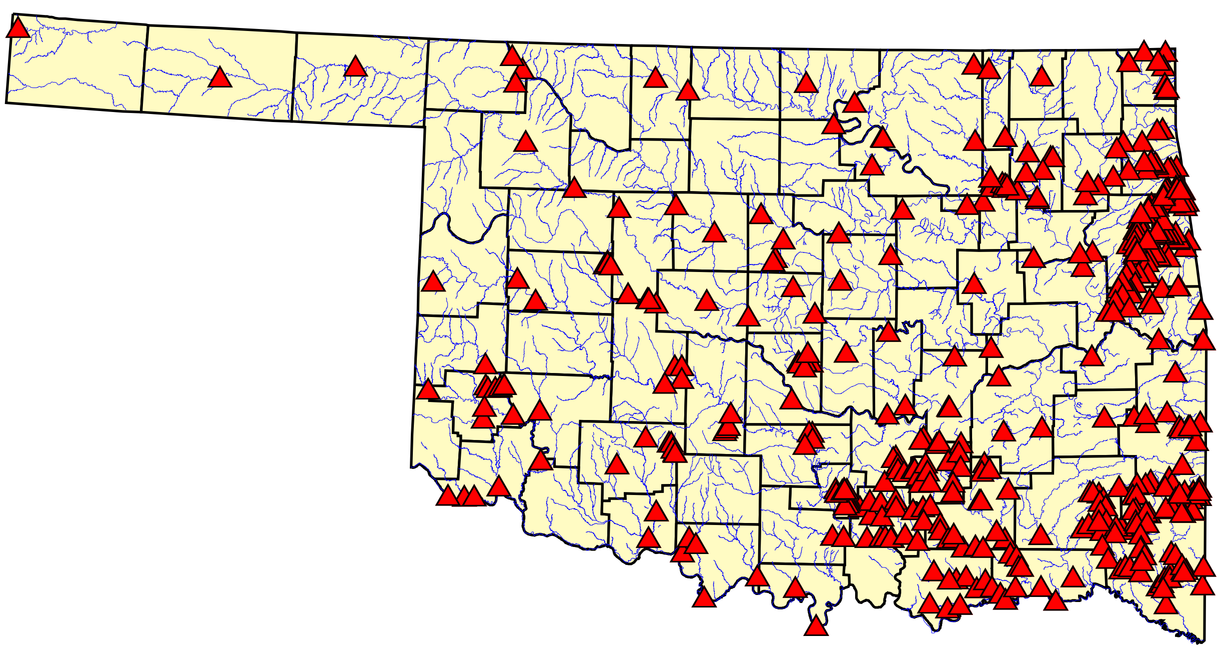
Prepared in cooperation with the
OKLAHOMA WATER RESOURCES BOARD

Percentile Distributions of Median Nitrite Plus Nitrate as Nitrogen, Total Nitrogen, and Total Phosphorus Concentrations in Oklahoma Streams, 1973–2001

Water-Resources Investigations Report 03–4084



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Percentile Distributions of Median Nitrite Plus Nitrate as Nitrogen, Total Nitrogen, and Total Phosphorus Concentrations in Oklahoma Streams, 1973–2001

By Brian E. Haggard[1], Jason R. Masoner[2], and Carol J. Becker[2]

Water-Resources Investigations Report 03–4084

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[1]U.S. Department of Agriculture, Agricultural Research Service
[2]U.S. Geological Survey

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
Length		
inch (in)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Area		
square foot (ft^2)	0.09290	square meter
square inch (in^2)	6.452	square centimeter
square mile (mi^2)	2.590	square kilometer
Volume		
gallon (gal)	3.785	liter
cubic foot (ft^3)	0.02832	cubic meter
Mass		
ounce, avoirdupois (oz)	28.35	gram
pound, avoirdupois (lb)	0.4536	kilogram
Hydraulic gradient		
foot per mile (ft/mi)	0.1894	meter per kilometer

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=1.8\ °C+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88)
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above or below NAVD 88.

Percentile Distributions of Median Nitrite Plus Nitrate as Nitrogen, Total Nitrogen, and Total Phosphorous Concentrations in Oklahoma Streams, 1973-2001

*B*y Brain E. Haggard, Jason R. Masoner, *and* Carol J. Becker

Abstract

Nutrients are one of the primary causes of water-quality impairments in streams, lakes, reservoirs, and estuaries in the United States. The U.S. Environmental Protection Agency has developed regional-based nutrient criteria using ecoregions to protect streams in the United States from impairment. However, nutrient criteria were based on nutrient concentrations measured in large aggregated nutrient ecoregions with little relevance to local environmental conditions in states. The Oklahoma Water Resources Board is using a dichotomous process known as Use Support Assessment Protocols to define nutrient criteria in Oklahoma streams. The Oklahoma Water Resources Board is modifying the Use Support Assessment Protocols to reflect nutrient information and environmental characteristics relevant to Oklahoma streams, while considering nutrient information grouped by geographic regions based on level III ecoregions and state boundaries.

Percentile distributions of median nitrite plus nitrate as nitrogen, total nitrogen, and total phosphorous concentrations were calculated from 563 sites in Oklahoma and 4 sites in Arkansas near the Oklahoma and Arkansas border to facilitate development of nutrient criteria for Oklahoma streams. Sites were grouped into four geographic regions and were categorized into eight stream categories by stream slope and stream order. The 50th percentiles of median nitrite plus nitrate as nitrogen, total nitrogen, and total phosphorus concentrations were greater in the Ozark Highland ecoregion and were less in the Ouachita Mountains ecoregion when compared to other geographic areas used to group sites. The 50th percentiles of median concentrations of nitrite plus nitrate as nitrogen, total nitrogen, and total phosphorus were least in first, second, and third order streams. The 50th percentiles of median nitrite plus nitrate as nitrogen, total nitrogen and total phosphorus concentrations in the Ozark Highland and Ouachita Mountains ecoregions were least in first, second, and third order streams with streams slopes greater than 17 feet per mile.

Nitrite plus nitrate as nitrogen and total nitrogen criteria determined by the U.S. Environmental Protection Agency for the Ozark Highland ecoregion were less than the 25th percentiles of median nitrite plus nitrate as nitrogen, total nitrogen, and total phosphorus concentrations in the Ozark Highland ecoregion calculated for this report. Nitrite plus nitrate as nitrogen and total nitrogen criteria developed by the U.S. Environmental Protection Agency for the Ouachita Mountains ecoregion were similar to the 25th percentiles of median nitrite plus nitrate as nitrogen and total nitrogen concentrations in the Ouachita Mountains ecoregion calculated for this report. Nitrate as nitrogen and total phosphorus concentrations currently (2002) used in the Use Support Assessment Protocols for Oklahoma were greater than the 75th percentiles of median nitrite plus nitrate as nitrogen and total phosphorus concentrations calculated for this report.

INTRODUCTION

Nutrients are one of the primary causes of water-quality impairments in our Nation's streams, lakes, reservoirs, and estuaries (U.S. Environmental Protection Agency, 1996). Forty percent of impaired streams in the United States were impaired due to nutrient enrichment; 51 percent of lakes and reservoirs and 57 percent of estuaries also were impaired by nutrients (U.S. Environmental Protection Agency, 1996).

The U.S. Environmental Protection Agency (USEPA) has developed regional-based nutrient criteria using ecoregions to protect streams in the United States from impairment (U.S. Environmental Protection Agency, 2000a, 2000b, 2000c, 2001a, and 2001b). However, nutrient criteria were based on nutrient concentrations collected in large aggregated nutrient ecoregions with little relevance to local environmental conditions in states. Robertson and others (2001) presented an alternative regional approach for USEPA Regions 5 and 7 by classifying streams based on environmental nutrient zones and environmental characteristics. Individual states and tribes are encouraged by the USEPA to modify or improve upon the ecoregion approach by Robertson and others (2001).

The nutrient criteria approach used by the Oklahoma Water Resources Board (OWRB) is a dichotomous process that stratifies or groups streams using environmental characteristics such as stream order, stream slope, turbidity, and percent canopy shading to identify streams in Oklahoma affected by nutrients (Oklahoma Water Resources Board, 2001). This classification process is called the Use Support Assessment Protocols (USAP), title 785, chapter 46, subchapter 15. An example of part of the USAP process currently (2002) used in Oklahoma is provided in figure 1. The USAP is based on nutrient information and environmental characteristics developed by a study in the Netherlands (Peeters and Gardeniers, 1998). The OWRB wished to modify the USAP to reflect nutrient information and environmental characteristics relevant to Oklahoma streams, while considering nutrient information grouped into four geographic regions based on level III ecoregions and state boundaries.

The U.S. Geological Survey (USGS), in cooperation with OWRB, calculated median percentile distributions from available nutrient data collected at 563 sites in Oklahoma and 4 sites in Arkansas near the Oklahoma and Arkansas border (fig. 2). The percentile distributions presented in this report can be used in the USAP to facilitate the development of nutrient criteria for Oklahoma streams.

Purpose and Scope

This report provides percentile distributions of median concentrations of nitrite plus nitrate as nitrogen (referred to as nitrate in this report), total nitrogen, and total phosphorus in Oklahoma streams based on samples collected from 1973 to 2001. Sites were grouped into four geographic regions and were categorized into eight stream categories by stream slope and stream order. Percentile distributions of median concentrations were calculated for each stream category for four geographic regions: (1) water-quality sites in the Ozark Highland ecoregion; (2) water-quality sites in the Ouachita Mountains ecoregion; (3) water-quality sites excluding those in the Ozark Highland and Ouachita Mountains ecoregions; and (4) all water-quality sites in Oklahoma and part of Arkansas. Differences in nutrient concentrations between geographic regions and stream categories are briefly discussed, but the purpose of this report is to provide tables of percentile distributions of median nutrient concentrations to the OWRB. A detailed literature review of previous studies on stream classification to establish nutrient criteria is provided in appendix 1.

Acknowledgments

The authors thank staff at the Oklahoma Conservation Commission and the OWRB for providing nutrient data bases used in this study; Evan Hornig, William Green, Lyn Osburn, and Robert Tortorelli of the USGS for their contributions to the report.

METHODS OF DETERMING NUTRIENT CRITERIA

U.S. Environmental Protection Agency Methods for Determining Nutrient Criteria

The USEPA is exploring several methods to define nutrient criteria to assess nutrient-threatened or

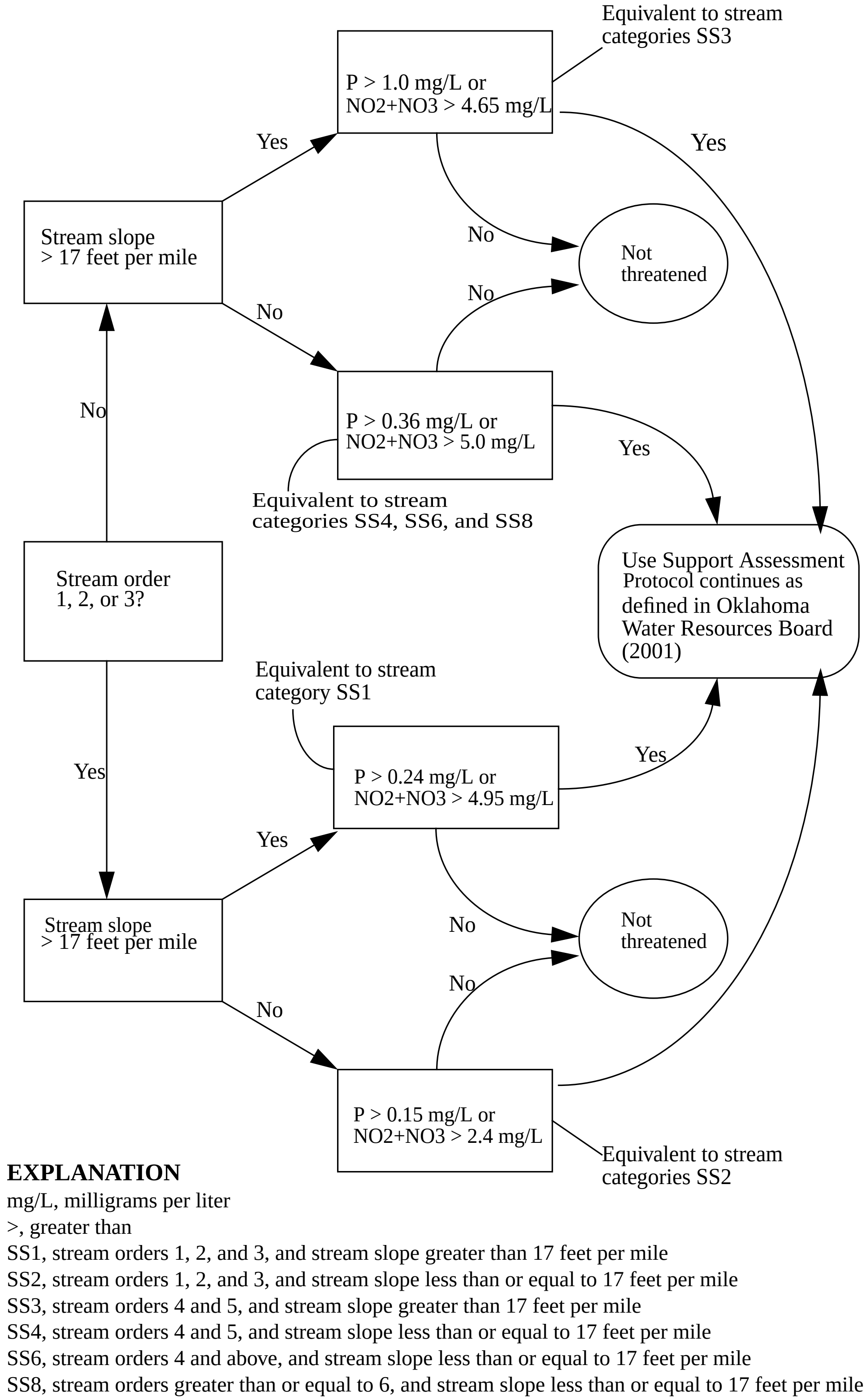


Figure 1. Dichotomous process of the Use Support Assessment Protocol used in Oklahoma to identify nutrient threatened streams.

impaired streams using nitrate, total nitrogen, and total phosphorous concentrations. One method used by the USEPA to define nutrient criteria for streams assigns a reference value based on nutrient concentrations in a specific geographic area (U.S. Environmental Protection Agency, 2000a). Nutrient data from the USEPA, USGS, and various universities were used to create a reference value based on the frequency distribution using all available nutrient data in a geographic area. The lower 25th percentile of all nutrient data represents the reference condition or the minimally impaired stream value (U.S. Environmental Protection Agency, 2000a).

A second method to define reference conditions is to select the upper 75th percentile of nutrient data collected from a subset of streams considered as being the least impaired streams in a defined area (U.S. Environmental Protection Agency, 2000a). The USGS Hydrologic Benchmark Network represents over 80 undeveloped basins throughout the United States. The 75th percentile was calculated using nutrient data collected from streams draining the undeveloped basins. The 75th percentile concentration for nitrate was 0.21 milligram per liter, total nitrogen was 0.50 milligram per liter, and total phosphorus was 0.04 milligram per liter (Clarke and others, 2000).

The USEPA is using these methods to develop tables of the cumulative distribution of nutrient concentrations for nutrient ecoregions and level III ecoregions throughout the United States (U.S. Environmental Protection Agency, 2001a, p. 4 and 5). Nutrient ecoregions are aggregations of level III ecoregions as defined by Omernik (2000). Nutrient ecoregions IV, V, IX and XI comprise various portions of Oklahoma (fig 3). The USEPA ambient water-quality criteria recommendations for nutrient ecoregions IV, V, IX, and XI are presented in table 1. The USEPA ambient water-quality criteria recommendations for portions of the level III ecoregions in Oklahoma are presented in table 2. Water-quality criteria from the two USEPA methods will be compared to median nitrate, total nitrogen, and total phosphorus concentrations calculated for a modified USAP approach presented in this report.

Modification of Use Support Assessment Protocols for Oklahoma

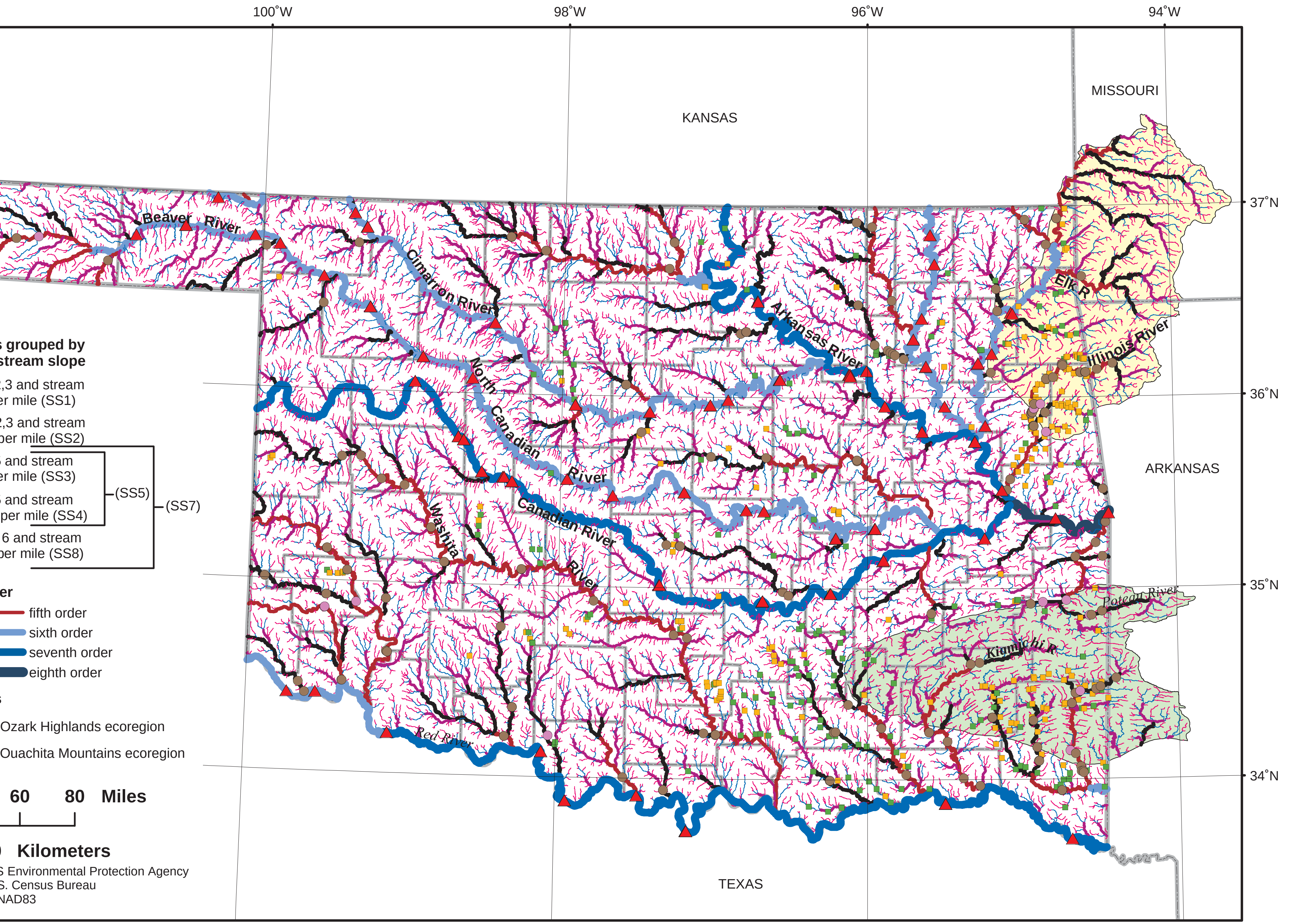
A modified USAP approach utilizing stream characteristics and geographic regions was used in this report to reflect nutrient and hydrological conditions in Oklahoma streams based on procedures defined by the U.S. Environmental Protection Agency (2000a) and Robertson and others (2001).

Geographic Regions and Stream Category Determination

A Geographical Information System (GIS) was used to group 563 water-quality sites in Oklahoma and 4 water-quality sites in Arkansas near the Oklahoma and Arkansas border into four geographic regions (table 3). Water-quality sites for each geographic region were grouped into eight stream categories (table 4) by stream order and stream slope. Individual stream characteristics for water-quality sites used in this report are available in Masoner and others (2002).

A digital stream network for Oklahoma was created using a flow accumulation model created from the National Elevation Dataset (U.S. Geological Survey, 2001) that represented streams at a consistent stream density. Stream order was determined from the digital stream network using methods described by Strahler (1952, 1957); this technique was automated using GIS techniques (Masoner and others, 2002). Headwater streams were designated as first order; a second-order stream was formed at the intersection of two first-order streams; a third-order stream was formed at the intersection of two second-order streams, and so forth. The technique worked well in areas with well-defined topography. Stream order estimations for streams draining lands with less pronounced topography generally under predicted stream order by a value of one.

Stream slope is defined as the change in elevation between stream confluences upstream and downstream from a water-quality site divided by the distance between stream confluences. A digital stream dataset was created using a hydrologically conditioned Digital Elevation Model with 60-meter cell size. The Digital Elevation Model was created from elevation data (hypsography) and streams (hydrography) from digital versions of U.S. Geological Survey 1:100,000-scale topographic maps (Cederstrand and Rea, 1995). The average length of a stream segment used to calculate stream slope was 1.7 miles. The minimum and



100˚W
98˚W
96˚W
94˚W
37˚N
36˚N
35˚N
34˚N
MISSOURI
KANSAS
ARKANSAS
TEXAS
Beaver River
Cimarron River
North Canadian River
Canadian River
Washita River
Arkansas River
Elk R.
Illinois River
Poteau River
Kiamichi R.
Red River
s grouped by
stream slope
2,3 and stream
er mile (SS1)
2,3 and stream
per mile (SS2)
5 and stream
er mile (SS3)
5 and stream
per mile (SS4)
(SS5)
(SS7)
6 and stream
per mile (SS8)
er
fifth order
sixth order
seventh order
eighth order
Ozark Highlands ecoregion
Ouachita Mountains ecoregion
60
80
Miles
Kilometers
S Environmental Protection Agency
S. Census Bureau
NAD83

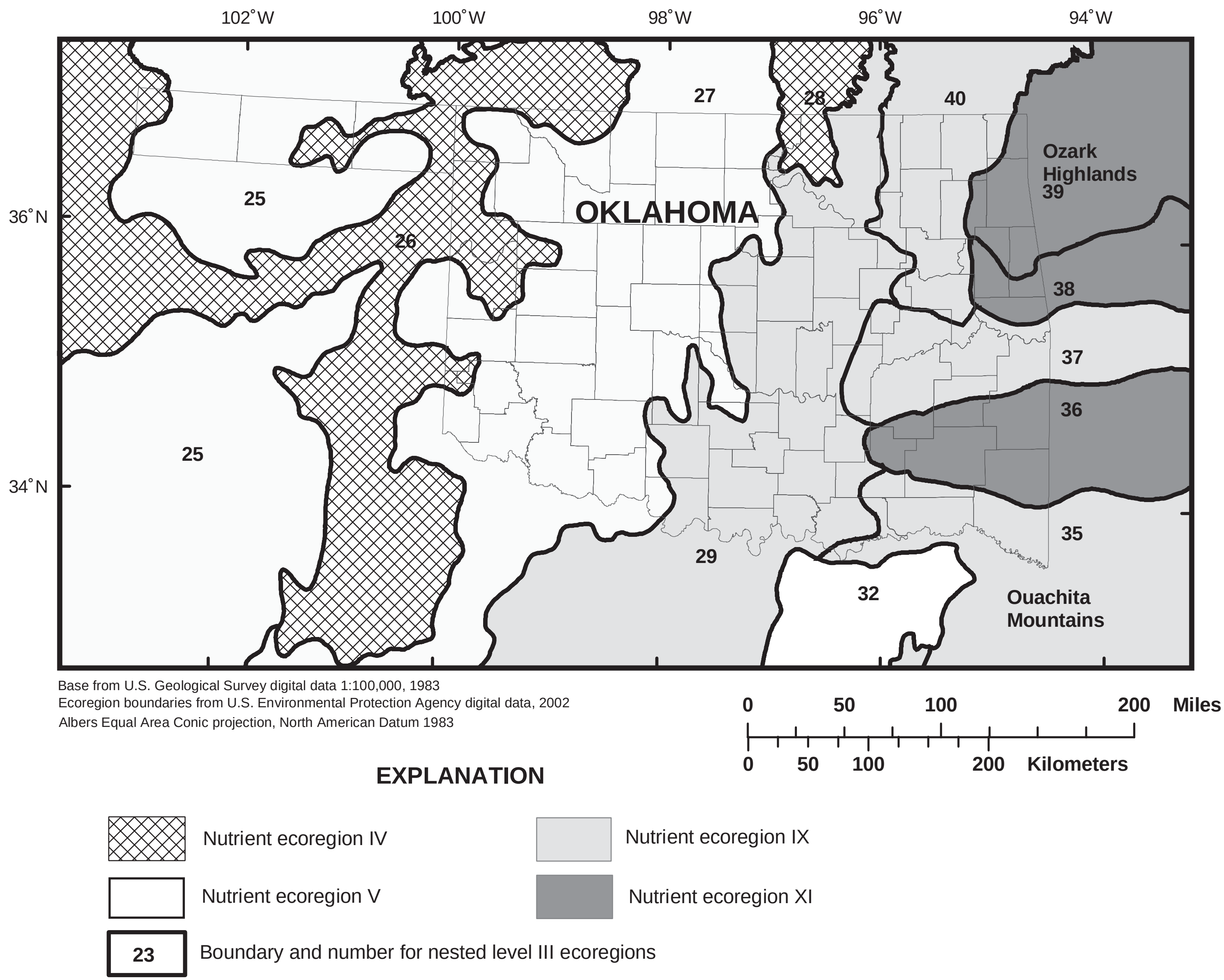


Figure 3. Aggregate nutrient ecoregions and nested level III ecoregions for Oklahoma (U.S. Environmental Protection Agency, 2001).

Table 1. Environmental Protection Agency ambient water-quality criteria recommendations, 25th percentile of nitrite plus nitrate as nitrogen, total nitrogen and total phosphorus concentrations for nutrient ecoregions IV, V, IX, and XI

[mg/L, milligrams per liter]

Nutrient ecoregions	Nitrite plus nitrate as nitrogen (mg/L)	Total nitrogen (mg/L)	Total phosphorus (mg/L)[1]	References
IV	0.050	0.560	0.023	U.S. Environmental Protection Agency (2001a)
V	0.260	0.880	0.068	U.S. Environmental Protection Agency (2001b)
IX	0.125	0.692	0.037	U.S. Environmental Protection Agency (2000c)
XI	0.093	0.305	0.010	U.S. Environmental Protection Agency (2000b)

[1]Total phosphorus values were originally reported in microgram per liter and have been converted to milligram per liter

Table 2. U.S. Environmental Protection Agency ambient water-quality criteria recommendations, 25th percentile for nitrite plus nitrate as nitrogen, total nitrogen, and total phosphorus concentrations for portions of level III ecoregions in Oklahoma

[mg/L, milligrams per liter]

Nutrient ecore-gions	Level III ecoregions	Nitrite plus nitrate as nitrogen (mg/L)	Total nitrogen (mg/L)	Total phosphorus (mg/L)[1]	References
IV	26	0.04	0.45	0.0250	U.S. Environmental Protection Agency (2001a)
	28	0.12	0.36	0.060	
V	25	0.72	1.07	0.060	U.S. Environmental Protection Agency (2001b)
	27	0.19	0.84	0.090	
IX	29	0.078	0.68	0.03750	U.S. Environmental Protection Agency (2000c)
	35	0.067	0.385	0.0500	
	37	0.075	0.683	0.04250	
	40	0.23	0.712	0.09250	
XI	36 (Ouachita Mountains)	0.01	0.30	0.01047	U.S. Environmental Protection Agency (2000b)
	38	0.03	1.383	0.00563	
	39 (Ozark Highlands)	0.239	0.379	0.00663	

[1]Total phosphorus values were originally reported in microgram per liter and have been converted to milligram per liter

Table 3. Geographic regions used to group water-quality sites

Geographic region	Description of geographic region	Tables in this report containing results
1	Water-quality sites in the Ozark Highland ecoregion (referred to as ecoregion 39)	Table 5.
2	Water-quality sites in the Ouachita Mountains ecoregion (referred to as ecoregion 36)	Table 6.
3	All water-quality sites in Oklahoma and part of Arkansas excluding those in the Ozark Highland and Ouachita Mountains ecoregion	Table 7.
4	All water-quality sites in Oklahoma and part of Arkansas	Table 8.

Table 4. Description of stream categories used to group water-quality sites

Stream categories	Criteria for stream categories
SS1	Stream orders 1, 2, and 3, and stream slope greater than 17 feet per mile
SS2	Stream orders 1, 2, and 3, and stream slope less than or equal to 17 feet per mile
SS3	Stream orders 4 and 5, and stream slope greater than 17 feet per mile
SS4	Stream orders 4 and 5, and stream slope less than or equal to 17 feet per mile
SS5	Stream orders 4 and 5, without slope criteria
SS6	Stream orders 4 and above, and stream slope less than or equal to 17 feet per mile
SS7	Stream orders 4 and above, without slope criteria
SS8	Stream orders greater than or equal to 6, and stream slope less than or equal to 17 feet per mile

maximum length used were 0.31 mile to 3.1 miles (Masoner and others, 2002).

Stream Water-Quality Data Compilation

Water-quality data compiled included nitrate, total nitrogen, and total phosphorus concentrations measured in water samples at 563 sites in Oklahoma and 4 sites in Arkansas near the Oklahoma and Arkansas border. There were 12,124 measurements of nitrate, 8,697 measurements of total nitrogen, and 14,259 measurements of total phosphorus. Water-quality data and site locations were retrieved from the OWRB, Oklahoma Conservation Commission (OCC), and the USEPA Storage and Retrieval (STORET) system database (U.S. Environmental Protection Agency, 2001). The data from OWRB were collected from 1998 through 2001. Data from OCC were collected from 1990 through 1999. The STORET data were collected from 1973 through 1995 and include data collected by state and federal agencies and the USGS.

Most water-quality sites had more than one sampling event during which one, two, or all three nutrient concentrations were measured; many sites had several hundred sampling events over a period of years. A median concentration was calculated for sites having more than one measurement for a nutrient. The large number of analyses used in this report, over 35,000, did not allow for an assessment of sampling techniques, preservation methods, analytical techniques, or method reporting levels. Data were screened for quality-assurance samples. Sampling events having quality-assurance samples were identified and a median concentration was calculated for that sampling event. Concentration values less than the detection limit were changed to 0 milligram per liter. Concentrations of nitrate and total nitrogen were measured directly or computed from the sum of individual nitrogen measurements.

There were 231 water-quality sites where water-quality data were collected at the same geographic location, but were maintained separately by multiple state and federal agencies. For these cases, one site was designated to represent multiple sites. The water-quality data at these locations were grouped and a median concentration was calculated.

Statistical Distributions

The 10th, 25th, 33rd, 50th, 67th, 75th, and 90th percentiles, minimum, and maximum values were calculated for median concentrations of nitrate, total nitrogen, and total phosphorus for each stream category (table 4) for four geographical regions (table 3). For sites with fewer than seven water-quality sites, only the median, mean, minimum, and maximum statistics were calculated. Stream categories SS3 and SS8 in the Ozark Highland ecoregion (table 5) and Ouachita Mountains ecoregion (table 6) had insufficient numbers of sites to calculate 10th, 25th, 33rd, 50th, 67th, 75th, and 90th percentiles. Stream category SS3 in geographic region 3, all sites excluding those in the Ozark Highland and Ouachita Mountains ecoregions (table 7), also had an insufficient number of sites to calculate percentiles.

PERCENTILE DISTRIBUTIONS OF MEDIAN NITRITE PLUS NITRATE AS NITROGEN, TOTAL NITROGEN, AND TOTAL PHOSPHORUS CONCENTRATIONS

Percentile distributions of median nutrient concentrations were calculated for four geographic regions categorized by eight stream categories (tables 5, 6, 7, and 8). Out of the four geographic regions in which statistics were calculated, the 50th percentiles of median nitrate and total nitrogen concentrations were greatest in the Ozark Highland ecoregion (table 5) and least in the Ouachita Mountains ecoregion (table 6); the 50th percentiles of total phosphorus concentrations were least in the Ouachita Mountains ecoregion (table 6). The 50th percentiles of median concentrations for total phosphorus were similar in the Ozark Highland ecoregion (table 5) and geographic regions 3 and 4 (tables 7 and 8). The 50th percentiles of median concentrations of nitrate, total nitrogen, and total phosphorus concentrations generally were least in first, second, and third order streams (SS1 and SS2) in all geographic regions.

The 50th percentiles of median total nitrogen, and total phosphorus concentrations sampled in the Ozark Highland and Ouachita Mountains ecoregions on first, second, and third order streams with stream

Table 5. Percentile distributions of median concentrations of nitrite plus nitrate as nitrogen, total nitrogen, and total phosphorus for water-quality sites in the Ozark Highland ecoregion in Oklahoma, geographic region 1

[concentrations are in milligrams per liter; mean, arithmetic average of median values; min, minimum median value; max, maximum median value; -, insufficient number of sites to calculate statistic]

Stream Category[1]	Number of sites[2]	Mean	Percentiles of Median Concentrations							Min	Max
			10	25	33	50	67	75	90		
						Nitrite plus Nitrate as Nitrogen					
SS1	57	1.59	0.16	0.59	0.97	1.40	1.85	2.00	3.00	0.00	5.95
SS2	13	2.27	0.70	1.00	1.37	2.00	2.77	3.13	5.04	0.50	6.00
SS3	4	1.54	-	-	-	1.58	-	-	-	1.00	2.00
SS4	10	1.92	1.20	1.75	1.96	2.00	2.04	2.11	2.47	1.19	2.50
SS5	14	1.81	1.07	1.28	1.87	2.00	2.00	2.03	2.33	1.00	2.50
SS6	12	1.65	0.24	1.22	1.48	2.00	2.00	2.08	2.40	0.13	2.50
SS7	16	1.62	0.40	1.16	1.26	2.00	2.00	2.00	2.26	0.13	2.50
SS8	2	0.32	-	-	-	-	-	-	-	0.13	0.51
						Total Nitrogen					
SS1	36	1.66	0.27	0.84	1.00	1.63	2.07	2.23	3.13	0.15	4.13
SS2	10	2.38	0.60	1.23	1.53	2.13	2.60	3.07	5.91	0.56	6.18
SS3	3	2.03	-	-	-	2.34	-	-	-	1.30	2.45
SS4	10	2.33	1.55	2.15	2.28	2.33	2.54	2.61	2.92	1.52	2.95
SS5	13	2.26	1.38	2.05	2.28	2.33	2.47	2.56	2.82	1.30	2.95
SS6	12	2.08	0.77	1.60	1.96	2.31	2.46	2.58	2.85	0.64	2.95
SS7	15	2.07	0.90	1.52	1.95	2.32	2.42	2.51	2.76	0.64	2.95
SS8	2	0.86	-	-	-	-	-	-	-	0.64	1.07
						Total Phosphorus					
SS1	59	0.068	0.003	0.003	0.010	0.020	0.030	0.040	0.100	0.000	0.770
SS2	17	0.119	0.018	0.035	0.049	0.070	0.101	0.118	0.434	0.010	0.670
SS3	4	0.074	-	-	-	0.073	-	-	-	0.003	0.150
SS4	10	0.129	0.044	0.103	0.110	0.118	0.170	0.179	0.189	0.040	0.190
SS5	14	0.113	0.022	0.070	0.104	0.110	0.151	0.168	0.185	0.003	0.190
SS6	14	0.122	0.040	0.088	0.110	0.118	0.158	0.175	0.187	0.040	0.190
SS7	16	0.110	0.029	0.050	0.095	0.110	0.144	0.161	0.183	0.003	0.190
SS8	2	0.090	-	-	-	-	-	-	-	0.040	0.140

[1]SS1, stream orders 1, 2, and 3, and stream slope greater than 17 feet per mile
SS2, stream orders 1, 2, and 3, and stream slope less than or equal to 17 feet per mile
SS3, stream orders 4 and 5, and stream slope greater than 17 feet per mile
SS4, stream orders 4 and 5, and stream slope less than or equal to 17 feet per mile
SS5, stream orders 4 and 5, without slope criteria
SS6, stream orders 4 and above, and stream slope less than or equal to 17 feet per mile
SS7, stream orders 4 and above, without slope criteria
SS8, stream orders greater than or equal to 6, and stream slope less than or equal to 17 feet per mile
[2]Number of water-quality sites with median concentration

Table 6. Percentile distributions of median concentrations of nitrite plus nitrate as nitrogen, total nitrogen, and total phosphorus from water-quality sites in the Ouachita Mountains ecoregion in Oklahoma, geographic region 2

[concentrations are in milligrams per liter; mean, arithmetic average of median values; min, minimum median value; max, maximum median value; -, insufficient number of sites to calculate statistic]

Stream Category[1]	Number of sites[2]	Mean	Percentiles of Median Concentrations							Min	Max
			10	25	33	50	67	75	90		
					Nitrite plus Nitrate as Nitrogen						
SS1	46	0.08	0.00	0.00	0.00	0.01	0.01	0.01	0.07	0.00	3.00
SS2	16	0.05	0.00	0.00	0.01	0.03	0.05	0.09	0.16	0.00	0.19
SS3	3	0.29	-	-	-	0.13	-	-	-	0.11	0.62
SS4	14	0.18	0.00	0.00	0.02	0.09	0.13	0.20	0.74	0.00	1.05
SS5	17	0.20	0.00	0.01	0.03	0.11	0.13	0.26	0.71	0.00	1.05
SS6	15	0.19	0.00	0.00	0.02	0.09	0.14	0.36	0.68	0.00	1.05
SS7	18	0.21	0.00	0.01	0.05	0.12	0.14	0.38	0.66	0.00	1.05
SS8	0	-	-	-	-	-	-	-	-	-	-
					Total Nitrogen						
SS1	24	0.26	0.00	0.00	0.00	0.08	0.19	0.28	0.53	0.00	3.30
SS2	7	0.37	0.02	0.15	0.20	0.40	0.55	0.60	0.70	0.02	0.70
SS3	2	0.52	-	-	-	-	-	-	-	0.41	0.63
SS4	13	0.52	0.15	0.20	0.28	0.39	0.59	0.70	1.27	0.12	1.45
SS5	15	0.52	0.16	0.20	0.34	0.41	0.61	0.64	1.18	0.12	1.45
SS6	14	0.54	0.15	0.20	0.33	0.46	0.65	0.78	1.22	0.12	1.45
SS7	16	0.54	0.17	0.23	0.35	0.47	0.63	0.72	1.13	0.12	1.45
SS8	0	-	-	-	-	-	-	-	-	-	-
					Total Phosphorus						
SS1	46	0.023	0.008	0.010	0.013	0.020	0.023	0.030	0.040	0.003	0.110
SS2	16	0.042	0.019	0.020	0.20	0.030	0.040	0.048	0.097	0.016	0.160
SS3	4	0.047	-	-	-	0.045	-	-	-	0.020	0.080
SS4	17	0.059	0.018	0.021	0.024	0.030	0.040	0.072	0.177	0.010	0.255
SS5	21	0.057	0.020	0.021	0.025	0.030	0.058	0.072	0.156	0.010	0.255
SS6	18	0.061	0.019	0.021	0.026	0.030	0.058	0.078	0.167	0.010	0.255
SS7	22	0.058	0.020	0.021	0.025	0.030	0.065	0.078	0.155	0.010	0.255
SS8	0	-	-	-	-	-	-	-	-	-	-

[1]SS1, stream orders 1, 2, and 3, and stream slope greater than 17 feet per mile
SS2, stream orders 1, 2, and 3, and stream slope less than or equal to 17 feet per mile
SS3, stream orders 4 and 5, and stream slope greater than 17 feet per mile
SS4, stream orders 4 and 5, and stream slope less than or equal to 17 feet per mile
SS5 stream orders 4 and 5, without slope criteria
SS6, stream orders 4 and above, and stream slope less than or equal to 17 feet per mile
SS7, stream orders 4 and above, without slope criteria
SS8, stream orders greater than or equal to 6, and stream slope less than or equal to 17 feet per mile
[2]Number of water-quality sites with median concentration

Table 7. Percentile distributions of median concentrations of nitrite plus nitrate as nitrogen, total nitrogen, and total phosphorus from water-quality sites in Oklahoma and part of Arkansas, excluding sites with the Ozark Highland and Ouachita Mountains ecoregions, geographic region 3

[concentrations are in milligrams per liter; mean, arithmetic average of median values; min, minimum median value; max, maximum median value; -, insufficient number of sites to calculate statistic]

Stream Category[1]	Number of sites[2]	Mean	Percentiles of Median Concentrations							Min	Max
			10	25	33	50	67	75	90		
			Nitrite plus Nitrate as Nitrogen								
SS1	76	0.45	0.00	0.00	0.03	0.11	0.27	0.45	1.22	0.00	5.00
SS2	127	0.35	0.00	0.00	0.00	0.07	0.14	0.25	1.00	0.00	7.00
SS3	4	0.32	-	-	-	0.31	-	-	-	0.13	0.55
SS4	84	0.63	0.11	0.13	0.13	0.32	0.50	0.80	1.73	0.00	6.30
SS5	88	0.61	0.11	0.13	0.13	0.32	0.49	0.78	1.71	0.00	6.30
SS6	149	0.53	0.09	0.13	0.13	0.32	0.50	0.64	1.38	0.00	6.30
SS7	153	0.52	0.09	0.13	0.13	0.32	0.50	0.60	1.28	0.00	6.30
SS8	65	0.41	0.07	0.13	0.15	0.34	0.50	0.60	0.86	0.00	1.64
			Total Nitrogen								
SS1	44	1.07	0.17	0.40	0.49	0.72	1.31	1.57	2.52	0.00	3.66
SS2	74	1.06	0.22	0.35	0.45	0.60	0.95	1.37	2.76	0.00	7.49
SS3	4	0.88	-	-	-	0.85	-	-	-	0.64	1.20
SS4	72	1.20	0.51	0.64	0.70	1.00	1.30	1.50	2.14	0.31	3.96
SS5	76	1.18	0.53	0.62	0.70	0.93	1.26	1.49	2.12	0.31	3.96
SS6	135	1.18	0.55	0.69	0.78	0.99	1.28	1.48	2.08	0.31	3.96
SS7	139	1.17	0.56	0.69	0.78	0.97	1.27	1.45	2.07	0.31	3.96
SS8	63	1.16	0.59	0.73	0.80	0.99	1.27	1.41	1.93	0.34	3.11
			Total Phosphorus								
SS1	87	0.077	0.006	0.020	0.028	0.040	0.065	0.080	0.168	0.003	1.315
SS2	133	0.083	0.025	0.040	0.041	0.060	0.085	0.100	0.168	0.006	0.476
SS3	5	0.107	-	-	-	0.060	-	-	-	0.030	0.290
SS4	68	0.140	0.030	0.055	0.065	0.088	0.138	0.158	0.331	0.003	0.850
SS5	91	0.138	0.030	0.055	0.062	0.086	0.136	0.158	0.320	0.003	0.850
SS6	151	0.156	0.030	0.060	0.075	0.110	0.155	0.190	0.333	0.003	0.850
SS7	156	0.154	0.030	0.060	0.075	0.110	0.155	0.190	0.329	0.003	0.850
SS8	65	0.176	0.045	0.071	0.099	0.133	0.186	0.223	0.352	0.021	0.790

[1]SS1, stream orders 1, 2, and 3, and stream slope greater than 17 feet per mile
SS2, stream orders 1, 2, and 3, and stream slope less than or equal to 17 feet per mile
SS3, stream orders 4 and 5, and stream slope greater than 17 feet per mile
SS4, stream orders 4 and 5, and stream slope less than or equal to 17 feet per mile
SS5 stream orders 4 and 5, without slope criteria
SS6, stream orders 4 and above, and stream slope less than or equal to 17 feet per mile
SS7, stream orders 4 and above, without slope criteria
SS8, stream orders greater than or equal to 6, and stream slope less than or equal to 17 feet per mile
[2]Number of water-quality sites with median concentration

Table 8. Percentile distributions of median concentrations of nitrite plus nitrate as nitrogen, total nitrogen, and total phosphorus of all water-quality sites in Oklahoma and part of Arkansas, geographic region 4

[concentrations are in milligrams per liter; mean, arithmetic average of median values; min, minimum median value; max, maximum median value; -, insufficient number of sites to calculate statistic]

Stream category[1]	Number of sites[2]	Mean	Percentiles of median concentrations							Min	Max
			10	25	33	50	67	75	90		
Nitrite plus Nitrate as Nitrogen											
SS1	179	0.72	0.00	0.01	0.01	0.13	0.73	1.00	2.00	0.00	5.95
SS2	156	0.48	0.00	0.00	0.00	0.08	0.16	0.49	1.82	0.00	7.00
SS3	11	0.75	0.11	0.13	0.13	0.55	1.01	1.15	2.00	0.11	2.00
SS4	108	0.69	0.06	0.13	0.13	0.33	0.70	0.91	2.00	0.00	6.30
SS5	119	0.69	0.08	0.13	0.13	0.36	0.70	0.95	2.00	0.00	6.30
SS6	176	0.58	0.07	0.13	0.13	0.34	0.50	0.70	1.69	0.00	6.30
SS7	187	0.59	0.08	0.13	0.13	0.35	0.51	0.71	1.71	0.00	6.30
SS8	68	0.40	0.08	0.13	0.15	0.35	0.50	0.59	0.80	0.00	1.64
Total Nitrogen											
SS1	104	1.09	0.00	0.22	0.38	0.69	1.42	1.76	2.74	0.00	4.13
SS2	91	1.15	0.21	0.40	0.45	0.61	1.19	1.55	3.00	0.00	7.49
SS3	9	1.18	0.41	0.63	0.68	0.91	1.27	1.82	2.45	0.41	2.45
SS4	95	1.22	0.39	0.60	0.68	1.00	1.45	1.53	2.38	0.12	3.96
SS5	104	1.22	0.40	0.61	0.68	0.97	1.43	1.53	2.40	0.12	3.96
SS6	161	1.19	0.48	0.65	0.75	0.99	1.32	1.51	2.31	0.12	3.96
SS7	170	1.19	0.47	0.64	0.75	0.98	1.31	1.51	2.32	0.12	3.96
SS8	66	1.15	0.59	0.73	0.75	0.98	1.22	1.40	1.88	0.34	3.11
Total Phosphorus											
SS1	192	0.061	0.003	0.010	0.018	0.026	0.040	0.050	0.121	0.000	1.315
SS2	166	0.083	0.020	0.030	0.040	0.055	0.080	0.100	0.162	0.006	0.670
SS3	13	0.079	0.010	0.027	0.036	0.060	0.090	0.110	0.234	0.003	0.290
SS4	113	0.127	0.024	0.047	0.060	0.084	0.129	0.156	0.228	0.003	0.850
SS5	126	0.122	0.023	0.040	0.055	0.080	0.118	0.151	0.227	0.003	0.850
SS6	68	0.172	0.043	0.069	0.095	0.132	0.179	0.214	0.339	0.021	0.790
SS7	181	0.144	0.030	0.055	0.066	0.106	0.150	0.178	0.292	0.003	0.850
SS8	68	0.172	0.043	0.069	0.095	0.132	0.179	0.214	0.339	0.021	0.790

[1]SS1, stream orders 1, 2, and 3, and stream slope greater than 17 feet per mile
SS2, stream orders 1, 2, and 3, and stream slope less than or equal to 17 feet per mile
SS3, stream orders 4 and 5, and stream slope greater than 17 feet per mile
SS4, stream orders 4 and 5, and stream slope less than or equal to 17 feet per mile
SS5 stream orders 4 and 5, without slope criteria
SS6, stream orders 4 and above, and stream slope less than or equal to 17 feet per mile
SS7, stream orders 4 and above, without slope criteria
SS8, stream orders greater than or equal to 6, and stream slope less than or equal to 17 feet per mile
[2]Number of water-quality sites with median concentration

slopes greater than 17 feet per mile (SS1) were less than those with stream slopes less than or equal to 17 feet per mile (SS2). There was little difference for nitrate and total nitrogen concentrations on fourth order streams or higher (SS3 through SS8).

The U.S. Environmental Protection Agency (2000a) reports the lower 25th percentile nutrient concentrations analyzed from all nutrient data available for a geographic area as being representative of the minimally impaired reference condition. Nutrient criteria for median nitrate, total nitrogen, and total phosphorus concentrations provided by the USEPA for the Ozark Highland ecoregion (table 2) were less than the 25th percentiles of median concentrations calculated for this report (table 5). The USEPA criteria for the Ouachita Mountains ecoregion (table 2) for nitrate and total nitrogen were similar to the 25th percentiles of median concentrations calculated for this report (table 6). The 25th percentiles of median total phosphorus concentrations calculated for this report were similar to those reported by the USEPA for the Ouachita Mountains ecoregion.

The 75th percentiles of median nitrate and total phosphorus concentrations in geographic region 4 (table 8) calculated for this report were less than the nutrient criteria currently (2002) used in the Oklahoma USAP (fig. 1). The 90th percentiles of median total phosphorus concentrations in geographic region 4 (table 8) were less than the nutrient criteria currently (2002) used in the Oklahoma USAP except for stream category SS2.

The percentile distributions of median concentrations of nitrate, total nitrogen, and total phosphorus presented in tables 5, 6,7, and 8 will facilitate the development of nutrient criteria for use in the USAP for Oklahoma. Using nutrient information collected from streams in Oklahoma and grouping these data by geographic regions and stream characteristics will allow nutrient criteria to be established that represent local water-quality conditions relevant to Oklahoma.

SUMMARY

The U.S. Environmental Protection Agency has developed regional-based nutrient criteria using ecoregions to protect streams in the United States from impairment. However, nutrient criteria were based on nutrient concentrations collected in large aggregated nutrient ecoregions with little relevance to local environmental conditions in states. The Oklahoma Water Resources Board is using a dichotomous process known as Use Support Assessment Protocols to define nutrient criteria in Oklahoma streams. The Oklahoma Water Resources Board is modifying the Use Support Assessment Protocols to reflect nutrient information and environmental characteristics relevant to Oklahoma streams, while considering nutrient information grouped by geographic regions based on level III ecoregions and state boundaries.

This report provides percentile distributions of median nitrite plus nitrate as nitrogen (referred to as nitrate), total nitrogen, and total phosphorus concentrations measured in water samples collected from 1973-2001 at 563 sites in Oklahoma and 4 sites in Arkansas near the Oklahoma and Arkansas border. Sites were grouped into eight stream categories by stream slope and stream order. Percentile distributions were calculated for four geographic regions in Oklahoma and part of Arkansas: (1) water-quality sites in the Ozark Highland ecoregion; (2) water-quality sites in the Ouachita Mountains ecoregion; (3) water-quality sites excluding those in the Ozark Highland and Ouachita Mountains ecoregions; and (4) all water-quality sites in Oklahoma and part of Arkansas.

The 50th percentiles of median nitrate, total nitrogen, and total phosphorus concentrations were greatest in the Ozark Highland ecoregion and least in the Ouachita Mountains ecoregion compared to the other geographic regions. The 50th percentiles of median concentrations of nitrate, total nitrogen, and total phosphorus generally were less in first, second, and third order streams (SS1 and SS2). The 50th percentiles of median total nitrogen, and total phosphorus concentrations in the Ozark Highland and Ouachita Mountains ecoregions in first, second, and third order streams with stream slopes greater than 17 feet per mile (SS1) were less than streams with stream slopes less than or equal to 17 feet per mile (SS2).

Nutrient criteria reported by the U.S. Environmental Protection Agency for the Ozark Highland ecoregion were lower than the 25th percentiles of median nitrate, total nitrogen, and total phosphorus concentrations calculated for this report. Nitrate and total nitrogen criteria developed by the U.S. Environmental Protection Agency for the Ouachita Mountains ecoregion were similar to the 25th percentiles of median values for the Ouachita Mountains ecoregion calculated for this report. The 75th percentiles of median nitrate and total phosphorus concentrations in geographic region 4 were less than the nutrient criteria currently (2002) used in the Oklahoma Use Support Assessment Protocols. The 90th percentiles of median total phosphorus concentrations in geographic region 4 were less than the nutrient criteria currently (2002) used in the Oklahoma Use Support Assessment Protocols except for stream category SS2.

The percentile distributions of median nitrate, total nitrogen, and total phosphorus concentrations calculated in this report will facilitate the development of nutrient criteria that can be used to modify the Use Support Assessment Protocols for Oklahoma. By using nutrient information collected in Oklahoma streams and grouping nutrient data by local geographic regions and stream characteristics will facilitate nutrient criteria that represents water-quality conditions in Oklahoma.

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APPENDIX

Nutrients and Stream Impairment

Establishing nutrient concentrations for potentially impaired streams has been a slower process compared to lakes (Welch and others, 1989; Dodds and others, 1997; Dodds and others 1998; Robertson and others, 2001). Eutrophic nutrient concentrations in lakes have been defined by relations between algal biomass or indirect biomass assessment by chlorophyll-*a* concentrations and the limiting nutrient (nitrogen or phosphorus) of the aquatic system (Carlson, 1977; Kratzner and Brezonik, 1981). Similar to lakes or lentic systems, the aesthetic, ecological, and economic value of streams or lotic systems is often impaired by excessive nutrient concentrations and algal growth. Excessive algal growth impedes boat traffic, obstructs fishing, and creates unsightly and malodorous masses (Caffrey, 2002). Welch and others (1989) report that nuisance (peak) algal biomass can be present in streams when benthic chlorophyll-*a* concentrations exceed 100 to 150 milligrams of chlorophyll-*a* per meter squared (10-15 micrograms per centimeter squared). Few studies have established water column nutrient concentrations characterizing excessive algal growth and eutrophic or potentially impaired stream ecosystems.

Nutrient and algal concentrations generally are the basis of trophic state classification in lakes and reservoirs (Carlson, 1977; Kratzner and Brezonik, 1981). Correlation between nutrient concentrations and algal productivity (chlorophyll) is expected and significant in lakes and reservoirs (Dillon and Rigler, 1974; Canfield and Bachman, 1981). However, the correlation between nutrient concentrations and chlorophyll is more variable in streams, because of the effects of floods, water velocity, turbidity, grazing, shading, and catchment area among other factors (Biggs, 1996; 2000; Delong and Brusven, 1992; Dodds, 1991; Lohman and Jones, 1999; Lohman and others, 1992; Jones and others, 1984; Van Nieuwenhuyse and Jones, 1996; and Winterbourn and others, 1992). Physical factors not only affect chlorophyll concentrations, but also shift the taxonomy of algal species in streams (Carpenter and Waite, 2000). Thus, deriving chlorophyll concentrations, based on stream nutrient concentrations has a higher degree of uncertainty compared to the predictions made for lakes and reservoirs.

Increasing nutrient concentrations in streams generally produce increased chlorophyll concentrations and algal production in the water column and in the stream-bottom environment. Stream algae respond to the addition of nutrients as commonly observed in nutrient limitation experiments using *in situ* artificial substrata and nutrient enrichment (Chessman and others, 1992; Lohman and others, 1992; Matlock and others, 1999a). The uptake kinetics of algae also indicates that algal production is stimulated by enrichment of nutrients; however, the concentrations at which algal cellular growth is saturated are quite low. For example, Bothwell (1985) reported that diatom saturation occurred at dissolved phosphorus concentration less than 5 micrograms per liter. Horner and others (1983) reported that an average dissolved phosphorus concentration of 15-25 micrograms per liter provided apparent saturation for chlorophyll accrual. However, a dissolved phosphorus concentration of 50 micrograms per liter was needed to achieve maximum biomass accrual (Bothwell, 1989). These concentrations are typical of many streams, especially in Oklahoma, yet nuisance biomass accrual is limited by disturbance factors such as flooding and grazing.

Where disturbances inhibit the production of nuisance algal growth, conditions can favor the development of excessive algal biomass; the summer season may be the most likely period of sustained algal growth because fewer episodic flood events occur. Management of stream nutrient concentrations and algae require the ability to predict the occurrence of nuisance algae. Biggs (1995) reported the following range in chlorophyll values for streams: 1) 0.5-3 milligrams of chlorophyll-*a* per meter squared (0.05-0.3 micrograms per centimeter squared) for unenriched, forested streams, 2) 3-60 milligrams of chlorophyll-*a* per meter squared (0.3-6 microgram per centimeter squared) for moderately enriched stream draining catchments with moderate agricultural land use, and 3) 25-260 milligrams of chlorophyll-*a* per meter squared (2.5-26 micrograms per centimeter squared) for highly enriched streams draining catchments with highly developed agricultural land use, and underlain by nutrient-rich bedrock. Welch and others (1988) reported that nuisance algal biomass might be present in streams when benthic chlorophyll-*a* concentrations exceed 100-150 milligrams of chlorophyll-*a* per meter squared (10-15 micrograms per centimeter squared). Below these measurements, the proportion of filamentous periphytic coverage was less than 20 percent. Nuisance levels of algal biomass affect the beneficial use of stream systems. Biggs (1985) summarized water-quality problems associated with nuisance biomass accrual. For example, high biomass accrual may impair water withdrawals for irrigation and municipal water supply. The large amount of autochthonous algal production also may contribute to oxygen demand and produce substantial diurnal variations in dissolved oxygen concentrations resulting in fish kills; similar diurnal variations in pH also are observed. Increased coverage of filamentous species further alters ecosystems by changing the habitat and macro invertebrate community structure.

Nuisance production of algal biomass represents a management issue for streams, an unacceptable degree of eutrophication. Simple statistical models have predicted algal biomass as a function of dissolved nutrient concentrations, total nutrient concentrations, flooding frequency (days of biomass accrual), water velocity, and temperature (Welch and others, 1989, 1992; Dodds and others, 1997; Winter and Duthie, 2000). Statistical models were improved after seasonal variation was removed using mean water chemistry and chlorophyll concentrations (Winter and Duthie, 2000); statistical models also more closely predicted maximum chlorophyll concentrations (Biggs, 2000). Statistical models using total nutrient concentrations can perform better than those using dissolved nutrients (Dodds and others, 1997) because dissolved nutrient concentrations are determined by the balance between uptake and regeneration, similar to lakes. Dodds and others (1997) reported that using dissolved nutrient concentrations as predictors of chlorophyll concentrations is unwarranted without site-specific models for uptake and regeneration. However, Biggs (2000) and Welch and others (1992) have shown significant correlation between dissolved nutrient concentrations and chlorophyll concentrations.

Other statistical models relate total nutrient concentrations, catchment area, and land use to sestonic chlorophyll concentrations (Lohman and Jones, 1999; Jones and others, 1984; Van Nieuwenhuyse and Jones, 1996); the sestonic algae were assumed to result from sloughing of periphytic algae. These reports indicate that sestonic chlorophyll is related to total nutrient concentrations, but also may vary with some physical factors, similar to benthic chlorophyll concentrations. Sestonic chlorophyll concentrations in Iowa streams averaged 55 milligrams of chlorophyll-*a* per meters cubed (55 micrograms per liter) whereas benthic chlorophyll concentrations averaged 160 milligrams of chlorophyll-*a* per meter squared (16 micrograms per centimeter squared) (Swanson and Bachman, 1976). These averages were 2 to 10 times greater than those observed in Missouri Ozark streams (Jones and others, 1984). Because of the complexity and variability involved in measuring benthic chlorophyll concentrations, measurements of sestonic chlorophyll may be an easier method to monitor the occurrence of nuisance biomass accrual provided some relation between sestonic and benthic chlorophyll concentrations exist.

Statistical models developed between total nutrient concentrations and chlorophyll concentrations have been used to estimate total nutrient concentrations relating to nuisance biomass accrual (Dodds and others, 1997), where streams with total nutrient concentrations greater than those required to limit nuisance biomass accrual may represent eutrophic conditions. Dodds and others (1997) used a second complementary approach identifying reference portions or stream reaches where mean and maximum chlorophyll does not exceed desirable levels. The two techniques used produced similar results for the Clark Fork River in Montana. Maintaining mean total nitrogen and total phosphorus below 350 micrograms per liter and 30 micrograms per liter will result in mean chlorophyll concentrations less than 100 milligrams of chlorophyll-*a* per meter squared (10 micrograms per centimeter squared) (Dodds and others, 1997).

Statistical models have been developed relating total nutrient concentrations and sestonic chlorophyll concentrations. Van Nieuwenhuyse and Jones (1996) confirmed a positive relation between sestonic chlorophyll concentrations and total phosphorus concentrations; the standard error of regression for this stream model was within the range reported in large-scale lake models. The U.S. Environmental Protection Agency (2000a) reported a sestonic chlorophyll concentration of 8 micrograms of chlorophyll-*a* per liter as the mesoeutrophic-eutrophic boundary based on this investigation. This sestonic chlorophyll concentration corresponded to a total phosphorus concentration of 42 micrograms per liter; the Redfield ratio (Smith and others, 1997) was used to estimate the total nitrogen concentration of 300 micrograms per liter. The source of sestonic chlorophyll concentrations is from the proliferation of stream phytoplankton or pseudo-phytoplankton; the source of pseudo-phytoplankton could be sloughing of benthic algae.

An alternative approach to identifying eutrophic streams is to use cumulative distributions of total nutrient and chlorophyll concentrations (Dodds and others, 1998; U.S. Environmental Protection Agency, 2000a); it was suggested that the upper third of the distribution be considered eutrophic. The cumulative distribution of trophic state-related variables collected in temperate streams of North America and New Zealand (Dodds and others, 1997; Van Nieuwenhuyse and Jones, 1996; Omernik, 1977) were used to compute the oligotrophic, mesotrophic and eutrophic boundaries (U.S. Environmental Protection Agency, 2000a). The oligotrophic-mesotrophic boundary for mean benthic chlorophyll, maximum benthic chlorophyll, sestonic chlorophyll, total nitrogen, and total phosphorus are 20 milligrams of chlorophyll-*a* per meter squared (2 micrograms per centimeter squared), 60 milligrams of chlorophyll-*a* per meter squared (6 micrograms per centimeter squared), 10 micrograms of chlorophyll-*a* per liter, 700 micrograms of total nitrogen per liter, and 25 micrograms of total phosphorus per liter. The mesotrophic-eutrophic boundary for mean benthic chlorophyll, maximum benthic chlorophyll, sestonic chlorophyll, total nitrogen, and total phosphorus was 70 milligrams of chlorophyll-*a* per meter squared (7 micrograms per centimeter squared), 200 milligrams of chlorophyll-*a* per meter squared (20 micrograms per centimeter squared), 30 micrograms of chlorophyll-*a* per liter, 1,500 micrograms per liter, and 75 micrograms per liter. Streams with trophic state-related variables with concentrations greater than the mesotrophic-eutrophic boundary may represent eutrophic systems. These data were compiled from different sources; the data source used for the cumulative distribution of total nitrogen and total phosphorus concentrations was different than the data source used for the benthic and sestonic chlorophyll concentrations. These boundaries were used to provide a source of comparison when developing nutrient criteria.

Another approach uses the ratio of periphytic growth on artificial substrate with and without nutrient enrichment (Matlock and others, 1999a; 1999b); this method is referred to as the Lotic Ecosystem Trophic Status Index (LETSI). LETSI is simply the ratio of periphytic growth (chlorophyll-*a* concentration) on the control artificial substrate to periphytic growth (chlorophyll-*a* concentration) on a nutrient enriched artificial substrate; thus, LETSI theoretically ranges from 0 to 1. A LETSI of 1 indicates that a stream exceeds the nutrient assimilative capacity of the stream biota or a factor other than nutrients is limiting periphytic growth. Therefore, the stream has reduced nutrient retention efficiency, and nutrients are transported downstream without substantial biotic uptake. Thus, a long nutrient uptake length (Stream Solute Workshop, 1990) would be expected in streams with a LETSI approaching 1. LETSI has been used to define eutrophic conditions in tributaries of the Illinois River in northeastern Oklahoma (Matlock and others, 1999a) and for the Bosque River in central Texas (Matlock and others, 1999b), LETSI was used in the Bosque River to determine a potential criterion for phosphorus in the streams draining the Lake Waco watershed (Kiesling and others, 2001); this study assumed a LETSI of 0.5 represented the boundary between mesotrophic and eutrophic conditions. A dissolved phosphorus concentration of about 40 micrograms per liter was the phosphorus target using an asymptotic relation between LETSI and dissolved phosphorus concentration in the water column of these streams (Kiesling and others, 2001). As with any measure of periphytic growth (especially on artificial substrate), there are many sources of variability to be recognized and addressed when using the LETSI method (Matlock and others, 1999a)