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Stream Nutrient Criteria for Evaluating Water Eutrophication and Biota Conditions

Mingxin Guo*

Department of Agriculture and Natural Resources, Delaware State University, Dover, DE 19901, USA

Water flew vividly over stones in a wadablestream, singing and winding through mountains toward east. Small fishes swam in water pools enjoying the penetrating sunlight. Several turtles were getting sun on rocks along the banks. A mother crab and a school of baby crabs ran in panic after a random stone in the stream was turned over. This was a typical scene in China before 1980. Now turtles and crabs have disappeared from most streams, and fishes become scarce. The wide use of chemical fertilizers and pesticides in China's agriculture since the beginning of 1980s has resulted in severe contamination of the natural water system, extinguishing many sensitive aquatic organisms. Synthetic fertilizers containing 29.5 million tons of N and 6.1 million tons of P were applied to China's cropland in 2010, as compared with the 1980 level at 9.1 million tons of N and 1.2 million tons of P [1]. It was estimated that 6.8 and 0.41 million tons of N and P, respectively, were lost in from cropland to China's surface water and groundwater via runoff, leaching, and soil erosion in 2010 [1]. Counting other nutrient sources in the food chain (e.g., livestock, household, and food processing), in 2010 China's freshwater system received in total 15.2 and 2.8 million tons of N and P, respectively [1].

Elevated N, P, fine particulates, and toxic chemicals are the main stressors affecting freshwater ecosystems [2]. Excess nutrients in water lead to eutrophication, whereby growth of Cyanobacteria (blue-green algae), algae and other nuisance plants weeds is significantly stimulated. This enhanced plant growth, often called algal blooms, reduces dissolved oxygen in the water when dead plant material decomposes and can cause other organisms to die. Many native fish species may disappear and be replaced by species more resistant to the new conditions [3]. Total phosphorus (TP) concentrations of non polluted natural waters are mostly within 10-50 μgL^{-1} over a range of <1 to >200 μgL^{-1} [3]. A stream is viewed as "eutrophic" if the concentration of TP in water is greater than 100μgL^{-1} [4]. As a matter of fact, 40% of the U.S. fresh water streams are impaired by eutrophication and demonstrate poor biological conditions, unsuitable for swimming or fishing [5]. Non-point sources of nutrients and contaminants in runoff from agricultural land, city streets, and residential lawns are responsible for the water quality degradation. The Clean Water Act was enacted in 1972 to control pollution of rivers, lakes, and wetlands in the U.S. by eliminating discharge of contaminants from point sources (e.g., industrial facilities, wastewater treatment plants, and animal feedlots). In 1998, Clean Water Action Plan was implemented to authorize states to develop numeric criteria for N and P nutrients in water bodies and to promote farmers and other landowners to adopt practices that reduce runoff losses of nutrients from nonpoint sources (farms, highways, streets, etc.). Each state or tribe was expected to establish stream nutrient criteria for protecting and restoring natural waters [6].

Stream nutrient criteria are essential for assessing water quality status, aiding in management efforts, and evaluating the effectiveness of water protection practices. Considering the uniqueness in hydro geological, ecological, and anthropogenic characteristics of different areas and states, the stream nutrient criteria should be regionally specific and locally appropriate. USEPA proposed fourteen aggregate ecoregionsof the conterminous U.S. for the National Nutrient Assessment and Management Strategy (Figure 1), each region possessing similar ecosystems and nutrient characteristics. For each of these regions, stream nutrient criteria for water quality have been developed based on reference stream conditions or by relating nutrient variables to stream biological condition changes that indicate eutrophication.

Percentile analysis is commonly used to derive water quality nutrient criteria from reference stream conditions. All streams in a region would be surveyed for total nitrogen (TN), TP, suspended chlorophyll *a* (chl-*a*), and turbidity levels. Frequency distribution of the data would be analyzed to determine the 75th percentile of uncontaminated (with minimal human impacts) streams or the 25th percentile of all surveyed streams as the reference streams [7]. The two statistical measures are nearly identical and often the 25th percentile is slightly more conservative than the 75th percentile [7]. Based on percentile analysis, the USEPA suggested TN, TP, chl-a, and turbidity criteria for different eco-region streams [8]. As in many eco-regions unpolluted streams were difficult to identify, the 25th percentile of all streams within each region was treated as the reference condition. A number of studies were later conducted by scientists using a similar approach and the results were largely consistent with the criteria suggested by USEPA (Tables 1 and 2).

Another approach for establishing stream nutrient criteria is to analyze the predictive relationships between nutrient variables and responsible variables (biota conditions) by regression. The biota conditions (e.g., algal biomass, benthic diatoms, macro invertebrates, fish community) of a stream often respond rapidly to a small change in water nutrients (e.g., TN, TP, chl-*a*, turbidity). The threshold nutrient level at which the rapid change of biota conditions occurs is identified as the criteria concentration [9]. Statistical methods used for identifying the thresholds include piecewise regression, cumulative frequency distribution analysis, nonlinear curve fitting, nonparametric change point analysis, quartile regression, recursive partitioning, and regime shift detection, significant zero crossings, threshold indicator taxa analysis, and two-dimensional Kolmogorov-Smirnov test [8]. Stream nutrient criteria determined by studies using predictive relationship analysis are given in Table 3. In general, the suspended chl-*a* concentration of a stream shows a positive curvilinear relationship with the water TP level [10], varying with light availability, catchment area,

***Corresponding author:** Mingxin Guo, Department of Agriculture and Natural Resources, Delaware State University, Dover, DE 19901, USA, Tel: 1-302-857-6479; Fax: 1-302-857-6455; E-mail: mguo@desu.edu

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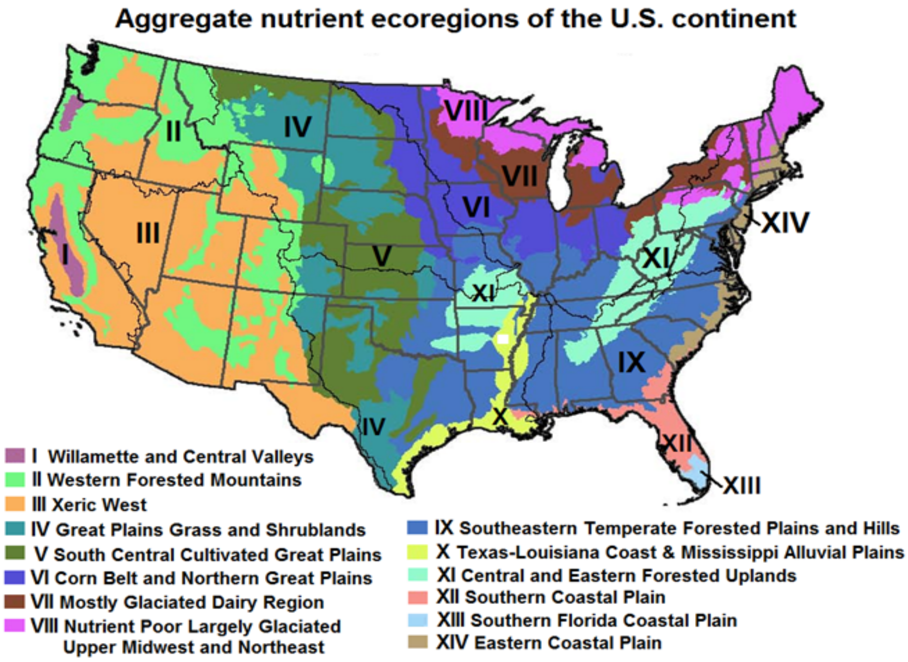

Figure 1: Aggregations of Level III eco-regions of the U.S. continent for the national nutrient strategy.

Ecoregion	Total nitrogen, mg L^{-1}			Total phosphorus, µg L^{-1}		
	USEPA suggested	25th percentiles	75th percentiles	USEPA suggested	25th percentiles	75th percentiles
I	0.31	-	0.18-0.21	47	-	20
II	0.12	0.07-0.08	0.13-0.21	10	3-13	9-20
III	0.38	0.78	0.05-0.29	22	10	30-40
IV	0.56	0.44-0.61	0.12-1.30	23	19-20	70-170
V	0.88	0.60-0.99	0.37-1.19	67	20-70	70-140
VI	2.18	1.86	0.44-2.50	76	66-70	60-181
VII	0.54	0.48-1.56	0.17-0.33	33	17-60	30
VIII	0.38	0.27-0.40	0.18-0.39	10	7-24	10-20
IX	0.69	0.33-2.01	0.17-0.68	37	20-90	50-60
X	0.76	0.92	0.55-0.67	128	147	60
XI	0.31	0.16-0.29	0.17-0.38	10	4-20	18-20
XII	0.90	-	0.61-0.71	40	-	30
XIII	-	-	0.65-0.79	-	-	40
XIV	0.71	0.62-1.85	0.63-0.76	31	23-82	20

Table 1: Stream total nitrogen and total phosphorus criteria suggested by USEPA for the fourteen aggregate eco regions [8] and the 25th and 75th percentiles reported in the literature [7].

Ecoregion	Suspended chlorophyll *a*, mg L^{-1}		Turbidity, FTU	
	USEPA suggested	25th percentiles	USEPA suggested	25th percentiles
I	1.80	-	4.25	-
II	1.08	-	1.30†	-
III	1.78	-	2.34	-
IV	2.40	1.52	4.21	-
V	3.00	6.78	7.83	-
VI	2.70	-	6.36	-
VII	1.50	-	1.70†	1.70-2.70†
VIII	0.63	-	1.30	1.40†
IX	0.93	3.47-3.76	5.70	4.00†
X	2.10	0.75-4.35	17.50	-
XI	1.61	-	2.30†	1.60†
XII	0.40	-	1.90†	-
XIII	-	-	-	-
XIV	3.75	4.00	3.04	4.50†

† turbidity in NTU

Table 2: Stream suspended chlorophyll *a* and turbidity criteria suggested by USEPA for the fourteen aggregate eco-regions [8] and the25th percentiles reported in the literature [7].

Biological condition	Total nitrogen, mg L^{-1}	Total phosphorus, μg L^{-1}
Suspended chlorophyll *a*	0.172–0.765	6-119
Benthic algal biomass	0.367-0.918	27-62
Benthic diatom index	0.872-1.169	11-74
Benthic macroinvertebrates	0.63-1.92	40-150
Stream fish	0.54-1.83	60-139

Table 3: Literature reported stream total nitrogen and total phosphorus thresholds determined by predictive relationship threshold analyses of various biological response variables [7].

and hydrology [8]. Benthic algal community composition (e.g., diatom taxa, evenness, and the number of high P taxa) is also positively related to the stream TN and TP concentrations [11]. The biological traits and species composition of macro invertebrates and fishes in a stream is linked to the water quality. In environmentally relevant concentration ranges, total macro invertebrate taxa richness and salmonid abundance as well as the carnivore percentage of fish are negatively related to stream TN and TP, while the omnivore percentage of fish is positively related [12].

The nutrient criteria estimated by predictive relationships (Table 3) are slightly higher in numeric value than those derived from percentile analysis (Table 1). This is reasonable, as "Fish cannot survive in extremely clean water" (a Chinese proverb). It is noteworthy that development of watershed-specific stream nutrient criteria involves tremendous research efforts from local governments and the scientific community. To protect water quality and conserve aquatic ecosystems, the TN of location-regardless streams should be maintained below 2.0 mg L^{-1} and TP below 0.15 mg L^{-1}. Best management practices such as proper land use, agronomic fertilization, cover crop planting, appropriate manure handling, storm water bio-retention treatment, and corridor buffer strips can be extensively installed to reach the goal.

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