# AGRICULTURAL PESTICIDES AND GROUNDWATER IN NORTH CAROLINA: IDENTIFICATION OF THE MOST VULNERABLE AREAS

by

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# INTRODUCTION

The popular press has reported widespread contamination of groundwater by agricultural pesticides in the midwestern states, Florida, and elsewhere. As a result of the media reports, North Carolinians are asking with increasing frequency: Is North Carolina's groundwater being contaminated by pesticides? Unfortunately, that question cannot be answered fully with existing information.

It is commonly known that North Carolina is a large consumer of agricultural pesticides, and many people are also aware that a part of the state, namely the Coastal Plain, is underlain by groundwater aquifers that are particularly vulnerable to contamination. Some experts have pointed out, however, that factors like soils, aquifer types, and temperatures in North Carolina are quite different from those in other states where widespread contamination has been found. They point out that soils in this region are less acidic than those in the Midwest and that temperatures are considerably higher. Both of these factors have important effects on the chemistry and biology of pesticides in the soil and subsurface environment. The implication is that North Carolina is unlikely to have problems of groundwater contamination similar to those reported for the Midwest and Florida.

However, this is an assumption that can be neither proved nor disproved because the information base needed to assess the threat that pesticides pose to groundwater in North Carolina does not exist. Rates of pesticide use are not reported in North Carolina, and there is no history of comprehensive monitoring for pesticides in groundwater.

A survey for pesticides in groundwater has been proposed by the Interagency Working Committee on Groundwater Monitoring (IWCGM, 1988), but that activity has not yet begun. Such a survey could produce some of the information needed to evaluate the pesticide threat. The information in this report is intended to aid in the assignment of priorities to pesticides and areas of the state where monitoring should occur.

Design of monitoring systems for pesticides in groundwater should be based on information about both the pesticides and the medium through which they are moving. Among the most important aspects of the pesticides are: (1) identification of the particular set of pesticides that are being used; (2) quantities and spatial patterns in which these chemicals are being used; (3) their potential for movement in the unsaturated and saturated zones of affected aquifers; and (4) adverse effects on human health and the environment that are associated with exposure to these chemicals.

Among the more important characteristics of the aquifers are: (1) types of soils and rock; (2) stratigraphy; and (3) depth to the saturated zone.

Without this information, monitoring systems are likely to be inefficient and unnecessarily costly. Without knowledge of what kinds of pesticides may be present, analytical methods become costly, and their results are less precise. Furthermore, the simple fact that a particular pesticide, say A, is being used in an area may not be sufficient to justify its inclusion in a monitoring program. If another pesticide, say B, with leaching properties similar to A is being used in much greater amounts than A, then it may be sufficient to monitor only for B, at least until it is established that B is contaminating groundwater at unacceptable levels. If the same pesticide is being used at similar rates in two different locations, then it may be sufficient to monitor in only one of those locations where pesticides are more like to move into groundwater aquifers.

This report responds to North Carolina's needs for information on pesticide use and areas of vulnerability. Estimates of quantities and spatial patterns of use are reported for the most heavily used pesticides that have the potential to leach into groundwater. Secondary data sources were used to construct these estimates. In addition, those counties which have the highest potential for groundwater contamination are identified. Identification of these counties is based on a combination of pesticide use and indicators of the vulnerability of aquifers that underlie each county in the state.

Among the limitations of this analysis, two are worthy of special note at the beginning. One results from using counties as the unit of spatial analysis. Variations in cropping patterns, rates of pesticide use, soils, and the structure of aquifers within counties can result in subareas of some counties being more likely to be contaminated that is indicated when using county-wide averages. Another limitation is that no attempt is made here to evaluate human health impacts of pesticide use. Such an effort would require, in addition to the analysis presented here, an evaluation of the toxicity of pesticides and an estimate of the extent and intensity to which users are exposed to contaminated water. Given the limited data now available, such an effort does not seem to be justified.

## AGRICULTURAL PESTICIDES IN NORTH CAROLINA

Pesticides are important in North Carolina. In 1989 there were 11,852 brand-name products registered under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) for use in North Carolina. Many of those products are household disinfectants and other products that do not pose great risks to consumers, but over 2100 of those products have been included on list of "Restricted Use Pesticides" as established by the U.S. Environmental Protection Agency. Products included on that list

Table 1. Pesticides With High Leaching Potential

| LEACHING POTENTIAL | |
|---|---|
| LARGE | MEDIUM |
| <u>Herbicides</u> | <u>Herbicides</u> |
| atrazine | aciflurfen |
| chlorimuron | alachlor |
| chloramben | ametryne |
| chlorsulfuron | amitrole |
| clomazone | bentazon |
| dalapon | cyanazine |
| dicamba | dichlobenil |
| ethofumesate | EPTC |
| fomesafen | imazethabenz |
| hexazinone | linuron |
| imazapyr amine | metolachlor |
| MCPA | molinate |
| metribuzin | pebulate |
| metsulfuron-methyl | vernolate |
| propachlor | |
| propanil | |
| pyrazon | |
| simazine | |
| terbacil | |
| <u>Insecticides</u> | <u>Insecticides</u> |
| aldicarb | dimethoate |
| carbofuran | fonofos |
| diazinon | lindane |
| ethoprop | methomyl |
| trichlorfon | mevinphos |
| | phorate |
| | <u>Fungicides</u> |
| | carboxin |
| | dichloropropene |
| | ferbam |
| | metalaxyl |
| | propiconazole |
| | thiadimefon |
| | vinclozolin |

can be purchased only by trained and licensed users. The North Carolina Agricultural Chemicals manual produced annually by the Agricultural Extension Service lists 400-500 brand-name chemicals, 150-200 of which are "restricted use" products. Over 80 common (generic)-name agricultural pesticides are on the restricted use list.

Several of these chemicals are used in large quantities. One recent estimate puts the use of selected pesticides in North Carolina at 10.8 million pounds per year (Gianessi, 1986). Since North Carolina is one of the larger agricultural states in the country that is to be expected. When ranked by the annual amounts of all pesticides used, this state falls well below national leaders like Iowa, Illinois, and Minnesota. It also falls below several other mid-western states, California, and Texas. For selected pesticides, however, North Carolina accounts for a significant share of national totals. About 24 percent of the national use of ethoprop occurs in North Carolina, primarily for tobacco and peanuts; 13 percent of national vernolate use and nearly 10 percent of carbaryl use occurs here, as does 7 percent of metiram (for apples) and about 5 percent of the national use of acifluorfen (Gianessi and Puffer, 1988).

Data exist to show that pesticides have found their way into some wells used to supply drinking water to municipalities and individual households, but those data are of such limited scope that no general conclusions can be drawn from them (for a discussion of past monitoring for pesticides and groundwater in NC, see Appendix A of IWCGM, 1988). No instances of widespread contamination have been reported in North Carolina, but very little effort has been made to determine whether such conditions exist.

Leaching Potential

Not all pesticides are equally likely to leach into groundwater. Some pesticides have chemical properties that make them highly adsorptive to soil particles, a property that is measured by the soil adsorption coefficient of each pesticide. Furthermore, some pesticides are readily degradable in the environment as indicated by their very short half-lives in soils. A first step toward the establishment of priorities among pesticides based on their potential to contaminate groundwater is to identify those that have relatively small adsorption coefficients and long half-lives.

The U.S. Department of Agriculture (USDA), through state offices of the Soil Conservation Service (SCS) and Cooperative Extension Service, has developed a classification system based on these properties in its prototype standards and specifications for nutrient and pest management. (SCS, 1989a) This classification is incorporated in field office technical guides for each state (SCS, 1989b). Each pesticide used in a state was rated by its potential loss to leaching, the potential being either "Large", "Medium", "Small", or "Very Small". In this report, attention is limited to pesticides rated as having either large or medium potential for leaching. A list of those pesticides is given in Table 1 by type of pesticide and leaching class. That list contains 24 common-name pesticides with large leaching potential and 27 with medium leaching potential.

In designing its survey, the IWCGM identified 31 pesticides that satisfied two criteria: (1) they were rated by the U.S. Environmental Protection Agency as having the greatest potential for leaching into groundwater; and (2) they were commonly used on crops in North Carolina. Of those 31 chemicals, 22 are listed in Table 1 and 9 are not. The absence of 4 of those chemicals is attributed to the fact that the Soil Conservation Service, from whom Table 1 was derived, rated carbaryl, chlorothalonil, disulfoton, and trifluralin as having "Small" potential to leach into groundwater. All of those 4 were rated by SCS as having either a large or medium potential for movement in surface runoff, but they were rated as having a small potential to move into groundwater. The other 5 identified by the IWCGM (butylate, diphenamid, diuron, fluometuron, and oxamyl) were not listed by SCS.

Rates of Use

A second step in selecting priority pesticides for assessing groundwater contamination potential is to identify pesticides that are heavily used in the state. Unfortunately, primary data on use are not available in North Carolina. In an effort to construct a national data base of pesticide use, Gianessi (1986) noted that North Carolina was among four major agricultural states that had no reports of any kind. The absence of primary data makes the identification of priority pesticides more difficult, and it makes estimates based on secondary data sources more uncertain. It does not make the task impossible, however.

Gianessi and Puffer (1988) estimated pesticide use in North Carolina by multiplying acreage of major crops by crop-specific effective application rates for selected pesticides. An effective application rate is defined as the actual application rate of a specific pesticide to a specific crop in pounds per acre per year multiplied by the fraction of crop that is treated with that pesticide. Those rate coefficients were compiled from a variety of special studies such as the pesticide assessment of field corn and soybeans in the Southeast (USDA, 1985).

Although estimates constructed in this manner may be the best available, a number of limitations are associated with their

## Table 2. Estimated Pesticide Use in North Carolina in 1988 by Type of Crop (from Gianessi and Puffer, 1988)

CROP (Use in lbs/yr)

| Pesticide | Fruits & Vegetables | Alfalfa | Grains | Alfalfa & Other Hay | Pasture | Corn | Cotton | Peanuts | Potatoes | Sorghum | Soybeans | Tobacco | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aciflurofen | | | | | | | | 5,817 | | | 118,781 | | 124,598 |
| Alachlor | | | | | | 1,610,323 | | 238,652 | | 16,830 | 1,544,148 | | 3,409,953 |
| Atrazine | | | | | | 2,037,924 | | | | 22,441 | | | 2,060,365 |
| Carbofuran | 7,562 | 30,249 | | 30,249 | | 312,967 | | 1,641 | 12,765 | | 128,388 | 66,862 | 590,683 |
| Cyanazine | | | | | | 68,234 | 3,438 | | | | | | 71,672 |
| 2,4 - D | 120 | | 49,083 | 27,183 | 138,600 | 144,050 | | | | 4,675 | | | 363,711 |
| Diazinon | 1,278 | 30,249 | | 30,249 | | | | | 16,894 | | | 20,599 | 99,269 |
| Ethoprop | | | | | | 90,978 | | 23,866 | 104,943 | | 41,223 | 125,496 | 686,506 |
| Malathion | 1,212 | | 27,517 | | | | | | | | | 4,052 | 32,781 |
| Metalachlor | 112 | | | | | 489,768 | | 14,916 | 14,360 | 16,830 | 205,420 | | 741,406 |
| Methyl Parathion | 106,938 | | | | | | | | | | 72,316 | 30,799 | 210,053 |
| Phorate | | | | | | 12,130 | 206 | 48,028 | 480 | | 54,499 | | 115,343 |
| Vernolate | | | | | | | | 236,266 | | | 137,296 | | 373,562 |

use. First, the data are incomplete. There are 51 pesticides listed in Table 1 with either large or medium leaching potential. There are only 25 pesticides listed in Gianessi's matrix, and 12 of those are classified as having small leaching potential. While the set of available rate coefficients covers most of the pesticides widely used in the state, it obviously does not cover all of those with large and medium leaching potential. Second, pesticide application rates vary over time. The available coefficients were compiled from a series of studies that spanned several years in the mid-1980's; they may not be representative of application rates in 1988, the year for which latest crop figures are available. A third limitation arises from the variability in application rates by region of the state. Coefficients taken from the literature are often based on regional or even multi-state averages.

Of the 25 pesticides covered by the Gianessi-Puffer data set, 13 were rated by USDA as having large or medium leaching potential. As can be seen in Table 2, those 13 account for about 8.9 million pounds annually in North Carolina. That total is nearly 90 percent of the total poundage reported for all pesticides on the Gianessi-Puffer list. Because a large number of other pesticides with medium or large leaching potential are not included in the SCS list mentioned earlier, it is not possible to estimate from that data how much of all pesticide use is accounted for by the 13. Conversations with a number of agricultural experts suggest that this list covers most of the important uses in the state. Table 2 shows estimated uses of these chemicals by crop.

These estimates point to atrazine as the most heavily used pesticide in North Carolina with a large leaching potential. Its primary use is on corn. Other pesticides with large leaching potential used in substantial quantities in North Carolina include carbofuran, used heavily on soybeans, and ethoprop, used on tobacco. Pesticides with medium leaching potential used in North Carolina in significant amounts include alachlor, widely used on corn, peanuts, and soybeans; metolachlor, heavily used on corn and soybeans, and vernolate, applied to peanuts.

## Spatial Patterns of Intensity of Use

Spatial patterns of pesticide use intensity in North Carolina can be determined from county-level use estimates. General patterns have been determined by making estimates for the most important pesticides on crops with the largest acreage. While the patterns identified in this manner may not be complete, they are sufficient to locate the primary areas of use in the state while reducing the size of the data base that is required for analysis. As shown in Table 3, five crops account for large fractions of the total amounts of most of the pesticides of interest in this study.

Table 3. Percent of Pesticide Use Accounted for by Selected Crops

| | CROP | | | | |
|---|---|---|---|---|---|
| PESTICIDE | Wheat | Corn | Peanuts | Soybeans | Tobacco |
| Aciflurfen | | | 4.67 | 95.33 | |
| Alachlor | | 47.22 | 7.00 | 45.28 | |
| Atrazine | | 98.91 | | | |
| Carbofuran | | 52.98 | 0.28 | 21.74 | 11.32 |
| Cyanazine | | 95.20 | | | |
| 2,4-D | 13.50 | 39.61 | | | |
| Diazinon | | | | | 20.75 |
| Ethoprop | | 13.25 | 3.48 | 6.00 | 61.98 |
| Malathion | 83.94 | | | | 12.36 |
| Metolachlor | | 66.06 | 2.01 | 27.71 | |
| Methyl Parathion | | | | 34.43 | 14.66 |
| Phorate | | 10.52 | 41.64 | 47.25 | |
| Vernolate | | | 63.25 | 36.75 | |

County-level estimates of pesticide use on these five crops have been made by adding crop-specific estimates for each pesticide within each county. Estimates for each pesticide for each crop in each county were constructed by multiplying the Gianessi-Puffer coefficients by county-level acreage figures for each of the crops. The pesticide use coefficients are given in Table 4. Crop data was for 1988 (N.C. Department of Agriculture, 1989). Results of these calculations showing use by county for selected pesticides are given in the appendix to this report.

Raw estimates of use by county should be adjusted by size of county to better reflect spatial patterns of intensity of use. Without some form of adjustment for size, larger counties might standout simply because of their size and not because of the intensity of pesticide use. That adjustment can be made on the basis of one of several possible indicators of county size -- total land area, total cropland, or cropland for the five selected crops. For this purpose, the total land area seems to be an appropriate basis for adjustment. No important differences were noticeable between spatial patterns or intensity using total land area and those using total cropland. There are obvious limitations, however, to the use of total land area to adjust for size. Pesticide use divided by total land area of the county represents the intensity of use as if the pesticides were spread

Table 4. Pesticide Treatment and Use Coefficients (from Gianessi and Puffer, 1988)

| PESTICIDE | PERCENT OF CROP TREATED | | | | |
|---|---|---|---|---|---|
| | Tobacco | Corn | Soybeans | Wheat | Peanuts |
| Alachlor | | 59.00 | 40.00 | | 80 |
| Aciflurfen | | | 17.00 | | 13 |
| Atrazine | | 96.00 | | | |
| Carbofuran | 4.50 | 24.00 | 7.00 | | 1 |
| Cyanazine | | 3.00 | | | |
| Diazinon | 12.20 | | | | |
| Ethoprop | 20.00 | 4.00 | 2.00 | | 8 |
| Malathion | 1.00 | | | 5.00 | |
| Methyl Parathion | 2.40 | | 6.00 | | |
| Metolachlor | | 19.00 | 7.00 | | 5 |
| Phorate | | 1.00 | 3.00 | | 23 |
| 2,4-D | | 19.00 | | 69.00 | |
| Vernolate | | | 3.00 | | 66 |

| PESTICIDE | APPLICATION RATE, lbs/acre/yr | | | | |
|---|---|---|---|---|---|
| | Tobacco | Corn | Soybeans | Wheat | Peanuts |
| Alachlor | | 1.8 | 2.21 | | 2 |
| Aciflurfen | | | 0.4 | | 0.3 |
| Atrazine | | 1.4 | | | |
| Carbofuran | 4.4 | 0.86 | 1.05 | | 1.1 |
| Cyanazine | | 1.5 | | | |
| Diazinon | 2.5 | | | | |
| Ethoprop | 6.3 | 1.5 | 1.18 | | 2 |
| Malathion | 1.2 | | | 0.69 | |
| Methyl Parathion | 3.8 | | 0.69 | | |
| Metolachlor | | 1.7 | 1.68 | | 2 |
| Phorate | | 0.8 | 1.04 | | 1.4 |
| 2, 4-D | | 0.5 | | 0.5 | |
| Vernolate | | | 2.62 | | 2.4 |

evenly over all lands in the county, and, of course, it underestimates the rate of use in particular areas of the county. Nonetheless, because the analysis is intended to identify broad areas of the state where these pesticides are used most intensely, this approach is acceptable.

Spatial patterns for use of the seven compounds in Table 2 for which estimated use exceeded 250,000 pounds in NC in 1988 are shown in Figures 1-7. The scale used to indicate relative intensity of use is the ratio of intensity in each county to the average intensity over all counties. That scale is divided into 5 intervals, namely: 0 to 0.5 times the average; (2) 0.51 to 1.0 times the average; (3) 1.01 to 1.5 times average; (4) 1.51 to 2.0 times average; and (5) over twice the average.

A scan over all seven of these figures leads to the obvious and expected conclusion that most of the heavy pesticide use is in the Coastal Plains region. That, of course, is where agricultural production is most highly concentrated.

Some differences exist among the various pesticides. Because they tend to be used on similar crops, alachlor, atrazine, carbofuran, and metolachlor have similar patterns of use, heaviest in a broad band of 25 or more coastal plains counties extending from South Carolina to Virginia. Use of 2,4-D is more widely distributed across the state, probably even more so than is shown in Figure 5 because that figure does not reflect its use on pastures as indicated in Table 2. Because ethoprop is used on a variety of crops, including tobacco, its use is also more widely dispersed. Even so, it shows up in many of the same counties as alachlor, atrazine, carbofuran, and metolachlor. Vernolate use is heavily influenced by the distribution of the peanut crop and tends to be more heavily used in 10-12 northeastern counties.

## VULNERABLE AQUIFERS

Areas where the use of pesticides with high leaching potential is heaviest also cover some of the state's most vulnerable aquifers. From these aquifers water is drawn to serve a number of municipalities and a large number individual rural households. As shown in Figure 8, the principal aquifers in North Carolina are those in the Coastal Plains.

A somewhat more detailed county-level analysis of the relative vulnerability of aquifers is provided by the so-called DRASTIC index. That index, developed by the National Water Well Association (NWWA) for the U.S. Environmental Protection Agency (Aller et al., 1985), has been widely used in recent years for determining the relative vulnerability of different areas to

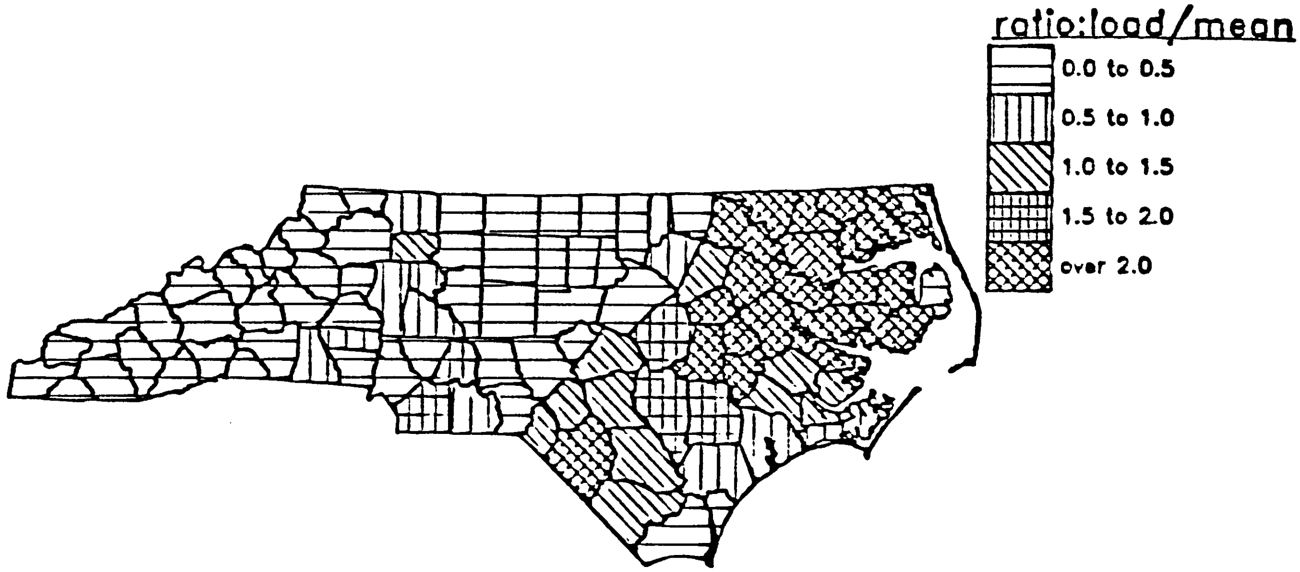


Figure 1. Relative Intensity of Alachlor Use

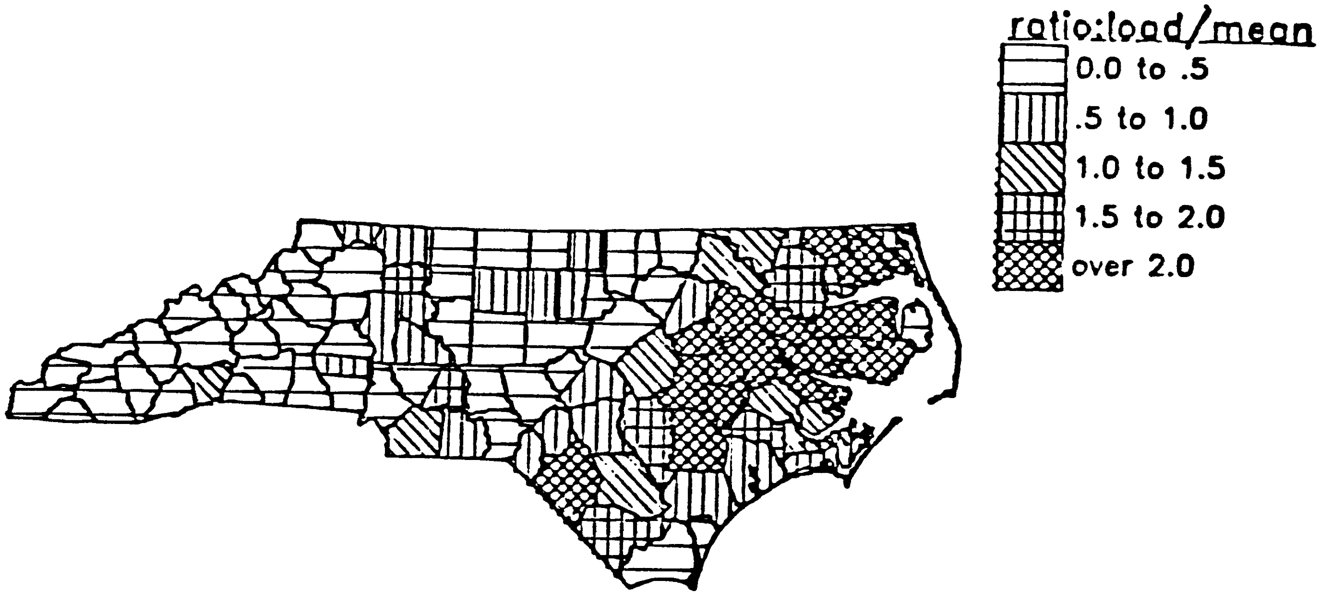


Figure 2. Relative Intensity of Atrazine Use

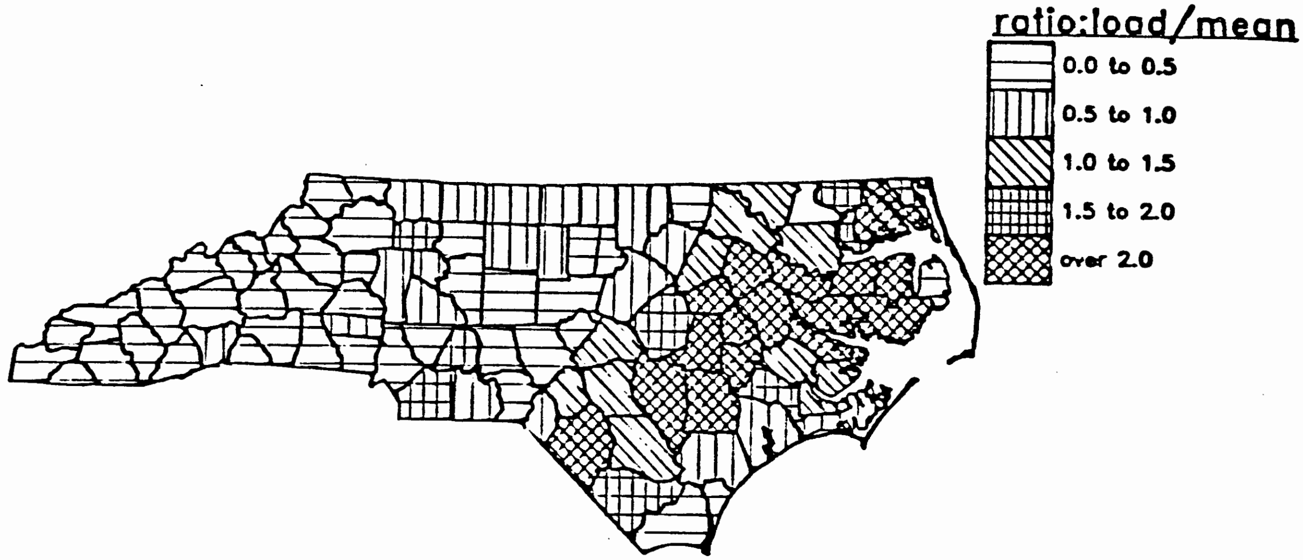


Figure 3. Relative Intensity of Carbofuran Use

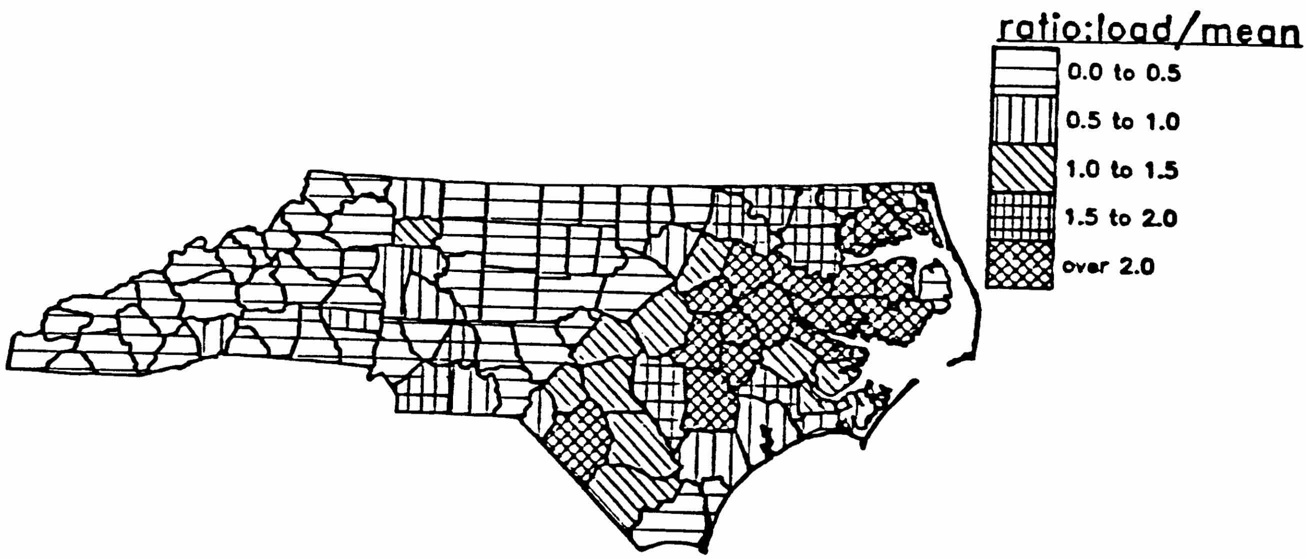


Figure 4. Relative Intensity of Metolachlor Use

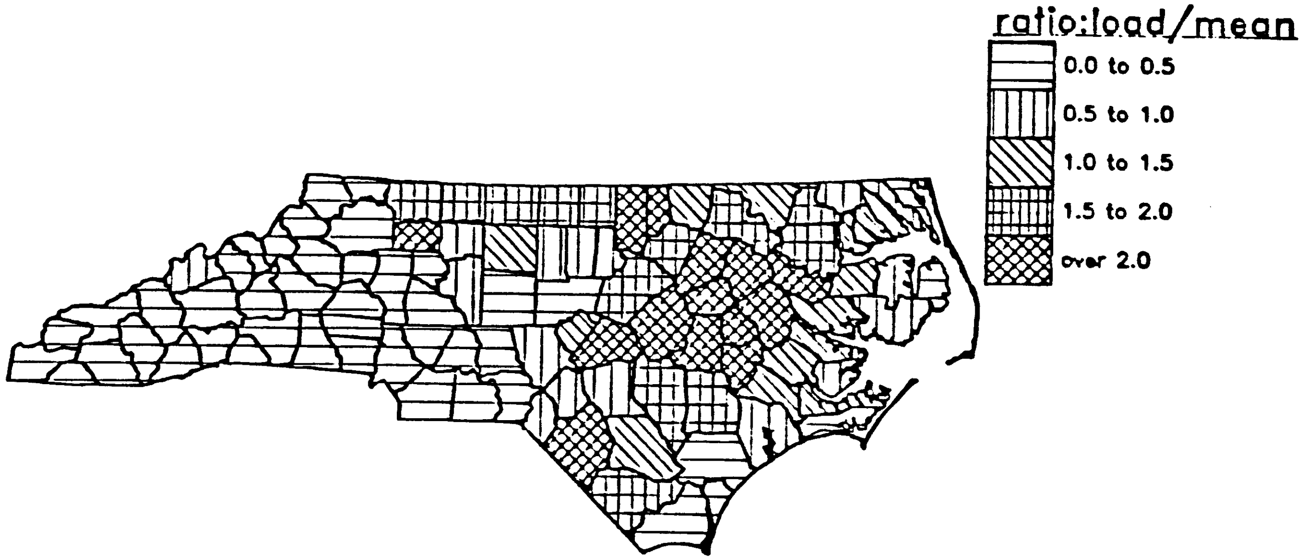


Figure 5. Relative Intensity of Ethoprop Use

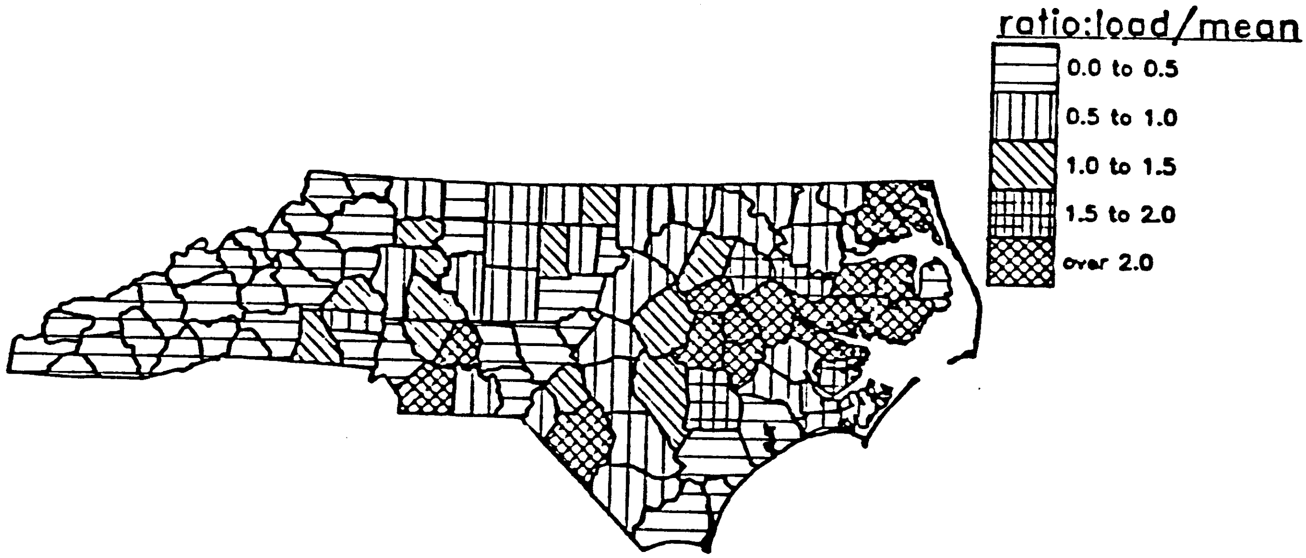


Figure 6. Relative Intensity of 2,4-D Use

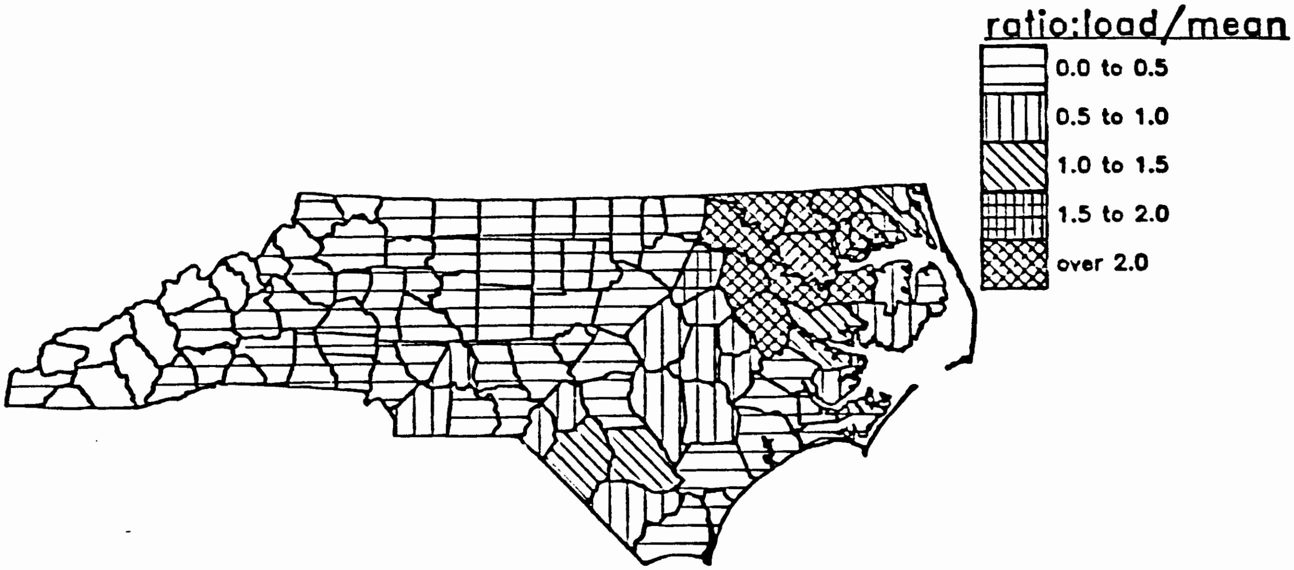


Figure 7. Relative Intensity of Vernolate Use

groundwater pollution. It uses a set of weights and rankings to combine into a single index of pollution potential several factors that affect the migration of chemicals into groundwater. Those factors are:

- D - depth to water table;
- R - recharge (net);
- A - aquifer media;
- S - soil media;
- T - topography;
- I - impact of the vadose zone media; and
- C - conductivity (hydraulic) of the aquifer.

In the process of developing an index for these variables, expert opinion has been used to establish a sets of weights, ranges, and ratings for each of those factors. A set of relative weights, ranging from 1 to 5, was established to reflect the relative importance of the seven factors listed above. One set of weights has been established especially for the analysis of agricultural pesticides. Those weights are reproduced in Table 5.

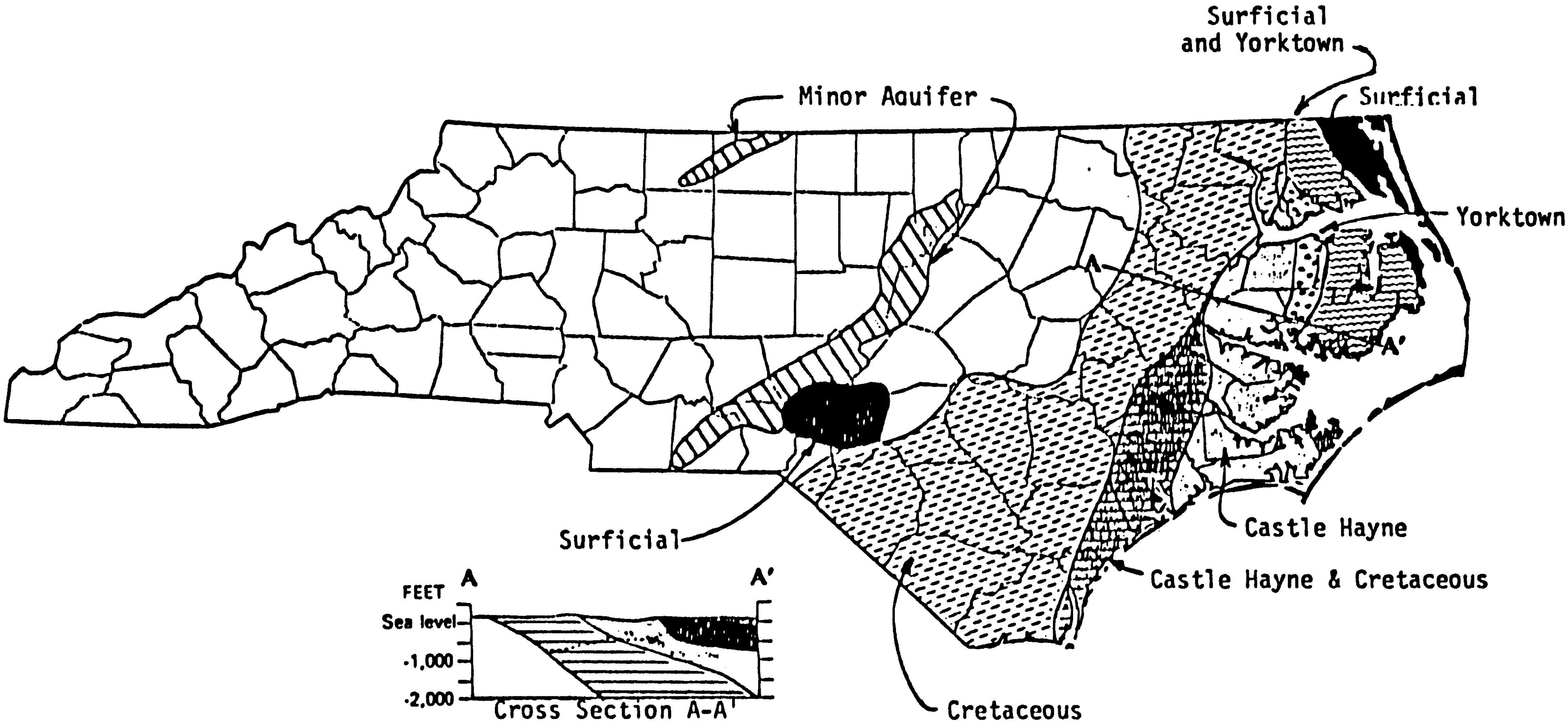


**Figure 8.** Principal Aquifers of North Carolina (from U.S. Geological Survey, National Water Summary 1986)

Ranges or categories for each factor were established. For each range or category, a rating, in the interval 1 to 10, was established to reflect the relative importance of each range or category to pollution potential. For example, the range and ratings for soil media are reproduced in Table 6. Ranges and rating for the other factors can be found in the reference material (Aller et al., 1987).

Once the ratings are determined for each factor for a given area, the index is computed by adding the products of the weight and rating for each of the seven factors. Since each of the ratings varies from 1 to 10, and the weights sum to 26, the index can vary from a low of 26 to a high of 260. The higher the index, the more vulnerable the area is to pollution.

DRASTIC scores computed using pesticide weights have been assigned to each county in the United States (Liddle and Ganley, 1988). Values of the index for North Carolina range from 119 to 216, and for purposes of mapping, that range has been divided into 5 equal intervals of 25 units each. The map is shown in Figure 9. As expected, it indicates the most vulnerable areas to be in the Coastal Plains and the Sandhills area where sandy soils are widely found. Valleys in the mountains are also vulnerable. Piedmont counties are less vulnerable because of the high clay content of soils, the thin layer of soils, and the crystalline rock geology. One reviewer of this report has expressed the opinion that the DRASTIC index probably overstates the vulnerability of the Albemarle-Pamlico Peninsula because the high organic content of soils in that area tend to restrict the movement of pesticides (Dr. Wendell Gilliam, NCSU Dept. of Soil Science, per. com. 1990). County-level values for the index obscure variations that occur within counties, of course, but like the pesticide data, they are probably sufficient for purposes of this analysis.

It is important to note that DRASTIC scores do not reflect loadings of pesticides. They are intended to reflect only characteristics of aquifers, not how the land above them is used. A more complete identification of the most vulnerable areas requires consideration of both the vulnerability of aquifers and loading rates for pesticides with high leaching potential. That can be done by overlaying the DRASTIC scores on the relative intensities of use. Results of that exercise are shown in Figures 10-12. There the relative vulnerability to pesticide contamination is divided into four categories: (1) most vulnerable; (2) next most vulnerable; (3) next least vulnerable; and (4) least vulnerable. The most vulnerable areas are those with high DRASTIC scores and high pesticide use rates. The least vulnerable are those with the lowest DRASTIC scores and lowest use rates. For the pesticide group that includes alachlor, atrazine, carbofuran, and metolachlor, referred to here as Group I for brevity, the areas of relative likelihood of groundwater contamination are shown in Figure 10; those for ethoprop are shown in Figure 11, and those for vernolate are shown in Figure 12.

Table 5. Assigned Weights for Pesticide DRASTIC Features

| Feature | Pesticide Weight |
|---|---|
| Depth to Water | 5 |
| Net Recharge | 4 |
| Aquifer Media | 3 |
| Soil Media | 5 |
| Topography | 3 |
| Impact of the Vadose Zone Media | 4 |
| Hydraulic Conductivity of the Aquifer | 2 |

Table 6. Ranges and Ratings for Soil Media

| SOIL MEDIA | |
|---|---|
| Range | Rating |
| Thin or Absent | 10 |
| Gravel | 10 |
| Sand | 9 |
| Peat | 8 |
| Shrinking and/or Aggregated Clay | 7 |
| Sandy Loam | 6 |
| Loam | 5 |
| Silty Loam | 4 |
| Clay Loam | 3 |
| Muck | 2 |
| Nonshrinking and Nonaggregated Clay | 1 |
| Weight:2 | Pesticide Weight:5 |

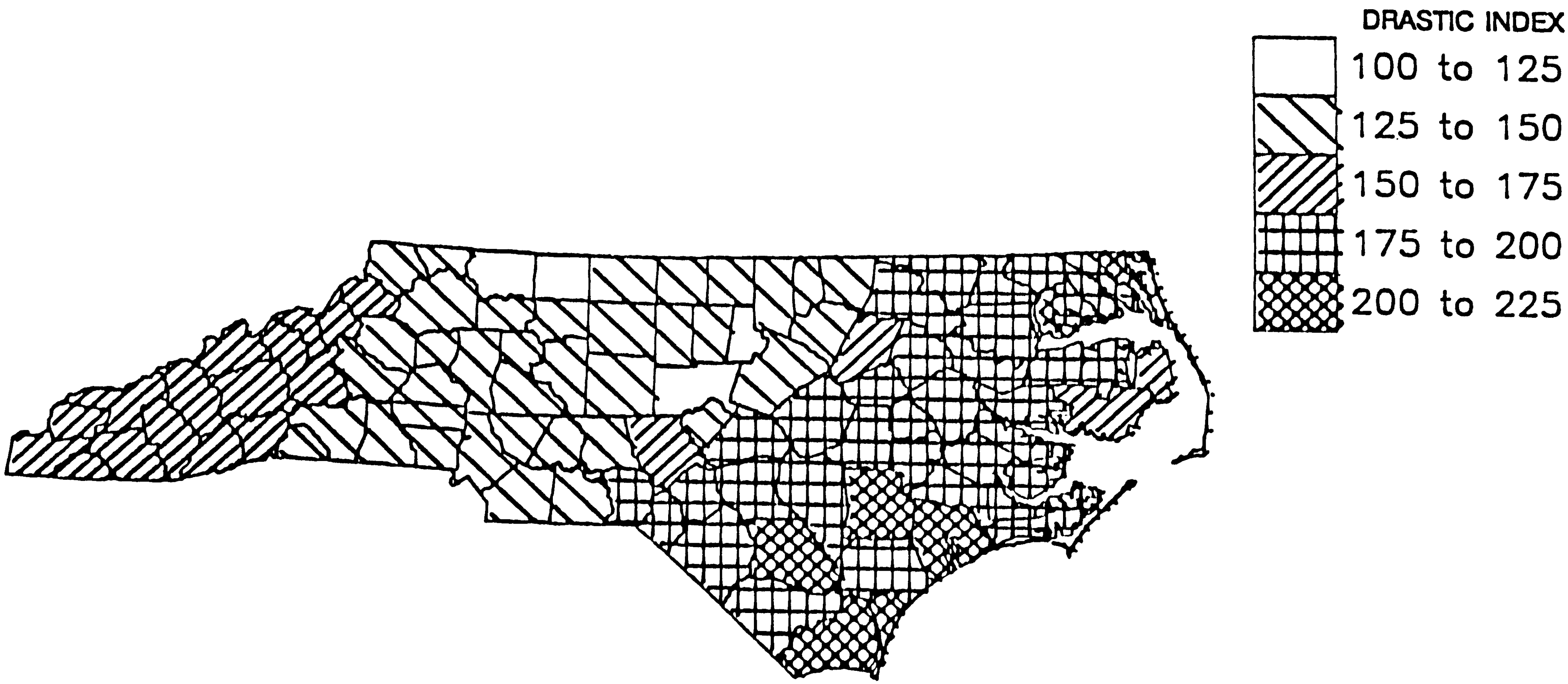


Figure 9. Relative Vulnerability of Aquifers to Contamination

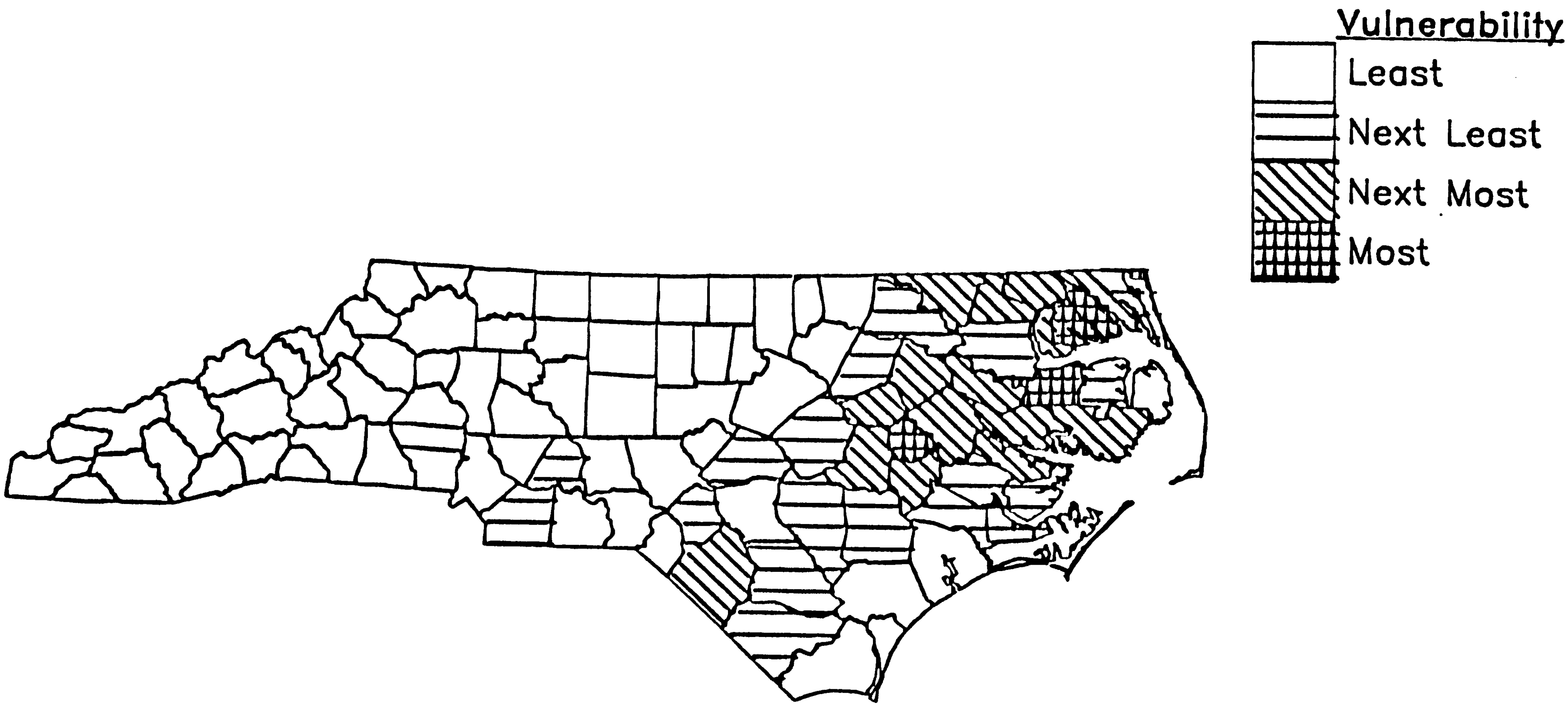


Figure 10. Vulnerability of Groundwater to Contamination by Group I Pesticides

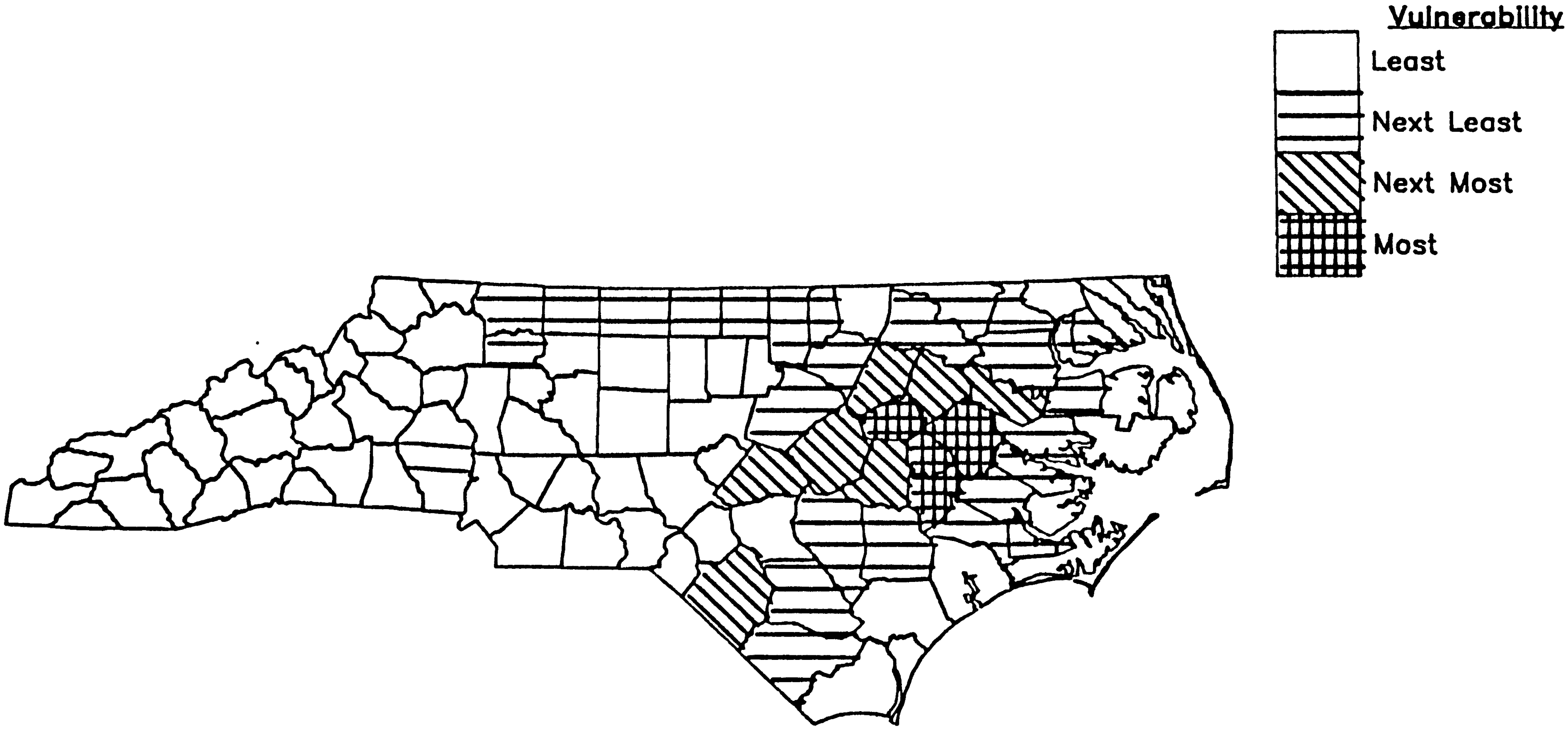


Figure 11. Vulnerability of Groundwater to Contamination by Ethoprop

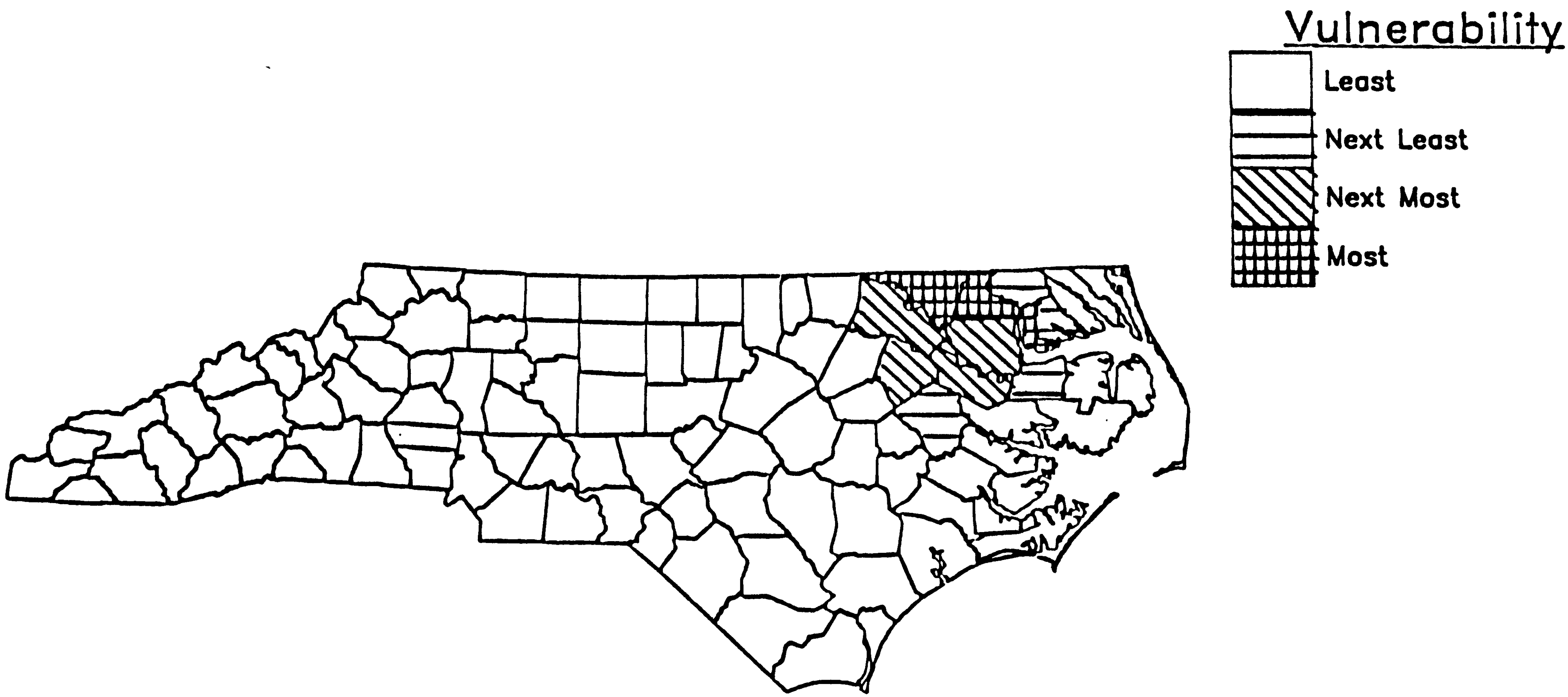


Figure 12. Vulnerability of Groundwater to Contamination by Vernolate

## CONCLUSIONS AND RECOMMENDATIONS

It may be worth repeating that Figures 10-12 show the relative likelihood of groundwater contamination from agricultural pesticides as calculated from secondary data sources. There is no systematic collection and reporting of pesticide use or groundwater contamination from pesticides in North Carolina to confirm or deny whether the groundwater is actually contaminated in the priority areas identified here. The conclusion that can be drawn from the secondary data sources used in this analysis is: if the groundwaters of North Carolina are being systematically contaminated through the use of agricultural pesticides, the greatest contamination is likely to be occurring in the priority areas identified in Figures 10-12 for the particular groups of pesticides associated with each of those maps.

Certain recommendations follow logically from the analysis. They are:

1. If budget limitations restrict choices about which pesticides are to be included in a comprehensive monitoring program, priority should be given to atrazine, carbofuran, and ethoprop. Alachlor, metolachlor, and vernolate should also be given priority but lower than the first group mentioned. Diazinon and 2,4-D should also be considered high on the priority list.

2. If budget limitations restrict locations for sampling, then priority should be given to the regions indicated in Figures 10-12. Before any particular locations are selected, however, additional analysis of aquifer vulnerability and cropping patterns at the sub-county level will be necessary.

3. Primary data on the sale and use of pesticides in North Carolina should be collected. Without reliable information on the quantities and spatial patterns of use, public officials are hindered in their responsibilities to protect public health and the environment.

4. Data on sales and use of pesticides should be obtained in a cost-effective manner. Several options for gathering information on pesticide use should be examined. They include: (1) reporting by farm users; (2) reporting of local sales by the industry; and (3) annual or biennial surveys using statistically valid sampling techniques. A joint endeavor should be undertaken by the Department of

Agriculture and the Department of Environment, Health and Natural Resources to design a cost-effective data collection program.

5. Groundwater sampling should be implemented with a sustained funding base with priorities established as necessary to fit the program into available funds.

6. Finally, steps should be taken to refine the indicators of vulnerability presented in this report to identify priority sites for investigation. In particular, North Carolina should develop the capability of identifying sub-county areas that are likely to be the most vulnerable to groundwater contamination from pesticides.

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# APPENDIX

## Distribution by County of Pesticide Use on Selected Crops

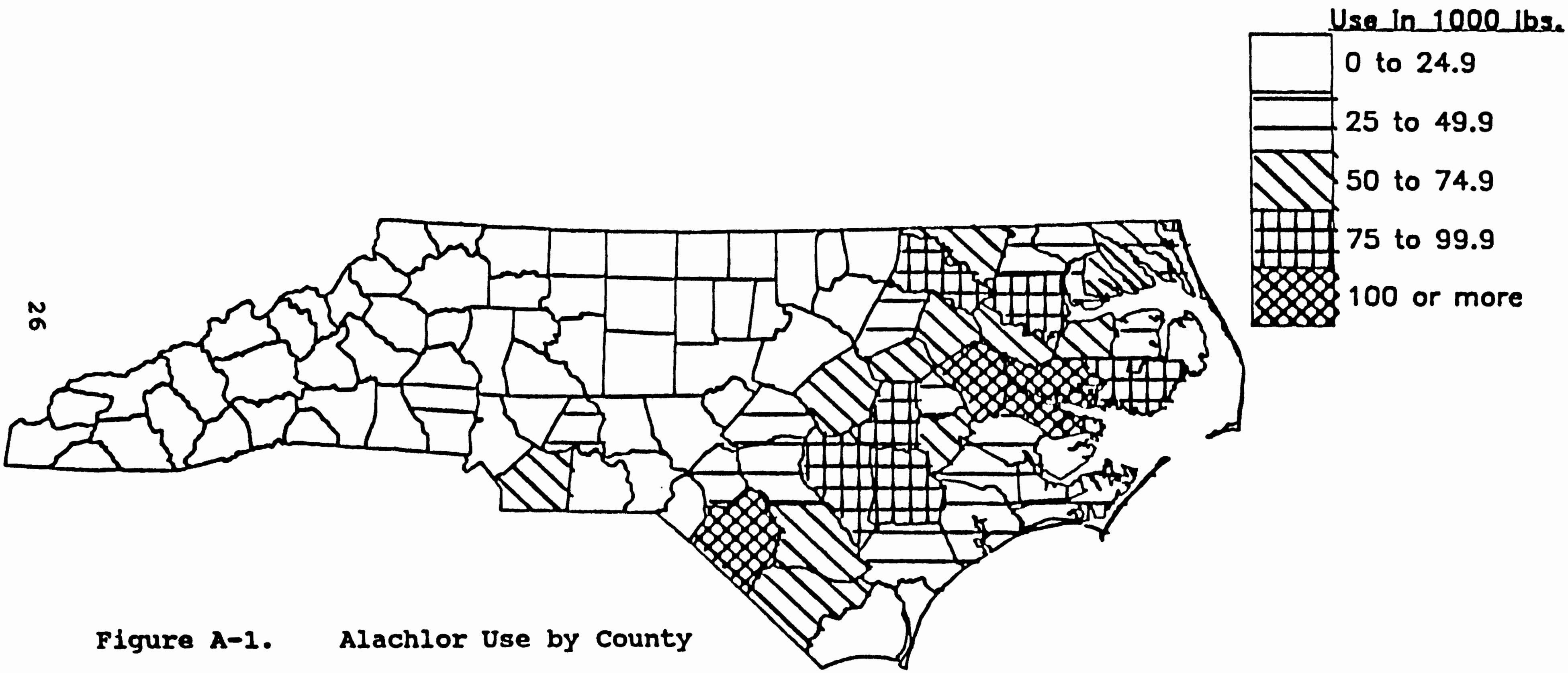


**Figure A-1. Alachlor Use by County**

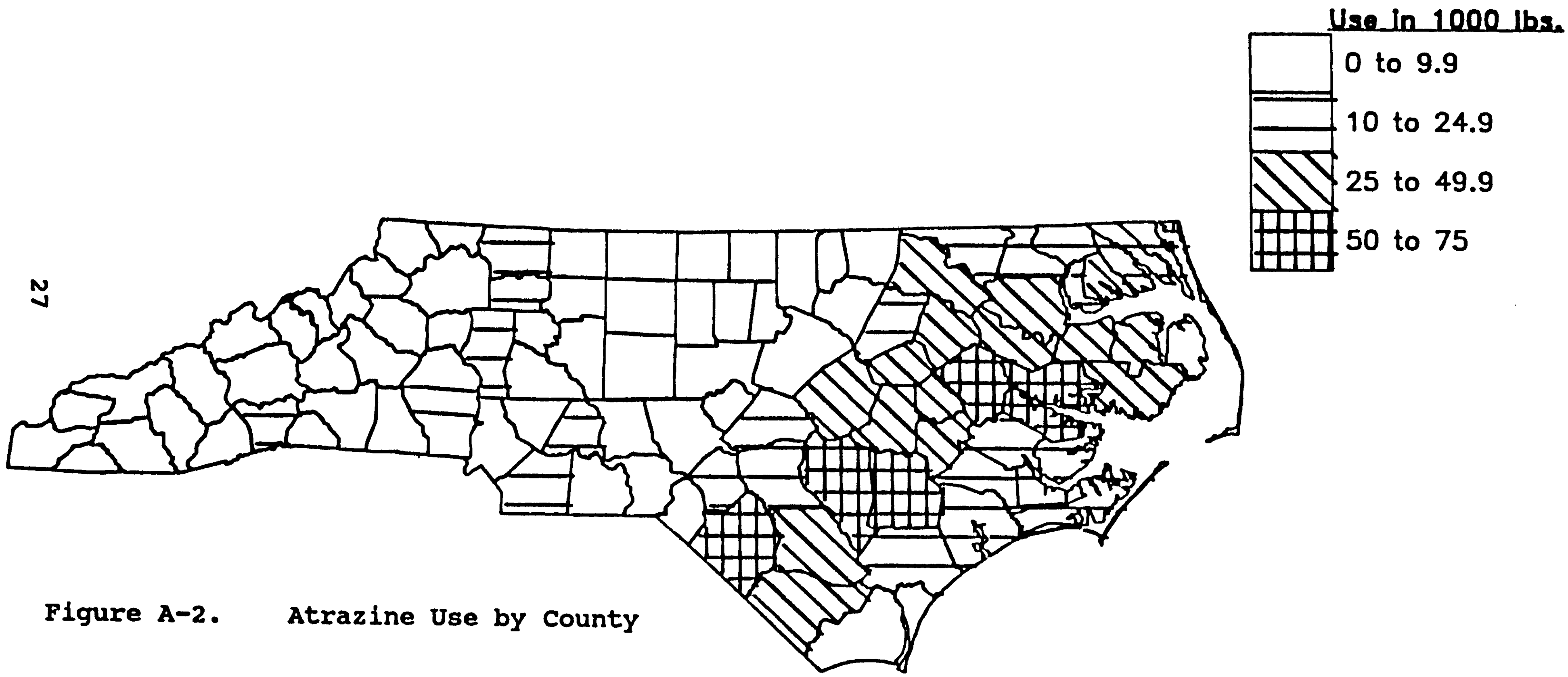


Figure A-2. Atrazine Use by County

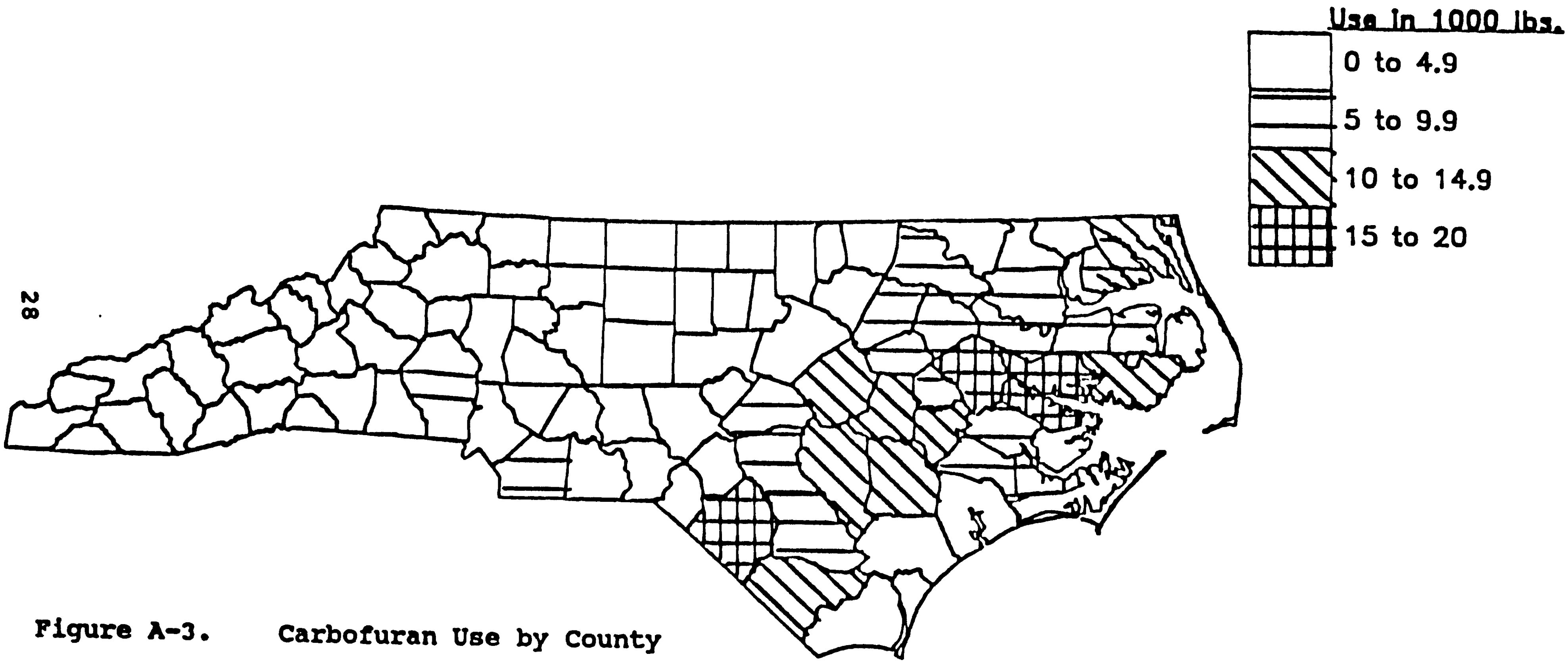


Figure A-3. Carbofuran Use by County

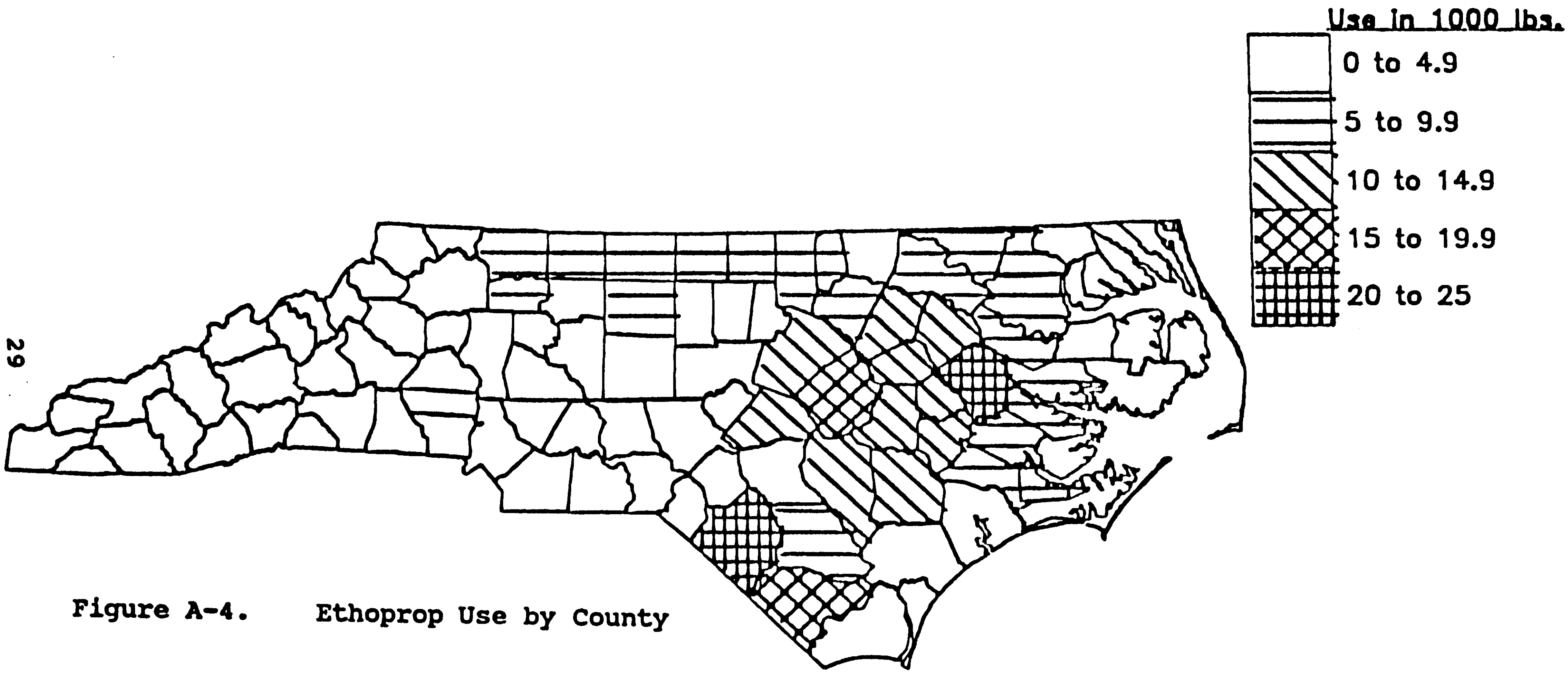


Figure A-4. Ethoprop Use by County

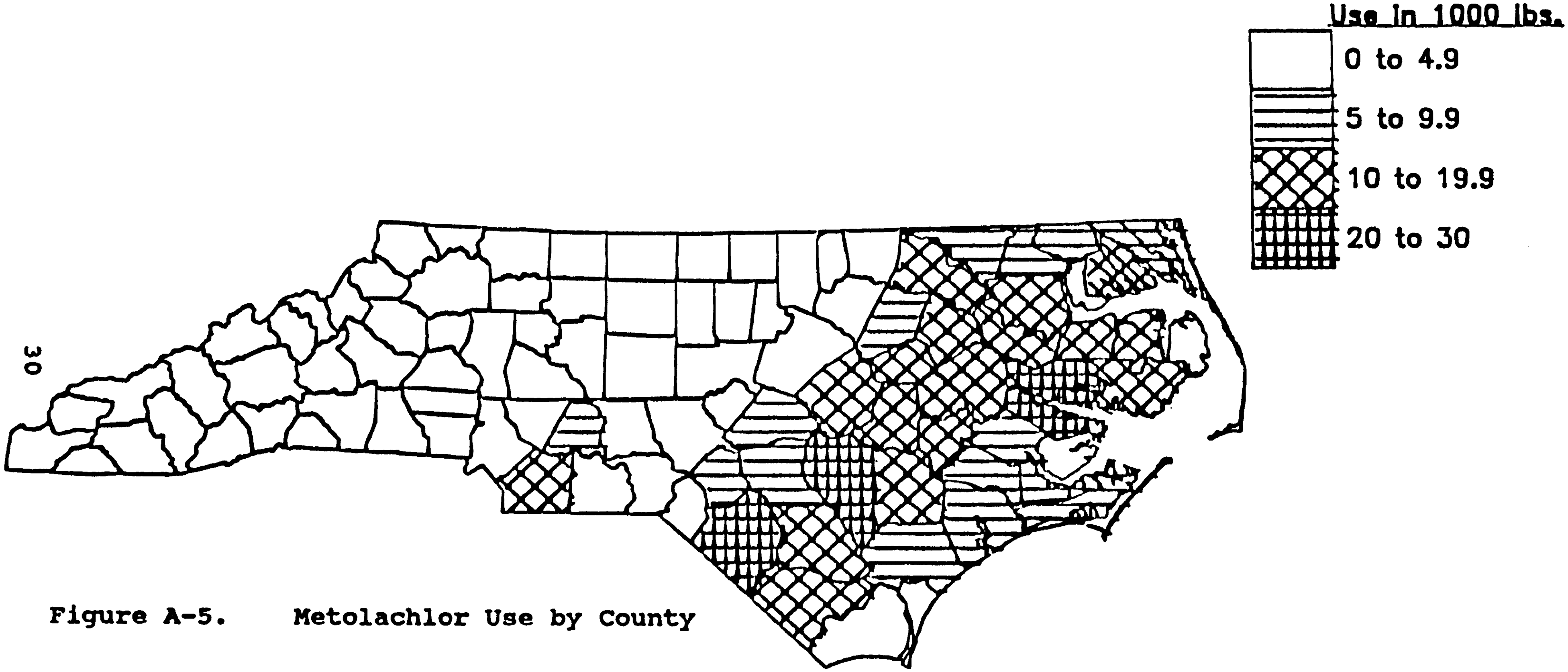


Figure A-5. Metolachlor Use by County

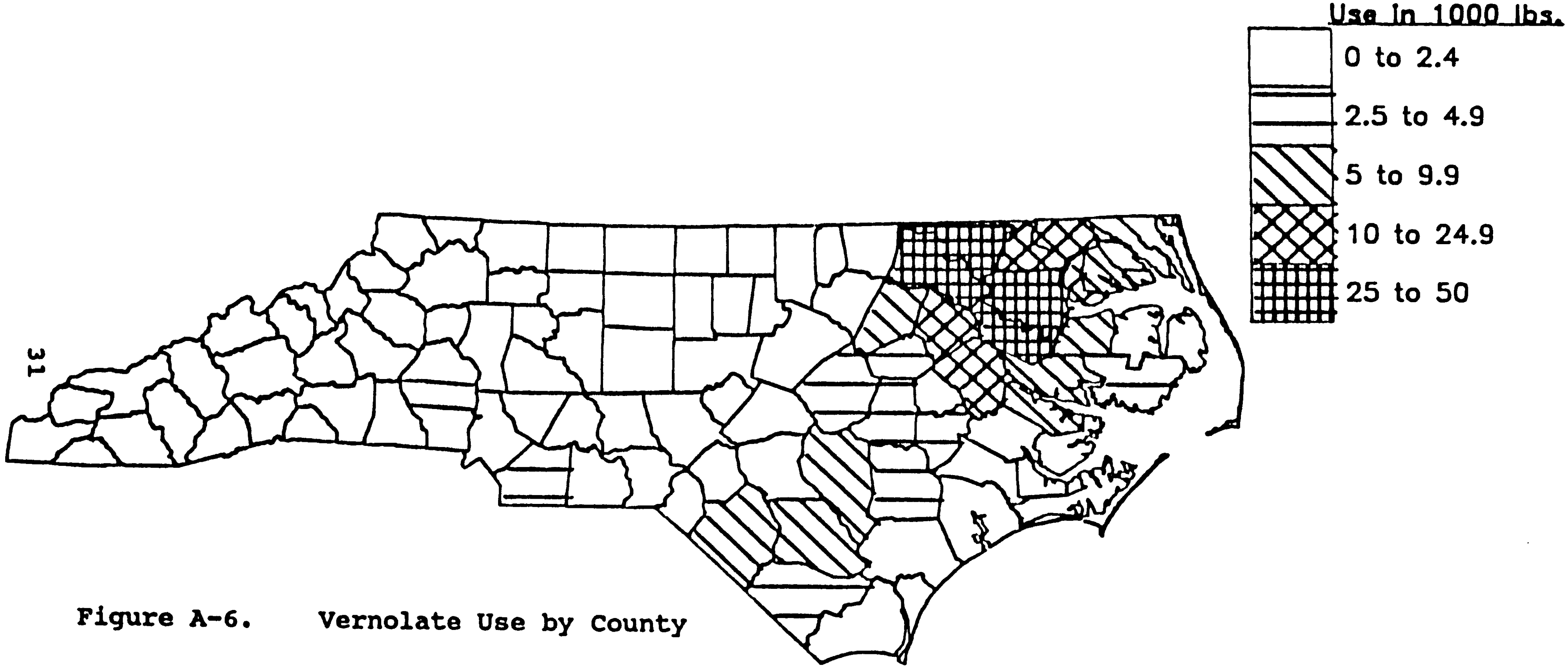


Figure A-6.    Vernolate Use by County