Potential Priority Watersheds for Protection of Water Quality from Contamination by Manure Nutrients

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A paper presented at the Animal Residuals Management Conference 2000,
November 12-14, Kansas City, Missouri

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Introduction

Manure applied to the land is susceptible to leaching and runoff, and can be a significant source of contamination of groundwater and surface water. Government programs and policies addressing this issue are presently under discussion. Proposals by EPA are regulatory in nature, while proposals by USDA are voluntary but may include subsidies. USDA technical assistance will probably be a component of both. Once agreement has been reached about the specifics of these programs and policies, attention will turn to implementation. Because of the large number of farms involved in animal agriculture, it will probably require several years to fully implement the programs and policies.

Programs and polices will need to be targeted to priority watersheds first if protection of the environment is the primary goal. The purpose of this paper is to identify those priority watersheds at the national level. The production of manure nutrients has been estimated previously for each county by Kellogg, Lander, Mofitt, and Gollehon (2000). However, nutrient loadings are not sufficient for estimating priority watersheds. The potential for manure nutrients to contaminate ground and surface water would be expected to be greatest not only where the manure application rates are high but also where environmental factors such as rainfall, leaching potential of the soil, runoff potential of the soil, and soil erosion rates are conducive to the loss of manure nutrients from the fields. Vulnerability indexes are derived in this paper from manure loading rates <u>and</u> environmental factors to identify areas of the country that are potentially most at risk.

Accounting for Environmental Factors

The best way to account for environmental factors would be to apply a hydrologic model to each major watershed in the country to define the potential for manure nutrients to move from farm fields to groundwater and surface water. However, this modeling technology is not yet developed well enough to be used to develop vulnerability indexes. Instead, three environmental indicators were developed that incorporate factors that are known to be important in the movement of materials from farm fields. Although these environmental indicators are not as precise as those that could be produced using a hydrologic model, they are adequate for screening of major watersheds at the national level.

The three environmental indicators are: 1) a percolation factor that measures the potential for leaching, 2) an annual runoff factor that measures the potential for contaminants dissolved in water to run off farm fields, and 3) a soil erosion factor that measures the potential for nutrients adsorbed onto soil particles to move from farm fields. These indicators have previously been used by Kellogg, Wallace, Alt, and Goss (1997) to identify priority watersheds for protection of water quality.

The National Resources Inventory (NRI) was used as an analytical framework for obtaining watershed-level estimates of each of these indicators. The NRI is a national survey of private land use that is based on about 800,000 sample points throughout the 50 states, including cropland, pastureland, rangeland, forest land, urban land, and other uses of private land (Kellogg, TeSelle, and Goebel, 1994). The county and 8-digit hydrologic group is identified for each NRI sample point. The 8-digit hydrologic unit, or cataloguing unit, was used to define the major watersheds for this study.

Percolation Factor. The percolation factor estimates the average amount of rainfall in inches per year that percolates through the root zone based on rainfall and soil properties. It was originally developed for use as a nitrate leaching index by Williams and Kissel (1991). The equations for the percolation factor are:

$$PF = SI*PI + 1$$

where:

$SI = [(2PW)/P]^{1/3}$

$PI = (P-0.4s)^2 / (P+0.6s)$ where $P>0.4s$

$PI = 0$ where P is less than or equal to 0.4s

PW = the sum of October through March precipitation

P = annual precipitation

s = parameter for the soil hydrologic group

The calculation of PF weighs precipitation during non-growing periods (fall and winter months) more than during growing periods to account for plant uptake. Hydrologic group is a soil interpretation used by NRCS to categorize soils by their potential for water to infiltrate the soil. Hydrologic groups have been assigned to all soils in the country by NRCS, and are an attribute in the NRI. Williams and Kissel used EPIC (Erosion-Productivity Impact Calculator) to estimate an s value for each of the four hydrologic groups, as follows:

Hydrologic group A: s=26
Hydrologic group B: s=38
Hydrologic group C: s=49
Hydrologic group D: s=57

Precipitation data were obtained from a network of 1,473 climate stations throughout the US and imputed to the NRI sample points. A database of average monthly precipitation for each climate station was assembled by Dr. Don Goss, Texas Agricultural Experiment Station, Temple, Texas. The monthly average was determined using 25 years of daily precipitation data. Monthly precipitation data were imputed to NRI sample points on the basis of the proximity of the NRI sample points to the climate stations. A GIS surface layer was constructed for each of the 12 months using precipitation data for the 1,473 climate stations. The centroid of the NRI polygon formed by the intersection of MLRA, 8-digit hydrologic unit, and county boundaries was used to extrapolate precipitation estimates from the GIS surface to the NRI polygon. All the NRI points in the NRI polygon were assigned the same monthly precipitation values.

The average value for the percolation factor for cultivated cropland and pastureland for each county-watershed polygon is shown in map 1.

Annual Runoff Factor. The annual runoff factor is an estimate of the inches of rainfall that runs off the surface, rather than percolates into the soil or evaporates, throughout the year. The NRCS curve number method was used to calculate daily runoff for 1,473 climate stations throughout the 48 states by Dr. Don Goss. Daily estimates were accumulated to monthly values. These monthly runoff values were imputed to NRI sample points according to the proximity of the sample point to one of the weather stations and according to curve number associated with each NRI sample point. Curve numbers are not an attribute reported for NRI sample points, so curve numbers were assigned by Dr. Don Goss to NRI sample points using information on the soil hydrologic group, tillage, conservation practice, and land cover in the NRI database. A GIS surface layer was constructed for each of the 12 months and 12 curve numbers using runoff data for the 1,473 climate stations. The centroid of the NRI polygon formed by the intersection of MLRA, 8-digit hydrologic unit, and county boundaries was used to extrapolate runoff estimates from the GIS surface to the NRI polygon centroid. All the NRI points in the NRI polygon were assigned the same runoff values The annual runoff factor at each NRI sample point is a sum of monthly runoff estimates.

The average value for the annual runoff factor for cultivated cropland and pastureland for each county-watershed polygon is shown in map 2.

Soil Erosion Factor. The Universal Soil Loss Equation (USLE) was used as the soil erosion factor. The USLE is a measure of the potential for soil particles to move from one point to another within a field as a result of sheet and rill erosion, and thus measures the potential for soil loss in tons per year that is due to water erosion. USLE estimates are available directly from the NRI for pastureland and cropland sample points. The average value for USLE (pounds per acre) for cultivated cropland and pastureland for each county-watershed polygon is shown in map 3.

Converting County Estimates of Manure Loadings to Watershed Estimates

Estimates of manure nutrient loadings at the county level were obtained from Kellogg, Lander, Mofitt, and Gollehon (2000). To estimate priority watersheds, these county estimates must first be converted to watershed estimates.

County estimates were converted to a watershed basis (8-digit hydrologic units) using conversion factors developed from acreage estimated in the 1992 National Resources Inventory (NRI). Total cropland and pastureland acres were used to develop conversion factors. The watershed conversion factor is the proportion of pastureland and cropland acres in a county that are associated with a specific watershed. County-watershed polygons representing less than 11 percent of the county acreage were discarded to make the algorithm manageable, which limited the number of watersheds per county to five or less. For these counties, the original conversion factors were normalized to account for all the acres in a county. (Thus, the sum of the watershed conversion factors was equal to 1 for each county.) Manure nutrients for all farms within a county were allocated to the watersheds that intersected that county in proportion to the cropland and pastureland acreage in each county-watershed polygon. In the few cases where there was too little cropland and pastureland to construct a conversion factor, rangeland was used to derive the conversion factors.

Maps 4 and 5 show the distribution of manure nutrients available for application (i.e., recoverable manure nutrients) by watershed. For the most part, these maps show the same spatial distribution of manure nutrients as corresponding county maps of recoverable manure nutrients reported in Kellogg, Lander, Mofitt, and Gollehon (2000). Differences between these two sets of maps arise because of three reasons. First, spatial distortions occur in the county maps where the counties and combined counties are large, but livestock production is limited to a small area within those counties. This spatial bias occurs for some of the large counties or combined counties in the West. The conversion of county estimates to watershed estimates eliminates some of this spatial bias, in part because the original county estimates were used, rather than estimates for combined counties. (Kellogg, Lander, Mofitt, and Gollehon (2000) reported some estimates for combined counties to meet confidentiality criteria.) Second, the conversion of county estimates to watersheds introduces additional bias when farms are allocated to multiple watersheds. Farms are allocated to counties and combined counties without error, but because the exact watershed for each farm is not known, error is introduced when converting county estimates to watersheds. The third reason for differences between the two sets of maps is that the breaks used to make the maps differ. This is necessary because, on average, 8-digit watersheds are about 50 percent larger than the average county. Consequently, the breaks used for maps 4 and 5 must be slightly larger than for the corresponding county maps to depict similar spatial trends.

Calculating Watershed Vulnerability Indexes

Kellogg, Lander, Mofitt, and Gollehon (2000) estimated four measures of manure nutrient loadings:

1. Pounds of manure nutrients as excreted for all livestock (confined animals and animals not held in confinement).
2. Pounds of manure nutrients as excreted for confined livestock.
3. Pounds of <u>recoverable</u> manure nutrients, which is the estimated amount that could be collected from the confinement area and would be available for land application or other use.
4. Pounds of excess manure nutrients, which is the amount of manure nutrients that exceed the assimilative capacity of the land on each farm assuming no off-farm export.

The third measure--recoverable manure nutrients--was selected for use in calculating watershed vulnerability indexes. While all four measures are legitimate choices, recoverable manure nutrients are believed to be more directly associated with water quality impairments from livestock manure than the other measures. The first measure includes manure nutrients from livestock on grazing lands, which is much more disperse and less likely to contaminate groundwater and surface water. The second measure includes nitrogen lost to the atmosphere through volatilization, which could contribute to loadings through deposition, but it is not clear how much of this nitrogen to account for or where the deposition would occur. The fourth measure is appropriate only under the unrealistic condition that all operators were meeting the nitrogen standard for nitrogen and the phosphorus standard for phosphorus when applying the manure to cropland and pastureland on their farms, so that the excess represents the amount that is over-applied, ignoring possibilities for land application on surrounding properties.

Nitrogen is highly soluble in water and is lost from fields primarily as dissolved nitrogen in runoff, in tile drainage, and in leachate. Phosphorus is only moderately soluble in water, and solubility depends on the levels of phosphorus in the soil. When phosphorus levels in the soil are low, solubility is low; when phosphorus levels in the soil are high, solubility is greater. Other soil characteristics such as organic matter content, temperature, and pH also affect phosphorus solubility. Compared to nitrogen, however, phosphorus is generally not very mobile in soils, remaining adsorbed to soil particles. Phosphorus loss occurs primarily by soil erosion, with some additional dissolved runoff and leachate loss from soils with high phosphorus levels.

Three vulnerability indexes were derived to represent the potential for loss of manure nitrogen and phosphorus from farm fields: 1) nitrogen dissolved in runoff, 2) nitrogen in leachate, and 3) phosphorus adsorbed to soil particles and removed by water erosion. Vulnerability indexes for phosphorus dissolved in runoff and in leachate are not included here because they only apply to areas where phosphorus levels in the soil are high, which could not be factored into the vulnerability indexes because these areas are not known at the national/regional scale. (Vulnerability indexes for dissolved phosphorus were calculated and found to correspond very closely to the two nitrogen vulnerability indexes. Consequently, the vulnerability indexes for dissolved nitrogen in runoff and nitrogen in leachate also function as proxies for dissolved phosphorus.)

Estimates of recoverable manure nutrients for county-watershed polygons were combined with the three environmental indicators related to leaching and runoff to produce vulnerability indexes. Since the environmental indicators were also derived from the NRI, estimates were available for each county-watershed polygon. Average percolation scores, average annual runoff scores, and average annual soil erosion rates were obtained for each county-watershed polygon separately for cultivated cropland and for pastureland and assigned to each watershed for each farm. Averages were the weighted average over NRI sample points within each polygon, where the weights were the expansion factors for NRI sample points. Generally, average annual runoff scores and average annual soil erosion rates had higher scores for cultivated cropland than for pastureland, and average percolation scores had higher values for pastureland.

Vulnerability indexes were calculated for each watershed associated with each farm, multiplied by the watershed conversion factors for each farm, and then aggregated to produce vulnerability indexes for each watershed. At the farm level, separate vulnerability scores were calculated for pastureland and cultivated cropland and then combined based on the amount of cultivated cropland and pastureland for each farm. The farm-level vulnerability score was designed to be a multiplicative factor applied to pounds of recoverable manure nutrients that inflated the pounds estimate in areas of higher vulnerability and deflated the pounds estimate in areas of lower vulnerability. Thus, the farm-level vulnerability scores are vulnerability adjusted pounds of manure nutrients.

The general form for the farm-level vulnerability score for a single watershed is as follows:

Farm-level vulnerability score = (manure nutrients)*(pcnt_past*past_envratio + pcnt_crop*crop_envratio).

Where:
Farm-level score = vulnerability score for each farm, representing vulnerability adjusted pounds of manure nutrients per farm.
Manure nutrients = Pounds of recoverable manure nitrogen or phosphorus (available for application) for the farm
Pcnt_past = Percentage of acreage of 24 crops plus pasture that is pasture for the farm.
Pcnt_crop = Percentage of acreage of 24 crops plus pasture that is cropland for the farm.
Past_envratio = The ratio of the farm-level value of the environmental factor associated with pasture to the national average of the environmental factor.
Crop_envratio = The ratio of the farm-level value of the environmental factor associated with cultivated cropland to the national average of the environmental factor.

Estimates of the index for nitrogen leaching were obtained using percolation factor (PF) values for the environmental factor in the equation, estimates of the index for nitrogen runoff were obtained using annual runoff factor values for the environmental factor, and estimates of the index for phosphorus runoff loss were obtained using the soil erosion factor (USLE) values for the environmental factor. These calculations were made for each watershed associated with the farm. For aggregation to watershed vulnerability indexes, these adjusted pounds estimates were simply added up over all the farms in each watershed after multiplying by the watershed conversion factors for each farm.

The resulting watershed vulnerability indexes are shown in map 6 for manure nitrogen leachate, map 7 for manure nitrogen dissolved in runoff, and map 8 for manure phosphorus adsorbed to soil particles and removed by water erosion. Comparison of these maps to maps 4 and 5 show how manure loadings are re-distributed when adjusted for vulnerability.

Potential Priority Watersheds

Potential priority watersheds for protection of water quality are those watersheds with both high manure nutrients applied to the land and environmental indicator scores higher than other areas of the country. These would be the watersheds where government programs could be targeted first to quickly meet the goals of protecting watersheds from contamination by manure nutrients. This assessment is only able to define these watersheds as potential priority watersheds, however, because the extent to which manure nutrients are already being properly applied to the land and the extent to which alternatives to land disposal are being implemented are not known and not taken into account. Furthermore, the "environmental setting" is not addressed by these vulnerability indexes. For example, some areas of the country, such as the Chesapeake Bay, have a greater potential for use impairment than other areas of the country because of high demand for use of the water resource for recreation, commercial activities, shoreline housing, drinking water, and general aesthetics.

Potential priority watersheds were identified as watersheds with the most vulnerability-adjusted pounds of manure nutrients after summing over the three vulnerability indexes. Watersheds (8-digit hydrologic units) with more than 3 million vulnerability-adjusted pounds were defined to be priority watersheds. These 450 watersheds corresponded to the top one-fourth of the watersheds. These potential priority watersheds are shown in map 9. The highest ranked priority watersheds in map 9 represent the top 150 watersheds, the medium ranked watersheds represent the next 150 watersheds, and the lowest ranked priority watersheds represent the last 150 watersheds. Of these 450 potential priority watersheds, 63 percent had vulnerability index scores in the top quartile for all three contributing indexes, and 29 percent had 2 indexes that were in the top quartile for that index. The remaining 8 percent of the watersheds had a single index in the top quartile for that index. Thus, over 90% of the potential priority watersheds had high scores for at least two of the three indexes.

While the watersheds depicted in map 9 represent the 8-digit watersheds where EPA and USDA should probably focus their attention first when implementing programs and policies to protect water quality from manure nutrients, a more generalized regional assessment may be better suited for decision-makers. For this purpose, vulnerability-adjusted pounds of manure nutrients were aggregated to water resource subregions (corresponding to 4-digit hydrologic units). The top 20 subregions accounted for 50 percent of the vulnerability-adjusted pounds of manure nutrients, shown in map 10 (colored red). The next highest 25 subregions accounted for another 25 percent (shown as pink in map 10). The next 32 subregions accounted for 15 percent (shown as yellow in map 10). Thus, these 77 water resource subregions account for 90 percent of the vulnerability-adjusted manure nutrients in the country. The remaining 153 subregions accounted for only 10 percent, with 113 of the 204 subregions accounting for less than 2 percent.

Map 10 also shows the rank for the top 10 subregions. The top ranked subregion was the Cape Fear River and associated coastal areas in North Carolina. The top 20 subregions are identified in table 1.

Table 1. Top 20 subregions with 50 percent of the vulnerability-adjusted pounds of manure nutrients.

Rank	Water Resource subregion name	Sub-region number	Sum of vulnerability adjusted pounds	Percent of total vulnerability adjusted pounds
1	Cape Fear and coastal drainage	303	245,724,474	4.318%
2	Lower Arkansas	1111	212,483,545	3.734%
3	Pee Dee and coastal drainage	304	200,874,320	3.530%
4	Susquehanna	205	187,422,455	3.293%
5	Red-Sulphur	1114	165,328,456	2.905%
6	Potomac	207	163,406,741	2.871%
7	Mobile-Tombigbee	316	151,193,407	2.657%
8	Alabama River basin	315	149,603,221	2.629%
9	Pearl River Basin	318	145,478,485	2.556%
10	Wabash River Basin	512	133,821,229	2.351%
11	Upper Mississippi-Iowa-Skunk-Wapsipinicon	708	126,973,971	2.231%
12	Middle Tennessee-Elk	603	126,462,256	2.222%
13	Upper White River Basin	1101	117,385,010	2.063%
14	Altamaha--St. Mary's and coastal drainage	307	116,098,831	2.040%
15	Neuse-Pamlico and coastal drainage	302	110,326,641	1.939%
16	Appalachicola and coastal drainage	313	108,948,941	1.914%
17	Ogeechee-Savanah and coastal drainage	306	106,951,318	1.879%
18	Pascagoula and coastal drainage	317	103,085,658	1.811%
19	Lower Red-Ouchita	804	99,937,361	1.756%
20	Neosho-Verdigra	1107	99,051,433	1.740%

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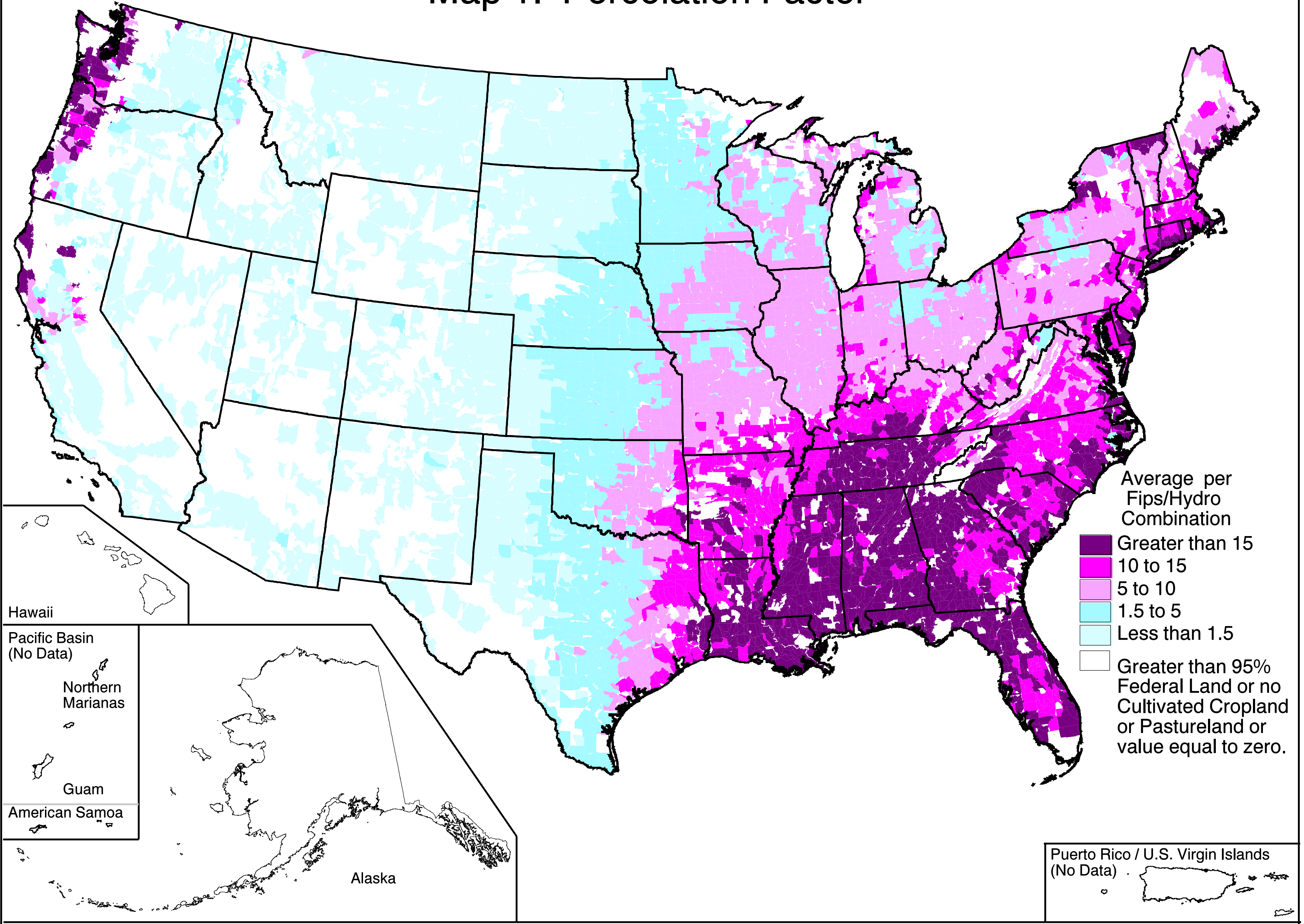
Map 1. Percolation Factor



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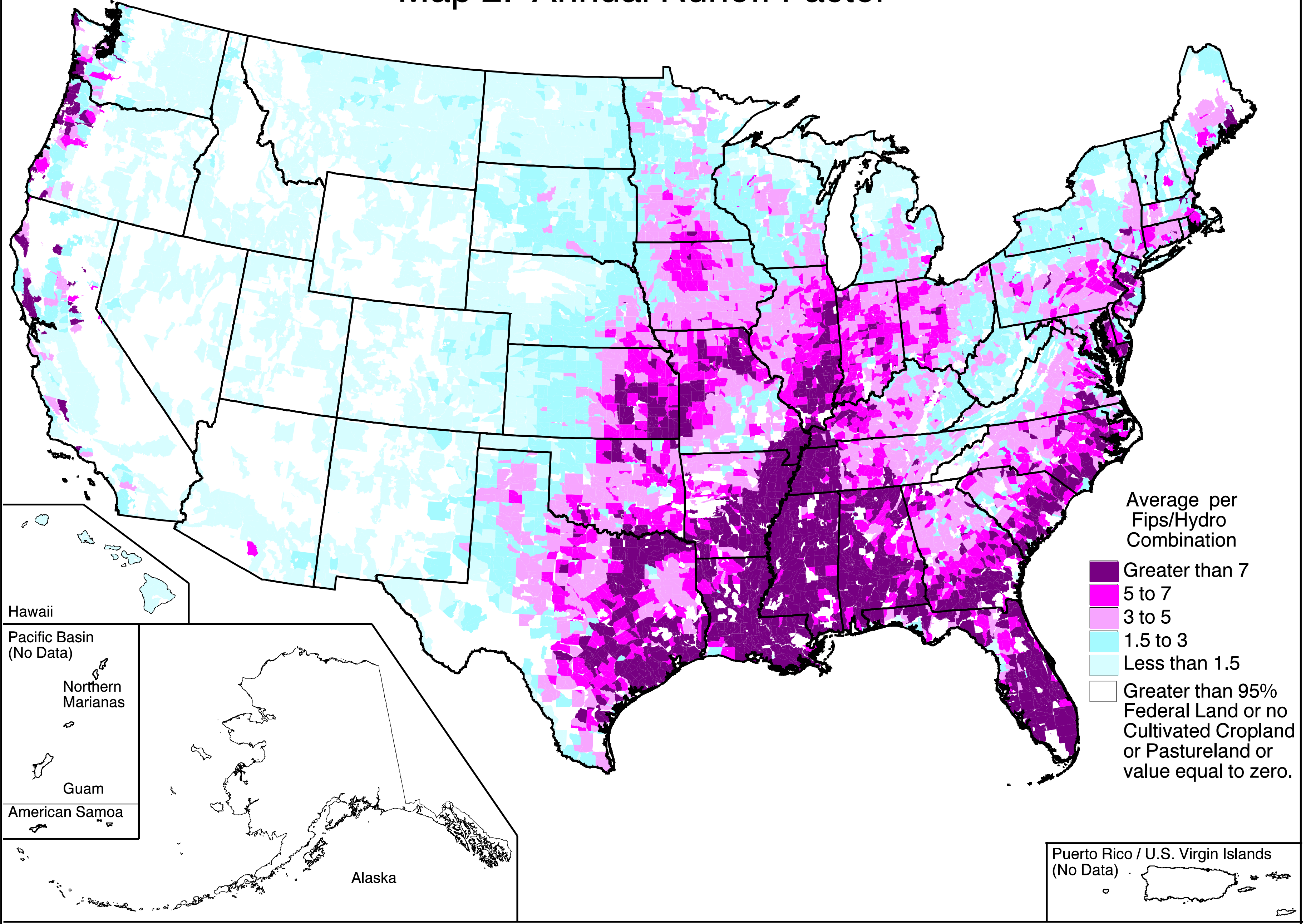
Map ID: m5657

Map 2. Annual Runoff Factor



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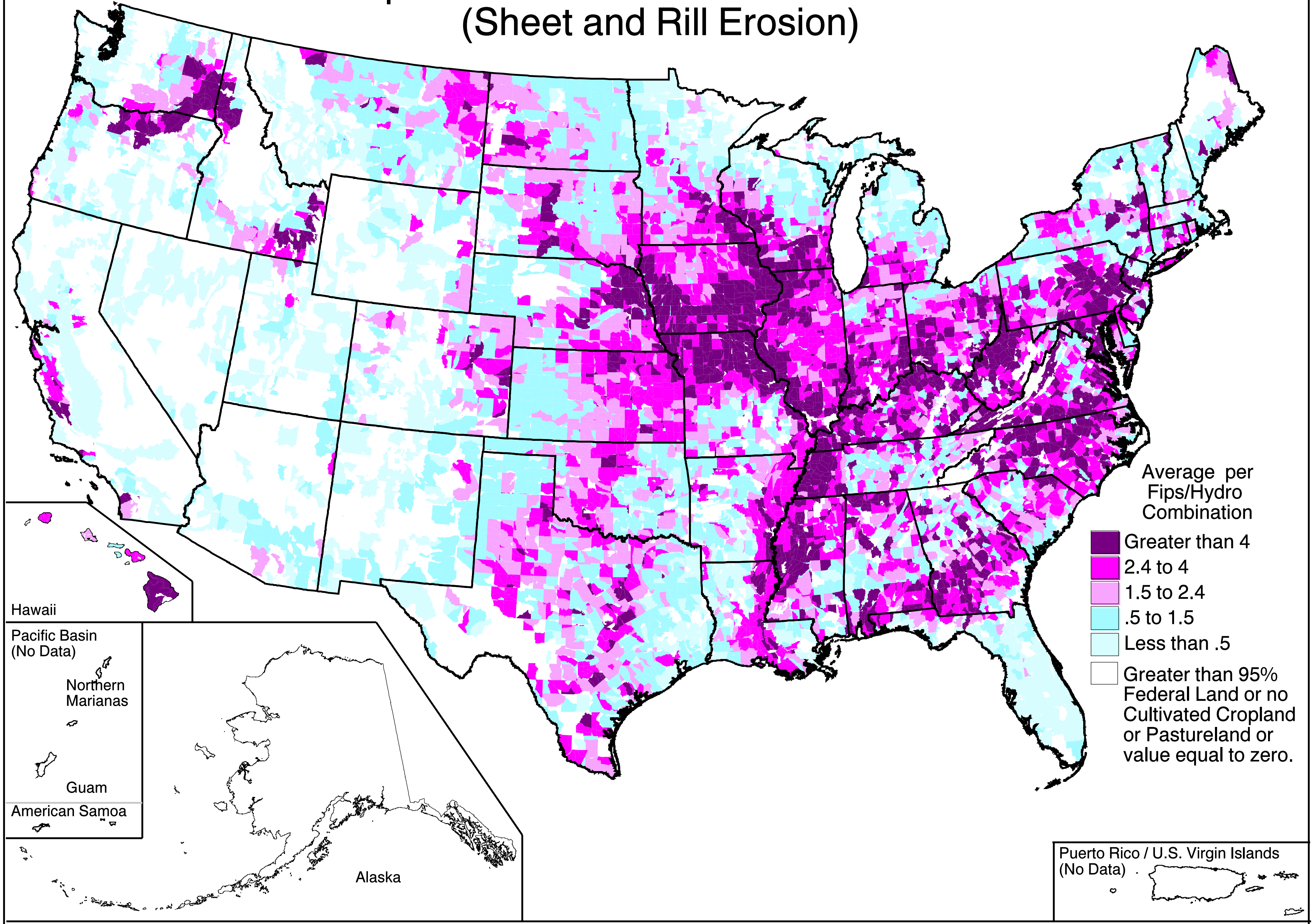
Map ID: m5658

Map 3. Rate of Soil Loss From Erosion (Sheet and Rill Erosion)



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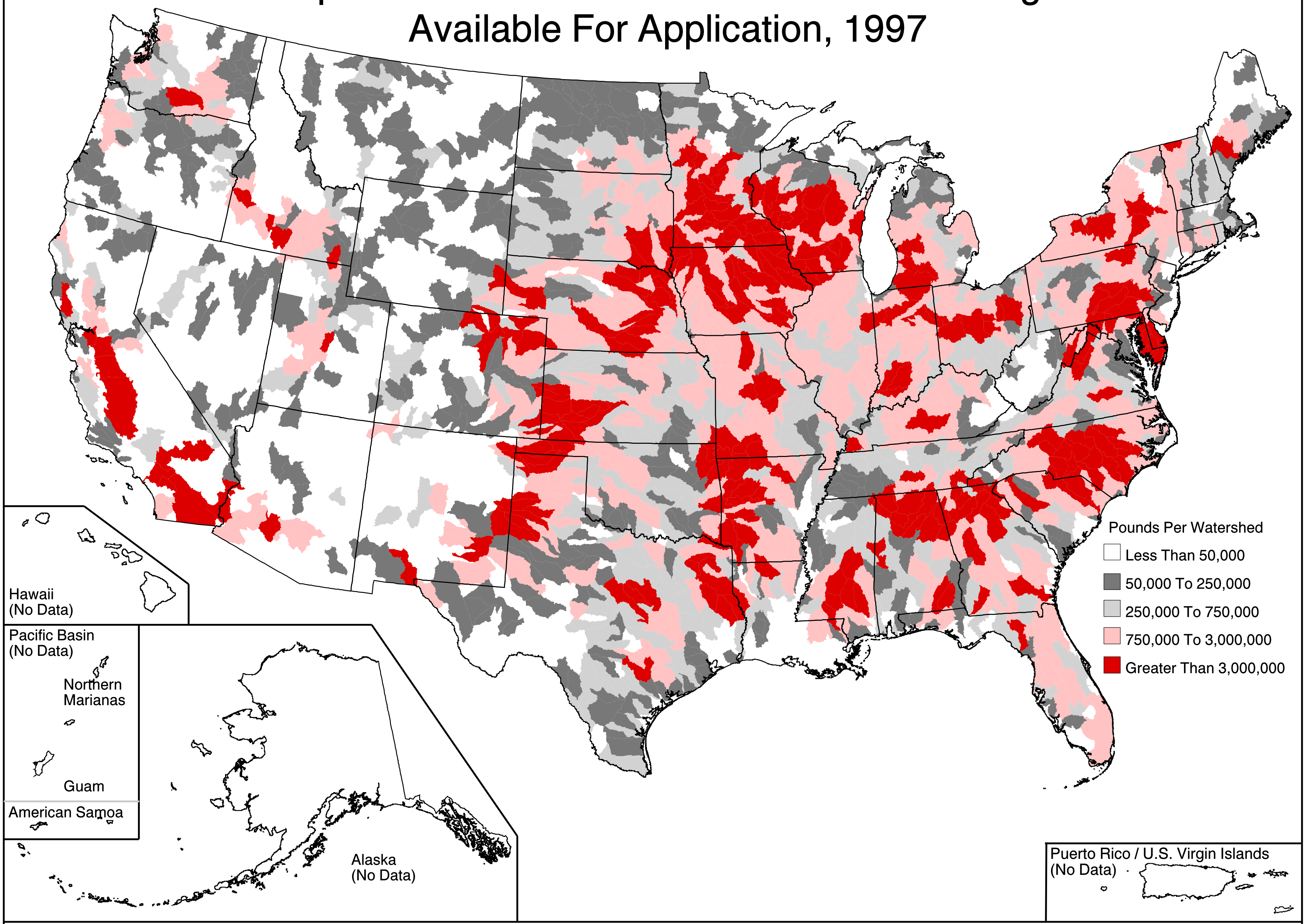
Map ID: m5659

Map 4. Watershed Estimates of Manure Nitrogen Available For Application, 1997



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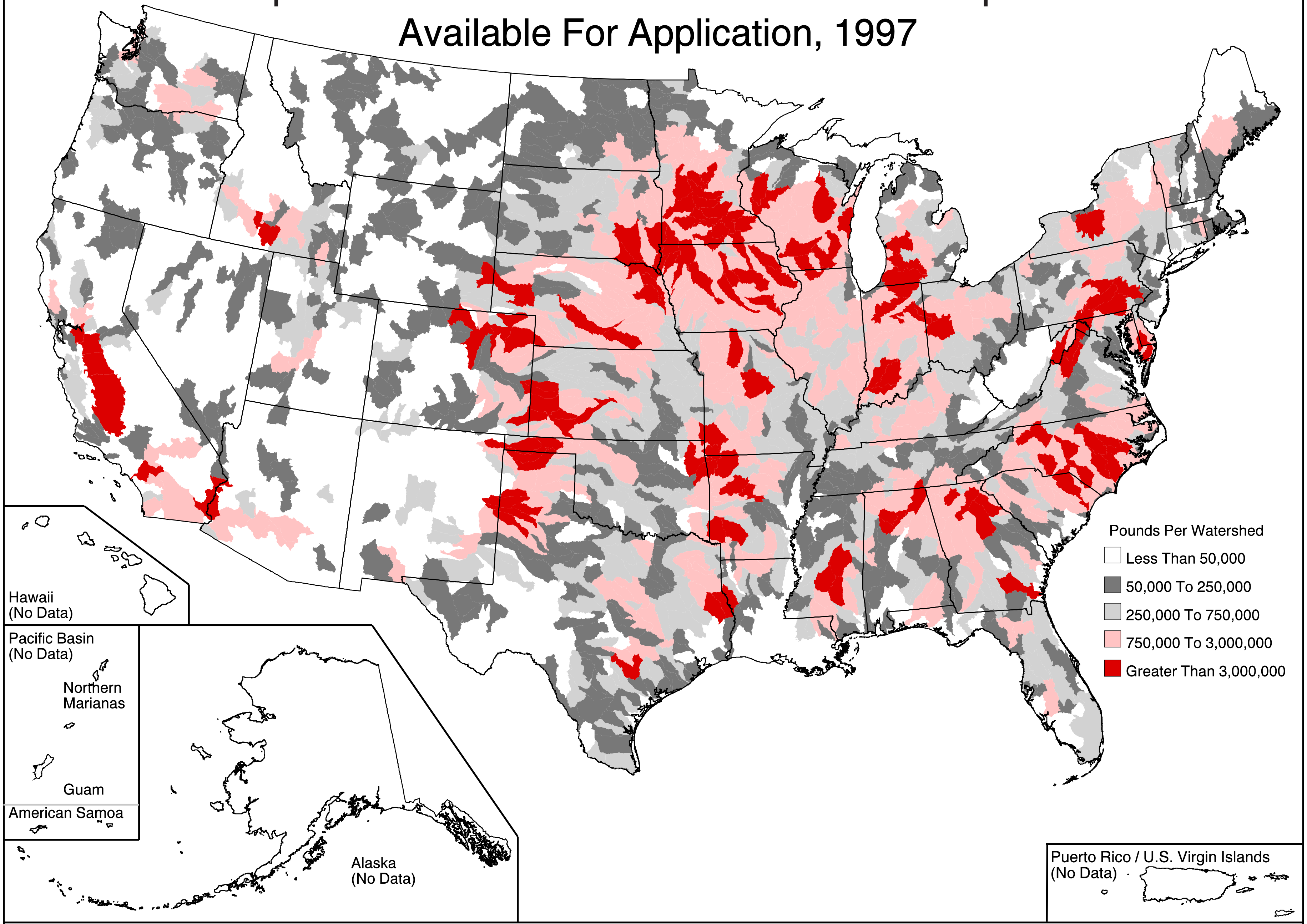
Map ID: m5281

Map 5. Watershed Estimates of Manure Phosphorus Available For Application, 1997



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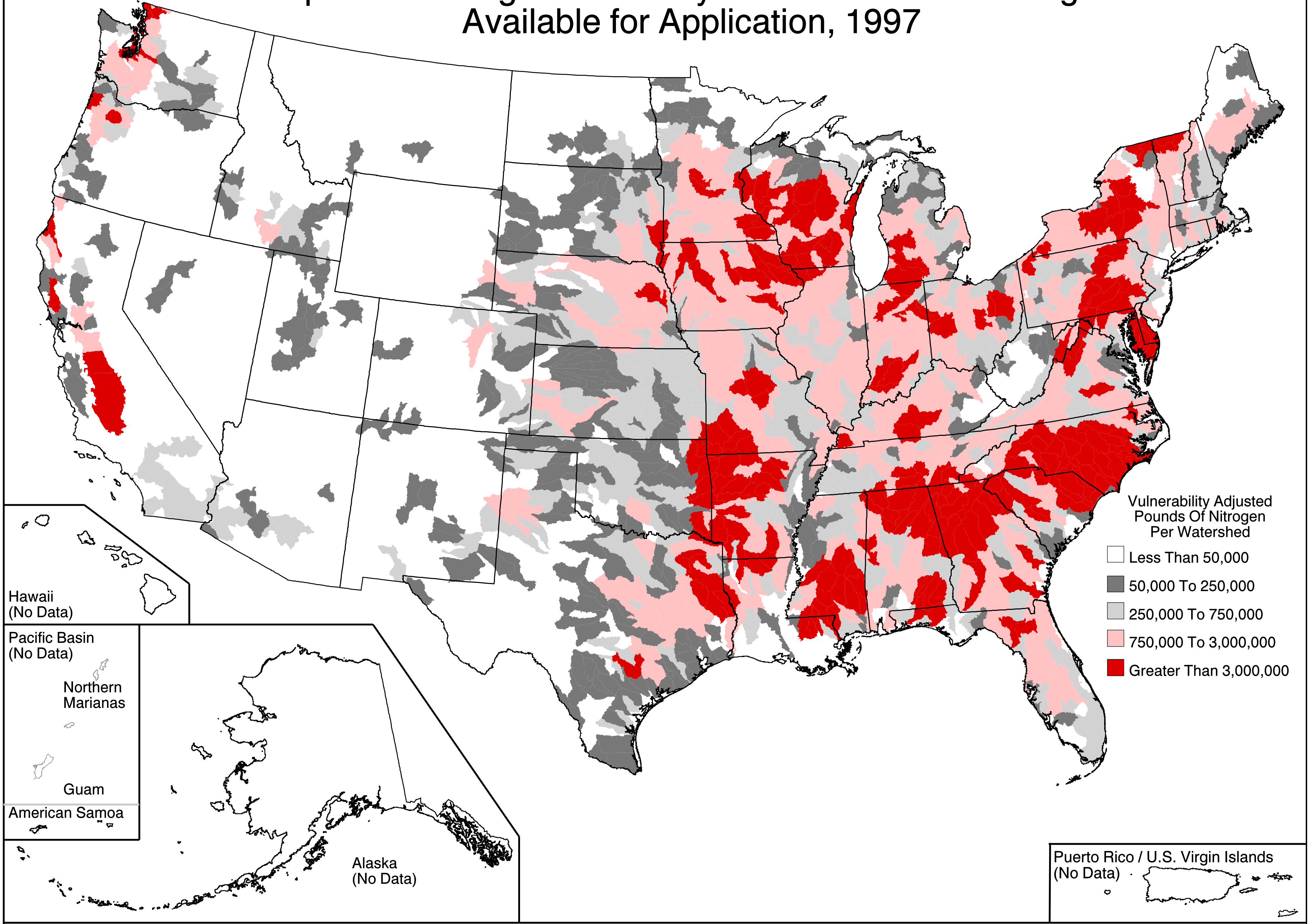
Map ID: m5282

Map 6. Leaching Vulnerability Index for Manure Nitrogen Available for Application, 1997



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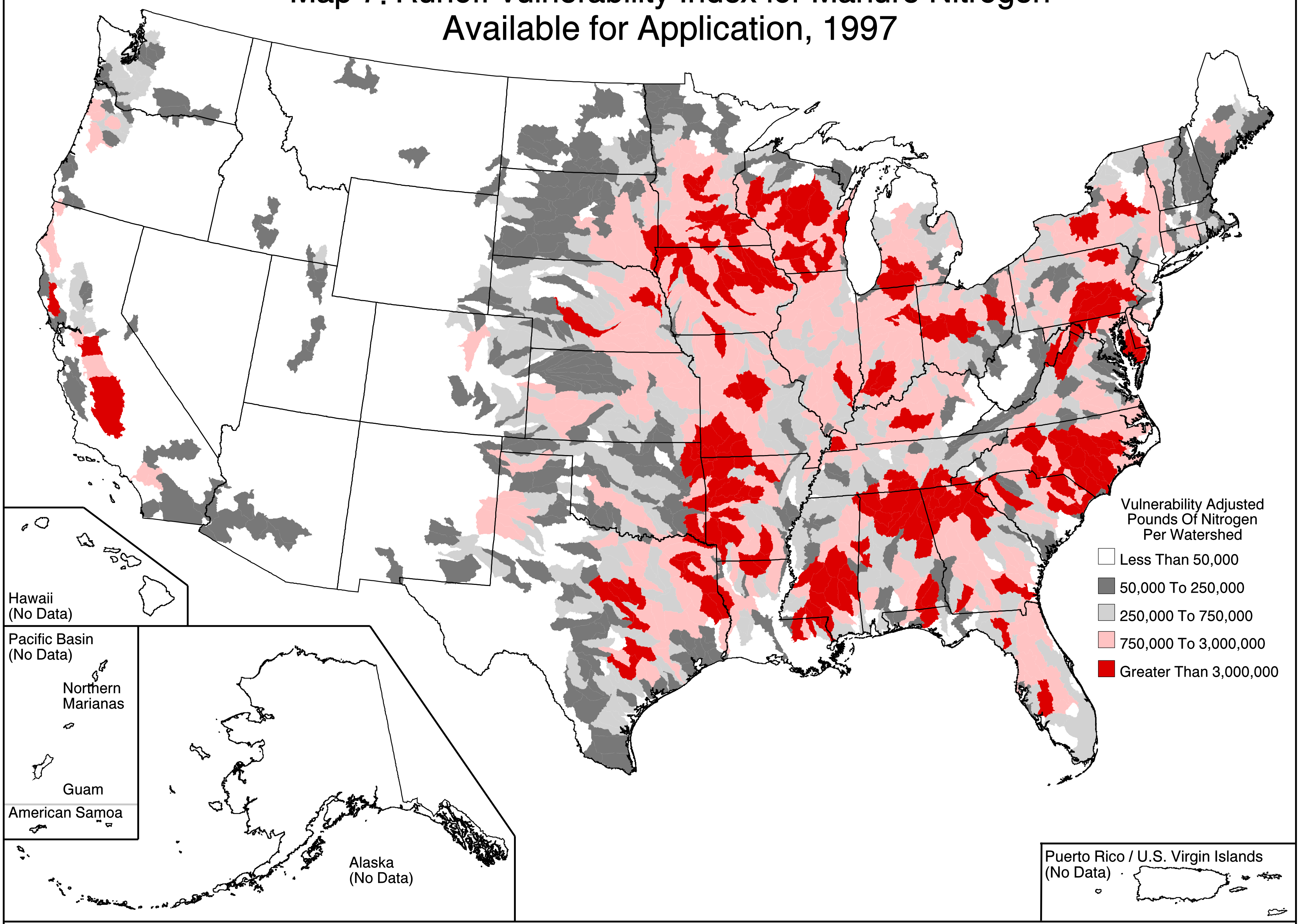
Map ID: m5285

Map 7. Runoff Vulnerability Index for Manure Nitrogen Available for Application, 1997



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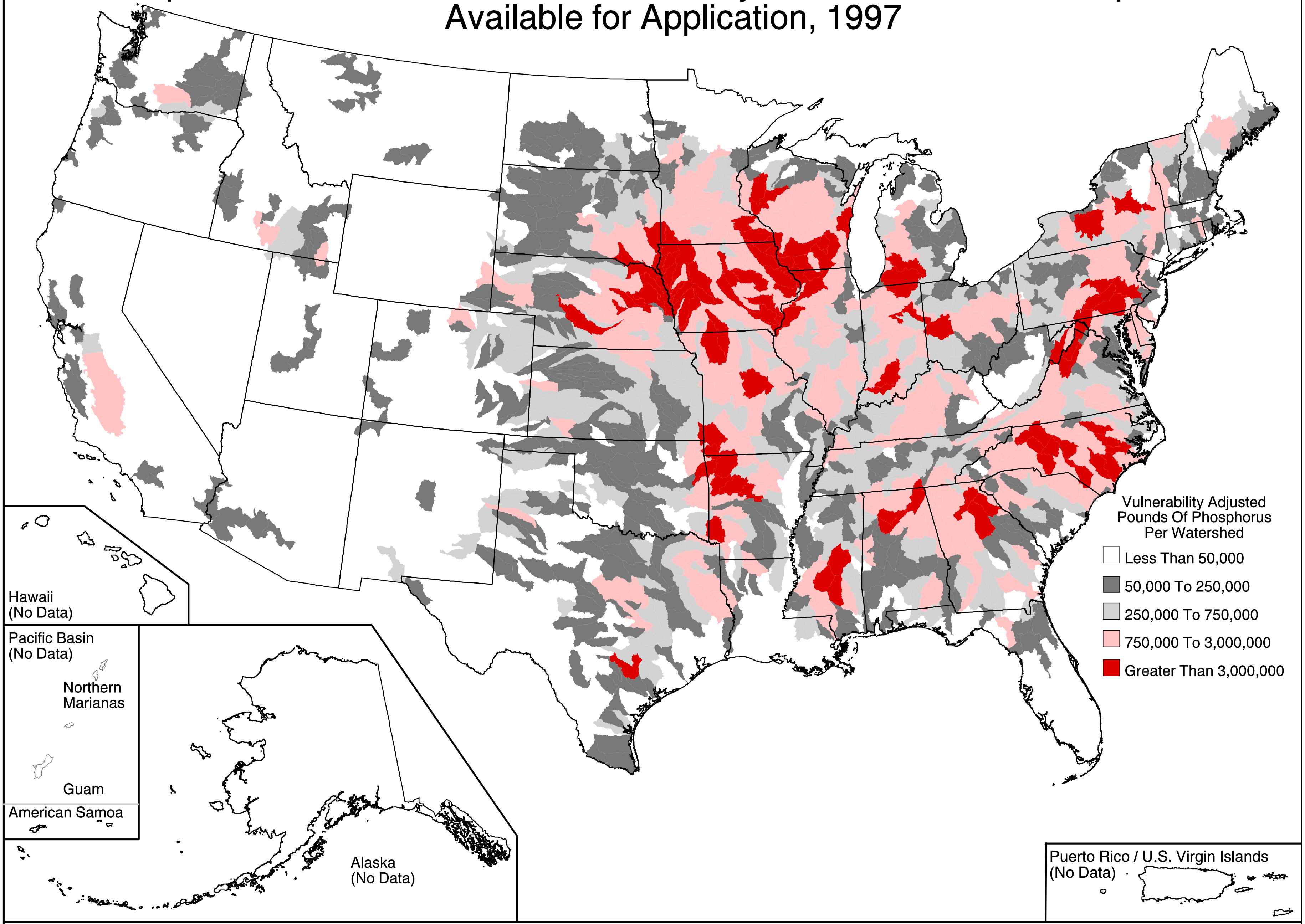
Map ID: m5289

Map 8. Soil Adsorbed Runoff Vulnerability Index for Manure Phosphorus Available for Application, 1997



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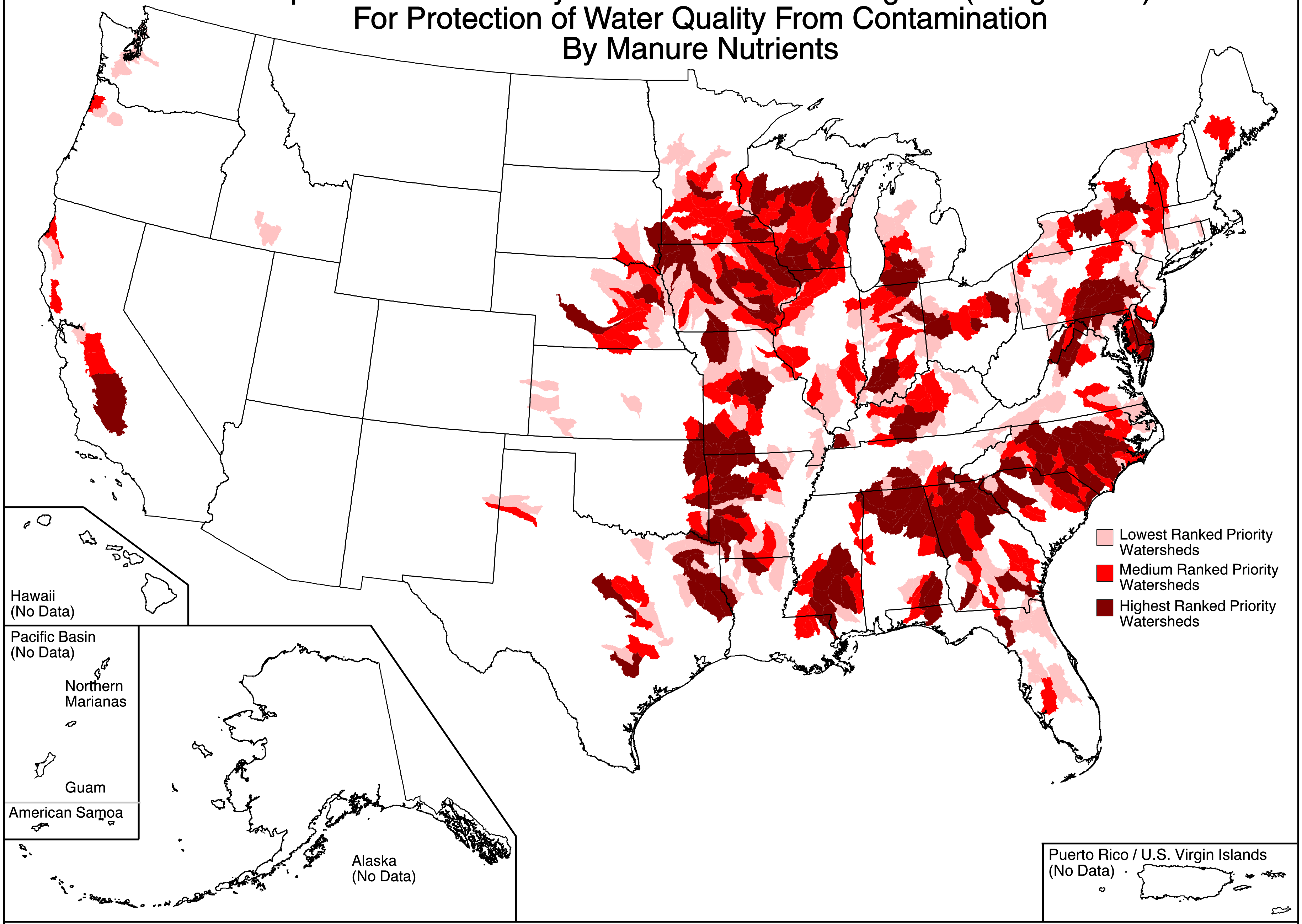
Map ID: m5651

Map 9. Potential Priority Water Resource Subregions (4-Digit Code) For Protection of Water Quality From Contamination By Manure Nutrients



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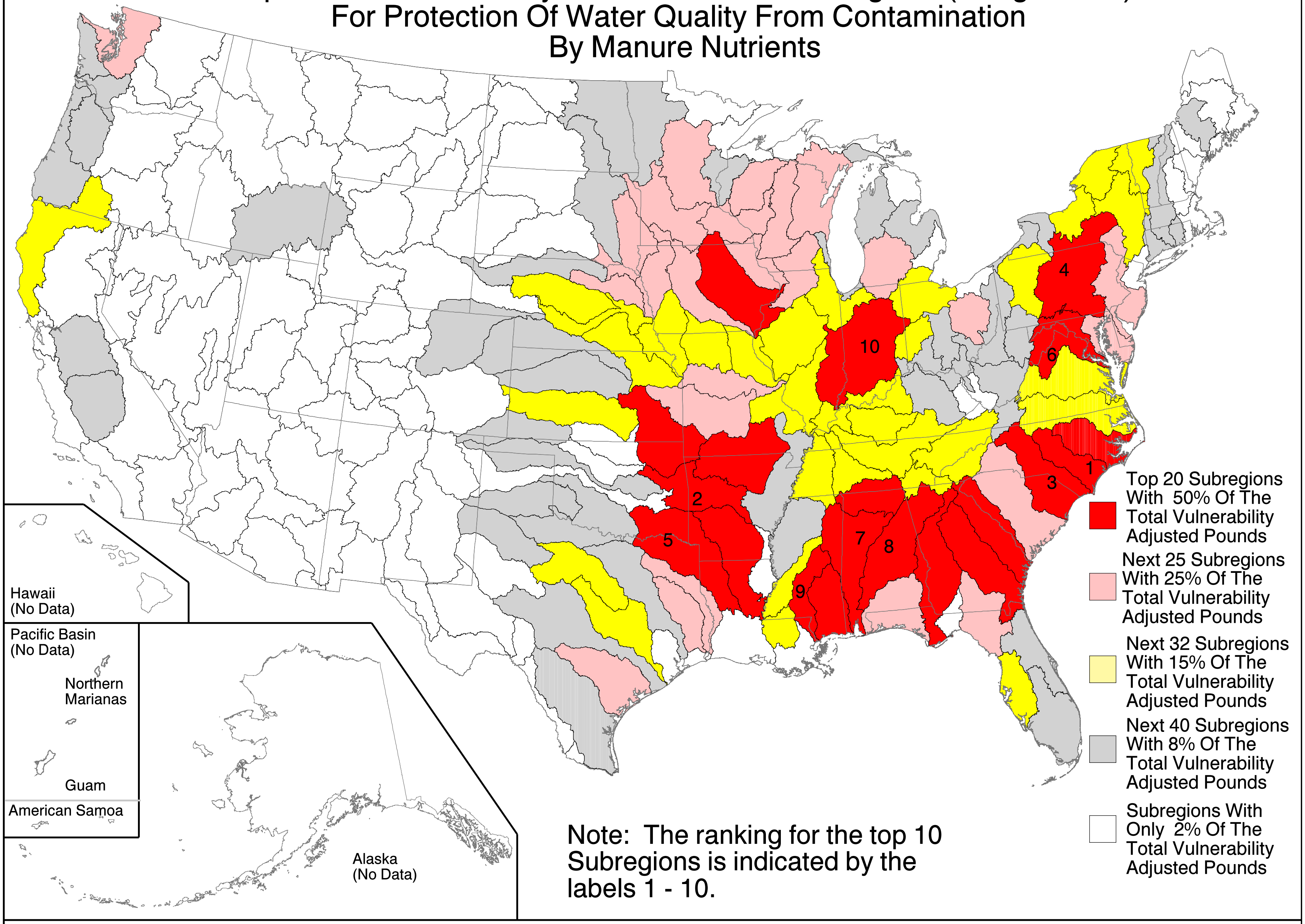
Map ID: m5753

Map10. Potential Priority Water Resource Subregions (4-Digit Code) For Protection Of Water Quality From Contamination By Manure Nutrients



Note: The ranking for the top 10 Subregions is indicated by the labels 1 - 10.

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Map ID: m5754