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Report to the Chairman, Subcommittee on Superfund, Ocean and Water Protection, Committee on Environment and Public Works, U.S. Senate

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GROUNDWATER PROTECTION

Measurement of Relative Vulnerability to Pesticide Contamination

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Program Evaluation and
Methodology Division

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October 31, 1991

The Honorable Frank R. Lautenberg
Chairman, Subcommittee on Superfund, Ocean and Water Protection
Committee on Environment and Public Works
U.S. Senate

Dear Mr. Chairman:

On February 27, 1991, you asked us to evaluate the feasibility of differentially protecting groundwater from pesticide contamination based on the relative vulnerability of different geographic areas. This is an approach that is being considered by the Environmental Protection Agency (EPA) within its proposed Pesticides and Ground-Water Strategy. We have completed work on the first part of our two-part evaluation, and we now present our findings on the degree to which states and counties are uniform in their susceptibility to groundwater contamination. We also describe the degree to which two common measures of relative vulnerability diverge in identifying areas that are susceptible to contamination. Other work you requested in this area will be addressed in a subsequent report.

Background

Groundwater is a vital and irreplaceable source of drinking water in the United States. Approximately half our population obtains drinking water from underground sources. Therefore, ensuring the purity of groundwater is of vital importance to the nation. This importance is even further reinforced by the lack or cost of alternatives. Indeed, most users of groundwater live in areas where replacing a well that has been contaminated may not be practical. Moreover, once contaminated, groundwater is very expensive to clean up.

The extent to which pesticides are currently present in groundwater and how best to prevent contamination from occurring are questions that have lately received a great deal of attention. When pesticides were first found in groundwater in 1980, the popular notion that they could not migrate to such depths through soil strata was destroyed. Since then, across the nation reports have been published periodically concerning the extent of local groundwater pesticide contamination incidents.

In addition, several national studies of groundwater contamination by pesticides have been published recently. These studies found pesticides in a relatively small percentage of groundwater sites and, by and large, at fairly low concentrations. The most comprehensive, EPA's National Pesticide Survey, concluded that pesticides are present in 10.4 percent of wells serving public water systems and in 4.2 percent of private wells. According to the study, fewer than 1 percent of both rural domestic wells (0.6 percent) and community water system wells (0.8 percent) across the nation contain pesticides at levels exceeding EPA's health guidelines. Overall, these studies appear to reinforce the view that vulnerability to contamination varies widely across the nation. That is, not all areas where pesticides were applied have had their groundwater contaminated. It should be noted, however, that we have not reviewed the EPA study to determine the accuracy of these conclusions.

The fact that pesticides are found in groundwater at all, and more importantly, that in some locations they were detected at levels exceeding health guidelines established by EPA, is commonly considered a cause for concern. Indeed, with approximately 10.5 million rural domestic wells and 94,600 community water system wells in the United States, the numbers of wells containing one or more pesticides are large: about 441,000 rural and 9,838 community wells. Moreover, some people fear that current contamination may be only the tip of the iceberg, heralding what could turn into a much larger problem in the future if current pesticide application rates continue.

We have recently criticized EPA for not instituting adequate safeguards to prevent groundwater contamination by pesticides.[1] We reported on the limited scope of actions that the agency has taken and found that EPA could more fully use its regulatory authority to limit groundwater contamination.

In the past, EPA has sought to limit groundwater pesticide contamination largely through uniform national restrictions, using authority granted to it in the Federal Insecticide, Fungicide, and Rodenticide Act (originally enacted in 1947). Under this authority, the most important regulatory decisions are made by the federal government and applied by states more or less uniformly throughout the nation. When EPA controls pesticide contamination under the act, it must weigh the economic cost of limiting the pesticide against the benefits stemming from the reduction in groundwater contamination.

[1]See U.S. General Accounting Office, Pesticides: EPA Could Do More to Minimize Ground Water Contamination, GAO/RCED-91-75 (Washington, D.C.: April 29, 1991).

The recognition that current regulation strikes uniformly across the nation whereas vulnerability to contamination is not at all uniform has led EPA to conclude that the problem warrants a new approach. The agency has therefore drafted a new strategy that emphasizes local prevention of further contamination.

EPA's Proposed Strategy

EPA's new approach is embodied in its proposed Pesticides and Ground-Water Strategy. Under this new regulatory scheme, the states will be granted a large degree of freedom to create individual "management plans" for controlling pesticide use to prevent groundwater contamination. Under their plans, the states will target vulnerable areas, distinguishing areas that warrant enhanced protection (through pesticide use restrictions or other controls) from areas that merit less attention because there is a lower probability of groundwater contamination. This component of EPA's proposed strategy is termed "differential management." EPA sees differential management of groundwater as a way of managing pesticide use as efficiently as possible by taking advantage of the fact that vulnerability to contamination, and thus the need to control pesticides, varies from area to area.

Rather than mandate a national limitation on the use of a pesticide, EPA points out that it seems reasonable to impose controls only where groundwater is endangered. It contends that this is particularly appropriate for actions taken under the Federal Insecticide, Fungicide, and Rodenticide Act, given its requirement that the benefits of a pesticide be weighed against its risks and given the disproportionate nature of applying a national response to risks that are specifically localized.

The wisdom of differentially managing groundwater rests on the fact that vulnerability varies over regions as a function of physical, hydrogeologic factors. Considerations such as the depth of the groundwater supply, the type of soil, and the subsurface geology all influence groundwater vulnerability, as do the amount of rainfall and the soil temperature. For example, shallow groundwater supplies are generally at greater risk of being contaminated by a pollution source than are deeper groundwater supplies. Groundwater supplies overlaid by porous sandy soils have a greater chance, by and large, of being contaminated by a pollution source than groundwater that is overlaid by heavy clay soils. EPA has indicated that it proposes to provide guidance to the states for these assessments, along with the U.S. Department of Agriculture and the U.S. Geological Survey.

In responding to the February 27 request, we focused on two important issues that we believe will determine the success of EPA's proposed strategy. One of them was to determine the geographic scale at which areas are uniform enough in their degree of vulnerability to contamination to warrant their being treated differently. It seems reasonable to expect that uniformity would increase as the size of the geographic area decreased. Smaller areas should be more uniform than larger areas: for example, states should be more uniform than multistate regions, and counties should be more uniform than states. EPA's position has been that assessments for smaller areas are needed in order to capture the degree of local variability that has to be taken into account if a pesticide management program is to avoid underprotecting small but highly vulnerable areas or overregulating areas with little real groundwater vulnerability. But it is not apparent at what geographic scale an acceptable amount of uniformity appears. And while EPA does not explicitly state that county-level assessments are acceptable, neither does the agency indicate that they are not. In fact, EPA expects most states to conduct their vulnerability assessments at the county level.

An additional matter related to the question of geographic scale was whether current vulnerability assessment methods are feasible—that is, whether they have been shown to accurately predict contamination and are affordable at the scale at which uniformity in vulnerability appears. In other words, in order for differential protection to be successful, assessment methods must be feasible at the geographic level at which it makes sense to treat areas individually. Therefore, our first evaluation question was, At what geographic level do areas become sufficiently uniform in their relative vulnerability to contamination for them to be suitable for differential management of potential groundwater contamination, and is it feasible to conduct vulnerability assessments at that level?

A second important issue arose with respect to EPA's proposed Pesticides and Ground-Water Strategy. The methodology that EPA advances for targeting vulnerable areas does not involve incorporating the health and ecological effects of a contaminated groundwater supply. The methodology includes measures of the hydrogeologic vulnerability of the groundwater and the magnitude of pesticide use, but it does not include a measure of the population obtaining drinking water from a groundwater supply that has become contaminated (that is, exposure risk). Nor does it include a measure of the potential environmental implications of contamination (through an indication of whether a contaminated groundwater source is hydrologically connected to surface water supplying a critical habitat). Both of these concerns are raised in EPA's proposed strategy but do not figure in the targeting formula EPA presents. For reasons that are presented below, we restricted our analysis in this study to assessing the implications of excluding population use data, and we did not examine the implications of excluding information on groundwater-surface water connections. Therefore, our second evaluation question was, What is the effect of incorporating a measure of the population at risk when differentially targeting areas for protection from potential groundwater contamination by pesticides?

Appropriate Geographic Level for Differential Protection

The appeal of differential management and the validity of any differential approach both rest on the ability to implement pesticide management in geographic areas on the basis of their actual vulnerability. Accordingly, two central issues must be dealt with in devising a differential management strategy. They are (1) whether the predicted vulnerability within the geographic area used as the analytic unit varies to such an extent that an average estimate is useless for differentiating and (2) whether the predicted vulnerability at an acceptable scale is a good approximation of actual vulnerability.

Once the appropriate assessment level is defined—that is, the level at which uniformity within the geographic unit allows differentiation between these units to occur—the question arises of whether assessment at that level is practical. In other words, is the predictive capability of the vulnerability assessment method valid, and can it be implemented at reasonable cost? It is EPA's stated preference in the proposed Pesticides and Ground-Water Strategy that the differential management approach be implemented at the county level or possibly even in a smaller geographic unit.

Stability of Measures of Vulnerability and Risk

Groundwater vulnerability can be measured in a number of different ways. In this evaluation, we have identified three such approaches to differential management. The first approach estimates vulnerability solely as a function of geologic factors such as soil texture and depth to groundwater. We term this the hydrogeologic vulnerability approach. The second method estimates vulnerability as a function of these hydrogeologic factors, as well as the pesticide use factors that influence the site's susceptibility, such as the magnitude of pesticide use, the method that is used to apply the pesticide, and whether mixing and loading of pesticides take place close to wells. We term this the total vulnerability approach.

The last approach is even broader, for it incorporates the size of the population at risk from potential pesticide contamination—that is, the number of people who obtain their drinking water from groundwater in that area. This method does a better job of determining the relative magnitude of the threat to human health and the environment of pesticide contamination of different areas.[2] We term this the total risk approach.

These different methods should produce somewhat divergent estimates of vulnerability and risk. Determining the degree of divergence is important because in the past (in its proposed rule to prevent contamination of groundwater by the pesticide aldicarb), EPA classified areas using a variant of the total vulnerability definition without considering the potential exposure of people to pesticide-contaminated groundwater—that is, total risk. Moreover, in an appendix to the currently proposed strategy, EPA again suggests an approach very similar to the total vulnerability method, focusing on relative hydrogeologic vulnerability, monitoring data, and the magnitude of pesticide use. Thus, in spite of the fact that in a number of other places the document points out the importance of the states' considering present and future groundwater use, including its use as a drinking water source and thus considering risk exposure, EPA appears to be encouraging the states to assess vulnerability by using a total vulnerability rather than a total risk approach.

It should be noted that incorporating a measure of groundwater use does not necessarily imply that areas with few groundwater users should be left unprotected, nor does it imply that this measure should supersede other factors.

In order to determine whether the total risk approach is necessary, we compared the outcomes of the total vulnerability and total risk approaches. That is, we assessed the extent to which a total vulnerability approach yields assignments of different levels of vulnerability from a total risk approach that includes an estimate of potential population exposure.

[2]Optimally, one would also assess whether a critical ecosystem was supplied by groundwater in the area. As we were unable to obtain detailed information on groundwater sources supplying critical habitats, for the remainder of this report we focus only on potential human health effects.

It should be noted that we have not yet collected information that would enable us to determine how the states will conduct their vulnerability assessments or how many states will incorporate a measure of population use of groundwater. This will form part of a subsequent report.

Results in Brief

From our examination of a sample of counties across the country, we found that there is virtually as much variability in hydrogeologic vulnerability within counties as there is between counties. Many counties whose vulnerability scores we studied are composed of areas with a wide range of susceptibilities to contamination. For these reasons, we believe that the states will need to estimate the degree of uniformity of the hydrogeologic vulnerability of their groundwater before deciding to differentially manage pesticide use based on county-level distinctions in vulnerability. Where such assessments need to be conducted at subcounty levels, each state is likely to be faced with a trade-off between the cost and the validity of the assessment. The assessment techniques that have been applied at broad resolutions can be applied relatively inexpensively at the subcounty level, but their predictive validity has not been established at that scale. The techniques for which evidence of predictive validity does exist at the subcounty level suffer from expensive data requirements when applied across an entire county.

We also found that relative vulnerability rankings of counties across the nation can be influenced significantly by including an estimate of the number of people obtaining their drinking water from groundwater sources. There are many counties with only an average degree of vulnerability to groundwater contamination by pesticides (based on hydrogeologic factors and magnitude of pesticide use) that nevertheless have a relatively large number of people who obtain their drinking water from groundwater sources. We believe that it is important for the states to explicitly consider the number of groundwater users as a factor in the development of differential pesticide management plans.

GAO Analysis and Findings

While EPA has taken the position that the variation in statewide sensitivity to pesticide contamination of groundwater is too large for uniform state-level management of pesticides, it has not taken a stand on how large the within-state areas should be that are managed differentially. It appears that states will be free to identify vulnerable areas on a county-level scale.

For EPA's differential management approach to be viable at a county level, there should be more uniformity in vulnerability within counties than between them. For if groundwater vulnerability varies as much within counties as it does between them, the notion of a "vulnerable" (or "invulnerable") county loses much of its validity. Consequently, a plan to manage pesticide use by county might risk incorrectly categorizing a substantial fraction of a state's surface area. If county-level assessments are not meaningful, it becomes important to determine the feasibility of performing vulnerability assessments at finer resolutions.

The considerations above led us to our first evaluation question, "At what geographic level do areas become sufficiently uniform in their relative vulnerability to contamination for them to be suitable for differential management of potential groundwater contamination, and is it feasible to conduct vulnerability assessments at that level?" To address this question, we analyzed estimates of hydrogeologic vulnerability to surface contaminants that had been collected at varying levels of resolution. The data we used were (1) average vulnerability ratings across states, which we computed from county-level estimates; (2) average vulnerability ratings across counties; and (3) vulnerability ratings for subcounty areas known as hydrogeologic settings. The estimates of hydrogeologic vulnerability were all generated by the same method. Known by the acronym DRASTIC, this method incorporates seven factors thought to influence the susceptibility of groundwater to contaminants introduced at the surface of a given site. (See appendix I for a detailed description of DRASTIC.)

Our analysis consisted primarily of generating statistical estimates of variability at four levels: (1) between all U.S. states, (2) among all states within each of 10 regions, (3) among counties within each state, and (4) between census enumeration districts within a sample of 87 counties.[3] These estimates were compared to assess the extent to which hydrogeologic estimates of vulnerability become more uniform when smaller geographic areas are examined.

[3]It should be noted that, as for the county-level estimates, these subcounty scores are themselves average values of vulnerability scores for even smaller areas of a fairly uniform geologic structure known as "hydrogeologic settings." Therefore, we acquired estimated scores for the vulnerability of groundwater in individual hydrogeologic settings for 2 of the 87 counties that, according to our analysis of within-county variability, contain an average amount of variability. Comparing the estimates of variability from the hydrogeologic settings data with the estimates from the enumeration district data in the same counties should give us some indication of whether the larger data set of vulnerability scores for enumeration districts underestimates within-county variability.

The results of the analysis above indicated that the variability in hydrogeologic vulnerability does not become significantly smaller when moving from the national level to the state level and to the county level. (See tables II.1-II.4 and figures II.1-II.3.) Thus, we found that it generally makes no more sense to make distinctions between counties than it does to treat an entire state as a uniform area.[4]

It could be argued that the relatively high variability we observed across all levels of analysis holds true only for areas where contamination is unlikely to occur (for example, because of limited pesticide use). If this were the case, the variability we observed would not pose a problem for differential management because our findings would not hold in the areas that (on the average) are most likely to require protection. We tested this hypothesis by examining the correlations between measures of hydrogeologic variability and measures of vulnerability (that is, DRASTIC scores) and between measures of variability and pesticide use estimates. Interestingly, we found that counties with high levels of pesticide use tended to be more variable than counties with low levels of pesticide use. No significant relationship existed between county variability and county-level DRASTIC scores. Neither state-level DRASTIC scores nor average state pesticide use estimates were significantly related to measures of variability. (See table II.4.)

The lack of uniformity in vulnerability we observed both between and within counties led us to believe that EPA risks undermining the differential protection philosophy it embraces in the proposed Pesticides and Ground-Water Strategy if it permits states to differentially protect groundwater on the basis of county-level differences in vulnerability unless the suitability of doing so can be demonstrated. Further, a separate review we conducted of studies that have attempted to validate vulnerability models makes it appear that the only assessment techniques that have been shown to have predictive validity at the subcounty level (based on the conclusions of the authors themselves) are site-specific methods with major data collection requirements that could make them prohibitively expensive to implement repeatedly across entire counties. (These studies are listed in the bibliography.) It should be noted that EPA is presently reviewing the cost of implementing subcounty models.

[4]From our analysis of data from two counties in Ohio, it appears that the variability within counties (using hydrogeologic settings as the unit of analysis) is even greater than that of the subcounty enumeration district data. (See figure II.3, a map of DRASTIC scores for hydrogeologic settings within a county with an average degree of variability in within-county hydrogeologicvulnerability.)

Therefore, with respect to our first evaluation question, we found no evidence of uniformity in vulnerability at any practical level of analysis. To the extent that such uniformity appears at all, it will generally be at the subcounty scale. We have not, however, found any method for assessing groundwater vulnerability at that scale that is both demonstrably valid and sufficiently economical for widespread applicability.

Our second evaluation question was, "What is the effect of incorporating a measure of the population at risk when differentially targeting areas for protection from potential groundwater contamination by pesticides?" We answered this question by comparing the vulnerability rankings of 3,002 pesticide-using counties with and without incorporating estimates of the population obtaining drinking water from groundwater and determining whether the two sets of rankings were significantly different.

We started by calculating the relative vulnerability of the 3,002 counties as the rank of the average of their hydrogeologic vulnerability and magnitude of pesticide usage ranks (a total vulnerability approach). We compared this rank-order listing of counties with the ranking of counties by the number of people who obtain drinking water from a groundwater source. There was a striking divergence between the two rank-order listings. (See figure II.4.) There are many counties whose vulnerability to groundwater contamination by pesticides is average (based on hydrogeologic factors and magnitude of pesticide use) but that nevertheless have a relatively large number of people who obtain their drinking water from groundwater sources.

Although the two were correlated, we also found a striking divergence between the rank order of the former list and that of a broader measure of vulnerability (total risk) that averages all three factors (hydrogeologic vulnerability, pesticide use, and the number of people obtaining drinking water from groundwater sources). (See figure II.5.)

Next, we divided the 3,002 counties into five groups of equal size based on both the total vulnerability and the total risk measures. The high number of instances in which the groupings diverge serves to underscore the extent to which the two methods produce different rankings. (See table II.5.)

We found that the groupings diverge by two or more of the five categories in 577 (19.2 percent) of the counties. We identified 67 counties that are "moderate" in relative vulnerability yet are in the highest category with respect to their relative total risk. It is counties such as these, in which more than 11 million people obtain their drinking water from groundwater sources, that are at particular danger of an insufficient degree of control of pesticide usage if population exposure is not incorporated into the measure used to identify vulnerable areas.

Last of all, we compared how counties would fare under a total risk approach and an approach similar to that EPA used in the aldicarb rulemaking document and subsequently endorsed in the proposed strategy—that is, employing hydrogeologic vulnerability and magnitude of pesticide use. In an appendix to the proposed strategy, EPA suggests that the states prepare management plans for vulnerable areas in which a significant amount of pesticides are applied.

We attempted to determine the degree to which an assignment of counties with EPA's approach would coincide with that using a total risk approach. We applied a version of the approach that EPA had used for aldicarb to 10 pesticides that we had identified as posing the greatest threats to groundwater quality. This exercise yielded 472 counties as potentially requiring management plans. Then we selected the 472 counties that score highest on the total risk scale. We found that only about half (237) of these counties were also included within the initial EPA set. (See figure II.6.) This illustrates the extent to which the approach EPA endorses diverges from one that incorporates exposure considerations.

In sum, the inclusion of a measure of population at risk produced significantly different assessments of relative groundwater contamination risk. We found that the system EPA endorses would target manifestly different areas for differential protection than a system that includes data on population exposure.

Recommendations

We found (1) no evidence for uniformity of vulnerability at any practical level of analysis and (2) considerable evidence that including data on the size of the population dependent on the groundwater supply can make important improvements in a strategy for protecting people against pesticide exposure through groundwater contamination. Therefore, we recommend that EPA reevaluate its differential management strategy in the light of effectiveness considerations raised by these findings. Specifically, we recommend that

1. EPA provide explicit guidance on how the states should determine the geographic scale at which vulnerability assessments must be conducted to achieve an adequate level of protection and

2. EPA incorporate a measure of population use as a risk factor in determining which sources require special protection, thus removing the ambiguity on this point that currently exists in the proposed Pesticides and Ground-Water Strategy.

Agency Comments

As we agreed with your office, we did not ask for written comments from EPA; however, responsible agency officials did review and orally comment on the report. They agreed with our conclusion that there was no evidence for uniformity of vulnerability at any practical level of analysis. In addition, they commented that our conclusion concerning the prohibitive cost of subcounty vulnerability assessment methods might be preliminary and that they are looking into the issue. Finally, regarding the use of population-at-risk statistics in assessments designed to identify geographic areas requiring protection, the officials indicated that their strategy guidance alludes to that consideration but that it will be up to the states as to whether such information is used in their vulnerability conclusions.

As we agreed with your office, unless you publicly announce this report's contents earlier, we plan no further distribution of it until after its issue date. We will then send copies to the Administrator of the Environmental Protection Agency, and copies will be made available to interested organizations, as appropriate, and to others upon request.

If you have any questions or would like additional information, please call me at (202) 275-1854 or Kwai-Cheung Chan, Director of Program Evaluation in Physical Systems Areas, at (202) 275-3092. Other major contributors are listed in appendix III.

Sincerely yours,

Eleanor Chelimsky
Assistant Comptroller General

Contents

Abbreviations

DRASTIC	Depth . . . recharge . . . aquifer . . . soil . . . topography . . . impact . . conductivity
EPA	Environmental Protection Agency
GAO	U.S. General Accounting Office

Objective, Scope, and Methodology

Objective

EPA has proposed an approach for protecting groundwater from contamination by pesticides. Senator Frank R. Lautenberg expressed interest in determining how feasible EPA's approach is likely to be. This report examines the approach EPA proposed in its Pesticides and Ground-Water Strategy. In response to the senator's request, we developed two evaluation questions:

- At what geographic level do areas become sufficiently uniform in their relative vulnerability to contamination for them to be suitable for differential management of potential groundwater contamination, and is it feasible to conduct vulnerability assessments at that level?
- What is the effect of incorporating a measure of the population at risk when differentially targeting areas for protection from potential groundwater contamination by pesticides?

Scope

The geographic scope of the first evaluation question is 3,143 counties in 50 states. The geographic scope of the second evaluation question is counties throughout the country that have agricultural applications of one or more of a group of 10 pesticides we identified as posing the greatest threats to groundwater; this is 3,002 counties in 48 states. (There were no applications of these pesticides in Alaska and Hawaii, nor in several counties in a number of other states, according to the data base we analyzed.) The 10 pesticides are acifluorfen, alachlor, aldicarb, atrazine, bentazon, carbofuran, cyanazine, dcpa, metribuzin, and simazine.

Methodology

We employed both descriptive and inferential statistics to address these questions.

Data

For the first evaluation question, we obtained county-level estimates of hydrogeologic vulnerability. We also obtained an estimate of hydrogeologic vulnerability for more detailed areas within a group of 87 counties that had been the subject of a study of pesticide contamination of groundwater by Monsanto Agricultural Company and Research Triangle

Institute.[1] These more detailed areas are referred to as census enumeration districts (a unit of analysis developed by the Bureau of the Census), and a separate score was calculated for each setting. Our data set contained an average of 46 discrete districts per county.

State-level, county-level, and within-county estimates of relative hydrogeologic vulnerability were derived, using the DRASTIC parameter weighting methodology.[2] The DRASTIC methodology uses a seven-variable algorithm, each variable representing a factor thought to influence the relative vulnerability of groundwater being contaminated by a source at the surface of a given area. Each factor is weighted by a constant that reflects its hypothesized relative influence (that is, factors considered more important receive higher weights).[3] A rating system is used to assign numeric values to the observed characteristics for a given site for each of the variables. DRASTIC was developed by the National Water Well Association and used by EPA in its National Pesticide Survey and by Monsanto and the Research Triangle Institute for their survey of pesticide contamination of groundwater.

Using the DRASTIC methodology, EPA developed estimates of the average relative vulnerability of counties, and the Monsanto study included estimates of the average relative vulnerability of census enumeration districts. Although scores generated by the DRASTIC algorithm can theoretically reach 256, the range of scores for the 3,143 counties was 69 to 245, with a median score of 130 and a standard deviation of 27.0. The range of scores for the 4,009 enumeration districts in the Monsanto

[1]In 1989, Monsanto and the Research Triangle Institute conducted the National Alachlor Well Water Survey. The primary goal was to "estimate the proportion of private rural domestic wells with detectable concentrations of alachlor" (a common broadleaf herbicide used on corn, soybeans, and peanuts) in areas where alachlor is applied. The survey was conducted in 90 counties across the nation. (See figure II.6.) As part of the survey, estimates were made of hydrogeologic vulnerability using the DRASTIC methodology. We used the vulnerability estimates from this report because it is one of the only studies that estimates within-county vulnerability of groundwater for a relatively large number of counties in different hydrogeologic environments. However, in 3 of the counties the Research Triangle Institute studied, detailed hydrogeologic information was unavailable and all areas were assigned the same score. We excluded these counties from our analysis, leaving a total sample of 87 counties.

[2]Linda Aller et al., DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings (Ada, Okla.: U.S. Environmental Protection Agency, April 1987). We used the vulnerability estimates provided by DRASTIC because its methodology of identifying "hydrogeologic settings" and summarizing vulnerability as some function of hydrogeologic factors is the prototype for regional vulnerability assessments. Although the absolute accuracy of the model has not yet been established, it includes most of the factors influencing how easily a contaminant can be carried through the overlying material to groundwater.

[3]The seven variables are depth to groundwater, net recharge, aquifer media, soils, topography, vadose zone, and hydraulic conductivity.

study was 65 to 249, with a median of 150 and a standard deviation of 29.3.

For the second evaluation question, we used the county-level DRASTIC scores as well as estimates of pesticide use and the population using public and private wells for their drinking water—that is, a single number per county for each of these three factors. Our estimates of the intensity of pesticide applications were based on data developed for us by Resources for the Future. In conjunction with a panel composed of individuals expert in pesticide use and environmental science, we selected a set of 10 pesticides that pose a significant threat to groundwater. We accomplished this by starting with a set of 45 pesticides that EPA had identified in 1984 as being of greatest importance. We then created a table of a set of factors determining the extent to which they pose a threat to the environment. The factors on which we gathered data include the health advisory level, the quantity produced, and a number of variables influencing environmental fate and transport. Using the table we had constructed, we asked our experts to identify and rank the 10 most threatening pesticides from the set of 45. We averaged their responses to arrive at our list of 10 pesticides.

Using its own sources of information, Resources for the Future estimated the intensity of pesticide use for every county in the nation for each of the 10 pesticides. The measure of pesticide use that we employed was the sum of the amount used (in pounds) of the 10 pesticides.

We obtained our data on population exposure to groundwater from the U.S. Geological Survey, which periodically estimates this as well as other conditions of water use. The measure we used was the total population using groundwater as a source of drinking water from either public or private wells.

Methodology for First Evaluation Question

We answered the first evaluation question by assessing the relative variability in vulnerability at four different levels of resolution: national, regional, state, and county. EPA has taken the position that there is too much variability (or, alternatively, too little uniformity) in hydrogeologic vulnerability within most states for a state-based protection policy to be effective. A significantly greater degree of uniformity at some within-state level of resolution would indicate that it is feasible to differentiate among constituents at that level.

In order to determine whether relative uniformity in groundwater sensitivity was apparent at the county level, we compared estimates of hydrogeologic vulnerability using the DRASTIC method, examining variability at the national level (between mean scores of states and between counties within regional groups of states), at the state level (between counties), and at the county level (between census enumeration districts and between hydrogeologic settings). (Tables and figures to support our conclusions are contained in appendix II.)

We assessed variability using three different measures: the standard deviation, the total range of values, and the 80-percent range.[4] In the text, variability is described only in terms of standard deviation of DRASTIC scores. Our findings from all three indicators generally coincided. Cutoffs for the maps illustrating patterns of relative vulnerability (figures II.1-II.3, II.10, and II.11) were established by ordering the 3,143 counties by DRASTIC score and performing a quinary split.

Primary Analyses

In order to determine whether counties have an acceptable degree of uniformity in vulnerability to support differential protection (that is, whether the minimal condition is satisfied that there be more uniformity within counties than between them), we compared between-county variability for 3,143 counties with within-county variability for a group of 87 counties studied by Monsanto and the Research Triangle Institute. We compared the degree of variability in vulnerability scores for counties within states with that for enumeration districts within counties.[5] (Results are presented in tables II.1.-II.4, II.6, and II.7 and figures II.8 and II.9.) Figure II.8 compares differences in the range of enumeration district DRASTIC scores within each of the 87 counties. Comparing the range of values in this figure with that of figure II.9 highlights the findings from the statistical tests we performed. Figure II.2 is a map of the enumeration districts within a county in Ohio that has an average degree of variability in within-county hydrogeologic vulnerability.

[4]These measures were selected because of their complementary nature. Standard deviation and range are the most commonly used estimates of variability, but both are heavily influenced by outliers. By eliminating the top and bottom 10 percent of scores (that is, by calculating the 80-percent range), we effectively skirt these problems.

[5]Tests of significance were run on the difference between these averages by calculating an F-ratio from the individual scores. For an additional test of within-county versus within-state variability, we ran separate regression equations using (1) state designations as predictors of associated county-level DRASTIC scores and (2) county designations as predictors of associated census enumeration district DRASTIC scores. We then compared the variance accounted for (R^2) by state and county designations. A higher degree of uniformity in hydrogeologic vulnerability is reflected by a higher R^2. If a higher degree of uniformity in hydrogeologic vulnerability exists at the county level than in the within-state level, then this should be reflected in a higher R^2.

Secondary Analyses

We also assessed the relative degree of variability among the 50 states in hydrogeologic vulnerability (in terms of state mean or "average" scores; see table II.1). We compared this to the variability within large national regions (EPA regions; see figure II.11).

Figure II.1 is a map of Tennessee, a state with an average degree of variability in county-level hydrogeologic vulnerability. It indicates into which of five relative vulnerability groups—based on balanced groups of all 3,143 counties in our sample—each county in that state was placed.

We also tested whether certain conditions were present that would alter the significance of our findings with respect to variability in vulnerability. Specifically, we were interested in the question of whether areas of high pesticide use or high vulnerability tend to be less variable than other areas. If variability were inversely related to measured vulnerability or level of pesticide use, this would mitigate the significance of our findings by indicating that they are true largely for areas that are least in need of protection. We tested these possibilities by calculating the Pearson product-moment correlations between our three measures of variability and both DRASTIC scores and estimates of pesticide use. We made separate calculations using both the state-level and county-level data. The results are reported in table II.4.

Methodology for Second Evaluation Question

We answered the second evaluation question by using a number of different measures. We started by determining whether there is a significant divergence in the sorted rankings of counties with and without including a measure of the use of groundwater for drinking. The approach we used to answer the second evaluation question was to place 3,002 pesticide-using counties in rank order using two approaches (with and without allowance for population use of groundwater) and then to assess differences between the rankings. First, each county was assigned a rank-order score by taking its average rank on two scales: hydrogeologic vulnerability (that is, average DRASTIC score) and intensity of pesticide use. Next, we assigned each county a rank-order score with respect to the total population obtaining drinking water from groundwater sources.

In order to visually depict the degree of divergence between the rank-order listings, we created two scattergrams of the 3,002 counties. The first (figure II.4) compares their total vulnerability rank order (considering hydrogeologic vulnerability and pesticide use) and their rank order in terms of the number of groundwater drinkers. The concern would evidently be with the large number of counties in the upper right-hand quadrant—counties ranking high in both vulnerability and groundwater use.

The second (figure II.5) relates their rank according to their total vulnerability rank order and their total risk rank order (considering hydrogeologic vulnerability, pesticide use, and the number of drinkers of groundwater). Here counties whose total risk and total vulnerability ranks approximately coincide would be clustered along a diagonal line through the origin. The wide spread of points away from this line suggests just how much divergence in risk scores is introduced by consideration of the size of the at-risk population.

Then we placed the counties into five equal groups based upon their ranking under the first method, repeated the process for the second method, and compared the groupings established by each method to determine the extent to which the two sets of groupings diverged. Last of all, we compared two approaches for targeting counties for comprehensive ("level one") management plans under the agricultural chemicals strategy: (1) an approach similar to that EPA used in the aldicarb rulemaking document and subsequently endorsed in the proposed strategy (that is, employing hydrogeologic vulnerability and magnitude of pesticide use) and (2) a total risk approach. We applied a version of the approach that EPA had used for aldicarb to 10 pesticides that we had identified as posing the greatest threats to groundwater quality. This exercise identified certain counties as requiring comprehensive management plans. Then we selected the same number of counties that scored the highest on the total risk scale to determine the extent to which the two lists overlap.

Our review was conducted in accordance with generally accepted government auditing standards.

Tables and Figures Supporting Our Findings

The following tables and figures present data and results that support our findings. References to them are made in the letter and in appendix I.

Table II.1: Comparison of Measures of Variability

Scale	Data	Standard deviation	Range	80% range
1. All counties	3,143 counties	27.0	176.0	69.0
2. All counties by region[a]	3,143 counties	20.2	101.1	53.7
3. Between states[b]	3,143 counties	23.6	115.3	60.7
4. Within states[c]	3,143 counties	15.9	63.9	39.9
5. Within counties[d]	4,009 census enumeration districts	13.6	49.0	32.8

[a]As the average across 10 EPA regions for all counties in each region.

[b]The variability in the 50 state average values.

[c]The average statistics for 50 states.

[d]The average statistics for 87 counties.

Table II.2: Significance Tests for Within-County Versus Between-County Measures of Variability

Dependent variable	Sum of squares	DF	Mean square	F-ratio
Standard deviation				
Comparison	160.9	1	160.9	1.80
Residual	12,073.0	135	89.4	
Range				
Comparison	7,019.5	1	7,019.5	6.94*
Residual	136,584.3	135	1,011.7	
80% range				
Comparison	1,558.1	1	1,558.1	2.47
Residual	85,380.3	135	632.4	

*$p < .05$.

Table II.3: Test of Relative Within-Area Variability (R^2)

Model	Sum of squares	DF	Mean square	R-square
EPA region[a]				
Regression	15,842.9	9	1,760.3	.5810*
Residual	11,428.6	40	285.7	
State[b]				
Regression	1,305,925.9	49	26,651.5	.5716*
Residual	978,808.2	3,093	316.5	
County[c]				
Regression	2,022,536.2	86	23,517.9	.5874*
Residual	1,420,581.1	3,922	362.2	

[a]Criterion = state mean DRASTIC score.

[b]Criterion = county DRASTIC score.

[c]Criterion = district DRASTIC score.

*$p < .01$.

Table II.4: Correlations Between Variability Estimates and Measures of Vulnerability and Pesticide Use[a]

Data	Standard deviation	Range	80% range
State[b]			
DRASTIC	.205 (50)	−.035 (50)	.162 (50)
Pesticide use	.065 (48)	.109 (48)	.064 (48)
County			
DRASTIC	.032	−.043	.065
Pesticide use	.237*	.265**	.233*

[a]N = numbers in parentheses.

[b]All $p > .15$.

*$p < .05$.

**$p < .01$.

Table II.5: Comparison of Vulnerability and Risk Groupings[a]

Vulnerability group without exposure	Risk group including exposure: Lowest	Second	Middle	Fourth	Highest	Total
Lowest	346	135	90	29	0	**600**
	11.53	4.35	3.00	0.97	0	**19.99**
Second	184	171	130	104	11	**600**
	6.13	5.70	4.33	3.46	0.37	**19.99**
Middle	66	172	145	150	67	**600**
	2.20	5.73	4.83	5.00	2.23	**19.99**
Fourth	3	107	151	177	162	**600**
	0.10	3.56	5.03	5.90	5.40	**19.99**
Highest	0	16	84	140	362	**602**
	0	0.53	2.80	4.66	12.06	**20.05**
Total	**599**	**601**	**600**	**600**	**602**	**3,002**
	19.95	20.02	19.99	19.99	20.05	**100.00**

[a]The top number in each cell is frequency; the bottom is percent.

Table II.6: State-Level DRASTIC Scores[a]

State	Mean score	Standard deviation	Range	80% range
Alabama	150.3	15.2	56	45
Alaska	97.8	16.5	62	45
Arizona	97.0	5.4	18	15
Arkansas	128.3	19.5	77	54
California	119.6	23.9	92	77
Colorado	122.4	13.2	56	33
Connecticut	146.6	5.9	17	17
Delaware	172.0	10.4	18	18
Florida	212.3	16.3	69	47
Georgia	159.3	21.6	83	57
Hawaii	173.0	4.2	9	9
Idaho	111.5	20.2	77	52
Illinois	111.3	20.3	81	54
Indiana	132.4	15.9	79	42
Iowa	124.9	10.8	43	29
Kansas	121.0	11.8	69	26
Kentucky	152.7	16.4	66	45
Louisiana	139.9	23.8	91	66
Maine	149.6	7.6	31	15
Maryland	154.1	23.2	68	59
Massachusetts	173.8	23.8	69	57
Michigan	140.5	18.2	81	41
Minnesota	132.1	19.9	89	51
Mississippi	134.5	17.8	76	45
Missouri	105.9	19.5	113	38
Montana	124.3	9.4	42	23
Nebraska	118.7	11.4	52	27
Nevada	120.3	14.8	78	23
New Hampshire	157.7	9.5	26	23
New Jersey	157.6	26.1	85	62
New Mexico	120.2	8.3	39	21
New York	140.4	17.6	91	34
North Carolina	159.0	28.5	99	69
North Dakota	122.1	11.1	47	27
Ohio	120.5	14.7	64	40
Oklahoma	130.3	10.8	52	29
Oregon	109.2	14.9	56	44
Pennsylvania	137.5	12.7	68	33
Rhode Island	168.2	17.6	44	44

State	Mean score	Standard deviation	Range	80% range
South Carolina	166.9	28.8	102	66
South Dakota	103.8	10.1	52	26
Tennessee	138.6	16.3	0	35
Texas	124.9	13.4	85	31
Utah	103.4	12.6	51	33
Vermont	143.6	8.1	23	19
Wisconsin	134.1	28.6	104	73
Wyoming	107.7	8.0	29	19
Virginia	147.8	21.6	84	54
Washington	113.9	19.0	70	51
West Virginia	115.6	18.8	81	50

[a]Averaged across counties.

Table II.7: County-Level DRASTIC Scores[a]

County	Mean score	Standard deviation	Range	80% range
1. Calhoun, Ala.	127.9	12.8	39	33
2. Coffee, Ala.	145.6	10.0	42	8
3. Covington, Ala.	164.4	29.7	79	79
4. Pickens, Ala.	167.3	6.7	22	14
5. Fresno, Calif.	162.7	37.8	154	110
6. Windham, Conn.	161.5	28.0	127	58
7. Kent, Del.	166.8	31.9	93	70
8. Bulloch, Ga.	216.9	2.7	12	6
9. Effingham, Ga.	201.5	3.2	12	8
10. Laurens, Ga.	178.0	1.7	7	3
11. Miller, Ga.	186.8	1.7	4	4
12. Seminole, Ga.	184.8	3.3	9	9
13. Thomas, Ga.	191.4	1.7	4	4
14. Bureau, Ill.	132.2	25.0	98	53
15. McHenry, Ill.	160.9	19.9	69	53
16. Boone, Ind.	139.0	4.7	25	12
17. Fountain, Ind.	122.9	4.8	14	11
18. Grant, Ind.	132.8	9.4	25	25
19. Hamilton, Ind.	141.0	17.0	65	50
20. Jay, Ind.	120.2	4.3	17	6
21. Lagrange, Ind.	186.3	13.5	46	36
22. La Porte, Ind.	169.2	19.2	73	47

(continued)

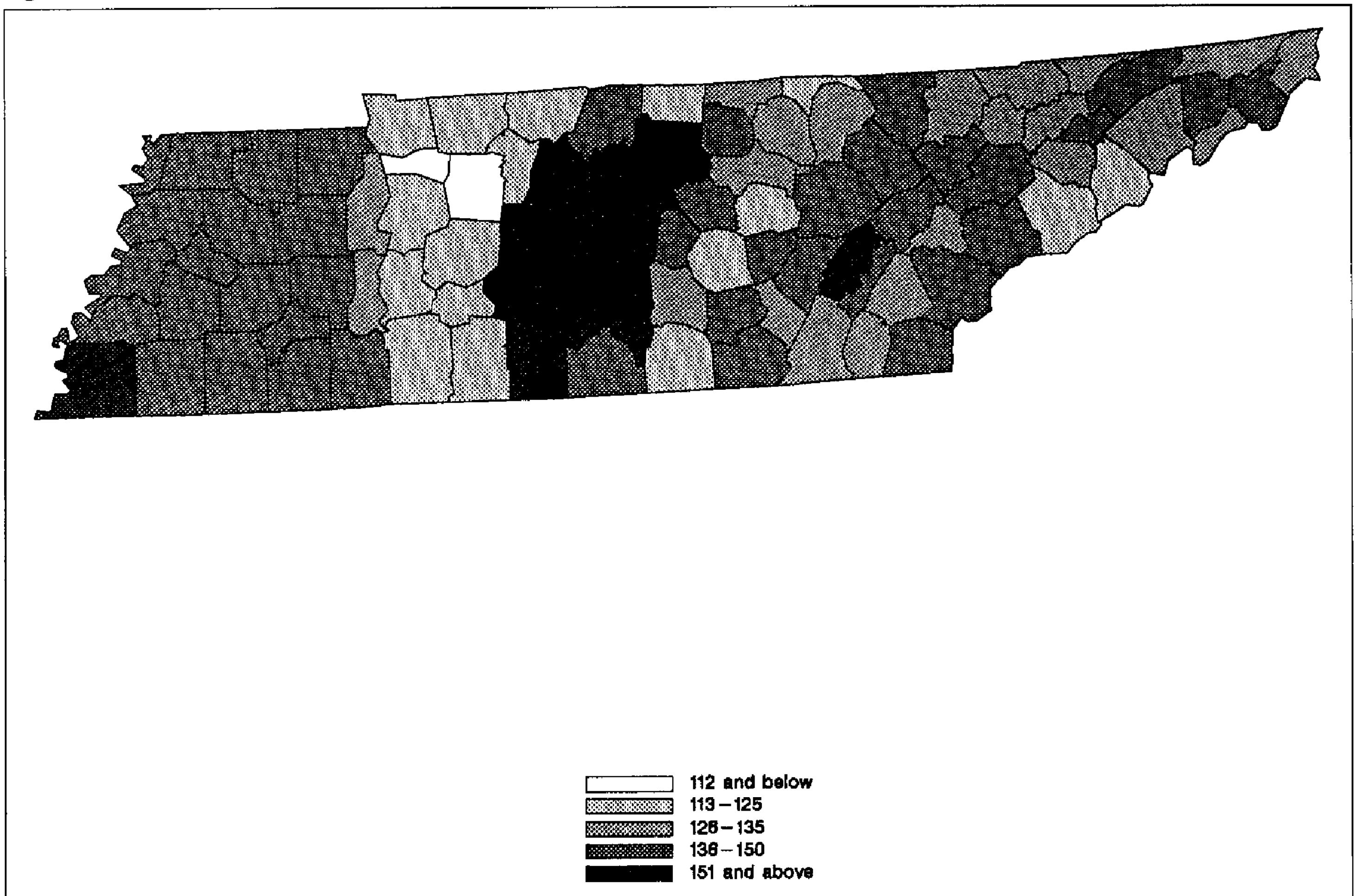
County	Mean score	Standard deviation	Range	80% range
23. Newton, Ind.	172.9	52.8	115	115
24. St. Joseph, Ind.	165.2	22.8	64	56
25. Spencer, Ind.	160.6	23.3	73	52
26. Cerro Gordo, Iowa	134.9	19.1	76	49
27. Fayette, Iowa	143.9	17.7	65	49
28. Grundy, Iowa	118.5	15.0	62	23
29. Mitchell, Iowa	163.2	23.1	67	62
30. Wright, Iowa	118.4	7.3	22	20
31. Reno, Kans.	174.4	20.9	78	51
32. Shelby, Ky.	123.5	1.7	7	5
33. East Carroll, La.	159.1	2.0	5	5
34. Rapides, La.	163.1	1.5	8	2
35. St. Tammany, La.	167.9	3.4	25	5
36. Baltimore, Md.	119.8	11.2	30	30
37. Harford, Md.	134.6	4.2	15	11
38. Wicomico, Md.	177.7	12.9	42	30
39. Allegan, Mich.	170.3	29.1	119	80
40. Cass, Mich.	168.1	13.2	45	32
41. Ingham, Mich.	165.8	11.4	44	31
42. Kalamazoo, Mich.	176.8	9.3	57	17
43. Big Stone, Minn.	183.5	10.1	38	24
44. Clearwater, Minn.	162.1	18.2	65	55
45. Meeker, Minn.	182.0	12.8	64	16
46. Olmsted, Minn.	144.9	17.0	73	46
47. Otter Tail, Minn.	164.9	29.8	98	75
48. Wabasha, Minn.	151.6	10.2	31	24
49. Brunswick, N.C.	203.6	11.6	41	41
50. Columbus, N.C.	185.1	5.2	23	10
51. Nash, N.C.	158.3	7.9	38	16
52. Sampson, N.C.	199.0	4.1	17	9
53. Stanly, N.C.	114.1	2.1	6	5
54. Washington, N.C.	164.0	8.9	20	20
55. Mercer, N.J.	164.6	13.2	38	31
56. Orleans, N.Y.	167.2	3.5	14	9
57. Rensselaer, N.Y.	127.2	16.7	81	27
58. Suffolk, N.Y.	171.5	40.9	118	118
59. Clermont, Ohio	109.6	9.8	62	10
60. Crawford, Ohio	109.8	3.0	10	9

(continued)

County	Mean score	Standard deviation	Range	80% range
61. Fayette, Ohio	122.2	10.1	44	13
62. Knox, Ohio	111.4	11.9	60	21
63. Licking, Ohio	109.0	14.0	69	29
64. Lucas, Ohio	139.1	53.2	148	141
65. Wood, Ohio	97.3	7.2	26	12
66. Hughes, Okla.	162.0	19.6	45	45
67. Lincoln, Okla.	126.0	7.3	32	19
68. Malheur, Oreg.	116.7	19.7	82	48
69. Columbia, Pa.	157.2	18.0	58	53
70. Lancaster, Pa.	144.8	7.9	23	21
71. Montgomery, Pa.	133.0	4.1	18	8
72. Westmoreland, Pa.	140.5	2.2	17	4
73. Allendale, S.C.	207.8	5.9	28	6
74. Calhoun, S.C.	133.7	6.6	28	12
75. Florence, S.C.	169.7	1.9	20	3
76. Bradley, Tenn.	149.3	1.7	5	5
77. Claiborne, Tenn.	138.6	14.2	44	38
78. DeKalb, Tenn.	184.9	13.0	29	29
79. Jefferson, Tenn.	156.7	9.6	38	21
80. Augusta, Va.	164.0	35.3	126	95
81. Southampton, Va.	171.1	20.3	54	50
82. Yakima, Wash.	148.4	13.5	93	28
83. Dane, Wis.	141.3	12.0	62	34
84. Grant, Wis.	120.0	21.1	91	47
85. Polk, Wis.	189.3	11.2	41	26
86. Rock, Wis.	139.4	12.6	38	37
87. Walworth, Wis.	148.6	15.9	53	46

[a]Averaged across census enumeration districts.

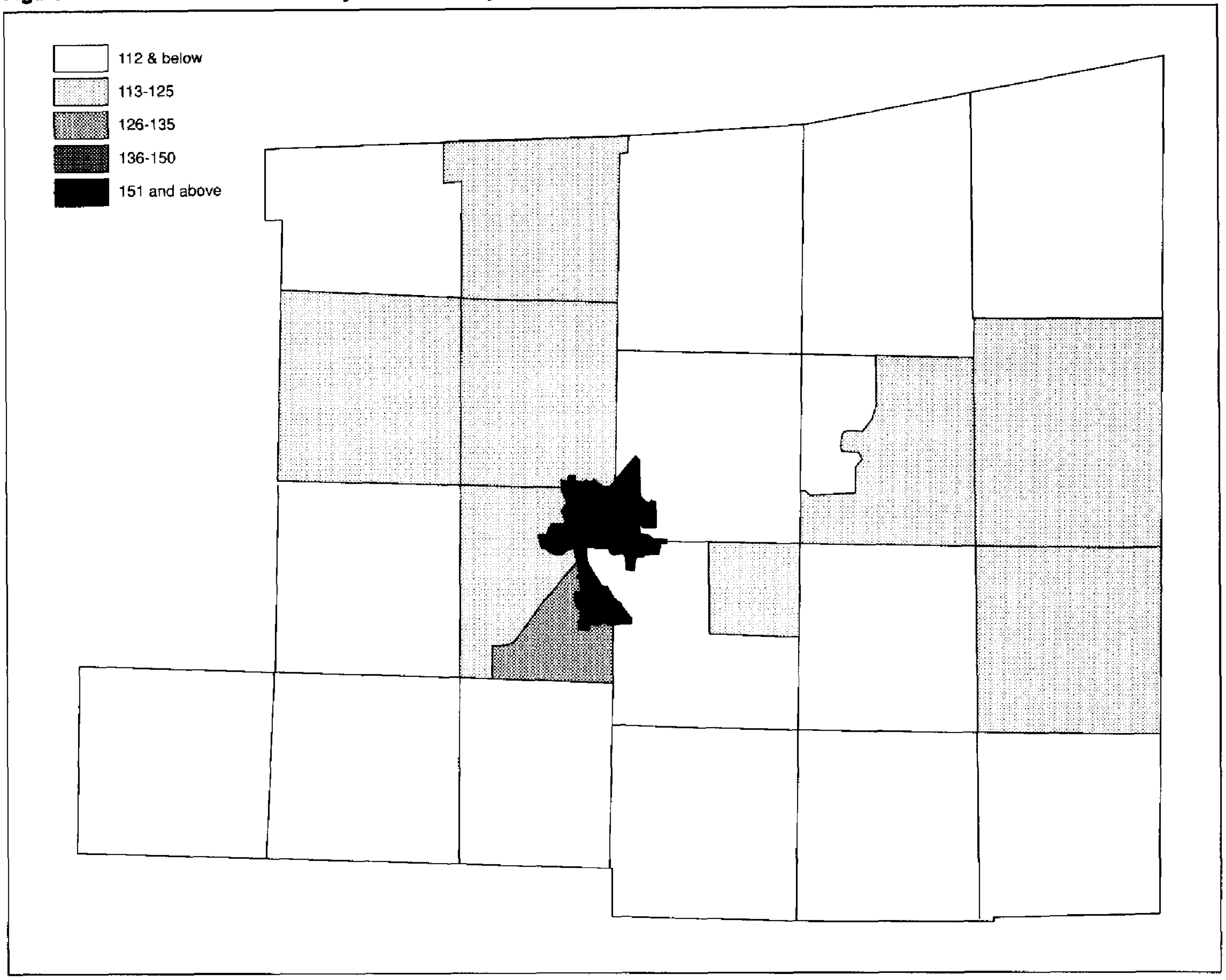
Figure II.1: Groundwater Vulnerability: Between-County Estimates for a State With an Average Degree of Variability in Scores[a]



[a]Tennessee.

Source: GAO analysis of data obtained from EPA.

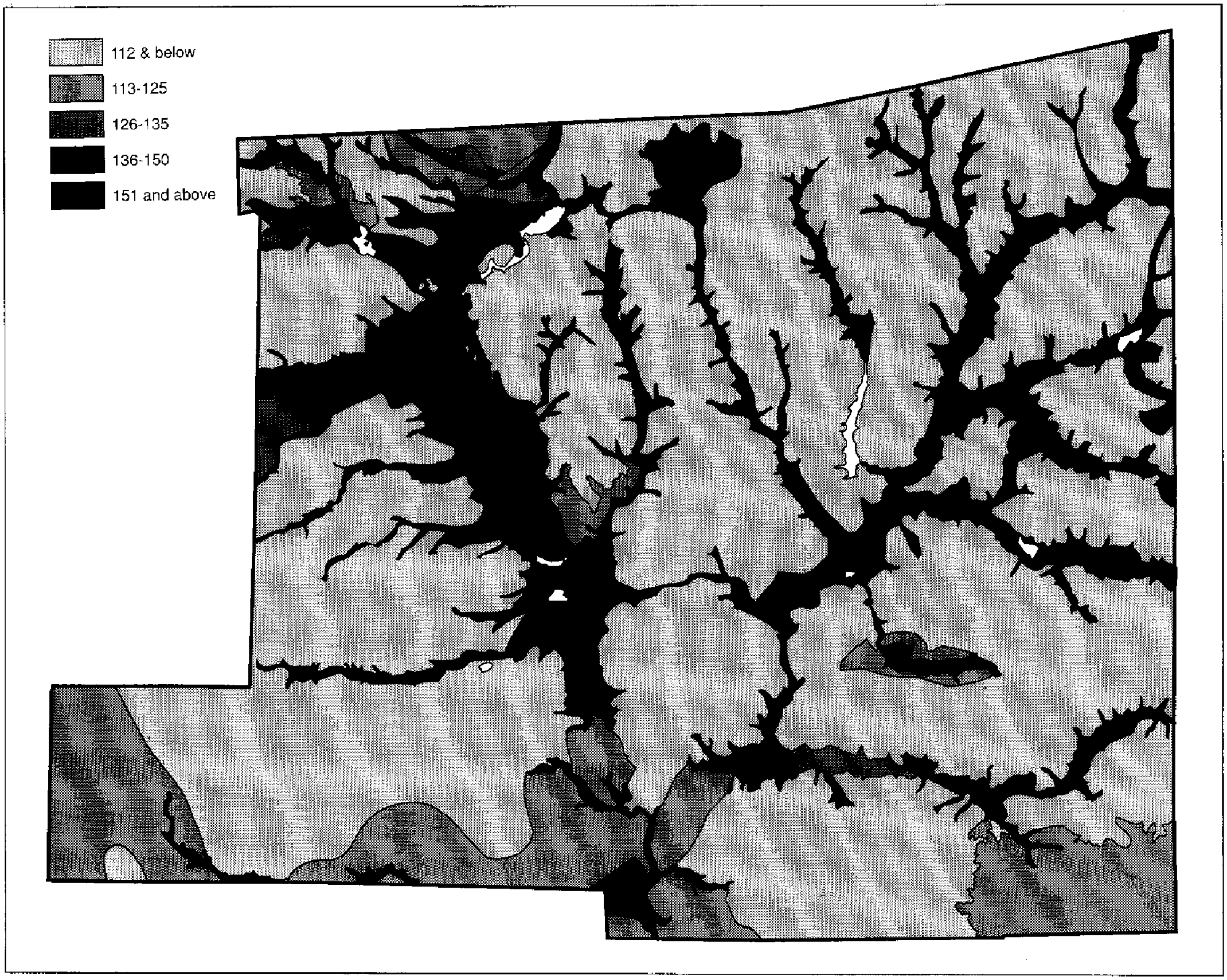
Figure II.2: Groundwater Vulnerability: Within-County Estimates by Census Enumeration District[a]



[a]Knox County, Ohio.

Source: GAO analysis of data obtained from Research Triangle Institute.

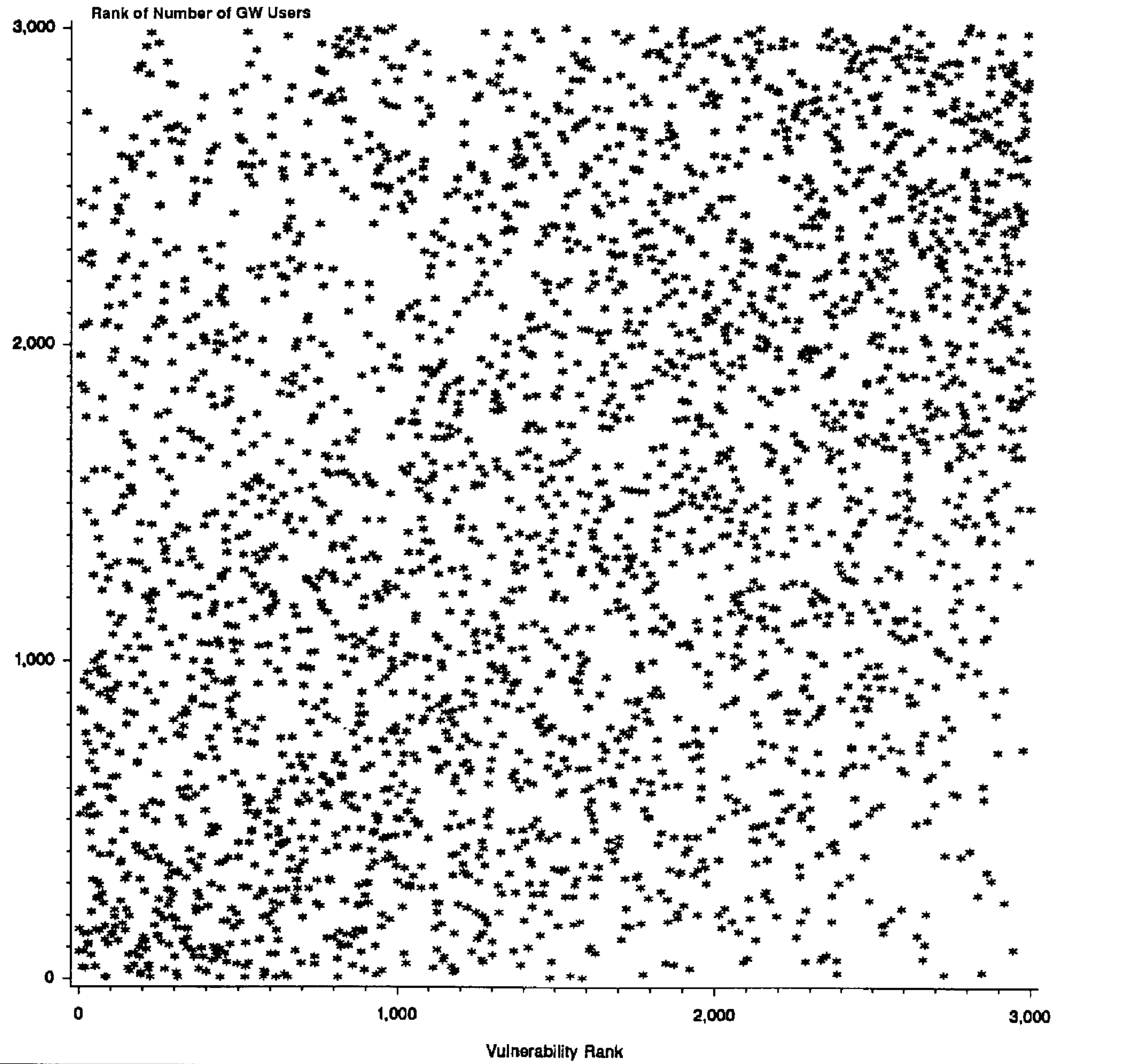
Figure II.3: Groundwater Vulnerability: Within-County Estimates by Hydrogeologic Setting[a]



[a]Knox County, Ohio.

Source: GAO analysis of data obtained from Ohio Department of Natural Resources.

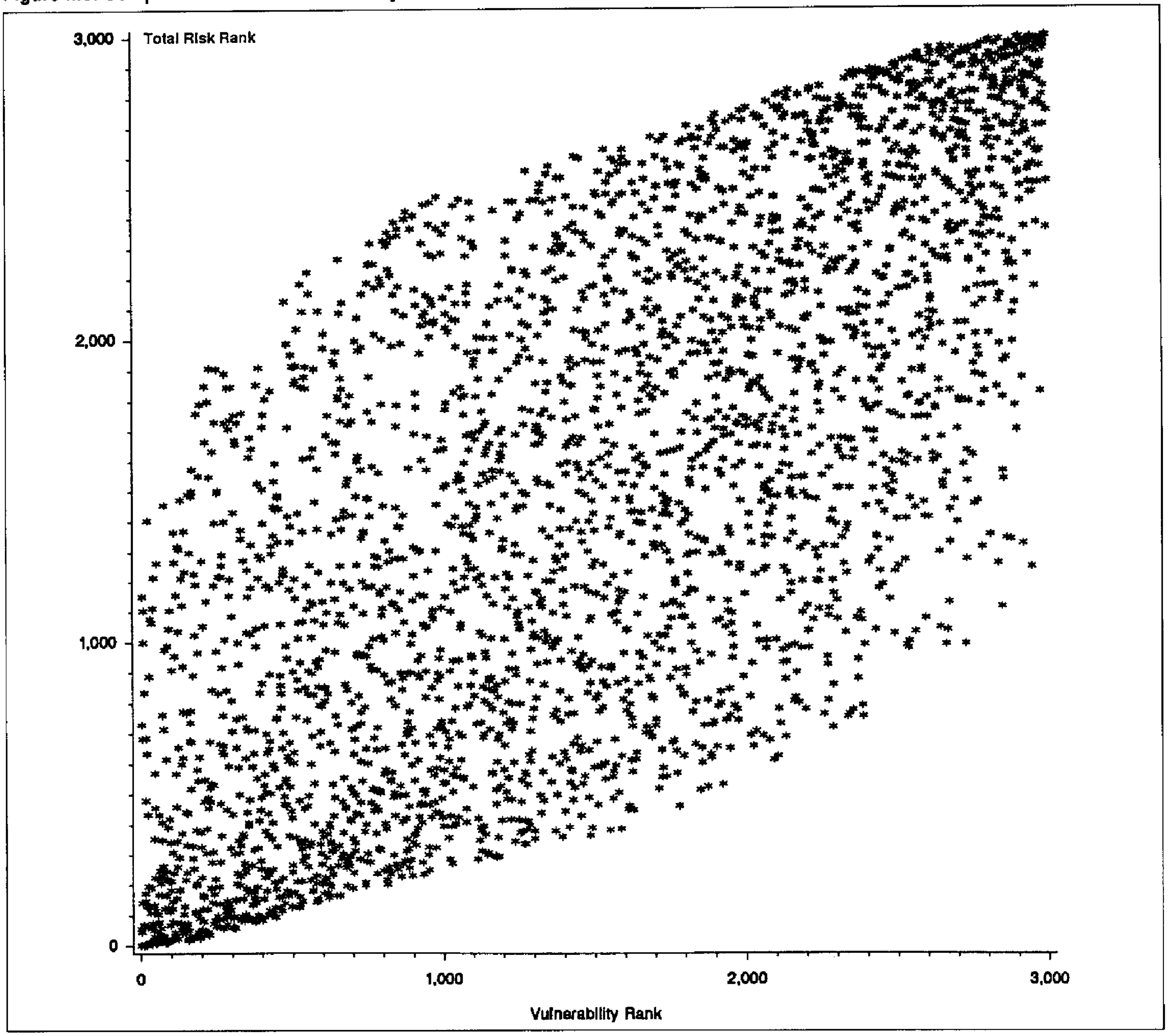
Figure II.4: Comparison of Total Vulnerability Rank With Rank of Number of Groundwater Users[a]



[a]3,002 counties.

Source: GAO analysis of data obtained from EPA, Resources for the Future, and U.S. Geological Survey.

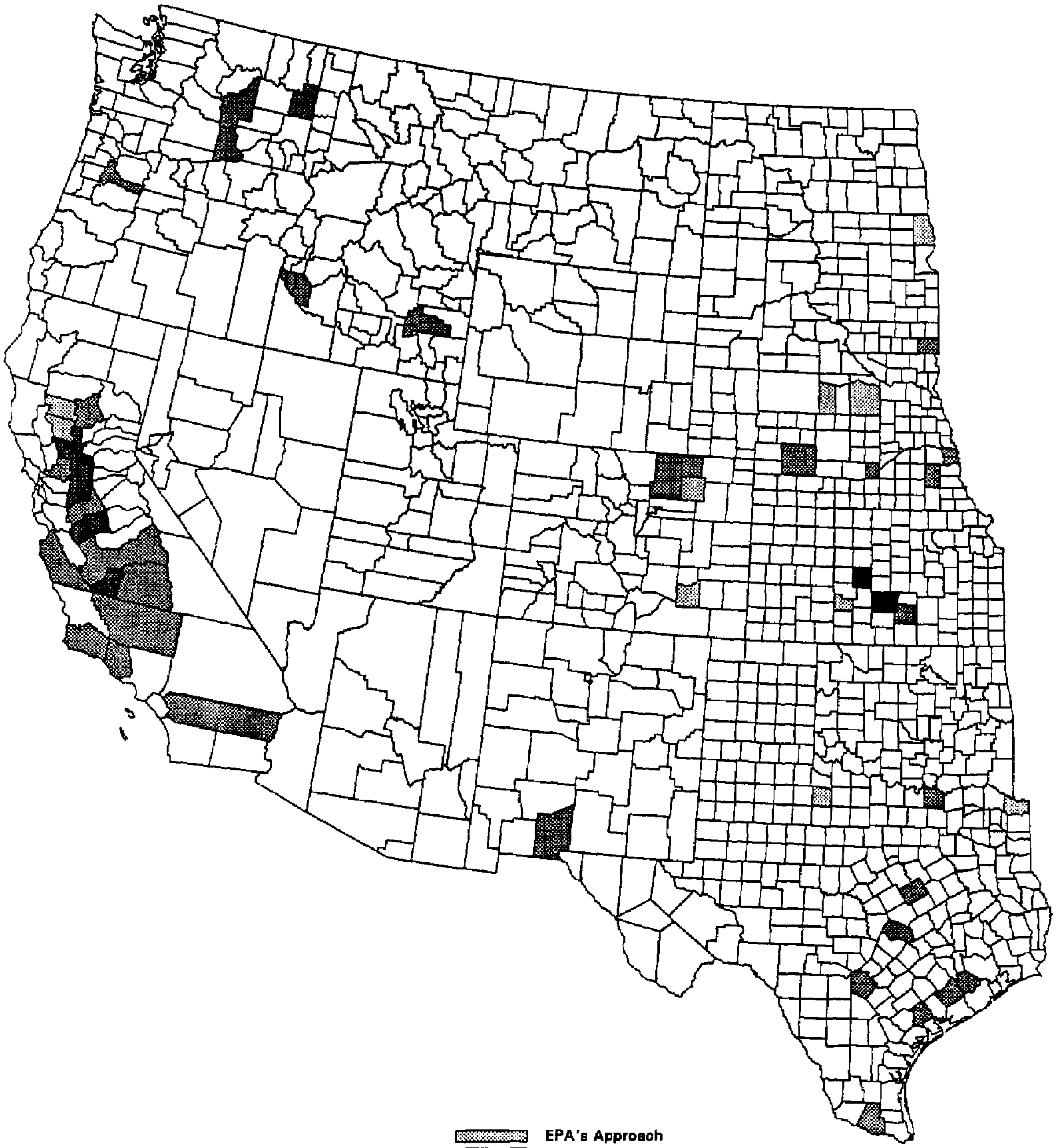
Figure II.5: Comparison of Total Vulnerability Rank With Total Risk Rank[a]

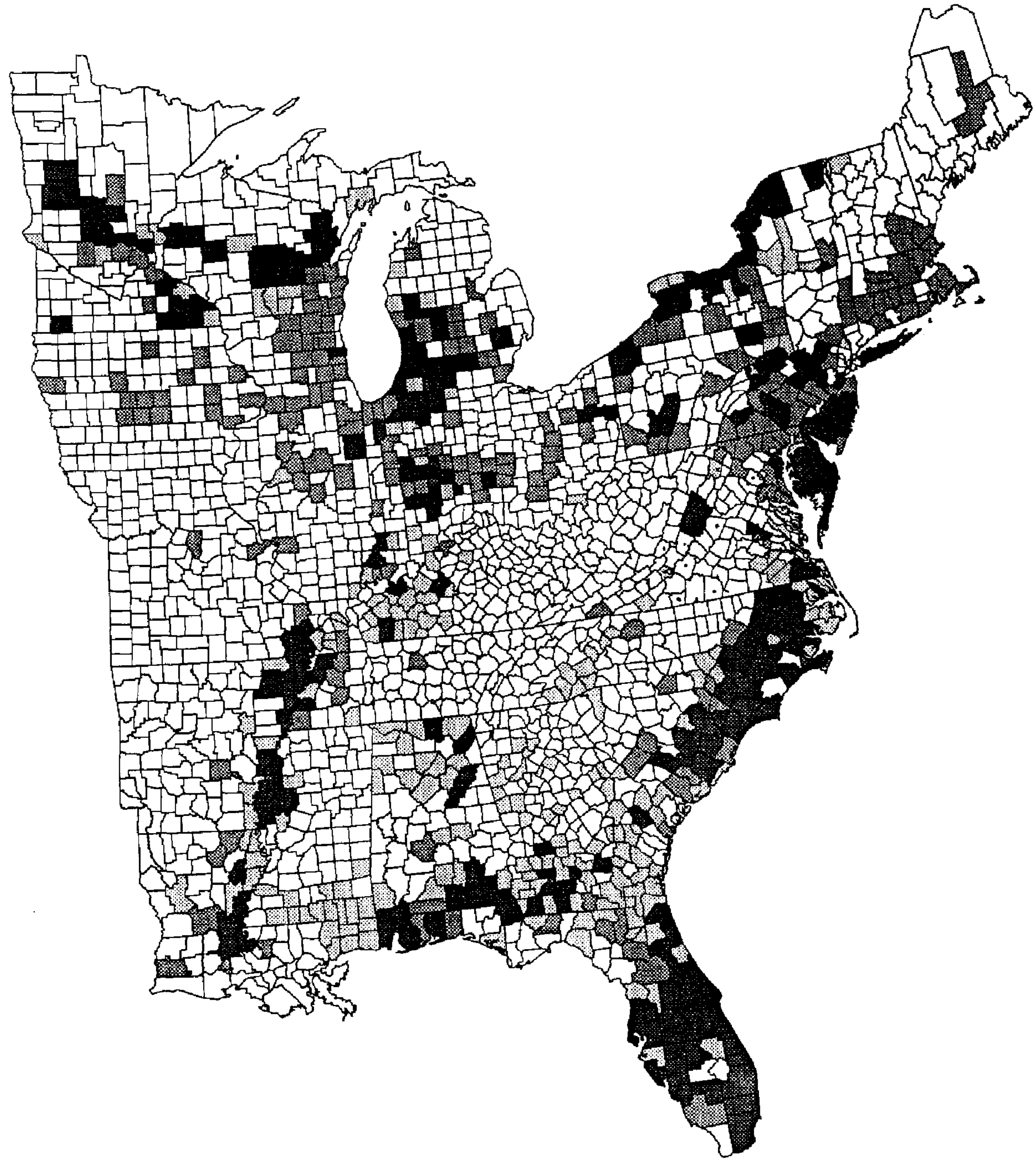


[a]3,002 counties.

Source: GAO analysis of data obtained from EPA, Resources for the Future, and U.S. Geological Survey.

Figure II.6: Counties Selected by Using EPA and Total Risk Approaches[a]

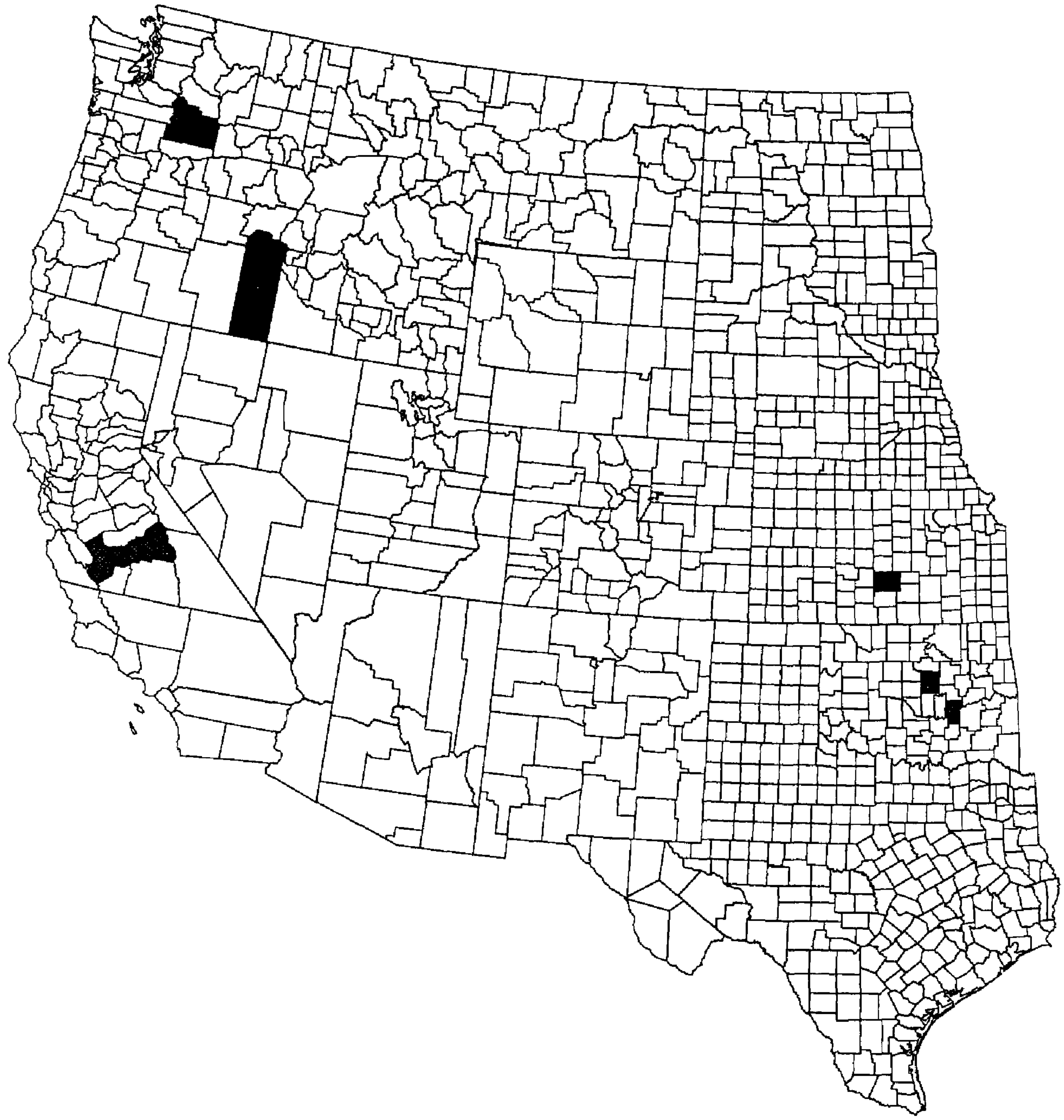


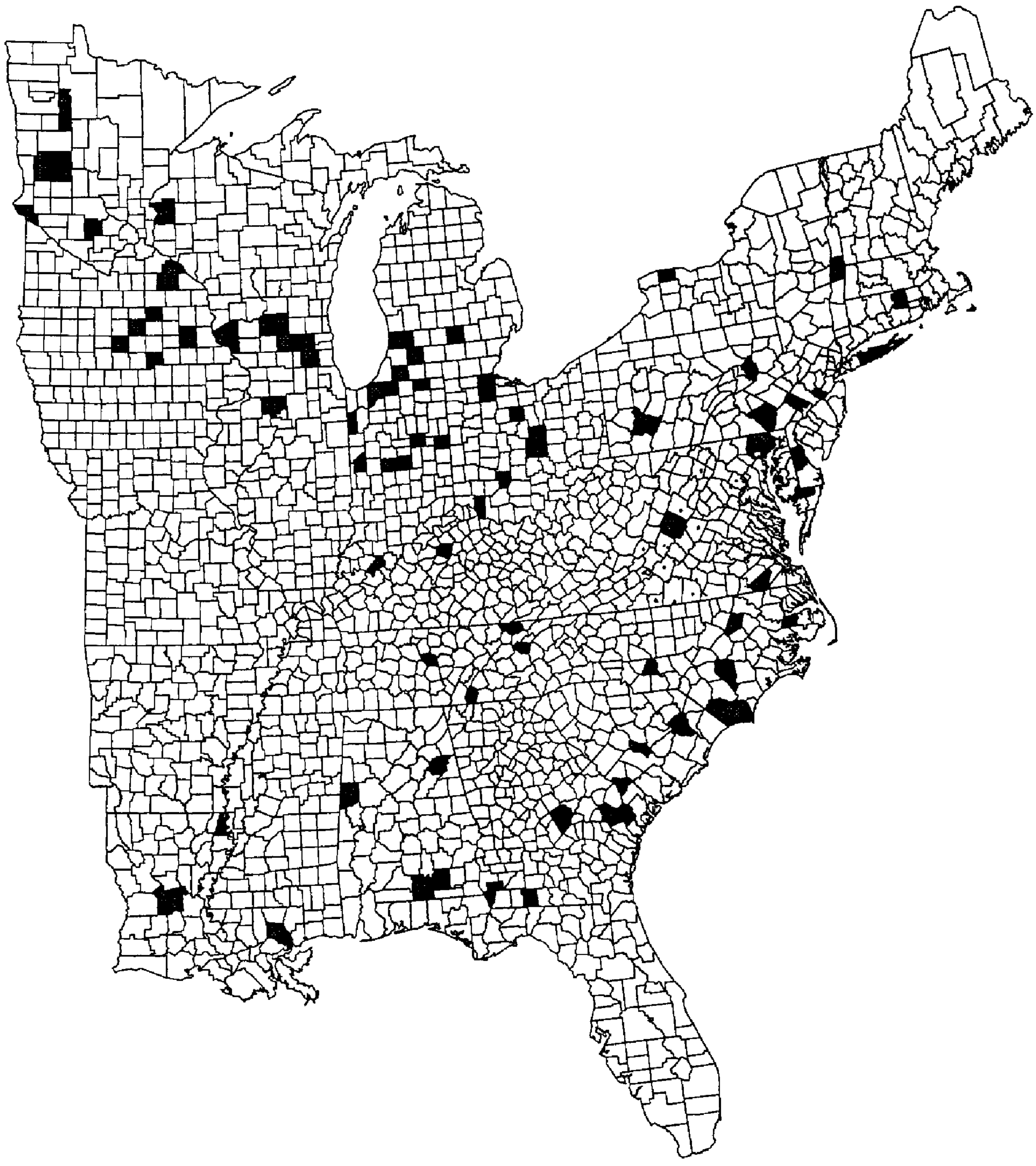


[a]3,002 counties.

Source: GAO analysis of data obtained from EPA, Resources for the Future, and U.S. Geological Survey.

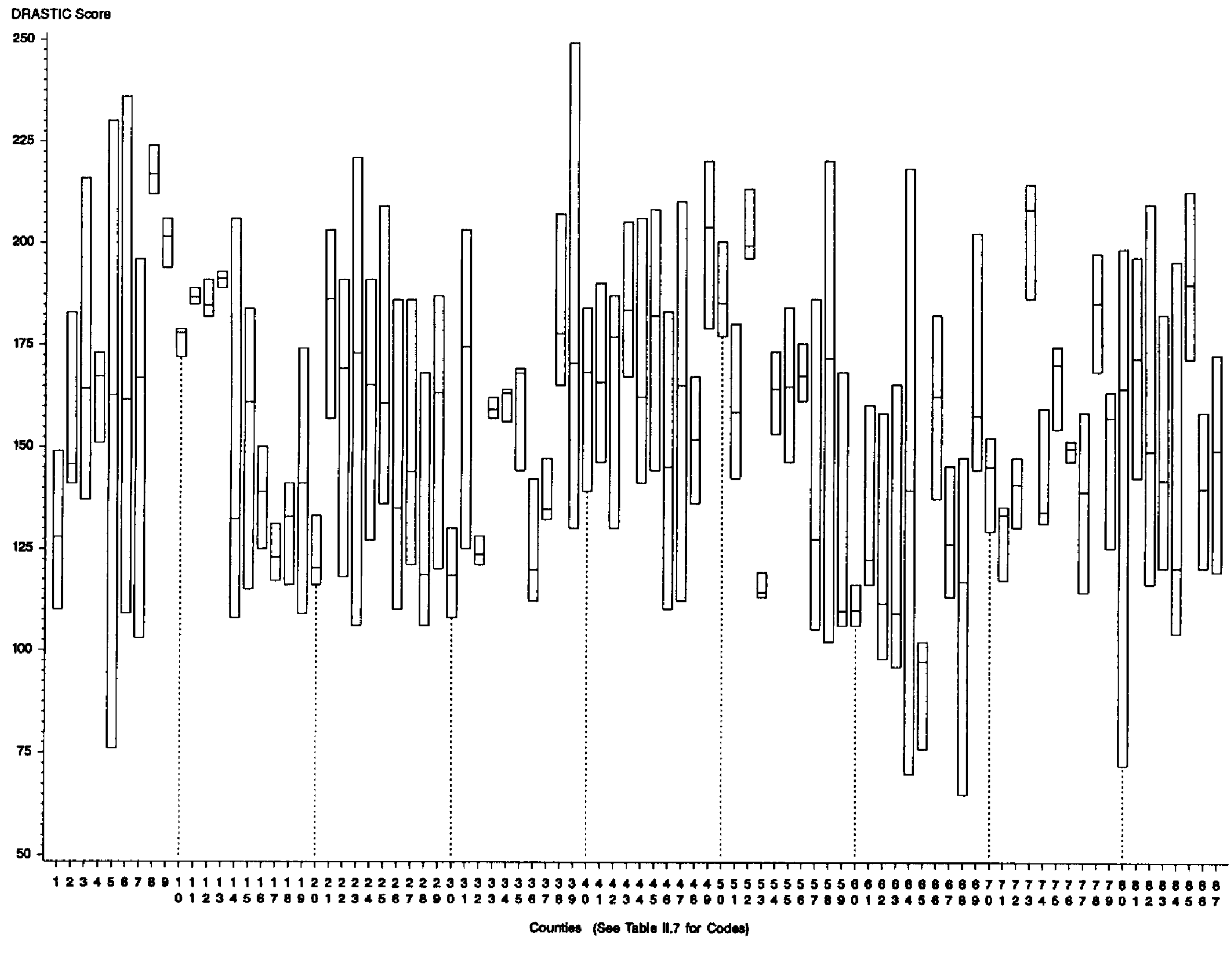
Figure II.7: Counties Studied for Within-County Variability





Source: GAO analysis of data obtained from Research Triangle Institute.

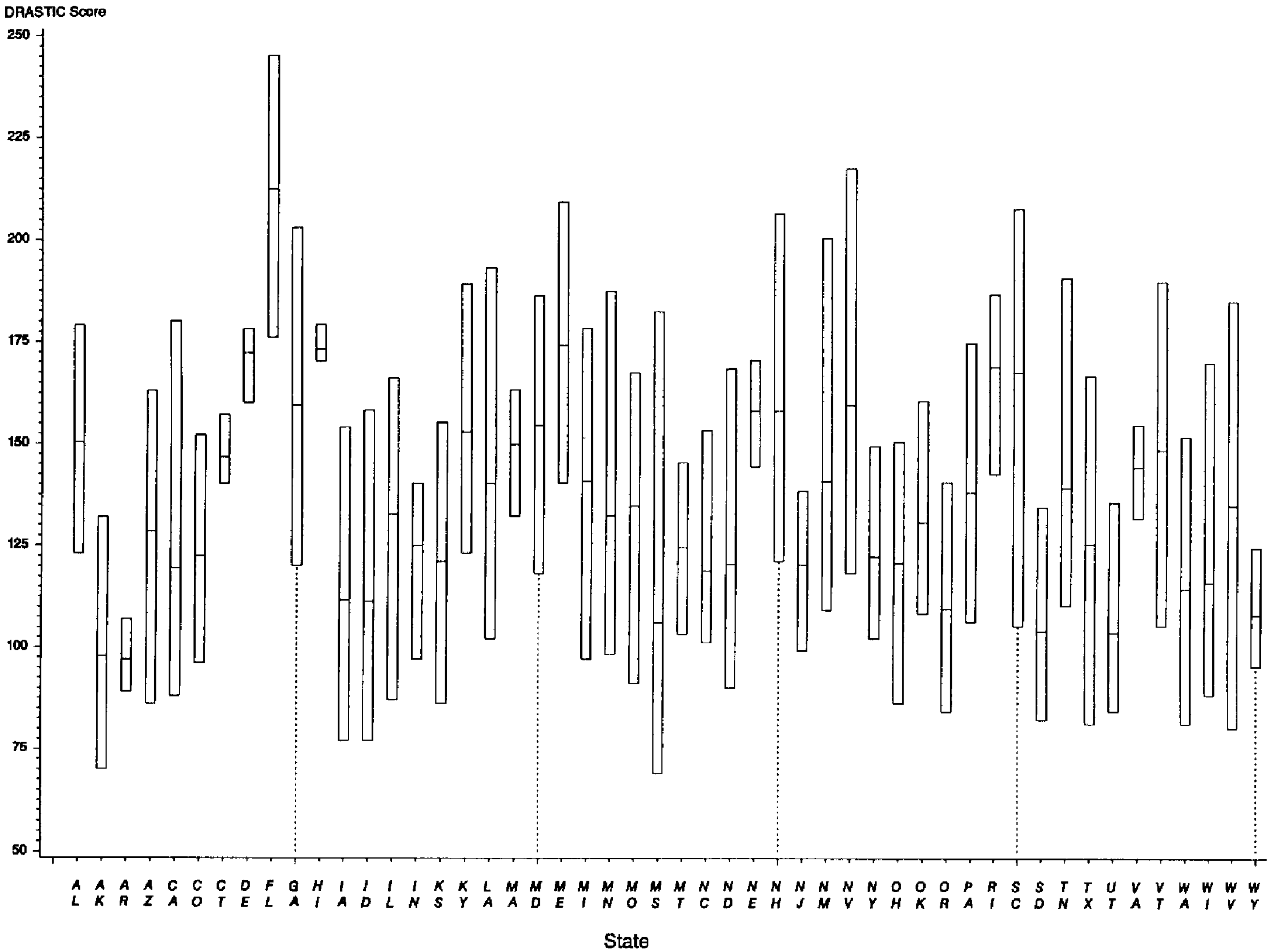
Figure II.8: Variability in Hydrogeologic Vulnerability: Minimum, Maximum, and Mean Scores in 87 Counties[a]



[a]By census enumeration district.

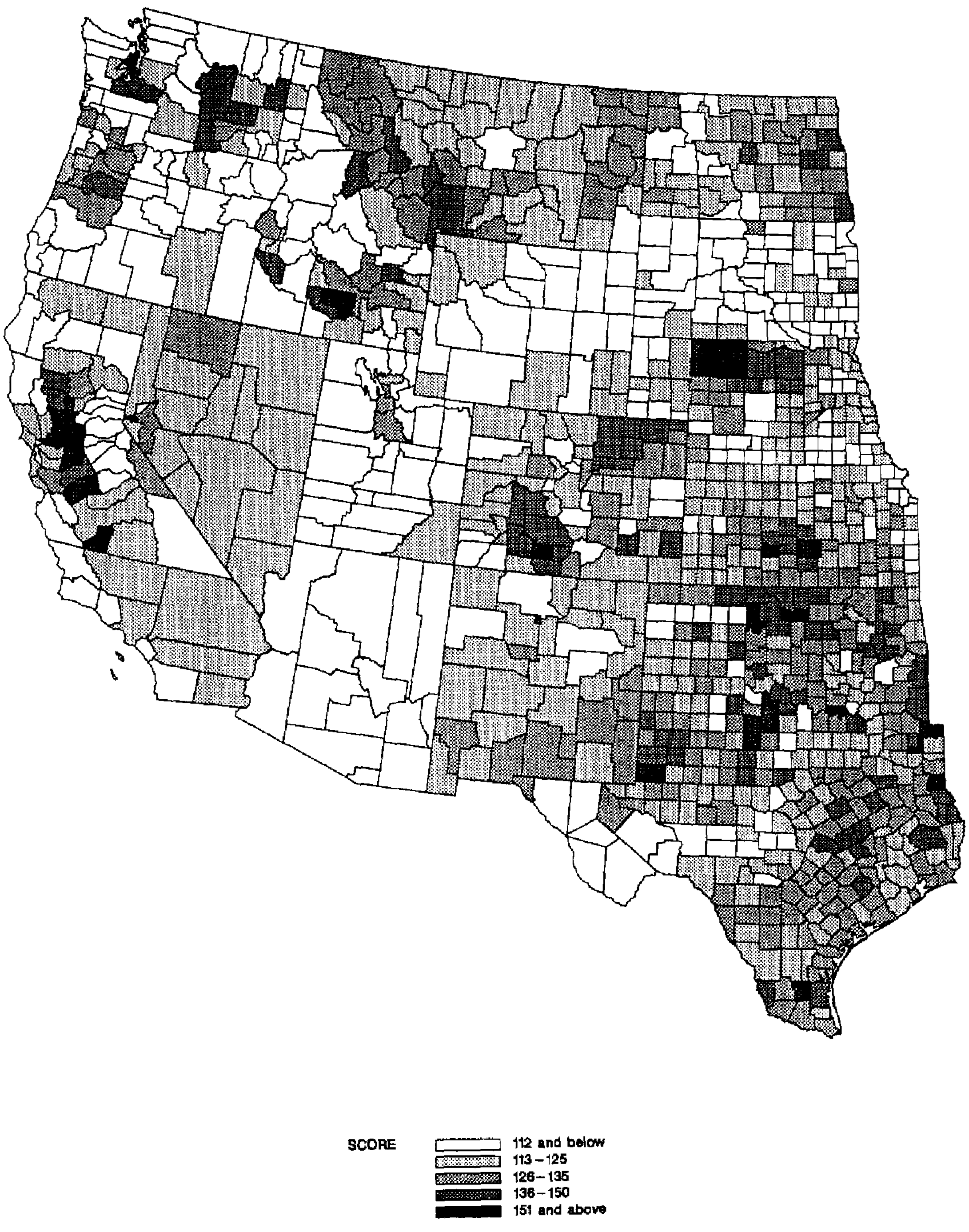
Source: GAO analysis of data obtained from Research Triangle Institute.

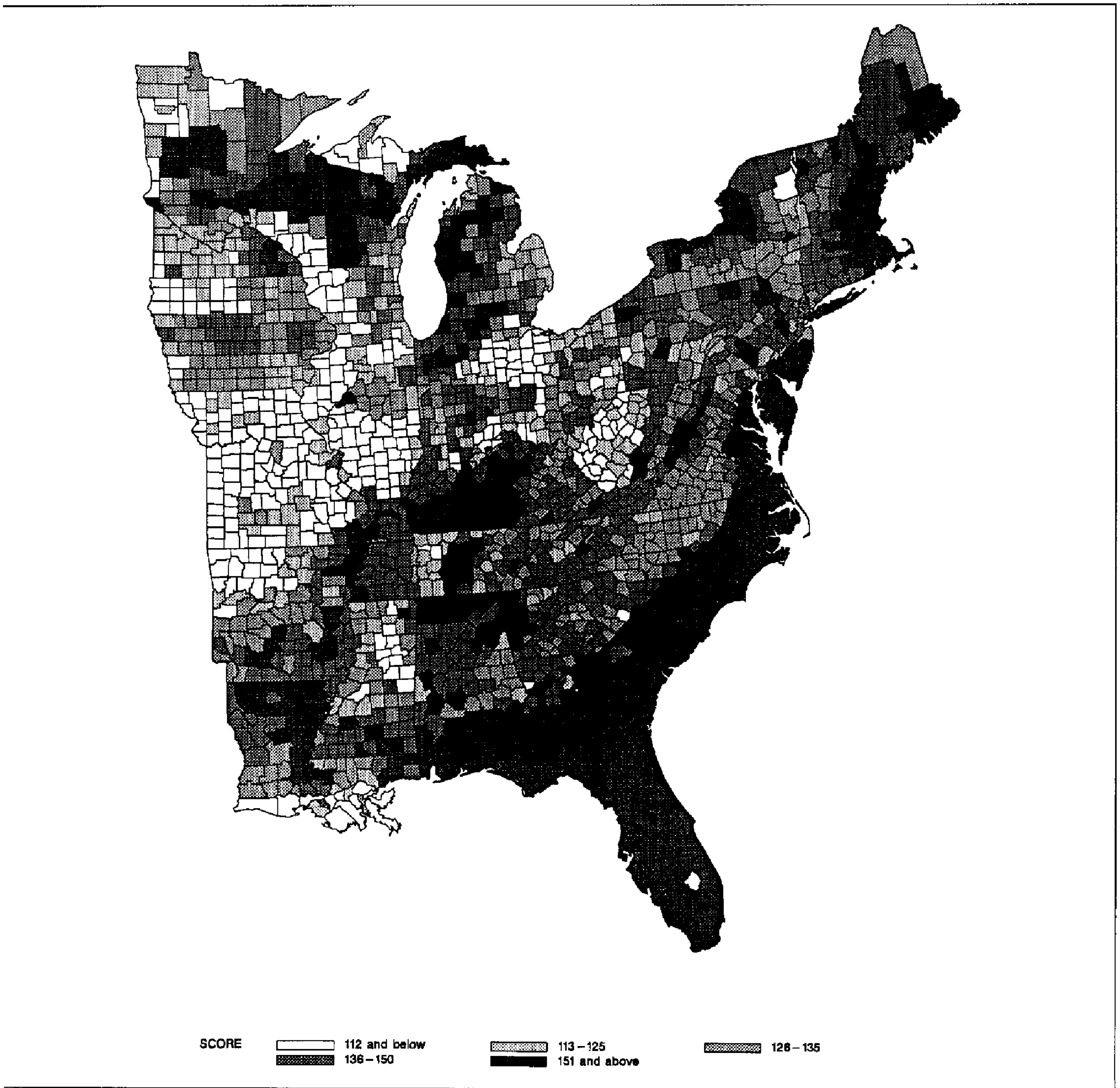
Figure II.9: Variability in Hydrogeologic Vulnerability: Minimum, Maximum, and Mean County-Level Scores in 50 States



Source: GAO analysis of data obtained from EPA.

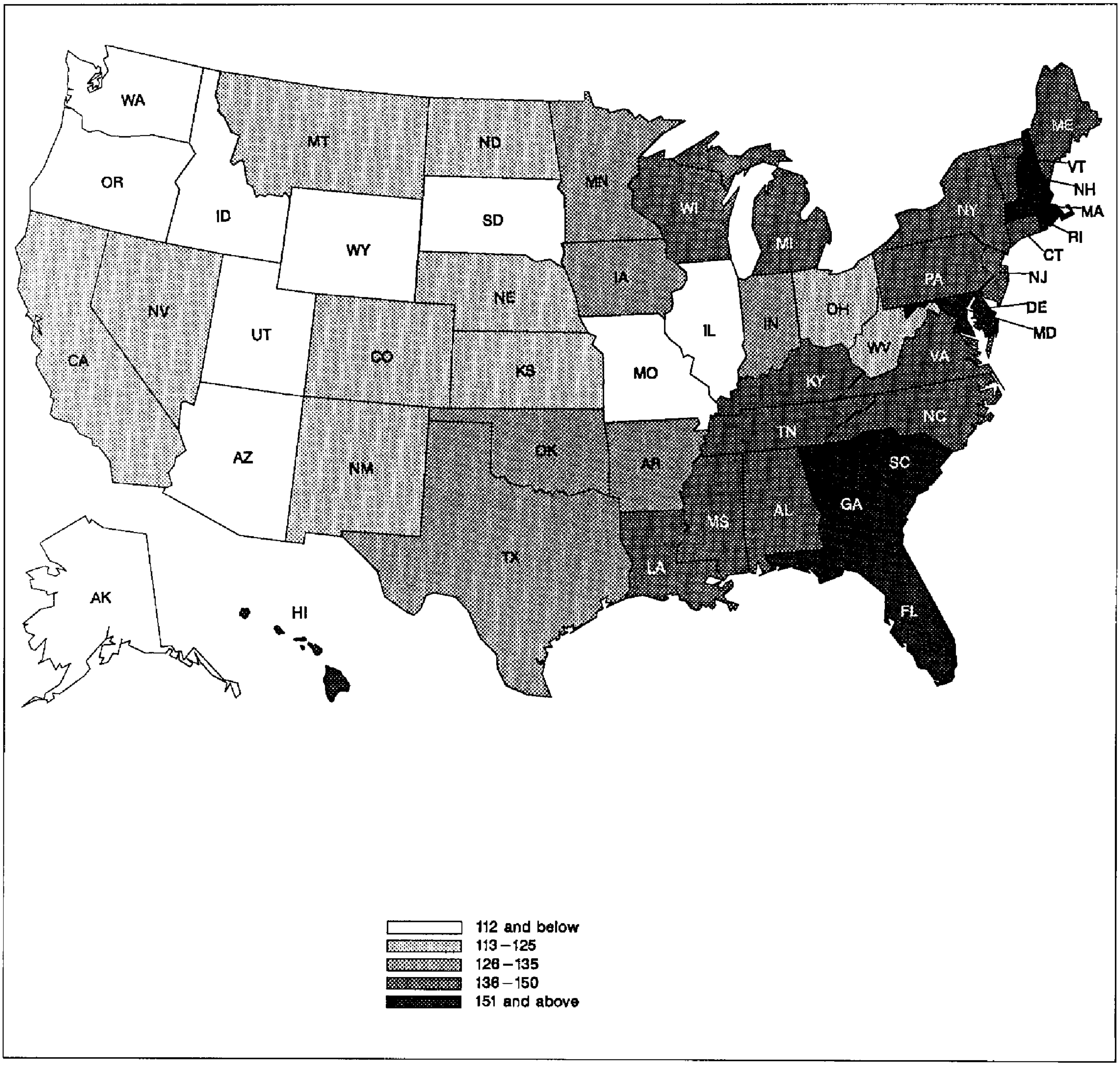
Figure II.10: Relative Hydrogeologic Vulnerability in 3,143 Counties





Source: GAO analysis of data obtained from EPA.

Figure II.11: State Relative Hydrogeologic Vulnerability Groups[a]



[a]By median county score.

Source: GAO analysis of data obtained from EPA.

Major Contributors to This Report

Program Evaluation and Methodology Division

Boris Kachura, Assistant Director
Dan Engelberg, Project Manager
Stephen Smith, Social Science Analyst

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This bibliography is composed of validations of vulnerability assessments that we reviewed. Our review of model validation studies was based on a search of on-line data bases and contacts with individuals who conduct groundwater quality research. We did not independently evaluate the quality of the studies but accepted the authors' own statement of findings.

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