Recommendations for numeric nutrient criteria and eutrophication standards for Illinois streams and rivers

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Prepared for:

Illinois Environmental Protection Agency
and
Illinois Nutrient Loss Reduction Strategy

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List of Acronyms and Abbreviations

In alphabetical order:

Ambient Water Quality Monitoring Network	AWQMN
Chlorophyll-*a*	Chl-*a*
Chlorophyll-*a*.seasonal	chlac.seas
Coldwater Biotic Index	Coldwater BI
Dissolved Oxygen	DO
Ecological Risk Assessment	ERA
Ephemeroptera, Plecoptera, and Trichoptera	EPT
Facility Related Stream Surveys	FRSS
Fish Index of Biotic Integrity	Fish IBI
Five-day Biochemical Oxygen Demand	BOD_5
Harmful Algal Bloom	HAB
Hilsenhoff Biotic Index	HBI
Illinois Council on Food and Agricultural Research	C-FAR
Illinois Environmental Protection Agency	Illinois EPA
Illinois Nutrient Loss Reduction Strategy	Illinois NLRS
Intensive Basin Surveys	IBS
Large River Index of Biotic Integrity	Large River IBI
Macroinvertebrate Index of Biotic Integrity	MIBI
Method Detection Limit	MDL
Minnesota Pollution Control Agency	MPCA
Non-detect	ND
Nutrient Ecoregion 6	Nut 6
Nutrient Science Advisory Committee	NSAC
Qualitative Habitat Evaluation Index	QHEI
Receiver Operating Characteristic	ROC
Small Watershed Area	Sm Ws Area
Soluble Reactive Phosphorus	SRP
Total Kjeldahl Nitrogen	TKN

Total Nitrogen	TN
Total Nitrogen.seasonal	TN.seas
Total Phosphorus	TP
Total Phosphorus.seasonal	TP.seas
Total Suspended Solids	TSS
United States Environmental Protection Agency	U.S. EPA
Work Plan Framework	WPF

Executive Summary

Background and approach

As part of the Illinois Nutrient Loss Reduction Strategy (Illinois NLRS), the Nutrient Science Advisory Committee (NSAC) was established to make recommendations to Illinois Environmental Protection Agency (Illinois EPA) regarding numeric river and stream eutrophication water quality standards that are appropriate for protecting aquatic life and human uses of Illinois waterbodies. NSAC was composed of six scientists, including one from the United States Environmental Protection Agency (U.S. EPA).

The term “eutrophication water quality standards” was used to encompass the potential suite of causal and biological response variables for which numeric and/or narrative criteria might be appropriate. Causal variables included total nitrogen (TN) and total phosphorus (TP) concentrations. The biological response variables included measures known or expected to respond to changes in total N or P concentrations: algal biomass (as chlorophyll-*a*) and measures of macroinvertebrate and fish community health. Physical habitat quality, light conditions, and other variables that modify expected responses to changes in total N or P concentrations were also considered.

Illinois EPA provided NSAC all available surface water quality data from 1999 through 2014 from throughout Illinois. All ecoregions in Illinois were well represented with 1,679 station-sites in the final data set. After deliberation on whether the entire data set, or a seasonal subset, would be most relevant to eutrophication water quality standards, NSAC decided to focus analyses on the May 1 through October 31 growing season. Therefore, analyses were limited to data collected during this period.

NSAC considered using ecoregions as a means of accounting for variability in geology, topography, soils, vegetation, and climate across Illinois. The analyses indicated support for using a modified ecoregion approach in which U.S. EPA Nutrient Ecoregions 6 and 7 where combined into a North Ecoregion, and Nutrient Ecoregions 9 and 10 where combined into a South Ecoregion.

Analyses also supported classifying streams by size. Two size classes were identified, referred to hereafter as *wadeable* and *non-wadeable*. These terms are used by convention and should not be interpreted literally. Wadeable streams included all stream segments of 1st through 4th order using the Strahler method of stream ordering. Non-wadeable streams and rivers included all segments of 5th order or larger.

NSAC devoted considerable time and effort to identify relationships among causal (i.e., stressor) and response variables that could provide a statistical basis for derivation of numeric criteria. However, a lack of benthic chlorophyll-*a* (i.e., periphyton) data constrained the options for using a stressor-response approach for wadeable streams. Across all stream sizes, bivariate relationships among stressors (TN or TP) and response variables had very low predictive power, even in the few instances where a relationship was supported statistically. In general, the data were too variable to derive defensible numeric criteria from empirical stressor-response relationships.

Non-wadeable streams and rivers

Analyses indicated the presence of a potentially useful non-linear relationship between water column (sestonic) chlorophyll-*a* and TP in the non-wadeable streams and rivers at a statewide scale. No such relationship was observed for total N, so subsequent analyses for the non-wadeable sites were limited to total P. NSAC used a receiver operating characteristic (ROC) curve to derive numeric criteria for non-wadeable streams and rivers. The ROC framework allows for a range of candidate predictor and response criteria to be evaluated with respect to both sensitivity and specificity.

In this application, specificity refers to the proportion of total phosphorus-chlorophyll-*a* data pairs that agree in their assessment of water quality conditions when the candidate response variable (chlorophyll-*a*) meets the numeric target. Sensitivity refers to the proportion of total P-chlorophyll-*a* data pairs that agree in their assessment of water quality conditions when the candidate response variable (chlorophyll-*a)* does not meet its numeric target value. Stated another way, specificity characterizes the extent of agreement between the variables regarding acceptable conditions, based on the target chlorophyll-*a* (chl-*a*) value, and sensitivity characterizes agreement about unacceptable conditions (i.e., chlorophyll-*a* exceeds the target value).

Because Illinois does not currently have a numeric criterion for water column chlorophyll-*a* in streams and rivers, and none could be identified from analysis of Illinois EPA data, an alternative set of candidate water column chlorophyll-*a* criteria were compiled from literature and agency reports. The potential criteria for acceptable water column chlorophyll-*a* were 17, 25, and 35 µg/L. For each of these values, sensitivity was set at 75, 80, 85, 90, and 95% and the corresponding TP values were determined via ROC. The total phosphorus values are presented below for the three water column chlorophyll-*a* targets and the five sensitivity values.

Table ES.1

	Water column chlorophyll-*a* target:		
	17 µg/L	**25 µg/L**	**35 µg/L**
Sensitivity:			
75 %	148 µg/L total P	153 µg/L total P	154 µg/L total P
80 %	136 µg/L total P	140 µg/L total P	137 µg/L total P
85 %	123 µg/L total P	129 µg/L total P	124 µg/L total P
90 %	107 µg/L total P	115 µg/L total P	108 µg/L total P
95 %	84 µg/L total P	96 µg/L total P	87 µg/L total P

To interpret this analysis, recall that a sensitivity of 95 % means that in 95 % of the cases in which chlorophyll-*a* exceeds the target, TP will exceed the value in the table. This analysis does not result directly in a recommended TP threshold for non-wadeable streams and rivers. Rather, it allows scientists and policy makers to select among more or less restrictive total P criteria while trying to minimize instances of a false positive result—that is, exceedance of the chlorophyll-*a* target but TP below the target.

Specificity over this range of potential total P numeric criteria was low, from 10 % to 43 %, indicating a high probability (i.e., 90 % to 57 %) that exceeding these TP values will not be associated with exceedance of the water column chlorophyll-*a* value. The low specificities reflect the variability in the chlorophyll-*a* concentrations as a function of TP concentrations. This variability is likely due to effects from natural and anthropogenic factors that modify simple nutrient-algal relationships. There is strong evidence within the data from Illinois EPA that exceeding these TP values is not, by itself, a reliable predictor of exceeding the chlorophyll-*a* target. NSAC recommends that for non-wadeable streams and rivers, both TP and water column chlorophyll-*a* be considered in an integrated eutrophication water quality standard (sometimes referred to as a 'combined criterion' approach) in which an exceedance of total phosphorus alone would not result in waterbody being deemed impaired by eutrophication.

To protect Illinois non-wadeable rivers from eutrophication (defined as sestonic chlorophyll-*a* concentration > 25 µg/L), NSAC recommends a total phosphorus criterion of 100 µg/L. This TP value is somewhat less than the criterion for rivers in southern Minnesota and identical to the criterion for non-wadeable rivers in Wisconsin. Further, NSAC recommends that an integrated standard be adopted in which TP must exceed 100 µg/L and sestonic chlorophyll-*a* must exceed 25 µg/L in order for a non-wadeable river to be designated as exceeding the eutrophication standard. For both chlorophyll-*a* and TP the above criteria refer to seasonal geometric mean values.

Wadeable streams

To derive numeric criteria for wadeable streams, NSAC compiled lines of evidence from the peer-reviewed literature, U.S. EPA guidance documents, and statistical distributions of Illinois EPA data. Data from Illinois were weighted more heavily than other sources. The following table contains the recommended numeric TP and TN criteria for wadeable streams in the North and South Ecoregions. Also included are the 95 % confidence limits (CL) around the numeric criteria, which can be interpreted as a measure of uncertainty on the estimated numeric criteria. That is, based on available lines of evidence, there is a 95 % likelihood that the true value of the numeric criteria falls within the upper and lower confidence limits. The numeric criteria identified in Table ES.2 represent the mean value of those lines of evidence.

Table ES.2

	Total Phosphorus (µg/L)			**Total Nitrogen (µg/L)**	
	North Ecoregion	**South Ecoregion**		**North Ecoregion**	**South Ecoregion**
Numeric Criteria	113	110		3979	901
Lower 95 % CL	33	18		-78†	256
Upper 95 % CL	193	202		8036	1546

† the negative concentration is a statistical artefact and can be interpreted as zero.

These numeric criteria are recommendations for geometric mean values of chlorophyll-*a* for the growing season of May through October. For TP, the difference in numeric criteria between ecoregions is small and a single state-wide criterion is likely worth consideration by Illinois EPA. For TN, the estimated numeric criteria are much more variable, suggesting an ecoregion approach might be warranted.

NSAC recommends integrating causal and response variables in a eutrophication water quality standard (sometimes referred to as a 'combined criterion' approach). For wadeable streams, the numeric nutrient criteria identified in Table ES.3 preferably would be combined with criteria on benthic chlorophyll-*a*. Because benthic chlorophyll-*a* data were not available from Illinois, NSAC compiled data from Indiana, Iowa, and Ohio and used these lines of evidence to derive recommendations for Illinois. Table ES.3 presents recommended criterion for benthic chlorophyll-*a* in Illinois wadeable streams per the available lines of evidence. This recommendation applies statewide for Illinois and is applicable to the May through October growing season.

Table ES.3

	Benthic chlorophyll-*a* (mg/m^2)
Numeric criterion	79
Lower 95 % CL	51
Upper 95 % CL	108

Although water column (sestonic) chlorophyll-*a* is not normally a representative measure of algal biomass for wadeable streams, it is much easier to collect than benthic chlorophyll-*a* and is likely to remain part of Illinois EPA's monitoring program. Therefore, NSAC identified numeric criteria for water column chlorophyll-*a* using Illinois EPA data. The following table presents the recommended criterion for water column chlorophyll-*a* in wadeable streams. This recommendation applies to the May through October growing season.

Table ES.4

	Water column chlorophyll-*a* (µg/L)	
	North Ecoregion	**South Ecoregion**
Numeric criteria	5.1	5.0
Lower 95 % CL	0.6	0.3
Upper 95 % CL	9.6	9.7

The numeric criteria for water column chlorophyll-*a* are very similar between ecoregions and a single statewide value of 5 µg/L is recommended by NSAC.

With an integrated approach, the eutrophication water quality standard would <u>not</u> be met if (1) the TP criterion was exceeded and either of the chlorophyll-*a* criteria was exceeded, or (2) either of the chlorophyll-*a* criteria was exceeded regardless of the total P concentration. In the latter case, NSAC recommends that additional information be gathered to identify the cause of excess chlorophyll-*a*.

Recommendations for future efforts

First, NSAC strongly recommends that Illinois EPA include benthic chlorophyll-*a* (periphyton) sampling in future monitoring programs. The lack of benthic chlorophyll-*a* data was a significant constraint on the development of numeric criteria for wadeable streams. Second, the continuous monitoring of dissolved oxygen should be expanded if resources allow. NSAC examined the continuous dissolved oxygen data in depth, but the low number of sites with data was a limitation. Third, NSAC recognizes that there may be a desire for site-specific criteria development for certain streams or rivers. It was not feasible for NSAC to undertake site-specific criteria development, but Illinois EPA could consider pursuing this if there is justification and appropriate data are available.

1. Introduction

1.1 History of efforts to derive numeric nutrient criteria in Illinois

1.1.1 United States Environmental Protection Agency efforts to derive nutrient criteria

In 2000 the United States Environmental Protection Agency (U.S. EPA) published recommendations for ambient water quality criteria for nitrogen and phosphorus in surface waters. The U.S. EPA directed states to set numeric water quality standards for these constituents "to protect the physical, biological and chemical integrity of their waters." The U.S. EPA allowed individual states to modify the recommended criteria to better reflect state-specific conditions or to adopt other scientifically defensible criteria. Accordingly, the Illinois Environmental Protection Agency (Illinois EPA) initiated efforts to determine whether the recommended U.S. EPA criteria were applicable for Illinois water bodies and, if not, to develop state-specific nutrient criteria. Activities included organizing the Illinois Nutrient Standards Workgroup (comprised of various stakeholders including state, federal, and local governments, environmental advocacy groups, water and wastewater facilities and organizations, and concerned citizens), identifying available information and needs, and participating with other states on the U.S. EPA Regional Technical Assistance Group for nutrient standard development.

1.1.2 Illinois Council on Food and Agricultural Research

To assist with this effort, the Illinois Council on Food and Agricultural Research (C-FAR), developed a Strategic Research Initiative to help develop the scientific basis for nutrient standards in surface waters of Illinois. Working together with the Illinois EPA and the Illinois Department of Agriculture, and building collaborative efforts with additional agencies, four nutrient-specific research efforts were funded through C-FAR during 2003-2007. The C-FAR-funded research provided valuable insights regarding the development of nutrient standards. The research studies also raised additional questions and identified other factors that might have greater impacts on biotic integrity than nutrient concentration alone, including physical habitat, sediment and turbidity, light availability, temperature, and hydrology. The C-FAR studies concluded that cause and effect relationships are difficult to establish in Illinois because nutrients are almost never the primary limiting factor to algal production in Illinois streams and rivers. Physical habitat characteristics can affect biological community health as much, or more than, nutrients (see also: Section 2.2 Conceptual Models). Based on results from the C-FAR studies, the Illinois EPA determined that there were no definitive stressor-response relationships from which scientifically-defensible nutrient criteria could be established.

1.1.3 U.S. EPA and Tetra Tech analyses of Illinois EPA data

In 2008, U.S. EPA contracted with Tetra Tech, Inc. to perform an analysis using all suitable and available data from Illinois to determine candidate nutrient criteria using distribution-based and stressor-response analyses (Tetra Tech 2008). The analyses included Illinois EPA and Illinois Department of Natural Resources water chemistry and biology data, United States Geological Survey (USGS) National Water Quality Assessment water chemistry and biology data, and water chemistry and biology data generated by the C-FAR studies. The goals of the analyses were:

- Calculation of candidate total nitrogen (TN) and total phosphorus (TP) endpoints using algal and macroinvertebrate metrics as response variables including estimate of error generated with resampling techniques.
- Calculation of candidate TN and TP endpoints using algal and macroinvertebrate metrics translated into conditional probabilities using response levels derived from distributional data or metric-based thresholds including an estimate of error with resampling techniques.

Because of differences in data-collection methodology, data age, and geographic coverage among the data sets from different entities, the data sets were not combined but were analyzed separately. Tetra Tech summary statements from these analyses indicate that significant variability was present in the analyses because of differences between streams within ecoregions. In addition, the fact that Illinois has few low-nutrient sites to serve as a reference population against which the effects of elevated TN and TP on biotic integrity can be evaluated makes it difficult to assess the influence of anthropogenic influence on stream water quality. For example, few watersheds, especially in the northern part of Illinois, have undisturbed forest or prairie landscapes that can help to clearly describe expected conditions in the absence of human disturbance.

Tetra Tech chose to analyze a broader range of metrics than originally planned in hopes that some general tendencies and relationships might emerge; no strong distribution-based or stressor-response relationships were identified. However, candidate endpoints (criteria values) for the distribution-based analyses ranged from 0.024 – 0.244 mg/L for TP and from 0.63 – 8.79 mg/L for TN. These candidate endpoints were derived from conditional probability and other analyses. For the stressor-response based analyses, candidate endpoints (criteria values) ranged from 0.017 - 0.98 mg/L for TP and from 1.49 – 7.17 mg/L for TN.

Tetra Tech's report recommended additional investigation and analyses, including modeled reference conditions and stressor-response analyses.

1.2. U.S. EPA analyses of regional data, 2011

A 2011 report by the U.S. EPA stated that "in locations of significant nutrient-related disturbance, other parameters compete with nutrients in terms of impacting biology or otherwise confounding the identification of nutrient-biology relationships (Angradi 2011)." These other factors include high turbidity/sediment concentrations and agricultural chemical effects (e.g., pesticides). The report stated that "where such conditions exist across most of a state, strong biological response to nutrients may not consistently be observed if using data from only within a state." The purpose of Angradi's analysis was to identify nutrient response relationships from a cross-regional data set that could be used by individual states across the data analysis area. The analysis considered data from the Plains, Corn Belt, and Upper Midwest Regions using data from the U.S. EPA Wadeable Streams Assessment.

The major conclusions of Angradi's report included:

1. Macroinvertebrate assemblages in streams in the Corn Belt Plains did not differ from streams elsewhere in the Plains/Upper Midwest.
2. Mean TN concentration was highest in the Temperate Plains (5.25 mg/L) and mean TP concentration was highest in the Northern Plains (283 μg/L).

3. Background concentrations in the Plains/Upper Midwest streams predicted from linear regression were 0.436 mg/L for TN and 16 µg/L for TP.
4. Background nutrient concentrations for Illinois and Indiana streams were 0.196 mg/L for TN and 34 µg/L for TP.
5. There were stronger relationships between macroinvertebrate responses and nutrients in streams with coarse substrata versus streams with fine substrata.
6. A purely empirical approach was not possible, with the author noting that "[t]he determination of thresholds based on breakpoints in this report was, in some cases, partly subjective because of variability at the extremes of data range and/or weak responses to nutrients for some metrics."
7. Statistically, relationships between most of the biotic metrics and nutrient concentrations were weak (r^2 values mostly < 0.2).

1.3 U.S. EPA analyses of regional data, 2013

Additional analyses of Illinois and Indiana data by U.S. EPA were conducted to explore the effect of nutrients on stream biology in these two states in 2013 (Angradi).

Major findings included:

1. Piecewise regression and changepoint analyses identified statistical threshold values where the mean and/or variance in biological response metrics for fish and macroinvertebrates were determined to be different as a function of nutrient concentrations for 8% and 41%, of the metric-nutrient combinations, respectively, with more thresholds determined for TP as compared to TN or chlorophyll-*a*.
2. Based on the 25th percentile of metric threshold vales, a nutrient threshold of <75 µg/L and <12 µg/L TP was determined for Indiana and Illinois streams, respectively.

2. Nutrient Science Advisory Committee Approach and Methods

2.1 Formation of Nutrient Science Advisory Committee

In 2008 the U.S. Environmental Protection Agency (U.S. EPA) produced the 2008 Gulf Hypoxia Action Plan, which called for all of the states in the Mississippi River basin to develop plans to reduce nutrient transport in rivers to the Gulf of Mexico. Consequently, the Illinois Nutrient Loss Reduction Strategy (Illinois NLRS) was developed through the leadership of the Illinois Environmental Protection Agency, the Illinois Department of Agriculture, and the Illinois Water Resources Center, with vital contributions from many varied interest groups, and local and state agencies. One of the six key strategy components of the Illinois NLRS was the development of the Nutrient Science Advisory Committee (NSAC).

Following release of the Illinois NLRS in July of 2015, the Policy Workgroup and Illinois EPA worked to establish the NSAC. The selection process was modelled after the U.S. EPA's Science Advisory Board Hypoxia Advisory Panel. Sector Members (agriculture, point source, environmental, government, and university) of the NLRS Policy Workgroup nominated up to four scientists each. Eighteen nominations were received and vetted through a selection panel (one member each representing: agriculture, point source, environmental, government, and university). The selection panel followed standard conflict of interest and confidentiality guidelines during the review process. Five scientists were selected to make up the committee and an invitation was made for a scientist from U.S. EPA to also be part of the team.

NSAC members included:

- Dr. Candice Bauer, U.S. Environmental Protection Agency
- Dr. Walter Hill*, Oak Ridge National Laboratory
- Dr. Douglas McLaughlin**, National Council for Air and Stream Improvement, Inc.
- Dr. Christopher Peterson*, Loyola University Chicago, Institute of Environmental Sustainability
- Dr. Todd Royer, Indiana University, School of Public and Environmental Affairs
- Paul Terrio, U.S. Geological Survey, Central Midwest Water Science Center
- Dr. Matt Whiles, Southern Illinois University, Department of Zoology and Cooperative Wildlife Research Laboratory

*Dr. Walter Hill resigned from the NSAC in 2016 and Dr. Christopher Peterson was selected to fill the resulting vacancy on the NSAC.
** Dr. McLaughlin resigned from the NSAC in June 2018 in conjunction with moving to a new employer.

2.1.1. NSAC charge and scope

The charge given to NSAC:

- Make a recommendation(s) to Illinois EPA regarding numeric river and stream eutrophication water quality standards that are appropriate for protecting aquatic life uses in Illinois waterbodies, which may include numeric water quality criteria for phosphorus, nitrogen, and biological response variables as components of eutrophication water quality standards and may include narrative eutrophication water quality standards to supplement numeric criteria.

- Consider whether recommended standards should vary spatially (e.g., statewide, ecoregion, watershed, or river specific site), by water body type, or by other classification factors, and consider recommending procedures that may be used to derive site-specific eutrophication water quality standards.
- Consider characteristics of eutrophication water quality standards that may assist Illinois EPA in obtaining U.S. EPA approval for standards recommended by NSAC.

Given this charge, the first two orders of business were to compile and assess all available data and develop a Work Plan Framework (WPF). The WPF document was finalized on June 9, 2016 and presented to the Policy Workgroup on June 16, 2016.

2.2 NSAC's approach

The following approach, as explained further in the WPF, was established by NSAC to guide the process of making recommendations to Illinois EPA.

The term "eutrophication water quality standards" was used to encompass the potential suite of causal physical and chemical variables, as well as biological response variables, for which meaningful numeric and/or narrative criteria components could be determined. Causal (or stressor) variables included phosphorus and nitrogen; biological response variables included, but were not limited to, measures of, and surrogates for, algal or primary productivity and measures of macroinvertebrate and fish community health. The biological response variables included metrics expected to be altered by increased phosphorus and nitrogen concentrations.

In deriving recommendations for eutrophication water quality standards consistent with the charge to the committee, NSAC adopted an approach based generally on U.S. EPA's Ecological Risk Assessment (ERA) framework, with application to numeric criteria development. Additional documents that helped guide NSAC activities included U.S. EPA's ecological risk assessment guidance (U.S. EPA 1998), Suter and Cormier (2008), and nutrient-criteria related guidance and supporting documents provided by U.S. EPA (2000, 2010, 2014). Adoption of this approach was not a commitment by the NSAC to implement all aspects of a formal ERA but was intended to provide a clear context and a general outline to guide NSAC activities by conducting the work through planning/problem formulation, developing an analysis plan, and synthesizing/characterizing the results consistent with the ERA process.

2.2.1 Summary of literature review

In 2016, the U.S. EPA contracted Tetra Tech, Inc. to provide a literature review of "existing numeric criteria and numeric endpoints linked to aquatic life use impacts in states and regions adjacent to Illinois." This provided a summarization of existing numeric nutrient criteria, endpoints, and thresholds. Midwestern states with approved numeric criteria for rivers and streams (as of May 2016) were limited to Minnesota, Oklahoma, and Wisconsin. The literature review also provided information from other studies that were more regional in nature or a bit removed from the geographical focus of the review.

Most states included in the review had only narrative nutrient criteria with various requirements or qualifications on point-source discharges and response variable indicators used to support attainment decisions. These findings are presented in Table 2.1.

Table 2.1

State or Region	**Nutrient Criteria**	**Use-attainment Decision Variables**
Arkansas	Narrative Criteria	Clarity, periphyton or phytoplankton, dissolved oxygen (DO) concentration, saturation and diurnal swing, pH, aquatic biota
Iowa	Proposed Criteria (2013): TKN median ≤ 0.80 mg/L TP median ≤ 0.10 mg/L	Benthic MIBI, Fish IBI, Coldwater BI, periphyton or phytoplankton, DO
Indiana	Narrative Criteria	TP ≥ 0.3 mg/L, TN ≥ 10.0 mg/L, DO < 4.0 mg/L, pH > 9.0 SU, "excessive" algal growth
Kansas	Narrative Criteria	No information
Kentucky	Narrative Criteria	No information
Michigan	Narrative Criteria	Best professional judgement
Minnesota	North region: TP ≤ 0.050 mg/L, Chl-*a* ≤ 7 µg/L, DO flux ≤ 3.0 mg/L, BOD_5 ≤ 1.5 Central region: TP ≤ 0.10 mg/L, Chl-*a* ≤ 18 µg/L, DO flux ≤ 3.5 mg/L, BOD_5 ≤ 2.0 South region: TP ≤ 0.15 mg/L, Chl-*a* ≤ 35 µg/L, DO flux ≤ 4.5 mg/L, BOD_5 ≤ 3.0	Listed as eutrophic when a water exceeds the TP criteria plus one or more of the response variable criteria (chl-*a*, DO, BOD_5)
Missouri	Narrative Criteria	No information
Nebraska	Narrative Criteria	No information
Ohio	Narrative Criteria	No information
Oklahoma	TP 30-day mean ≤ 0.037 mg/L	Narrative criteria, trophic state index, TP, nitrate, chlorophyll-*a*
Tennessee	Narrative Criteria	Reference-based ecoregional criteria used to interpret narrative criteria: TP ≤ 0.01-0.25 mg/L, TN ≤ 0.22-3.48 mg/L
West Virginia	Narrative Criteria	Stream Condition Index, MIBI
Wisconsin	TP ≤ 0.1 mg/L in 47 large rivers; TP ≤ 0.075 mg/L all other streams	Numeric criteria

Note: Total Kjeldahl Nitrogen (TKN), Benthic Macroinvertebrate Index of Biotic Integrity (MIBI), Fish Index of Biotic Integrity (Fish IBI), Coldwater Benthic Index (Coldwater BI), Five-Day Biological Oxygen Demand (BOD_5)

2.2.2 Conceptual model development

Nitrogen and phosphorus are required for plant and algal growth. The concentration of these nutrients is often the primary factor driving plant and algal productivity and biomass accrual in streams; however, physical, biological, and chemical characteristics of water bodies and the bioavailability of various forms of nitrogen and phosphorus are also important factors in how nutrients affect an aquatic system. For example, nitrogen is typically found in highest concentrations as the oxidized form, nitrate. Phosphorus is most readily available to biological organisms as orthophosphate (often referred to as soluble reactive phosphorus, SRP), but total P is generally considered a better indicator of overall P availability in aquatic ecosystems because of the rapid turnover of organic P to SRP. In general, concentrations, forms, and biological use of nutrients can vary temporally, and nutrients present in, and transported by, stream and river systems are important both locally and downstream.

Decades of scientific research have demonstrated that elevated nutrient concentrations can result in excessive plant and algal growth, resulting in adverse effects to aquatic ecosystems. Too much plant or algae growth can cause large diurnal variations in dissolved oxygen, inducing stress on fish and macroinvertebrates critical to maintaining a healthy stream ecosystem. Excessive nutrients can also alter algal and plant community composition and contribute to proliferation of undesirable species such as cyanobacteria. Eventual die-off and decomposition of excessive plant and algal biomass can result in prolonged periods of low dissolved oxygen conditions. Thus, excess concentrations of nitrogen and phosphorus in stream ecosystems affects fish and invertebrate communities both directly and indirectly. Substrate and habitat features can be become overgrown with algae under eutrophic conditions, limiting use by aquatic fauna. Community composition can shift to favor species more tolerant of high nutrient levels, higher temperatures, and less light availability with resultant alteration of habitat, food resources, and water clarity characteristic of a healthy stream ecosystem.

Recent scientific studies have also documented that many human uses of surface waters can be impacted by high nutrient levels and increases in plant and algal growth. Excessive aquatic vegetation impairs the aesthetic appeal and recreational use of waters, including fishing, boating, and swimming. Increased algal growth, particularly phytoplankton, can affect the taste and odor of water supplies, degrading drinking water quality and increasing treatment costs. Harmful algal blooms (HABs) often develop when nutrient levels are high. These blooms, which frequently are comprised of toxic cyanobacterial species, are of concern because of the potential health effects on humans and animals from contact or ingestion.

The effects of high nitrogen and phosphorus concentrations and loadings are not transient, nor are they limited to local water bodies. Soluble forms of nitrogen and phosphorus can be transported great distances downstream; particulate and organic forms of these nutrients are transported in large quantities during high-flow events or can be released from sediments into the stream water under certain physical and chemical conditions. Consequently, the effects of nutrient loading on stream and river ecosystems can be manifest both near and far downstream and in the near- and long-term. Based upon this scientific understanding, numerous conceptual models describing the impact of excessive nutrients on aquatic ecosystems have been published in the scientific literature and by U.S. EPA and environmental agencies in many states (U.S. EPA 2010; Heiskary and Bouchard 2015).

NSAC developed conceptual models for rivers and streams in Illinois based upon these previously published models after consideration of the biotic and abiotic factors present in Illinois ecosystems (Figures 2.1 and 2.2). NSAC incorporated biotic and abiotic measurements collected by Illinois EPA that were deemed potentially useful to help identify and understand parameters that could be further investigated in NSAC's evaluation of stressor-response relationships, NSAC's preferred method for deriving numeric nutrient criteria for flowing waters in Illinois. NSAC determined that the conceptual models for rivers and streams were sufficiently different, in terms of the type of primary producer that was most influential, to warrant employing separate models for these systems. We determined, however, that ecoregional differences or other Illinois-specific factors did not necessitate the development of separate models (i.e., the important pathways of effects on biota are similar across ecoregions even if the physical factors and species present in the waters may have some difference).

2.2.2.1 Conceptual model for non-wadeable streams and rivers

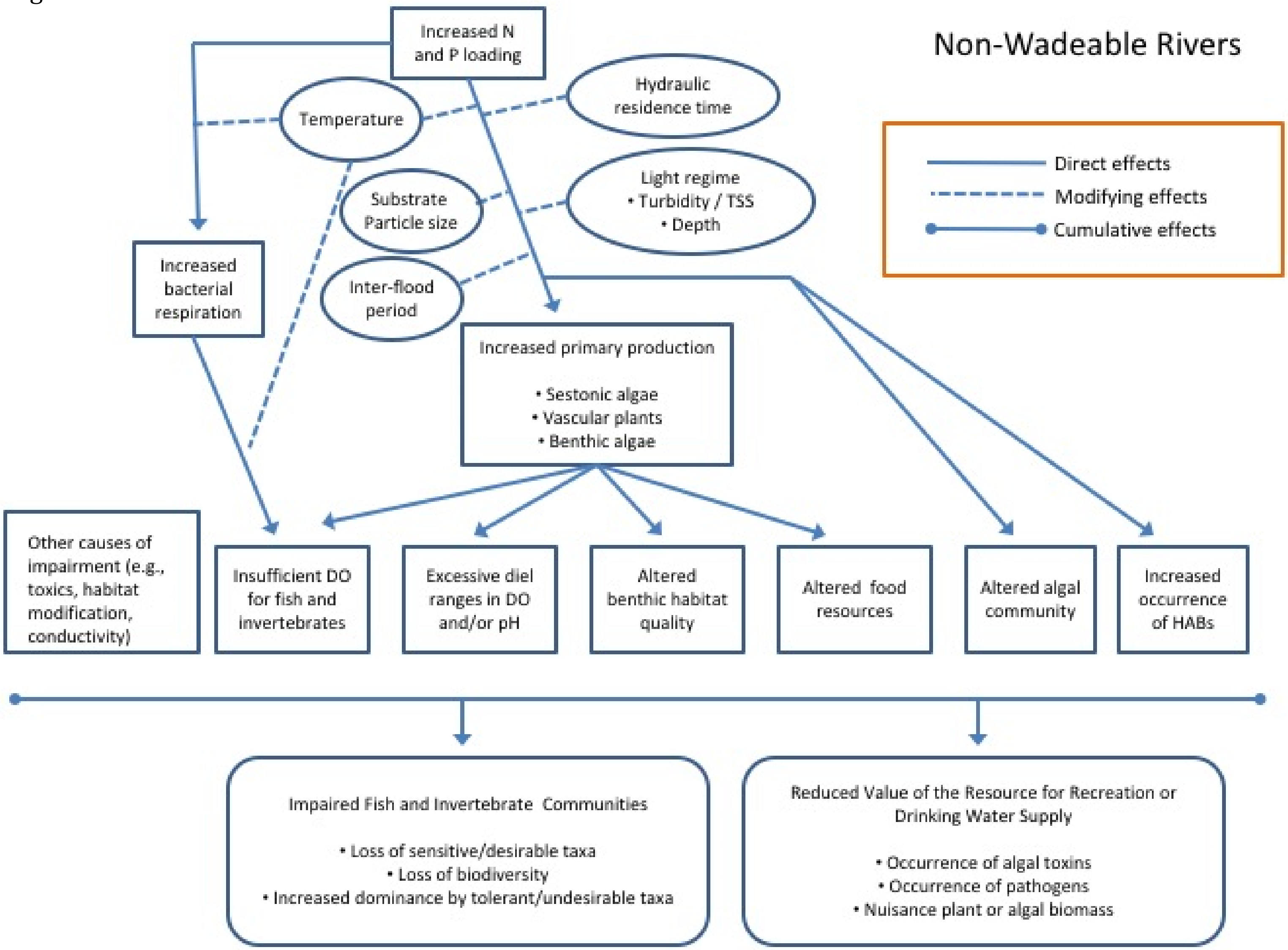
As noted previously, NSAC considered river size, measured by stream order and watershed area, in its evaluation of stressor-response relationships because differences in flowing water food webs as waters increase in size (i.e., width and depth) are well documented. As put forth in the River Continuum Concept (Vannote et al. 1980), larger rivers are predicted to be dominated by sestonic (water column) algal production when light, flow, and nutrient conditions support algal growth. In Illinois, primary production in non-wadeable streams and rivers (defined as those waters with a Strahler Stream Order classification of 5 and greater) is quantified as concentration of sestonic chlorophyll-a (chl-*a*). Although other types of primary producers may also be present in littoral zones, including benthic algae and rooted plants, use of seston-based metrics to assess eutrophication in these systems is justified, as this group is likely the greatest contributor to primary production in these systems.

For lotic systems in Illinois, NSAC proposed (see model – Figure 2.2) that under some conditions increased nutrients can lead to increased primary productivity and changes in algal community composition (although community composition data are not part of Illinois EPA collection protocol). The scientific literature provides strong support for this portion of the conceptual model. For example, Royer et al. (2008) found that, in waters with watershed areas greater than 2000 km^2, increased sestonic chl-*a* was correlated with increasing total phosphorus concentrations and that high sestonic chl-*a* levels were more likely to occur in Illinois streams with TP greater than 0.07 mg/L (for the subset of streams with low canopy cover and TP concentrations less than 0.2 mg/L). Similar predictive relationships between sestonic chlorophyll-*a* concentrations and total phosphorus concentrations were also found in a subset of Minnesota rivers chosen to represent sites spanning a nutrient gradient **(**Heiskary and Bouchard 2015**)**. However, differences in riparian canopy cover, yearly differences in flow regime (including differences in base flow and the timing and frequency of flood events), sampling frequency, and temporal variability in nutrient concentrations, algal production, and turbidity can make it difficult to develop predictive relationships among sestonic chl-*a* and nutrient concentrations.

Direct and indirect effects on plant and microbial production can affect macroinvertebrate and fish communities in non-wadeable lotic systems (Evans-White et al. 2009), which can lead to significant changes in the function and health of riverine ecosystems. As in smaller systems, increased nutrient loading can alter dissolved oxygen and pH regimes, which may directly affect biota due to the physiological stress.

Heatherly et al. (2007**)** demonstrated that macroinvertebrate community composition in Illinois streams and rivers is linked to habitat quality and nutrient concentrations. Miltner (2018) also demonstrated that in Ohio rivers with watershed areas greater than ~1800km^2 fish biotic integrity scores decreased strongly at sestonic chl-*a* concentrations above ~30 µg/L. This corresponded with increases in 24-hour ranges in dissolved oxygen and biological oxygen demand which, at diurnal minima, can lead to insufficient DO for resident river biota (effects noted between 20-50 µg/L chl-*a*). Further, Ephemeroptera, Plecoptera, and Trichoptera (EPT) invertebrate taxa scores declined as chlorophyll, BOD, total suspended solids (TSS), and nitrite concentrations increased in river sites not influenced by historical contamination. This is consistent with predictions outlined in the NSAC conceptual model, even though clear relationships between phosphorus and chlorophyll-*a* were not found in all rivers. The United States Geological Survey (USGS) reported in 2008 that total phosphorus in Wisconsin rivers was negatively correlated with multiple metrics for macroinvertebrates (species richness, mean pollution tolerance value, percent Ephemeroptera, Hilsenhoff Biotic Index (HBI), percent Plecoptera, and percent scrapers) and fish (large river index of biotic integrity (IBI), percent suckers, number intolerant species, percent and number of river species, and percent lithophilic spawners). These findings served as the basis of Wisconsin's adoption of numeric total phosphorus criteria of 0.1 mg/L TP in rivers. Like Wisconsin, Illinois habitat factors and environmental factors (and interaction between nutrients and these factors) also had strong impacts on macroinvertebrate and fish health.

Figure 2.1


Non-Wadeable Rivers
Direct effects
Modifying effects
Cumulative effects
Increased N and P loading
Temperature
Hydraulic residence time
Substrate Particle size
Light regime
• Turbidity / TSS
• Depth
Inter-flood period
Increased bacterial respiration
Increased primary production
• Sestonic algae
• Vascular plants
• Benthic algae
Other causes of impairment (e.g., toxics, habitat modification, conductivity)
Insufficient DO for fish and invertebrates
Excessive diel ranges in DO and/or pH
Altered benthic habitat quality
Altered food resources
Altered algal community
Increased occurrence of HABs
Impaired Fish and Invertebrate Communities
• Loss of sensitive/desirable taxa
• Loss of biodiversity
• Increased dominance by tolerant/undesirable taxa
Reduced Value of the Resource for Recreation or Drinking Water Supply
• Occurrence of algal toxins
• Occurrence of pathogens
• Nuisance plant or algal biomass

2.2.2.2 Conceptual model for wadeable streams

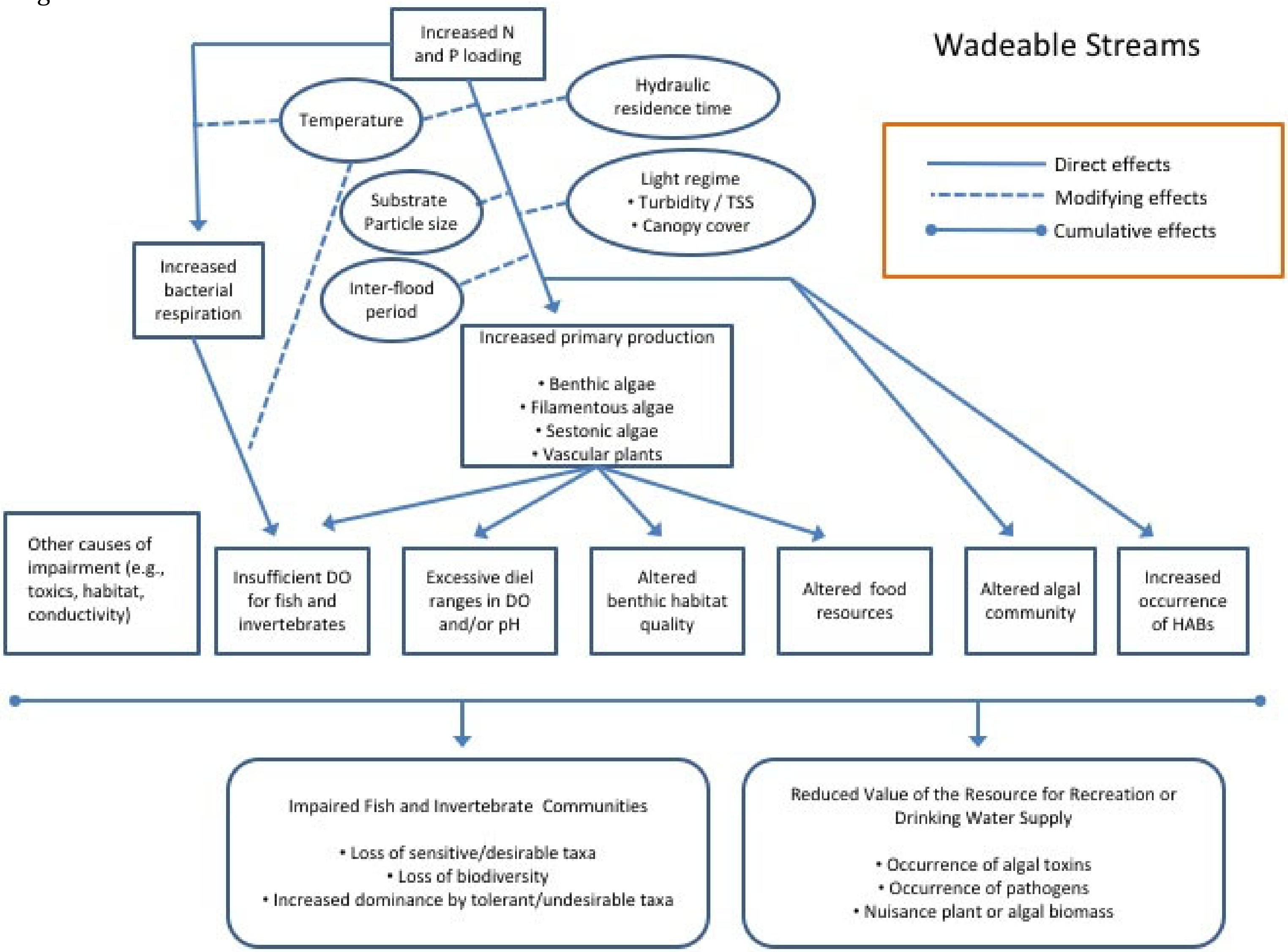
Wadeable stream systems are defined in Illinois as those waters with a Strahler Stream Order of 4 or less. In these systems enough light can penetrate to fuel primary productivity in the presence of increased nutrients. This can lead to increased primary productivity, as illustrated in the conceptual model that shows a strong influence of higher biomass or macrophytes (rooted plants) and benthic (associated/attached to the stream bed) algae, which includes filamentous green algae. Sestonic algae (i.e., those algal cells suspended in the water column) are not a good indicator for wadeable stream because they are simply dislodged benthic cells, as opposed to true phytoplankton. As such, assessment of the effects of eutrophication in small systems is most effective focusing on benthic algae and rooted plant growth; however, Illinois EPA does not collect quantitative data for these parameters. NSAC's analyses were constrained to use of sestonic algal biomass (represented by measurement of chlorophyll-*a*) and indirect measures of productivity collected by Illinois EPA. The indirect measures included diurnal changes in dissolved oxygen and pH at a subset of sites and for limited time periods.

Also unavailable to NSAC in our assessment was data on taxonomic composition of algal communities, as Illinois EPA does not collect these data. Increased nutrients can lead to changes in algal community composition, as shown in the conceptual model. The scientific literature provides support for this portion of the conceptual model (Stevenson et al. 2008, Paul et al. 2017). Many factors, such as substrate characteristics, flow, the timing and frequency of precipitation-caused scouring events, light penetration, and presence of herbivores affect the likelihood that increased nutrients will result in increased primary production (Royer et al. 2008).

As depicted in the conceptual model, changing the quantity and quality of primary producers, as well as changes to microbial productivity**,** affects secondary production, species composition, and diversity of macroinvertebrate and fish communities (Evans-White et al. 2009). Such changes can lead to significant changes in the health of lotic ecosystems and are measured in Illinois waters through macroinvertebrate and fish indices of biological integrity. Further, increased nutrients can affect dissolved oxygen and pH regimes (measured as minimum, maximum, average, and 24-hour range from continual monitoring), which can directly affect biota due to the physiological stress of low dissolved oxygen and/or pH outside the normal range.

In a 2006 report, the U.S. Geological Survey demonstrated that total phosphorus was significantly correlated to multiple measures of macroinvertebrate (Hilsenhoff biotic index, percent EPT individuals, and percent EPT taxa) and fish community health (i.e. index of biotic integrity, percent carnivorous fish, and percent intolerant fish) in Wisconsin streams. The threshold responses of these relationships contributed to the derivation of Wisconsin's numeric total phosphorus criteria of 0.075 mg/L TP in rivers. In Illinois, as in Wisconsin, habitat factors, environmental factors, and interaction between nutrients and these factors have strong impacts on macroinvertebrate and fish health (as measured by IBIs and other community metrics). Similarly, the correlation of phosphorus and 14 biological metrics from which threshold responses were derived contributed significantly to the derivation Minnesota's eutrophication standards (Heiskary and Bouchard 2015). In addition, the Minnesota Pollution Control Agency (MPCA) identified a threshold in the response of biological metrics to variation in measures of primary and bacterial production (i.e. sestonic chl-*a*, DO range, and biological oxygen demand). Miltner (2010) identified the level of DO range and minimum DO in Ohio streams that led to significant thresholds in the number of EPT macroinvertebrate taxa and other macroinvertebrate indicators, respectively.

Figure 2.2


Wadeable Streams
Direct effects
Modifying effects
Cumulative effects
Increased N and P loading
Temperature
Hydraulic residence time
Substrate Particle size
Light regime
• Turbidity / TSS
• Canopy cover
Inter-flood period
Increased bacterial respiration
Increased primary production
• Benthic algae
• Filamentous algae
• Sestonic algae
• Vascular plants
Other causes of impairment (e.g., toxics, habitat, conductivity)
Insufficient DO for fish and invertebrates
Excessive diel ranges in DO and/or pH
Altered benthic habitat quality
Altered food resources
Altered algal community
Increased occurrence of HABs
Impaired Fish and Invertebrate Communities
• Loss of sensitive/desirable taxa
• Loss of biodiversity
• Increased dominance by tolerant/undesirable taxa
Reduced Value of the Resource for Recreation or Drinking Water Supply
• Occurrence of algal toxins
• Occurrence of pathogens
• Nuisance plant or algal biomass

2.3 Data compilation

2.3.1 Description of Illinois EPA data

Illinois EPA provided NSAC available surface water quality data from 1999 through 2014 from throughout Illinois. This included station location information and data on macroinvertebrates, habitat, water quality (chemistry), fish, and continuous monitoring of pH and dissolved oxygen. All ecoregions in Illinois were well represented with 1,679 station sites in the final data set.

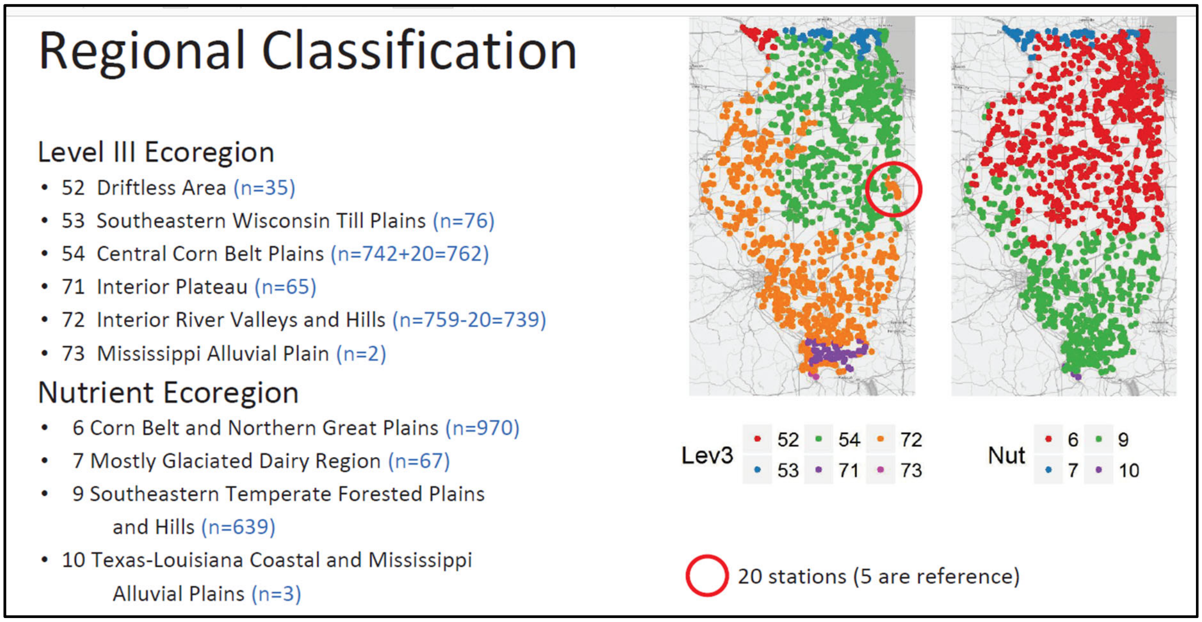


Figure 2.3: *Monitoring stations in Illinois. Ecoregions are defined as in Omernik (1987) and U.S. EPA (2000).*

The stations represent information from the three primary river and stream water monitoring programs at Illinois EPA: Ambient Water Quality Monitoring Network (AWQMN), Intensive Basin Surveys (IBS), and Facility Related Stream Surveys (FRSS).

Water quality - chemistry

Along with nutrient-related data (phosphorus, total and dissolved, and five forms of nitrogen), data were provided for total alkalinity, dissolved oxygen, dissolved oxygen saturation, pH, specific conductivity, temperature, total dissolved solids, total suspended solids, and turbidity.

Continuous monitoring

At each IBS station continuous monitoring equipment is deployed for two seven-day periods (June 1 – July 31 and August 1 – October 15). Parameters collected are: dissolved oxygen, water temperature, pH, and conductivity. Because this program is relatively recent, some stations had data from only one round of continuous monitoring, whereas other stations had data from two rounds of continuous monitoring.

Macroinvertebrates

Assessment of macroinvertebrate community structure and species diversity are the foundation of many federal and state biological assessment programs, because they reflect stressors in the water column and substrata. Accordingly, macroinvertebrates are collected and identified by Illinois EPA as part of the IBS program. The data provided included a final IBI (index of biotic integrity) number, the score of each metric and the raw values for each metric. Metrics for the IBI calculation are: Coleoptera taxa, Ephemeroptera taxa, total taxa, intolerant taxa, Hilsenhoff biotic index value (also called MBI), percent scrapers, and percent Ephemeroptera, Plecoptera, and Trichoptera (EPT).

Habitat

Characterization of physical habitat quality is critical for assessing nutrient enrichment and impacts thereof. Through the IBS and FRSS programs, Illinois EPA biologists collect habitat information that is used to develop a Qualitative Habitat Evaluation Index (QHEI) value. QHEI data and associated metrics were included in the data provided to NSAC. Raw metric data included information about: substrate, instream cover, channel morphology, bank erosion, and riparian zone, pool/glide and riffle/run quality, and gradient/drainage area. Additional information provided includes canopy cover, stage, and aesthetics.

Chlorophyll

Chlorophyll is collected at all IBS sites, a subset (50) of the AWQMN sites beginning in 2000, and at some FRSS sites. The chlorophyll sample is analyzed for chlorophyll-*a* (corrected and uncorrected for phaeophytin), *b*, *c*, and phaeophytin. Periphyton is not routinely collected by Illinois EPA, although a special study was completed in 2006 at six stations. Those data (chlorophyll-*a* and biomass) were forwarded to NSAC but not used as part of the large dataset because of the limited number of sites sampled.

Fish

Illinois EPA partners with Illinois Department of Natural Resources to collect fish data as part of the IBS program. Data collected at IBS stations are used to develop a Fish Index of Biotic Integrity. The Fish IBIs were sent to NSAC as part of the data transfer.

2.4 Data decisions

Several decisions were made by NSAC and Tetra Tech concerning data usability for the development of a recommendation to Illinois EPA on eutrophication water quality standards.

- The time period of interest is 2005 through 2014, with 2014 being the most recent data available at the time.
- Data of questionable quality according to field/lab notes or qualifying codes were screened from further analysis.
- Duplicate samples were screened from further analysis.
- Data identified at non-detect (ND) were set to one-half the reported method detection limit (MDL) preferentially according the following hierarchy:
    - use ½ * MDL
    - if no MDL reported, use ½ * the average parameter/method MDL
    - if no MDL reported and no method reported, use ½ * the average analyte MDL
- Due to the multiple programs from which the data were derived, each having separate goals, NSAC determined that the data would be constrained to that collected during the growing season (defined as May 1 – October 31).

- Chlorophyll data presented a special set of circumstances when it was determined that most of the data were generated from samples that exceeded the maximum recommended holding time (28 days). The lab had misinterpreted the standard method and was preparing and preserving the sample and placing the prepared samples in the lab freezer where they were stored until analyzed within 180 days. While NSAC researched chlorophyll analysis methods, Tetra Tech continued to perform analysis using two sets of chlorophyll-*a* data:

    1. data with the collection to analysis time less than or equal to 28 days and
    2. data with the collection to analysis time less than or equal to 180 days

    Further analysis of the data indicated that chlorophyll values from samples analyzed within 28 days of collection are similar to those held between 29 and 180 days. Ultimately NSAC decided to exclude from further analysis chlorophyll-*a* data from samples with a <u>collection-to-extraction</u> holding time of *greater* than 28 days **or** an <u>extraction-to-analysis</u> holding time of *greater* than 90 days.

2.3.2 Consideration of data from stakeholders

The NSAC also considered using data sets available from other agency, stakeholder, and watershed groups. In July 2016, the NSAC, in coordination with the Nutrient Monitoring Council, identified and solicited information from watershed or regional monitoring entities to determine the composition, spatial and temporal coverage, accessibility, and suitability of their monitoring data for incorporation into, or as supplemental information to, the data set used to examine nutrient-related stressor-response relationships. Several different monitoring data sets were considered and discussed either through personal or phone conversations or via a webinar during which several groups presented information on their monitoring programs. These data sets included:

- Metropolitan Water Reclamation District of Greater Chicago
- Illinois State Water Survey
- City Water Light and Power
- Fox River Study Group
- DuPage River Salt Creek Workgroup
- U.S. EPA's National Rivers and Streams Assessment
- U.S. Geological Survey's Midwest Stream Quality Assessment

The content and quality of the individual databases was generally acceptable and, in some respects, more comprehensive than the Illinois EPA database (for example, some data sets included a greater sampling frequency and inclusion of additional biological metrics and benthic algae collection). However, the temporal periods of data collection, collection and analyses methodologies, or data formatting were often different enough from the Illinois EPA data that it was determined impractical or infeasible to incorporate these data sets in our analysis, given time and funding constraints. Additionally, incorporation of spatially-limited data sets or data sets from individual water-bodies would potentially bias the overall data set towards certain streams or regions.

3. Key Decisions and Rationales

3.1 Data analysis performed by Tetra Tech

The Nutrient Science Advisory Committee (NSAC) worked with Tetra Tech, under contract with U.S. EPA, to conduct new analyses of biological and water quality data (as described in Section 2.3 of this report) to support NSAC's development of numeric nutrient criteria recommendations. The analyses were extensive and iterative; details are provided below and in work plans available through Illinois EPA.

3.2 Evaluation of conceptual models in light of Tetra Tech analyses

Analyses completed by Tetra Tech (see Appendix) of available Illinois EPA datasets showed general support for the conceptual model. Additionally, they also confirmed that factors other than nutrients (i.e., habitat and other physical factors) are important in Illinois waters, as predicted by NSAC in its construction of the conceptual models and explained further below.

NSAC's observations from the Tetra Tech analysis of the Illinois EPA data set can be summarized as follows:

- Environmental data, when expressed as a bivariate plot of two variables (i.e., concentrations of chlorophyll-*a* (chl-*a*) as a function of total phosphorus from sites across a large landscape), can often show highly variable responses and may result in a wedge-shaped response (Cade and Noon 2003). This is due to the impact of: (1) spatial and temporal variability, (2) measurement error, (3) natural factors affecting the relationship between the two variables, such as water depth and flow rate, and (4) the presence of co-stressors. An example is provided in Fig. 3.1 below, where the upper boundary of the wedge-shaped response, demonstrated by the thick blue line, indicates the effect of phosphorus on chl-*a* concentration. The chl-*a* points below the upper thick blue line are lower due to confounding factors such as high turbidity or other anthropogenic conditions that inhibit algal growth in the presence of high phosphorus. Both the previous analyses and the updated NSAC analysis of Illinois' available data used to explore the relationships between nutrients, sestonic chl-*a*, and biological communities have shown this high degree of scatter in all of the stressor-response relationships.

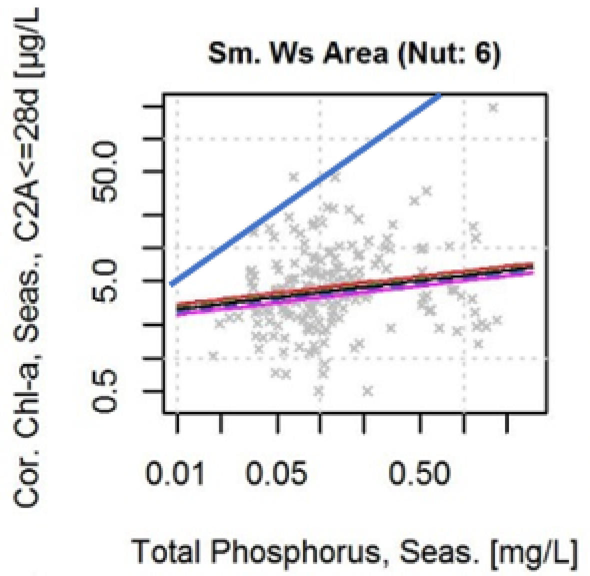


Figure 3.1. *Hierarchical linear regression (model 4) results for Illinois EPA data from 2005-2014 in small watersheds (sm. ws. area). These results are based upon the seasonal geometric mean total phosphorus concentrations for each site-year combination as related to the geometric mean corrected seasonal chlorophyll-a concentration (for the dataset that met the holding time requirement of 28 days) for the site-year combination for the lower third of watershed size in km^2 found in Nutrient Ecoregion 6 (Nut 6). The pink linear regression lines in the middle of the figure represent the effects of habitat quality (measures as a qualitative habitat evaluation index (QHEI)) and canopy cover on the relationship between chlorophyll-a and total phosphorus, and the upper blue line reflects the hypothetical upper boundary of a wedge-shaped plot per Cade and Noon (2003). This figure is taken from Stressor Response Summary based upon Tetra Tech analyses dated 01/02/17 and can be found in the Appendix on page 60. Note: Corrected (Cor.), Chlorophyll-a (Chl-a.Seas), Small watershed area (Sm. Ws. Area).*

- While environmental data can be highly variable, stressor-response relationships can inform management decisions like establishing nutrient criteria when the variability can be explained and controlled through various analyses, management targets for various responses have been identified a priori, and/or the relationship exhibits a threshold response (U.S. EPA 2010). NSAC analyses determined some stressor-response models and correlation coefficients were statistically significant and exhibited relationships consistent with the conceptual model of nutrient impacts on rivers and streams (see pages 52, 54, and 56-58 of the Appendix for examples). Nevertheless, NSAC conclude that statistical significance alone does not support the derivation of numeric recommendations to Illinois EPA if the relationship lacks predictive power or a clear threshold response.

- NSAC did not find relationships between nutrients and either macroinvertebrate or fish metrics that were considered sufficient to support numeric nutrient recommendations (see the Appendix for examples). NSAC evaluated the relationship between total phosphorus (TP) and the Illinois macroinvertebrate index of biotic integrity (mIBI) to assess whether this relationship could be used to determine what level of phosphorus led to a significant decline in macroinvertebrate community health. While mIBI values decreased as TP increased, the relationship did not show a strong threshold response and there was a wide range in phosphorus concentrations at the sites meeting their mIBI score threshold for assessing attainment of Aquatic Life Use designation in Illinois streams. The relationship between nutrient levels and mIBI is shown in Figure 3.2 for small watersheds in Nutrient Ecoregion 6 for both TP and total nitrogen (TN) (Appendix). The lack of threshold response is likely due to the fact that other natural and anthropogenic factors, such as habitat and water quality, have strong impacts on both macroinvertebrate and fish community health, thereby confounding relationships with nutrient levels.

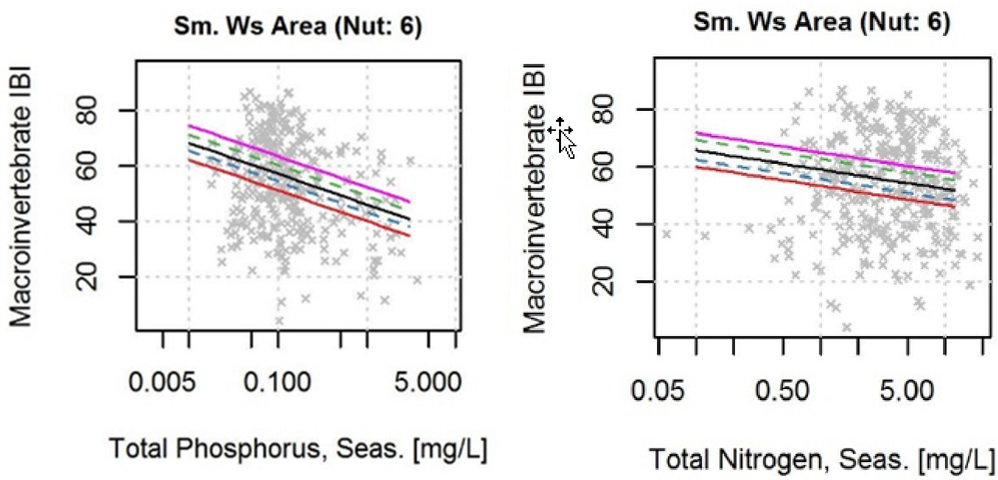


Figure 3.2. *Hierarchical linear regression (model 4) results for Illinois EPA data from 2005-2014 based upon the seasonal geometric mean nutrient concentrations for each site -year combination as related to the macroinvertebrate IBI for the site-year combination in small watersheds (lower third of watershed size in km^2) found in Nutrient Ecoregion 6 (Nut 6). The linear regression lines represent the effects of habitat quality (measures as QHEI) and canopy cover on the relationship between macroinvertebrates and total phosphorus (left panel) or total nitrogen (right panel).*

- NSAC analyses also investigated relationships between sestonic chl-*a* and (1) macroinvertebrate and fish metrics, (2) dissolved oxygen (DO) measures, and (3) other biological response variables to determine whether they supported derivation of a chl-*a* recommendation (e.g. pages 54 and 64 in the Appendix). However, NSAC did not find stressor-response relationships between chl-*a* and these measures that were considered sufficient to support numeric chl-*a* recommendations.

- In light of the conceptual models based upon the scientific literature and consideration of Illinois analyses summarized above, Figure 3.3 below, and those presented in the Appendix, NSAC supports the conclusion that nutrients can be important drivers of biological health in flowing waters. When exploring data at the statewide-scale in Illinois and other states (USGS 2006), the impact of nutrients alone explains a relatively small portion of the variation in biological communities. NSAC has concluded, based upon its best professional judgement, that reducing nutrient concentrations across the state will generally improve biotic community health, increase stream ecological functions, and improve water quality of downstream waters, although habitat and other stressors may limit the amount of improvement seen at individual sites. Because of the variety of relationships between stressor and response variables, NSAC worked to derive numeric nutrient criteria recommendations based upon the relationship between nutrients and sestonic chl-*a* in rivers and reference-based concentrations of nutrients in streams.

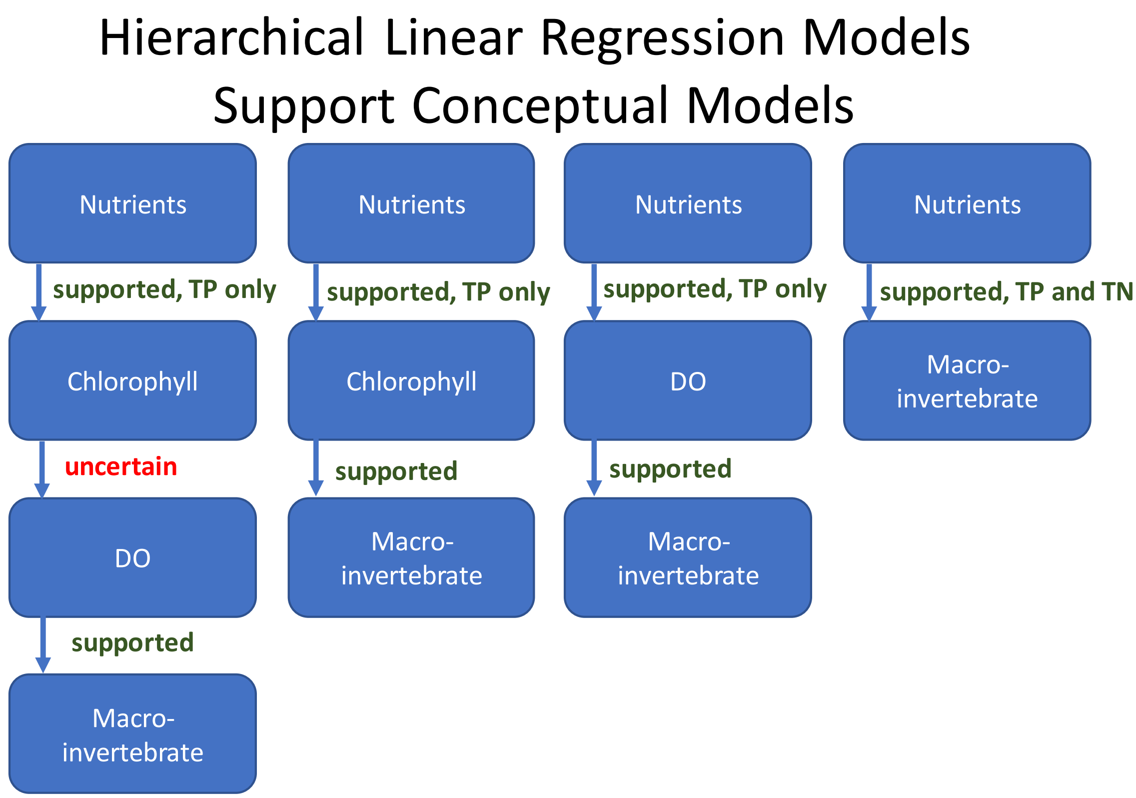


Figure 3.3. *Statistically significant linear hierarchical models of the updated Illinois EPA dataset between nutrients and measures of response variables (sestonic chlorophyll-a concentrations (chlorophyll), dissolved oxygen concentrations for various metrics (DO), and macroinvertebrate response variables) generally showed support for the conceptual models, and these relationships are summarized in the above figure. Significant model results had model coefficient values that were consistent with the expected relationship denoted in the conceptual model. However, the statistically significant model results had model coefficients that were not predicted by the conceptual models for some total nitrogen relationships (i.e., those between nitrogen and chlorophyll-a concentrations) and the relationship between chlorophyll-a and dissolved oxygen. The relationship between chlorophyll-a and DO showed that average concentrations of dissolved oxygen calculated from short-term summer continual DO measurements increased, not decreased, as a result of increased chlorophyll-a at the time of the measurements.*

4. Recommendations for Non-wadeable Streams and Rivers

4.1 Nutrient Science Advisory Committee focus on nutrient relationships with sestonic chlorophyll-*a*

Based on the results of the Tetra Tech analysis of Illinois Environmental Protection Agency (Illinois EPA) data, the Nutrient Science Advisory Committee (NSAC) focused its subsequent evaluation on bivariate relationships between seasonal geometric means of total nitrogen and sestonic chlorophyll-*a* (chl-*a*) and total phosphorus (TP) and chl-*a* for non-wadeable rivers, defined as Strahler Stream Orders 5 and higher. This decision was based the fact that the bivariate relationship between nutrients and algae in the Illinois EPA dataset was stronger than other relationships, particularly those between various macroinvertebrate or fish metrics and nutrients. This was especially true when the relationship was limited to those higher order streams where sestonic algal are expected to be the primary form of algal biomass. Grouping the data this way removes some of the confounding effect of stream order and watershed size observed in the Tetra Tech analyses. Other potential covariates, such as turbidity or canopy cover, did not improve the strength of these nutrient-chlorophyll relationships. NSAC utilized analyses on a statewide scale since rivers cross ecoregion boundaries and there were not significant relationships at the ecoregion scale.

The analyses indicated a potentially useful, non-linear relationship between total phosphorus and sestonic chl-*a* for non-wadeable rivers. Higher-than-expected frequency of elevated seasonal geometric mean corrected chl-*a* concentrations (for the dataset that met the holding time requirements) occurred at mid-range seasonal geometric mean TP concentrations. The presence of many cases in which TP concentrations were high (i.e., greater than 0.5 mg/L) while chl-*a* remain relatively low clearly supported the view that the causal relationship between phosphorus and algal growth was complex and not well-captured in a simple bivariate model (e.g., Royer et al. 2008). Nonetheless, the direct link between chl-*a* and phosphorus established in the literature and described in the conceptual model for non-wadeable rivers was consistent with the observation that increased phosphorus concentrations increased the likelihood of observing elevated chl-*a* concentrations in these systems. No such relationship was observed between TN and chl-*a*; consequently, the rest of this section focuses on the TP and chl-*a* data.

4.2 Data analysis for stressor-response relationships

NSAC used a receiver operating characteristic curve (ROC) approach to evaluate a range of candidate criteria as they relate to the following questions. An acceptable condition is defined as a situation where the value is at or below an agreed-upon numeric target value that has been determined to support attainment of designated uses:

- If TP is considered acceptable, how likely is it that chl-*a* is also considered acceptable?
- If chl-*a* is considered unacceptable, how likely is it that TP also will be considered unacceptable?

NSAC chose to pursue the ROC approach because it provides a quantitative estimate of the potential for decision errors in bivariate relationships where numeric criteria, such as TP or chl-*a* criteria, may be used as possible decision points in water quality assessment, as further discussed below (McLaughlin 2012).

Because Illinois lacks a numeric target/criterion for a chl-*a* concentration that can distinguish between acceptable and unacceptable algal growth conditions, and because no sufficiently strong relationships between chl-*a* and other biological response variables were found, NSAC identified a set of numeric chl-*a* thresholds from the peer-reviewed literature and reports on nutrient criteria generated by state agencies for use in ROC analysis (Dodds et al. 1998, Royer et al. 2008, MPCA 2013).

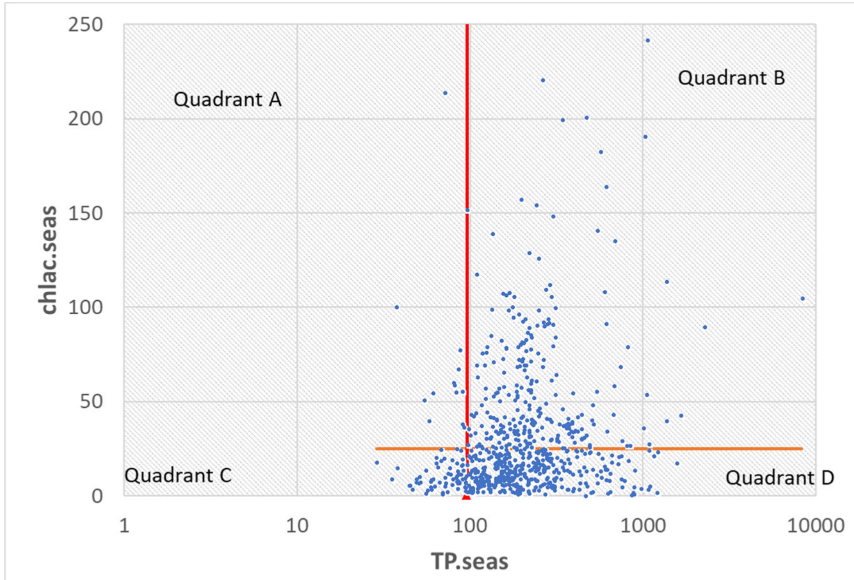
ROC analysis was implemented using an MS Excel workbook ("SpecSensCalculator_NSAC.xlsx," hereafter "the Workbook"). Results were validated using the R program "pROC" (Robin et al. 2011). The area under the ROC curve (AUC) was estimated using pROC to allow for comparison to an AUC of 0.5, which is expected when two variables are uncorrelated. Additional validation of the NSAC analyses was provided by Tetra Tech, which reviewed the spreadsheet and pROC results and found no errors in the calculations. The workbook and R code are included as part of the NSAC report and available by request from Illinois EPA.

4.3 Results

Analysis indicated that a non-random relationship existed between total phosphorus and chl-*a*. Two panels in Figure 4.1 show the same data in different ways. Both show the positive, nonlinear relationship between TP and chl-*a*. The increased likelihood of observing higher chl-*a* concentrations when TP is in the middle of its observed range is also apparent, especially in comparison to the lowest TP values. However, it is important to note that two unrelated lognormally distributed variables would also have a visual appearance similar to that in Panel A, though the y-axis values at mid-range on the x-axis would be elevated to a lesser degree (see charts in worksheet "no correlation roc example" in the Workbook for comparison). The apparent increased occurrence of elevated chl-*a* (i.e., beyond random scatter) also is affirmed using a LOWESS line in a TP:chl-*a* scatter plot (Figure 4.2) and through ROC analysis.

Note: the figures in Section 4 use the term chlac.seas to denote chlorophyll-*a* levels and TP.seas for total phosphorus levels.

Panel A



Panel B

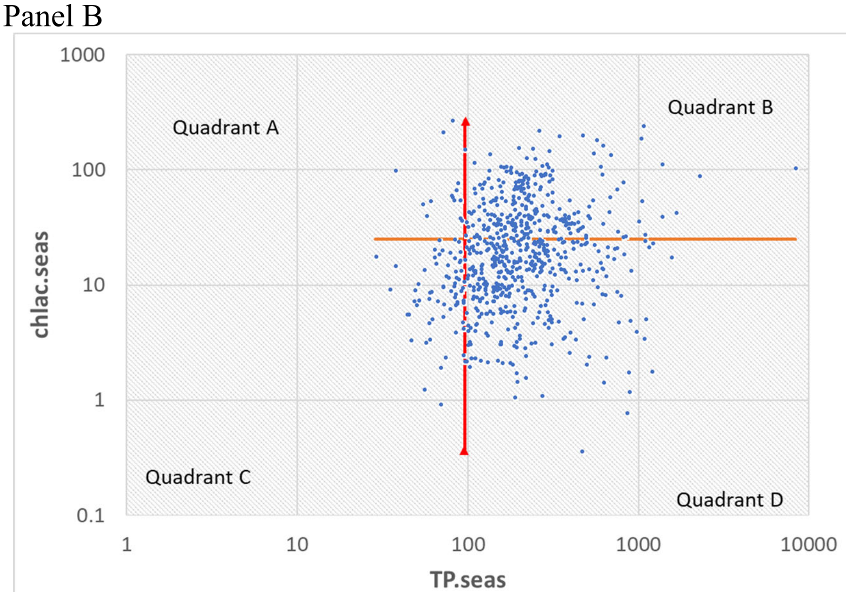


Figure 4.1: *Plots of seasonal geometric mean sestonic chlorophyll a (chlac.seas) and seasonal geometric mean total phosphorus (TP.seas) for Stream Order 5 and higher (Illinois EPA data set). Panel A shows a linear y-axis and a logarithmic-x axis; Panel B shows logarithmic y and x-axes. Units for both variables are µg/L. The red vertical line corresponds to a candidate total phosphorus criterion of 100 µg/L and the horizontal orange line corresponds to a candidate chlorophyll-a criterion of 25 µg/L. Red and orange lines form four quadrants that are used to estimate proportions of agreement and disagreement between the two variables with respect to their candidate criteria.*

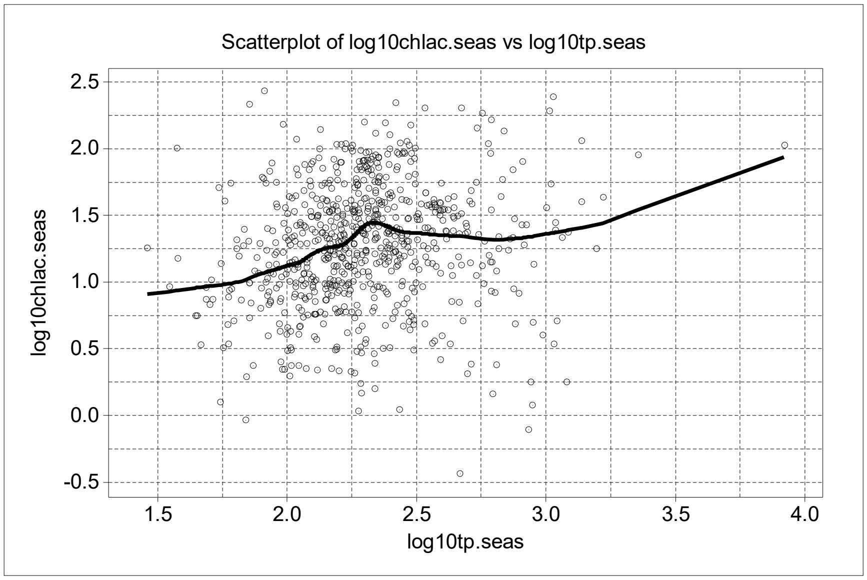


Figure 4.2: *A different expression of same data as Figure 4.1: Panel B with LOWESS smoother (degree of smoothing = 0.3, number of steps = 4), indicating a trend of increased chlorophyll-a concentrations at mid-range total phosphorus concentrations.*

In ROC analyses, the term "specificity" describes the extent of agreement between the variables regarding acceptable conditions and "sensitivity" describes the agreement about unacceptable conditions (McLaughlin 2012). For example, when chl-*a* is below some specified level that distinguishes between acceptable and unacceptable conditions (i.e., a numeric target above which algae levels are considered "too high"), specificity refers to how often the associated TP value also is below a candidate criterion used for the same purpose (quadrant C in Figure 4.1). Conversely, when chl-*a* exceeds its numeric target (i.e., the level above which eutrophic conditions may impair designated uses), sensitivity refers to how often the associated TP concentration also exceeds a candidate TP criterion (quadrant B in Figure 4.1).

The ROC approach allows for a range of candidate predictor and response criteria to be evaluated with respect to both sensitivity and specificity. An example is shown in Figure 4.3 for the total phosphorus; chl-*a* data and a candidate chl-*a* criterion of 25 µg/L using pROC. The figure shows 95% confidence limits for the ROC curve. The lack of overlap between the confidence intervals and the diagonal line supports the idea that a non-random relationship exists between these variables. When both specificity and sensitivity are high, a predictor variable such as TP concentration indicates acceptable and unacceptable chl-*a* conditions with a high degree of accuracy. Where relationships are more uncertain, ROC analysis can help characterize the degree of uncertainty in relating numeric criteria to water quality to inform management decisions.

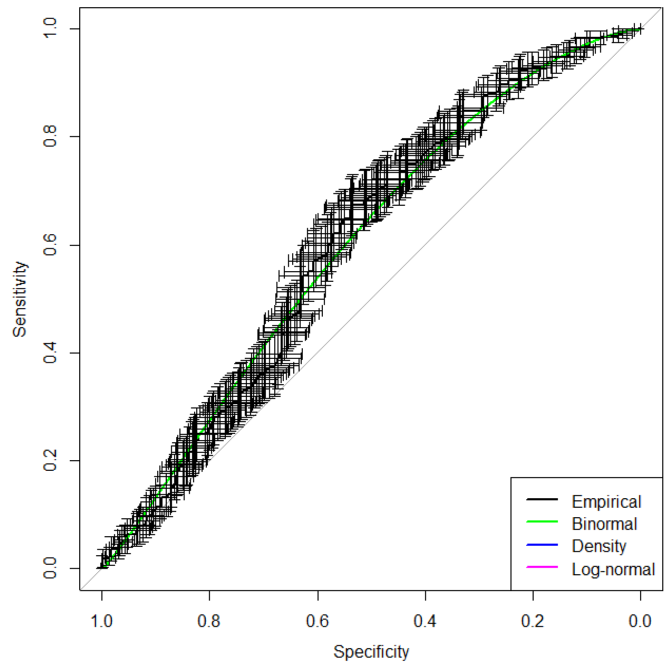


Figure 4.3: *Plot of sensitivity versus specificity across all total phosphorus concentrations for candidate chlorophyll-a criterion of 25 µg/L using pROC. The ROC curve with 95% bootstrap confidence limits is shown. The area under the ROC curve is 0.60. The diagonal line depicts the expectation for two unrelated variables.*

The Workbook provides a means by which candidate criteria for both total phosphorus and chl-*a* can be examined to determine corresponding changes in specificity, sensitivity, and other ROC parameters. NSAC used the Workbook by first identifying a range of sensitivities that could reflect appropriate Illinois EPA criteria choices based on existing data. That is, given the uncertainty in the true TP:chl-*a* relationship, NSAC determined that appropriate TP criterion could be derived from sensitivity targets from 75%-95%. This is due to the fact that sensitivity refers to how often both the chl-*a* and TP concentrations exceeds a candidate TP criterion (quadrant B in Fig. 4.1). NSAC chose the sensitivity targets ranging from 75% to 95% to ensure that few sites (25% to 5%, respectively) would have chl-*a* concentrations greater than the acceptable chl-*a* target level when TP concentrations are below the identified TP concentration (quadrant A in Fig. 4.1). This approach errs on the side of water quality protection by minimizing the number of points in quadrant A. NSAC concluded that this was a defensible approach.

4.4 Candidate numeric nutrient criteria

Next, candidate chl-*a* values of 17, 25, and 35 µg/L were selected for evaluation. Because Illinois does not currently have a numeric criterion for chl-*a* in streams and rivers, and none were identified by NSAC from analysis of Illinois EPA data, the alternative set of candidate chl-*a* criteria from literature and other state agency nutrient criteria studies were used (Dodds et al. 1998, Royer et al. 2008, MPCA 2013).

Once NSAC identified ranges of target sensitivities and candidate chl-*a* criteria to evaluate, the Workbook was used to identify the total phosphorus concentration that achieved each target sensitivity for all candidate chl-*a* criteria. The corresponding specificity also was recorded. Results are shown in the following table. Prevalence, or the proportion of chl-*a* data points that exceed the corresponding candidate criterion, is also shown.

Table 4.1. *Results for TP, specificity, and prevalence from the Workbook for selected sensitivities and candidate chl-a criteria.*

Sensitivity (%)	**Chlorophyll-*a* criterion (μg/L)**	**Total Phosphorus (μg/L)**	**Specificity (%)**	**Prevalence (%)**
75	17	148	43	55
80	17	136	38	55
85	17	123	33	55
90	17	107	24	55
95	17	84	11	55
75	25	153	43	40
80	25	140	35	40
85	25	129	33	40
90	25	115	26	40
95	25	96	16	40
75	35	154	41	28
80	35	137	32	28
85	35	124	27	28
90	35	108	20	28
95	35	87	10	28

Results show that similar ranges and patterns of TP specificity occur across all three candidate chl-*a* criteria. That is, as the sensitivity target increases from 75% to 95% for all three chl-*a* criteria, the associated TP criterion that achieves the sensitivity target decreases from 154 μg/L (75% sensitivity and chl-*a* = 35 μg/L) to 84 μg/L (95% sensitivity and chl-*a* = 17 μg/L).

Specificity over this range of candidate TP concentration criteria is relatively low, from 10% (95% sensitivity and chl-*a* = 35 μg/L) to 43% (75% sensitivity and chl-*a* = 17 μg/L and 25 μg/L). These low specificities indicate a high probability (i.e., 90% and 57% chance, respectively) that exceeding these candidate TP criteria will not be associated with seasonal geometric mean sestonic chl-*a* above the 17-35 μg/L range. That is, low specificities observed here reflect the variability in the chl-*a* concentrations as a function of TP concentrations due to the impacts of non-enrichment related natural and anthropogenic factors as further explained in the conceptual model and the strong evidence from Illinois EPA data that exceeding these candidate TP criteria alone is not a reliable predictor of high chl-*a* concentrations. This finding supports NSAC's conclusion that a combined criterion approach is recommended in order to avoid a high frequency of incorrect water quality impairment determinations based on TP alone. Rather, both TP and chl-*a* measurements should be included in characterizing whether a eutrophication water quality standard is being attained.

To protect Illinois non-wadeable rivers from eutrophication, defined as sestonic chl-*a* concentration > 25 μg/L (e.g., Dodds et al. 1998), NSAC recommends a total phosphorus criterion of 100 μg/L. This TP value is somewhat less than the criterion for rivers in southern Minnesota (MPCA 2013) and identical to the criterion for non-wadeable rivers in Wisconsin (as summarized at https://dnr.wi.gov/topic/surfacewater/documents/TP_factsheet4162013.pdf). This recommendation is supported by the ROC analysis in Fig. 4.1, which shows increased risk of excessive sestonic chl-*a* when TP exceeds 100 μg/L. Thus, NSAC recommends that an integrated standard be adopted in which total phosphorus must exceed 100 μg/L and sestonic chl-*a* must exceed 25 μg/L in order for a non-wadeable river to be designated as exceeding the eutrophication standard. For both chl-*a* and TP the above criteria refer to seasonal geometric mean values.

5. Recommendations for Wadeable Streams

5.1 Nutrient Science Advisory Committee recommended numeric criteria for total nitrogen and total phosphorus for both ecoregions

The Nutrient Science Advisory Committee (NSAC) used ecoregions as a means of accounting for variability in geology, topography, soils, vegetation, and climate across Illinois as a part of its analysis of stressor-response and reference-based nutrient criteria derivation approaches. The analyses indicated support for using a modified ecoregion approach in which the United States Environmental Protection Agency (U.S. EPA) Nutrient Ecoregions 6 and 7 were combined into the North Ecoregion, and Nutrient Ecoregions 9 and 10 where combined into the South Ecoregion. As described below, the results suggest a statewide TP criterion is likely possible, but in the interest of transparency the results are presented by Ecoregion.

The following table (5.1) contains the recommended numeric total phosphorus (TP) and total nitrogen (TN) criteria for the North and South Illinois Ecoregions. These criteria are based on the mean values of the lines of evidence further described in Tables 5.2 and 5.3. Also included are the 95 % confidence limits (CL) around the proposed numeric criteria. The confidence limits should be interpreted as a measure of uncertainty on the estimated numeric criteria. That is, based on the lines of evidence available to us, there is a 95 % likelihood that the true value of the numeric criteria falls within the upper and lower confidence limits.

Table 5.1: Recommended numeric nutrient criteria by Illinois ecoregion

	Total Phosphorus (µg/L)			**Total Nitrogen (µg/L)**	
	North Ecoregion	**South Ecoregion**		**North Ecoregion**	**South Ecoregion**
Numeric Criteria	113	110		3979	901
Lower 95 % CL	33	18		-78†	256
Upper 95 % CL	193	202		8036	1546

† the negative concentration is a statistical artefact and can be interpreted as zero.

These numeric criteria recommendations were based largely upon geometric mean nutrient concentrations for the growing season of May through October of the Illinois Environmental Protection Agency (Illinois EPA) data as described in Table 5.2, although the other lines of evidence in Table 5.3 were also considered. Consequently, the attainment of acceptable conditions at a site should be determined by comparing the geometric mean of samples taken during the growing season of May through October to these numeric nutrient criteria recommendations. Sestonic and benthic algal chl-*a* concentrations should also be collected along with nutrient samples, and recommendations for sestonic and benthic algae chl-*a* concentration targets are further explained below as part of our proposed integrated (combined) approach.

Table 5.2: Reference conditions in Illinois wadeable streams

Line of Evidence	North Ecoregion TP (μg/L)	South Ecoregion TP (μg/L)	North Ecoregion TN (μg/L)	South Ecoregion TN (μg/L)
25th Illinois EPA data (seasonal); orders 1-4	80	100	2000	700
75th Illinois EPA minimally disturbed sites (seasonal) as determined in Tetra Tech (2015); orders 1-4	140	100	6500	1000
75th Illinois EPA attaining Macroinvertebrate Index of Biotic Integrity sites (seasonal); orders 1-4	180	200	6500	1500
Mean of reference estimates (see Table 5.3)	63	39	1058	673

NSAC arrived at these proposed numeric nutrient criteria values for the North and South Ecoregions using the following reference-based lines of evidence, weighted equally, where reference waterbodies represent least disturbed and/or minimally disturbed conditions within a region (Stoddard et al. 2006) and support designated uses (U.S. EPA 2000a). As explained by U.S. EPA (U.S. EPA 2010), the range of conditions observed within reference waterbodies provides appropriate values upon which criteria can be based. Using the updated Illinois EPA dataset, NSAC evaluated three metrics meant to represent minimally-impacted nutrient conditions in Illinois streams with a Strahler stream order of 4 or below.

1. NSAC used the 25th percentile of the geometric growing season mean concentrations of TP and TN from sites in the Illinois dataset, as recommended by U.S. EPA (2000).

2. NSAC also considered the TP and TN concentrations from sites that have been determined to be representative of reference conditions in Illinois based upon the land use and/or biological community health. These values are described in Table 5.2 as the 75th percentile of minimally disturbed sites. Following the approach of U.S. EPA (2000), NSAC determined the TP and TN of the 75th percentile of reference sites, where reference sites were categorized as “reference” and “best reference” based upon the presence of natural land uses as described in Tetra Tech (2015).

3. NSAC also considered the seasonal geometric mean concentrations of TP and TN found in sites attaining the Illinois EPA macroinvertebrate index of biotic integrity (mIBI) threshold used to evaluate sites for listing on the Illinois Clean

Water Act 303(d) list. The 75th percentile of those sites attaining the mIBI were deemed by NSAC (per Illinois EPA's 303(d) listing guidance) as representative of the nutrient concentrations necessary to support aquatic life in Illinois streams.

Finally, NSAC considered estimates of reference conditions for Nutrient Ecoregions 6 and 9 (Table 5.3) based upon data from across the entire ecoregion (including outside of Illinois) as one of the four lines of evidence supporting the NSAC recommendations (Table 5.2). NSAC concluded that it is scientifically defensible to consider data from across the midwestern United States in deriving criteria recommendations for Illinois. However, this evidence was not weighted as heavily as the Illinois EPA data (which comprised three of the four lines of evidence in Table 5.3). Additionally, the data from outside of Illinois differed in some characteristics, namely those data included stream orders greater than 4 and time periods outside of the May – October growing season. Nonetheless, NSAC determined these were important and relevant data to use in deriving criteria for Illinois. NSAC noted that the reference-based criteria recommendations summarized in Table 5.1 were similar to thresholds and values determined in other Illinois data analyses described earlier in this report and were also similar to criteria developed for other midwestern states, as summarized earlier in Table 2.1 and the studies described in the conceptual model portion of this report.

In considering the criteria recommendation for total phosphorus, the difference in numeric criteria between ecoregions is small and a single state-wide criterion is likely worth consideration by Illinois EPA. For total nitrogen, the estimated numeric criteria are not well constrained, but suggest an ecoregion approach might be warranted.

Table 5.3: Reference stream nutrient concentrations

Estimated Reference Conditions	Ecoregion 6 TP (μg/L)	Ecoregion 9 TP (μg/L)	Ecoregion 6 TN (μg/L)	Ecoregion 9 TN (μg/L)
25th U.S. EPA (annual)	76	37	2180	690
Dodds and Oakes (2004)	23	31	215	370
Smith et al. (2003)	54	48	355	150

The mean of reference estimates from Table 5.2 above were derived from the following lines of evidence from Ecoregion 6 (comprises most of the North Ecoregion as used here) and Ecoregion 9 (comprises most the South Ecoregion as used here).

5.2 Response variable criteria recommendations

NSAC recommends integrating causal and response variables in a eutrophication water quality standard, which is also known as a combined criterion approach. For wadeable streams, the above numeric nutrient criteria preferably would be combined with criteria on benthic chl-*a*. Because benthic chl-*a* data were not available from Illinois, NSAC compiled data from available stressor-response studies in similar nutrient ecoregions to those found in Illinois. By using available studies that demonstrated important measures of biological community health were correlated to increasing benthic chl-*a,* NSAC determined that it would be scientifically defensible to derive benthic chl-*a* (response variable) criteria to use in combination with numeric nutrient criteria recommendations for Illinois. This was also consistent with the wadeable streams conceptual model. Available studies that were considered by NSAC were conducted in Indiana, Iowa, and Ohio and are described in Table 5.4. The following table presents the recommended criterion for benthic chl-*a* in wadeable streams. This recommendation applies statewide for Illinois and is applicable to the May through October growing season.

Table 5.4

	Benthic chlorophyll-*a* (µg/m^2)
Numeric criterion	79
Lower 95 % CL	51
Upper 95 % CL	108

The benthic chl-*a* recommendations above were derived using the lines of evidence summarized in Table 5.5, each weighted equally. They were determined to be consistent with previous Illinois studies showing that benthic chl-*a* concentrations in Illinois streams are often well below this level (Royer et al. 2008). This fact supports the use of benthic chl-*a* as a response variable in combination with the recommended numeric nutrient criteria for wadeable streams.

Table 5.5.

Line of Evidence	**Benthic chlorophyll-*a* (µg/m^2)**	**Notes**
Caskey et al. (2010), Indiana data	60	relationship with shredders
Caskey et al. (2010), Indiana data	68	relationship with sensitive fish taxa
Caskey et al. (2010), Indiana data	54	percent relative abundance of largemouth bass in wadeable streams
Miltner (2010), Ohio data	107	protection goal; protection of existing high-quality waters & EPT taxa; table 9
Iowa DNR (2013), draft report	107	conditional probability threshold for macroinvertebrate index of biotic integrity; table 47

Although water column (sestonic) chl-*a* is not the preferred measure of algal biomass for wadeable streams, it is much easier to collect than benthic chl-*a* and is likely to remain part of Illinois EPA's monitoring program. Therefore, NSAC identified reference-based numeric criteria for water column chl-*a* using three lines of evidence from Illinois EPA data in Table 5.6. The same approach as described for TP and TN for the North and South Ecoregions of Illinois was used. Because few estimates exist of reference concentrations of sestonic chl-*a* across nutrient ecoregions found in Illinois, no data from outside Illinois were used. The following table presents the recommended criterion for water column chl-*a* in wadeable streams. This recommendation applies to the May through October growing season.

Table 5.6

Line of Evidence	(North) Ecoregion 6 sestonic chl-*a* (µg/L)	(South) Ecoregion 9 sestonic chl-*a* (µg/L)
25th percentile of all sites (seasonal chl-a); orders 1-4	2.5	2.3
75th percentile of minimally disturbed sites (seasonal chl-*a*); orders 1-4	6.3	6.4
75th percentile of attaining mIBI Sites (seasonal chl-*a*); orders 1-4	6.4	6.3

The numeric criteria for water column chl-*a* are very similar between ecoregions (Table 5.7) and a single statewide value of 5 µg/L is recommended by NSAC. Specifically, the water column chl-*a* values were derived using the lines of evidence in table 5.6, all from Illinois and all weighted equally.

Table 5.7

	Water column chlorophyll-*a* (µg/L)	
	North Ecoregion	**South Ecoregion**
Numeric criteria	5.1	5.0
Lower 95 % CL	0.6	0.3
Upper 95 % CL	9.6	9.7

With an integrated approach, the eutrophication water quality standard for wadeable streams would be considered to not be met if (1) the total phosphorus criterion was exceeded and either the sestonic or benthic chl-*a* criteria was exceeded, or (2) either of the chl-*a* criterion was exceeded regardless of the total phosphorus concentration. In the latter case, NSAC recommends that additional information be gathered to identify the cause(s) of excess chl-*a*.

6. Recommendations for Future Efforts

The Nutrient Science Advisory Committee (NSAC) has a number of recommendations that should be considered in future monitoring and assessment efforts in wadeable streams that may assist in developing new water quality criteria or modifying the numeric nutrient criteria presented here. These include:

- Inclusion of benthic chl-*a* (periphyton) sampling. Currently the only variable that allows direct assessment of the biomass of primary producers is sestonic chlorophyll. While this is appropriate for larger, non-wadeable streams and rivers, its use for smaller streams is problematic for a number of reasons. Sestonic samples from wadeable streams are comprised, almost entirely, of material of benthic origin. As such, chlorophyll concentrations may not be indicative of production related to nutrient enrichment. Algal cell density in the water column of wadeable streams varies with community age relative to time since last disturbance, time of day as algal drift exhibits mid-day maxima (Peterson 1996), and current velocity (Biggs and Thompson 1995).

  Benthic algae are the main primary producers in these ecosystems and periphyton biomass and nitrogen content are sensitive to variation in nutrient supply associated with land use (Biggs 1995). They thus provide a direct response variable for nutrient enrichment. Visual assessment of benthic algal distribution is also useful to identify nutrient 'hot spots' such as enriched water entering surface streams from the hyporheic zone or the downstream side of meanders (Valett et al. 1994).

  Benthic samples could be preserved and stored for microalgal taxonomic analysis to identify the influence of stressors, including nutrients (Munn et al. 2018)

- Incorporation of qualitative assessment methods into regular monitoring. Use of a perception survey to derive a numeric standard for sestonic and benthic chlorophyll associated with nuisance algal blooms with concurrent sampling for nutrient analysis would be beneficial.

- Expand use of continuous monitoring of dissolved oxygen. Increasing the number of sites at which permanent dissolved oxygen (DO) monitoring is employed would enhance the ability to identify sites under eutrophication stress in the absence of algal indicators (i.e. heavily shaded sites). The magnitude of diel fluctuation in dissolved oxygen is an indicator of respiration that can be linked to nutrient enrichment. Increasing the number and diversity of sites may allow detection of a relationship between magnitude of DO flux and nutrient concentrations.

- Develop site-specific criteria for certain streams or rivers. NSAC was unable to undertake development of site-specific criteria development, but the Illinois Environmental Protection Agency could consider pursuing this if there is justification and appropriate data are available.

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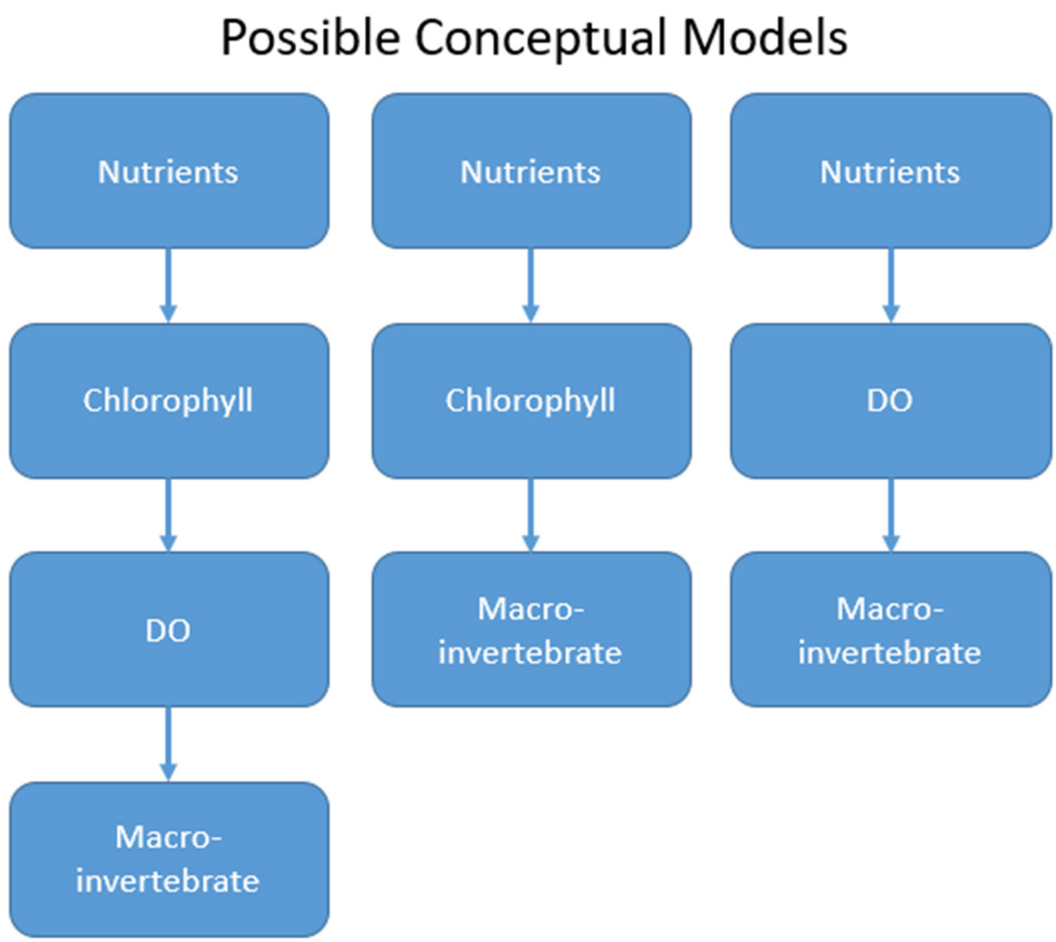
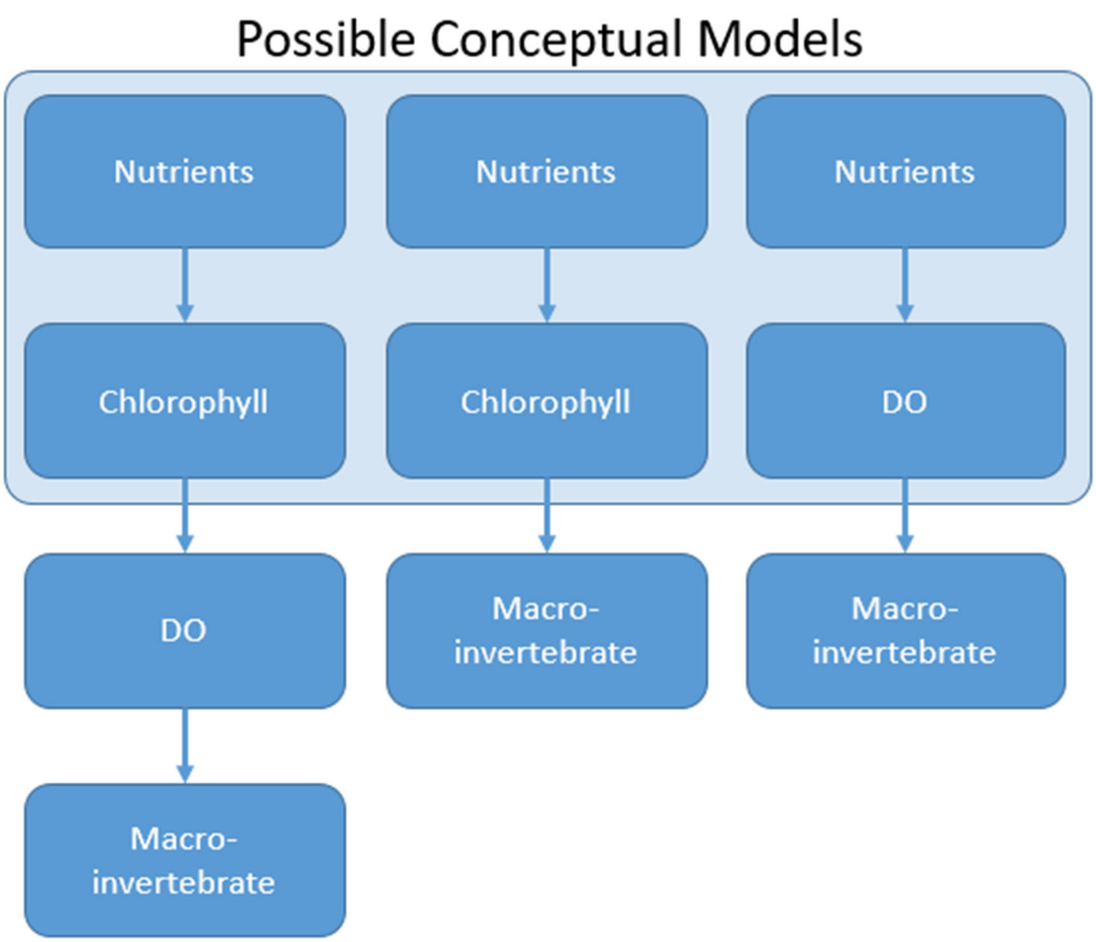
8. Appendix

Stressor Response Summary based upon Tetra Tech analyses dated 01/02/17



Regression Options (w/Nutrient Stressor)

- Nutrients
  - Seasonal Geometric Mean TN
  - Seasonal Geometric Mean TP
- Sestonic Chlorophyll
  - Seasonal Geometric Mean Chl-*a*
  - Seasonal Geometric Mean Chl-*a* (<=28d)
- Dissolved Oxygen
  - Grab
    - Minimum 24-Hr DO [mg/L]
    - Average 24-Hr DO [mg/L]
  - Continuous
    - Maximum 24-Hr DO [mg/L]
    - Delta 24-Hr DO [mg/L]
    - Dissolved Oxygen, Seas. [mg/L]
    - Dissolved Oxygen [mg/L]



Stressor/Response

- Hierarchical Linear Regression
  - Build sequential (nested) regression models by adding variables at each step.
  - Run ANOVAs and regressions
  - Compare sum of squares (SS) between models from ANOVA results.
  - Find corresponding F-statistics and p-values for the SS differences

Average 24-Hr DO [mg/L]

doMeanCont ~ Seasonal TP & Nutrient Ecoregion

Table: Models

	model	R.Squared	Adj.R.Squared
model.1	~ log10(TP.seas) + Nut	0.3035	0.2991
model.2	~ log10(TP.seas) + Nut + QHEI_SCORE	0.3036	0.2977
model.3	~ log10(TP.seas) + Nut + QHEI_SCORE + log10(WsAreaSqKm)	0.3409	0.3339
model.4	~ log10(TP.seas) + Nut + QHEI_SCORE + log10(WsAreaSqKm) + CANOPY	0.3994	0.3917
model.5	~ log10(TP.seas) + Nut + QHEI_SCORE + log10(WsAreaSqKm) + CANOPY + log10(TP.seas) * Nut	0.4003	0.3900

Total Sum of Squares: 1569.99270237666

Table: Analysis of Variance Table-Model Comparison

	Res.Df	RSS	Df	Sum.of.Sq	F	p_Value	Signif.
model.1	472	1093.4220	NA	NA	NA	-	NA
model.2	471	1093.2673	1	0.1546928	0.0767231	0.7819	-
model.3	470	1034.8009	1	58.4664876	28.9976807	<0.0001	***
model.4	469	942.9353	1	91.8655672	45.5626547	<0.0001	***
model.5	467	941.5874	2	1.3479202	0.3342647	0.7160	-

Table: Model Coefficients

Parameter	model.1	pVal	model.2	pVal	model.3	pVal	model.4	pVal	model.5	pVal
(Intercept)	7.5834158	***	7.5168290	***	5.8731626	***	6.5402482	***	6.4734359	***
log10(TP.seas)	-0.3501509	*	-0.3456284	*	-0.6240899	***	-0.5098324	**	-0.5911972	**
Nut7	0.7652604	+	0.7513380	+	0.9010199	*	0.6047778	-	0.6946688	-
Nut9	-2.0213617	***	-2.0214241	***	-1.8891028	***	-1.6904798	***	-1.4395230	***
QHEI_SCORE	NA	NA	0.0011957	-	0.0025334	-	0.0092202	*	0.0099184	*
log10(WsAreaSqKm)	NA	NA	NA	NA	0.5640574	***	0.3793789	***	0.3643790	***
CANOPY	NA	NA	NA	NA	NA	NA	-0.0189718	***	-0.0190855	***
log10(TP.seas):Nut7	NA	NA	NA	NA	NA	NA	NA	NA	0.1229054	-
log10(TP.seas):Nut9	NA	NA	NA	NA	NA	NA	NA	NA	0.2932423	-

Illinois EPA stressResponse, TN&TP (2017-01-02).docx

Significance levels: '***'p<0.001; '**'p<0.01; '*'p<0.05; '+'p<0.10

Notes: Figure on how to look at hierarchical linear regression (keep in mind this isn't Hierarchical Linear Modeling [HLM; multilevel modeling). Orange boxes from this page cross walk to next page's orange boxes). Selected "model.4"s adjusted R2, and corresponding coefficient/sign. Level to give a sense of whether the model had any value (R2), and whether the coefficient is in the right direction (+/-).

Regression Options (with Nutrient Stressor)

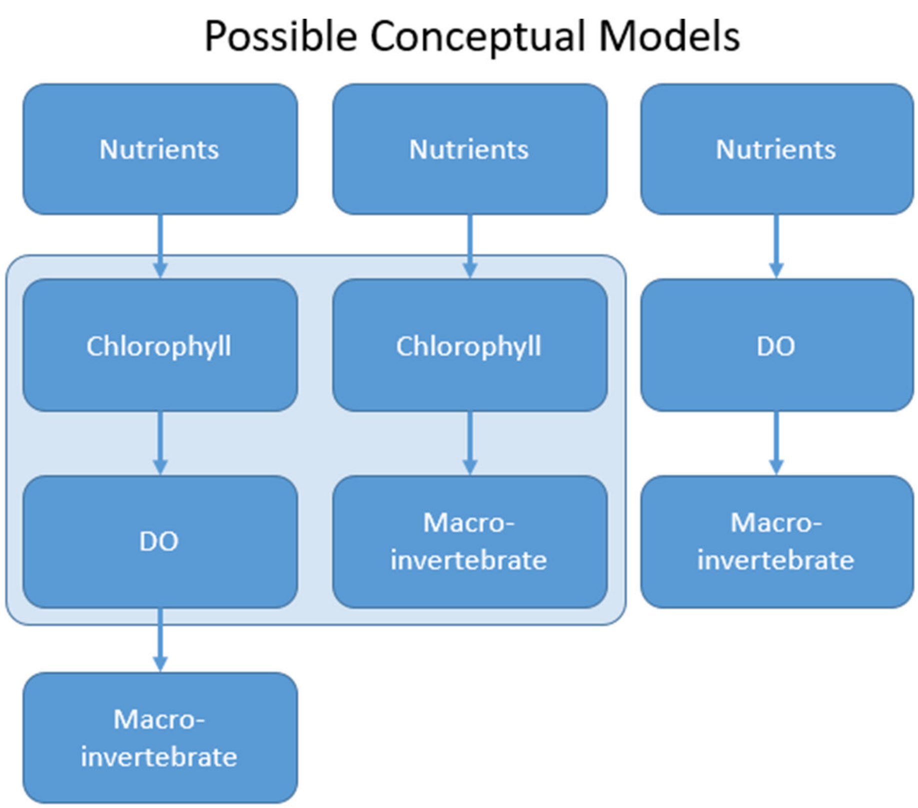
			Nutrient			Level III		
	Response Var	Stressor	Adj.R.Squared	Model Coeff.	Sign.	Adj.R.Squared	Model Coeff.	Sign.
	Cor. Chl-a, Seas. [µg/L]	Total Nitrogen, Seas. [mg/L]	0.2479	-0.06793	+	0.2771	-0.05199	-
		Total Phosphorus, Seas. [mg/L]	0.2547	0.10837	**	0.2839	0.10263	**
	Cor. Chl-a, Seas., C2A<=28d	Total Nitrogen, Seas. [mg/L]	0.1462	-0.01392	-	0.1702	-0.01060	-
		Total Phosphorus, Seas. [mg/L]	0.1661	0.15125	***	0.1851	0.13258	**
Grab	Diss. Oxygen, Seas. [mg/L]	Total Nitrogen, Seas. [mg/L]	0.3358	0.79818	***	0.2925	1.01823	***
Grab		Total Phosphorus, Seas. [mg/L]	0.3160	-0.34969	**	0.2625	-0.48636	***
Grab	Diss. Oxygen [mg/L]	Total Nitrogen, Seas. [mg/L]	0.3052	0.69316	***	0.2700	0.88345	***
Grab		Total Phosphorus, Seas. [mg/L]	0.2902	-0.29093	*	0.2473	-0.41236	**
Continuous	Minimum 24-Hr DO [mg/L]	Total Nitrogen, Seas. [mg/L]	0.3016	0.92767	***	0.2716	1.24574	***
Continuous		Total Phosphorus, Seas. [mg/L]	0.2773	-0.44354	**	0.2184	-0.52963	**
Continuous	Average 24-Hr DO [mg/L]	Total Nitrogen, Seas. [mg/L]	0.4116	0.97918	***	0.3780	1.31094	***
Continuous		Total Phosphorus, Seas. [mg/L]	0.3917	-0.50983	**	0.3334	-0.60635	***
Continuous	Maximum 24-Hr DO [mg/L]	Total Nitrogen, Seas. [mg/L]	0.3804	1.13454	***	0.3562	1.52235	***
Continuous		Total Phosphorus, Seas. [mg/L]	0.3709	-0.65805	*	0.3333	-0.78859	**
Continuous	Delta 24-Hr DO [mg/L]	Total Nitrogen, Seas. [mg/L]	0.1920	0.20687	-	0.1927	0.27661	-
Continuous		Total Phosphorus, Seas. [mg/L]	0.1924	-0.21451	-	0.1929	-0.25895	-

Illinois EPA stressResponse, TN&TP (2017-01-02).docx
Significance levels: '***' $p<0.001$; '**' $p<0.01$; '*' $p<0.05$; '+' $p<0.10$

Notes: Orange box is just a reference back to the orange boxes on previous page.

Regression Options (with Chlorophyll-*a*)

- Sestonic Chlorophyll
    - Seasonal Geometric Mean Chl-*a*
    - Seasonal Geometric Mean Chl-*a* (<=28d)
- Dissolved Oxygen
    - Grab
        - Minimum 24-Hr DO [mg/L]
        - Average 24-Hr DO [mg/L]
    - Continuous
        - Maximum 24-Hr DO [mg/L]
        - Delta 24-Hr DO [mg/L]
        - Diss. Oxygen, Seas. [mg/L]
        - Diss. Oxygen [mg/L]
- Biology
    - Fish IBI Score
    - Macroinvertebrate IBI [mIBI]
    - Richness Score
    - Coleoptera Score
    - Ephemeroptera Score
    - Intolerant Taxa Score
    - MBI Score
    - EPT Score
    - Scraper Score



Regression Options (with Chl-*a* Stressor)

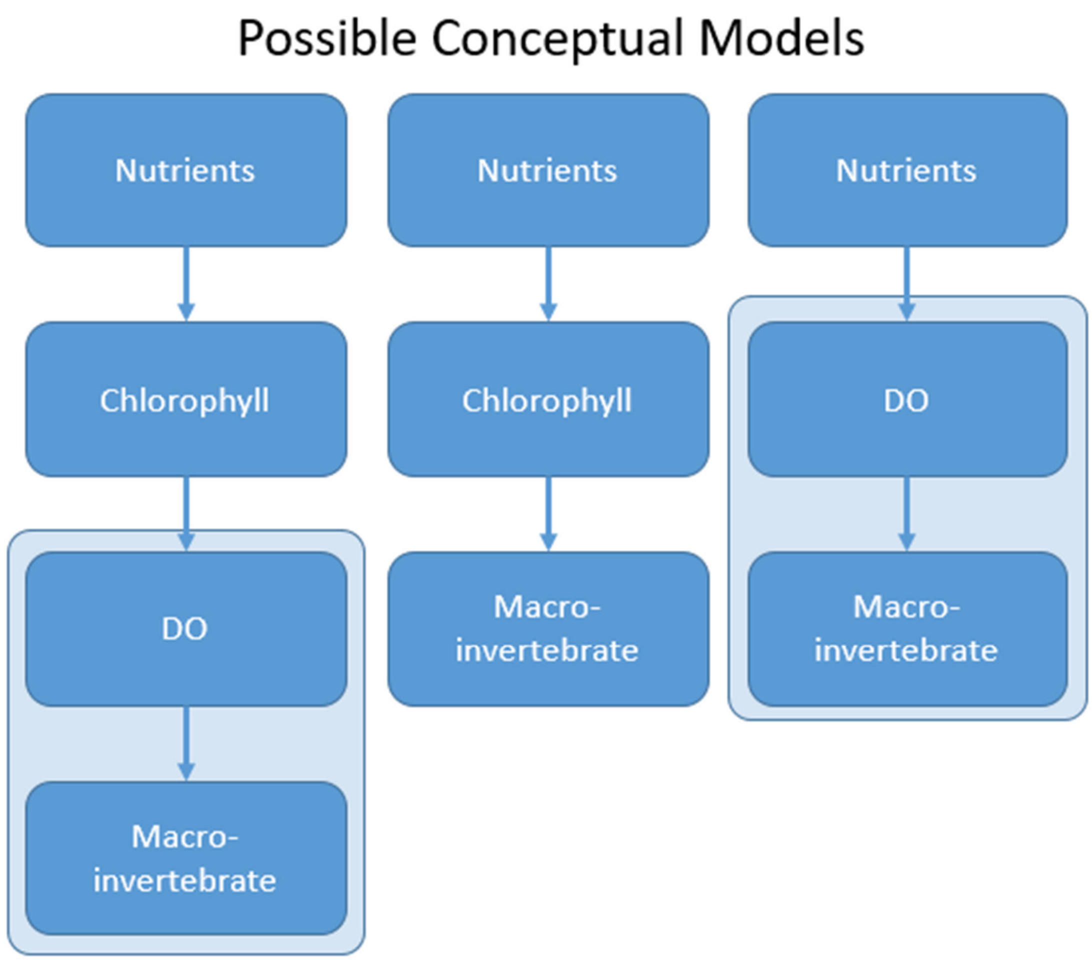
			Nutrient			Level III		
	Response Var	Stressor	Adj.R.Squared	Model Coeff.	Sign.	Adj.R.Squared	Model Coeff.	Sign.
Grab	Diss. Oxygen, Seas. [mg/L]	Cor. Chl-a, Seas. [µg/L]	0.3336	-0.04272	-	0.2557	-0.07002	-
		Cor. Chl-a, Seas., C2A<=28d [µg/L]	0.3060	-0.11301	-	0.2308	-0.17410	-
	Diss. Oxygen [mg/L]	Cor. Chl-a, Seas. [µg/L]	0.2978	-0.01843	-	0.2373	-0.03680	-
		Cor. Chl-a, Seas., C2A<=28d [µg/L]	0.2867	-0.09440	-	0.2241	-0.13829	-
Continuous	Minimum 24-Hr DO [mg/L]	Cor. Chl-a, Seas. [µg/L]	0.2738	0.41825	*	0.2155	0.44222	*
		Cor. Chl-a, Seas., C2A<=28d [µg/L]	0.3317	0.58359	*	0.2780	0.44549	+
	Average 24-Hr DO [mg/L]	Cor. Chl-a, Seas. [µg/L]	0.3915	0.48241	**	0.3331	0.53017	**
		Cor. Chl-a, Seas., C2A<=28d [µg/L]	0.4181	0.73491	**	0.3612	0.62428	*
	Maximum 24-Hr DO [mg/L]	Cor. Chl-a, Seas. [µg/L]	0.3690	0.61117	*	0.3311	0.68831	*
		Cor. Chl-a, Seas., C2A<=28d [µg/L]	0.3562	1.05582	**	0.3160	0.96272	*
	Delta 24-Hr DO [mg/L]	Cor. Chl-a, Seas. [µg/L]	0.1894	0.19291	-	0.1899	0.24609	-
		Cor. Chl-a, Seas., C2A<=28d [µg/L]	0.1378	0.47223	-	0.1358	0.51723	-
	Fish IBI Score	Cor. Chl-a, Seas. [µg/L]	0.1629	-3.12331	**	0.1659	-2.86104	**
		Cor. Chl-a, Seas., C2A<=28d [µg/L]	0.2179	-1.61723	-	0.2104	-1.74345	-
	Macroinvertebrate IBI	Cor. Chl-a, Seas. [µg/L]	0.2872	-5.97106	***	0.2407	-6.29385	***
		Cor. Chl-a, Seas., C2A<=28d [µg/L]	0.3268	-6.07718	***	0.2773	-5.99384	**
	Richness Score	Cor. Chl-a, Seas. [µg/L]	0.0856	-4.55136	**	0.0924	-4.48189	**
		Cor. Chl-a, Seas., C2A<=28d [µg/L]	0.0834	-5.35826	**	0.1120	-4.10640	*
	Coleoptera Score	Cor. Chl-a, Seas. [µg/L]	0.1429	-6.56298	**	0.1115	-7.82625	**
		Cor. Chl-a, Seas., C2A<=28d [µg/L]	0.1476	-10.34384	**	0.1116	-9.91756	**
	Ephemeroptera Score	Cor. Chl-a, Seas. [µg/L]	0.1751	-6.28503	**	0.1609	-5.94132	**
		Cor. Chl-a, Seas., C2A<=28d [µg/L]	0.2175	-7.44378	**	0.1974	-7.36866	*
	Intolerant Taxa Score	Cor. Chl-a, Seas. [µg/L]	0.1992	-7.35514	**	0.1660	-7.95836	**
		Cor. Chl-a, Seas., C2A<=28d [µg/L]	0.2364	-7.63212	*	0.1951	-7.54829	*
	MBI Score	Cor. Chl-a, Seas. [µg/L]	0.2643	-7.30421	***	0.2116	-7.80431	***
		Cor. Chl-a, Seas., C2A<=28d [µg/L]	0.2581	-6.62552	***	0.2000	-6.95685	***
	EPT Score	Cor. Chl-a, Seas. [µg/L]	0.2334	-1.45231	-	0.2009	-1.71176	-
		Cor. Chl-a, Seas., C2A<=28d [µg/L]	0.2583	-1.15740	-	0.2190	-3.30622	-
	Scraper Score	Cor. Chl-a, Seas. [µg/L]	0.0885	-8.28640	***	0.0870	-8.33303	**
		Cor. Chl-a, Seas., C2A<=28d [µg/L]	0.0811	-3.97932	-	0.0831	-2.75288	-

Illinois EPA stressResponse, chlac (2017-01-29).docx 6

Significance levels: '***'p<0.001; '**'p<0.01; '*'p<0.05; '+'p<0.10

Regression Options (with Continuous DO)

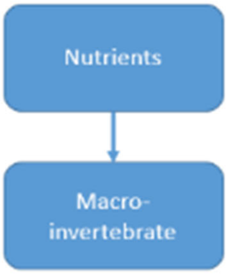
- Dissolved Oxygen
  - Minimum 24-Hr DO [mg/L]
  - Average 24-Hr DO [mg/L]
  - Maximum 24-Hr DO [mg/L]
  - Delta 24-Hr DO [mg/L]
- Biology
  - Fish IBI Score
  - Macroinvertebrate IBI [mIBI]
  - Richness Score
  - Coleoptera Score
  - Ephemeroptera Score
  - Intolerant Taxa Score
  - MBI Score
  - EPT Score
  - Scraper Score



Regression Options (with DO Stressor)

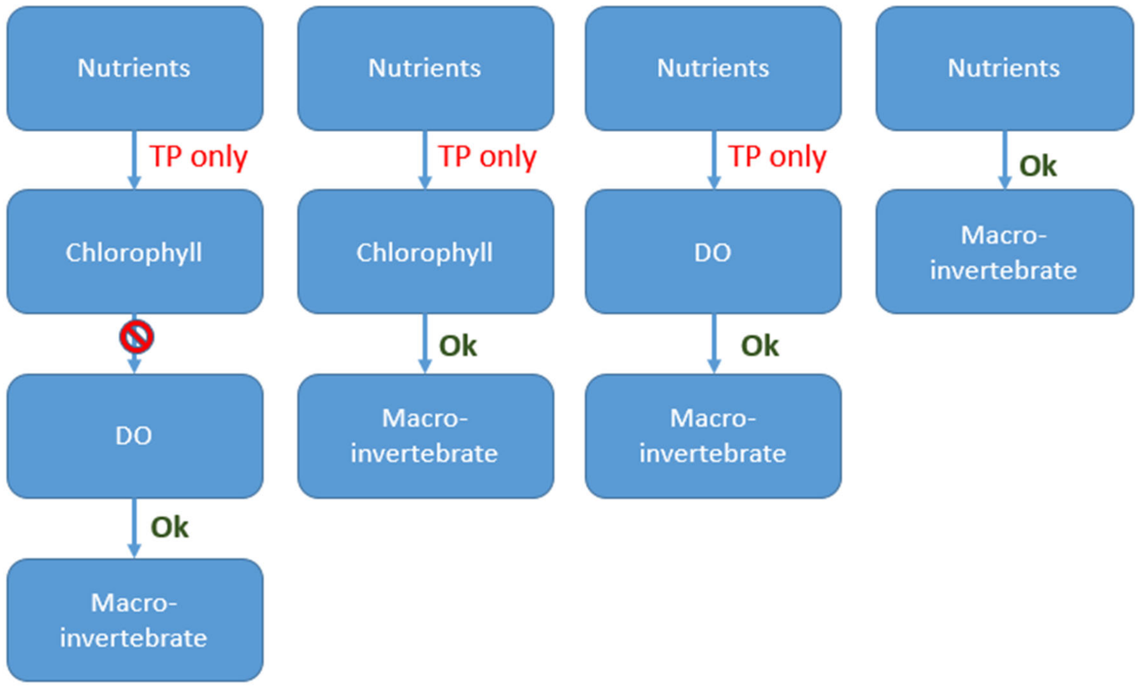
		Nutrient			Level III		
Response Var	Stressor	Adj.R.Squared	Model Coeff.	Sign.	Adj.R.Squared	Model Coeff.	Sign.
Fish IBI Score	Minimum 24-Hr DO [mg/L]	0.1689	1.15422	**	0.1828	1.37530	***
	Average 24-Hr DO [mg/L]	0.1664	1.09080	**	0.1805	1.32654	***
	Maximum 24-Hr DO [mg/L]	0.1556	0.46667	*	0.1654	0.61694	**
	Delta 24-Hr DO [mg/L]	0.1465	0.00141	-	0.1490	0.05303	-
Macroinvertebrate IBI	Minimum 24-Hr DO [mg/L]	0.2987	1.90905	***	0.2867	3.07109	***
	Average 24-Hr DO [mg/L]	0.2916	1.57415	***	0.2782	2.79400	***
	Maximum 24-Hr DO [mg/L]	0.2801	0.58469	+	0.2486	1.29656	***
	Delta 24-Hr DO [mg/L]	0.2748	-0.18709	-	0.2182	0.08273	-
Richness Score	Minimum 24-Hr DO [mg/L]	0.0779	0.61054	-	0.1129	1.19245	**
	Average 24-Hr DO [mg/L]	0.0750	0.18717	-	0.1059	0.80316	+
	Maximum 24-Hr DO [mg/L]	0.0761	-0.25152	-	0.0996	0.09816	-
	Delta 24-Hr DO [mg/L]	0.0809	-0.56525	+	0.1036	-0.46448	-
Coleoptera Score	Minimum 24-Hr DO [mg/L]	0.1892	1.80814	*	0.1859	3.75821	***
	Average 24-Hr DO [mg/L]	0.1844	1.10877	-	0.1760	3.12912	***
	Maximum 24-Hr DO [mg/L]	0.1816	0.20243	-	0.1599	1.29944	*
	Delta 24-Hr DO [mg/L]	0.1831	-0.58217	-	0.1491	-0.25069	-
Ephemeroptera Score	Minimum 24-Hr DO [mg/L]	0.1749	3.11230	***	0.1871	4.27804	***
	Average 24-Hr DO [mg/L]	0.1702	2.76979	***	0.1827	3.99116	***
	Maximum 24-Hr DO [mg/L]	0.1558	1.05971	*	0.1567	1.82497	***
	Delta 24-Hr DO [mg/L]	0.1479	-0.18228	-	0.1314	0.13835	-
Intolerant Taxa Score	Minimum 24-Hr DO [mg/L]	0.2113	3.54313	***	0.2158	5.17246	***
	Average 24-Hr DO [mg/L]	0.2039	2.98906	***	0.2072	4.69006	***
	Maximum 24-Hr DO [mg/L]	0.1890	1.05780	+	0.1758	2.07532	***
	Delta 24-Hr DO [mg/L]	0.1831	-0.37878	-	0.1489	0.00651	-
MBI Score	Minimum 24-Hr DO [mg/L]	0.2687	1.55943	***	0.2392	2.74731	***
	Average 24-Hr DO [mg/L]	0.2617	1.27350	**	0.2316	2.53744	***
	Maximum 24-Hr DO [mg/L]	0.2497	0.41546	-	0.1953	1.15237	***
	Delta 24-Hr DO [mg/L]	0.2465	-0.22446	-	0.1609	0.06483	-
EPT Score	Minimum 24-Hr DO [mg/L]	0.2202	4.46312	***	0.2201	5.66843	***
	Average 24-Hr DO [mg/L]	0.2108	3.92143	***	0.2154	5.35394	***
	Maximum 24-Hr DO [mg/L]	0.1905	1.74277	**	0.1840	2.72002	***
	Delta 24-Hr DO [mg/L]	0.1715	-0.00423	-	0.1366	0.55327	-
Scraper Score	Minimum 24-Hr DO [mg/L]	0.0968	-1.73330	+	0.1041	-1.31928	-
	Average 24-Hr DO [mg/L]	0.0934	-1.23070	-	0.1021	-0.94686	-
	Maximum 24-Hr DO [mg/L]	0.0898	-0.13380	-	0.0998	-0.09435	-
	Delta 24-Hr DO [mg/L]	0.0918	0.62752	-	0.1012	0.53134	-
Illinois EPA stressResponse, contDO (2017-01-02).docx							
Significance levels: '***'p<0.001; '**'p<0.01; '*'p<0.05; '+'p<0.10							

Other Regression Options (w/ Nutrient Stressor)



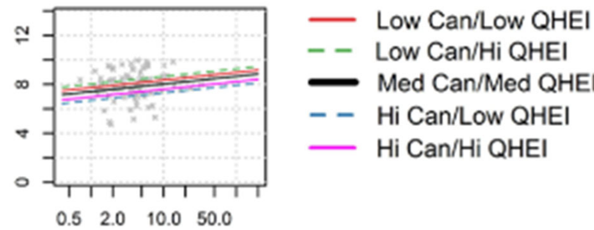
		Nutrient			Level III		
Response Var	**Stressor**	**Adj.R.Squared**	**Model Coeff.**	**Sign.**	**Adj.R.Squared**	**Model Coeff.**	**Sign.**
Fish IBI Score	Total Nitrogen, Seas. [mg/L]	0.16	-2.5858	*	0.16	-1.6283	-
	Total Phosphorus, Seas. [mg/L]	0.20	-6.3592	***	0.21	-6.3942	***
Macroinvertebrate IBI	Total Nitrogen, Seas. [mg/L]	0.29	-6.7006	***	0.23	-0.9122	-
	Total Phosphorus, Seas. [mg/L]	0.34	-11.0708	***	0.29	-10.8107	***
Richness Score	Total Nitrogen, Seas. [mg/L]	0.09	-6.3836	***	0.09	-3.5823	*
	Total Phosphorus, Seas. [mg/L]	0.13	-9.4336	***	0.13	-8.8785	***
Coleoptera Score	Total Nitrogen, Seas. [mg/L]	0.14	-6.5609	*	0.10	0.0011	-
	Total Phosphorus, Seas. [mg/L]	0.15	-9.3069	***	0.12	-9.1198	***
Ephemeroptera Score	Total Nitrogen, Seas. [mg/L]	0.19	-10.8203	***	0.16	-2.8308	-
	Total Phosphorus, Seas. [mg/L]	0.28	-21.4555	***	0.26	-20.9539	***
Intolerant Taxa Score	Total Nitrogen, Seas. [mg/L]	0.21	-9.1050	***	0.16	0.5960	-
	Total Phosphorus, Seas. [mg/L]	0.26	-17.6183	***	0.22	-17.1391	***
MBI Score	Total Nitrogen, Seas. [mg/L]	0.23	-1.6509	-	0.17	3.3693	*
	Total Phosphorus, Seas. [mg/L]	0.25	-6.2744	***	0.19	-5.9448	***
EPT Score	Total Nitrogen, Seas. [mg/L]	0.24	-3.4613	-	0.20	4.2789	+
	Total Phosphorus, Seas. [mg/L]	0.25	-9.6048	***	0.22	-9.6343	***
Scraper Score	Total Nitrogen, Seas. [mg/L]	0.09	-8.9224	***	0.09	-8.2173	**
	Total Phosphorus, Seas. [mg/L]	0.08	-3.8021	+	0.08	-4.0046	+
Illinois EPA stressResponse, TN&TP (2017-01-02).docx							
Significance levels: '***'p<0.001; '**'p<0.01; '*'p<0.05; '+'p<0.10							

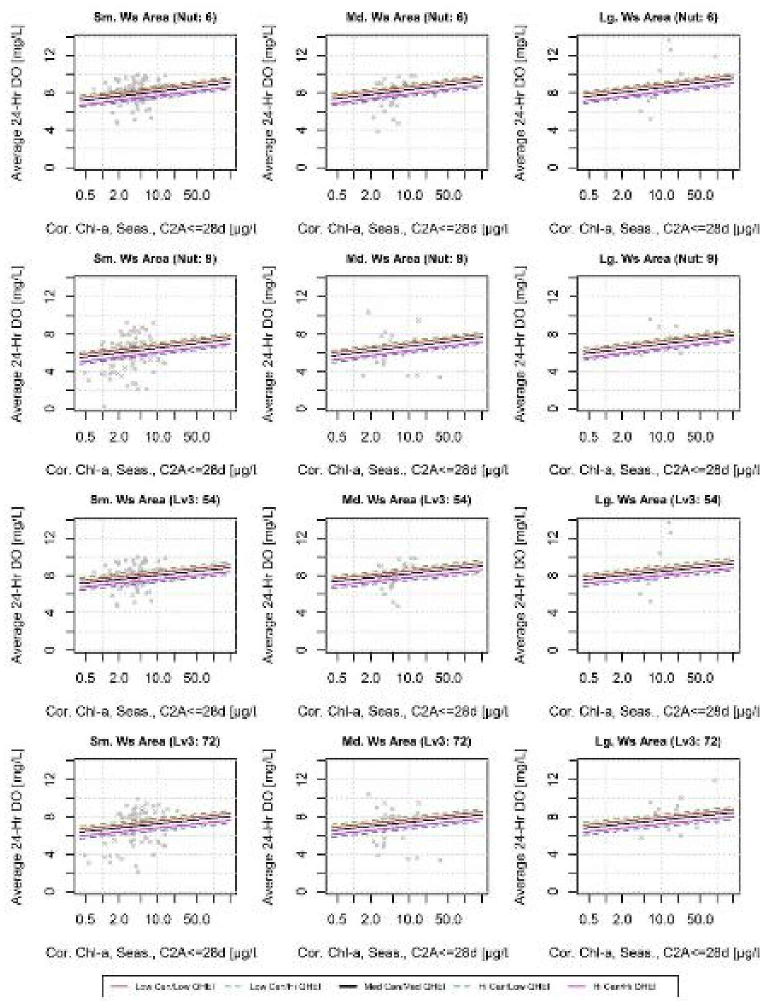
Possible Conceptual Models



Prediction Plot Organization

- Columns:
  - Small Watersheds – 93.44 km^2
  - Medium Watersheds – 325.5 km^2
  - Large Watersheds – 1689 km^2
- Rows:
  - Nutrient Ecoregion 6 & 9
  - Level III Ecoregions 54 and 72
- Prediction lines: (see right)





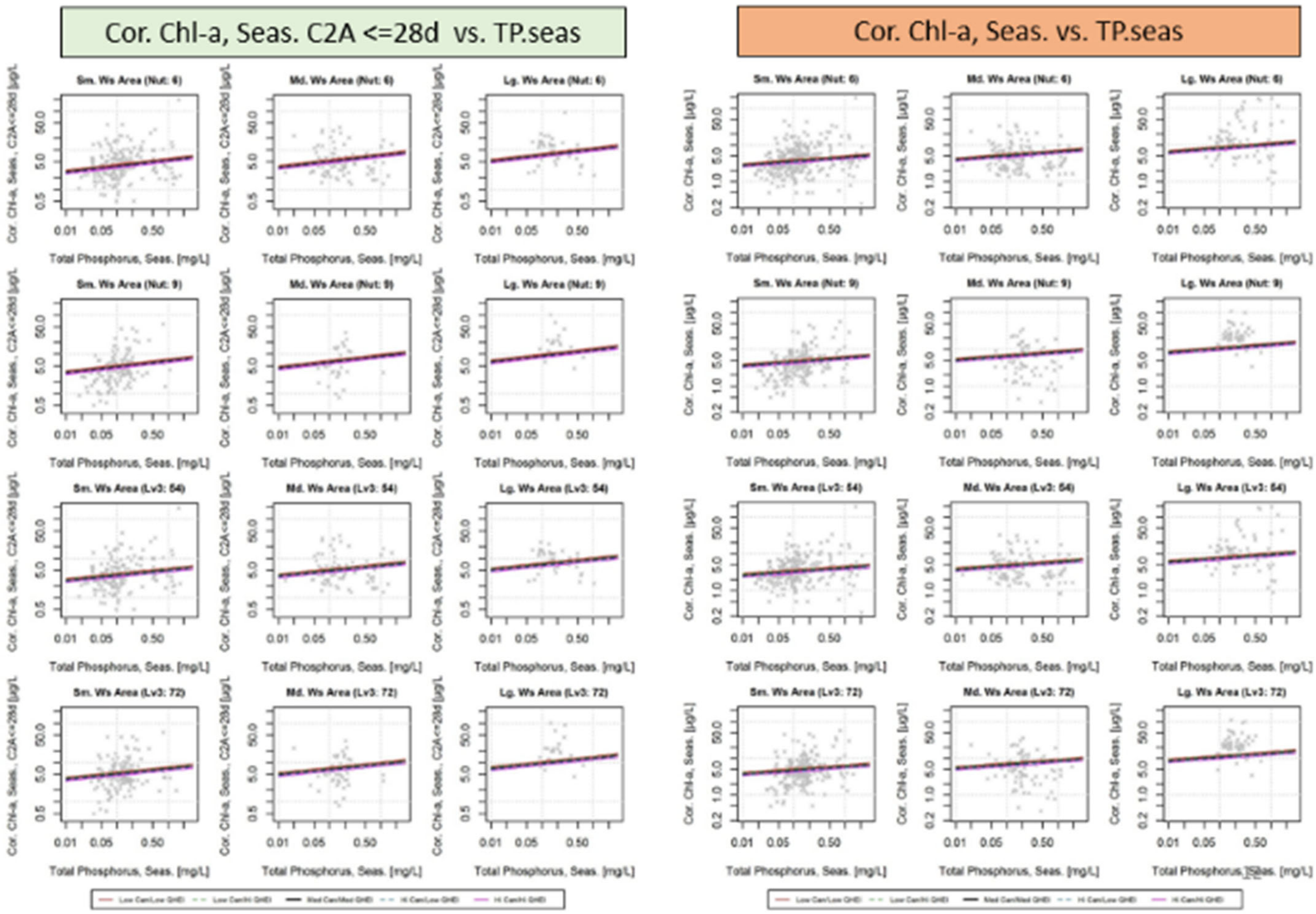
Notes: low, medium, high QHEI_SCORE (quartiles of all data)

1st Qu.	Median	3rd Qu.
49.0	59.5	70.0

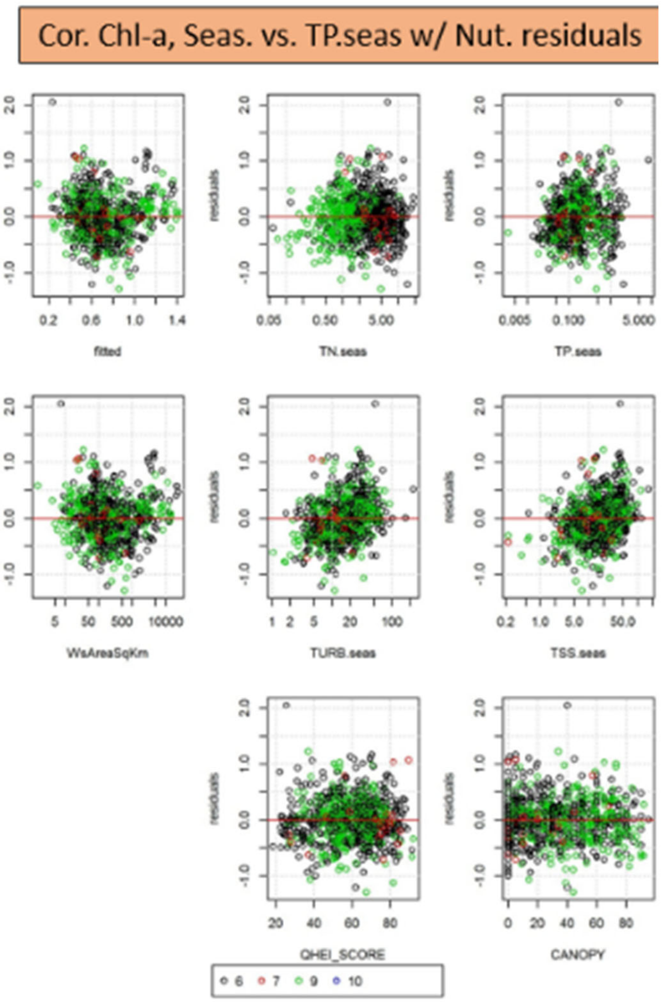
low, medium, high CANOPY (quartiles of all data)

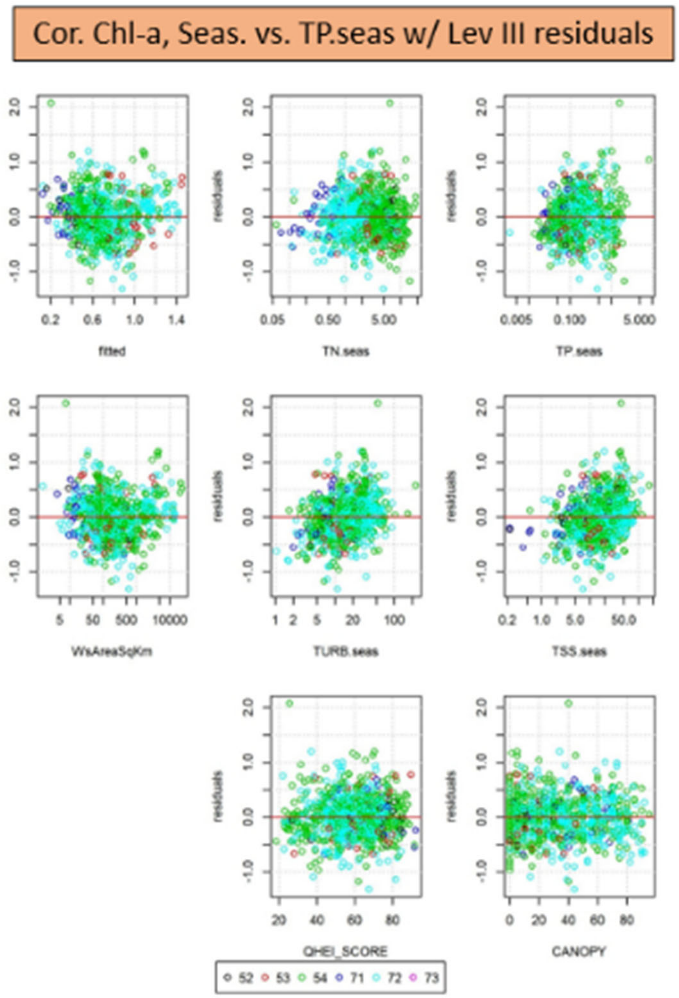
1st Qu.	Median	3rd Qu.
10	30	55

Solid red/magenta on outside Canopy/QHEI have same sign
Dashed green/blue on outside Canopy/QHEI have opposite sign

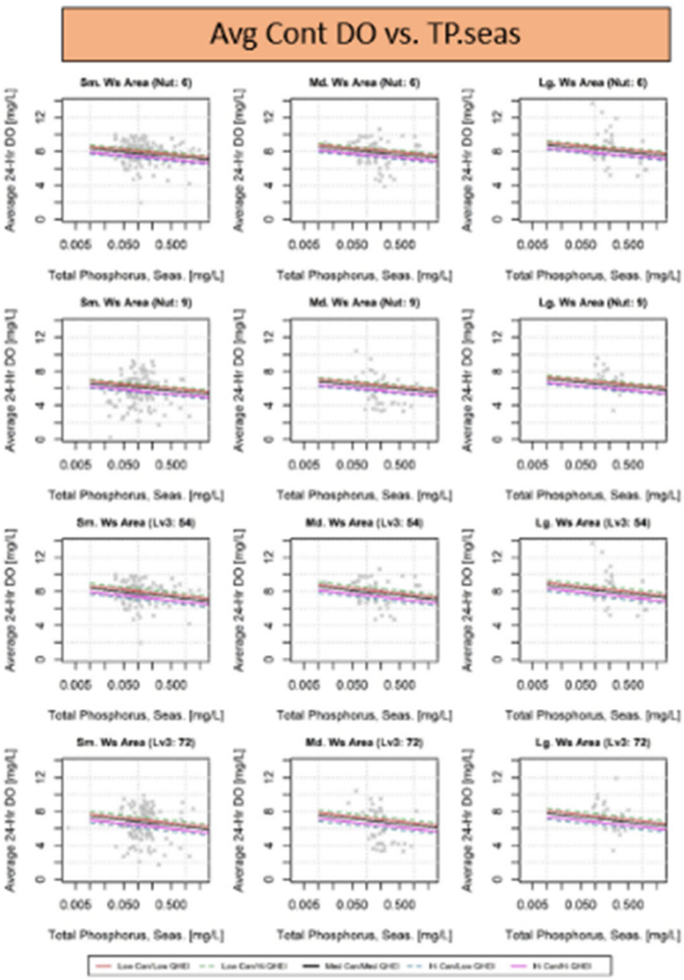


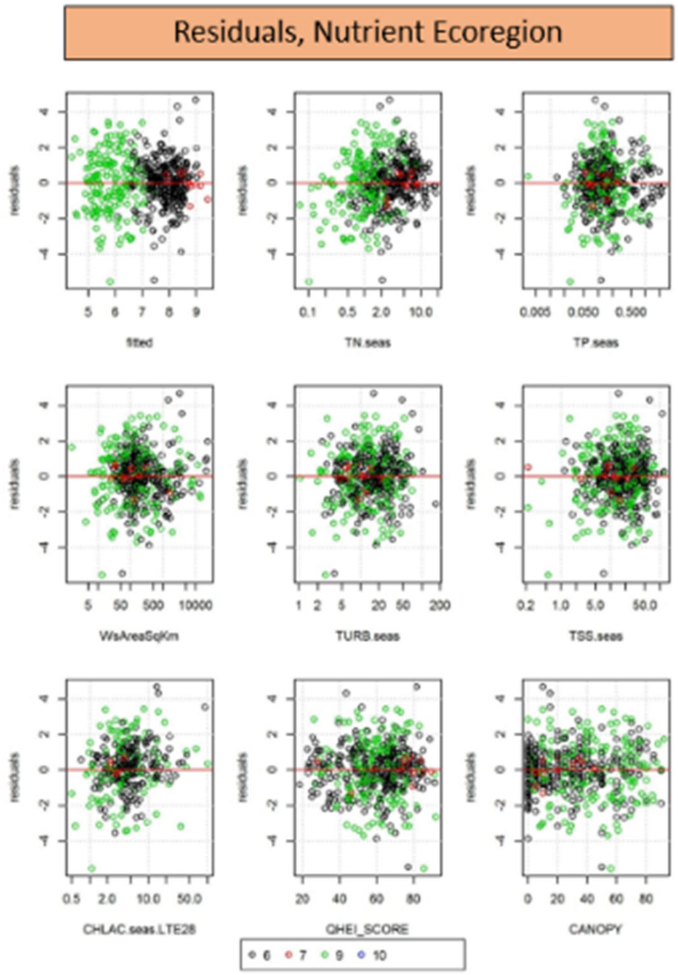
Notes:
Y-axis left panel: Cor. Chl-a, Seas., C2A<=28d [µg/L]
Y-axis right panel: Cor. Chl-a, Seas. [µg/L]



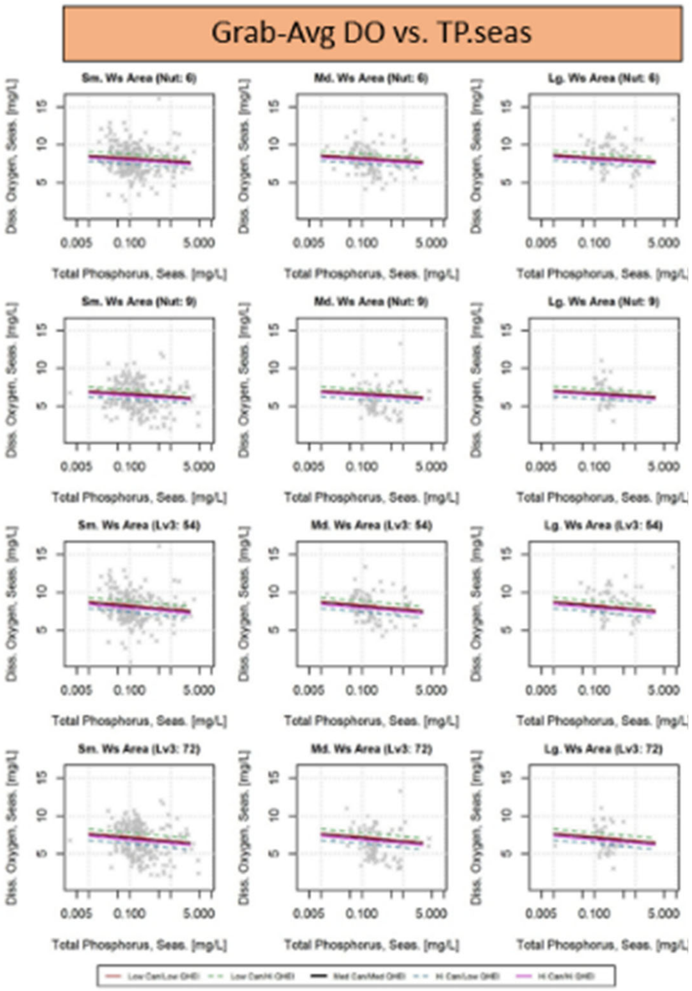


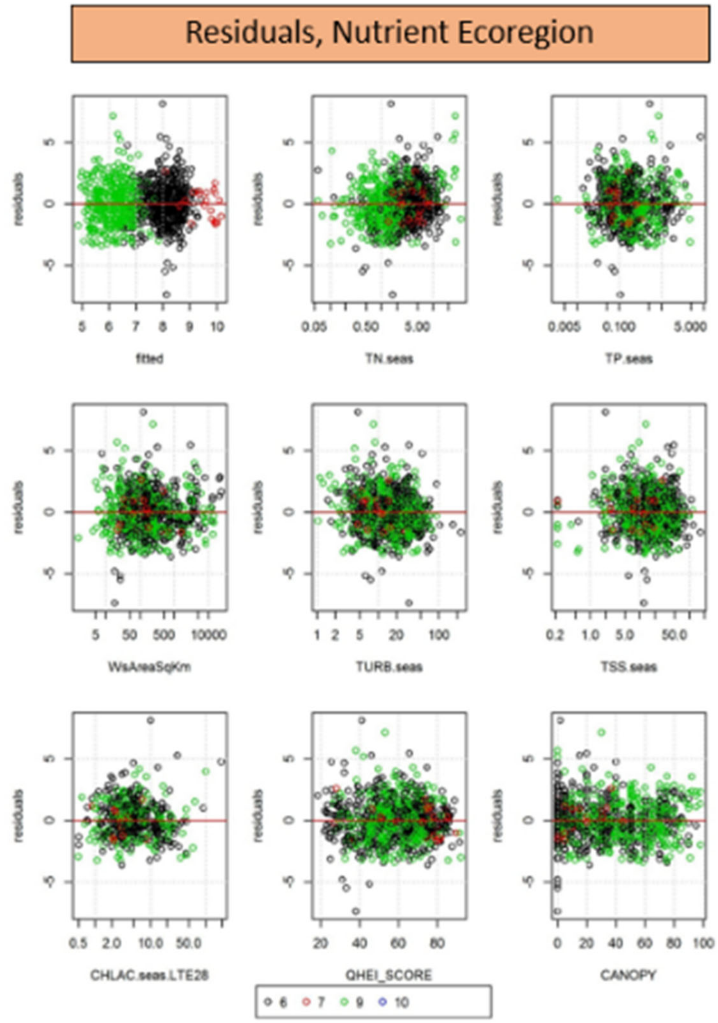
Notes:
Can get a 0.15 increase in R2 for CHLAC.seas by adding watershed^2, TSS, and turbidity
Can get a 0.1-0.15 increase in R2 for CHLAC.seas.LTE28 **vs TP** by adding watershed^2, TSS, and turbidity





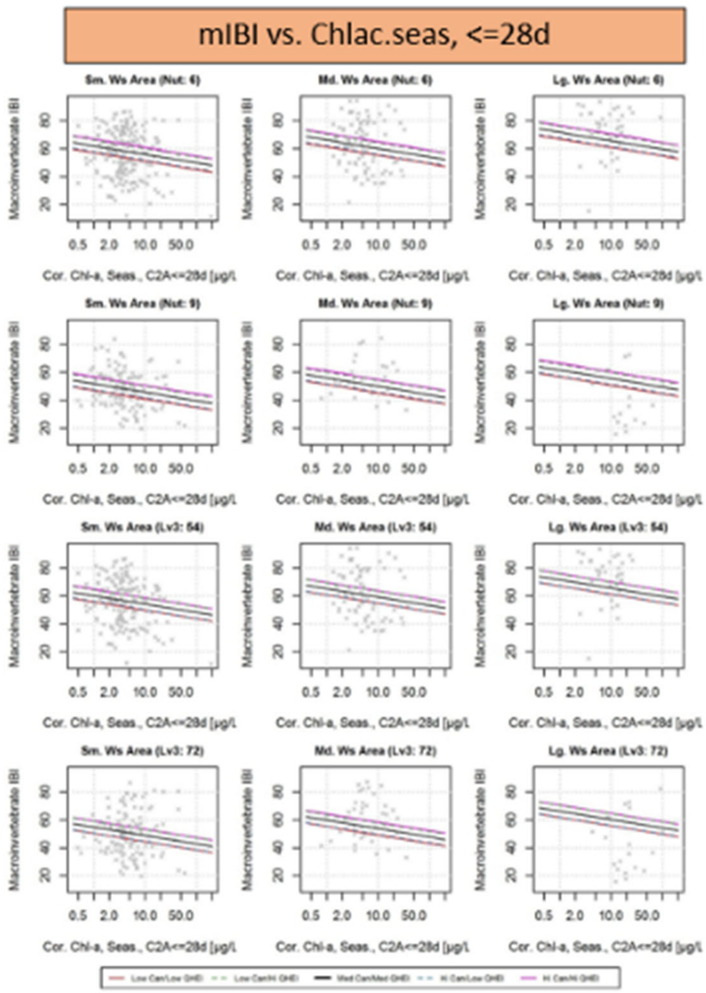
Notes:
Marginal differences in R2 for doMeanCont by adding watershed^2, TSS, and turbidity

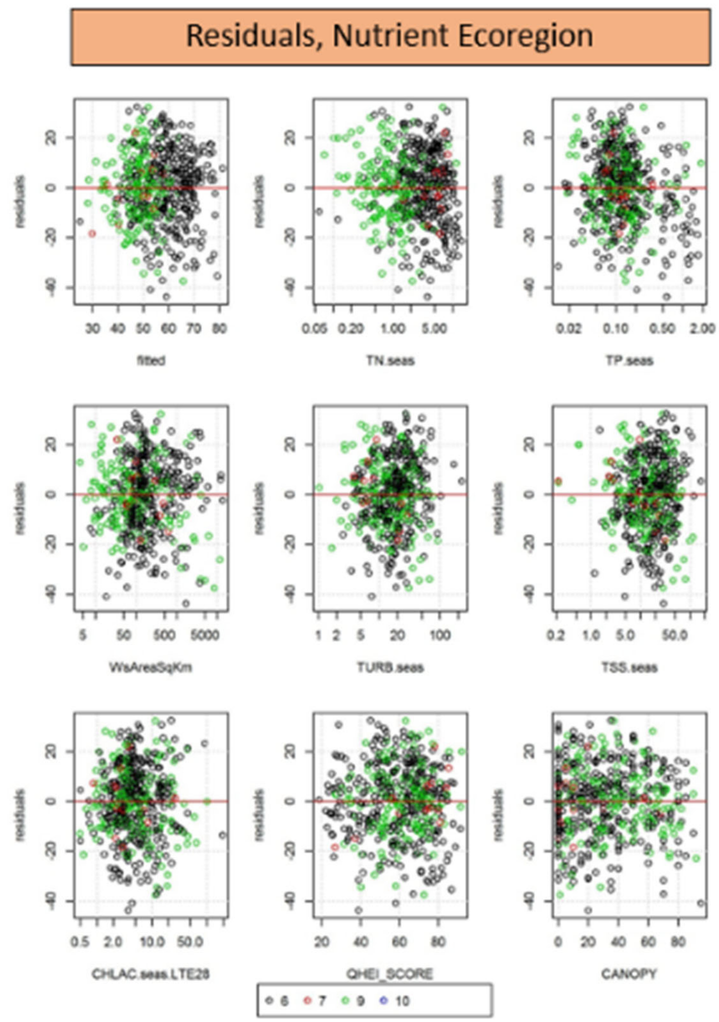


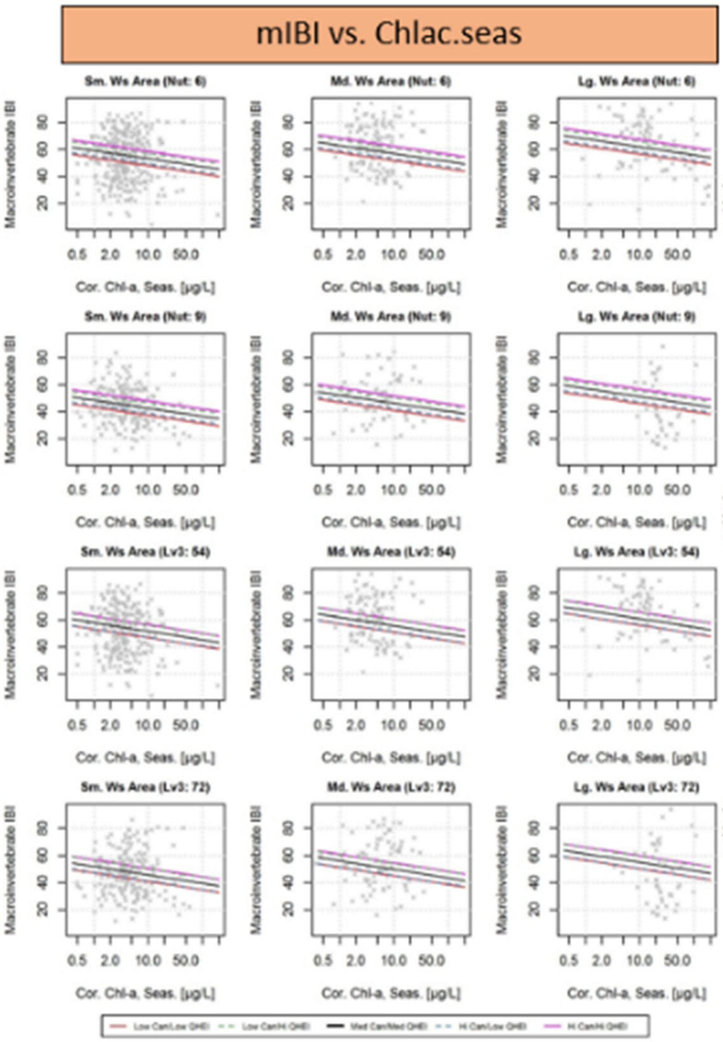


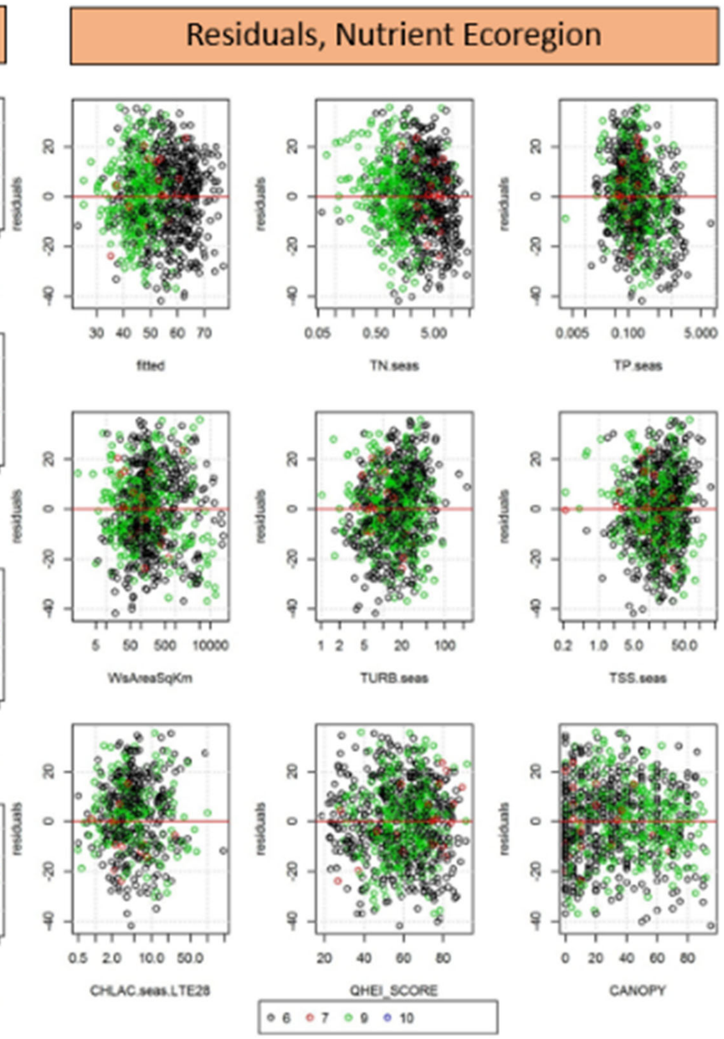
Notes:

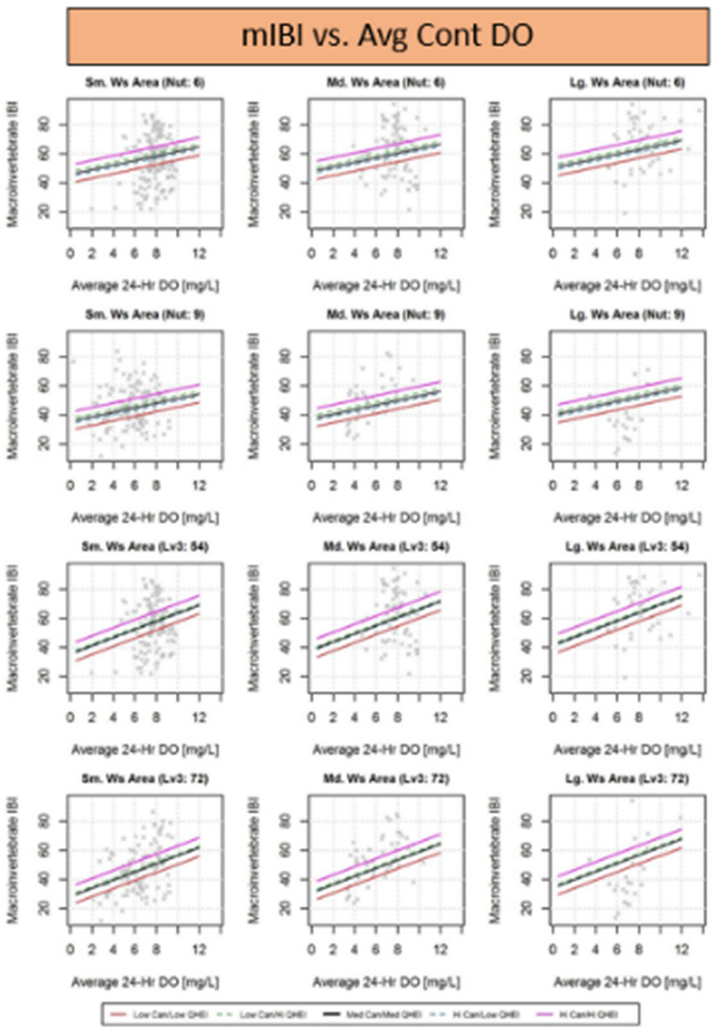
<0.03 increase in R2 for DO.seas by adding watershed^2, TSS, and turbidity

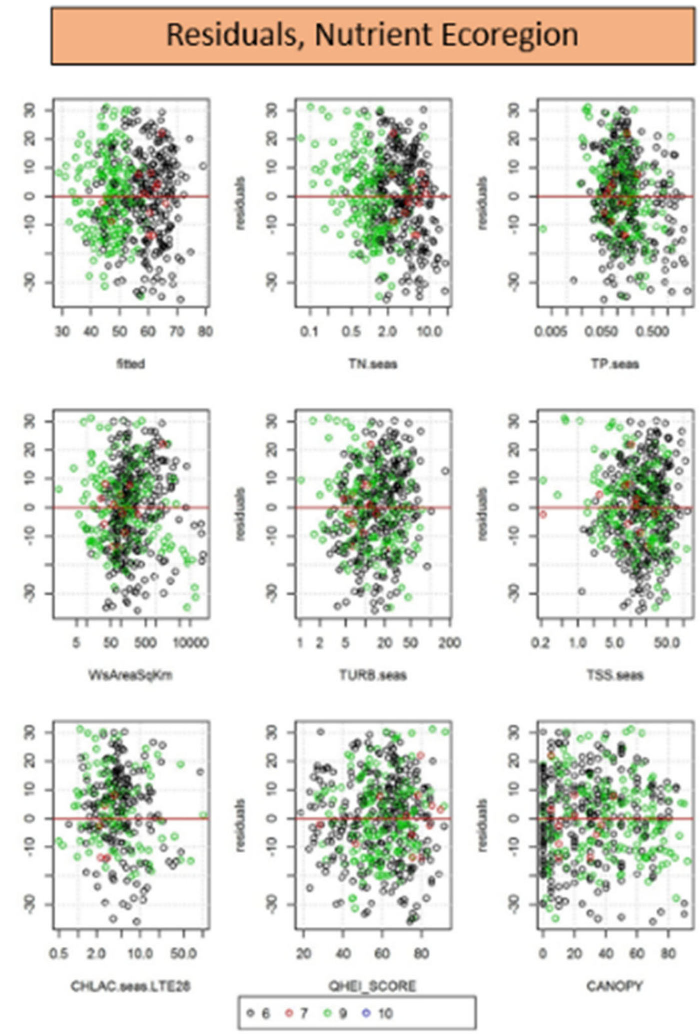

mIBI vs. Chlac.seas, <=28d
Sm. Ws Area (Nut: 6)
Md. Ws Area (Nut: 6)
Lg. Ws Area (Nut: 6)
Sm. Ws Area (Nut: 9)
Md. Ws Area (Nut: 9)
Lg. Ws Area (Nut: 9)
Sm. Ws Area (Lv3: 54)
Md. Ws Area (Lv3: 54)
Lg. Ws Area (Lv3: 54)
Sm. Ws Area (Lv3: 72)
Md. Ws Area (Lv3: 72)
Lg. Ws Area (Lv3: 72)
Macroinvertebrate IBI
Cor. Chl-a, Seas., C2A<=28d [µg/L

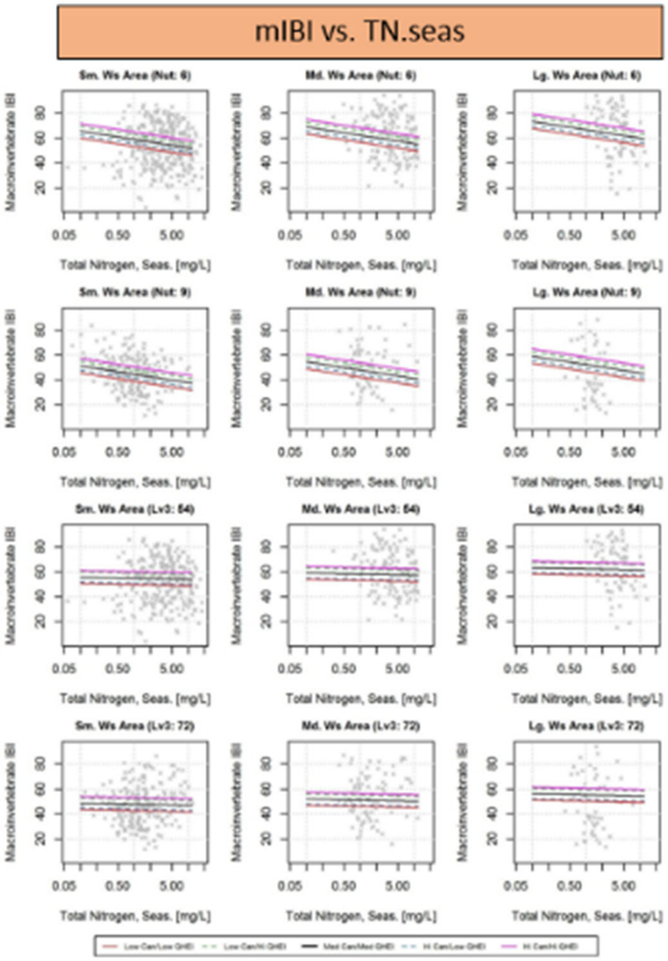

Residuals, Nutrient Ecoregion
residuals
fitted
TN.seas
TP.seas
WsAreaSqKm
TURB.seas
TSS.seas
CHLAC.seas.LTE28
QHEI_SCORE
CANOPY
6
7
9
10

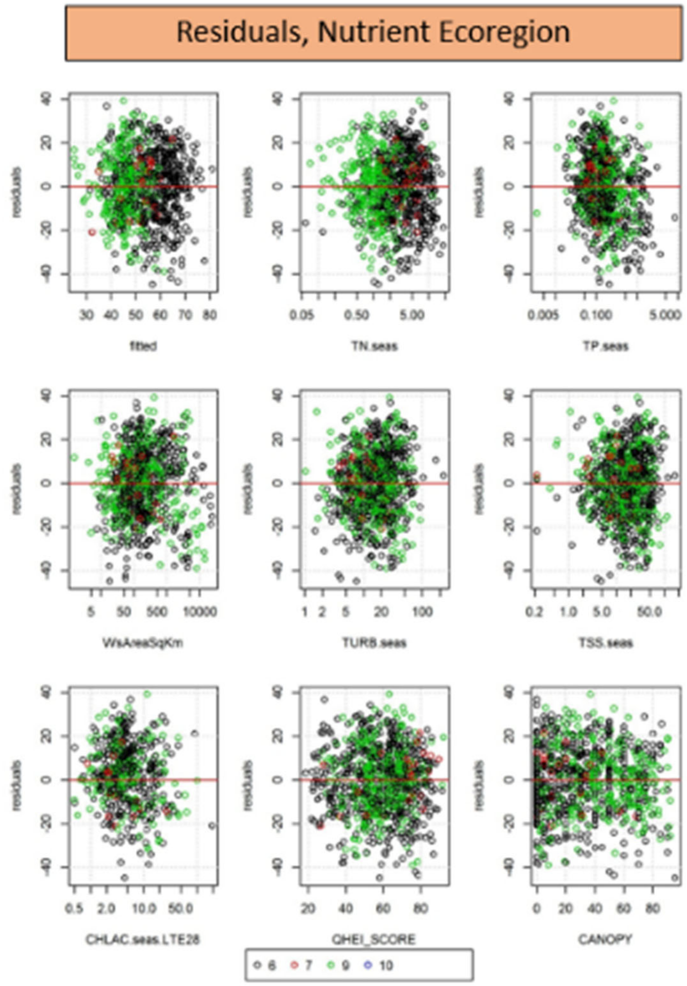

mIBI vs. Chlac.seas
Sm. Ws Area (Nut: 6)
Md. Ws Area (Nut: 6)
Lg. Ws Area (Nut: 6)
Sm. Ws Area (Nut: 9)
Md. Ws Area (Nut: 9)
Lg. Ws Area (Nut: 9)
Sm. Ws Area (Lv3: 54)
Md. Ws Area (Lv3: 54)
Lg. Ws Area (Lv3: 54)
Sm. Ws Area (Lv3: 72)
Md. Ws Area (Lv3: 72)
Lg. Ws Area (Lv3: 72)
Macroinvertebrate IBI
Cor. Chl-a, Seas. [µg/L]
Low Can/Low QHEI
Low Can/Hi QHEI
Med Can/Med QHEI
Hi Can/Low QHEI
Hi Can/Hi QHEI


Residuals, Nutrient Ecoregion
residuals
fitted
TN.seas
TP.seas
WsAreaSqKm
TURB.seas
TSS.seas
CHLAC.seas.LTE28
QHEI_SCORE
CANOPY
6
7
9
10


mIBI vs. Avg Cont DO
Sm. Ws Area (Nut: 6)
Md. Ws Area (Nut: 6)
Lg. Ws Area (Nut: 6)
Sm. Ws Area (Nut: 9)
Md. Ws Area (Nut: 9)
Lg. Ws Area (Nut: 9)
Sm. Ws Area (Lv3: 54)
Md. Ws Area (Lv3: 54)
Lg. Ws Area (Lv3: 54)
Sm. Ws Area (Lv3: 72)
Md. Ws Area (Lv3: 72)
Lg. Ws Area (Lv3: 72)
Macroinvertebrate IBI
Average 24-Hr DO [mg/L]


Residuals, Nutrient Ecoregion
residuals
fitted
TN.seas
TP.seas
WsAreaSqKm
TURB.seas
TSS.seas
CHLAC.seas.LTE28
QHEI_SCORE
CANOPY
6
7
9
10


mIBI vs. TN.seas
Sm. Ws Area (Nut: 6)
Md. Ws Area (Nut: 6)
Lg. Ws Area (Nut: 6)
Sm. Ws Area (Nut: 9)
Md. Ws Area (Nut: 9)
Lg. Ws Area (Nut: 9)
Sm. Ws Area (Lv3: 54)
Md. Ws Area (Lv3: 54)
Lg. Ws Area (Lv3: 54)
Sm. Ws Area (Lv3: 72)
Md. Ws Area (Lv3: 72)
Lg. Ws Area (Lv3: 72)
Macroinvertebrate IBI
Total Nitrogen, Seas. [mg/L]


Residuals, Nutrient Ecoregion
residuals
fitted
TN.seas
TP.seas
WsAreaSqKm
TURB.seas
TSS.seas
CHLAC.seas.LTE28
QHEI_SCORE
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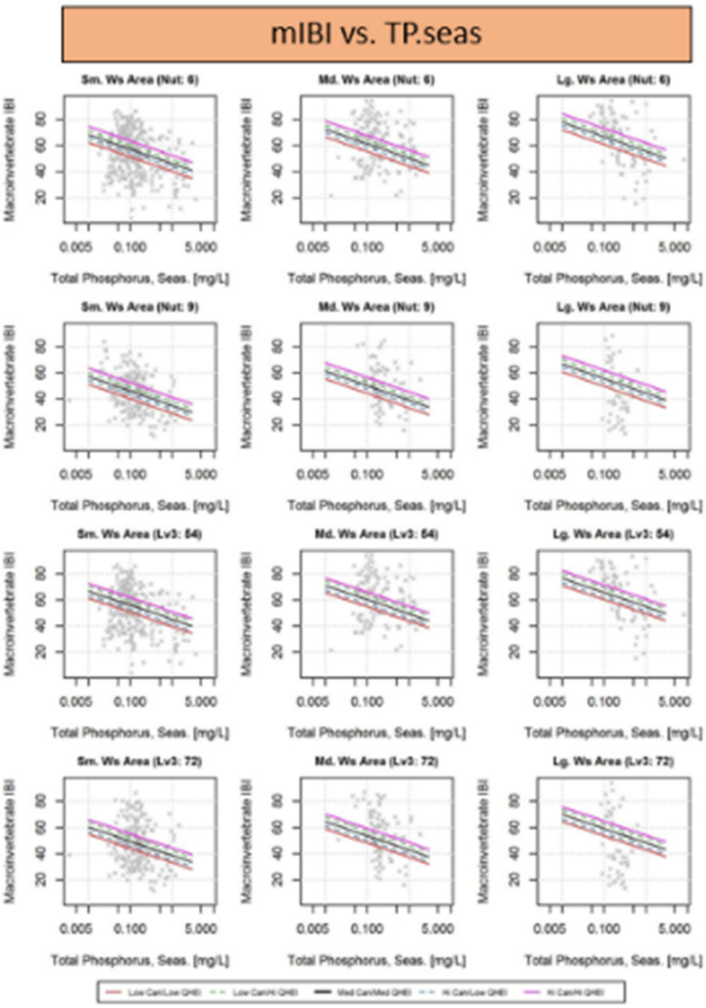
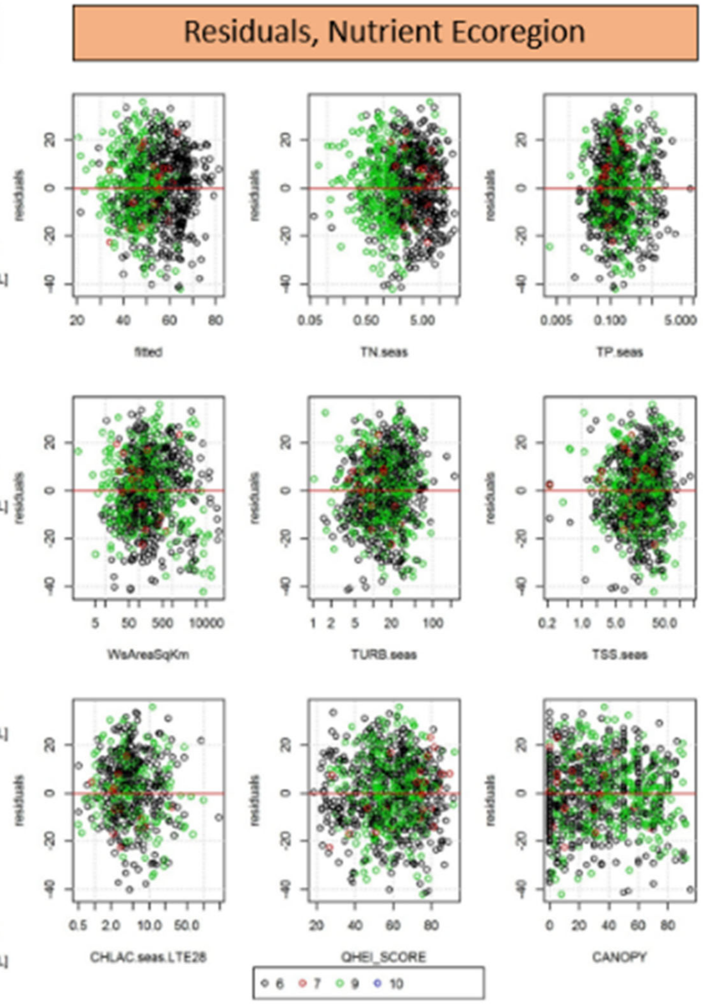
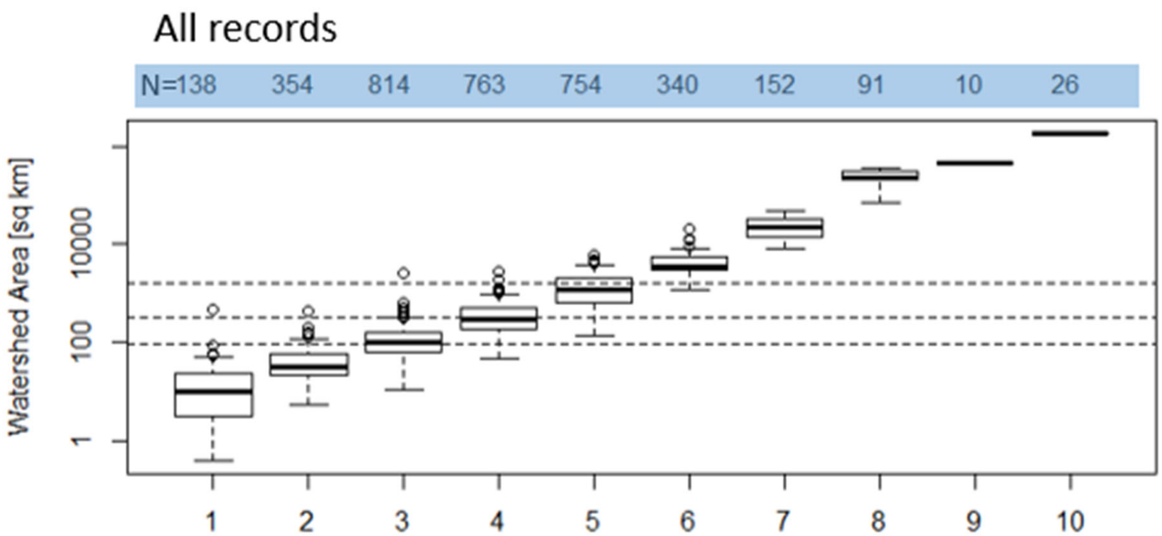
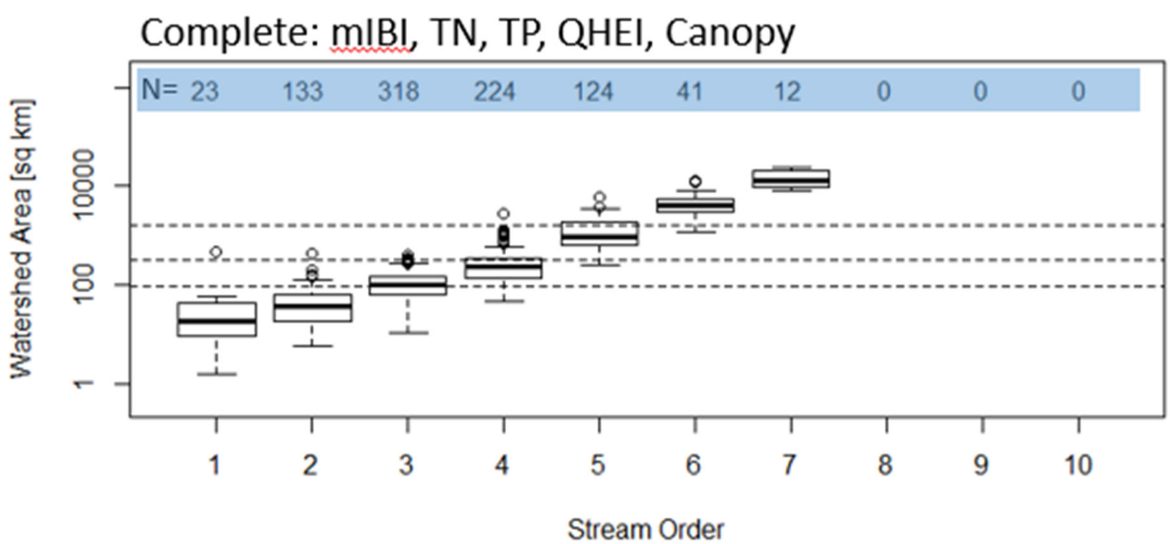
6
7
9
10


mIBI vs. TP.seas
Sm. Ws Area (Nut: 6)
Md. Ws Area (Nut: 6)
Lg. Ws Area (Nut: 6)
Sm. Ws Area (Nut: 9)
Md. Ws Area (Nut: 9)
Lg. Ws Area (Nut: 9)
Sm. Ws Area (Lv3: 54)
Md. Ws Area (Lv3: 54)
Lg. Ws Area (Lv3: 54)
Sm. Ws Area (Lv3: 72)
Md. Ws Area (Lv3: 72)
Lg. Ws Area (Lv3: 72)
Macroinvertebrate IBI
Total Phosphorus, Seas. [mg/L]


Residuals, Nutrient Ecoregion
residuals
fitted
TN.seas
TP.seas
WsAreaSqKm
TURB.seas
TSS.seas
CHLAC.seas.LTE28
QHEI_SCORE
CANOPY
6 7 9 10

Watershed Area (km^2) as a function of Stream Order





Notes:
All data: watershed area quartiles 93.440 325.50 1689.00
Complete set (based on mIBI, TN, TP, QHEI, canopy): watershed area quartiles: 70.450 142.30 403.30