# USE OF GEOGRAPHIC INFORMATION SYSTEM AND A COMPUTER SIMULATION MODEL TO ESTIMATE VADOSE ZONE LOADING OF PESTICIDES

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## INTRODUCTION

Pesticide contamination of groundwater has become a major concern by the U. S. Environmental Protection Agency in recent years. The main source of drinking water in the United States is groundwater which is used by over 50% of the overall population and 95% of the rural population (Cheng and Koskinen 1985). Farm communities in the United States that are actively involved in crop production use pesticides to sustain yields. Most aquifers which are the sources of drinking water are recharged by downward movement of surface water through the soil profile. The primary soil and molecular factors affecting the transport of pesticides to the groundwater have been well documented (Wagenet and Hutson 1986).

There is much unknown about the extent of pesticide contamination of groundwater in Arkansas. Several research projects, in recent years, have been conducted where wells used for domestic and irrigation water uses have been sampled and analyzed for pesticides (Lavy et al. 1988; Nichols et al. 1993). For state and federal regulatory agencies, evaluation of the potential groundwater contamination begins with considering those areas in the state where pesticides are used. With relatively large cropland and only limited financial resources available for chemical analyses, the question of where these agencies should begin to sample the groundwater for pesticides is pertinent. Therefore, there is a need to develop a scheme that can be used to optimize the available, but scarce, resources. It was the objective of this study to estimate areas in Woodruff County, Arkansas, where the groundwater was highly vulnerable to pesticide contamination and to simulate the transport of mobile pesticides in those areas.

## MATERIALS AND METHODS

**Study Site Location.** The location of the study site was Woodruff County, Arkansas. Woodruff County lies in the Mississippi Alluvial Valley in eastern Arkansas. It consists of about 153,340 ha with 71% in farmland and 53% in crop harvested. The 1992 statistical reports on agricultural landuse documented that about 56,275 ha were planted in soybean; 22,672 ha in rice; 2,227 ha in cotton; 3,927 ha in corn; 9,514 ha in grain sorghum; and 13,765 ha in double cropped wheat (Arkansas Agricultural Statistics 1992). The Arkansas Soil and Water Conservation Commission recorded 1,108 irrigation wells in the county.

**Determination of the Vulnerable Areas.** The estimation of areas where the groundwater was vulnerable to pesticide contamination was accomplished by using a pesticide vulnerability model along with geographic information systems (GIS) techniques. The groundwater vulnerability model used in this study considered the characteristics given in Table 1. For each model characteristic, ranges within a factor were multiplied by the weighting factor. The resulting value was summed over the seven characteristics and the total designated as a pesticide groundwater vulnerability index (PGVI). The higher the PGVI, the more vulnerable the groundwater to pesticide contamination. The PGVI for a given area was then normalized to a scale of 1 to 100 by dividing the PGVI by the total possible index of 276 and multiplied by 100. Three sandy loam soils of the Bosket, Bulltown, and Wiville series were identified as having relatively high (≥80) PGVI. The spatial distribution of the relative high PGVI for Woodruff County is presented in Figure 1. A complete description of each model characteristic is given elsewhere (Smith et al. 1994).

**Simulation of Pesticide Transport in Soil.** The pesticide transport model chosen for this study was the Chemical Movement in Layered Soils (CMLS) model. This model has been fully described elsewhere (Nofziger and Hornsby 1986) and a revised version (Nofziger and Hornsby 1993) of the simulator was used in this work. The concept employed in the development of CMLS was that solute is moved by piston displacement through the soil profile and assumed that all rainfall or irrigation water infiltrated the soil. Since the intent of this work was to simulate a worse case scenario for pesticides loading of the vadose zone in sandy soils, the use of this model was appropriate. Simulation of pesticide transport through the soil profile requires considerable inputs on soil characteristics at the vulnerable sites, the types and characteristics of the pesticides applied, and weather data. These data were obtained from a variety of sources (Soil Conservation Service 1993; Wauchope 1992; Arkansas Extension Service

1992). The crop, soil, and pesticide input parameters for CMLS are presented in Table 2. Estimated area of soybean treated with pesticides, rate of pesticide application, and pesticide characteristics are presented in Table 3. Selected soil chemical and physical properties are presented in Table 4. Four pesticides were used in the simulation for each soil with soybean [Glycine max (L) Merr.] as the test crop in one growing season. However, the simulation was continued for 365 days. The pesticides applied in the simulation were bentazon [3-isopropyl-(1h)-benzo-2,1,3-thiadiazin-4-one 2,2-dioxide, trade name Bassagram] at 0.84 kg a.i/ha, imazaquin {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-quinolinecarboxylic acid, trade name Scepter} at 0.12 kg a.i./ha, linuron [N'-(3,4-dichlorophenyl)-N-methoxy-N-methylurea, trade name Lorox] at 0.42 kg a.i./ha, and metolachlor [2-chloro-6-ethyl-N-(2-methoxy-1methylethyl)acet-o-toluidide, trade name Dual] at 2.24 kg a.i./ha. Date of application for imazaquin and metolachlor was 1 June 1993 and for bentazon and linuron was 16 June 1993.

**Weather Data.** Weather data used in the simulation was generated by a submodel, Weather Generator, WGEN (Richard and Wright 1984). The submodel provided generated values of rainfall, maximum and minimum air temperatures, and solar radiation for n-years period at a given location. The rationale was that the occurrence of rainfall on a given day had a major influence on temperature and solar radiation for that day. Edwards and Mayfield (1990) provided WGEN parameters near the study site and a complete description of WGEN is given elsewhere (Richard and Wright 1984).

## RESULTS AND DISCUSSION

The random selection of sites to conduct groundwater quality study may result in the identification of non-vulnerable sites. At a time when both scientific and financial resources are scarce, the selection of vulnerable areas for such study is essential. The values of PGVI in Woodruff County ranged from 20 to 89 (Figure 1). The highest PGVI occurred from the central to the western portion of the county, while the lowest PGVI was observed in the eastern half. The total land area of the county covered 2.2% of PGVI ranging from 80 to 89 and 8.9% of PGVI ranging from 70 to 79. These relatively high PGVI are located near the Cache and White Rivers. The high PGVI indicates the capacity of the hydrologic environment and the landscape factors to readily move water borne contaminants to the groundwater.

Of the three pesticides used in the simulation, linuron was the most sorbing while imazaquin was the least (Table 3). Bentazon had the lowest percentage of mass (0.0003) remaining, while metolachlor had the highest (5.8). The mass remaining for imazaquin was 1.3% and that of linuron was 1.4%. The front of bentazon was located the deepest (261 to 324 cm), while linuron was located the shallowest (29 to 32 cm, Table 5). The location of the front of linuron was not surprising since it was the most sorbing of all the pesticides used in the simulation. Assessment of pesticides in the vadose zone and groundwater is largely dependent on the nature and property of the pesticides, the quantity of the pesticides applied, the hydraulic and physical properties of the aquifer, and the degree of health hazards they may pose in the environment (Moreau and Danielson 1990). As was illustrated in the simulation, soil properties and pesticide sorption characteristics played major roles in determining the position of the pesticides in the soil after one year of elapsed time. It was shown that pesticides with high partition coefficients (i.e. the sorptive ability of the soil-pesticide combination) have large impact on the pesticides redistribution in the soil profile (Tables 3 and 5). This impact, on some cases, may be influenced by the organic carbon content in the soil.

Three of the pesticides simulated had medium leaching potential except for imazaquin with a high potential to leach. The physico-chemical process of fluid movement in the soil profile is of prime importance in the study of groundwater loading. While the leaching potentials of the pesticides under study ranged from medium to high, the maximum depth of the least sorbing pesticide (imazaquin) was less than 5 m (Table 5). Groundwater monitoring for possible contaminants requires a systematic scheme to identify the loci of contamination. The combination of GIS and pesticide transport model can be useful in predicting the most vulnerable locations of groundwater for pesticide contamination.

## REFERENCES


Arkansas Agriculture Statistics. 1992. Arkansas Agricultural Experiment Station Report Series 325.

Arkansas Cooperative Extension Service. 1992. Groundwater state management plan.

Cheng, H.H. and W.C. Koskinen. 1985. Processes and factors affecting transport of pesticides to ground water. Evaluation of pesticide in ground water. Am. Chem. Soc. Symposium series 315. 2-13.

Edwards, D.R. and J.D. Mayfield. 1990. Computer generation of daily weather data for Arkansas. Arkansas Farm Research No. 39(6):8.

Levy, T., J. Mattice, J. Massey, S. Skullman, S. Senseman, and E. Gbur. 1988. Minimizing the potential for groundwater contamination due to pesticides. EPA Award N. CRT-815154-01-0.

Moreau, D.H. and L.E. Danielson. 1990. Agricultural pesticides and groundwater in North Carolina: Identification of the most vulnerable areas.

Nichols, T., P. Vendrell, K. Steele, C. Armstrong, and H.D. Scott. 1993. Arkansas state pesticides in groundwater monitoring project. Completion Report. Arkansas Water Resources Center Miscellaneous Report No. 136.

Nofziger, D. L. and A. G. Hornsby. 1986. A microcomputer-based management tool for chemical movement in soil. Applied Agric. Research. 1(1):50-56.

Nofziger, D.L. and A.G. Hornsby. 1993. Chemical movement in layered soils (CMLS; beta testing version). Department of Agronomy, Oklahoma State University, Stillwater, OK.

Richardson, C.W. and D.A. Wright. 1984. WGEN: A model generating daily weather variables. USDA-ARS, ARS-8.

Smith, P.A., H.D. Scott, and T. Fugitt. 1994. Influence of geographic database scale on prediction of groundwater vulnerability to pesticides. J. of soil Contamination. 3(3):285-298.

Soil Conservation Service. 1993. Soil survey for Woodruff County, Arkansas.

Wagenet, R.J. and J.L. Hutson. 1990. LEACHP: Leaching Estimation and Chemical Model-Pesticides. Department of Soil, Crop and Atmospheric Sciences, Cornell University, Ithaca, NY.

Wauchope, R.D., T.M. Butler, A.G. Honsby, P.W.M. Augustin-Beckers, and J.P. Burt. 1991. The SCS/ARS/CES pesticide properties database for environmental decision-making. Rev. Environ. Toxicol. 123:1-155.

**Table 1. Characteristics and weighting factors of the groundwater vulnerability model.**

| Model Characteristics | Weighting Factor |
|---|---|
| Depth to groundwater | 5 |
| Recharge | 4 |
| Aquifer Media | 2 |
| Soil Influence | 6 |
| Topography | 3 |
| Impact of Vadose Zone | 7 |
| Conductivity of the Aquifer | 2 |

**Table 2. Crop, soil and pesticide input parameters required for CMLS.**

| | |
|---|---|
| Crop parameter | *Crop coefficient<br>*Rooting depth |
| Soil Parameter<br>(required by depth) | *Organic carbon<br>*Percent saturated water content<br>*Percent drainage upper limit<br>*Percent drainage lower limit<br>*Bulk density |
| Pesticide parameter | *Half-life<br>*Partition coefficient |

Table 3. Estimated area of soybean treated with pesticides in Woodruff County, application rates and pesticides characteristics.

| Pesticide | Area | Rate of application | Half-life[a] | Partition coefficient[a] | Leaching potential[b] |
|---|---|---|---|---|---|
| | (ha) | (kg a.i./ha) | (days) | (ml/g Oc) | |
| Bentazon | 9,567 | 0.84 | 20 | 34 | Medium |
| Imazaquin | 16,883 | 0.12 | 60 | 20 | High |
| Linuron | 2,251 | 0.42 | 60 | 400 | Medium |
| Metolachlor | 14,069 | 2.24 | 90 | 200 | Medium |

[a]Adopted from Wauchope 1992.

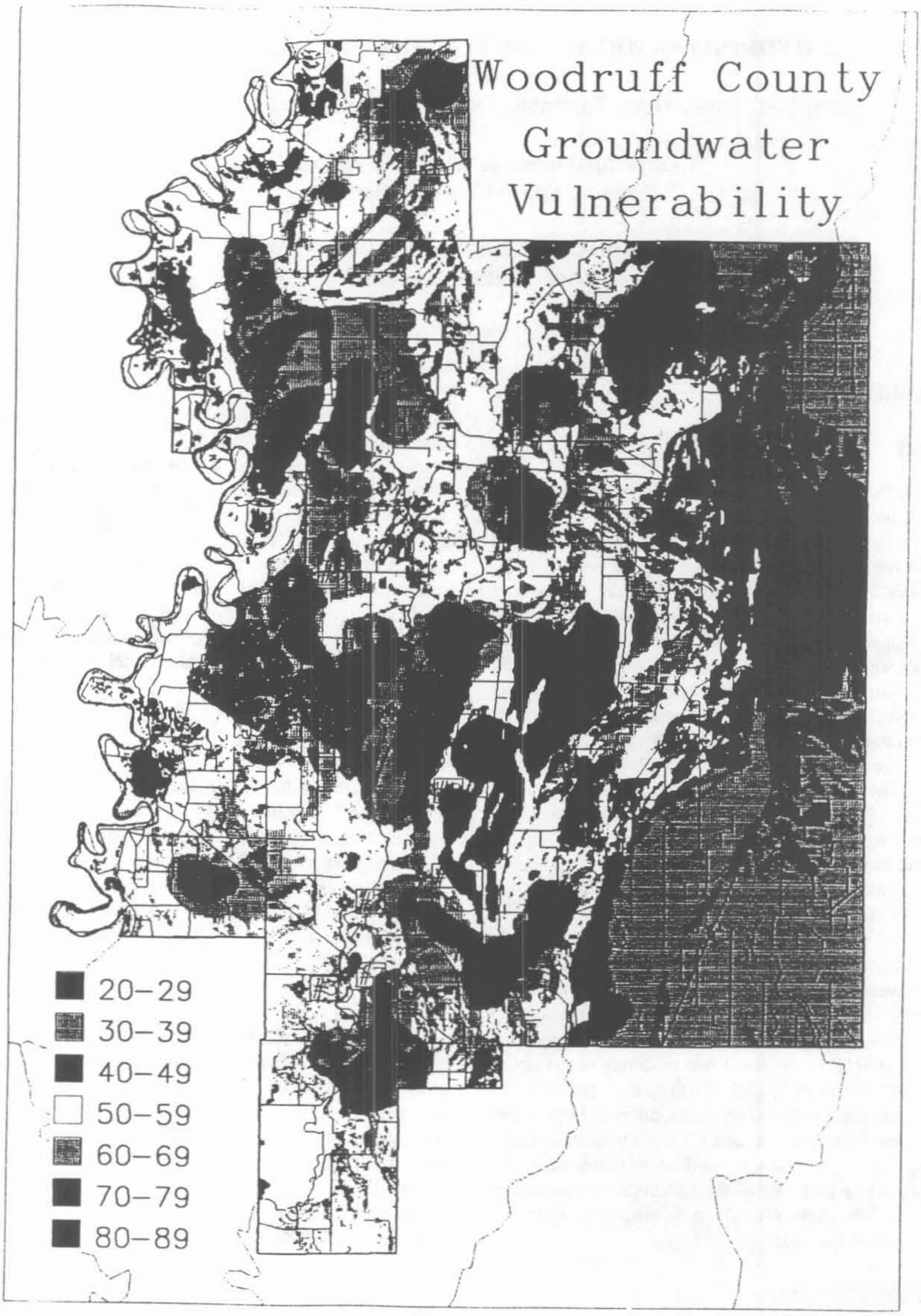
[b]Adopted from Arkansas Cooperative Extension Service 1992.

Table 4. Selected soil chemical and physical characteristics required for CMLS.

| Soil | Depth | OC | Sat | DUL | LL | BD |
|---|---|---|---|---|---|---|
| | (m) | | ----------- % ----------- | | | (g/cm$^3$) |
| Bosket sl | 0.46 | 0.73 | 42.5 | 18.9 | 5.9 | 1.40 |
| | 0.86 | 0.29 | 42.5 | 18.9 | 5.9 | 1.40 |
| | 1.22 | 0.29 | 43.1 | 29.0 | 18.0 | 1.38 |
| | 1.52 | 0.29 | 42.5 | 18.9 | 5.9 | 1.40 |
| Bulltown sl | 0.20 | 0.73 | 37.4 | 18.8 | 6.3 | 1.55 |
| | 0.66 | 0.44 | 37.4 | 18.9 | 6.5 | 1.55 |
| | 1.30 | 0.44 | 39.7 | 20.4 | 19.5 | 1.48 |
| | 1.75 | 0.44 | 37.4 | 19.6 | 17.6 | 1.55 |
| | 2.03 | 0.44 | 37.4 | 17.5 | 5.9 | 1.55 |
| Wiville sl | 0.28 | 0.73 | 39.1 | 24.1 | 9.6 | 1.50 |
| | 0.46 | 0.44 | 38.0 | 20.5 | 8.8 | 1.53 |
| | 1.43 | 0.44 | 38.0 | 21.2 | 10.4 | 1.53 |
| | 1.62 | 0.44 | 38.0 | 23.2 | 9.1 | 1.53 |
| | 2.03 | 0.44 | 37.4 | 19.8 | 7.3 | 1.55 |

Table 5. Maximum depth (cm) as a function of pesticides after one year of simulation.

| Pesticide | Bosket sl | Bulltown sl | Wiville sl |
|---|---|---|---|
| Bentazon | 323.9 | 278.6 | 261.2 |
| Imazaquin | 198.6 | 186.1 | 172.5 |
| Linuron | 30.3 | 32.2 | 28.9 |
| Metolachlor | 32.7 | 37.1 | 32.4 |


Woodruff County
Groundwater
Vulnerability
20–29
30–39
40–49
50–59
60–69
70–79
80–89