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Assessment of Chlorophyll-*a* and Phosphorus in New Hampshire Lakes for Nutrient Criteria Development

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Introduction

The New Hampshire Department of Environmental Services is responsible for developing nutrient water quality criteria for lakes, impoundments, rivers and estuaries in New Hampshire. In 2005, DES completed an analysis of existing data in the Environmental Monitoring Database for lakes and impoundments (Trowbridge, 2005). This analysis determined that the phosphorus concentration associated with typical chlorophyll-a impairments in lakes was approximately 20 ug/L. These results were considered preliminary pending additional analysis. Specifically, it was recommended that the analysis be repeated after the University of New Hampshire Lay Lakes Monitoring Program data had been imported to the Environmental Monitoring Database. In addition, it was recommended that the analysis be repeated using the actual impairment determinations for chlorophyll-a from New Hampshire's Section 303(d) list.

In 2008, DES repeated the analysis of chlorophyll-a and phosphorus data in the Environmental Monitoring Database for lakes. Data from the UNH Lay Lakes Monitoring Program were included in this dataset. The methods used for the analysis were similar to those used in the 2005 assessment except that: (1) impairment determinations were assigned based on the Draft 2008 Section 303(d) list; (2) a reference concentration approach was used to identify targets for criteria for different trophic levels; (3) the analysis of covariate factors was not repeated; and (4) riverine impoundments were not evaluated. The objective of this analysis was to more accurately determine the median phosphorus concentration for which chlorophyll-a impairments

occur in New Hampshire lakes. For a lake to be considered impaired for chlorophyll-a, more than ten percent of summer samples must have concentrations greater than 15 ug/L, which impairs the swimming designated use.

Methods

All valid results for total phosphorus or chlorophyll-a (uncorrected for pheophytin) from lake or pond stations between January 1, 1975 and December 31, 2007 were queried from the Environmental Monitoring Database. A total of 26,368 chlorophyll-a results and 29,095 results for total phosphorus were returned. The majority of the results (25,961 chlorophyll-a, 28,680 for phosphorus) were collected by the DES Volunteer Lake Assessment Program, DES Lake Trophic Surveys, or the UNH Lay Lakes Monitoring Program. Additional data were contributed from water quality assessments of specific lakes. A small number of results for either chlorophyll-a or phosphorus (211 total) from beach monitoring, complaint investigation, and river assessments were deleted from the dataset because they were not representative of typical conditions in lakes.

Independent samples from the epilimnion of lakes during the summer season were selected from the dataset. Samples collected for quality control purposes (e.g., field duplicate samples) and readings from *in-situ* probes were excluded. Only results from June, July, August, and September were included. Data from impoundments were removed by requiring the assessment unit for the waterbody to contain "LAK" as the third, fourth, and fifth characters. Surface results were selected by requiring that the depth

zone be characterized as either "epilimnion," "upper," or "composite," or if the depth zone was blank, for the depth of the sample to be less than or equal to 2 meters. If there was more than one result for chlorophyll-a or phosphorus at the same station on the same date with the same depth zone, the two values were averaged. In most cases, these values were identical because it was the same result applied to two different programs, e.g., VLAP and Lake Trophic Surveys. If there was a "composite" sample, that value was preferentially selected over other values to represent a station visit. There was a slight difference in the DES and UNH methods for collecting a composite sample in thermally stratified lakes. DES composite samples include the epiliminion and half of the metalimnion, while UNH composite samples only cover the epilimnion. Often algae will accumulate at the thermocline in the metalimnion so a composite sample collected using the DES methods will generally have the higher chlorophyll-a value than if the UNH methods had been used. After these filters were applied to the data, there were 23,720 results for chlorophyll-a and 12,468 results for phosphorus for the analysis. More than half of the phosphorus results were excluded by these filters. The majority of the phosphorus results were excluded because they were taken from the hypolimnion or metalimnion.

Lakes with insufficient sample size were excluded from the database. Lakes with fewer than five results for chlorophyll-a or fewer than five results for phosphorus were identified. Data for these lakes was removed from the dataset. Five or more results for both parameters were available for 233 lakes. Twenty-six of the lakes were listed as impaired for chlorophyll-a in the draft Section 303(d) list for New Hampshire in 2008.

The final dataset for the analysis contained 22,234 results for chlorophyll-a and 11,657 results for phosphorus.

Median values of chlorophyll-a and phosphorus in each lake were calculated. For results reported as less than the method detection level, a value of one-half the method detection limit was substituted for the median calculations. Medians were selected as the statistic to represent central tendency water quality conditions in each lake.

The relationship between the median values of chlorophyll-a and phosphorus in each lake was determined through linear regression. The median values for both parameters were log-transformed to satisfy conditions of homoscedasticity. In a previous analysis in 2005, it was determined that the linear relationship between log(chlorophyll-a) and log(phosphorus) was the best representation of the data (Trowbridge, 2005).

Several options for criteria for median chlorophyll-a and phosphorus concentrations in lakes were established using the reference concentration approach and the cumulative distribution functions for impaired and unimpaired lakes.

Results

Median values for chlorophyll-a and phosphorus were calculated for 233 lake assessment units in New Hampshire. Twenty-six of the lakes were on the New Hampshire Section

303(d) list for chlorophyll-a impairments. The study lakes encompassed more than one-fourth of all of the 886 lakes in New Hampshire.

The study lakes were distributed evenly across the Level III ecoregions that cover New Hampshire. For all New Hampshire lakes, approximately 20 percent of the waterbodies are in the Northeastern Coastal Zone ecoregion and the rest are in the Northeastern Highlands ecoregion. For the study lakes, 25 percent of the lakes were in the Northeastern Coastal Zone ecoregion and the remaining 75 percent of lakes were in the Northeastern Highlands ecoregion.

With respect to lake morphology, the distribution of study lakes did not match the distribution of all lakes. Table 1 shows the summary statistics for lake morphology parameters for the study lakes and for all lakes in New Hampshire. Relative to all lakes, the study lakes tended to have lower elevations, greater depths, larger surface areas, larger watersheds, larger volumes, and be flushed less often. The difference between the study lakes and all lakes is probably the result of concentrated sampling on lakes of interest to shoreland property owners through the DES Volunteer Lake Assessment Program and the UNH Lay Lakes Monitoring Program.

Table 1: Summary statistics for lake morphology parameters

Parameter	Population	N	Minimum	25th Pct	Median	75th Pct	Maximum
Elevation (ft)	Study Lakes	228	95	416	623	1,058	1,603
	All Lakes	815	4	475	818	1,230	3,790
Mean Depth (m)	Study Lakes	224	0.4	2.4	3.5	5.5	22.5
	All Lakes	731	0.1	1.5	2.7	3.9	22.5

Surface Area (ha)	Study Lakes	228	2.2	21.2	54.9	109.9	18,043
	All Lakes	851	0.4	6.1	13.7	40.0	18,043
Watershed Area (ha)	Study Lakes	227	19	323	907	2,877	284,268
	All Lakes	747	4	121	374	1,505	874,300
Volume (10^6 m3)	Study Lakes	223	0.013	0.70	2.13	4.61	2,376
	All Lakes	727	0.003	0.12	0.38	1.68	2,376
Flushing Rate (1/yr)	Study Lakes	223	0.2	1.0	2.1	5.3	353.0
	All Lakes	719	0.1	1.5	3.8	14.5	965.0

The trophic status of the study lakes was compared to all lakes in New Hampshire (Table 2). The proportion of lakes that were mesotrophic was identical for the study lakes and all lakes populations (52%). There was a higher proportion of oligotrophic lakes in the study lakes population (34%) than for all lakes (26%). Eutrophic lakes were under-represented in the study lakes population compared to all lakes in New Hampshire. The difference between the study lakes and all lakes is likely a reflection of concentrated sampling in more pristine lakes due to shoreland property owner interest.

Table 2: Lake trophic classification for study lakes

Trophic Status	Study Lakes	All Lakes
Oligotrophic	79 (34%)	203 (26%)
Mesotrophic	122 (52%)	412 (52%)
Eutrophic	26 (11%)	180 (23%)
NA	6 (3%)	0
Total	233	795

Chlorophyll-a and phosphorus concentrations in the study lakes covered a wide range of values. For the 233 study lakes, the median of the individual lake medians for chlorophyll-a was 3.7 ug/L. In impaired lakes, the median chlorophyll-a value rose to 10.5 ug/L. Similarly, the median value for phosphorus in all lakes was 9.1 ug/L, but was 26.5 ug/L in impaired lakes. The summary statistics for water quality parameters in

individual lakes are shown in Table 3. Figures 1 and 2 show the cumulative distribution of median values for chlorophyll-a and phosphorus in study lakes. In these figures, the lakes that are impaired for chlorophyll-a are distinguished from unimpaired lakes to illustrate where impairments occur within the distribution.

Table 3: Summary statistics for summer, epilimnetic water quality in study lakes

Parameter	Population	N	Mini-mum	25th Pct	Median	75th Pct	Maxi-mum
Chlorophyll-a (ug/L)	Impaired Lakes	26	3.9	8.2	10.5	13.9	59.0
	Unimpaired Lakes	207	1.0	2.4	3.5	4.8	13.9
	Total	233	1.0	2.5	3.7	5.2	59.0
Phosphorus (ug P/L)	Impaired Lakes	26	8.0	15.3	26.5	30.8	81.0
	Unimpaired Lakes	207	2.9	7.0	9.0	11.0	27.5
	Total	233	2.9	7.0	9.1	12.5	81.0

Note: The values in this table represent the distribution of median values from individual lakes. Impaired lakes are lakes that do not support the swimming designated use due to elevated chlorophyll-a concentrations.

Median chlorophyll-a concentrations in lakes were found to be correlated with median phosphorus concentrations. Both chlorophyll-a and phosphorus values were log-transformed to remove heteroscedasticity. Figure 3 shows the linear relationship (r^2 = 0.60, standard error 0.169) between these two parameters. The equation and r^2 found in this analysis are almost identical to the relationship from DES' assessment in 2005 (Trowbridge, 2005).

Lake morphology parameters were added to the linear regression in an attempt to improve the relationship. The morphology parameters of surface area, mean depth, volume, watershed area, and flushing time were auto correlated ($0.31<|r|<0.96$ for log-transformed values). Therefore, mean depth and elevation were chosen as the independent morphology parameters for the multivariate regression. Mean depth was log-transformed to conform to normality requirements for regression. Step-wise regression was performed with both forward and backward elimination. In both cases, the lake morphology parameters were not statistically significant at the 0.05 level.

The regression was completed for lakes within each of the Level III ecoregions to determine if grouping lakes by ecoregion would improve the relationship. For the 59 lakes in the Northeastern Coastal Plain ecoregion, the linear relationship had a r^2 value of 0.50 and a standard error of 0.22, which is worse than the relationship for all the study lakes combined. For the Northeastern Highlands ecoregion, the standard error in the regression was slightly better than for the regression of all lakes (0.159 versus 0.169). The r^2 for this relationship was 0.59. This result indicates that the regression for lakes might be improved if ecoregion is considered. However, for this study, the effect of this stratification is too small to be worth developing separate nutrient criteria by ecoregion. Moreover, the relationship for the Northeastern Coastal Plain ecoregion was poor.

Potential water quality criteria for chlorophyll-a and phosphorus were developed using a reference concentration approach. EPA guidance (EPA, 2000a) recommends using the distributions of water quality parameters in reference lakes and all lakes to identify

targets for water quality criteria. The 75th percentile of concentrations in the reference lakes provides one estimate of the criteria. The 25th percentile of concentrations in all lakes is another estimate. These two values bound the range of potential criteria concentrations for a parameter. Reference lakes should have minimal human disturbance.

For this study, reference lakes were defined as lakes within the study lakes population with average specific conductance values less than 50 uS/cm. A sample size of 30 specific conductance measurements was required for reference lakes so that the central limit theorem would apply. Specific conductance is a general measure of water quality degradation due to human disturbance, e.g., road density, septic systems, and erosion (Dow and Zampella, 2000). The threshold of 50 uS/cm specific conductance was selected based on measurements in reference lakes defined by DES using land use data for another project. (These reference lakes could not be used for this study because there was insufficient chlorophyll-a and phosphorus data for all but two of them.)

Sixty-nine of the 233 study lakes met the criteria to be considered "reference lakes." Thirty of the reference lakes (43%) were oligotrophic, and 38 (55%) were mesotrophic. Only one of the reference lakes was eutrophic. None of the reference lakes was impaired for chlorophyll-a. Therefore, the reference lakes population was predominantly representative of oligitrophic and mesotrophic conditions. The 233 study lakes were assumed to be representative of all lakes in New Hampshire. However, based on comparison of morphological parameters, the lakes in this study tend to be bigger than typical lakes and ponds in New Hampshire.

Estimates of water quality criteria for chlorophyll-a and phosphorus in lakes of all trophic levels from the reference concentration approach are shown in Table 4. The values in the table refer to median values in the epilimnion of the lakes collected during the summer months. For all trophic levels combined, the 75th percentile of median chlorophyll-a values in reference lakes was 4.4 ug/L. In all lakes, the 25th percentile of median chlorophyll-a values was 2.5 ug/L. Therefore, the reference concentration approach would indicate criteria for median chlorophyll-a between 2.5 and 4.4 ug/L. The linear equation relating chlorophyll-a and phosphorus can be used to show that these criteria would correspond to median phosphorus concentrations of 6.3 to 11 ug/L. The reference concentration approach for phosphorus confirms these estimates. The 75th percentile of median phosphorus concentrations in reference lakes was 10.0 ug/L. The 25th percentile of median phosphorus concentrations in study lakes was 7.0 ug/L. Therefore, the criteria for median phosphorus in lakes should be between 7.0 and 10.0 ug/L.

Table 4: Reference concentrations for summer, epilimnetic phosphorus and chlorophyll-a concentrations for all trophic levels combined

Trophic Status	Population	N	25th Pct	Median	75th Pct
Chlorophyll-a	Study Lakes	233	2.5	3.7	5.2
(ug/L)	Reference Lakes	69	2.3	3.5	4.4
Phosphorus	Study Lakes	233	7.0	9.1	12.5
(ug/L)	Reference Lakes	69	6.1	8.0	10.0

The estimated ranges for chlorophyll-a and phosphorus developed from the reference concentration approach in this study are consistent with other reports. NEIWPCC

completed an assessment of lake water quality data in New England using a similar methodology (ENSR, 2000). The NEIWPCC report developed preliminary nutrient criteria for phosphorus in lakes in New England in the Northeastern Highlands ecoregion between 6.5 and 10.0 ug/L. EPA determined the 25th percentile phosphorus concentration in lakes in the whole Northeastern Highlands ecoregion to be 7 ug/L (EPA, 2000b). The methods for this study, the NEIWPCC study, and the EPA study were similar except the EPA estimate was based on measurements from all seasons, not just summer. The similarity of the reference concentrations developed for this study and others should be expected because the same methods were used. The concurrence of the results, therefore, is more of a validation of the methods than a confirmation of criteria values through several independent lines of evidence.

The reference concentration approach may not be the best way to develop nutrient criteria for lakes. First, defining the criteria range to be between the 25th percentile of all lakes and the 75th percentile of reference lakes is arbitrary and is not specifically related to support of designated uses. Second, the definition of "reference lakes" is critical for the outcome of the reference concentration approach. According to EPA, reference lakes "should represent the best range of minimally impacted conditions that can be expected of similar lakes within the region" (EPA, 2000a). However, the upper range of minimally impacted lakes may still be well below the level at which designated uses are impacted.

When compared to the distributions of chlorophyll-a and phosphorus in the study lakes, the criteria targets for the reference concentration approach are very low. For both

parameters, the ranges of possible criteria from the reference concentration approach approximately correspond to the 25th to 50th percentiles of the distribution of all study lakes. Therefore, between 50 and 75 percent of all lakes would be in violation of the criteria if the reference concentration approach is used. Figures 1 and 2 show that nearly all of the lakes that are impaired for chlorophyll-a occur in the upper quartiles of the distributions. Therefore, the 75th percentiles of all study lakes may be more appropriate criteria for protecting designated uses.

The 75th percentile of the distribution of all lakes is coincident with the overlap of the distributions of impaired and unimpaired lakes. The 75th percentile concentrations for phosphorus and chlorophyll-a in all study lakes were 12.5 ug/L and 5.2 ug/L, respectively. For phosphorus, 17 percent of the unimpaired lakes had higher concentrations than 12.5 ug/L and 13 percent of impaired lakes had lower concentrations. For chlorophyll-a, 19 percent of the unimpaired lakes had higher concentrations than 5.2 ug/L and 15 percent of impaired lakes had lower concentrations. Therefore, if the 75th percentile concentrations are used as criteria, the Type I and Type II errors in classifications would be approximately balanced. However, balancing the errors in this way introduces the opportunity for a small fraction of impairments to be overlooked.

There were only a handful of lakes with chlorophyll-a impairments below the 75th percentile concentrations for phosphorus and chlorophyll-a. These lakes should be investigated to understand the cause of the impairment. Three of the 26 impaired lakes had median phosphorus values below 12.5 ug/L. These three lakes were Clough Pond

(NHLAK700060202-03-01), Forest Lake (NHLAK802010401-01-01), and Tom Pond (NHLAK700030304-05). The chlorophyll-a impairments in these lakes were marginal and often driven by older data, some of which were not included in the most recent designated use assessments. The morphological characteristics of these lakes are not unusual with respect to all lakes in New Hampshire, except the elevations (383-466 ft) were in the bottom quartile of all lakes. All three of the lakes were in the Northeastern Highlands ecoregion. These lakes should be studied to determine if they are more susceptible to phosphorus than other lakes or if the impairments are due to the sampling design.

Five of the 26 impaired lakes had median chlorophyll-a concentrations below the 75th percentile concentration (5.2 ug/L): Robinson Pond (NHLAK7000061203-06-01), Flints Pond (NHLAK700040402-01), Baboosic Lake (NHLAK700060905-01-01), McQuesten Pond (NHLAK700060803-03), and Horseshoe Pond (NHLAK700061002-03). Cyanobacteria impairments were reported for Robinson Pond, Baboosic Lake, and Horseshoe Pond, which indicates atypical conditions for these lakes. The recent sampling frequencies in Flints Pond and McQuesten Pond have been one station visit per year. The data from these lakes may not be a good representation of actual conditions. All five of these lakes were in the Northeastern Coastal Zone, where the relationship between chlorophyll-a and phosphorus is poor. The elevation of these lakes (95-231 ft) was below the 25th percentile of New Hampshire lakes. These lakes should be investigated further to validate the chlorophyll-a impairments.

Another option for refining the appropriate range for criteria is to develop different reference concentrations for each trophic level. Separate reference concentrations can be calculated for oligotrophic and mesotrophic lakes. For oligotrophic lakes, the interquartile range of phosphorus concentrations was almost identical for the study lakes population (5.4 to 8.1 ug/L) and the reference lakes population (5.0 to 8.0 ug/L). The reference concentration approach for oligotrophic lakes indicates that criteria would be between 5.4 and 8.0 ug/L for phosphorus (Table 5) and 1.7 and 3.2 ug/L for chlorophyll-a (Table 6). For mesotrophic lakes, the reference concentration range is higher than for oligotrophic lakes. Criteria for mesotrophic lakes would be between 8.0 and 11.0 ug/L for phosphorus and 3.4 and 5.0 ug/L for chlorophyll-a. There were insufficient reference lakes with eutrophic classification to complete an analysis for this lake trophic level.

The number of impaired lakes in each trophic level are shown in Tables 5 and 6. None of the oligotrophic lakes were impaired for chlorophyll a. A small proportion (7%) of mesotrophic lakes had chlorophyll-a impairments. The majority of the eutrophic lakes (58%) were considered impaired. Chlorophyll-a data from lakes are evaluated uniformly regardless of trophic level. These data illustrate that the methodology for determining chlorophyll-a impairments typically detects when a lake moves from mesotrophic to eutrophic. Therefore, to maintain the high quality of oligotrophic and mesotrophic lakes, DES relies on the antidegradation regulations included in Env-Wq 1708.

If lakes were to be managed based on trophic status, threshold concentrations for phosphorus and chlorophyll-a would be needed to mark the boundaries between different

classes. The fact that the high end of the phosphorus reference range for oligotrophic lakes and the low end of the reference range for mesotrophic lakes are both 8.0 ug/L suggests that 8.0 ug/L of phosphorus represents a threshold between these two trophic classes. Similarly, the phosphorus threshold between mesotrophic and eutrophic lakes appears to be 12 ug/L because the high end for the mesotrophic reference range is 11 ug/L and the distributions of impaired and unimpaired lakes overlap at 12.5 ug/L. Following the same methods but for chlorophyll-a, the apparent threshold between oligotrophic and mesotrophic lakes would be 3.3 ug/L and the threshold between mesotrophic and eutrophic lakes would be 5.0 ug/L.

Table 5: Reference concentrations for summer, epilimnetic phosphorus concentrations for each trophic level

Trophic Status	Population	N	25th Pct	Median	75th Pct	Impair-ments
Oligotrophic	Study Lakes	79	5.4	7.0	8.1	0
	Reference Lakes	30	5.0	6.0	8.0	0
Mesotrophic	Study Lakes	122	8.0	10.0	12.5	8
	Reference Lakes	38	8.0	9.0	11.0	0
Eutrophic	Study Lakes	26	13.3	20.5	27.5	15
	Reference Lakes	1	13.0	13.0	13.0	0

Table 6: Reference concentrations for summer, epilimnetic chlorophyll-a concentrations for each trophic level

Trophic Status	Population	N	25th Pct	Median	75th Pct	Impair-ments
Oligotrophic	Study Lakes	79	1.7	2.2	3.2	0
	Reference Lakes	30	1.7	2.2	3.2	0
Mesotrophic	Study Lakes	122	3.4	4.3	5.7	8
	Reference Lakes	38	3.5	4.0	5.0	0
Eutrophic	Study Lakes	26	4.9	8.1	10.9	15
	Reference Lakes	1	4.4	4.4	4.4	0

Conclusions and Recommendations

1. This study evaluated median chlorophyll-a and phosphorus concentrations for 233 of the 886 lakes in New Hampshire (26% of all NH lakes). The previous analysis was based on median values for 168 lakes (Trowbridge, 2005).
2. The linear relationship between median chlorophyll-a and phosphorus concentrations was nearly the same as from the previous analysis. The regression from 2005 was Log(chlorophyll-a) = 0.925*Log(phosphorus) + 2.468 (r^2=0.62, SE=0.147, n=168). The regression from this analysis was Log(chlorophyll-a) = 0.944*Log(phosphorus) + 2.479 (r^2=0.60, SE=0.177, n=233). For these regressions, the units for chlorophyll-a and phosphorus were ug/L and mg/L, respectively.
3. The reference concentration approach was used to identify target ranges for chlorophyll-a and phosphorus criteria. The target range for median chlorophyll-a concentrations was 2.5 to 4.4 ug/L. The target range for median phosphorus concentrations was 7.0 to 10.0 ug/L. These results were similar to the results from other reference concentration analyses by EPA and NEIWPCC (EPA, 2000b; NEIWPCC, 2000). However, the ranges identified by the reference concentration approach were very conservative when compared to distributions of chlorophyll-a and phosphorus concentrations in New Hampshire lakes.
4. The majority of chlorophyll-a impairments occurred for lakes in the upper quartile of the distributions for chlorophyll-a and phosphorus concentrations. Therefore, the 75th percentile of the distributions may be more appropriate criteria for the maintenance of designated uses. The 75th percentile concentrations for median chlorophyll-a and

phosphorus were 5.2 ug/L and 12.5 ug/L. Using these concentrations as criteria would balance the Type I and Type II classification errors.

5. DES should investigate the handful of lakes which are impaired for chlorophyll-a but have median chlorophyll-a or phosphorus concentrations below the 75th percentile concentrations.
6. If oligotrophic lakes are evaluated separately, the reference concentration approach results in criteria ranges of 5.4 to 8.0 ug/L for phosphorus and 1.7 to 3.2 ug/L for chlorophyll-a. The criteria ranges for mesotrophic lakes were 8.0 to 11.0 ug/L for phosphorus and 3.4-5.0 ug/L for chlorophyll-a. There were not enough reference lakes in the eutrophic trophic level to calculate criteria ranges for this trophic level.
7. The relationship between chlorophyll-a and phosphorus may be improved if lakes in the two Level III ecoregions are evaluated separately. The relationship for lakes in the Northeastern Highlands ecoregion is marginally better than the relationship for all lakes combined. DES should expand the database for lakes in the Northeastern Coastal Plain ecoregion.
8. The assessment methodology for determining chlorophyll-a impairments typically detects when a lake moves from mesotrophic to eutrophic. Therefore, to maintain the high quality of oligotrophic and mesotrophic lakes, DES relies on the antidegradation regulations included in Env-Wq 1708.

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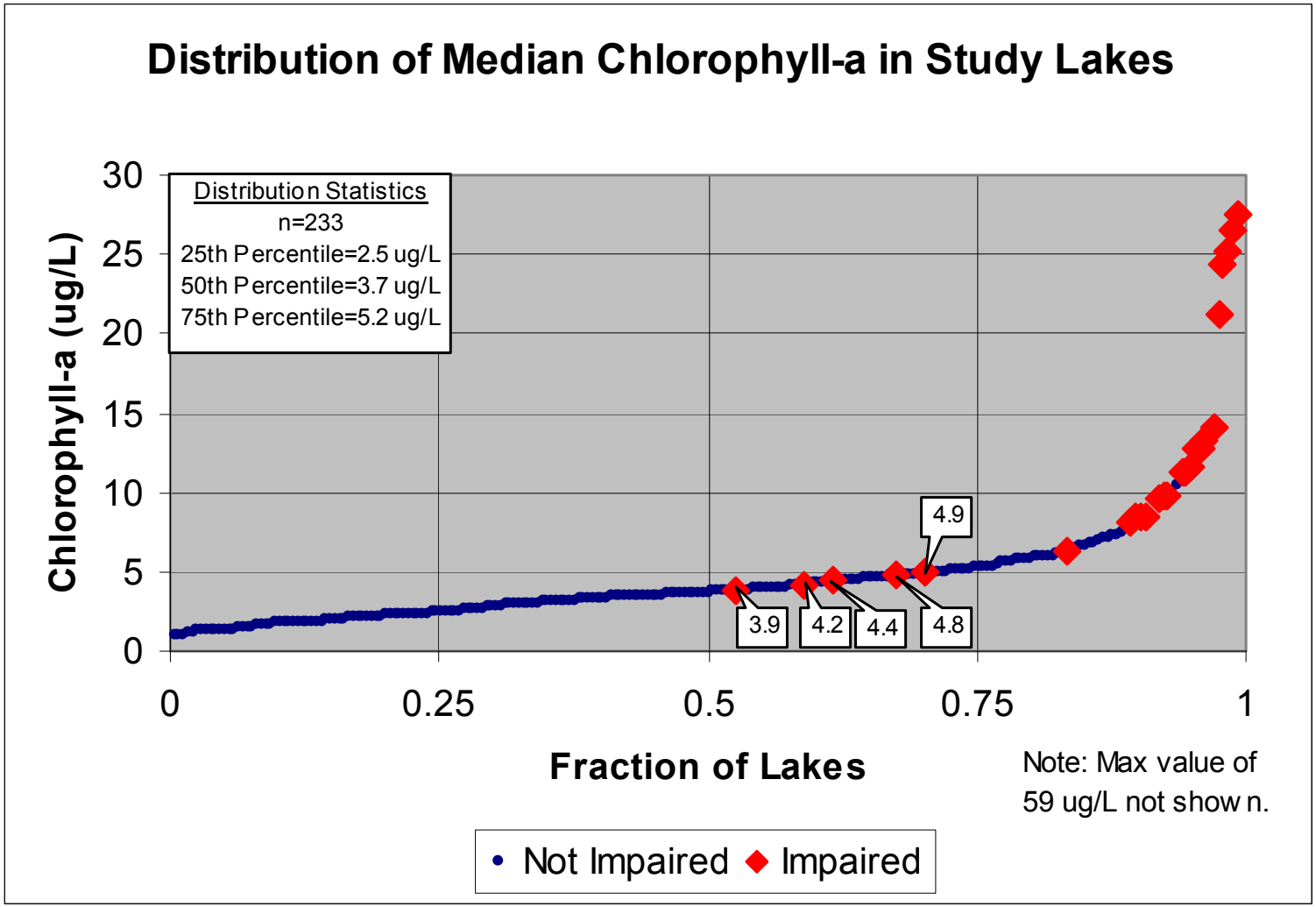
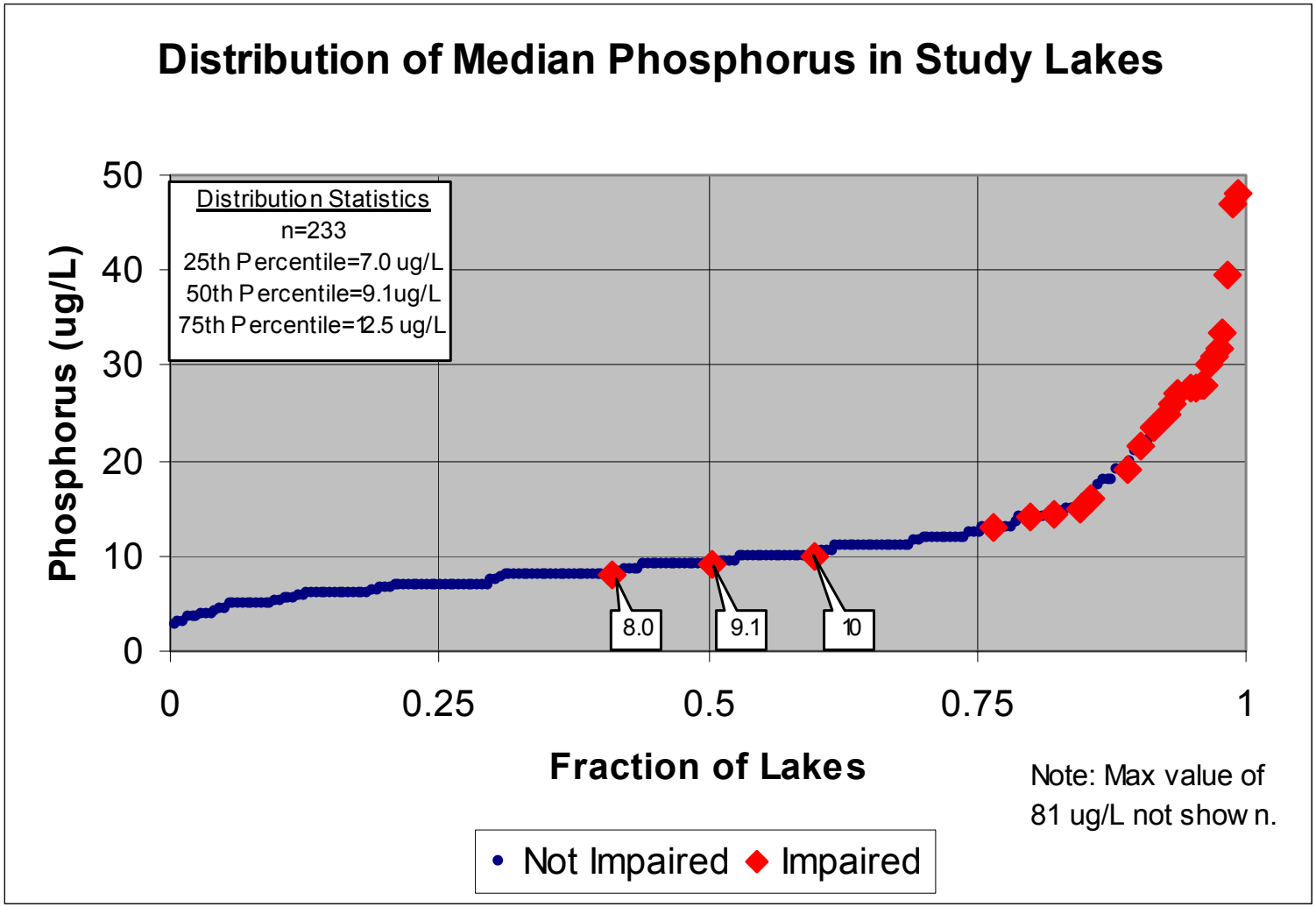
Figure 1: Distribution of median summer, epilimnetic chlorophyll-a concentrations in study lakes



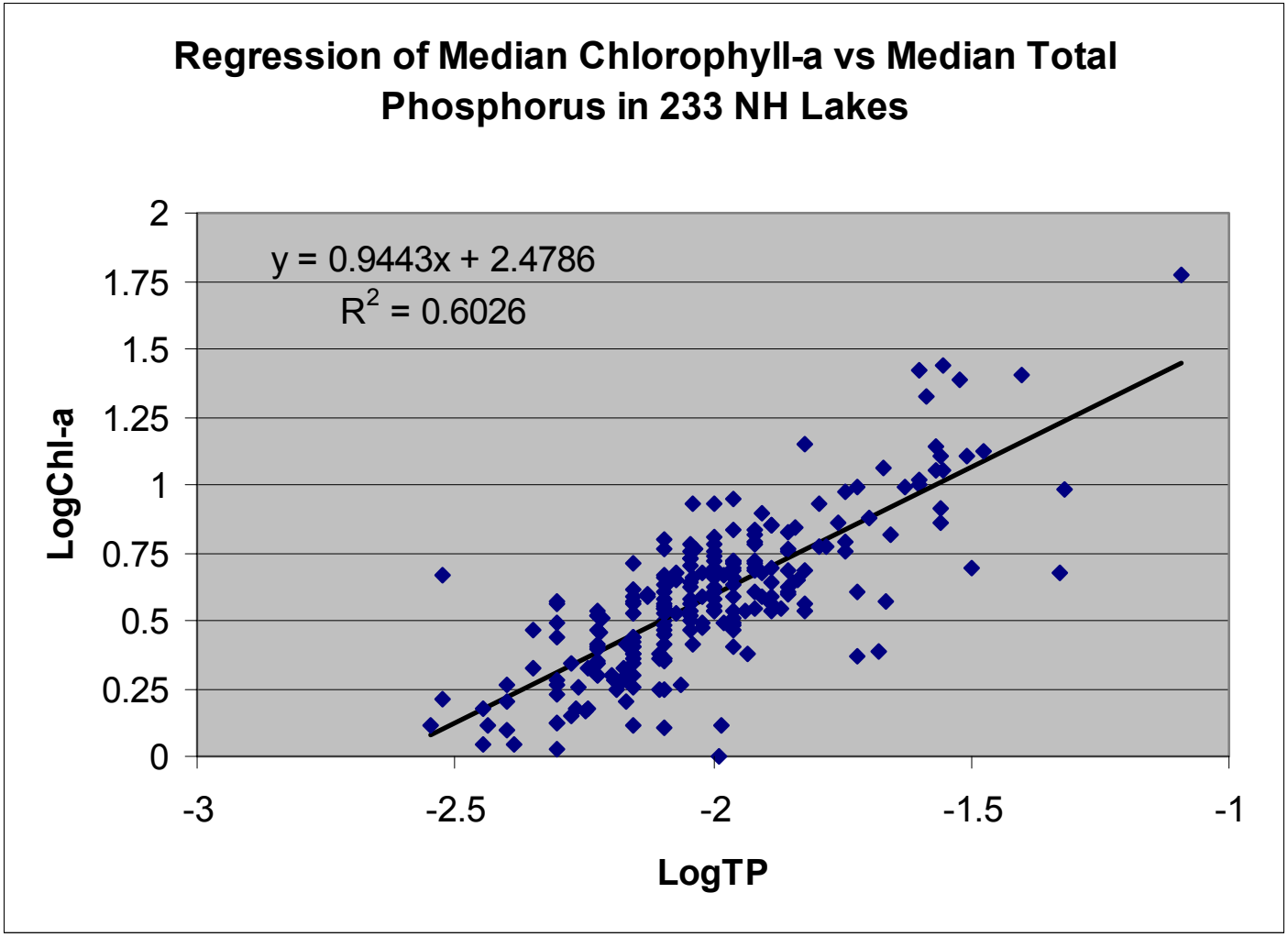
* Impaired lakes are lakes that do not support the swimming designated use due to elevated chlorophyll-a concentrations.

Figure 2: Distribution of median summer, epilimnetic phosphorus concentrations in study lakes



* Impaired lakes are lakes that do not support the swimming designated use due to elevated chlorophyll-a concentrations.

Figure 3: Regression of median summer, epilimnetic chlorophyll-a vs median summer, epilimnetic phosphorus in 233 NH lakes



* Before the log-transformation, the units for chlorophyll-a and phosphorus were ug/L and mg/L, respectively.