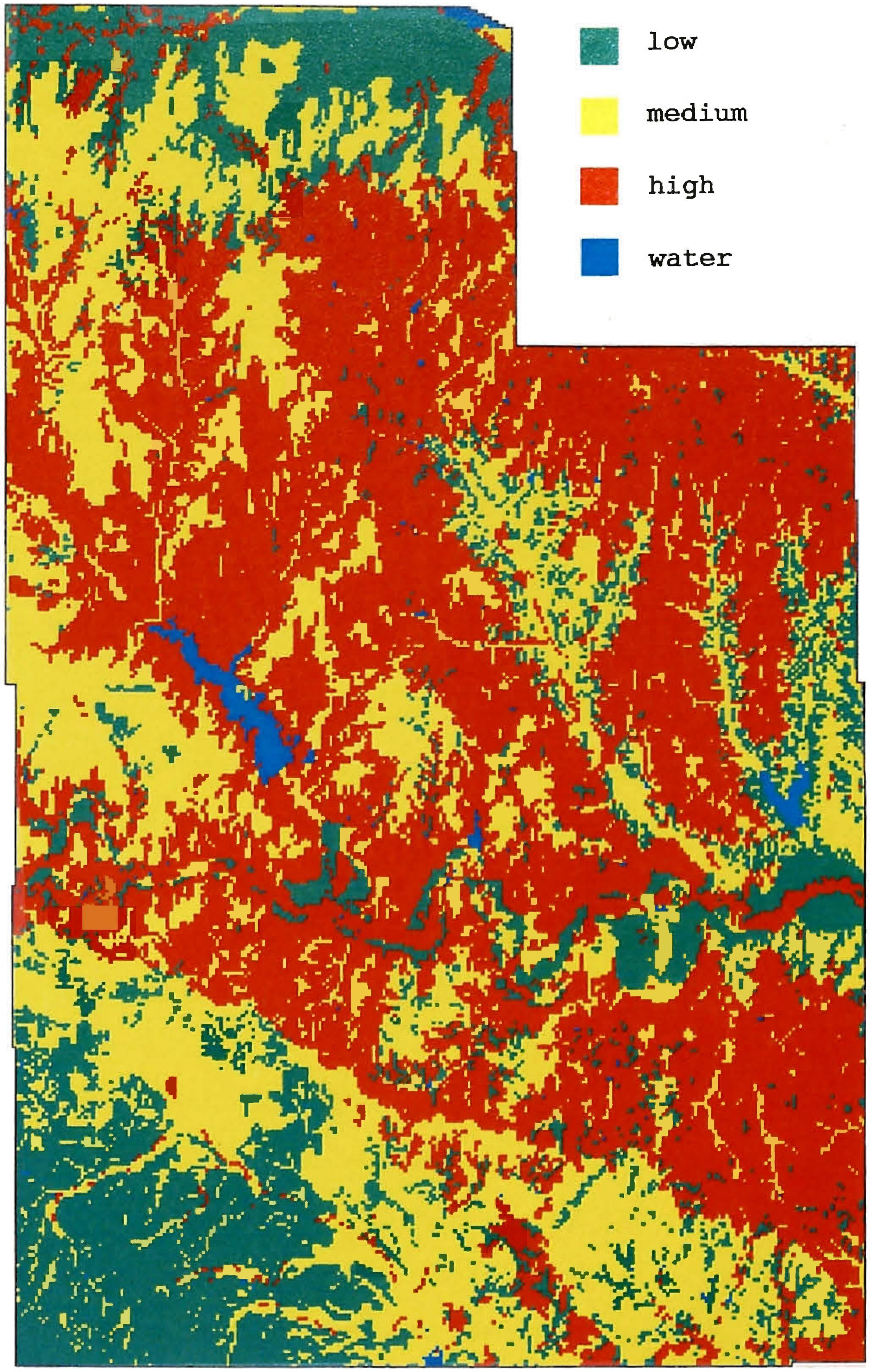

Figure 2. Location of Soils in Caddo Count by Leaching Probability

and other warm-season, row crops commonly found in the county such as cotton and grain sorghum. The Dougherty-Eufaula series comprises nearly 4% of the agricultural land in the county. The Pond Creek soils are used widely for row crops and for winter wheat in the county. The Pond Creek series of soils is classified as moderate leachers. The Pond Creek soils are the most common agricultural soils in the county, found on 12.75% of the farm land. Small areas of the Reinach series can be found in the peanut growing areas of the county. The Reinach series has a nominal potential to leach.

Ground Water of the County

There are alluvial deposits of ground water in the county and two confined aquifers. The placement of these aquifers is shown on Figure 3. The Rush Springs Aquifer is in Western Oklahoma under an area of 1,900 square miles. This confined aquifer is a cross-bedded sandstone of the Permian Age (Oklahoma Water Resources Board, 1990). Nearly one-half of the aquifer lies within Caddo County. North of the Washita River, the Rush Springs Aquifer has been developed for irrigation of peanuts. The water is primarily used for irrigation, with 96 percent of the pumping attributed to this purpose. Wells in this formation have yielded as much as 1000 gallons per minute (gpm) but 400 gpm is more typical. Saturated thickness of the aquifer ranges from 200 feet to 330 feet (Harlin and Wijeyawickrema, 1985). Although the water is generally suitable for household use,

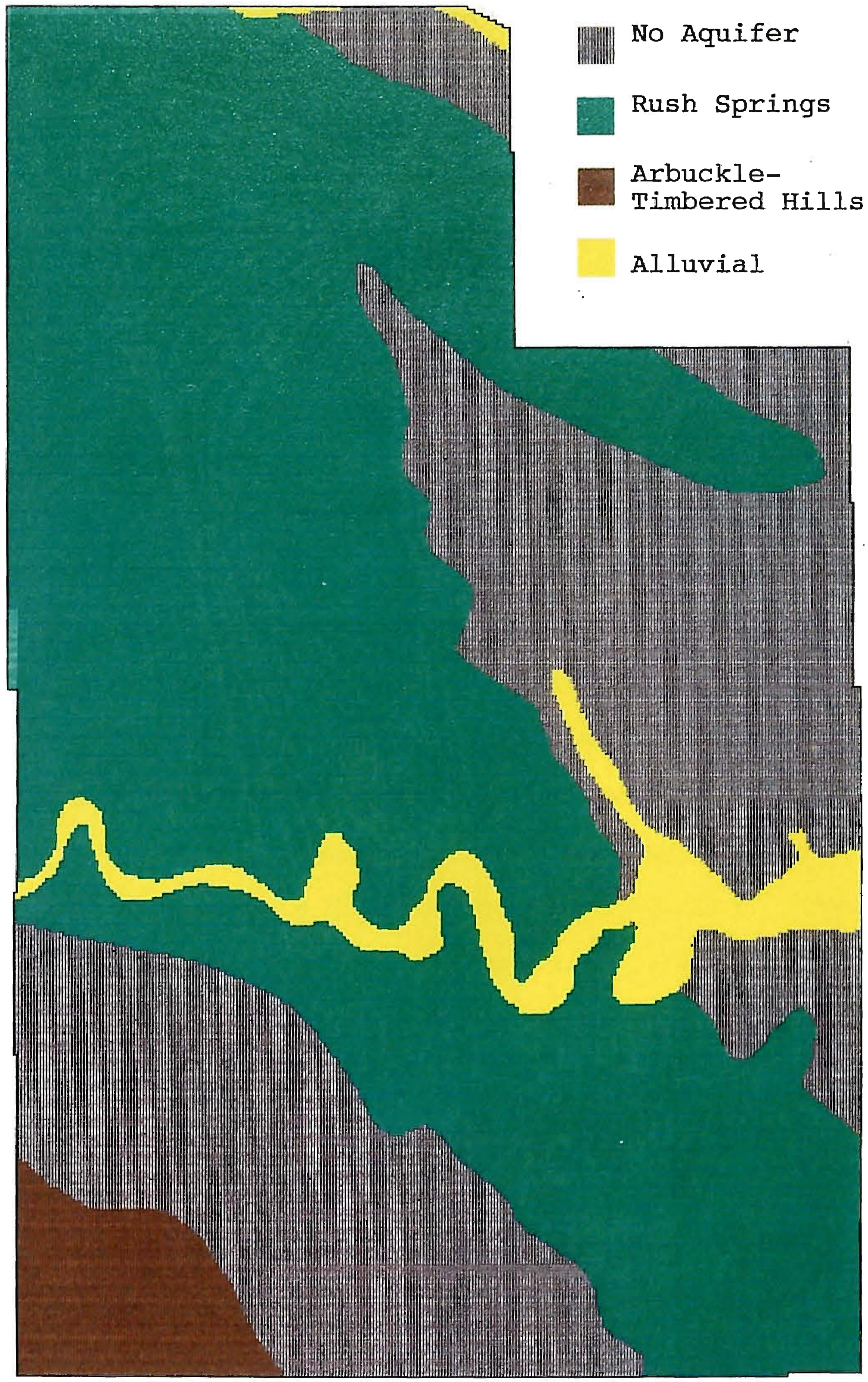

Figure 3. Primary Ground Water Deposits in Caddo County

in some areas the water exceeds safe drinking water standards for chloride and sulfate concentrations.

Minor sources of ground water include alluvial deposits and portions of the Arbuckle-Timbered Hills aquifer. The alluvial deposits have two limiting factors, low pumping rates and a narrow geographical range. The Arbuckle-Timbered Hills formation is primarily pumped for irrigating cotton in the southwest portions of the county. High levels of naturally occurring minerals in the Arbuckle-Timbered Hills Aquifer limit its use for drinking water (OWRB, 1990).

This study will focus on the land use in the peanut producing area overlying the Rush Springs Formation. The location of the soils grouped by leaching potentials, overlying the Rush Springs aquifer is given in Figure 4. Areas colored red indicate the extensiveness of the potential problem for ground water contamination by agricultural chemicals used in peanut production. These areas are of particular concern because of the soils' high leaching potentials coupled with the vulnerability of the ground water.

County Crop Production

Rainfall distribution is the major limitation to summer crop production. The county farmers depend heavily upon irrigation for peanuts, with 96% irrigated, and to a lesser extent for cotton and grain sorghum, with 30% and 25% irrigated, to insure a harvestable crop.

Ten year averages for acres harvested for the major

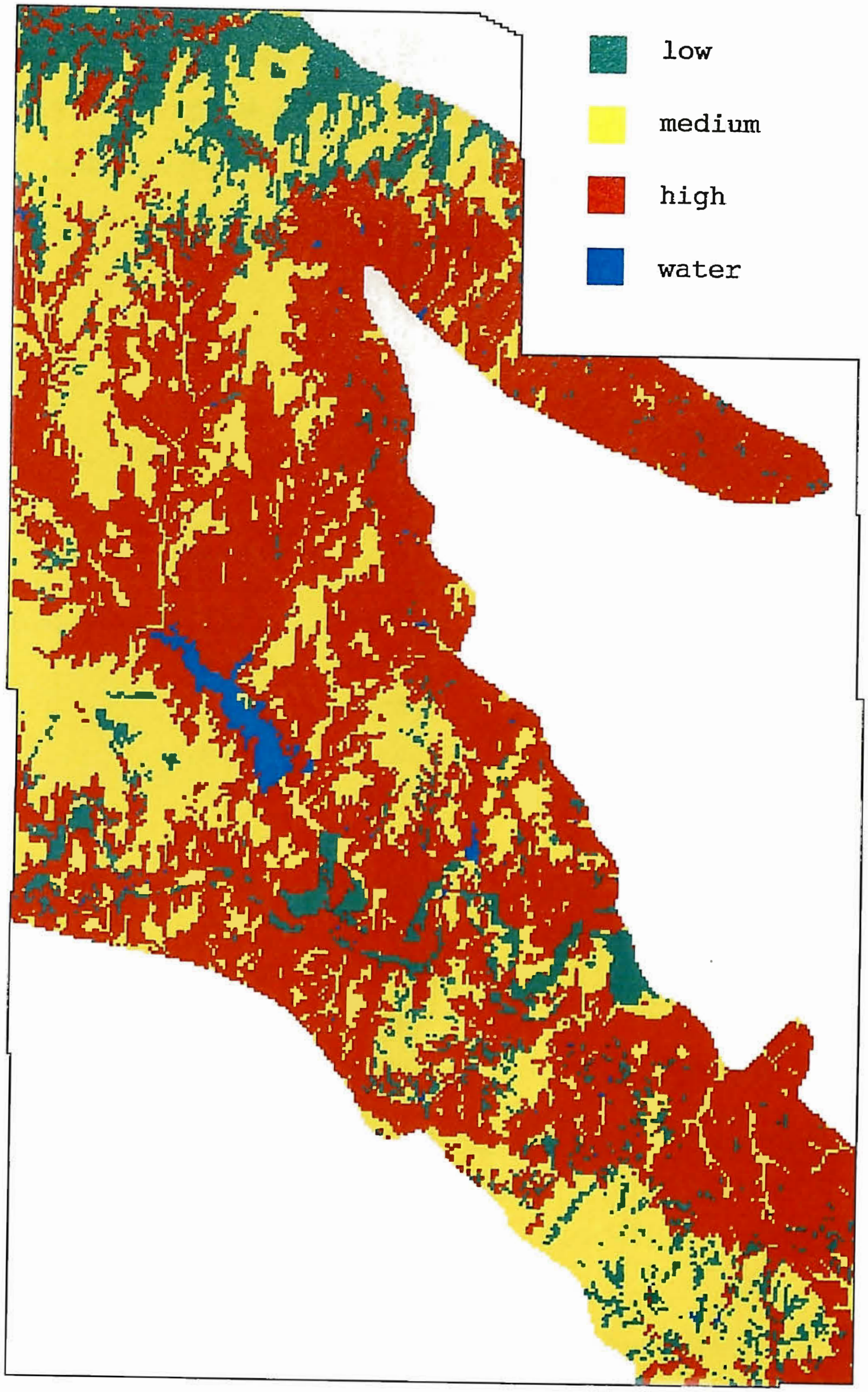

Figure 4. Soils Overlying the Rush Springs Aquifer

crops of cotton, peanuts, grain sorghum and wheat are shown in Table 2. Wheat is by far the crop with the most extensive harvested acreage, nearly 170,000 acres. Average peanut acreage was just over 31,000. Cotton and grain sorghum average 19,800 acres and 9,700 acres respectively.

TABLE 2

ANNUAL HARVESTED ACREAGE OF PRIMARY CADDO COUNTY CROPS

Year	Irrigated Cotton (acres)	Dryland Cotton (acres)	Peanuts (acres)	Grain Sorghum (acres)	Wheat (acres)
1982	4800	17400	28000	15200	190000
1983	4400	8000	29000	9500	120000
1984	6800	11100	32000	7500	125000
1985	6500	9500	26800	7400	159000
1986	7000	11000	31000	9000	170000
1987	7100	13200	32650	6100	170000
1988	7300	15700	31400	8500	150000
1989	4000	12250	31000	9500	210000
1990	4150	12350	35300	14500	220000
1991	2600	16400	35000	9500	168800
Average	5465	13690	31215	9670	168280

Source: Oklahoma Department of Agriculture, Agricultural Statistics. 1982-1991.

Gross receipts are defined here as the product of the reported values for harvested acreage times the yield per acre times the price per unit (acres X unit/acre X price/unit). Annual gross reciepts are given in Table 3.

Table 3 shows the importance of peanuts to the county, relative to the other crops.

TABLE 3

ANNUAL GROSS RECEIPTS OF CROP PRODUCTION IN CADDO COUNTY

Year	Cotton (mil $)	Peanuts (mil $)	Grain Sorghum (mil $)	Wheat (mil $)
1982	2.88	18.64	1.66	28.13
1983	2.53	20.78	1.24	19.77
1984	2.70	24.79	.91	18.51
1985	3.79	20.93	.82	18.25
1986	4.10	26.29	.67	16.34
1987	5.26	26.24	.54	14.22
1988	4.78	27.53	1.04	24.18
1989	1.67	23.39	1.11	22.47
1990	5.22	47.33	1.49	23.02
1991	3.39	29.62	.86	19.32
Average	3.63	26.55	1.03	20.42

Source: Oklahoma Department of Agriculture, Agricultural Statistics. 1982-1991.

Over the ten year period with limited acreage, peanuts remain the highest value crop in the county, annually generating $26.2 million in gross receipts. The value of wheat for grain and estimated value of winter pasture[3] from

[3]The value for wheat pasture grazed during the winter and subsequently harvested for grain in the following summer, was taken from survey. The estimated rental value was $16/acre (Doye and Kletke, 1990).

wheat harvested for grain averages $21.2 million dollars. Cotton[4] and grain sorghum harvested for grain have significantly lower average sales at $3.7 million and $1.0 million respectively (Oklahoma Department of Agriculture, 1982-91).

Statewide, the county ranks high in harvested acreage for its major crops. Rankings from the 1991 crop year show Caddo County leading peanut acreage for the state. The county ranked 5th in harvested acres of grain sorghum, and 7th in both acres harvested of wheat and cotton (Oklahoma Department of Agriculture, 1991).

Overview of the Thesis

The following chapter includes a discussion of the factors contributing to ground water contamination and issues relating to ground water quality management. The third chapter will be a detailed presentation of the methods and data sources used in obtaining the model parameters. Included in the third chapter are the baseline results. The fourth chapter discusses the issues surrounding the chance-constraints and the related policy goals associated with the risk levels. The final chapter will be a total summary of the research. Included in this chapter will be conclusions and suggestions for ground water quality management policies

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[4]Annual value of cotton production includes both the value of lint and the value of the cotton seed. The reader should be aware many Agricultural Economics authors omit value of the cotton seed as a proxy for the ginning costs incurred by the farmer. Ginning costs were not considered for this study.

for Oklahoma. Finally suggestions for future research will be given.

CHAPTER II

MODELING WATER QUALITY MANAGEMENT

Defining Ground Water Quality

Naturally occurring low quality of ground water can be attributed to its mineral concentration. Rainfall is slightly acidic, thereby dissolving some of the bedrock the water travels through and contacts at the aquifer (Canter, Knox and Fairchild, 1987). Water passing through geological materials may leach such high concentrations of minerals into the aquifer that the water may exceed National Drinking Water Standards (NDWS) for total dissolved solids (TDS), hardness or minerals, making them unusable for human use (Jackson et al., 1987; USGS, 1986).

Most of Oklahoma's ground water is safe for human consumption in its natural state. The naturally occurring factors limiting the use of some minor Oklahoma ground water deposits are: TDS, hardness, fluoride, sulfate and chloride (Horak and Stoner, 1986). Some of the significant aquifers in Oklahoma occasionally exceed the enforceable primary NDWS at a few locations within the entire aquifer. The primary NDWS for fluoride was set by EPA at 4 mg/L. The secondary NDWS are recommendations based on aesthetic qualities. They are 500 mg/L for TDS, 2.0 mg/L for fluoride, 250 mg/L for chloride and 250 mg/L for sulfate (Horak and Stoner, 1986).

The EPA has also developed quality standards for some organic contaminants in drinking water. Maximum contaminant levels (MCLs) or health advisory levels (HALs) are used to evaluate drinking water quality. MCLs and HALs are set to prevent any adverse health effects. MCLs are enforceable limits for public water systems under the Safe Drinking Water Act (US EPA, 1991). The MCL is the concentration of the pesticide in drinking water that if consumed daily for a lifetime (70 years) would increase the likelihood of cancer to 1 in 1,000,000. The FDA considers this level of risk to be insignificant (Rodricks and Taylor, 1991). HALs serve as interim reference points in evaluating water quality until permanent MCLs are developed for a particular contaminant. The HAL's are developed using the same criteria but have not been finalized. By setting the HALs the policy makers have determined any concentration beyond the HAL is significant to the public.

Water samples are analyzed in laboratories to determine concentration levels of contaminants and their implied human health risks. Detection of pesticides in ground water sources does not automatically determine that a human health risk exists. The capability of modern laboratories to test for and detect pesticides or nutrients in water has advanced beyond the exact knowledge of the potential human health risk associated with each organic at minute levels. Cancer studies of potential carcinogens are difficult and costly to undertake as they require large amounts of time and money to adequately reflect the impacts of long-term exposure. With population studies, it is also difficult to rule out other causes or interactions of carcinogens.

Environmental Factors Influencing Water Quality

Soil Characteristics

The three physical phases of elements are seen in soils: 1) solids as minerals and organic matter, 2) oxygen and other elements in gaseous form and 3) soil water as a liquid (Foth, 1990). Soils are categorized by the differing amounts of these minerals, organic matter, water and air contained in their layers. Soils with more than 18 percent organic matter are considered organic and those with more than 82 percent mineral matter are termed mineral soils. Organic soils are home to a diverse and large population of soil organisms that feed on the organic matter. Soil organisms that live in organic soils break down pesticides (Jackson et al., 1987).

Based upon the constituents of the soil, the soil will exhibit different physical properties. The soil can be further characterized by these physical properties. Physical properties of soil commonly discussed are: texture, structure, consistence, porosity, density, color and seasonal temperature (Foth, 1990; Jackson et al, 1987). Texture, structure, porosity and permeability are considered the most important physical factors impacting the movement of pesticides downward through the soil layers (Jackson et al., 1987). The physical properties influence the soil's water infiltration rate and water holding capacity, which in turn influence pesticide movement (Jackson et al., 1987).

Soil texture is a measure of how coarse or fine the individual particles are and the distribution of particle sizes that comprise the soil mixture (Foth, 1990). Sands are the class of soils with the largest individual particle size. Clay soils have the finest texture. Loamy soils are an intermediate combination of sand and clay particles.

The arrangement of the soil particles is referred to as structure (Foth, 1990). The four basic shapes of soil aggregates or peds are prismlike, spheroid, platelike and blocklike. Two conditions without structure are single grained and massive (Foth, 1990). Structure influences infiltration rates of water into the soil profile (Jackson et al., 1987). Soil management and cultural practices can affect the soil's structure. Practices which result in frequent additions of organic material to the soil increase ped formation (Foth, 1990).

Porosity is the amount of space in soil that can be filled with water or air. Soil structure and texture greatly influence porosity. Pores can be found between and within peds. Coarse soils have low values for porosity resulting from poor aggregation of sand particles (Foth, 1990). Low porosity limits the water holding capacity of soils and allows water to move deeper in the soil profile, moving pesticides and nutrients deeper with every rainfall or irrigation. Finer textured soils are more likely to form aggregates, which increase porosity, and enable more storage of soil water at every soil layer. Additional effective water storage area in a finer textured soil limits the amount of water leaching into the next layer (Jackson et al., 1987).

The size of the pores is often as important as the total amount of pore space in storing soil water. Small pores are called capillaries or micropores. These micropores act as many small pockets holding water and can better withstand the forces of gravity, allowing them to store more soil water. Macropores promote quicker drainage, which may increase a soil's potential to leach contaminants to shallow ground water deposits (Hall, Mumma and Watts, 1991). Macropores can also be caused by decaying roots, worm holes or cracking of the soil during periods of drought (Baker, 1987).

Permeability measures the rate of water infiltration. Permeability rates are a function of porosity and the water potential gradient (to be discussed in the next section). Jackson et al. report clay soils with small pores have permeability rates less than .01 meters a day whereas a coarse sand can range from 10 to 3,000 meters per day.

Although sands have less total pore space than clay or loam soils, water can infiltrate sands quicker. This rapid infiltration of water is due to the presence of more macropores within sands (Foth, 1990). The quick drainage and rapid infiltration of soil water contribute to pesticide leaching. The smaller pores of clay combined with their higher porosity allow them to store more water (Foth, 1990). Clay soils slow water movement and retain a larger portion of infiltrating water within the root zone, reducing the potential of pesticide leaching (Jackson et al., 1987).

The soil's physical properties play a complex role in regulating pesticide movement. Clay particles and organic matter are two principle factors of a soil's ability to bond with most pollutants and prevent them from reaching ground water (Jackson et al., 1987). Even with the most vague generalizations it is not easy to estimate pesticide leaching. Due to the interactions between soil properties, it would not be possible to predict precisely the leaching potential at two different sites without the aid of computer technology.

Soil Water and Hydrology

Soil water can be categorized into three groups: adhesion water, cohesion water and gravitational water (Foth, 1990). Adhesion water is an ultra-thin film surrounding the soil particles, so strongly bonded it can only be removed by oven drying. This adhesion water is even present in airborne dust particles. Cohesion water is the next film of water surrounding the soil particles. This is the water available for crop use. The gravitational water is farthest removed from the soil particles. Gravitational water is not bonded to the soil particles or is bonded very weakly. Generally, the gravitational water is not available for plant use as it is drained from the root zone within a few days of rainfall. If a hardpan or other geological structure exists prohibiting the soil from draining, the soil becomes anaerobic. When the soil becomes anaerobic, the plant eventually dies, thereby losing the opportunity to make use of the gravitational water.

Field capacity is how much cohesion water a soil can store. The water is stored in the small pores and in the film around the particles (Jackson et al., 1987). Field capacity is an important variable in the amount of pesticides reaching ground water. A larger field capacity maintains more water within the root zone, lowering the depth to which water infiltrates for a specific rainfall.

Water movement in the soil is a critical factor in determining the extent of contamination. Soil water moves from areas of high energy to low energy. Movement rates are determined by two factors: driving force and hydraulic conductivity (Jackson et al., 1987).

Driving force is the water potential gradient between two points (Foth, 1990). Foth describes the water potential as "the amount of work needed to move water from a reference pool to another point" (1990). The water potential gradient is then describe as

$$f=\frac{h}{d} \tag{1}$$

where h is the water potential difference between two points and d is the distance between the points.

When a field is at capacity or less, the primary direction of water movement is horizontal, from soil to roots. Limited amounts of soil water move vertically in response to evaporation from the soil surface. However, in saturated soils the primary driving force is gravity, moving the gravitational water downward. Gravity remains the primary force until field capacity has been reached. Significant downward movement only occurs when field capacity is exceeded. When gravitational water has sufficiently drained to reach field capacity, little downward movement takes place. Avoiding saturation increases soils' ability to retain water (along with nutrients or pesticides) in the root zone.

Hydraulic conductivity is the soil's ability to transfer water. Pore size, soil texture and the degree of saturation largely determine hydraulic conductivity. Hydraulic conductivity is dynamic in a field of growing crops. Water use by crops changes the amount of soil water and degree of saturation. During a rainfall event with the soil becoming wetter, the infiltration rate falls (Foth, 1990). The infiltration rates fall due to diminishing hydroconductivity and increasing distance water must travel to dry soil. Falling hydroconductivity can be due to the smaller pores filling with cohesion water, limiting the avenues for gravitational water to drain. The macropores in sandy soil maintain a high hydroconductivity even when saturated. This high hydroconductivity contributes to the potential for these coarse textured soils to leach pesticides (Foth, 1990).

The velocity of water movement is described by

$$V=kf \tag{2}$$

where k is the hydroconductivity and f is the water potential gradient. The rate of water flow is directly related to hydroconductivity and the water potential difference between the two points, but inversely related to the flow distance.

Soil water can affect the microorganisms in the soil and how they biodegrade the pesticides' active ingredients. When the soil becomes saturated, anaerobic conditions prohibit the microorganisms from breaking down pesticides. Extreme temperatures can be responsible for slowed soil organism activity, with more activity taking place at warmer temperatures. Ground water deposits are generally cooler than surface temperatures during the growing season when most pesticides are applied. These cooler temperatures and limited oxygen cause the contaminants that reach the ground water to have slower biological degradation rates than pesticides nearer the surface. The pH level of soil water affects the solubility and breakdown of chemicals present in the soil.

Leaching is influenced by three hydrological processes:

water entry into soil, soil moisture storage and movement of water through the soil. These factors are primarily influenced by the soils's properties. Based on these three factors, the producer's only significant opportunity to control leaching is through controlling the amount of irrigation water applied.

Pesticide Properties

Pesticides entering soil bond to organic matter in the soil, slowing pesticide movement. Desorption is the process whereby pesticides detach from soil particles, as a result of rainfall or irrigation, and easily leach with water (Hornsby, 1991). Some pesticides do not adhere to soil particles but mix with the water held between the soil. Solubility of a pesticide is generally inversely related to its adhesion ability. Partition Coefficients (PC) are measures of how the pesticide mixes between the soil and water. The PC is the ratio of pesticide bonded to the soil to the amount remaining in the soil water (Jackson et al., 1987). Larger values are preferred, indicating a higher proportion adhered to soil and temporarily not available to leach.

A pesticide's half-life is one measure of its persistence in the soil. Generally expressed in days, this is the time required for one-half of the pesticide's active ingredient to decompose. Alternatively, half life can be expressed as the time required for one-half the active ingredient to become inactive, which is less time than required for complete degradation (Hornsby, 1991). In general, if the half-life of a pesticide is less than two weeks the potential for it to reach the ground water is limited (Jackson et al., 1987).

When pesticides are eventually broken down by chemical, physical and biological activity, they are decomposed into metabolites (Jackson et al., 1987). Metabolites can range from harmless to just as toxic as the original compound. The chemical process of pesticide breakdown is governed by hydrolysis and oxidation. Hydrolysis dissolves the pesticide into different molecules. Oxidation is where oxygen reacts with the pesticide, altering molecular makeup. Physical factors that may influence the breakdown of pesticides in some circumstances are sunlight and temperature (Jackson et al., 1987).

Microorganisms tend to break down compounds faster than do purely chemical processes. Biological activity can eventually decompose most pesticides into carbon dioxide, water and other compounds. Microorganisms respond to the addition of new pesticides in their environment. Biological activity can be impacted by temperature, number and type of microorganisms, soil and water pH and the presence of other pesticides that either nourish or poison the soil organisms. Populations will increase in response to new food sources. Increasing population levels of microorganisms have been responsible for reduced performance of previously effective pesticides (Jackson et al., 1987).

Controllable Farm Management Factors

Irrigation Management

Irrigation of crops probably had its beginnings in Mesopotamia over 7,000 years ago. The Egyptians used irrigation 5,000 years ago and the Japanese and Iranians are each thought to have irrigated crops for at least 2,500 years (Foth, 1990; Troeh, Hobbs and Donahue, 1980). Some of these systems are still in use while other irrigation projects have not fared as well.

The environmental consequences of irrigation cannot be ignored (Troeh, Hobbs and Donahue, 1980). Excess irrigation rates contributed to the salinization of many previously irrigated soils in dry climates, rendering them useless. Soil erosion can be compounded by poor irrigation system design. Pesticides and nutrients applied to excessively irrigated lands often reach ground water quicker than those applied to rainfed or moderately irrigated fields (Hillel, 1990).

The producer's management objectives will affect the irrigation rate, timing of water applications and system type. Some management objectives might be maintaining storage capacity, salinity control, maximizing yield, maximizing profit or limiting nutrient or pesticide loss.

Irrigation management has been identified as one of the most under-utilized aspects of farm management (Chesnut, 1991). Research has found that carefully managing irrigation scheduling to coincide with crop needs results in substantial savings in water with increases or minor decreases in net profits (Harris and Mapp, 1980; Bernardo et al., 1987). Excessive water applications may hasten the leaching of pesticides below the root zone. Sites with sandy soils and shallow ground water are more susceptible to pesticide contamination. These sites can obtain economic and environmental benefits from careful irrigation management.

Storage of water in the soil for the crop's use during the growing season is necessary for growth. Allowable depletion of soil water is one of the most important factors in irrigation management. When soil water becomes scarce, the energy potential, mobility and availability of water to plants decreases. Plants using water from more distant and finer soil pores require greater suction which induces wilting. Soil water movement to plants limited to less than the amount required for plant use results in additional wilting (Foth, 1990). By allowing soil water levels to approach allowable depletion, soil water movement is slowed which aids in the control of pesticide movement. The negative aspect of allowing plants to reach wilting is that it often lowers yields for most crops at certain stages of growth (Boote et al., 1982).

Allowable depletion differs for soils, types of crops and the crop's growth stage. Knowing the allowable depletion for a growing crop on a particular soil and the exact soil water status may enable a producer to temporarily suspend an irrigation, capturing the benefit of rainfall that may occur in the interim. Irrigation can be delayed if rain is forecast or applied at a lower rate. After the chance of rain has diminished, a full application can applied (Sholar et al., 1991). When the soil has been irrigated up to storage capacity before any rainfall occurs, part of the recent irrigation will be wasted as water is displaced below the root zone.

Crop yields can be adversely affected either by excess water or drought stress. Producers are believed to base part of their irrigation applications on risk reduction, particularly in the production of high value crops often associated with high input costs (Bernardo, 1988). A crop's high marginal value product might facilitate using high levels of inputs until the marginal cost equals the marginal value product. High rates of irrigation generally result in over applications of water, particularly in the early and late stages of crop growth when crop water usage is low. Heermann et al. consider the use of excess water as an insurance policy to be a poor management tool (1990).

Coarse textured soils dry quickly, putting the crop at risk from dry weather. A producer may doubt a well's capacity to cover the growing crop's moisture needs during a minor short term drought, making over-watering less risky from the producer's standpoint. Conversely, ground water quality can be adversely impacted if saturated soil receives unexpected rain and chemicals are leached beyond the root zone.

Limiting the amount of water applied can be economically and environmentally preferred. Limiting irrigation applications can lower input costs and increase output if the irrigations were previously over-applied. Previous research for the Oklahoma Panhandle region suggests leaching can be reduced with lower irrigation rates used in conjunction with irrigation water conserving technologies which have higher application efficiencies (Sabbagh et al., 1992).

Scheduling is an important component in the proper management of irrigation systems (Heermann et al., 1990). For adequate scheduling the producer needs to know the expected water use by the crop over the next few days and the initial soil water status. Irrigation can be initiated when a certain threshold is reached based upon a fraction of field capacity. Recommendations are to allow a field to reach 50 percent of its field capacity before initiating irrigation. This threshold would allow the use of unforeseen rainfall by keeping some field capacity available for rainfall without limiting production for most crops (Heermann et al., 1990; Sholar et al., 1990). In arid areas with sandy soils having low water storage capacities it is generally not advisable to maintain storage space for rainfall as a production practice. Rather the producer should attempt to maintain soil water near capacity in the root zone for plant use (Heermann et al., 1990). In these regions the entire root zone may only be able to store a few days of crop water needs.

Another irrigation strategy that can help protect ground water is using a series of shallow wells rather than one deep well. This can aid in the protection of ground water by drawing from deposits closest to the surface that have a higher probability of being contaminated (Canter, Knox and Fairchild, 1987). Pumping from deep wells hastens movement of water from the uppermost deposits to the pumping site, along with associated contaminants (Jackson et al., 1987). Figure 5 shows the expected direction of water movement with alternative well depths.

Pesticide Management

Since pesticides are intended to be poisons, these chemicals can be the most harmful contaminants to people, ground water quality or wildlife (Hornsby, 1991). Loss of the pesticide from the target area represents both an economic loss to the producer as lowered efficacy and a potential hazard to the environment (Hornsby, 1991).

Management of pesticides to protect ground water quality may involve the following strategies:

1. The quantity of pesticides applied can be reduced;
2. Precision of application methods can be increased;
3. Applications can be timed to avoid the most environmentally sensitive seasons;
4. Pesticides are selected that have fewer hazards.

Some production systems may allow lowering the amount of pesticide applied by spraying a narrow band over the row (Fawcett, 1987). When large amounts of a pesticide are

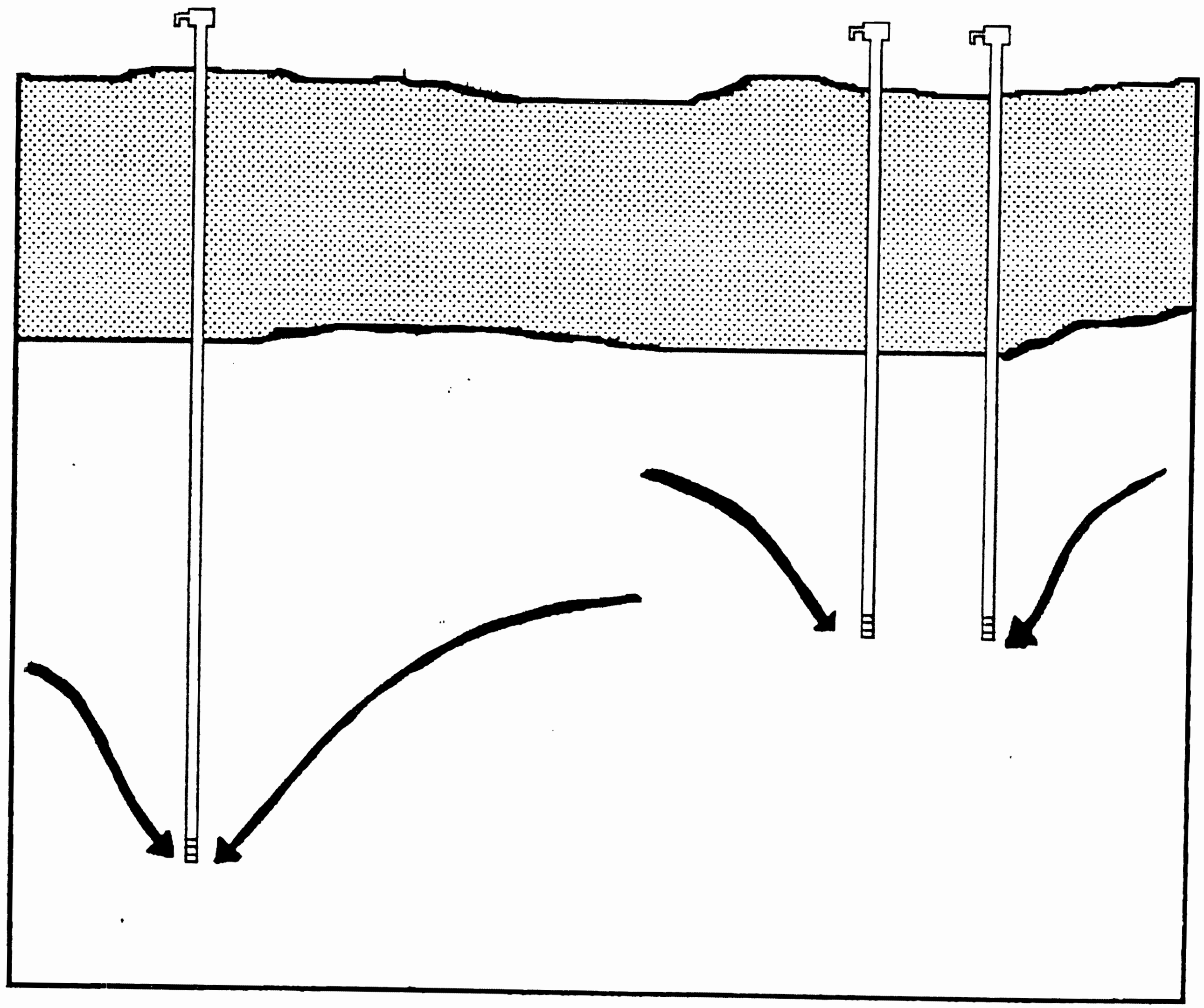

Figure 5. Directional Flow of Ground Water Under Alternative Well Depths

applied the quantity of active ingredient can exceed the soil's holding capacity and the microorganisms' ability to decompose the pesticide. This combination of events overloads the system and leads to ground water contamination. Unknown volumes of spray tanks, improper spray rig calibrations and miscalculations of field size are responsible for many errors in applications.

Scouting services can help reduce the quantity of pesticide applications under some circumstances (Crummett, 1992). Making use of computer models may aid some farmers in reducing the use of foliar sprays on some crops. As one example, meteorological data is used to predict conditions favorable for foliar disease, so crops are sprayed only when conditions make infestations likely (Damicone, 1992).

The amount of pesticide lost from the target site is sensitive to the timing of pesticide applications. Timing and method of application greatly effect volatilization of the pesticides. Leaching and runoff losses come after biological degradation and volatilization in magnitude of pesticide removal from the target site (Glotfelty, 1987). Preemergence herbicides can be lost or lose their effectiveness if applied too far in advance of planting. Rainfall may delay planting or severely erode a finely tilled seedbed without ground cover, carrying away the herbicide with the runoff. Postemergence herbicides can also be wasted if they are applied to target weeds that have passed their susceptible growth stages. Similarly, insecticides applied before a threatening population exists or after unrecoverable damage has occurred provide no economic benefit and present unnecessary environmental risk.

Pesticide properties are a greater concern than the quantities applied (Fawcett, 1987). Pesticides can be selected based upon their chemical properties, and thus their probable environmental threat. The three most readily available measures of environmental risk are biological half-life, Koc and toxicity. Biological half-life is reported in days, with shorter half-lives representing less risk. Small values for biological half-life indicate that soil microorganisms can rapidly degrade the active ingredients into carbon and water.

The Koc is a measure of how well chemicals bond with organic matter found in the soil relative to the proportion found in soil water. Where leaching is the primary concern, high Kocs are preferred[1]. For chemicals with large Koc values, more of the active ingredient remains bonded to the soil and is less mobile, lowering the potential for the chemical to move to ground water.

The toxicity of pesticides can be inferred from HALs and MCLs reported by the US EPA (1990). Lower reported values for MCLs or HALS for pesticides indicate more

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[1]For highly erodible fields large Kocs may not be preferred. Pesticides that bond well with soil particles may be more prone to be carried from the field surface by erosion rather than leaching. In such cases, pesticides that rapidly move beneath the surface may be preferred if surface water is more susceptible to runoff than ground water is to leaching.

carcinogenic compounds. Larger values indicate the substance is relatively less carcinogenic, requiring a larger dose or exposure to induce cancer.

Crop Management

Nationwide, the most widely used method of controlling pests is the use of resistant crop varieties. Resistant varieties can provide economic protection from the target pests without damaging species living nearby. Using resistant cultivars is compatible with other pest management practices. Selection for resistant cultivars has been more successful for defense against plant diseases than insects (Jackson et al., 1987).

Crop rotation historically was the first line of defense against pests. Rotations also provided benefits in soil erosion control, made better use of legumes' ability to fix nitrogen and distributed income and resource use more evenly (Troeh, Hobbs and Donahue, 1980). However, continuous cash crop farming, which allows for more total revenue each year by specializing in the single best locally-adapted cash crop, has become the standard production pattern. With the adoption of mono-crop, chemical intensive agriculture, some of the problems previously controlled by crop rotation are circumvented. Commercial fertilizer and chemical inputs in many cases, have been substituted for crop rotations to maintain high yields and control pests.

Reintroducing widespread crop rotations may provide some ground water protection by reducing requirements for pesticides and additional nutrients. Crop rotations are best used to prevent problems rather than cure ailments. Rotations should be sufficient in length to break the pest cycle by not providing a host species between susceptible crops (Jackson et.al., 1987). Following legumes with deep rooted crops allows the use of nitrogen before it can be leached below the root zone.

Tracking Chemical Movement

Predicting chemical movement can be approached either qualitatively or quantitatively (Hornsby, 1991). A qualitative approach would consist of categorizing the likelihood of chemical movement as high, medium or low, based on chemical characteristics of pesticides, soil properties and environmental factors. An example might be comparing a group of production systems on differing soil types and active ingredients for control of a pest when the objective is to determine which of the alternatives would leach less. This approach would not be appropriate when the precise quantity of active ingredient leaching was important.

For a quantitative approach, complex mathematical equations are required (Hornsby, 1991). Data requirements for the mathematical equations are high (Canter, Knox and Fairchild, 1987). Many models have been developed for estimating pesticide movement through soils (Canter, Knox and Fairchild, 1987; Hornsby et al., 1988). These models use agronomic formulas for calculating many of the dynamic factors in pesticide movement such as crop water use, daily evapotranspiration or field capacity.

Three types of quantitative models are research, management and instructional (Hornsby et al., 1988). Research models require the most computer power, technical knowledge and data. The instructional group makes use of the most simplified formulas available. Instructional models lack the accuracy found in either the research or management models but remain useful for demonstration or rough estimation. The management group tends to be intermediate in the level of technical knowledge and accuracy. Management type models are best adapted for managing on-farm pesticide problems. Although considerable data are required for most models in the management group, the information is obtainable (Hornsby et al., 1988).

The Chemical Movement through Layered Soils (CMLS) model was developed by Nofziger and Hornsby as a management tool (1986). CMLS requires data on the local environment and the chemical properties of the pesticides applied. The soil information required includes number of soil layers, bulk density, organic matter, field capacity, wilting point and depth of each layer. Chemical properties required are half-life and partition coefficient.

CMLS estimates chemical movement within the soil layers in the root zone. An example of the entire soil profile can be seen in Figure 5. Once the chemical has leached through

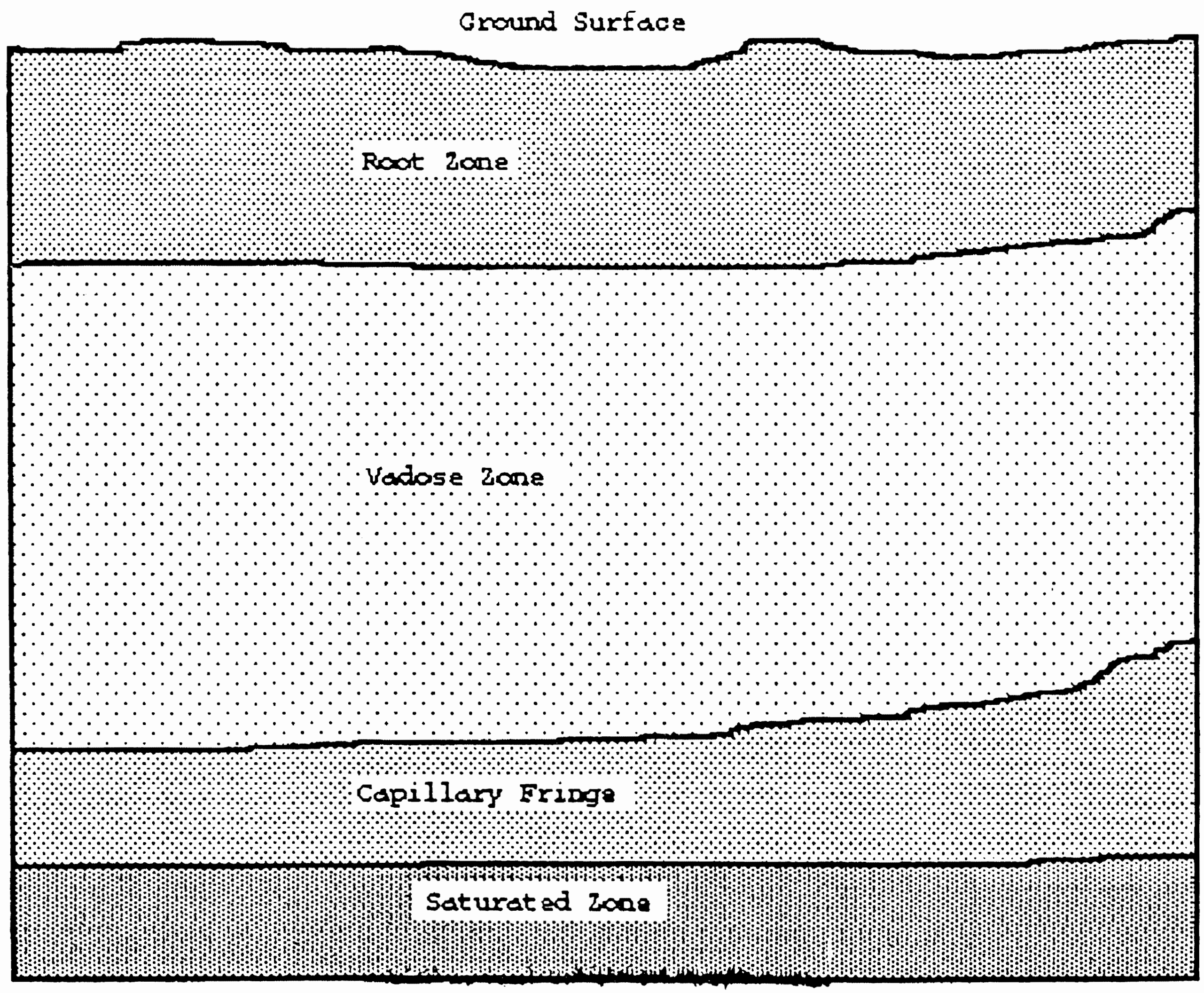

Figure 6. Representative Soil Profile

the top layers of the root zone and into the intermediate vadose zone, the chemical is assumed to reach the ground water deposit. Few opportunities exist for breakdown below the root zone because of decreased microbiological activity, limited oxygen and lower temperatures.

Using a specially altered, unreleased version of CMLS, named CMLS0052, irrigation management coefficients for irrigation efficiency, amount of water applied and length of irrigation season can be included (Chen, 1993). CMLS uses coefficients specific to the crop and field management. Crop root depth and the crop coefficient determine their influence on water movement. The curve number, which reflects tillage methods, is included for determining the rate of infiltration. Probabilistic results are obtained by using a weather generator to produce a large number of possible weather patterns.

CMLS uses the above information to estimate the position of the pesticide within the soil profile. The depth of the pesticide is estimated again with each water infiltrating event, either rainfall or irrigation. Change in depth is a function of the amount of water moving through the soil, soil water content, bulk density and partition coefficient. The fraction of the chemical remaining can be determined as a function of time. Appendix A details the quantitative steps performed by CMLS to estimate leaching parameters.

Modeling Producers' Decisions

There are many possible goals and motivating forces behind farm managers' decisions (Boehlje and Eidman, 1984). Goals of farm managers could be maximization of net returns, increase in net worth, control of a larger business, avoidance of net farm losses, family and community considerations, or retirement targets. Most of these are closely tied to the first goal of maximization of net returns. Positive net returns provide the ability to finance or purchase the other pursuits.

Farm managers, like most businesspeople, are assumed by researchers to be profit maximizers (Boehlje and Eidman, 1984). For farmers to achieve the largest net return possible, they must select the proper enterprises and levels of these enterprises to ensure marginal returns are equated to marginal costs. Even on a small farm the allocation of resources to their highest and best uses rapidly becomes complex, repetitive and highly quantitative.

Maximizing returns over a multiple year time frame is another factor adding to the complexity of farm management. Multiple year impacts should not be ignored. Inclusion of these factors is necessary to better reflect the whole farm situation compared to a short term or single year analysis. Multiple year analysis is necessary to evaluate decisions that impact future time periods but are not typically thought of as investments. Crop rotations are one example of practices that have impacts not easily evaluated within a single year analysis.

To deal with the problems of allocating resources for the whole farm, computer algorithms have been developed which allow complex problems to be solved with math programming. Some of the first applications of math programming were during World War II. Linear programming was used to find optimal allocations of resources and to find least cost shipping routes (Boehlje and Eidman, 1984).

Farm management problems have made use of linear programming (LP) for the last 30 years (Hazell and Norton, 1986). Components of the basic LP are production activities (X_j), resource availabilities (b_i), and technical coefficients (a_{ij}) which relate resource usage by the production activities. For each activity, the expected net return is given by the c_j.

For the a profit maximizer the objective function can be defined as

$$MAX \prod = \sum X_j c_j \tag{3}$$

where X_j is the activity levels for the n activities and the c_j is cost or revenue associated with X_j. The resource constraints take the form

$$\sum X_j a_{ij} \leq b_i, \tag{4}$$

for all i = 1 to m resources. Such that $X_j \geq 0$, for all j = 1 to n activities.

LP solutions also provide shadow prices for the m resources. These values are analogous to marginal values. One method of validating a model is to analyze these marginal values for land. If the marginal value is close to the rental rate for the study area or if the marginal value can be capitalized and approximates the value of regional land prices the researchers can place faith in the model (Hazell and Norton 1986).

There are several assumptions required for LP. They are optimization, fixedness, finiteness, determinism, continuity, homogeneity, additivity and proportionality (Hazell and Norton, 1986). Optimization refers to a correctly specified objective function that can either be minimized or maximized. Fixedness maintains at least one constraint with a non-zero right hand side value. Finiteness refers to a given number of activities and resources so a solution may be obtained. Determinism requires all c_j, a_{ij}, and b_i coefficient to be known constants. Continuity represents continuous production functions where resources can be used and activities produced in fractions such as employing one-half of a tractor or producing one-third of a cow. Homogeneity requires all units of a given resource are of identical quality and have identical responses in production. Additivity and proportionality require linear relationships with constant returns to scale. Determinism and linearity force the production function to appear like the corner of a pyramid (in a two input case), with the expansion path moving along the edge using fixed proportions of the inputs (Doll and Orazem, 1978). A basic assumption is that all activities (X_j) must be non-negative. Methods have been developed for dealing with a portion of these restrictions when they significantly interfere in modeling.

One restrictive assumptions of LP is the requirement for known parameters. Often responses to an input or production practice are not known with certainty. In this case the researcher may want to make assumptions about the distribution of yields. Other times the amount of resource available in an upcoming growing season may not be known with certainty when making the farm plans. An example of this may be when the labor requirements is expressed as a certain number of field days. These available days are a function of the rainfall received in the coming growing season.

Nonlinear programming (NLP) is an expansion of LP that allows for the inclusion of quadratic, stochastic or other special case variables in the model. One type of NLP is chance-constrained programming (CCP) developed by Charnes and Cooper (1959). CCP deals with stochastic variables in the model by selecting the variables within the model whose outcomes are stochastic but have known distributions in a way that will maximize (or minimize) the objective function subject to the constraints that must be met at the given level of probability (Charnes and Cooper, 1959).

CCP uses modifications to the resource constraints to reflect stochastic parameters in probabilistic terms, such as

$$Pr[\sum_j a_{ij}X_j \le b_i] \ge 1-\alpha_i \tag{5}$$

Where Pr is the probability of the left-hand side of the equation (LHS), a_{ij} is the resource usage of resource i by activity j, X_j is the level chosen of activity j, and b_i is the deterministic level of resource i. The right-hand side of the equation gives the safety level required. The allowable failure rate is given by α_i, which is a positive number less than one and generally approaches zero. When α_i is .05 (or 5%) the safety level would be 95%.

To modify this equation into a plausible constraint, the deterministic resource constraint is modified. Recall the deterministic resource constraint, Equation 4. Equation 4 is modified to predict the expected value of Z_i which is the sum of the a_{ij} times the X_j. The sum Z_i is assumed to be a normally distributed random variable, with the mean,

$$E[Z_i] = \sum \overline{a_{ij}} X_j \tag{6}$$

and has a standard deviation

$$\sigma_{zi} = [\sum_j \sum_k X_j X_k covar(a_{ij}, a_{ik})]^{1/2}. \tag{7}$$

Where covar(a_{ij}, a_{ik}) is the covariance between the means a_{ij} and a_{ik} for the resource i. Equation 5 then becomes

$$Pr[Z_i \le b_i] \ge 1-\alpha_i \tag{8}$$

or equivalently,

$$Pr\{(Z_i-E[Z_i])/\sigma_{zi} \le (b_i-E[Z_i])/\sigma_{zi}\} \ge 1-\alpha_i. \tag{9}$$

Dividing $(Z_i - E[Z_i])$ by σ_{iz} generates a standardized normal variable. A constant K_α can be found from the tables for the cumulative normal distribution for the corresponding level of α_i such that,

$$Pr\{(L_i-E[L_i])/\sigma_{zi} \le K_\alpha\} = 1-\alpha_i \tag{10}$$

The final modified chance constraint takes the form,

$$\sum_j \bar{a}_{ij}X_j + K_\alpha[\sum_j \sum_k \sigma_j \sigma_k \varrho_{jk}]^{1/2} \le B_i, \tag{11}$$

The first half of the left-hand side (LHS) is similar to the deterministic resource requirement from the traditional LP model. Since the K_α is positive, the second half of the LHS represents a reduction of allowable resource use from the maximum resource available, B_i (in the deterministic model). This reduction could be viewed as the risk premium charged to insure the chance-constraint is not violated. The constraint can be further modified into an approximately linear constraint if necessary. For a more complete discussion of the transformation from a probabilistic statement to the chance-constraint see Hazell and Norton (1986).

Model Application

The LP and CCP models are applied to the representative farm in Caddo County, Oklahoma. GAMS (General Algebraic Modeling System) is used to solve the LP and CCP models (Brooke, Kendrick and Meeraus, 1988). The LP model establishes the baseline position of the representative farm in terms of discounted returns for the study period and in pesticide leaching under the current farm plan.

Enterprise budgets were used to find baseline farm returns for the production systems. The budgets reflect only the variable costs of production. No fixed costs were included. These budgets were constructed from a combination of input from OSU Extension personnel and standard Enterprise Budgets prepared by the Agricultural Economics Department at OSU. The baseline budgets reflect the current typical production systems and practices employed in the study area. These budgets are specific to alternative chemicals and cropping systems. The linear programming model determined the optimal crop mix given the initial assumption of profit maximization in the absence of environmental constraints.

Prices for the crop yields and deficiency payments were largely taken from USDA estimates for the 1993 crop year program provisions (USDA, ERS, 1993b, 1993c and 1993d). Most of the input costs built into the budget generator were originally obtained in 1990 and in 1991 (Norris, 1991). Since 1993 estimates for crop prices were used, the production costs were inflated to 1993 values by using the index for purchased inputs (USDA, ERS, 1993a).

Making use of GIS (Geographic Information System) technology, representative soils were selected that overlie the principal ground water aquifer in the study area. GIS also was used to determine the extent of the soils that are prone to leach pesticides. GIS has allowed researchers to layer different data sets, integrating the information into a sole research tool (Gregory, 1992; Heatwole et al., 1987).

CMLS estimated contaminant movement through the representative soils. CMLS runs were performed for combinations of soil, crop rotation, irrigation schedule and alternative pesticides. Results of the runs provided the estimates for the mean and standard deviations of leaching.

Chance-constrained programming (CCP) was used to incorporate the stochastic aspects of the environmental constraints into the original LP model. Changes in crops grown and net returns under possible state policy goals can be analyzed with CCP. Chance-constraints were used to introduce alternative levels of safety for ground water protection. The economic impacts of satisfying the constraints were determined. The farm level cost of ground water quality management is the foregone profit under different possible protection policies.

CHAPTER III

A REPRESENTATIVE FARM LINEAR PROGRAMMING MODEL - PROCEDURES AND RESULTS

The Producer Decision Model

A multi-period LP model was used to determine the baseline for a representative farm in Caddo County, Oklahoma. The baseline model was solved for the resource allocation across production systems, maximizing discounted net returns as the objective function. Net returns discount rate was 5% annually, to approximate real returns to agricultural assets over time (Barry, 1980). The selection of the production systems was limited by resource availability. The resource constraints applicable to the LP model were land, irrigation capacity, soil class, farm and purchased labor, and farm program constraints. Leaching was not constrained for the baseline solution, but accounting rows were included to estimate the leaching under the baseline solution. Activities included production, input purchasing and output sales. The technical coefficients inside the matrix included labor, land, crop rotation and base acreage[1] requirements. Also included as technical

[1]Base acreage refers to the amount of land allowable to be planted to the program crops wheat, cotton and grain sorghum.

coefficients were crop yields, government payments and leaching parameters.

Model Activities

The objective of the model is to select the activities that maximize the discounted net returns. The activities include production of crops, purchasing inputs needed for growing the crops and selling of the production. The crops grown are irrigated and dryland peanuts, irrigated and dryland cotton, wheat and grain sorghum.

There are 36 peanut production activities for each of the six years. These systems have combinations of two crop rotations, three soil types, two alternative nematicides and three irrigation levels. The crop rotations are either one or two years between peanut crops. The shorter rotation requires an additional herbicide compared to the long rotation. Three soil types are available having high, intermediate or nominal leaching potentials. The two nematicides have differing leaching potentials and yield impacts. The irrigation levels are dryland, medium and high. The soil types, nematicides and irrigation levels are discussed in following sections.

There are 30 cotton production systems for each year. These include choices for growing cotton on dryland or irrigated land, grown either continuously or in a rotation, and on any of the three soil types. Additionally there are two options for government payment for each of the cotton systems. Half of the systems can generate deficiency payments within the limit placed on the CAB and the others allow growing cotton on the normal flex acres without payments. There is a distinction between irrigated and dryland cotton systems for government participation. In addition to the 24 systems discussed above there are six systems for growing irrigated cotton that could generate deficiency payments at the smaller dryland rate. This allowance is made because there is more irrigated land than base acres established for irrigated cotton. These six systems are either continuous or rotated on any of the three soil types.

Grain sorghum and wheat activities are simpler. The grain sorghum activities number 12 per year. They consist of rotated or continuous, flex or payment acres, on any of the three soil types. There are six activities for wheat harvested for grain. These six activities are all continuously grown wheat on either flex acres or normal payment acres, grown on any of the three soil types. There are also three wheat activities for grazing-out wheat to fulfill government acreage reduction program (ARP) requirements. The three graze-out activities coincide with the three soil types.

All the row crops (peanuts, cotton and grain sorghum) can be grown in any rotation so long as peanuts are not grown in consecutive years on the same field. Cotton and grain sorghum are allowed to be grown either continuously or in a rotation. Peanut systems are designed to allow growing peanuts on a particular plot of land in either a one year out of two year rotation or in a one year out of three year rotation. Yields associated with these rotations are discussed in the following section.

Figure 7 displays the rotation constraint section of the LP matrix that deals with the production of cotton, grain sorghum or peanuts in a one year out of two rotation. The abbreviated activity names are at the top of the matrix. The subscripts on the letters P, C or S refer to the year in which peanuts, cotton or grain sorghum are grown. In the full LP matrix crop production activities are defined by the irrigation schedule used, rotation, soil type, pesticides and the year.

Transfer activities facilitate the flexibility of choosing between the other two crops not grown in the first year, in selecting the crop mix for the coming year. The model recognizes that an acre of land can be devoted to peanuts in year one and can grow either cotton or sorghum in year 2 on that acre. For an acre of peanuts in the first year there are two required transfer activities.

Transfer activities for a given acre are named according to which crop was grown in the first year and which crop it was not devoted to in the first year. For example, TGP1NOC1 would translate to mean an acre grew peanuts in year 1 and did not grow cotton, making it available to grow rotated cotton in year 2. The counterpart to TGP1NOC1 is TGP1NOS1, allowing grain sorghum to be grown in year 2 with the yield benefits of rotation.

There are accounting rows for what is grown and what

	PRODUCTION ACTIVITIES							TRANSFER ACTIVITIES		
	P_1	C_1	S_1	P_2	C_2	S_2		TGP_1NOC_1	TGP_1NOS_1	
GP_1	-1							1	1	≤ 0
GC_1		-1								≤ 0
GS_1			-1							≤ 0
NOP_1				1						≤ 0
NOC_1					1			-1		≤ 0
NOS_1						1			-1	≤ 0
GP_1				-1						≤ 0
GC_1					-1					≤ 0
GS_1						-1				≤ 0

Figure 7. Rotational Constraints for Two Year Systems

is not grown in a given year. The row that accounts for how much land grew peanuts in year one is GP1. The row that accounts for how much land did not grow peanuts in year one is NOP1. All balance rows and transfer activities are replicated for each soil type.

Figure 8 depicts the portion of the LP matrix dealing with the one peanut crop in three years rotations. It is similar to the rotation constraints for the one crop in two years seen in Figure 7. The difference is there is one balance row per soil type, accounting for the production in three seasons. This long-term row is known as LTNOP3, or long-term no peanuts year 3. To start with, every acre of cotton or grain sorghum grown two years previous has the potential to contribute to the one peanut crop in three years rotation. In year 2, every acre grown in peanuts reduces the land potentially available for the long-term rotation. This is because peanuts must always be grown in a rotation with either cotton or grain sorghum. We now know the land for rotation provided in year 1 was partially consumed by the peanuts growing in year 2. Therefore, to grow the long rotation peanuts in year 3 the land must have grown either cotton or grain sorghum in year 1, and must not have grown peanuts in year 2.

The selling activities generate farm revenue by liquidating the production from the optimal crop mix. The implied estimates for market prices from the 1993-1994 farm program provisions are used as market prices throughout the six year model (USDA, ERS, 1993b, 1993c and 1993d). The

PRODUCTION ACTIVITIES

	P_1	C_1	S_1	P_2	C_2	S_2	P_3	C_3	S_3	LTP_3	P_4	C_4	S_4	LTP_4	LTP_5	
$LTNOP_1$		-1	-1	1						1						≤ 0
$LTNOP_2$					-1	-1	1							1		≤ 0
$LTNOP_3$								-1	-1		1				1	≤ 0

Figure 8. Rotational Constraints for Three Year Systems

implied estimate for market prices for the crops can be found by subtracting the estimated deficiency payments from the target prices. Implied crop prices are \$2.95/bu for wheat, \$.5235/lb for cotton and \$1.91/bu for grain sorghum. The prices used for peanuts and cotton seed are the ten year averages of prices received by farmers in the state (Oklahoma Department of Agriculture, 1982-1991). The prices are \$.289/lb. for quota peanuts and \$4.95/cwt. for cotton seed. The price for peanuts produced above the producer's quota were priced at \$.056/lb. or 19.42% of the quota price (USDA, ASCS, 1992b).

Production Costs

Production costs include charges for seed, tillage, fertilizer, pesticides and hauling harvested crops. Additionally, peanut production systems include are charged for scouting services, aerially applied fungicides and peanut cleaning charges for certain soils. Table 4 shows costs of production for the peanut systems.

Labor is the only purchased input not accounted in the budgets. Off-farm labor purchasing activities are included separately to allow for demands on the labor supply above operator labor if needed by the optimal crop mix. No opportunity cost is charged for using the operator's labor. This means profits are returns to land, operator labor and management. The wage rate charged for off-farm labor is \$5.00/hour. Appendix B has a detailed discussion of production costs for each system.

TABLE 4

ANNUAL PEANUT PRODUCTION COSTS

Nematicide	Irrigation Level	Soil	2 Year Rotation ($/acre)	3 Year Rotation ($/acre)
aldicarb	high	1	376.13	368.09
		2	377.82	370.07
		3	394.24	389.34
aldicarb	medium	1	355.67	347.63
		2	357.13	349.61
		3	373.16	368.27
aldicarb	dryland	1	264.03	252.85
		2	265.27	254.22
		3	276.60	266.68
fenamiphos	high	1	378.55	370.32
		2	379.57	372.19
		3	395.60	390.33
fenamiphos	medium	1	358.09	349.91
		2	359.67	351.72
		3	374.53	369.26
fenamiphos	dryland	1	266.78	255.52
		2	268.05	256.82
		3	278.59	268.54

The production costs for the cotton and grain sorghum differ only by the rotation and soil type. The rotations are either continuous or a two year rotation. Wheat production costs only differ by soil type and the intended use of the wheat. Wheat is grown continuously and harvested for grain or grazed-out to satisfy acreage reduction requirements. Table 5 shows the production costs for the cotton, grain sorghum and wheat. The production costs differ by soil type as hauling charges are a function of the yields. More productive soils have slightly higher production costs but are more than offset by the revenue from increased yields.

Crop Yields

Crop yields are influenced by the crop rotation, soil type, irrigation level and any chemical applications. The crop yields in the LP matrix are long-run expected averages and are not impacted within the model by annual fluctuations in weather conditions. Ten year average yields for Caddo County were obtained from the Oklahoma Agricultural Statistics as a starting point (Okla. Dept. of Ag, 1982-91). These base yields were 2983 lbs, irrigated peanuts; 1962 lbs dryland peanuts; 466 lbs, irrigated cotton; 283 lbs, dryland cotton; 39.5 bu.s, grain sorghum; and 34.5 bu.s, wheat. Tables from the County Soil Survey provided yield estimates by crop and soil type (USDA, SCS, 1973). The soils were grouped by the SCS soil leaching potential categories. Weighted averages for yields were determined for each soil type relative to the extent of their respective acreage within the county. Yield ratios were determined between the

TABLE 5

ANNUAL COTTON, GRAIN SORGHUM AND WHEAT PRODUCTION COSTS

Crop	Soil Type	Crop Grown Continuously ($/acre)	Crop Grown in a Rotation ($/acre)
Cotton			
Irrigated	1	92.99	93.50
	2	93.77	94.45
	3	93.38	93.97
Dryland	1	62.91	63.24
	2	63.49	63.93
	3	63.18	63.54
Grain Sorghum	1	44.39	44.68
	2	45.00	45.38
	3	44.60	44.92
Wheat			
For Grain	1	50.72	
	2	52.36	
	3	51.60	
Graze-out	1	46.53	
	2	46.53	
	3	46.53	

soil group yields for each of the crops. The ten year averages were assumed to represent the moderate leaching soil group. This group was the most prevalent within the county. The yields for the remaining two soils were determined by using the yield ratios and adjusting upward or downward depending upon the soil and crop grown.

The next step was to determine the crop yield and crop rotation interactions. Current research that isolates yield impacts due to crop rotations is rare. Peanut rotations help to use fertilizer efficiently and break the pest cycles. Peanuts are yield-sensitive to the crop rotation, being most impacted by the crop grown in the immediately preceding season (Henning, Allison and Tripp, 1982). The most reliable estimates of rotational effects on peanut yields come from Georgia (Sholar, 1992). This data provides estimates for yield increases under both irrigated and dryland conditions. For dryland peanuts the yield increase for going to the three year rotation is 10% and in irrigated peanuts the increase is 11% over the two year rotation (Davidson and Lamb, undated). Yields were also adjusted for the high irrigation level. Peanut yields plateau after the enough water has been supplied to fulfill the biological maximum (Boote et al., 1982). It was assumed the medium irrigation level nearly reached this plateau. Thus, the high irrigation level was determined to produce 100 lbs more than the similar medium irrigation systems. Discussion on how the irrigation levels were selected can be found in Appendix B.

Rotational effects on grain sorghum also were seldom reported. A Nebraska study found slight increases in yield for grain sorghum grown following a legume (Peterson and Varvel, 1989). Peterson and Varvel report continuous grain sorghum yielded 87% of the rotated systems. In Louisiana researchers also found minor yield improvements for rotated grain sorghum. There continuous systems yielded from 84.6% to 93.7% of rotated systems (Bouquet, Walker and Coco, 1984; Bouquet and Walker, 1983). The 87% value was used for this study.

Cotton lint yields were found to be highly responsive to crop rotations (Kirkpatrick and Sasser, 1984; Lacewell et al., 1989; and Greenhagen et al., 1991). There was a large range of impacts reported in these studies. An Oklahoma extension publication that reported dryland plots out-yielding irrigated cotton in Grady County, Oklahoma was one example of the yield impact available from crop rotation. The yield difference was believed to be from the dryland plots being in a rotation, whereas the irrigated plots were cotton grown continuously (Greenhagen, 1992). Kirkpatrick and Sasser found yield increases up to 29% from a three year rotation and 28% in a two year rotation over continuously grown cotton. Lacewell et al. found a 23% increase in lint yield for dryland cotton when in a two year rotation over continuously grown dryland cotton. Impacts from Lacewell et al. were used as conservative estimates and viewed as the most reliable and reflective of Caddo County. Cotton seed yields were derived as a function of lint yield for the production system[2].

Table 6 shows the yields of irrigated and dryland

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[2]Oklahoma cotton variety tests report the percent lint yield from seed cotton on average is 39% meaning the seed was 61% of the raw seed cotton (Greenhagen et al., 1991)

TABLE 6

IRRIGATED AND DRYLAND PEANUTS YIELDS

Nematicide	Irrigation Level	Soil[a] Type	2 Year Rotation (lbs/ac)	3 Year Rotation (lbs/ac)
aldicarb	high	1	2783.7	3266.8
		2	3038.0	3566.8
		3	2870.9	3369.6
aldicarb	medium	1	2683.7	3166.8
		2	2938.0	3466.8
		3	2770.9	3269.6
aldicarb	dryland	1	1773.7	1951.1
		2	1962.0	2158.2
		3	1911.0	2102.1
fenamiphos	high	1	2622.7	3076.8
		2	2861.7	3358.8
		3	2704.6	3173.5
fenamiphos	medium	1	2522.7	2976.8
		2	2761.7	3258.8
		3	2604.6	3073.5
fenamiphos	dryland	1	1667.3	1834.0
		2	1844.3	2028.7
		3	1796.3	1976.0

[a]Soil 1 is the Dougherty-Eufaula loamy fine sand, Soil 2 is the Pond Creek fine sandy loam and Soil 3 is the Reinach silty loam.

peanuts used in this study. Table 7 has the yields used in this study for cotton, grain sorghum and wheat. Wheat yields are only adjusted for soil type. Wheat is always grown continuously in this study so rotation adjustments do not apply. The yields used in this study are expected results for an extended period. Extension experts believe yield differences between years to be as great or greater than the impacts from crop rotation (Banks, 1992)

TABLE 7

COTTON, GRAIN SORGHUM AND WHEAT YIELDS

Crop	Soil Type	Crop Grown Continuously ($/acre)	Crop Grown in Rotation ($/acre)
Wheat (bu)	1	26.7	
	2	41.3	
	3	34.5	
Sorghum (bu)	1	26.1	30.0
	2	34.4	39.5
	3	28.9	33.2
Cotton lint (lb.s)			
Irrigated	1	322.3	396.4
	2	436.7	537.2
	3	378.9	466.0
Dryland	1	194.3	239.0
	2	276.7	340.3
	3	230.1	283.0

Model Constraints

Land Availability. Farm size was determined using the 1987 Census of Agriculture (US Department of Commerce, 1989). The average size reported for the county's farms was 469 acres in 1987, up from 430 acres in 1982. Estimates were also reported on the acres harvested for major field crops. For farms growing grain sorghum for grain or seed, the average acreage harvested was approximately 40 acres. Average harvested acres for wheat was 161. The cotton harvested averaged 65 acres per farm. On farms growing peanuts the average harvested acreage was 85 acres. The summation of the harvested crops equals 351 acres. Acreage reduction requirements[3] on applicable program crops would indicate more tillable land was available than the average 351 acres harvested in that year. These provisions indicate at least 400 acres of cropland were available on the typical farm and 400 acres was selected as the available cropland for the representative farm. The difference between the 400 acres of cropland and the reported average size of 469 acres can be accounted for by pasture land, farm buildings, roadways and other idle land.

After establishing the 400 acres of cropland, the land was allocated between soil groups. The SCS has developed

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[3]The acreage reduction program in 1987 required diversion of some land from crop production as a condition for deficiency payment eligibility. These set aside requirements were 37.93 percent for wheat, 33.33 percent for cotton and 20 percent for grain sorghum (USDA, ASCS, 1987a, 1987b and 1987c).

soil groupings for pesticide leaching potential for almost all counties (USDA,SCS, 1988). The county's soils were grouped as potentially high, medium and low leachers using the SCS tables. Using the GIS system, the proportion of cropland belonging to each group was estimated. These factors were multiplied by the base 400 acres of cropland to get the appropriate parameters to reflect the resources available to the representative farm.

These soils were further subdivided as irrigated or dryland. It was assumed the producer had two 1/4 mile center pivot sprinkler irrigation systems. When these systems are placed on a one-quarter section (160 acres) farm they can technically irrigate 120 acres each. However, local well capacity and crop rotation concerns often limit irrigation in one season to one half the area possibly covered by the center pivots[4]. Therefore two sprinkler systems were assumed to irrigate, together, a maximum of 120 acres each year. Final land allocation is shown in Table 8.

Representative soils were selected for each of the leaching potential groups. For the high leaching potential, group 1, the Dougherty-Eufaula soil was selected. The Dougherty series are members of the loamy, mixed, thermic family and the Alfisols order. The Eufaula series belongs to the sandy, siliceous family and Alfisols order. The Dougherty-Eufaula mapping unit is made up of loamy fine

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[4]Irrigated peanuts are often followed by dryland cotton in Caddo County, reducing usage of the pivot to one-half the circle.

sands on uplands. The Pond Creek series is representative of the intermediate leachers, group 2. The family of the Pond Creek series is fine-silty, mixed, thermic and the order is Mollisols. The Pond Creek series is made up of fine sandy loams and silty loams. Rienach is the series selected to represent the nominal leaching potential group 3. Coarse-silty, mixed, thermic is the family of the Reinach series and the order is Mollisols. These Reinach soils are silt loams (USDA,SCS, 1973).

TABLE 8

SOIL TYPE LAND AVAILABILITY FOR THE REPRESENTATIVE FARM

Soil Type	Irrigated (acres)	Dryland (acres)	Total (acres)
Dougherty-Eufaula	48.0	112.0	160
Pond Creek	43.2	100.8	144
Rienach	28.8	67.2	96
Total	120.00	280.00	400.00

Labor Requirements and Availability. Since this study includes only crop growing activities and no livestock activities, labor constraints reflect time available for field work. Labor resource constraints are based on the method developed by Reinschmiedt to estimate the probabilistic number of days available for field work (1973). Using the approach of Epplin et al., the 80 percent likelihood of available days was chosen for determining the labor supply (1983). Reinschmiedt's procedure determined feasible field work days as a function of rainfall patterns, limiting field work on days of actual rainfall and the following days until the soil has sufficiently dried. Daylight hours were obtained from Myers (1982).

The total hours of available labor by month were assumed to be the product of feasible days available for field work and the average daylight hours for that month. Table 9 shows the labor availability for each month. These expected monthly totals were used for all years of the analysis. This constrained farm labor only by rainfall and daylight and did not attempt to estimate the farmer's willingness to work[5]. The representative farm was assumed to be operated by a sole producer and the labor supply reflected that.

Machinery labor was the major constituent of required labor by the enterprises, reflecting tillage, planting and cultivation of the crops. Crop budgets include charges for custom hauling of the grain crops and the peanuts after harvest (Jobes and Kletke, 1991). No farm labor was required for hauling harvested crops.

Irrigated crops required additional labor for irrigation. Labor requirements for irrigation were obtained from the budget generator (Norris, 1989). Irrigation on

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[5]The daylight hours per month ranged from 10 to 14.5. The full use of the daylight hours was assumed possible if required by the optimal crop.

rainy days or on days when the soil is too wet for field work would be irrational. Forcing irrigation labor within the available field work days appears realistic and requires irrigation labor use to fall within the limited supply available.

TABLE 9

MONTHLY AVAILABLE FIELD WORK HOURS

Month	Average Days Available	Average Hours Daylight	Total Hours Available
January	27.25	10.08	274.68
February	23.50	10.92	256.62
March	26.00	11.97	311.22
April	22.50	13.29	299.03
May	19.00	14.03	266.57
June	22.00	14.51	319.22
July	25.50	14.27	363.89
August	25.50	14.26	363.63
September	21.50	12.40	266.60
October	22.50	11.29	254.02
November	25.25	10.32	260.58
December	27.00	10.14	273.78

The labor requirements for the crops were determined within the budgeting spreadsheet according to the tillage, planting, harvesting operations and any irrigation. Table 10 and Table 11 show the monthly labor requirements for the crops. Table 10 shows labor required for the different

TABLE 10

MONTHLY LABOR REQUIREMENTS FOR PEANUTS ACCORDING TO IRRIGATION SYSTEM

	3 Farmer-Applied Herbicides			2 Farmer-Applied Herbicides		
Month	high (hours)	medium (hours)	dryland (hours)	high (hours)	medium (hours)	dryland (hours)
March	.330	.330	.330	.330	.330	.330
April	.260	.260	.260	.260	.260	.260
May	.580	.580	.580	.510	.510	.510
June	.412	.302	.190	.412	.302	.190
July	.448	.336	.120	.448	.336	.120
August	.448	.336	0	.448	.336	0
September	.448	.224	0	.448	.224	0
October	1.532	1.532	1.420	1.532	1.532	1.420

TABLE 11

MONTHLY LABOR REQUIREMENTS FOR COTTON, GRAIN SORGHUM, WHEAT, AND WHEAT GRAZE-OUT

Month	Irrigated Cotton (hrs/month)	Dryland Cotton (hrs/month)	Grain Sorghum (hrs/month)	Wheat for Grain (hrs/month)	Wheat for Graze-out (hrs/month)
February	.11	.11	0	.10	.10
March	.33	.33	.35	0	0
April	.15	.15	.21	0	0
May	.44	.44	.08	0	0
June	.24	.24	.37	.22	0
July	.22	0	.12	.15	.15
August	.22	0	0	.49	.49
September	0	0	0	.17	.17
November	1.21	1.21	.22	0	0

chemical and irrigation scenarios for peanuts. Table 11 contains the labor required for cotton, wheat and grain sorghum. The labor requirements for crops are the same across all soil types.

Farm Program Constraints and Resources. The farm was assumed to participate in the farm programs available for wheat, cotton and grain sorghum. The farmer is entitled to deficiency payments for some crops by agreeing not to harvest program crops from a portion of the farm. Per acre deficiency payments are calculated by multiplying the difference between the target price and the season average price by the program yield. The target prices are held constant for the five years covered by the 1990 Farm Bill (Sanders and Anderson, 1992; Sanders, Anderson and Sahs, 1992). Estimated deficiency payments would vary according to the season average market price. Target prices and estimated deficiency payments have been published for the 1993-1994 crop year by the USDA, ERS (1993b, 1993c and 1993d). These projections are used for all years in the model.

The representative farm's proven yields and base acreages are shown in Table 12. In the past, the program yields were a running average of past years' program yields. Under the provisions of the Food, Agriculture, Conservation and Trade Act of 1990, crop payment yields are frozen at the 1990 payment level for the years 1991 through 1995 (Sanders and Anderson, 1991). The program yields selected for this study were the 10 year average crop yields from the county (Oklahoma Department of Agriculture, 1982-1991)[6]. Another provision prohibits irrigated yields from being established for acreage that did not have irrigated yields prior to 1986 (USDA,ASCS, 1992a). The Crop Acreage Base (CAB) is the five year running average for wheat and feed grain crops and the three year average for cotton of planted or considered planted acres (USDA,ASCS, 1992a)[7]. The acres selected for the base acreage were approximately the harvested acreage from the 1987 survey (U.S. Department of Commerce).

TABLE 12

PROGRAM YIELDS AND BASE ACREAGE

Crop	Proven Yield	Base Acreage
Irrigated Cotton (lbs lint)	466	19.5
Dryland Cotton (lbs lint)	283	45.5
Grain Sorghum (bu.s)	39.5	40
Wheat (bu.s)	34.5	160

Program provisions for wheat, cotton and grain sorghum during the 1993-1994 crop year are presented in Table 13.

[6]Program yields tend to be less then the actual yield. The difference is because of the increasing yields over time from technological advances. However, the difference here was not considered substantial enough to otherwise interfere with the results of the study.

[7]If the CABs for a representative farm are fully utilized each year for all crops, the historical averages for CABs will be effectively held constant over the entire period.

Maximum payment acres for all crops are no more than 85 percent of the proven CAB. This reflects the mandatory 15 percent normal flex which is always non-payment acres. The optional flex acres are set at 10 percent. Producers can grow a crop other than the program crop on the optional flex acreage and forego the deficiency payment on that 10 percent of the CAB.

TABLE 13

1993-1994 FARM PROGRAM PROVISIONS

	Wheat (bu.)	Cotton (lb.s)	Sorghum (bu.)
Target Price ($)	4.00	.729	2.61
Deficiency Payment ($)	1.05	.2055	.70
Implied Market Price ($)	2.95	.5235	1.91
Acreage Reduction Program (%)	0	7.5	5
Maximum Payment Acres (%)	85	77.5	80

All the budgets were constructed on a per acre basis. In contrast, government programs allow only a percentage of the CAB to be eligible for deficiency payments. Therefore, eligibility was constrained to the maximum payment percentage of each program crop's CAB. For the farm's 40 CAB of sorghum, deficiency payments would be paid on 32 acres, which is the maximum payment percentage for grain sorghum multiplied by the CAB (.80 X 40 = 32). This type of constraint allows the producer to grow and harvest the maximum possible acres with the benefit of deficiency payments while leaving the production technical coefficients on a per acre basis.

Under this design, the deficiency payments generated for each harvested acre are the product of program yield and estimated deficiency payment. Again using grain sorghum as an example 39.5 bu x $.70/bu = $27.65. The $27.65 would only be paid on the maximum payment acres. In the representative farm case of grain sorghum that would mean 32 acres eligible for the $27.65 of the total 40 acres CAB.

The acreage reduction program (ARP) is in effect for cotton and grain sorghum. The percentages are 7.5 for cotton and 5 for grain sorghum. To meet the ground cover requirements, graze-out wheat is grown on the ARP land (Sanders, Anderson and Sahs, 1992). This practice is common in the area. With the high ARP requirements in 1987, nearly 30% of the total cropland was used for pasture or grazing (US Department of Commerce, 1989).

In addition to these other farm programs, the farm was assumed to have 333,000 pounds of peanut quota. Judging from the available land and CAB for the program crops it was estimated the farm would produce approximately 120 acres of peanuts in the baseline solution. Of the 120 acres, 80% were assumed to be irrigated and 20% dryland. Using the 10 year average yields for the county, a weighted average was determined. Multiplying the weighted average by the 120 acres was roughly 330,000 pounds. The peanut program sets a support price for quota peanuts. Peanuts grown beyond the quota level must be sold as additional peanuts at a severely reduced price. The quota peanut price used is $.289 per lb. Additionals are valued at 19.42% of the quota price (USDA, ASCS, 1992b).

The Chemical Leaching Model

CMLS was used to determine the leaching that could be expected under the production systems. The CMLS model requires data on soil characteristics, chemical properties and irrigation coefficients while incorporating its own weather generator. Allowing the model to run for each scenario many times created a data set that can be transformed into probabilistic leaching parameters.

The study focused on the pesticides commonly used in producing peanuts. The three peanut pesticides considered were aldicarb, fenamiphos and metolachlor. HAL's for the pesticides were obtained from EPA reports (1990a). Values for the pesticides' Koc and half-life were obtained from the AgChems data sets (Nofziger, 1992). Aldicarb and fenamiphos are alternative nematicides applied at planting. Aldicarb is the nematicide with the higher potential to leach. Aldicarb's K_{oc} is smaller and its half-life is longer than that of fenamiphos. Metolachlor is an early-season, post-emergence herbicide applied after the peanut seedlings have broken through the ground. The alternative to metolachlor is a longer crop rotation that more adequately breaks the pest cycle so that the additional herbicide is no longer required. The pesticides' properties can be found in Table

14.

TABLE 14

CHEMICAL PROPERTIES

Chemical	HAL (ppb)	Koc	Half-life (days)
aldicarb	10	20	30
fenamiphos	2	200	20
metolachlor	100	200	20

Three anchor soils were selected from the SCS's leaching potential groupings based upon their predominance in the county (USDA,SCS, 1988). These soils were the Dougherty-Eufaula loamy fine sand, Pond Creek fine sandy loam, and Reinach silty loam. For each of these three soils, data were obtained on number of soil layers and depth, bulk density, organic carbon, field capacity, wilting point and runoff curve number (Nofziger, 1992).

The runoff curve number for each soil was determined from the SCS handbook (USDA,SCS, 1972). The curve number is a measure of a soil's permeability. The curve number is a function of the soil's hydrological group, field cover type, crop tillage practices and the hydrological condition. The high and medium leaching potential soils belong to the hydrological group A and the low potential leacher was a member of the group B (USDA,SCS, 1973). The crop cover was chosen to be row crops, reflecting peanuts as well as the types of crops traditionally grown in rotation with peanuts. Straight rows were assumed. The hydrological condition of the soils was chosen as good. This information resulted in runoff curve numbers for the high and medium leachers of 67 and the low leacher at 78. The difference was due to the hydrological grouping. Table 15 shows the soils' characteristics.

CMLS 0052 allows the use of automatic irrigation. The model would irrigate the soil only as warranted, determined by the information given. Root depth, crop coefficient, field capacity (FC) and the threshold fraction of field capacity were the important deciding factors which determine when to irrigate. Maximum root depth was set at .6 meters (Roth, Crow, and Mahoney; 1982). The crop coefficient selected was .70. Values for FC were available from the specific soil data (Nofziger, 1992). The threshold level of FC used was dependant upon the irrigation scenario used. The values selected were .8 for the high irrigation level and .5 for the medium irrigation level.

A value of .5 indicates the model will begin to irrigate when 50% of the field capacity water has been used. The high irrigation level was selected to represent the response of risk averse producers. These producers respond to imperfect weather information and limited irrigation capacity by beginning to irrigate when only 20 percent of the FC has been used (80 percent of the FC remains available even when the next irrigation is initiated). Irrigating when 75% of the FC remains will allow the peanut crop to fulfill its biological maximum if no other factors are limiting (Boote and Ketring, 1990). The high rate of

TABLE 15

SOILS' PROPERTIES

Soil Type	Layer Number	Bulk Density	Organic Carbon	Field Capacity	Wilting Point	Hydro. Group	Curve Number	Top Depth	Bottom Depth
1	1	1.43	.3	21	4	A	67	0.000	.686
	2	1.6	.0	28	9	A	67	.686	.991
	3	1.6	.0	28	9	A	67	.991	1.549
	4	1.6	.0	28	9	A	67	1.549	1.829
2	1	1.45	.8	29	9	A	67	0.000	.330
	2	1.55	.0	40	26	A	67	.330	1.676
3	1	1.48	.8	40	19	B	78	0.000	.813
	2	1.48	.0	37	17	B	78	.813	1.829

irrigation can be observed occasionally in the study area, but would be more typical of vegetable or other high value crops (Kizer, 1992). The medium irrigation level is the accepted rule recommended by agronomists that will generally not limit peanut yields (Boote and Ketring, 1990; Hillel, 1990; Sholar et al., 1992).

The irrigation period was set to reflect a typical irrigation season. After the peanuts reached about 45 days of age, the model was to begin irrigating when necessary. Water needs for crop growth and maturation should normally not require irrigation after the peanuts reach 120 days, which approaches the harvest date (Sholar et al., 1992). This resulted in a scheduled irrigation period starting on July 1 and lasting until September 30. This would encompass all normal irrigation periods. Table 16 contains the information necessary for the automatic irrigation routine.

Nine scenarios representing the combinations of the three irrigation levels (high, medium or none) on three soil types were modeled for each of the pesticides. Recall that peanuts may not be grow consecutively. A field growing peanuts in year 1 could not grow peanuts in year 2. When pesticides were applied to peanuts in year 1 and a subsequent peanut crop was irrigated on that field in either years 3 or 4 there were no statistical differences in the leaching. Similarly, there were no differences in the estimated pesticide leaching under dryland conditions as long as high levels of irrigation did not follow in the year

TABLE 16

AUTOMATIC IRRIGATION SCHEDULING INFORMATION

Characteristic	Value
Beginning Julian Date	182
Ending Julian Date	273
Maximum Root Depth (meters)	.6
Crop Coefficient	.7
Threshold of Field Capacity	
(medium irrigation)	.5
(high irrigation)	.8
Minimum Amount of Water Applied (millimeters)	50

after the peanut pesticides were first applied[8]. The results from 1,000 20-year simulations were compiled. The 1000 runs' results were used to calculate means and standard deviations for relative amounts of active ingredients reaching below the root zone.

The simulations were set to run for 20 year periods. It was assumed that all of the active ingredient reaching the bottom of the root zone within the 20 year simulation eventually reached the ground water. The pounds of active ingredient reaching the ground water were determined by multiplying relative amounts remaining by the amount applied per acre. The reported amount of active ingredient reaching

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[8]Although irrigated cotton is present in the peanut producing area, it is not managed or irrigated intensively as in other areas in the southwest (Banks, 1992). Limited irrigation that did not exceed crop needs or the soil's field capacity would not contribute to pesticide leaching.

the ground water does not necessarily reach the ground water in the year applied. CMLS simulates blocks of active ingredients moving through the soil layers according to when the pesticide was applied. Several of these blocks may be spread throughout the soil profile in any period but only one block should be reaching the ground water in any period. Because of this property of CMLS, constraints on ground water quality which are based on CMLS results constrain eventual impacts of pesticide leaching. The impacts are not necessarily occurring in the year the pesticide is applied.

CMLS Results

The CMLS output of interest is the relative amount of active ingredient (ai) reaching the bottom of the root zone. The results were approximately normally distributed. At high levels of irrigation on high leaching soils the distributions appeared normally distributed. Results for the dryland systems on the soils with the lowest potential to leach had several observations at zero remaining ai. For these scenarios, means and standard deviations for censored (lower limit of zero) distributions were calculated. Although the distributions for lower leaching systems did not appear as normally distributed, censored normal distributions were assumed.[9]

The unadjusted and the adjusted means and standard

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[9]Future research which tests the distribution of the censored results should determine the impact of the normality assumption on the study's results.

deviations for the relative amount of active ingredient remaining are all given in Appendix C. Tables 17 and 18 show the adjusted expected pounds of active ingredient reaching the ground water and the standard deviation of the amount of pesticide leaching.

TABLE 17

ADJUSTED MEANS OF ACTIVE INGREDIENT REACHING THE GROUND WATER

Soil Type	Irrigation Level	aldicarb (lb/acre)	fenamiphos (.001 lb/a)	metolachlor (.001 lb/a)
1	high	.09744	.01238	.01241
	medium	.01702	.01148	.01153
	dryland	.00495	.00078	.00078
2	high	.02286	.00754	.00488
	medium	.00370	.00074	.00063
	dryland	.00048	0	0
3	high	.00080	0	0
	medium	.00018	0	0
	dryland	.00001	0	0

TABLE 18

ADJUSTED STANDARD DEVIATIONS

Soil Type	Irrigation Level	aldicarb (lb/acre)	fenamiphos (.001 lb/a)	metolachlor (.001 lb/a)
1	high	.0511	.000095	.000094
	medium	.0266	.000090	.000089
	dryland	.0114	.000011	.000011
2	high	.0300	.000058	.000045
	medium	.0102	.000012	.000011
	dryland	.0024	0	0
3	high	.0037	0	0
	medium	.0011	0	0
	dryland	.0003	0	0

Baseline Results

The baseline results show the representative farmer's decisions in the absence of any restrictions based on water quality. Results from the baseline were representative of activities in the study area. The marginal values for dryland in the model closely reflect rental rates in the area. A survey reports the average rate at $25.46 and a range of $10-$50 (Doye and Kletke, 1991). Thirteen of the 18 marginal values (72%) for dryland in the solution were between $12.51 and $54.93.

Acreage allocation by crop is given in Table 19 for years 1 and 6. The results for years 2,3,4 and 5 were exact

TABLE 19

ACREAGE ALLOCATION

Year	Soil	Irr. Peanuts	Dryland Peanuts	Irr. Cotton	Dry. Cotton	Grain Sorghum	Wheat-Grain	Wheat -ARP	Total
1	1	48.0000			20.3750	32.000	52.75	6.875	160.00
	2	43.2000			43.2000		57.60	.000	144.00
	3	13.6875	15.1125	15.1125	13.6875		38.40	.000	96.00
	Total	104.8875	15.1125	15.1125	77.2625	32.000	148.75	6.875	400.00
6	1	48.0000	4.375		20.3750	27.625	52.75	6.875	160.00
	2	43.2000			43.2000		57.60	.000	144.00
	3	6.2147	22.5853	22.5853	6.2147		38.40	.000	96.00
	Total	97.4147	26.9603	22.5853	69.7897	27.625	148.75	6.875	400.00

duplicates of years 1. The baseline had different rotations for the soil types. On the Pond Creek land (soil 2) the rotation was fairly simple, irrigated peanuts followed by dryland cotton. Each year there would be 43.2 acres of irrigated peanuts and the same amount of dryland cotton. The following year the field that grew peanuts would grow cotton and vice versa. Figure 9 displays this rotation. Moving down the column is the same field in the next year. This same pattern is repeated for years 3, 4, 5 and 6.

Irrigated Peanuts 43.2 acres Year 1	Dryland Cotton 43.2 acres Year 1
Dryland Cotton 43.2 acres Year 2	Irrigated Peanuts 43.2 acres Year 2

Figure 9. Crop Rotation for Soil 2

The crops grown on the Reinach soil were an irrigated cotton-dryland peanut and an irrigated peanut-dryland cotton rotation. Each year every field that grew cotton would be planted to peanuts the next year. Every field that was irrigated would grow a dryland crop the next year. Figure 10 is similar to Figure 9 in its layout. Looking down the column will track the cropping history for each field. Year

5 was the same as year 1 and 3, but year 6 was different from all others. In year 6 the land allocation was slightly altered as shown previously in Table 19.

Irrigated Cotton 15.1125 a. Year 1	Irrigated Peanuts 13.6875 a. Year 1	Dryland Peanuts 15.1125 a. Year 1	Dryland Cotton 13.6875 a. Year 1
Dryland Peanuts 15.1125 a. Year 2	Dryland Cotton 13.6875 a. Year 2	Irrigated Cotton 15.1125 a. Year 2	Irrigated Peanuts 13.6875 a. Year 2
Irrigated Cotton 15.1125 a. Year 3	Irrigated Peanuts 13.6875 a. Year 3	Dryland Peanuts 15.1125 a. Year 3	Dryland Cotton 13.6875 a. Year 3
Dryland Peanuts 15.1125 a. Year 4	Dryland Cotton 13.6875 a. Year 4	Irrigated Cotton 15.1125 a. Year 4	Irrigated Peanuts 13.6875 a. Year 4

Figure 10. Crop Rotation For Soil 3.

There were 100.375 acres involved in the row crop rotations for the Dougherty-Eufaula (soil 1). This was a complex rotation system that could be tracked through the transfer activities discussed in a previous section. The rotations involved irrigated peanuts, grain sorghum and dryland cotton. There were 48 acres of irrigated peanuts, 32 acres of grain sorghum and 20.375 acres of dryland cotton grown on soil 1 each year. All the row crops were rotated with each of the other two row crops on a portion of soil 1 in 2-year rotations. Figure 11 attempts to explain how the rotation worked. In some cases it may help to imagine subfields within the entire area grown to one crop.

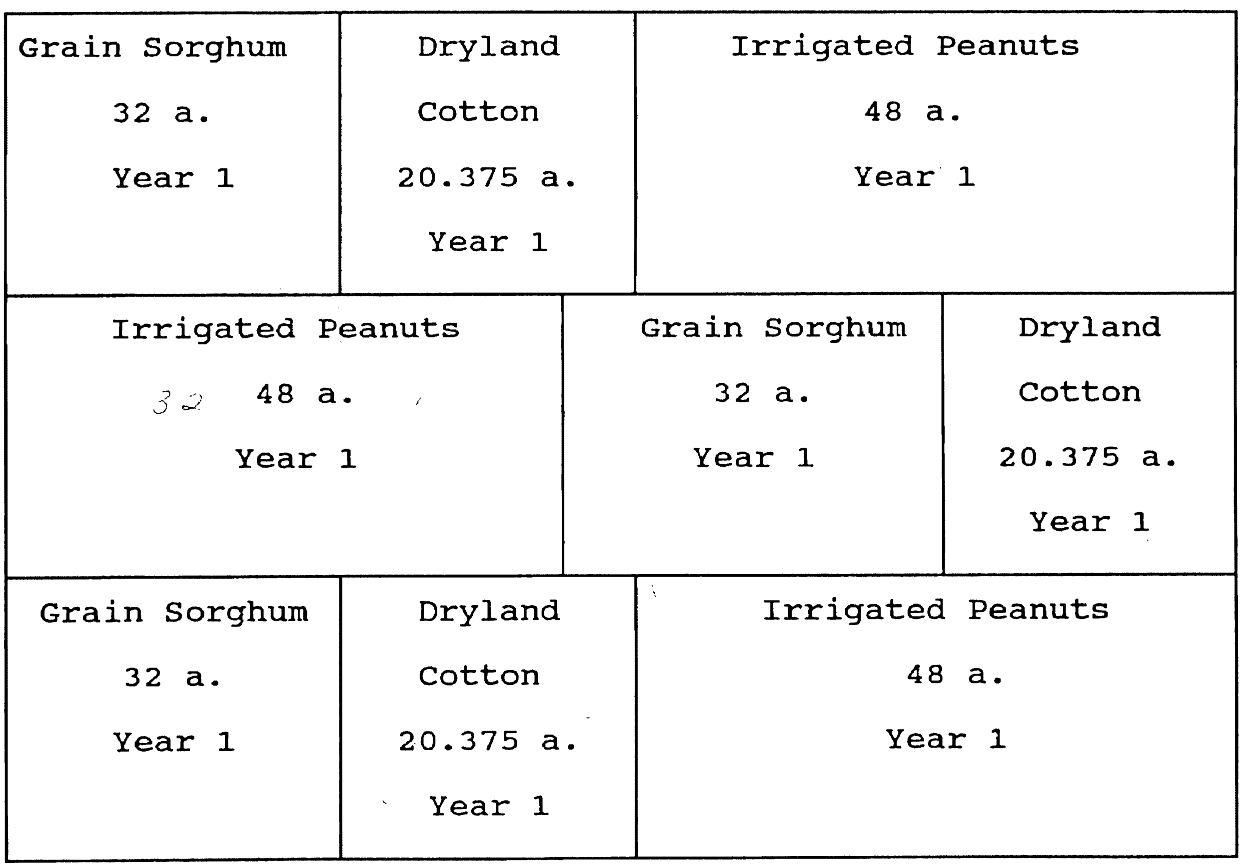

Figure 11. Crop Rotation for Soil 1

All 32 acres of old grain sorghum ground are planted to peanuts in the next season along with 16 acres of old cotton ground. The remaining 4.375 acres of old cotton ground and 27.625 acres of old peanut ground goes into grain sorghum in the next season. There is 20.375 acres of old peanut ground left which goes into cotton the next season. Lines could be drawn straight down through the missing pieces to create five subfields in each year. Doing this finds five rotations: GS-P, C-P, C-GS, P-GS and P-C[10] moving left to right.

Continuous wheat was also grown on all three of the soil groups. The acres devoted to each soil type were shown in Table 19 and are consistent throughout the 6 years. The graze-out wheat (ARP) was grown on the Dougherty-Eufaula dryland for all the years.

Annual commodity production is listed in Table 20. This production was sold at the USDA, ERS projected prices (1993b, 1993c and 1993d). The 6 years of discounted returns totaled $444,658.36. The annual discounted returns include $8,901.70 in government payments each year except for year 6 when the sorghum CAB was not fully utilized. Annual net returns are found in Table 21. No additional off-farm labor was required in any of the years.

[10]GS is grain sorghum; P is peanuts; and C is Cotton.

TABLE 20

ANNUAL COMMODITY PRODUCTION

Year	Peanuts (1000 lb.s)	Lint (1000 lb.s)	Cotton Seed (cwt.s)	Grain Sorghum (bu.s)	Wheat Grain (bu.s)	Wheat Pasture (acres)	Wheat Graze-out (acres)
1	333.0	30.29	473.77	960.00	5112.105	148.75	6.875
2	333.0	30.49	476.83	960.00	5112.105	148.75	6.875
3	333.0	30.49	476.83	960.00	5112.105	148.75	6.875
4	333.0	30.49	476.83	960.00	5112.105	148.75	6.875
5	333.0	30.49	476.83	960.00	5112.105	148.75	6.875
6	333.0	31.85	498.20	828.75	5112.105	148.75	6.875

TABLE 21

ANNUAL NET RETURNS

Year	Net Returns ($/year)
1	83,298.04
2	83,414.13
3	83,414.13
4	83,414.13
5	83,414.13
6	83,704.92
Total NPV Returns	444,658.36

The LP model has accounting rows to track the expected leaching. The accounting rows were used to establish the leaching in the baseline solution. The means of the relative amounts multiplied by the amounts applied were used for the accounting rows. Table 22 presents the annual leaching under the baseline solution. In the baseline solution, fenamiphos was not used; only aldicarb and metolachlor were applied.

The amount of metolachlor leaching under the baseline systems was never substantial, with .0008 lbs for the entire farm each year. Aldicarb was a more frequent and heavier leacher. Peanut acreage went up in the last year causing the aldicarb leaching to increase slightly. There were fewer acres irrigated on the low leaching soil but the minor increase in dryland peanuts on the high leaching soil was enough to raise the level of aldicarb leaching.

TABLE 22

WHOLE FARM ANNUAL LEACHING

Year	aldicarb (lbs/year)	metolachlor (.001 lbs/year)
1	5.6756	.8
2	5.6756	.8
3	5.6756	.8
4	5.6756	.8
5	5.6756	.8
6	5.6877	.8
Total Leaching	34.0657	4.8

CMLS results do not provide any information on eventual concentration of pesticides in ground water. However, using some specific assumptions, concentrations were calculated for use as a benchmark. The first step was to determine the amount of water the pesticide would enter. For simplicity, it was assumed that all the active ingredient leaching beyond the root zone eventually reaches the ground water deposit and mixes with the top 1 meter of water instantaneously and uniformly (Gregory, 1992). The total volume of water per acre was calculated by multiplying area (1 acre) times depth (1 meter) times porosity (40%) of the aquifer:

1 acre = 4047 m^2

4047 m^2 x 1 m x 40% porosity = 1618 m^3 of water

1,000,000 cm^3 = m^3 of water

1 cm^3 of water = 1 gram

1 m^3 of water = 1,000,000 grams of water

(2.20×10^{-3}) lbs = 1 gram .

1618 m^3 of water x 1,000,000 g x (2.20×10^{-3}) lbs = 3,559,600,000 lb.s of water underlying one acre.

The concentration of a pesticide in the water under one acre, in ppb, is found by:

$(\text{lbs ai} \times 10^9)$ / 3,559,600,000 lbs.

Similarly, to find the required amount of a pesticide per acre to reach the HAL, rearrange the terms so that:

[3,559,600,000 lbs x HAL (in ppb)] / 10^9 = lbs ai required.

The HALs for aldicarb, fenamiphos and metolachlor are 10, 2 and 100 respectively. The half-lives of the modeled pesticides are less than one year. Another assumption was that these short half-lives would allow pesticides to completely degrade within two years when the next block of pesticides may arrive, prohibiting any accumulation over time (Haan, 1992).

Based on this approach, results show that the pesticide leaching from the baseline farm plan will exceed the HAL for the pesticide aldicarb. The aldicarb leaching attributed to the production practices used in year one would lead to a concentration of 15.94 ppb which exceeds the HAL for aldicarb of 10 ppb. The potential problem of pesticide leaching contributing to low ground water quality does exist.

Policy makers are confronted with the problem of protecting ground water from pesticides. Careful management of chemical use, land use or some combination of production systems is needed to control the amount of pesticides reaching the ground water. The relative costs and benefits of the protection strategies for ground water are important information for policy makers who must determine how to implement changes in management at the farm level.

The uncertainty of the leaching process presents a special problem to policy makers. Under some scenarios the leaching can be quite variable. As can be seen from Tables 17 and 18 the standard deviations of the pounds of active ingredient leaching is nearly half as large as the means. The inherent stochastic nature of environmental impacts from agricultural practices cannot be ignored.

In order to incorporate these stochastic process into the decision model, CCP was used. The means and standard deviations were used to develop chance-constraints which allow constraining leaching to different safety levels. The economic and environmental trade-offs of different safety levels can then be observed.

CHAPTER IV

MODELING WATER QUALITY SAFETY LEVELS USING CHANCE CONSTRAINTS

Restricting Ground Water Pollution

When modeling environmental problems, the use of CCP is particularly applicable. Rainfall events and weather conditions make the outcomes of certain agricultural practices uncertain. The best way to account for this variability is through the use of long-term probabilistic assumptions. Kramer, McSweeny and Stavros, 1983; Segarra, Kramer and Taylor, 1985; and McSweeny and Shortle, 1990 have all used CCP or modifications of CCP to address the stochastic effect of weather impacts on farm problems.

Estimating pesticide leaching from cropland is complicated by uncertainty about the level of leaching across time periods from identical production practices. Large differences in leaching between years are the results of variable rainfall. Timing and amount of rainfall are both critical factors in determining the amount of leaching expected in a given year. Neither the amount nor timing of rainfall events are known.

Uncertainty's Impact on Policy

It is not uncommon for policy makers concerned with protecting ground water quality to suggest limits on how much pesticide leaching would be allowed. However, the amount of leaching in a year can not be known with certainty. Limits may be violated when conditions, such as a heavy rainfall, are extreme. Setting goals for the frequency of limit violations requires the recognition of trade-offs between safety and costs of meeting the limit.

The level of safety chosen is very important to the costs of meeting the constraints. It is very costly, if not impossible, to maintain a 100% safety level in most cases (Derby and Keeney, 1991). Banning a particular action or practice would ensure environmental compliance but at a large expense. Marginal abatement costs of most pollutants increase at an increasing rate. Previous water quality research limiting the amount of nitrate leaching into the vadose zone indicates that increasing costs will be true for most environmental problems that face agriculture (Johnson, Adams and Perry, 1991).

Figure 12 shows the traditional depiction of increasing marginal abatement costs and falling marginal social benefits from abating pollution. Initially high marginal benefits might be in those instances when carcinogenic pollutants are being removed with the slightest reduction resulting in a much lower incidence of cancer. Falling marginal benefits could be attributed to those situations

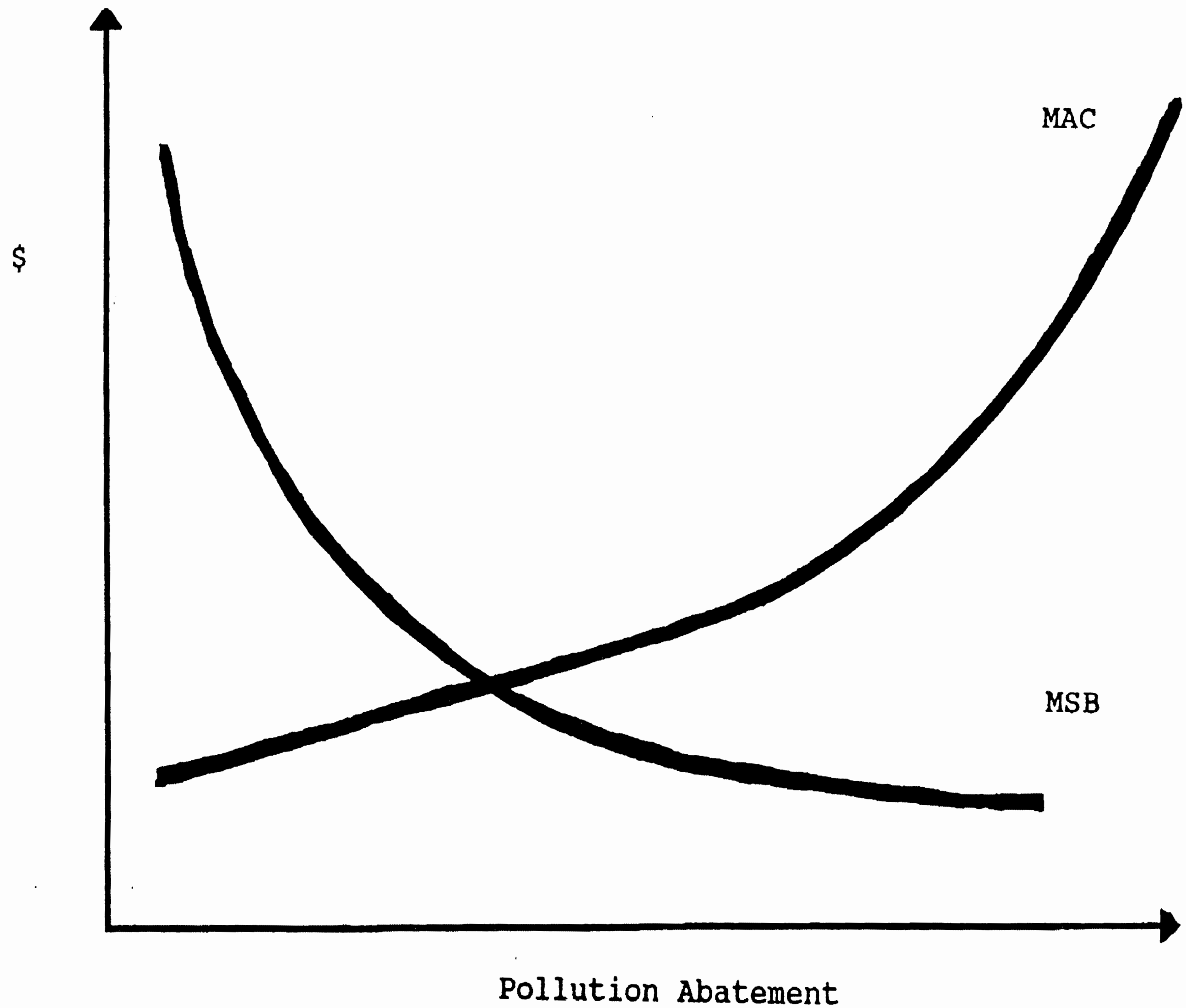

Figure 12. Marginal Abatement Cost and Social Benefit Curves of Pollution Abatement

when extremely low levels of a pollutant are in the environment presenting little health risk. When the marginal abatement cost curve is shaped like the curve in Figure 12, restrictions on leaching become more and more costly and achieve progressively smaller increments of benefits. The falling net returns received by farmers in the case of ground water quality management can be viewed as part of the increasingly costly abatement of pollution. Trade-offs between safety levels and net returns are likely. Sometimes accepting a slight decrease in the safety level can have great benefits (Derby and Keeny, 1991).

Even now some policies do allow for extreme circumstances. EPA's rules regarding concentrated animal feeding operations (CAFOs) are one example. In general, CAFOs are only allowed to discharge when rainfall exceeds a 25 year, 24 hour rainfall event (although permitted CAFOs are protected in other circumstances). These rules recognize that putting structures or practices in place to protect surface water against such natural phenomenon would be prohibitively expensive (40 CFR Part 122, undated).

Chance-Constrained Programming

Chance-constrained programming (CCP) modifies the deterministic resource constraints to incorporate stochastic parameters in probabilistic terms. Incorporating chance-constraints for leaching into the math programming model allows for the requirement that leaching not exceed some limit more than the established percent of the time. Recall from Chapter 2 the final modified chance constraint takes the form,

$$\sum_j \bar{a}_{ij} X_j + K_\alpha [\sum_j \sum_k \sigma_j \sigma_k \varrho_{jk}]^{1/2} \leq B_i .$$

In this study the adjusted mean leaching is represented by the $a_{ij's}$. The $a_{ij's}$ are the stochastic variable in this study. The X_j is the optimal level (acres) chosen by the model for production of the jth peanut system. The K_α is a constant from the cumulative normal distribution for the level α_i, which is the allowable failure rate. The term σ_j σ_k ϱ_{jk} is equivalent to the covar(a_{ij}, a_{ik}). The covariance quantifies the relationship between the expected leaching under two production systems. The σ_j and σ_k are the adjusted standard deviations for pounds of active ingredient i, leached for peanut production systems j and k. The ϱ_{jk} is the correlation between the quantity of pesticide i leached under the two production systems j and k. The β_i is the pounds of active ingredient in pesticide i that would cause the receiving waters to reach the health advisory level (HAL). The β_i constrains the total loading of pesticide i, for all acres treated with pesticide i.

Compared to a traditional linear resource usage constraint, the effect of a chance-constraint when the technical coefficients are stochastic is to reduce the level of leaching allowed by the amount,

$$K_\alpha [\sum_j \sum_k \sigma_j \sigma_k \varrho_{jk}]^{1/2} .$$

The reason for the reduction in the allowed leaching is to reflect the occurrences when leached quantities are greater than expected. For a normally distributed variable, one-half of the time the observed value would be greater than the expected value (mean). Obviously, the other one-half of the time the observed value would be less than the mean.

When the distributions are truncated at zero, the adjusted standard deviations are slightly smaller. The smaller values for the standard deviations make the values in the variance-covariance matrix smaller. This reduction makes the constraint less binding.

The K_α can be changed to reflect the different levels of safety chosen. For greater levels of safety the value of K_α gets larger. The values of K_α for the levels of safety considered in this study can be found in Table 23. The standard deviations and correlations for a given crop are constant and would not be impacted by any policy change.

TABLE 23

VALUES FOR K_α

alpha (%)	Safety Level (%)	Value of K_a
20	80	.845
15	85	1.035
10	90	1.282
5	95	1.645
1	99	2.326

By choosing higher levels of safety, a greater risk premium should be expected, or in the case of CCP, less expected leaching allowed. This ensures the expected quantity leached will be far enough away from the safety level that the actual quantity leached will not exceed the limit in a given year for the safety level implied by the K_α. The risk premium charged here is the foregone net returns to the producer.

To evaluate the levels of safety, a measure of health risk is necessary. For drinking water, health advisory levels (HALs) are based on concentration levels of pesticides. These HALs are commonly expressed in ppb of the pesticides in the water.

The value for β_i was determined by finding the total pounds of leaching over the whole peanut field that could occur before the ground water underlying the field would exceed the HAL for the pesticides used. The method for determining the maximum level of β_i was provided in the previous chapter. For the 120 acre peanut field, the whole farm-level constraint for aldicarb leaching was 4.27152 lbs. That is the quantity of active ingredient which would cause the water underlying the peanut fields to reach the HAL. The required amounts for fenamiphos and metolachlor were .854304 and 42.7152 lbs respectively.

Chance-Constrained Programming Results

Crop Mix and Production

The crop mix changed little with respect to crops other than the peanut acreage. The wheat acreage was largely unaffected by the changes in safety levels. Soil type 1 grew 59.625 acres of wheat (including 6.875 acres ARP graze-out). Soil type 2 grew 57.6 acres and soil type 3 grew 38.4 acres. However, at the 99% safety level, 4.375 acres of wheat harvested for grain was shifted from the medium leaching soil to the high leaching soil (from 2 to 1). This made way for row crops to be rotated through the medium leaching soil. The acreage allocation was the same in each year and all safety levels except the highest safety level.

The row crops were impacted by differing degrees. The grain sorghum acreage allocation was almost constant across years and safety levels. Like the baseline, acreage in the 80% and 90% safety levels was always 32 acres on soil 1 with the sixth year falling to 27.625 acres when the CAB was not fully utilized. The change in year 6 was because there was no need to provide ground that would be available to grow peanuts in the coming seasons. Furthermore, the model increased net returns by switching some dryland cotton to irrigated cotton and more dryland peanuts with the vacated sorghum ground. At the 99% safety level there were slight changes in the rotation with limited amounts of grain sorghum occasionally being grown on soil 2 (years 2 and 4).

Cotton acreage had similar minor fluctuations. One trend in the cotton systems was to irrigate fewer acres on the low leaching soil in year 6 as the safety level increased. Years 1 through 5 under the baseline, the 80% and 90% safety levels were always the same. The model produced 20.375 acres dryland cotton on soil 1, 43.2 acres dryland cotton on soil 2, 13.6875 acres dryland cotton on soil 3 and 15.1125 acres of irrigated cotton on soil 3. There were two changes under the 99% safety level, one being the acreage on soil 1. In years 1, 3 and 5 there were 16 acres dryland cotton, while years 2, 4 and 6 grew 20.375 acres. The other change was less irrigated cotton on soil 3 as more of the low leaching soil was put to irrigated peanuts. The number of irrigated acres on soil 3 fell from 15.1125 to 12.8047.

The peanut acreage changed little under the differing safety levels. The only difference that can be seen from looking at the acreage allocation by soil type was 2.3078 acres more irrigated peanuts on the low leaching soil under the 99% safety level.

The summarized acreage allocations for peanuts and cotton are presented in Table 24 for years 1 and 6 for the 80%, 90% and 99% safety levels. Year 2 for the 99% safety level is also included. Under the 80% safety level, pesticide concentrations from leaching were allowed to exceed the HAL 20% of the time. Under the 99% constraint, HAL's were exceeded only 20% of the time. As in the baseline, the model reached a whole farm long-term rotation.

TABLE 24

ANNUAL ACREAGE ALLOCATION FOR PEANUTS AND COTTON

Risk Level	Year	Soil Type	Irr. Peanuts	Dryland Peanuts	Irr. Cotton	Dryland Cotton
80%	1	1	48.0			20.4
		2	43.2			43.2
		3	13.7	15.1	15.1	13.7
	6	1	48.0	4.4		20.4
		2	43.2		26.1	43.2
		3	10.8	18.0	18.0	10.8
90%	1	1	48.0			20.4
		2	43.2			43.2
		3	13.7	15.1	15.1	13.7
	6	1	48	4.4		
		2	43.2			
		3	13.5	15.3	15.3	13.5
99%	1	1	45.7	2.3		16.0
		2	43.2			47.6
		3	16.0	12.8	12.8	16.0
	2	1	45.7	2.3		20.4
		2	43.2			43.2
		3	16.0	12.8	12.8	16.0
	6	1	45.5	2.5		20.4
		2	43.2	4.4		43.2
		3	16.1	12.7	12.7	16.1

Under the 80% and 90% safety levels, Years 1 through 5 were the same. In the 99% case years 1, 3 and 5 were the same and years 2 and 4 were identical.

The production from the crops grown is given in Table 25. The wheat production under the two lower safety levels is the same as the baseline, 5112.105 bu.s of grain, 148.75 acres winter grazing and an additional 6.875 graze-out. Wheat production fell slightly to 5048.23 bu.s when the safety level was increased to 99%. The other production figures are similar to the baseline. The largest change is in the peanut production. Under none of the safety levels is the quota fully utilized for every year. Only under the lower safety levels during the last year when generating land for the peanut rotation is no longer a concern, does the model fully utilize the quota. When the level of safety is at the 99% rate the peanut quota is never fully used.

Resulting Pesticide Leaching

The expected pounds of leaching under the different safety levels is given in Table 26. Under the baseline, the irrigated peanut production activities primarily used the high level of irrigation with accompanying high levels of leaching. All the peanut activities used aldicarb as the nematicide in the baseline.

When the chance-constraints for leaching were imposed, the producer abated aldicarb leaching by a combination of reducing irrigation levels and switching soils. The alternative lower leaching nematicide never entered the solution, with the model preferring not to produce the full quota. The opposition to fenamiphos came from a higher input cost and lower yield.

TABLE 25

ANNUAL COMMODITY PRODUCTION UNDER ALTERNATIVE SAFETY LEVELS

Safety Level	Year	Peanuts (1000 lb.s)	Lint (1000 lb.s)	Cotton Seed (cwt.s)	Grain Sorghum (bu.s)
80%	1	329.1	30.3	473.8	960.0
	2	329.1	30.5	476.8	960.0
	3	329.1	30.5	476.8	960.0
	4	329.1	30.5	476.8	960.0
	5	329.1	30.5	476.8	960.0
	6	333.0	31.0	485.0	828.8
90%	1	327.7	30.3	473.8	960.0
	2	327.7	30.5	476.8	960.0
	3	327.7	30.5	476.8	960.0
	4	327.7	30.5	476.8	960.0
	5	327.7	30.5	476.8	960.0
	6	333.0	30.5	477.3	828.8
99%	1	324.0	30.6	478.4	960.0
	2	324.0	30.4	475.9	958.7
	3	324.0	30.9	482.8	960.0
	4	324.0	30.4	475.9	960.0
	5	324.0	30.9	482.8	960.0
	6	332.6	30.4	475.8	960.0

TABLE 26

POUNDS OF EXPECTED ALDICARB LEACHING

Year	Baseline	80%	90%	99%
1	5.6756	2.5115	1.7114	.9619
2	5.6576	2.5115	1.7114	.9619
3	5.6576	2.5115	1.7114	.9619
4	5.6576	2.5115	1.7114	.9619
5	5.6576	2.5115	1.7114	.9619
6	5.6877	2.4994	2.2242	.9623
Total	34.0657	15.0569	10.7812	5.7718

From Table 27 it can be determined how the peanut producers adjusted irrigation on the different soil types to comply with the higher safety levels. The first reallocation the producers made was moving the majority of the high irrigation peanuts to the medium irrigation level on soil 1. Irrigated peanuts under the high irrigation level, using aldicarb as the nematicide on soil 1 (formerly the most profitable production activity) was no longer viable under the 90% safety level. At the 90% level, roughly 13% of the irrigated peanuts on soil 2 were shifted from high irrigation to the medium level. At the 99% level the constraint became so binding that soils 1 and 2 could not be irrigated at the high level. All high irrigation was stopped except for soil 3. There was also a pattern for ever increasing amounts of medium irrigation.

TABLE 27

IRRIGATION LEVEL BY SOIL TYPE MEETING
WATER QUALITY SAFETY CONSTRAINTS

Risk Level	Year	Soil Type	High (acres)	Medium (acres)	Dryland (acres)
Baseline	1	1	48.00		
		2	43.20		
		3	13.30	.35	15.11
	6	1	48.00		4.38
		2	43.20		
		3	6.21		22.59
80%	1	1	8.65	39.35	
		2	43.20		
		3	13.69		15.11
	6	1	8.34		4.38
		2	43.20		
		3		10.83	17.97
90%	1	1		48.00	
		2	37.76	5.44	
		3	13.69		15.11
	6	1	11.06	36.94	4.38
		2	17.40	25.80	
		3		13.51	15.29
99%	1	1		45.69	2.31
		2		43.20	
		3	16.00		12.80
		1		45.54	2.46
		2		43.20	4.38
		3	16.00		12.66

Discounted Net Returns

As expected, meeting higher safety goals was coupled with higher costs of reaching these safety goals. Table 28 shows the effect of rising safety levels on whole farm net returns. The loss in total discounted net returns between the base line and the 80% safety level was $1497.87 for the six years discounted total. Increasing the safety level from 80% to 90% had a cost of a $540.61 in lost net returns. Moving from the 90% safety level to the 99% level had a substantial decrease in net returns of $1849.53 for the additional 9% safety level.

TABLE 28

NET RETURNS UNDER ALTERNATIVE LEVELS OF RISK

Year	Baseline	80%	90%	99%
1	83298.04	82968.66	82849.76	82502.49
2	83414.13	83084.75	82965.85	82480.78
3	83414.13	83084.75	82965.85	82667.66
4	83414.13	83084.75	82965.85	82480.78
5	83414.13	83084.75	82965.85	82667.66
6	83704.10	83703.40	83703.25	83568.62
Discounted Total	444658.36	443160.49	442619.88	440770.35

The model was also solved at very low levels (50% and 65%) to obtaining points to plot the marginal cost of ground water protection. The 'average' marginal cost was found over small intervals (Doll and Orazem, 1978). Table 29 has the cost information for the safety levels. Figure 13 shows the marginal cost of increasing the safety level. As expected the cost to protect the ground water increased rapidly at higher and higher levels of protection.

TABLE 29

PROTECTION COST DATA

Safety Level	Discounted Profits	Total Cost	Marginal Cost
50	444000.47		
57.5			26.85
65	443597.70	402.77	
72.5			29.15
80	443160.49	839.98	
82.5			38.52
85	442967.89	1032.58	
87.5			69.60
90	442619.88	1380.59	
92.5			109.68
95	442071.50	1928.97	
97			352.29
99	440770.35	3230.12	

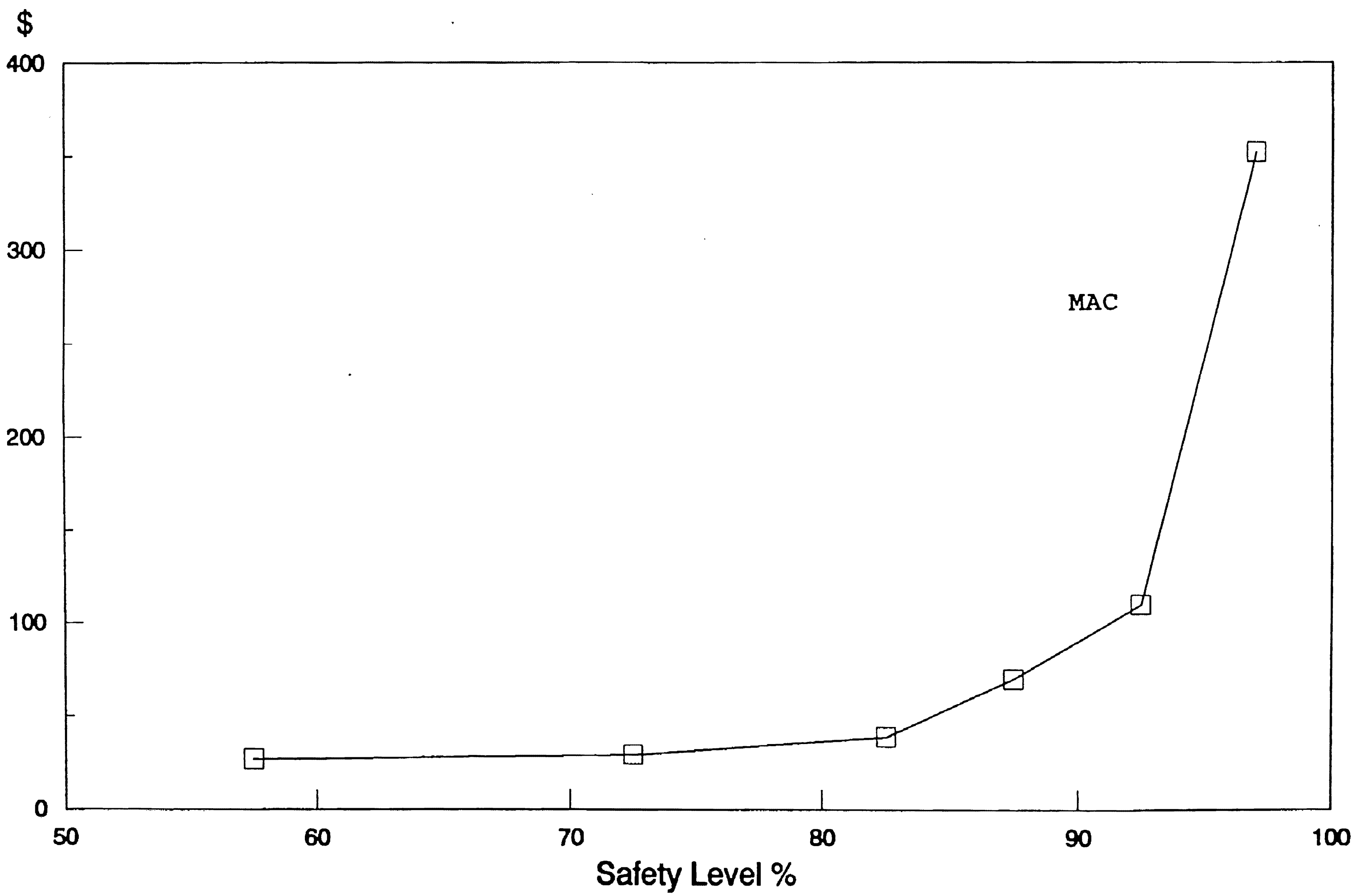

Figure 13. Marginal Cost of Protecting Ground Water

CHAPTER V

CONCLUSIONS AND IMPLICATIONS

Summary

The primary objective of this study was to evaluate trade-offs associated with increasing the safety protection level from pesticide contamination of ground water in Oklahoma. Underlying the primary objective were several secondary objectives. The secondary objectives were to identify the profit maximizing farm plan without environmental constraints, evaluate the changes in net farm income under alternative safety levels for ground water protection and compare the environmental and economic trade-offs of ground water quality management for a representative Caddo County, Oklahoma farm.

To determine the initial net returns a linear programming model was used. Chance-constrained programming was used to compare the outcomes of potential ground water quality policies based on probabilistic goals. Changes in net returns and total loadings were used to compare economic and environmental tradeoffs.

Results suggest policy could be put into place to protect the ground water at moderate to high levels of safety with very limited costs to the producer. Not all pesticides studied posed a threat to the area's ground water. When the level of safety is increased, the associated costs of adjusting production to reach this new level of safety also increases. Ground water quality management can accomplish protection of these resources. The question becomes at what safety level does society prefer to protect the ground water and who will bear the costs of protection.

Policy Implications

The Water Quality Incentive Program (WQIP) has been implemented in the Willow Creek Watershed within the study area (USDA,SCS, 1992). The WQIP is a voluntary program in which producers are eligible for incentive payments for adopting conservation and water quality protection practices. Initial provisions are to target production practices which create surface and ground water quality problems in the area (USDA,ASCS, 1993). Within the Willow Creek Watershed Project area, 5,000 acres have been targeted for irrigation water management and record keeping cost sharing. These practices are eligible for cost sharing up to $10/acre and $.25/acre, respectively. Integrated crop management practices are also targeted on 850 acres and these practices are eligible for cost sharing up to $10/acre for row crops or up to $20/acre for specialty crops. The WQIP cost sharing annual limit is $3500 per farm.

For ground water protection, the irrigation water management option holds certain promise. This study assumed that the high irrigation peanut systems yield 100 lbs/acre more than the medium irrigation level systems. The peanuts were valued at $.289/lb. The marginal cost of moving to the higher irrigation level was $18.50/acre multyplied by the inflation factor of 1.0175 for pumping costs of $18.82. This means the marginal net return realized by changing to the high irrigation level from the medium irrigation level was approximately $10.08 (100 lbs x $.289/lb - $18.82). The maximum cost sharing incentive available would nearly offset the loss in net returns realized from changing over to the medium irrigation system. Investing in water management technologies may allow the irrigators to cut water applications and maintain or increase yields[1].

The integrated crop management system may allow for some improvement in pest control. If producers were allowed to convert wheat CAB into row crop base, two opportunities for production systems with fewer environmental hazards exist. First, the option for longer crop rotations might become available. Longer rotations reduce the requirements for pesticides in most crops. Secondly, recall that for every acre of peanuts grown there needs to be an acre of non-peanut row crops per soil type to satisfy rotation

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[1]Excess water in peanuts contributes to the incidence of foliar disease and other plant disease, increasing pesticide costs and lowering yields (Wright et al., 1986). By moving to the medium irrigation level the producers may be able to reduce sprays for control of foliar disease.

constraints. If land (rotation constraints) is more constraining than the quota, the farmer is induced to maximize production per acre to fill the quota. Even when maximizing production the returns from peanuts are greater than or comparable to other crops. Granting more row crop base for rotations might allow the producer to reduce the high level of inputs that contribute to leaching (irrigation or pesticides) and concentrate on profit maximization rather than output maximization per acre.

When using cost sharing to induce producers to adopt ground water protection strategies, there are other costs in addition to losses in net returns that need to be considered. Changes in irrigation levels may require alterations to the current system or management. Increased labor and management charges would be anticipated for closely monitoring the soil water status. If the producer was unable to adequately monitor and interpret the information needed for reducing irrigation levels without harming crop yields, consulting fees might also be paid.

Transition costs are likely. One example of this is can be seen in the results for the higher safety levels. One of the strategies the model uses to limit the amount of pesticide leaching is to grow more acres of peanuts with lower irrigation levels. The constraints for peanut rotations are constant for all safety levels. Because the rotational acreage constraints become limiting under the high safety levels, the model is unable to grow enough of the lower yielding, medium irrigation peanuts to fill the quota in the early years. Thus, the producer may be resistant to changes in the farm plan if the initial losses are large.

Classical resource economics maintains that in most instances economic incentives (taxes or subsidies) for a particular pollution problem are more efficient at achieving the environmental goal than are strict standards or banning the practices that cause the pollution (Pearce and Turner, 1990). In the case of ground water contamination by pesticides, it would be very costly, if not impossible to correctly identify the polluter for reasons of assessing pollution taxes or fees. To circumvent this problem and achieve an efficient ground water protection policy, regulatory agencies should target those production systems with the highest potential to contribute to low water quality. Crutchfield et al. assert targeting the systems that contribute to leaching can make the environmental goals obtained with limited costs to producers or consumers (1992). By using cost sharing monies and technical assistance the problem of ground water contamination may be more easily reduced to an acceptable risk level than by attempting to locate and penalize the guilty parties.

The most efficient policies to constrain leaching would have the low cost abaters reducing pesticide loading more than the high cost abaters. Due to variable soil properties, when two producers are confronted with the problem of controlling leaching they will be equipped differently to comply with the requirements. Regulating or prohibiting a given production system on all soils with different potentials to leach may have drastically different economic and environmental results. For instance, prohibiting high irrigation levels on all soils would indeed control the leaching problem of most pesticides in the study area. However, the producer whose soil has a low leaching potential not contributing to the environmental problem would have his net returns unjustly penalized by the regulation.

Limitations of the Study

A comprehensive study of ground water quality should include attention to impacts on water quality in other production regions. True gains in protecting ground water would not be realized if production of chemical intensive crops is simply reallocated to other regions under non-regulated production practices. This could be foreseen if the competitive advantage of producers in one region were sufficiently diminished by restrictive ground water protection programs, while unrestricted producers in a second region remained free to produce the crop at an equal or greater cost to the environment. This raises questions about how the objectives are stated and which programs are selected. An objective to reduce the quantity of chemical inputs would likely require different policies than an objective to reduce pesticide leaching. The redistribution of pesticide leaching between regions may be as important as the local impacts of ground water protection programs when environmentally sensitive aquifers are placed at greater risk by the policies.

Another potential limitation of the study is that impacts on production risk by the proposed policies are ignored. Adoption of low-input agricultural practices has been hampered by producers' inability to bear additional production risk (Daberkow and Reichelderfer, 1988). How the adoption of low-input or IPM practices in the irrigated peanut producing areas of Western Oklahoma alter production risk is not fully known. Even if the risk of low yields is increased, that might not suggest that the risk of low net returns has increased. Studies in the area suggest moderate levels of inputs can generate bigger net returns than very high levels of inputs (Jackson, 1989; Jackson et al., 1988).

There are some assumptions made about irrigation in the study that have considerable impacts on the results and how cost effective the producers can be in achieving water protection. The model assumes instantaneous irrigation. If all fields need irrigated on the same day there is nothing in the model to prevent this. If the daily capacity of the irrigation system is significantly overestimated, the producer may have to irrigate in advance of the optimal time period for attaining environmental goals. The producers ability to cheaply abate some leaching losses may be overestimated if the producers are currently managing irrigation systems and chemical inputs carefully (Johnson, Adams and Perry, 1991). The assumption was made not all producers were currently using good management strategies.

A great unknown in modeling water quality is what happens to the chemical after it leaches below the root-zone. In this study, it was assumed that all the active ingredient leaching below the root-zone reached the ground water. It is difficult to calculate the impacts of the pesticide loading if it is not known how and when the pesticide reaches the ground water. These unknowns create a problem in calculating the precise concentration of pesticide in the water.

Suggestions for Future Research

The questions concerning agricultural production risk associated with water quality policy are beyond the scope of this study. A more thorough attempt to determine production risk and producers' risk attitudes may help to explain current high use of inputs. As one measure of producer risk, bio-economic simulation models could be developed to incorporate pesticide use with growth models to determine the impacts on expected yields from reducing pesticides.

Studies that closely analyze the true distributions of leaching could more adequately predict the resulting leaching from a production system. The distribution greatly impacts the restrictiveness of the chance-constraints in

CCP. A closer look should increase the power of this research tool.

This research could be improved upon by including other potential contaminants in the study area. Nitrate and pesticide losses from other crops could be included. Soil erosion carrying nutrients or pesticides is one of the problems facing surface water quality, and is variable from year to year. This annual variability suggests surface water protection should be addressed from a probabilistic perspective as well.

A comprehensive, integrated approach for managing farm resources is critical for addressing environmental concerns. As the producer reallocates resources in an attempt to maintain net returns, he may use production systems in other crops that are more erosive or use higher pesticide levels. Gains made in protecting ground water from pesticides used in peanut production could be offset by the practices used in the production of other crops. Research and education programs which address loss of pesticides and nutrients by both surface runoff and leaching will assure a more comprehensive, integrated farm-level resource management system.

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APPENDIXES

APPENDIX A

CMLS EQUATIONS AND ROUTINES

CMLS EQUATIONS AND ROUTINES

The following comes largely from Nofziger and Hornsby (1986). The Chemical Movement through Layered Soils is a management tool developed by Nofziger and Hornsby (1986). The formulas used by CMLS to estimate the pesticide location and quantity parameters are relatively simple. The model used to estimate the position of the pesticide is an alteration of a previous model by Rao, Davidson and Hammond (Nofziger and Hornsby, 1986). Pesticides are assumed to move only in the liquid phase. Up to 25 uniform soil layers may be used with different properties for each layer. The change in depth of the solute can be represented by

$$\Delta d_s = q / R\Theta_{FC}$$

when the amount of water passing downward (q) is positive. If q is zero, the change in solute depth is zero, as the model assumes no water movement upward. Here d_s represents the depth of the solute, R is the retardation factor and θ_{FC} is the volumetric soil water content at field capacity.

CMLS uses a linear and reversible equilibrium adsorption model. Thereby R is given as

$$R=1+\rho K_D/\Theta_{FC}$$

where ρ is the soil bulk density and K_D is the linear sorption coefficient.

The K_D can be given by the formula

$$K_D=K_{OC}OC,$$

where K_{OC} is the linear sorption coefficient adjusted by the organic content (OC).

To use these positioning models it is first necessary to determine the quantity of water passing. Therefore three steps must be undertaken each day:

1. Adjust water available for evaporation and crop transpiration for that day.
2. Adjust the water content for the quantity of rainfall or irrigation passing the solute front depth.
3. Determine the new solute depth.

Initially, soil water content is assumed to be at field capacity. When soil water is available in the root zone, the water is first used to meet evapotranspiration demand. The CMLS model considers any water available if the soil water content is above the permanent wilting point. If θ(j) is the water content for the soil layer j, the available water for that layer, AW(j) can be given by

$$AW(j) = t(j)\,[\Theta(j) - \Theta_{PWP}(j)]\,,$$

where t(j) is the thickness of layer, and $\Theta_{PWP}(j)$ is the water content at the permanent wilting point. The total water available can be found by summing the available water in each layer. If the evapotranspiration (ET) demand can be met that day by the soil water, the soil water content is lowered to reflect the day's use. The water content is adjusted proportionally across all layers within the root zone. The procedure is,

$$\Theta(j) = \Theta'(j) - \frac{[ET*AW(j)]}{[AW_{total}*t(j)]}\,,$$

where $\Theta'(j)$ is the initial water content. When AW_{total} is less than ET, $\Theta(j)$ is reduced to $\Theta_{PWP}(j)$, for all soil layers.

The second step requires adjusting for any daily moisture the soil receives either in the form of irrigation or rainfall. The soil layer closest to the surface is adjusted first, then the procedure continues downward through each soil layer. To find the soil water deficit of layer j (swd(j)), the model uses this equation

$$swd(j) = t(j)\,[\Theta_{FC}(j) - \Theta(j)],$$

where $\Theta_{FC}(j)$ is the field capacity. The swd(j) is the additional amount of water the soil layer can store before reaching field capacity. The infiltrating amount for each layer will be defined as I(j). I(j) is compared to the swd(j). If I(j) is greater than the swd(j) then,

$$\Theta(j) = \Theta_{FC}(j),$$

and the amount infiltrating the next layer is,

$$I(j+1) = I(j) - swd(j)$$

When the amount I(j) is less than the amount required to cover the swd(j) then,

$$\Theta(j) = \Theta'(j) + [I(j)/t(j)],$$

and the amount infiltrating layer I(j+1) is zero.

The quantity used in determining the amount of water (q) passing the solute front is dependent upon the position of the solute front relative to the bottom of the root zone. When the solute depth is less than the bottom of the root zone, q is set at the amount infiltrating past the next layer below the solute front. Alternatively, when the solute front depth is greater than the root zone depth, q is set at the amount passing the layer beneath the root zone.

The third step in tracking the solute depth is finding the new solute depth. Using the q determined by the relative position of the solute front, the new front can be found from equation (1). Because the soil properties in equation (1) differ between soil layers, the value of q required to move the solute front to the bottom of the current layer must first be determined. Assuming the front is at the bottom of layer J, the required amount of water to move the solute front to the bottom of layer J+1 can be found by

$$w_r = t(J+1) * R(J+1) * \Theta_{FC}(J+1) .$$

R(J+1) is given by equation (2) derived with the soil properties in layer J+1. If w_r is sufficient to move the solute front below the bottom of the layer J+1, the step is repeated for the next soil layer. For the next layer the water available is reduced by w_r, replacing q with $(q-w_r)$. Equation (10) is then repeated until $w_r>q$, in which case a new formula is required to determine the depth, when the solute front is moved within a portion of the soil layer. The new depth of the front is given by

$$d_s=d_s'+q/[R(J+1)*\Theta_{FC}(J+1)],$$

where d's is the initial solute front depth.

The model also calculates the amount of active ingredient remaining. The equation is,

$$F=\exp[-time*\ln(2)/half\text{-}life]$$

where time is the number of days since the chemical was applied and the half-life represents the biological half-life.

APPENDIX B

PRODUCTION SYSTEMS

PRODUCTION SYSTEMS

Peanut Production Systems

Yields and production costs for the budgets are reflective of spanish peanuts. Spanish peanuts are characterized as lower yielding and with lower input costs (Beerwinkle, 1992). Economic theory would agree that for lower marginal value products, the producers would use fewer inputs. The spanish peanuts are thought to be more resistant to many pests, making them less dependant on pesticides (Jackson, 1991; Porter et al., 1992).

Pesticides.

Peanuts are grown with an assortment of pesticides. All systems have a base group of pesticides. These pesticides that make up the base group are assumed to be non leachers. This base group includes both a preplant and a postemergence tank mix of herbicide. The preplant, soil-incorporated tank mix includes 2.3 pints of Vernam and 3.0 quarts of Balan. The post emergence tank mix contains 1.5 pints of Blazer and 1.2 pints of Bugle. In addition to these herbicides, metolachlor is required as a secondary herbicide for late emerging annual weeds for systems using short rotations (two year rotations rather than a three year rotation) (Greer, 1992). The target weeds are broadleaf annuals and grasses. The herbicides are farmer-applied.

Bravo is used for control of foliar diseases such as leaf spot. The baseline assumes the producers are using some type of scouting service or advisory system, spraying for foliar disease only when needed. Budgets for peanuts include a charge for a scouting service (Beerwinkle, 1992; Jones, 1992). The use of a scouting service or advisory system generally reduces the number of pesticides required in a growing season (Crummett, 1992; Knudsen, Johnson and Spurr, 1988; Damicone, 1992). The budgets reflect this lower number of required sprays.

The foliar spray is commercially applied and charged to the budget. Each application is 1.5 pints per acre. The number of applications per season differs with the irrigation schedule. Irrigation contributes to a moist environment favorable for development of the foliar disease (Wright et al., 1986). The irrigated systems receive 4 treatments, and the dryland systems get 2 treatments.

There is an insecticide used in the base group. It is aerially applied by commercial pilots. Orthene is a broad spectrum insecticide used to control thrips and other insects. Orthene is applied at 1 lb. per acre.

The alternative nematicides already mentioned in the text are aldicarb and fenamiphos. The nematicides are not used in combination. All peanut systems use either aldicarb or fenamiphos. Control of nematodes is an important factor in maintaining high yields (Wheeler and Starr, 1988). The peanuts treated with fenamiphos yield only 94% of similar systems treated with aldicarb (Jackson and Mulder, 1993; Jackson and Russell, 1992). Table 30 shows the pesticide input costs for the peanut systems.

TABLE 30

PESTICIDE COSTS FOR PEANUT PRODUCTION SYSTEMS - DRYLAND AND IRRIGATED

		Irrigated		Dryland	
Group	Pesticide	2 Year Rotation	3 Year Rotation	2 Year Rotation	3 Year Rotation
PPI	Vernam	8.10	8.10	8.10	8.10
PPI	Balan	10.14	10.14	10.14	10.14
Post	Dual	10.29		10.29	
Post	Blazer	11.61	11.61	11.61	11.61
Post	Bugle	9.60	9.60	9.60	9.60
Foliar	Bravo	35.16	35.16	17.58	17.58
Insect.	Orthene	7.67	7.67	7.67	7.67
Nemat.	aldicarb	39.90	39.90	39.90	39.90
Nemat.	fenamiph.	43.10	43.10	43.10	43.10
Totals:					
aldicarb		132.47	122.18	114.89	104.60
fenamiphos		135.66	125.37	118.08	107.79

Irrigation Scenarios

The peanuts were irrigated under two levels and as a dryland crop. CMLS provided the automatic irrigation system for applying water when it was needed. Unfortunately, CMLS does not provide output on the amount of water applied per season. Therefor, irrigation costs are not explicitly linked to the weather experienced in one year.

Data from the peanut research Center at Ft. Cobb was used to determine the amount applied by risk averse producers using the high level of irrigation. Over a 5 year period the research station at Fort Cobb applied nearly 30 inches of water (Jackson et al., 1987-1991). This served as the proxy for the high irrigation level[1]. The weather data from the research station records a 5 year average rainfall during the growing season of over 21.3 inches. Table 31 has the water supply data for the peanuts during the growing season, mid-May to mid-October.

Peanuts need from 20 to 28 inches of well distributed water for growth and maturity (Henning, Allison and Tripp, 1982). Even though the rainfall appears to satisfy the peanut requirements, additional irrigation is needed. Sandy soils in the peanut producing area have limited water holding capacities of 5-7 days (Sholar et al., 1992). Low water holding capacities require irrigation to accomplish this even, plentiful distribution throughout the growing season.

The medium irrigation level was selected to reflect an attitude more like profit maximization. Spanish peanuts reach a yield plateau after total water supply reaches 60 cm (23.64 in) if the seasonal distribution is good (Boote et al., 1982). Reducing the high level by one-third would

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[1]It is assumed the test plot manager would not want irrigation to be a limiting factor when conducting research trials. Since the manager would appear to be risk averse to drought stress, the amount applied at the station was used as the high irrigation level for the study.

TABLE 31

GROWING SEASON WATER SUPPLY

Year	Rainfall	Irrigation	Water Supply
1987	24.39	28.0	52.39
1988	17.22	34.0	51.22
1989	23.36	32.0	55.36
1990	15.42	34.0	49.42
1991	26.18	20.0	46.18
Averages	21.30	29.6	50.90

still allow plenty of safety to supplement rainfall during times of soil water deficit. Therefore, the medium level was chosen at 20 inches of irrigation.

After the amount applied was established the costs could be determined. Using the budget generator the irrigation costs were found (Norris, 1991). The budgeted cost are long run averages and do not reflect any one year. The irrigation pumping charges are found in Table 32 which is the base budget with the alternative costs according to the production system.

Tillage and Fertilizer.

The tillage practices are the same for all peanut systems. The peanut ground is moldboard plowed, spread with fertilizer, disked twice, springtooth harrowed, and planted. The irrigated peanuts systems are planted with 100 lbs of seed while the dryland systems are planted with 75 lbs per acre. During the growing season, the peanuts are cultivated twice. All irrigated peanut systems receive 100 lb.s of 18-46-0. The dryland peanuts are fertilized with 85 lb.s of 18-46-0.

Miscellaneous Expenses

Peanuts are best suited to sandy soils (Henning, Allison and Tripp, 1982). Harvesting losses occur on heavy or clay soils. Also peanuts must be cleaned if they were grown on heavy soils to remove dirt clods. For peanut systems on soil 3, there is a $10/ton cleaning charge included. The previously discussed scouting charge is $5/acre for all systems. The operating interest charged during the growing season was 10% per year. The hauling costs were charged at $13/ton. For simplicity, all irrigated systems are charged the hauling charge at the ten year average yield of 2938 pounds. The dryland systems are charged at the ten year average yield of 1962 pounds. Table 32 has the baseline production costs in the first column. The other columns have what the input cost would change to if the alternative was selected. The adjusted cost refers to the inflated total input cost.

TABLE 32

PEANUT BASE BUDGET

Input	Base Cost	Dryland	3 Year Rotation	Fenami-phos
Seed	74.00	55.50		
Fertilizer	10.90	9.27		
Herbicides	49.70		39.41	
Insecticide	7.97			
Fungicide	35.16	17.58		
Aerial Spray	14.00	7.00		
Nematicide	39.90			43.10
Irrigation	55.50			
Machinery	36.66			
Interest	19.83	15.85	19.32	19.67
Scouting	5.00			
Hauling	19.10	12.75		
Total	365.44			
Inflated Total	376.13			

Cotton Production Systems

Because this study focused on the peanut pesticides, the cotton systems had fewer production differences. The tillage operations are moldboard plowing, spreading fertilizer, offset disking, tandem disking with preplant herbicide, springtooth harrowing, and planting. The cotton row middles are cultivated twice during the growing season. After the cotton is harvested the stalks are mowed. The irrigated cotton is fertilized with 133 lbs of 45-0-0 and 100 lbs of 18-46-0. The dryland cotton receives 90 lbs of

45-0-0 and 50 lbs of 18-46-0. The irrigated cotton is planted with 22 lbs of seed per acre while the dryland systems are planted with 15 lbs of seed. The base costs for the cotton production systems are in Table 33.

TABLE 33

COTTON BASE BUDGET

Input	Irrigated Cotton	Dryland Cotton
Seed	7.26	4.95
Fertilizer	22.60	13.37
Herbicide	5.04	5.04
Irrigation	14.80	
Machinery	33.34	33.34
Hauling	3.11	1.89
Interest	6.21	3.86
Total	92.35	62.45
Inflated Total	93.97	63.54

Grain Sorghum Production Systems

The tillage operations for grain sorghum are chisel plowing, spreading fertilizer, tandem discing, springtooth harrowing and planting. The row middles are cultivated twice during the growing season. A mid-season herbicide is applied. The grain sorghum is fertilized with 65 lbs of 45-0-0 and 65 lbs of 18-46-0.

TABLE 34

GRAIN SORGHUM BASE BUDGETS

Input	Cost
Seed	5.04
Fertilizer	12.81
Herbicide	1.02
Machinery	19.41
Interest	3.46
Hauling	2.88
Total	44.60
Inflated Total	45.38

Wheat Production Systems

Wheat for grain tillage operations are discing previous years stubble, sweep plowing with anhydrous ammonia, spreading dry fertilizer, tandem disking, springtooth harrowing and sowing. The wheat is top-dressed with nitrogen in early spring. Wheat planted for graze-out has the same tillage operations, but anhydrous ammonia is not applied with the sweep plow. Wheat for grain is fertilized with 70 lbs of 82-0-0 and 65 lbs of 18-46-0 in the fall. The wheat for graze-out is fertilized with 65 lbs of 18-46-0 and 75 lbs of 30-0-0 in the fall. All wheat is top-dressed with 30-0-0 in the spring to replenish fertility requirements consumed when the winter forage is grazed. Wheat for grain receives 100 lbs and wheat for graze-out receives 75 lbs.

TABLE 35

WHEAT BASE BUDGETS

Input	Wheat-Grain	Wheat-Grazeout
Seed	9.00	9.00
Nitrogen	10.90	9.75
Mixed Fertilizer	7.09	7.09
Machinery	16.27	16.27
Interest	3.66	3.62
Hauling	3.80	
Total	50.71	45.73
Inflated Total	51.60	46.53

APPENDIX C

CMLS RESULTS - UNADJUSTED AND ADJUSTED MEANS AND STANDARD DEVIATIONS

CMLS RESULTS - UNADJUSTED AND ADJUSTED MEANS AND STANDARD DEVIATIONS

CMLS estimated the amount of active ingredient leaching below the root zone. Means and standard deviations from the raw data are given in Tables 36 and 37.

TABLE 36

UNADJUSTED MEANS OF ACTIVE INGREDIENT REACHING THE GROUND WATER

Soil Type	Irrigation Level	aldicarb (lb/acre)	fenamiphos (.001 lb/a)	metolachlor (.001 lb/a)
1	high	.09744	.01238	.01241
	medium	.01702	.01238	.01207
	dryland	.00495	.0078	.00078
2	high	.02286	.00754	.00488
	medium	.00370	.00078	.00070
	dryland	.00048	.1E-11	.3E-14
3	high	.00080	0	.1E-32
	medium	.00019	0	0
	dryland	.00002	0	0

TABLE 37

UNADJUSTED STANDARD DEVIATIONS OF ACTIVE INGREDIENT REACHING THE GROUND WATER

Soil Type	Irrigation Level	aldicarb (lb/acre)	fenamiphos (.001 lb/a)	metolachlor (.001 lb/a)
1	high	.0511	.09098	.09120
	medium	.0266	.09098	.08883
	dryland	.0114	.01098	.01101
2	high	.0300	.05813	.04483
	medium	.0102	.01098	.00988
	dryland	.0024	.2E-10	.1E-10
3	high	.0037	0	.1E-31
	medium	.0011	0	0
	dryland	.0003	0	0

There were nine systems modeled with CMLS. These represented the combinations of the irrigation levels (high, medium or dryland) and the three soil types (high, medium and low leaching potential). There were a large number of observations at zero for a portion of the production systems.

A censored distribution has a lower (or upper) limit for the observation. For the remainder of the distribution the observations are widely dispersed throughout the distribution (Tobin, 1958). For the leaching data there was a lower limit of zero remaining active ingredient. Because they were censored the means and standard deviations of the distributions have to be adjusted.

Results for two production systems using aldicarb were censored. These two systems were dryland systems. They were on the low and medium leaching potential soils. These were the only aldicarb production systems that had observations at the limit.

The chemical properties for metolachlor and fenamiphos systems were similar, resulting in similar means and standard deviations. Under two production systems on the low leaching soil the observations of remaining active ingredient were all at the limit of zero. The high irrigation system on the low leaching soil and dryland system on the medium leaching soil were both less than 1×10^{-10}. Any observation below 1×10^{-10} is considered undetectable and observations below 1×10^{-20} are stretching the models estimation power (Nofziger, 1992). Thus, these four systems are assumed not to leach.

Of the remaining metolachlor and fenamiphos systems, two were never at the limit and consequently not adjusted. These two systems were the high irrigation systems on the high and medium leaching soils. Three systems were adjusted for the metolachlor and fenamiphos systems. They were dryland and medium irrigation on the high leaching soil and the medium irrigation level on the medium leaching soil. Each of these three systems had several observations at the limit.

The TOBIT procedure was performed on the data with the statistical software package SHAZAM to obtain the adjusted mean and variance of the censored normal distributions (White et al., 1990). TOBIT analysis generates a vector of normalized coefficients. This vector is transformed into the B vector by multiplying the normalized coefficients by the standard error of the estimate. For this study, to derive the adjusted means and standard deviations the intercept was suppressed. A vector of ones was used as the independent variable. The model took the form,

$$Y = BX$$

where the vector Y was the CMLS data, B is the adjusted mean and X was the vector of ones. The adjusted means and standard deviations are given in Tables 38 and 39.

TABLE 38

ADJUSTED MEANS OF ACTIVE INGREDIENT REACHING THE GROUND WATER

Soil Type	Irrigation Level	aldicarb (lb/acre)	fenamiphos (.001 lb/a)	metolachlor (.001 lb/a)
1	high	.09744	.01238	.01241
	medium	.01702	.01148	.01153
	dryland	.00495	.00078	.00078
2	high	.02286	.00754	.00488
	medium	.00370	.00074	.00063
	dryland	.00048	0	0
3	high	.00080	0	0
	medium	.00018	0	0
	dryland	.00001	0	0

TABLE 39

ADJUSTED STANDARD DEVIATIONS OF ACTIVE INGREDIENT REACHING THE GROUND WATER

Soil Type	Irrigation Level	aldicarb (lb/acre)	fenamiphos (.001 lb/a)	metolachlor (.001 lb/a)
1	high	.0511	.0910	.0936
	medium	.0266	.0958	.0888
	dryland	.0114	.0110	.0111
2	high	.0300	.0581	.0448
	medium	.0102	.0118	.0105
	dryland	.0024	0	0
3	high	.0037	0	0
	medium	.0011	0	0
	dryland	.0003	0	0

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