LAND USE - NUTRIENT EXPORT RELATIONSHIPS IN THE NORTHEAST

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Figure 1

Mean Annual Phosphorus Concentration, Nitrogen Concentration, and Runoff in 21 Connecticut Watersheds

Component	Phosphorus (mg/m^3)			Runoff (cm/yr)			Nitrogen (mg/m^3)		
Watershed Category	All	NPS	non-NPS	All	NPS	non-NPS	All	NPS	non-NPS
Base-10 Logarithm 1.1									
1.2	66#	66							
1.3	2	2							
1.4	9	9							
1.5	1368	13	68						
1.6	145	145							
1.7				12677999999	77	126999999			
1.8	3		3	1111223666	1122366	116			
1.9	29		29						
2.0									
2.1	2		2						
2.2	145		145						
2.3	1		1						
2.4									
2.5									
2.6	3*		3*						
2.7	1*		1*				2	2	
2.8									
2.9							489	489	
3.0							35589	355	89
3.1							03559	5	0359
3.2							0256	2	056
3.3							28		28
3.4							9*		9*
3.5									
High Hinge	2.21	1.61	1.88	1.79	1.81	1.78	3.22	3.05	3.12
Median	1.65	1.51	2.17	1.79	1.82	1.79	3.13	3.03	3.20
Low Hinge	1.53	1.32	2.28	1.82	1.83	1.80	3.05	2.98	3.29
H-Spread	0.68	0.29	0.40	0.03	0.02	0.02	0.17	0.07	0.17

*Quinnipiac River

#Stem-and-Leaf Diagram (Mosteller and Tukey,1977); digit = second digit to right of decimal point.

Section 2

Land Use - Nutrient Export Relationships in the Northeast

In order to provide a basis for estimating the potential impacts of watershed development on the eutrophication of New Haven Water Company's reservoirs, an analysis of data describing land use and nutrient export for a number of watersheds in Connecticut and elsewhere in the Northeast has been performed. The data has been provided by the EPA's National Eutrophication Survey (EPA 1975) and the land use/nutrient export study associated with it (EPA, (1974), Omernik (1976), Omernik (1977)). In the work described below, these data are analyzed in an effort to characterize the total phosphorus and total nitrogen concentrations and amounts of run-off which are typical of various land use types in the region. Results will also provide a basis for comparing concentration levels detected in NHWC's monitoring program.

The EPA/NES sampled a total of eight lakes and reservoirs in Connecticut during 1972-3. For each impoundment, monthly grab samples of each tributary were also taken to provide a basis for calculating nutrient budgets. Among these tributaries, nine were selected as part of a nation-wide study on land use/nutrient export relationships (EPA, (1974), Omernik (1976), Omernik (1977)). These nine were selected because of the absence of identifiable point sources upstream of the sampling locations.

The variabilities in the flow-weighted-mean concentrations of total phosphorus and total nitrogen and in total runoff are characterized on logarithmic scales in Figure 1. For each component, histograms of data from three categories are presented: (1) all tributaries; (2) tributaries included in the EPA's Non-Point Source (NPS) study; and (3) tributaries not included in the NPS study. Presumably, the last category includes some tributaries which are influenced by point sources. For each data group, the distribution is characterized by the median, the upper hinge (value exceeded in 25 percent of the data points, Mosteller and Tukey (1977)), and the lower hinge (value exceeded in 75 percent of the points). The H-spread, the difference between the upper and lower hinges, is a measure of variability which is somewhat more robust to deviations from normality than is the standard deviation.

The variabilities of total runoff amounts are extremely small relative to variabilities in concentration. This suggests that land use or point-source effects on nutrient export are expressed more in terms of changes in concentration than in terms of changes in flow. It is apparent that phosphorus exhibits greater variability than nitrogen. In the category containing all watersheds, the H-spread of phosphorus values is .68, compared with .17 for nitrogen. In the NPS category, the H-spread of phosphorus values is .29, compared with .07 for nitrogen. The distinction between the NPS watersheds and the others is also greater in the case of phosphorus. This implies that point sources have greater influences on the relative concentrations of phosphorus than on the relative concentrations of nitrogen.

The ratio of median N to median P is 33.1 for the NPS watersheds and 10.2 for the non-NPS watersheds. This can be compared with the N/P requirements for algal growth which generally range from 7 to 10. The data suggest that phosphorus is more likely to be limiting algal growth in impoundments not subjected to point sources, whereas nitrogen would become increasingly important as a limiting nutrient as point source influence increases. This arises from the fact that naturally occurring runoff is enriched in nitrogen, whereas cultural pollution sources tend to be enriched in phosphorus, relative to algal growth requirements. For example, the N/P ratio for rainfall in the Northeast averages about 62, while the N/P ratio for sanitary sewage ranges from about 2 to 8 (EPA, 1974). Point source influences are clearly evident in the case of the Quinnipiac River, which is identified in Figure 1. The above analysis suggests the following:

1. Variabilities in nutrient concentration are considerably larger than variabilities in flow; therefore, any land use point source effects on nutrient export are more likely to be expressed as changes in concentration than as changes in flow.
2. Cultural impacts, either through point sources or nonpoint sources, are likely to be greater in the case of phosphorus than nitrogen, when logarithms or ratios of concentration are considered.
3. In the absence of point sources, phosphorus is likely to be the factor limiting algal growth in Connecticut impoundments.

The next step is to examine the variability within the NPS category in order to see whether some of it can be explained by land use.

It would first be appropriate, however, to present and discuss Omernik's (1976, 1977) results, which summarize some of the apparent relationships between land use and nutrient concentration on a regional basis, based upon an analysis of the EPA/NES data base.

The results of Omernik's analysis of the NES/NPS data base are summarized in Figures 2-5. In Figures 2 and 3, mean nitrogen and phosphorus concentrations are displayed for various land use types. The study did not include very many urban watersheds. Only 11 out of 904 had greater than 40 percent urban land use. The study does provide, however, a means of estimating baseline (undeveloped) conditions and agricultural impacts. Figures 4 and 5 display mean nitrogen and phosphorus concentrations for various regions and land use types ranging from > 90 percent forested to > 90 percent agricultural. The increase in nutrient concentration with percent agriculture appears to be fairly consistent across regions in the case of phosphorus and somewhat less consistent in the case of nitrogen.

Regression analyses were also performed by Omernik (1977) to estimate mean nutrient concentrations as functions of land use. For states east of the Mississippi River, the following relationships were derived:

$$C_P = 15 \left[10^{.971 (f_A + f_U)}\right] \quad (r^2 = .55) \qquad (1)$$

$$C_N = 820 \left[10^{.716 (f_A + f_U)}\right] \quad (r^2 = .72) \qquad (2)$$

Figure 2

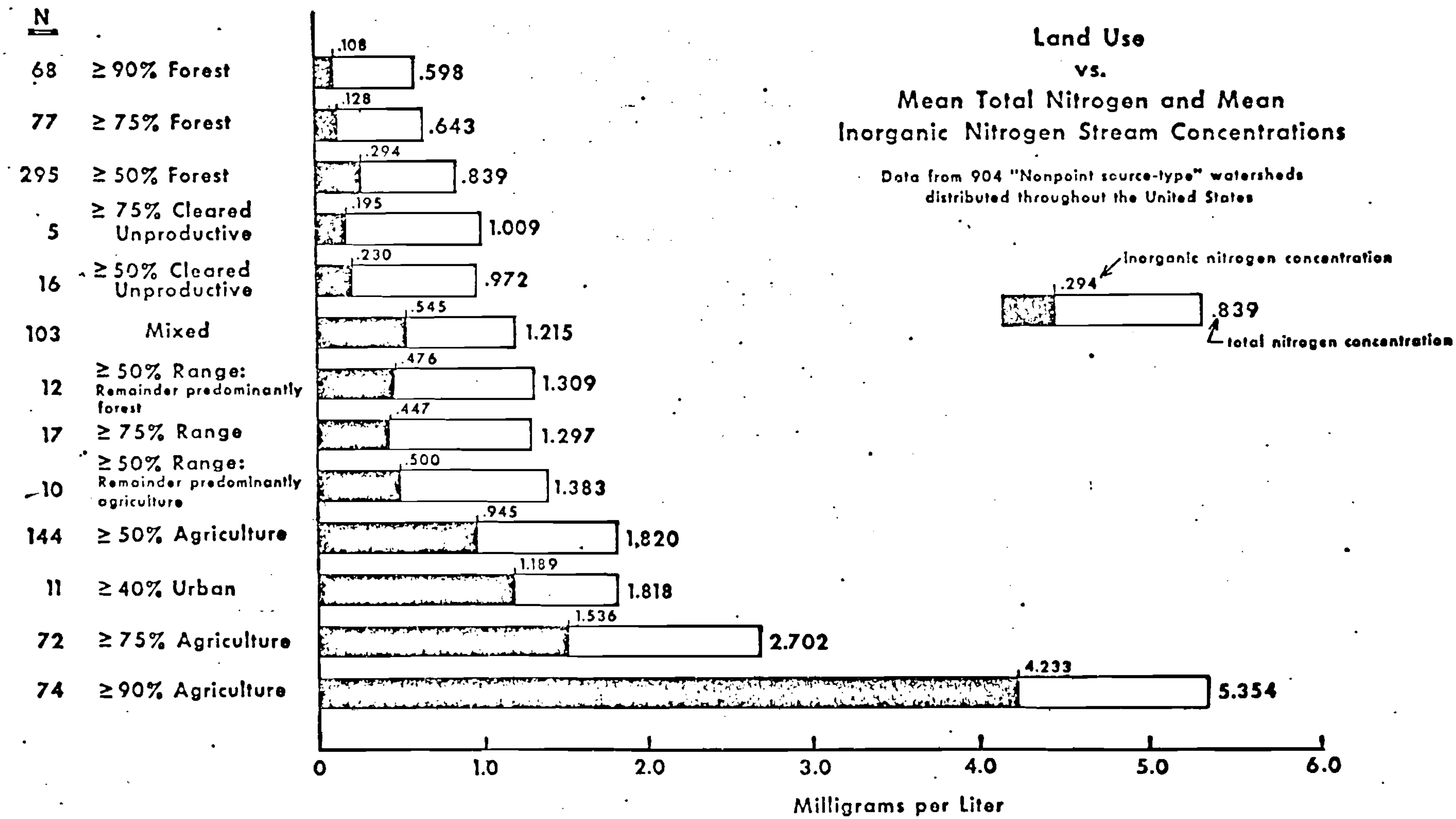

Land Use
vs.
Mean Total Nitrogen and Mean
Inorganic Nitrogen Stream Concentrations
Data from 904 "Nonpoint source-type" watersheds
distributed throughout the United States
Inorganic nitrogen concentration
total nitrogen concentration
.294
.839
N
68 ≥ 90% Forest .108 .598
77 ≥ 75% Forest .128 .643
295 ≥ 50% Forest .294 .839
5 ≥ 75% Cleared Unproductive .195 1.009
16 ≥ 50% Cleared Unproductive .230 .972
103 Mixed .545 1.215
12 ≥ 50% Range: Remainder predominantly forest .476 1.309
17 ≥ 75% Range .447 1.297
10 ≥ 50% Range: Remainder predominantly agriculture .500 1.383
144 ≥ 50% Agriculture .945 1.820
11 ≥ 40% Urban 1.189 1.818
72 ≥ 75% Agriculture 1.536 2.702
74 ≥ 90% Agriculture 4.233 5.354
0
1.0
2.0
3.0
4.0
5.0
6.0
Milligrams per Liter

Figure 3

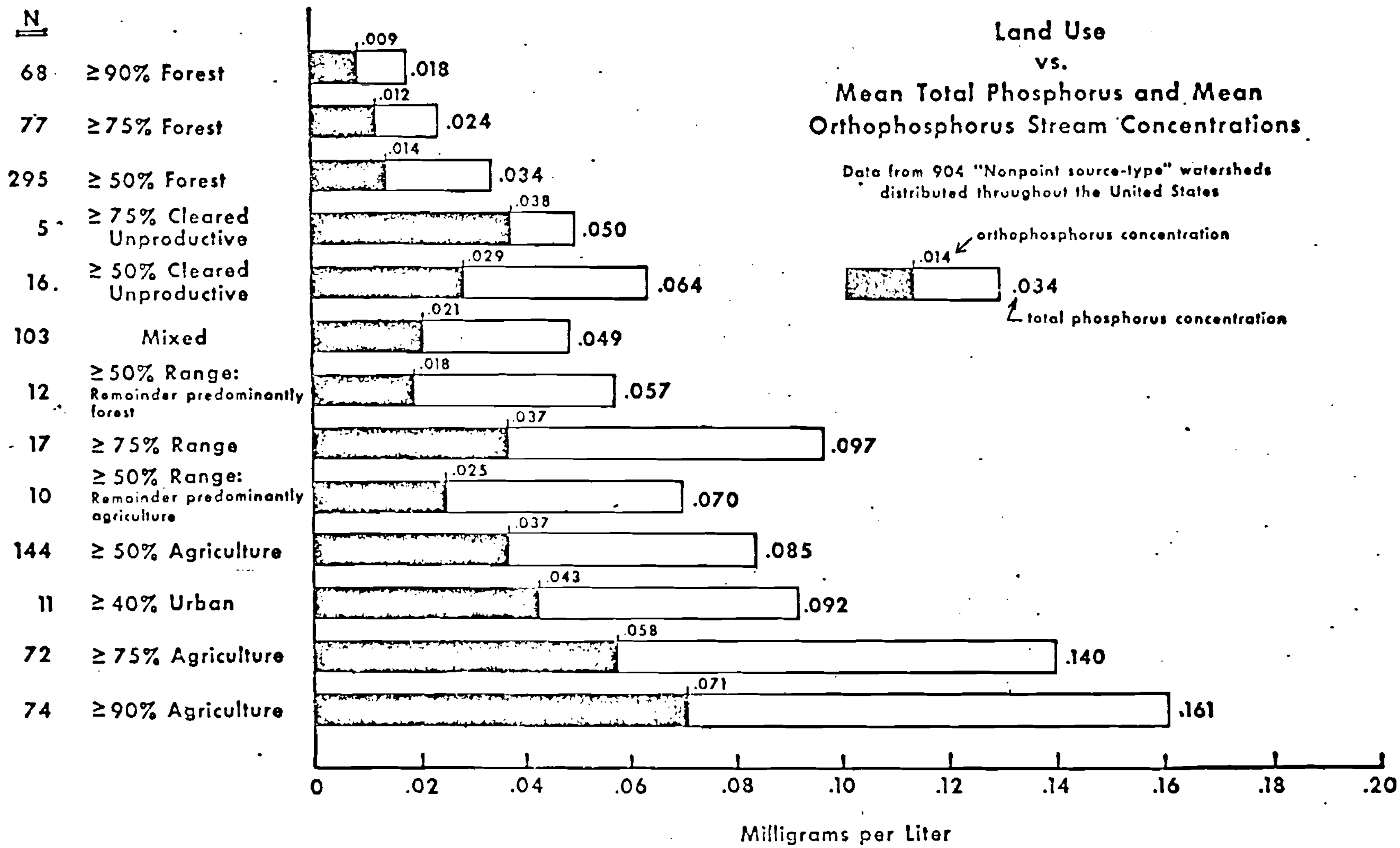
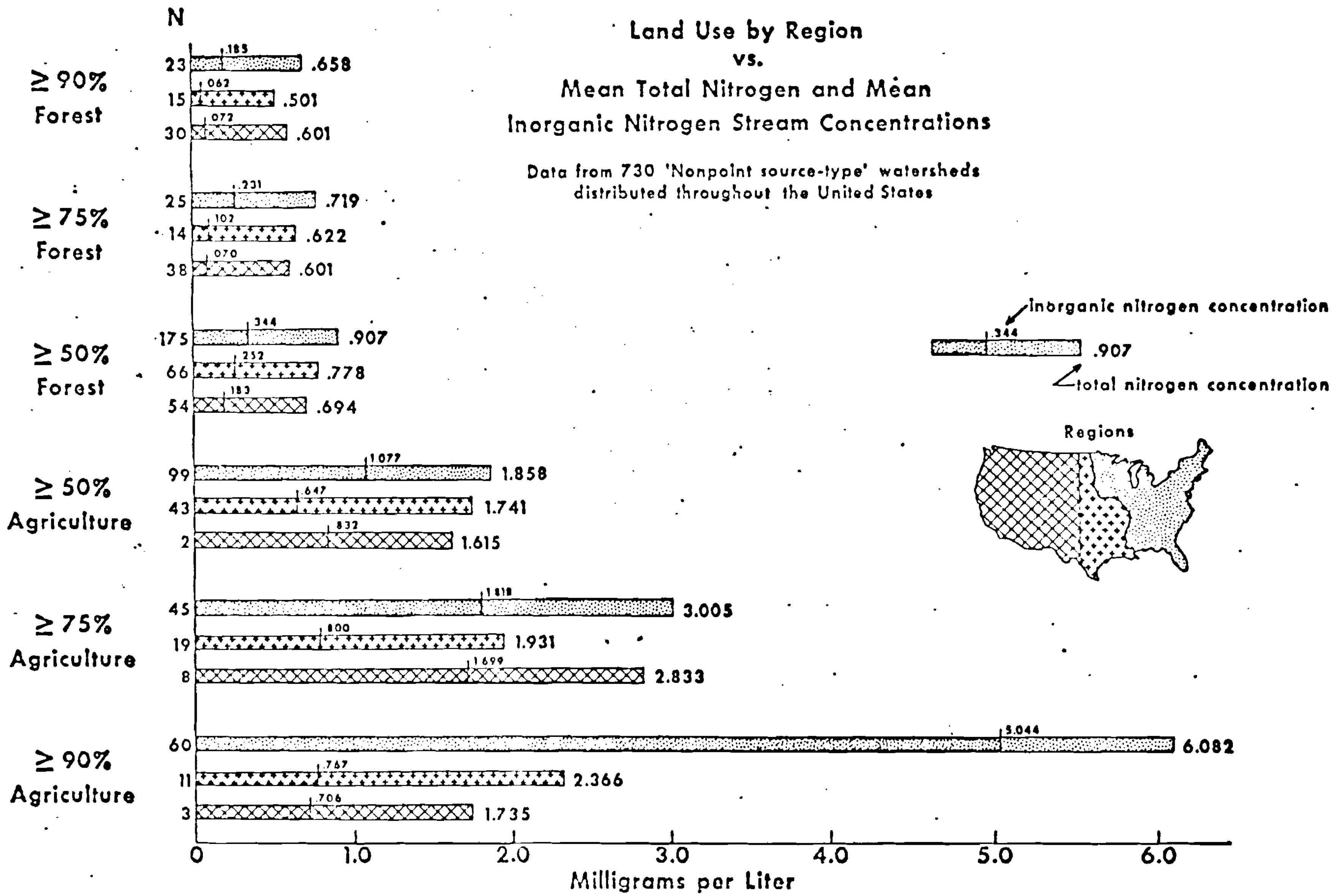
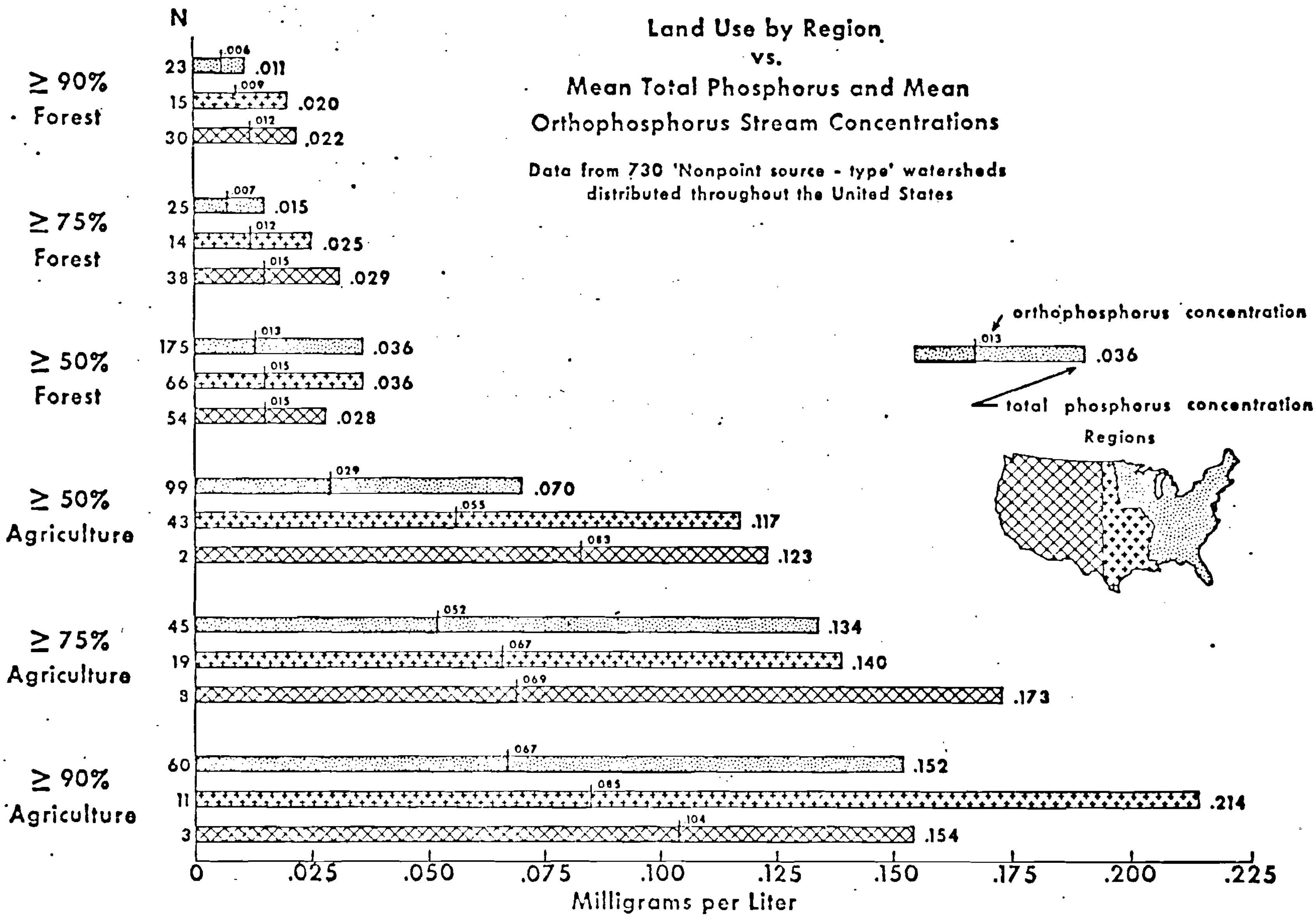

Land Use
vs.
Mean Total Phosphorus and Mean
Orthophosphorus Stream Concentrations
Data from 904 "Nonpoint source-type" watersheds
distributed throughout the United States
orthophosphorus concentration
.014
.034
total phosphorus concentration
N
68 ≥90% Forest .009 .018
77 ≥75% Forest .012 .024
295 ≥ 50% Forest .014 .034
5 ≥ 75% Cleared Unproductive .038 .050
16. ≥ 50% Cleared Unproductive .029 .064
103 Mixed .021 .049
12 ≥50% Range: Remainder predominantly forest .018 .057
17 ≥ 75% Range .037 .097
10 ≥ 50% Range: Remainder predominantly agriculture .025 .070
144 ≥ 50% Agriculture .037 .085
11 ≥ 40% Urban .043 .092
72 ≥ 75% Agriculture .058 .140
74 ≥90% Agriculture .071 .161
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
Milligrams per Liter

Figure 4



Land Use by Region
vs.
Mean Total Nitrogen and Mean
Inorganic Nitrogen Stream Concentrations
Data from 730 'Nonpoint source-type' watersheds
distributed throughout the United States
N
≥ 90% Forest
23 .185 .658
15 .062 .501
30 .072 .601
≥ 75% Forest
25 .231 .719
14 .102 .622
38 .070 .601
≥ 50% Forest
175 .344 .907
66 .252 .778
54 .183 .694
≥ 50% Agriculture
99 1.077 1.858
43 .647 1.741
2 .832 1.615
≥ 75% Agriculture
45 1.818 3.005
19 .800 1.931
8 1.699 2.833
≥ 90% Agriculture
60 5.044 6.082
11 .767 2.366
3 .706 1.735
0
1.0
2.0
3.0
4.0
5.0
6.0
Milligrams per Liter
inorganic nitrogen concentration
.344
.907
total nitrogen concentration
Regions

Figure 5



Land Use by Region
vs.
Mean Total Phosphorus and Mean
Orthophosphorus Stream Concentrations
Data from 730 'Nonpoint source - type' watersheds
distributed throughout the United States
N
≥ 90% Forest
23 .006 .011
15 .009 .020
30 .012 .022
≥ 75% Forest
25 .007 .015
14 .012 .025
38 .015 .029
≥ 50% Forest
175 .013 .036
66 .015 .036
54 .015 .028
≥ 50% Agriculture
99 .029 .070
43 .055 .117
2 .083 .123
≥ 75% Agriculture
45 .052 .134
19 .067 .140
8 .069 .173
≥ 90% Agriculture
60 .067 .152
11 .085 .214
3 .104 .154
orthophosphorus concentration
.013 .036
total phosphorus concentration
Regions
0 .025 .050 .075 .100 .125 .150 .175 .200 .225
Milligrams per Liter

where,

C_P = mean total phosphorus concentration (mg/m^3)

C_N = mean total nitrogen concentration (mg/m^3)

f_A = fraction of drainage area in agricultural land use

f_U = fraction of drainage area in urban land use

These relationships are not very useful for estimating the impacts of urban development, because they do not distinguish between agricultural and urban effects, which are likely to be different. It would be surprising if watersheds with 10 percent urban and 40 percent agricultural development were to have the same nutrient concentrations as ones with 40 percent urban and 10 percent agricultural development in the same region, although this is predicted by the above relationships.

The form of these regressions is also somewhat curious, since it suggests a multiplicative effect of development, rather than an additive one. For phosphorus, a simple additive model of a watershed with three land use types would be of the following form:

$$C_P = C_{PF}\, f_F + C_{PA}\, f_A + C_{PU}\, f_U \qquad (3)$$

where,

C_{PF} = typical concentration of phosphorus in forested drainage (mg/m^3)

C_{PA} = typical concentration of phosphorus in agricultural drainage (mg/m^3)

C_{PU} = typical concentration of phosphorus in urban drainage (mg/m^3)

This type of model represents the simple mixing of waters from subareas with different land uses in a given watershed, assuming that total flow amounts are not strongly influenced by land use. This would seem to be a more realistic physical model than the exponential relationship described above, which implies some sort of interaction among the land use types in a given watershed. As shown in Figures 6 and 7, however, both the categorized data and the regression analyses suggest that an exponential model is more appropriate for these data. Some evidence is presented below which suggests that this apparent multiplicative effect is primarily a result of the aggregation of data from different regions with different baseline conditions, types of agriculture, and agricultural impacts, i.e., some of the apparent land use effects are actually regional ones. Thus, Figures 2-7 should not be used as a direct basis for estimating the effects of changes in land use on stream nutrient concentrations in any given region, particularly in New England.

The relationships in Figures 6 and 7 were derived by aggregating all of the NES/NPS data from states east of the Mississippi (see insert in Figure 4). The locations and total phosphorus concentrations of the "mostly forested" (>75 percent Forest) watersheds are depicted in Figure 8. Most of the eastern watersheds in the forested category are located in the Appalachians, from Georgia to Maine, and in areas of Pennsylvania and New York. Figure 9 shows, however, that the mostly agricultural (>75 percent Agriculture) watersheds are located almost exclusively in the Corn Belt and North Central states. Thus if the average nutrient concentrations in forested and agricultural watersheds east of the Mississippi are compared, we cannot distinguish between the effects of land use and those of region.

Figure 6

Relationships between Agricultural Land Use

And Mean Total Phosphorus Concentration for Watersheds in Eastern U.S. (Omernik, 1977)

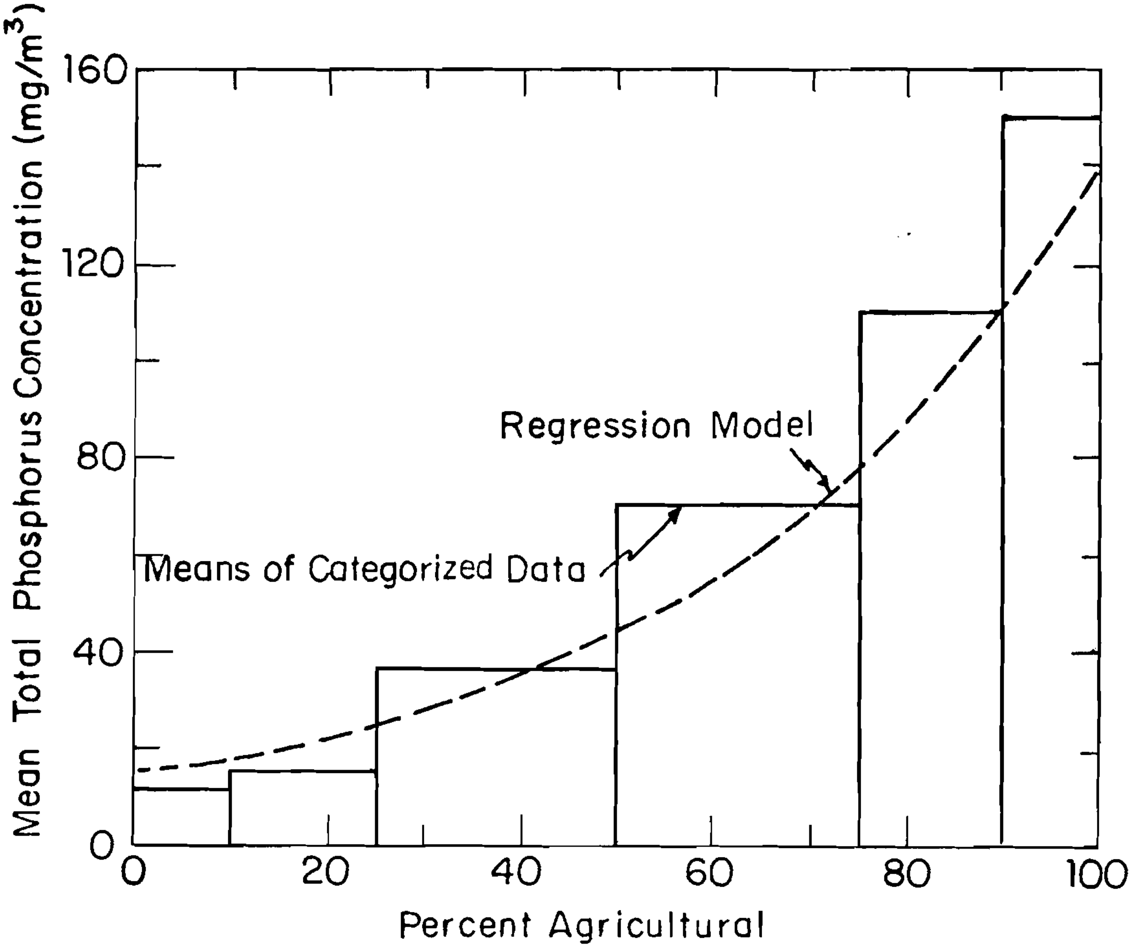


Figure 7

Relationship between Agricultural Land Use and
Mean Total Nitrogen Concentration for Watersheds in Eastern U.S. (Omernik, 1977)

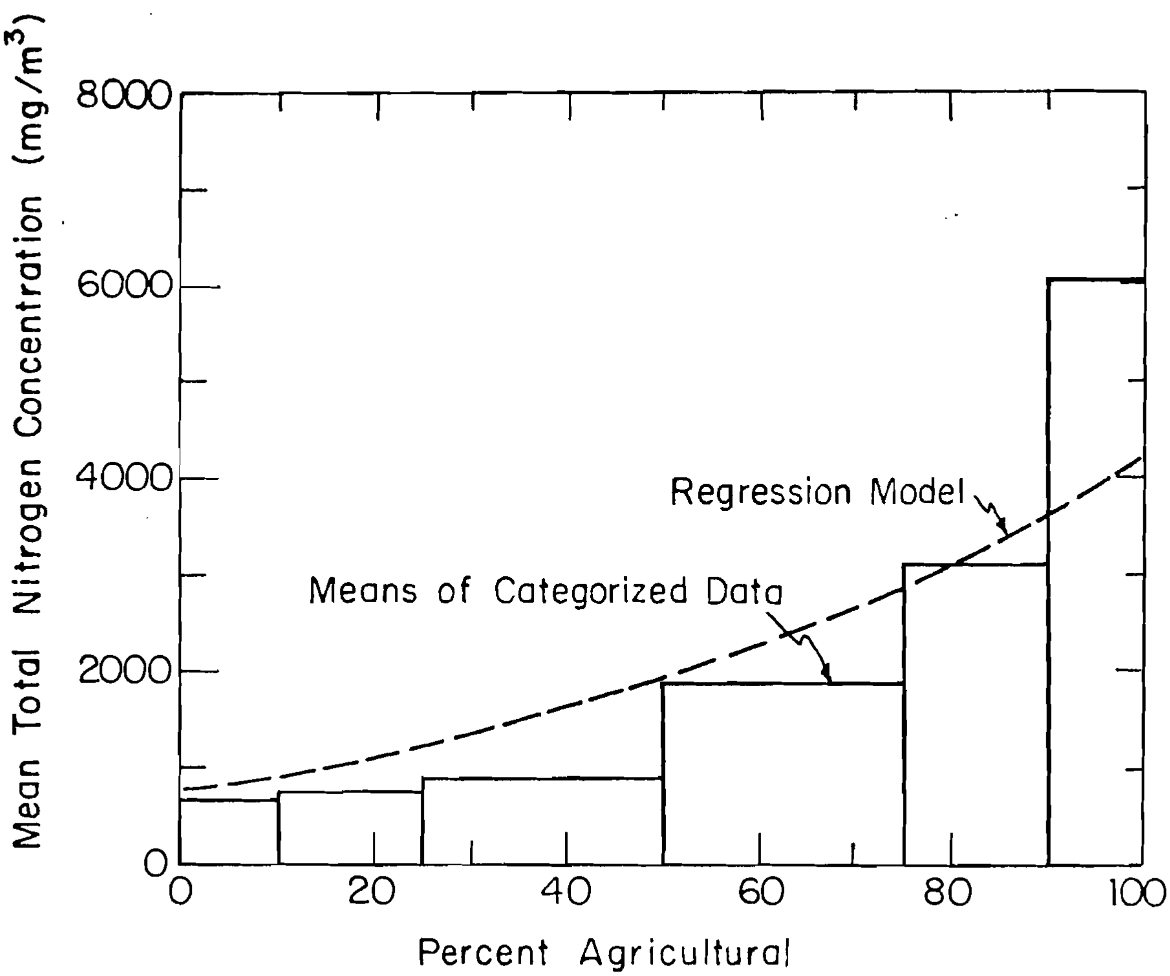


Figure 8

Regionalities of Total Phosphorus Concentrations in Streams Draining Mostly Forested Watersheds (Omernik, 1977)

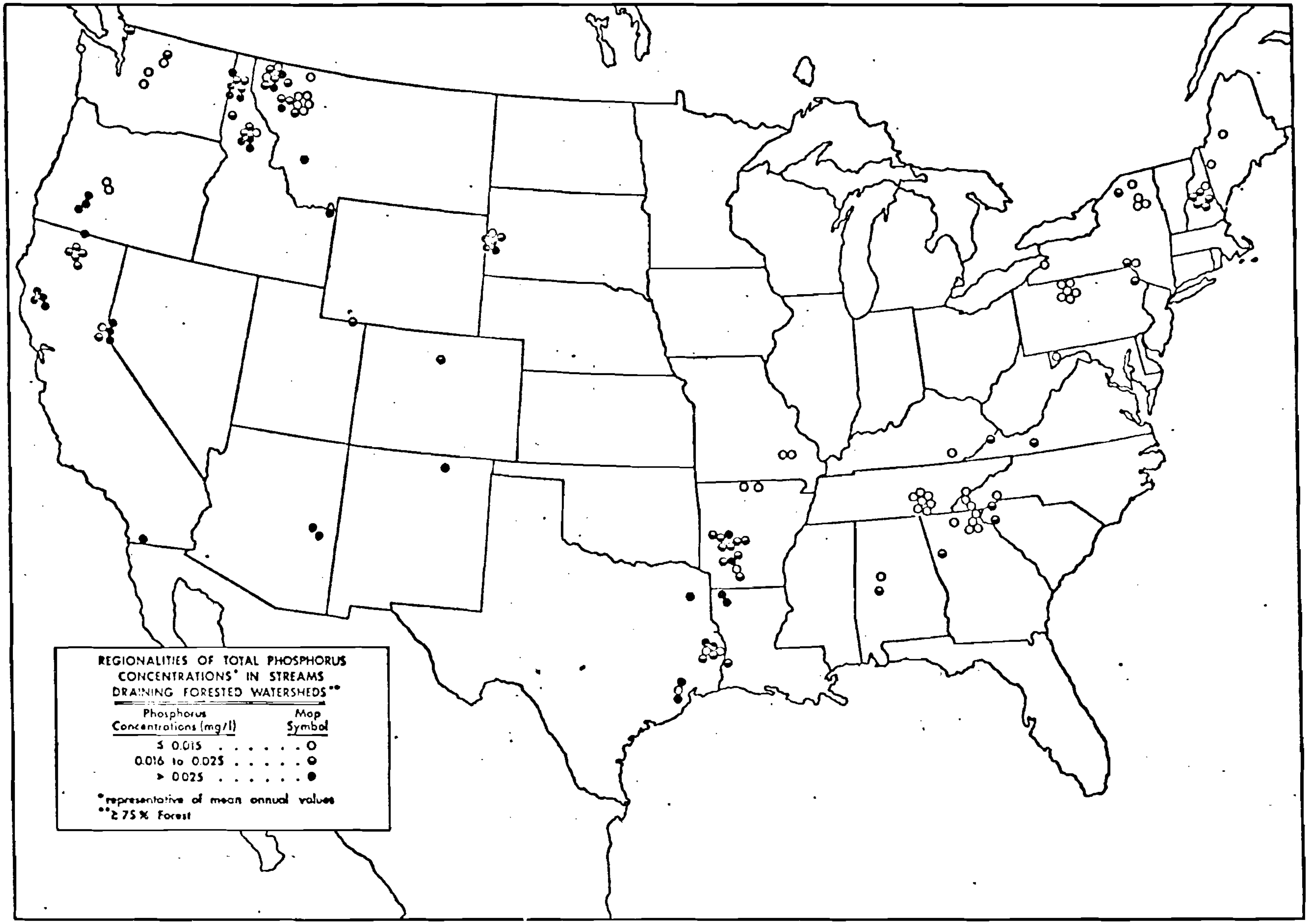
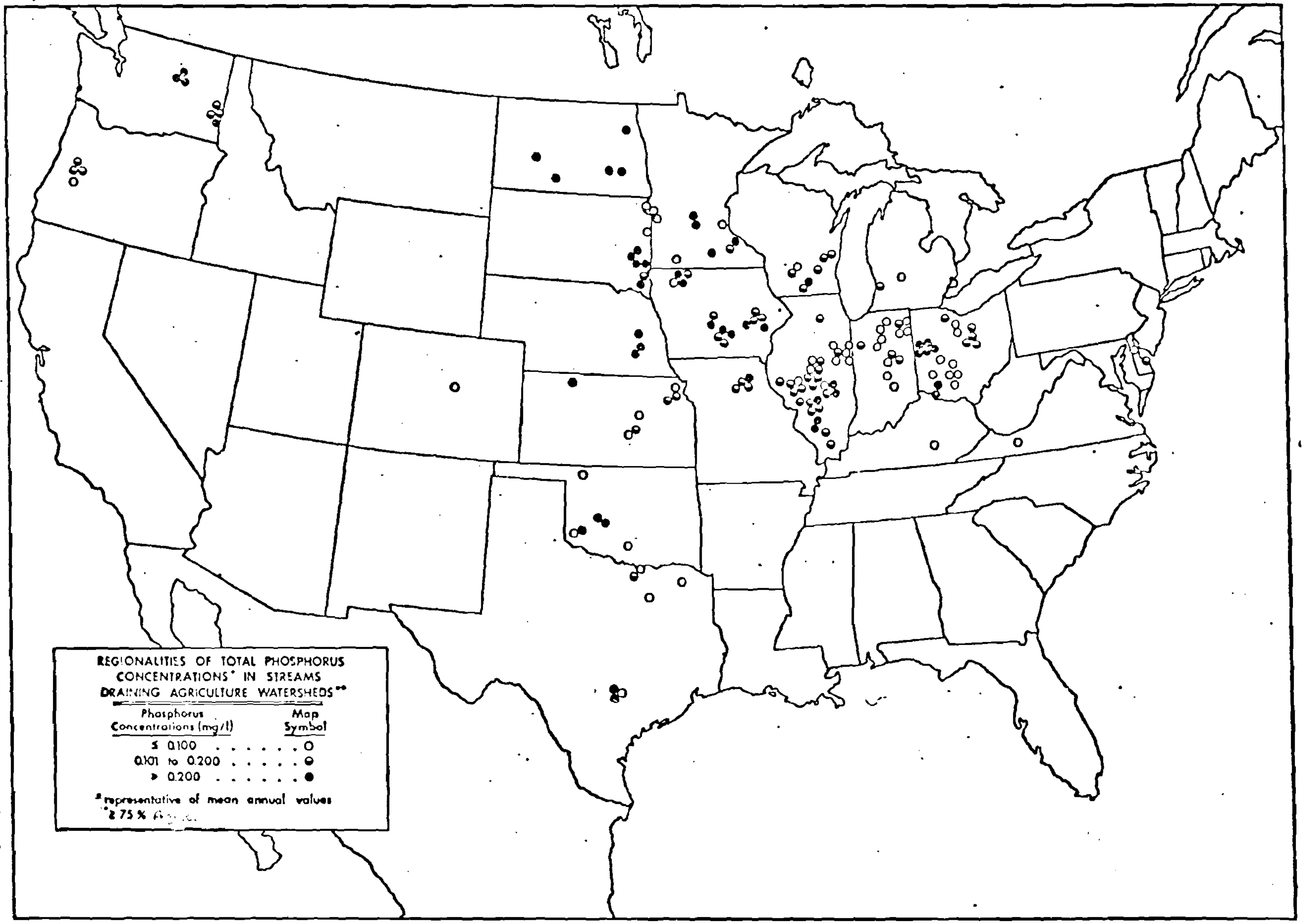


Figure 9

Regionalities of Total Phosphorus Concentrations in Streams Draining Mostly Agricultural Watersheds (Omernik, 1977)



Regional effects could be important. "Agriculture" takes on different forms in different regions (e.g., intensive row cropping in the Corn Belt vs. pastures in New England). In addition, baseline conditions may vary with region, due to geologic and/or climatologic factors. Figure 10 depicts regional variations in the phosphorus contents of the topsoil. Comparisons with Figures 8 and 9 indicate that many of the mostly forested watersheds are located in the lower Appalachian area with relatively phosphorus-deficient soils, whereas most of the agricultural watersheds are in regions with phosphorus-rich soils. A similar pattern is noted in the case of nitrogen (Figure 11). This is an additional indication that regional effects may be embedded in the apparent land use effects depicted in Figures 6 and 7 and in Equations (1) and (2).

In order to test for regional effects, EPA/NES data from 275 watersheds in the Northeast, Midwest, and north central States have been analyzed. The first objective is to identify background levels and agricultural impacts. Accordingly, data from watersheds with greater than 2.5 percent urban land use have been excluded initially. Watersheds have been grouped according to state and percent agricultural development. Six categories of agricultural development have been used: 0-10 percent, 10-25 percent, 25-50 percent, 50-75 percent, and 75-100 percent. Geometric mean phosphorus and nitrogen concentrations have been computed within each state/land use category. States have subsequently been aggregated according to whether the mean nutrient concentrations within each land use category are significantly different from each other. Most of the apparent regional effects can be accounted for

Figure 10

Phosphorus Content of Topsoil in U.S. (MRI, 1976)

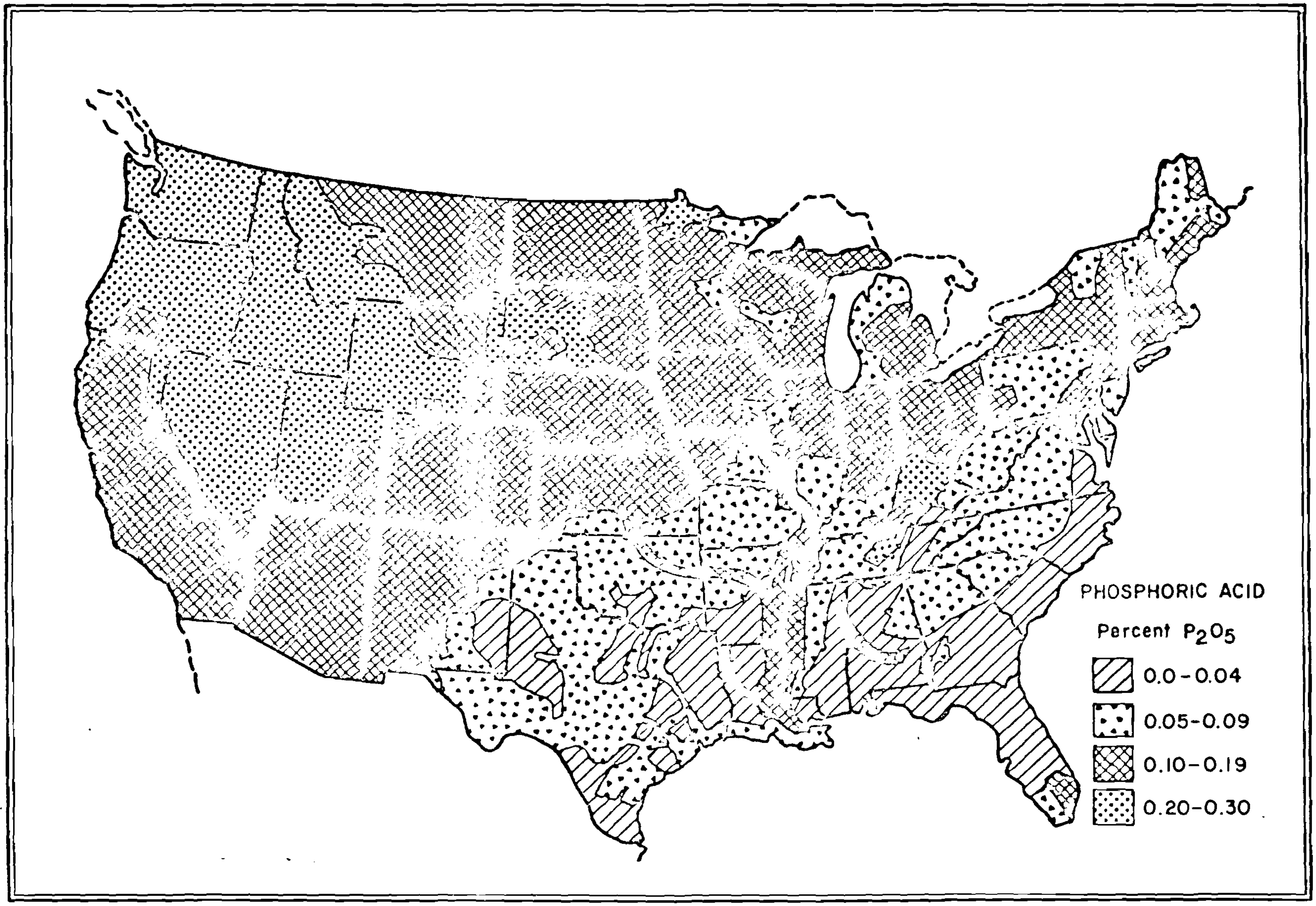


Figure 11

Nitrogen Content of Topsoil in U.S. (MRI, 1976)

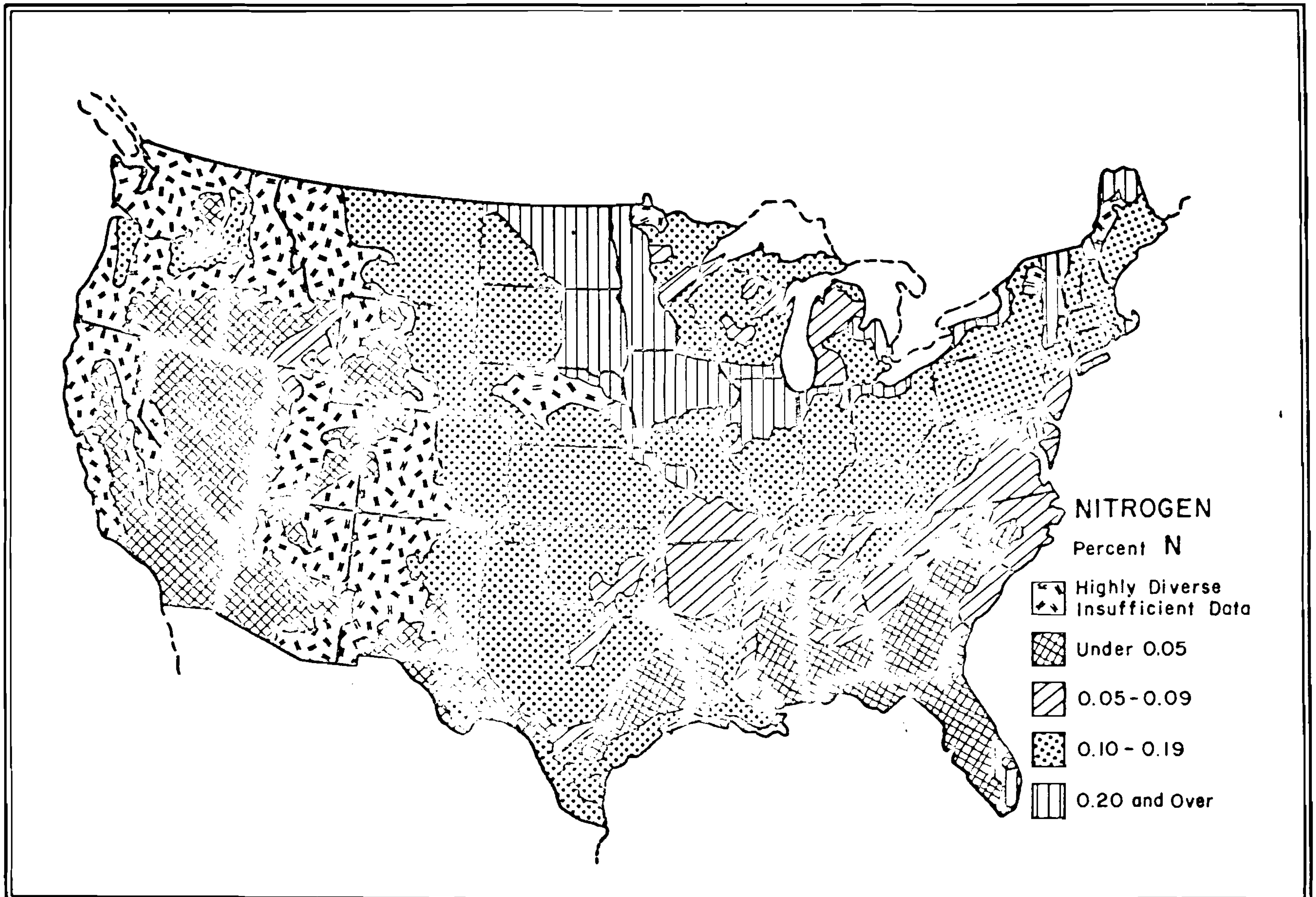
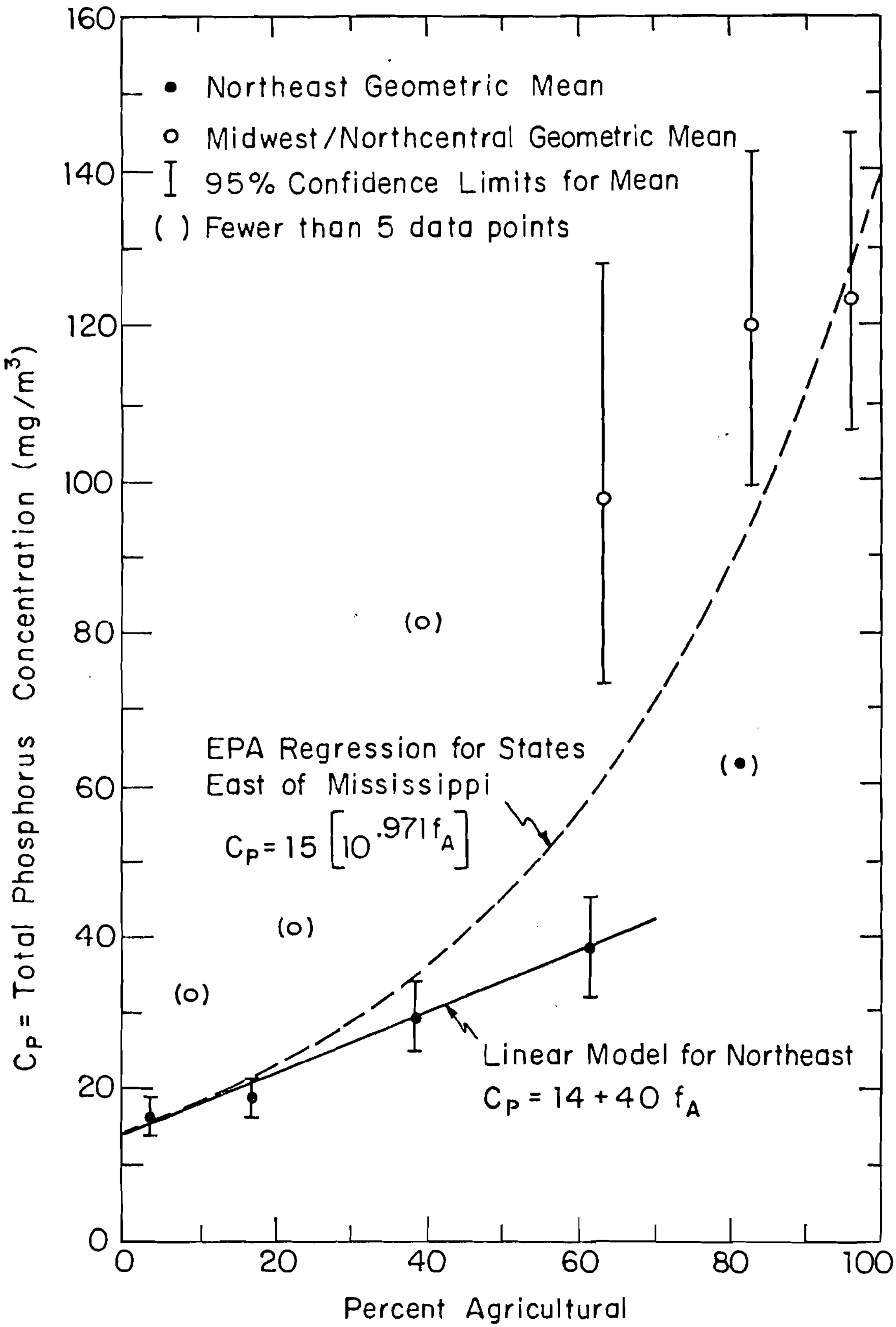


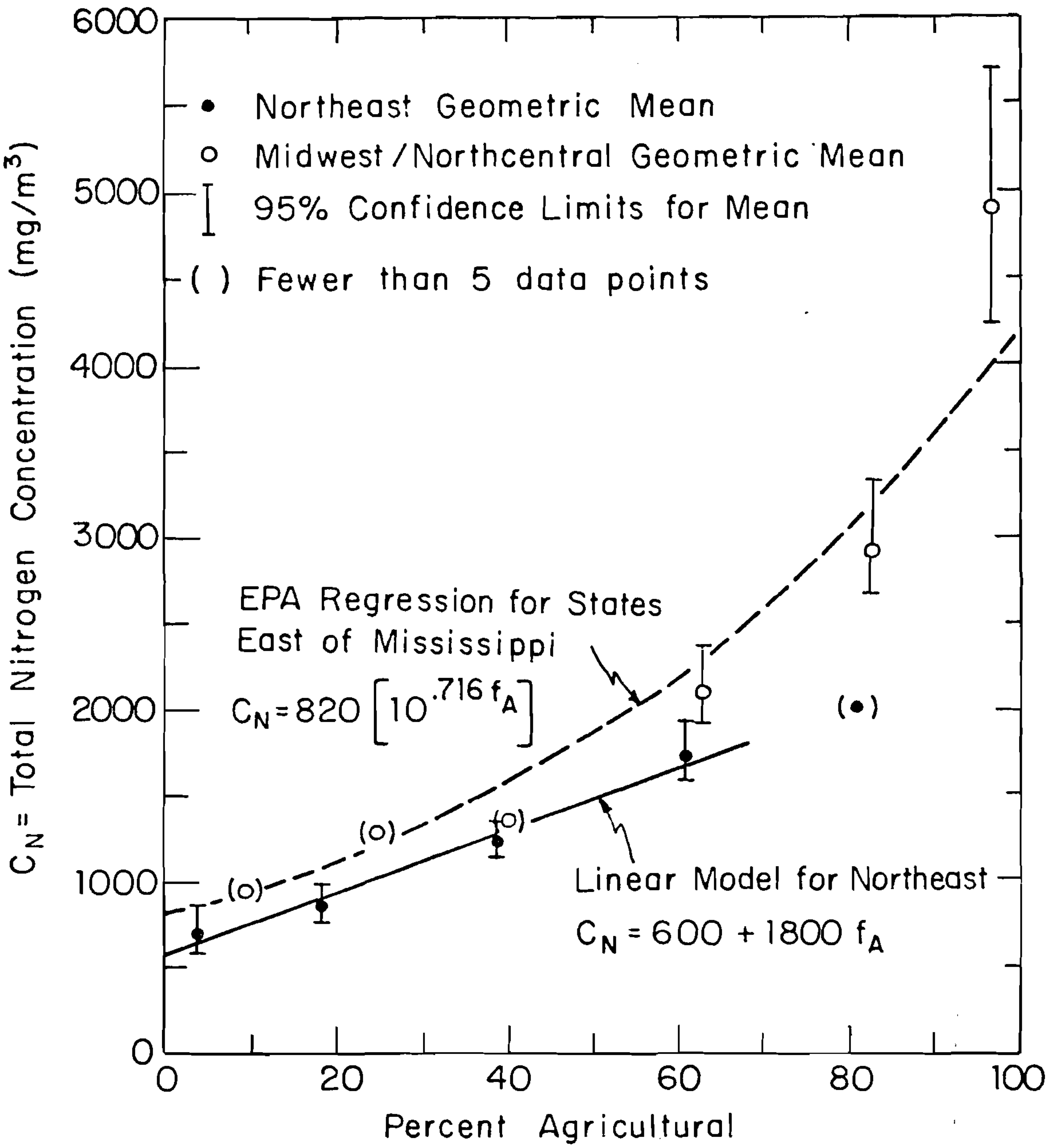
Figure 12



Relationship between Total Phosphorus Concentration and Agricultural Land Use for Watersheds in the Midwest and Northeast with Less that 2.5% Urban Land Use

Figure 13

Relationship between Total Nitrogen Concentration and Agricultural Land Use for Watersheds in the Midwest and Northeast with less Than 2.5% Urban Land Use



by aggregating the data into two groups: (1) the Northeast (including New England, New York, Pennsylvania, New Jersey, eastern Ohio, and northern Michigan); and (2) the Midwest/north central region, (including Minnesota, Wisconsin, Indiana, Illinois, western Ohio, and southern Michigan).

Figures 12 and 13 display the 95 percent confidence limits for the geometric mean phosphorus and nitrogen concentrations, respectively, for each region and degree of agricultural development. Within each land use category, average nutrient concentrations are higher in the Midwest/north central group, particularly in the case of phosphorus. For northeastern watersheds less than 75 percent agricultural the following linear models appear reasonable:

$$C_P = 14 + 40\, f_A = 14\, (1-f_A) + 54\, f_A \qquad (4)$$

$$C_N = 600 + 1800\, f_A = 600\, (1-f_A) + 2400\, f_A \qquad (5)$$

Figures 12 and 13 indicate that the EPA models for the "Eastern U.S." (Equations (1) and (2)) reflect both regional and land use effects, since they tend to fit the less agricultural watersheds in the Northeast and the more agricultural watersheds in the Midwest/north central regions. Equations (4) and (5) appear to be more appropriate for the Northeast and are consistent with the simple additive model discussed above (Equation (3)). Typical phosphorus and nitrogen concentrations for undeveloped land uses are 14 and 600 mg/m^3 respectively, while agricultural areas are characterized by 54 mg/m^3 and 2400 mg/m^3 respectively.

In order to estimate urban impacts on nutrient concentrations, data from the eleven watersheds in the Northeast group with greater than five percent urban land use have been analyzed. Assuming a linear model of the form specified by Equation (3), agricultural impacts have been removed by subtracting the predictions of Equations (4) and (5) from the reported phosphorus and nitrogen concentrations, respectively. The results are plotted against percent urban development in Figures 14 and 15. Based upon the slopes of these relationships, typical concentrations of phosphorus and nitrogen in urban drainage are estimated to be 128 mg/m^3 and 1930 mg/m^3, respectively. Thus, the following linear models approximately represent the impacts of agricultural and urban development on stream nutrient levels in the Northeast:

$$C_P = 14\ (1-f_A - f_U) + 54\ f_A + 128\ f_U \qquad (6)$$

$$C_N = 600\ (1-f_A - f_U) + 2400\ f_A + 1930\ f_U \qquad (7)$$

In each case, the first term represents the net impacts of undeveloped land uses, including forested, cleared, and wetlands. Insufficient data are available to identify differences among these land use types. Note that urban impacts are particularly significant in the case of phosphorus, whereas urban and agricultural impacts are similar in the case of nitrogen.

Multiple regression analyses have been performed in order to obtain refined estimates of typical phosphorus and nitrogen concentrations in streams draining undeveloped, agricultural, and urban areas in the Northeast. Based upon data from 116 watersheds with less than 60 percent agricultural development, the following results have been obtained for phosphorus:

Figure 14

Apparent Effect of Urban Land Use on Stream Phosphorus Concentrations in the Northeast

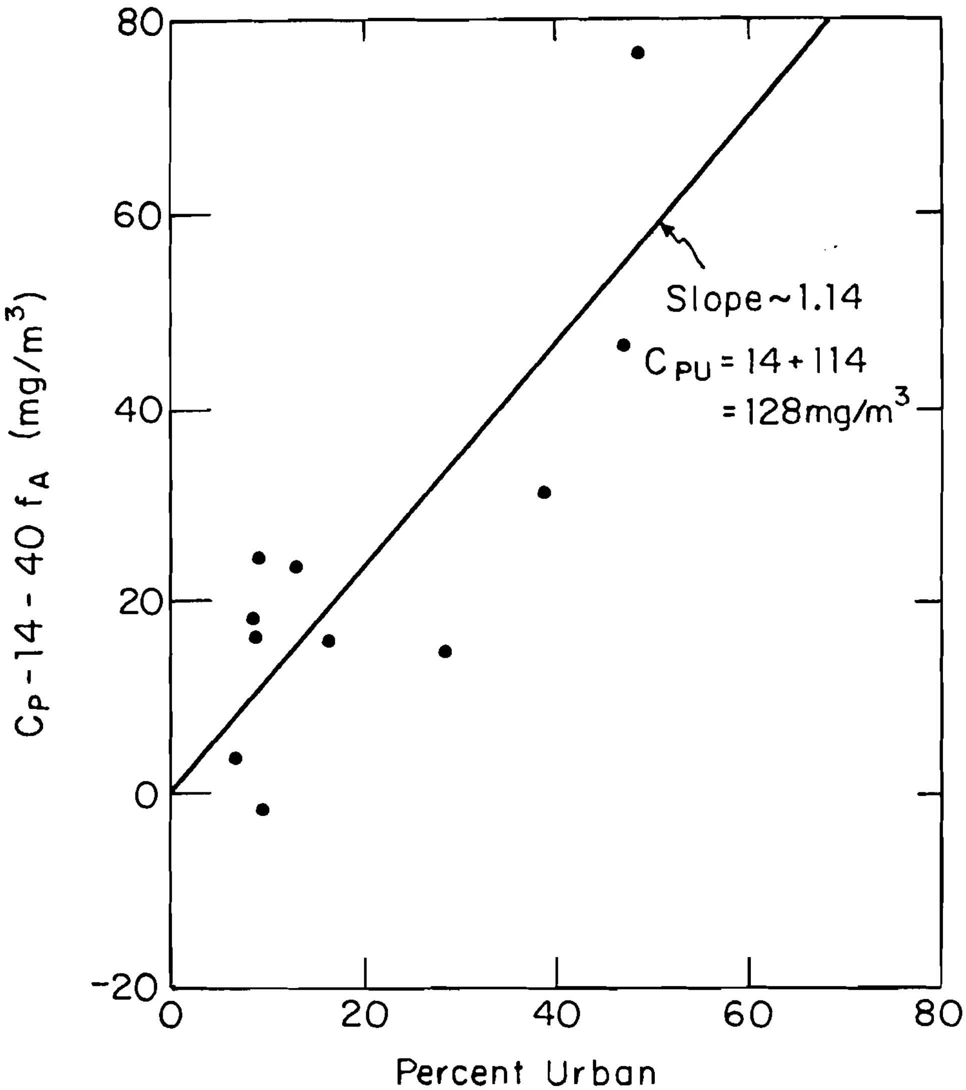
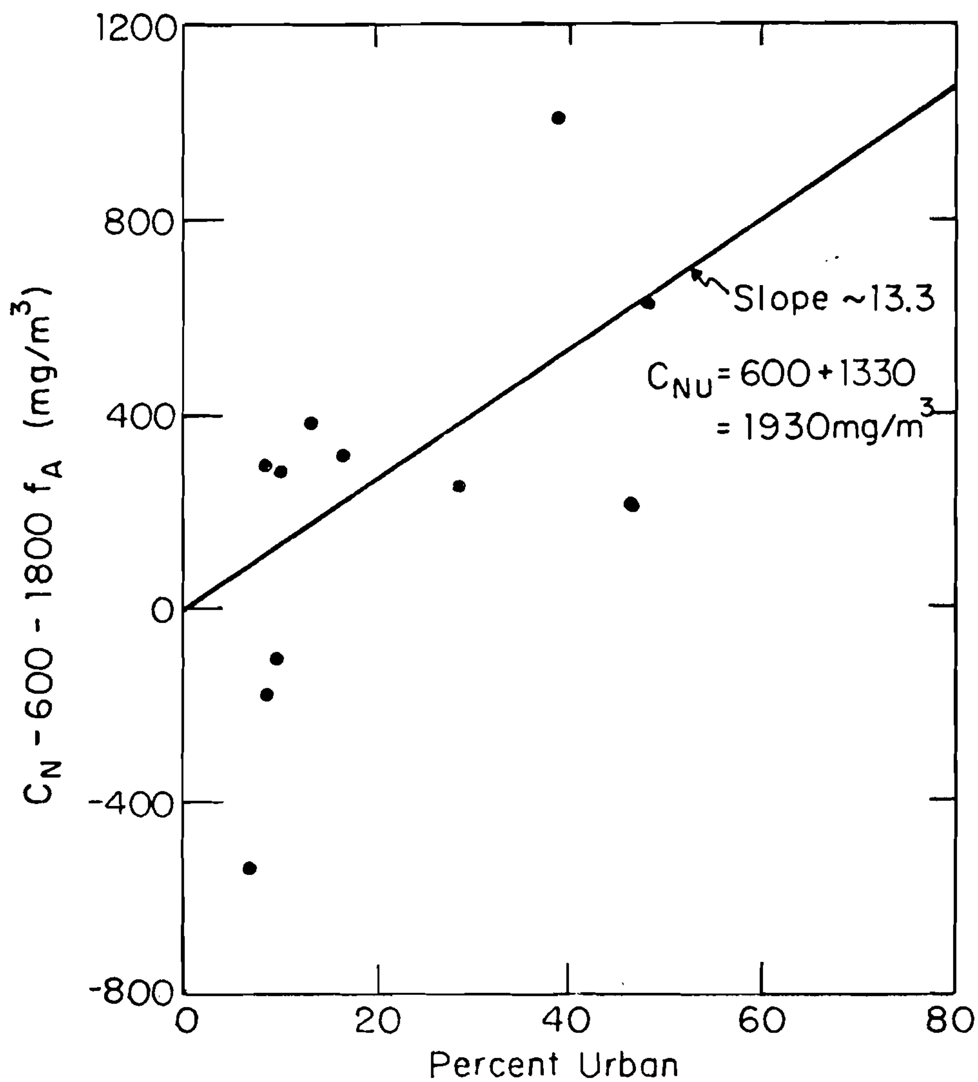


Figure 15

Apparent Effect of Urban Land Use on Stream Nitrogen Concentrations in the Northeast



$$C_P = C_{PO}\,(1-f_A-f_U) + C_{PA}f_A + C_{PU}f_U + C_{PS}d_{PS} \tag{8}$$

$C_{PO} = 15.0$

$C_{PA} = 56.5 \pm 6.3$

$C_{PU} = 138.7 \pm 30.9$

$C_{PS} = -8.0 \pm 4.0$

where,

C_{PO} = phosphorus concentration typical of undeveloped (non-agricultural and nonurban) areas (mg/m^3)

d_{PS} = state dummy variable

= 1.0 for Maine

= 0.0 otherwise

C_{PS} = adjustment for Maine watersheds (mg/m^3)

An adjustment has been included for Maine to account for the fact that average phosphorus concentrations in that state were about 8 mg/m^3 lower than indicated by a model based upon land use effects alone. Because the variance of the residuals generally increased with predicted concentration, the above parameter estimates have been derived by minimizing the sum of the weighted squares of residuals, with weights estimated as the inverse squares of the predicted concentrations. Despite the fact that the above model explains only 47 percent of the variance in the reported phosphorus concentration data*, the regression analysis has identified statistically significant land use effects and has shown that agricultural and urban impacts on phosphorus concentrations are significantly different from each other.

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* Standard error = 38% of mean estimate.

Corresponding results for nitrogen are:

$$C_N = C_{NO}(1-f_A-f_U) + C_{NA}f_A + C_{NU}f_U + C_{NS}d_{NS} \tag{9}$$

$C_{NO} = 873$

$C_{NA} = 1947 \pm 167$

$C_{NU} = 1800 \pm 380$

$C_{NS} = -366 \pm 76$

where,

C_{NO} = nitrogen concentration typical of undeveloped areas (mg/m^3)

d_{NS} = state dummy variable

= 1.0 for Maine, New Hampshire, or Vermont

= 0.0 otherwise

C_{NS} = adjustment factor for Maine, New Hampshire, or Vermont watersheds (mg/m^3)

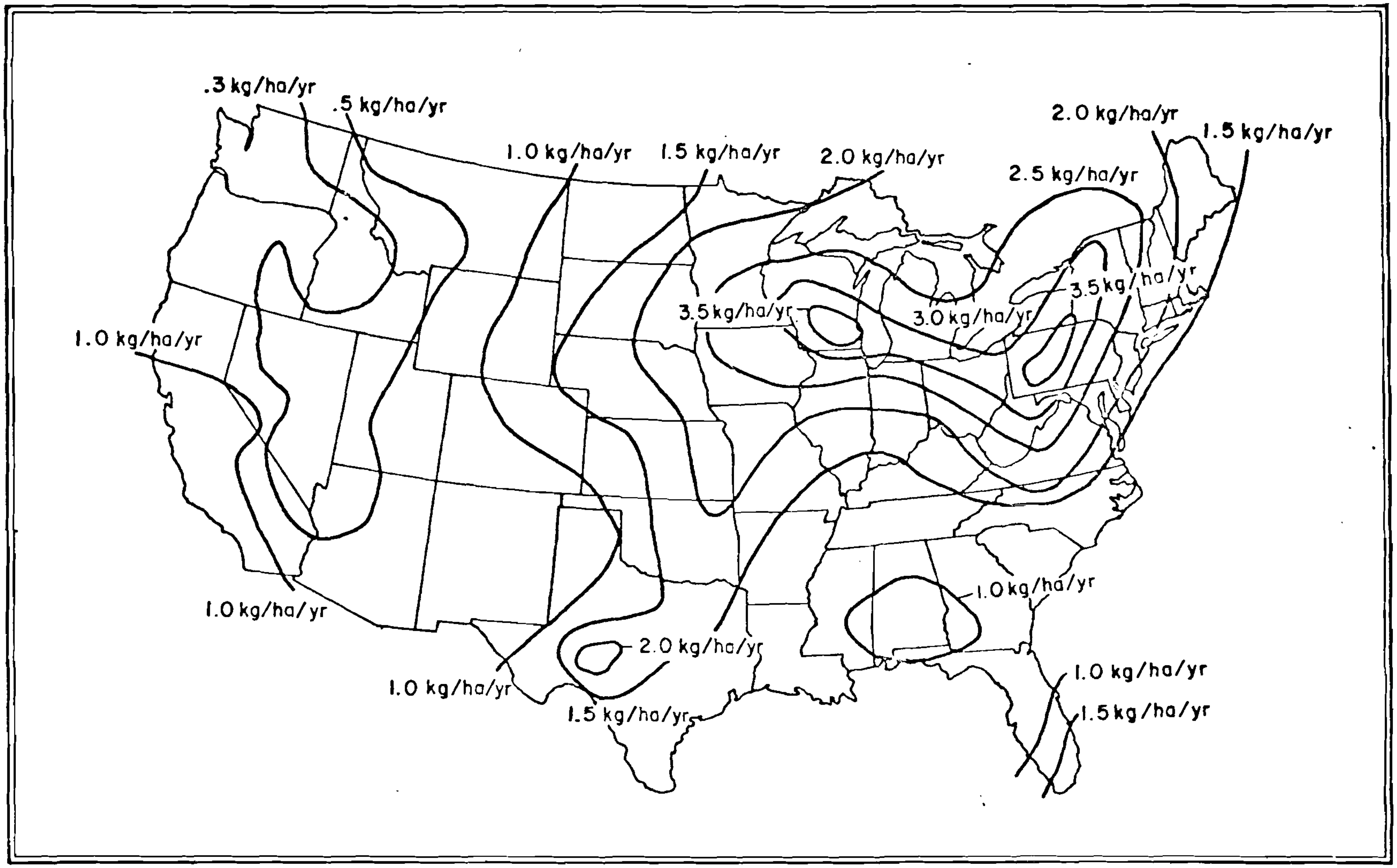
Since the variance of the residuals was apparently stable at different predicted levels, the above coefficients have been estimated using an unweighted multiple regression analysis. This model explains 49 percent of the variance in the reported nitrogen concentrations in 116 watersheds with a standard error of 307 mg/m^3. In this case, nitrogen concentrations in urban drainage are apparently not significantly different from those in agricultural drainage.

Within the Northeast, regional effects on both phosphorus and nitrogen concentrations may reflect lower atmospheric loadings of nutrients in precipitation or dustfall on northern New England watersheds. These, in turn, may reflect fewer significant air pollution sources in this region or in the regions upwind. This explanation is consistent with regionalities in the nitrogen content of precipitation, as depicted in Figure 16 (MRI, 1976). In the case of phosphorus, geologic factors may also account for some of the apparent regional differences (Dillon and Kirchner, 1975).

The regression analysis indicates that the mean phosphorus concentration typical of urban areas in Northeastern NES/NPS watersheds has an approximate 95 percent confidence range of 78 to 200 mg/m^3. Applied to a typical Connecticut runoff rate of .62 m/yr (see Figure 1), the above corresponds to a range of 48 to 124 mg/m^2-yr in total phosphorus export. This range is at the low end of values reported in the literature as being typical of urban land drainage. Based upon literature reviews, Uttormark, et al., (1974) reported a range of 100 to 500 mg/m^2-yr, Loehr (1974) reported a range of 110 to 560 mg/m^2-year, and Likens and Borman (1974) reported a range of 100 to 1700 mg/m^2-year. These literature values probably reflect some "end-of-pipe" measurements, which, unlike the estimates derived above, are representative of surface runoff only and do not include the diluting effects of base flow derived from infiltration in pervious areas of urban watersheds or effects of possible phosphorus losses due to biological uptake or adsorption/sedimentation reactions in stream transport. The comparatively low values derived here may also reflect a dominance of relatively low intensity urban land use in the NES/NPS watersheds. Omernik (1978) indicates that low density residential areas were considered urban when detected on the maps and aerial photographs used to estimate land use for each watershed in the NES/NPS study. In developing phosphorus budgets for New York lakes, Schaffner and Oglesby (1978) assumed an export value of 100 mg/m^2-year for urban

Figure 16

Inorganic Nitrogen Content of Precipitation in the U.S. (MRI, 1976)



areas which were predominately residential. The 48 to 124 mg/m^2-year range does not appear to be unreasonable if we are concerned with the effects of relatively low intensity urban development.

Section 2

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