Review of Progress on Developing Nutrient Criteria in California

Presentation to RTAG

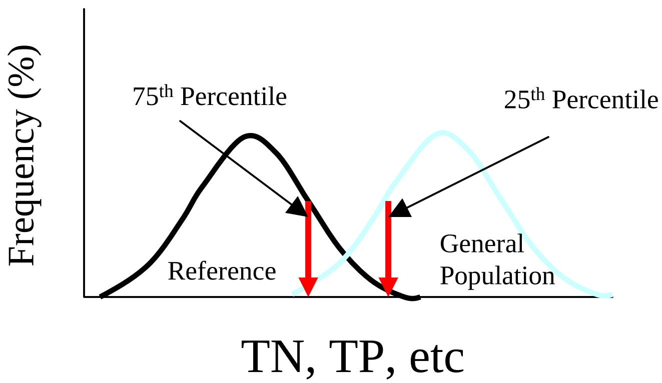
May 25, 2004

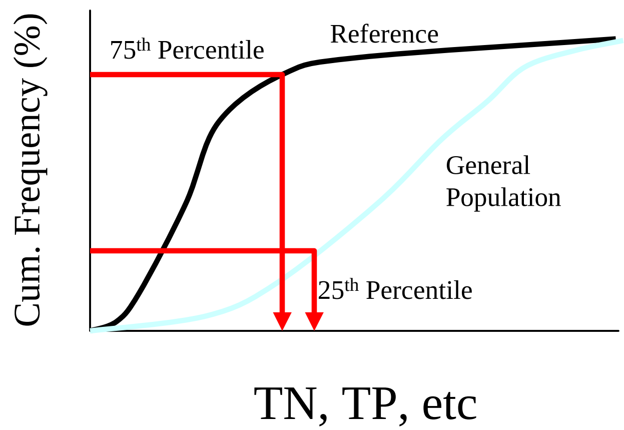
EPA Region IX, San Francisco, California

Overview

- Update on previous results
- Review of data and modeling for Ecoregion 6
- Recommended strategy for moving toward numeric criteria

Approach Presented in EPA Guidance Documents





Benefit: - Data easily accessible with adequate QA, especially for general population

Limitations: - Not validated for California

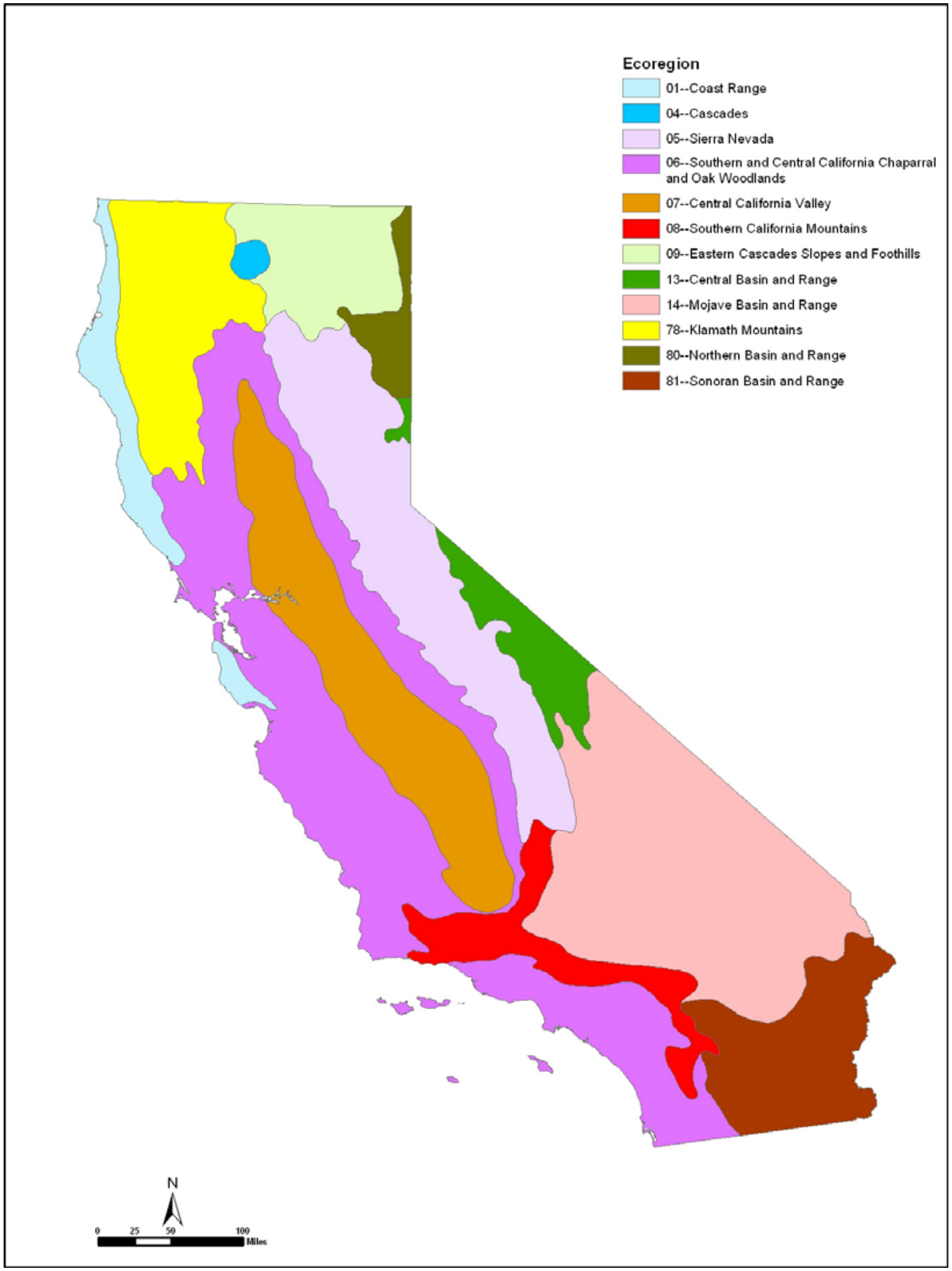
- No link to impairment of beneficial use

The Importance of "getting it right"

- ~ 150 CA water bodies impaired (1998 303(d) list) for nutrients and nutrient related parameters (DO, pH)
- Once established, nutrient criteria will be incorporated into state standards
- Are the 304(a) criteria correctly specified? Misspecification could lead to a large number of 303(d) listings

California Ecoregions

1	Coastal Range
4	Cascades
5	Sierra Nevada
6	Southern and Central California Chaparral and Oak Woodlands
8	Southern California Mountains
9	Eastern Cascades Slopes & Foothills
13	Central Basin and Range
14	Southern Basin & Range
22	Arizona/New Mexico Plateau
23	Arizona/New Mexico Mountains
24	Southern Deserts
78	Klamath Mountains



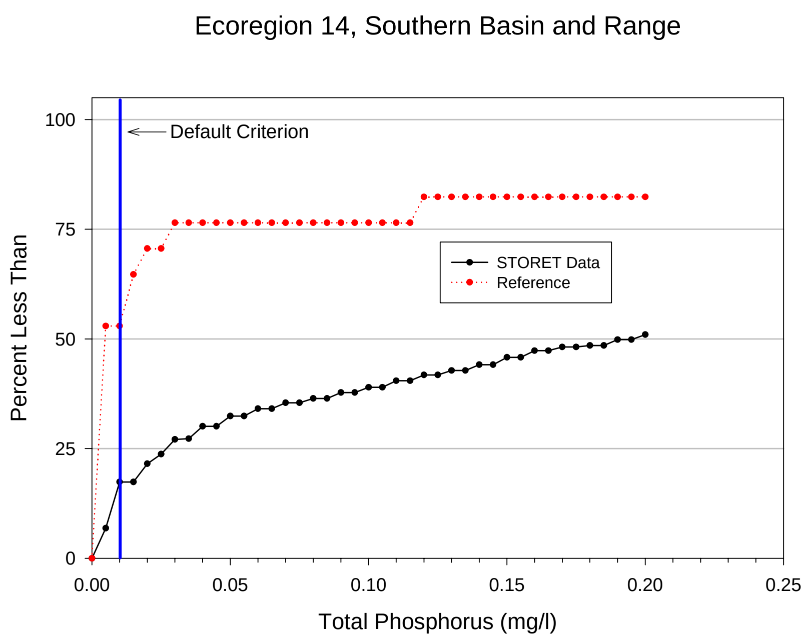
The Importance of "getting it right"

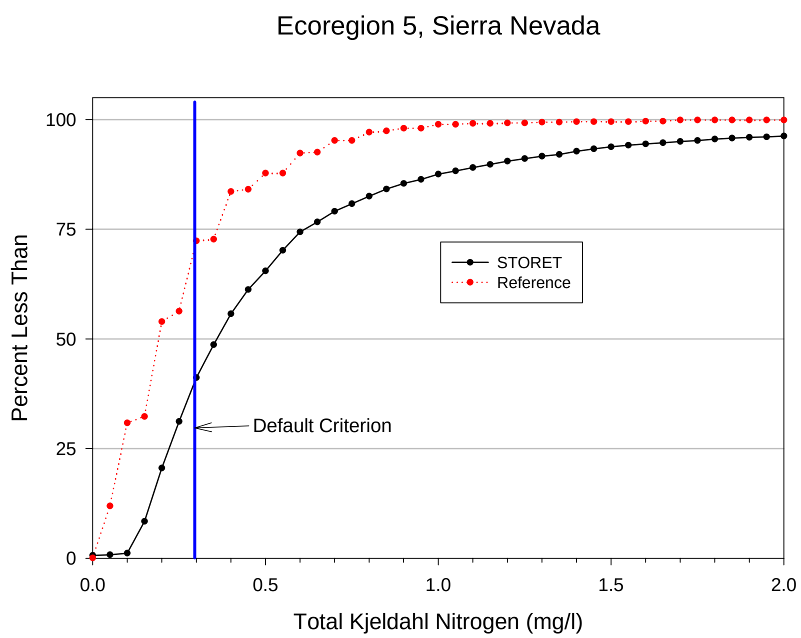
Ecoregion	Total Phosphorus (approx. mg/L)				
	304(a) Criterion	Reference 75%	% > 304(a)	STORET 25%	% > 304(a)
1	0.010	0.03	70	0.01	70
5	0.015	0.04	85	0.02	85
6	0.030	.09		0.06	88
8	0.011	na	na	0.002	44
9	0.030	0.13	67	na	na
14	0.010	0.03	47	0.03	80
22	0.015	0.07	62	0.02	97
23	0.011	0.06	85	0.005	85
24	0.018	0.07	56	na	na
78	0.032	0.05	28	0.12	98

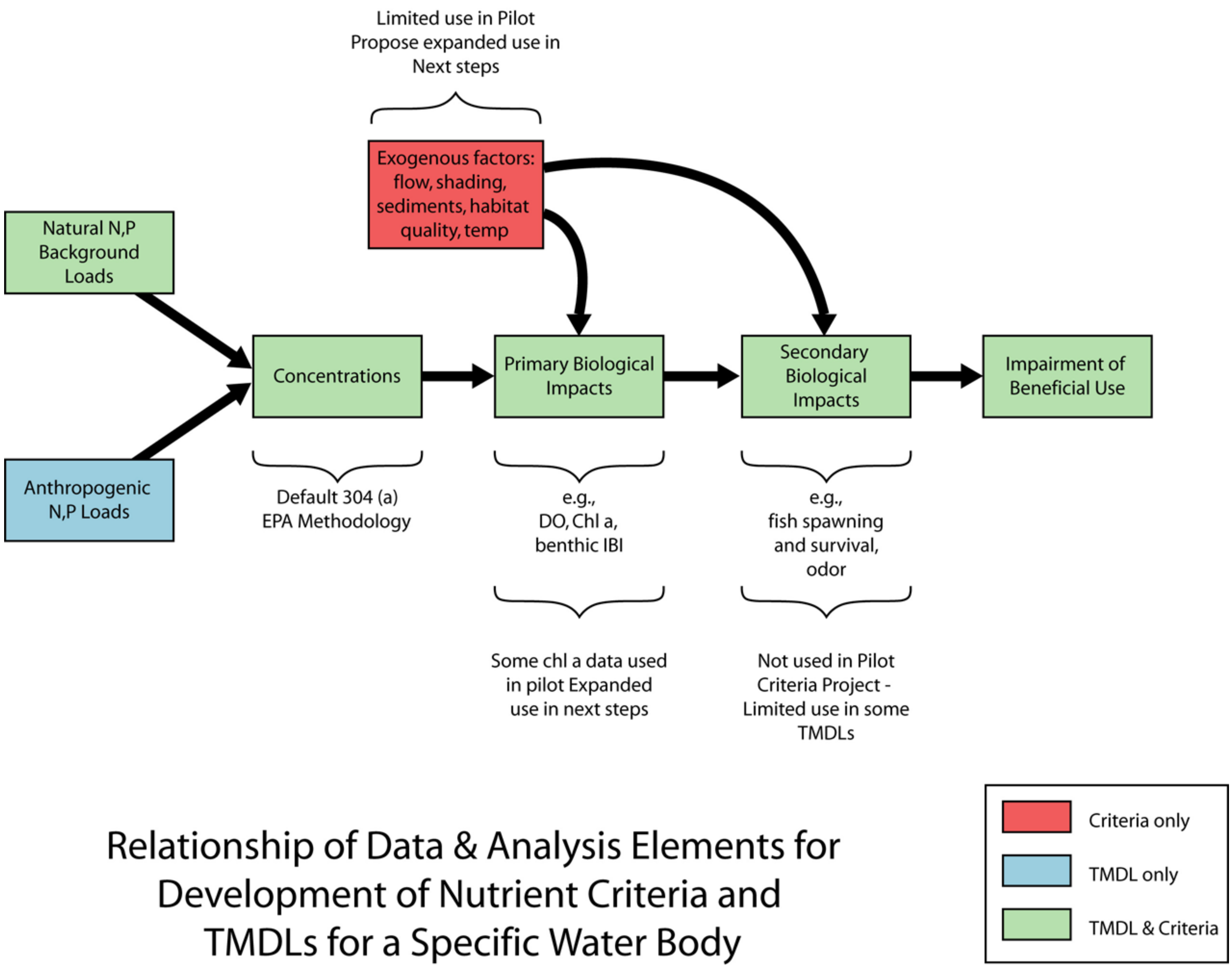
The Importance of "getting it right"

Total Nitrogen (approx. mg/L)					
Ecoregion	304(a) Criterion	Reference 75%	% > 304(a)	STORET 25%	% > 304(a)
1	0.13	na	na	0.17	85
5	0.29	0.36	33	0.22	62
6	0.50	0.5		0.40	69
8	0.52	na	na	0.10	17
9	0.15	0.40	97	na	na
14	0.67	0.25	0	0.55	66
22	0.23	0.48	60	0.18	47
23	0.28	0.48	58	0.13	47
24	0.62	0.32	12	na	na
78	0.53	0.58	25	na	na

Example Comparisons of Reference and STORET Data for Ecoregions





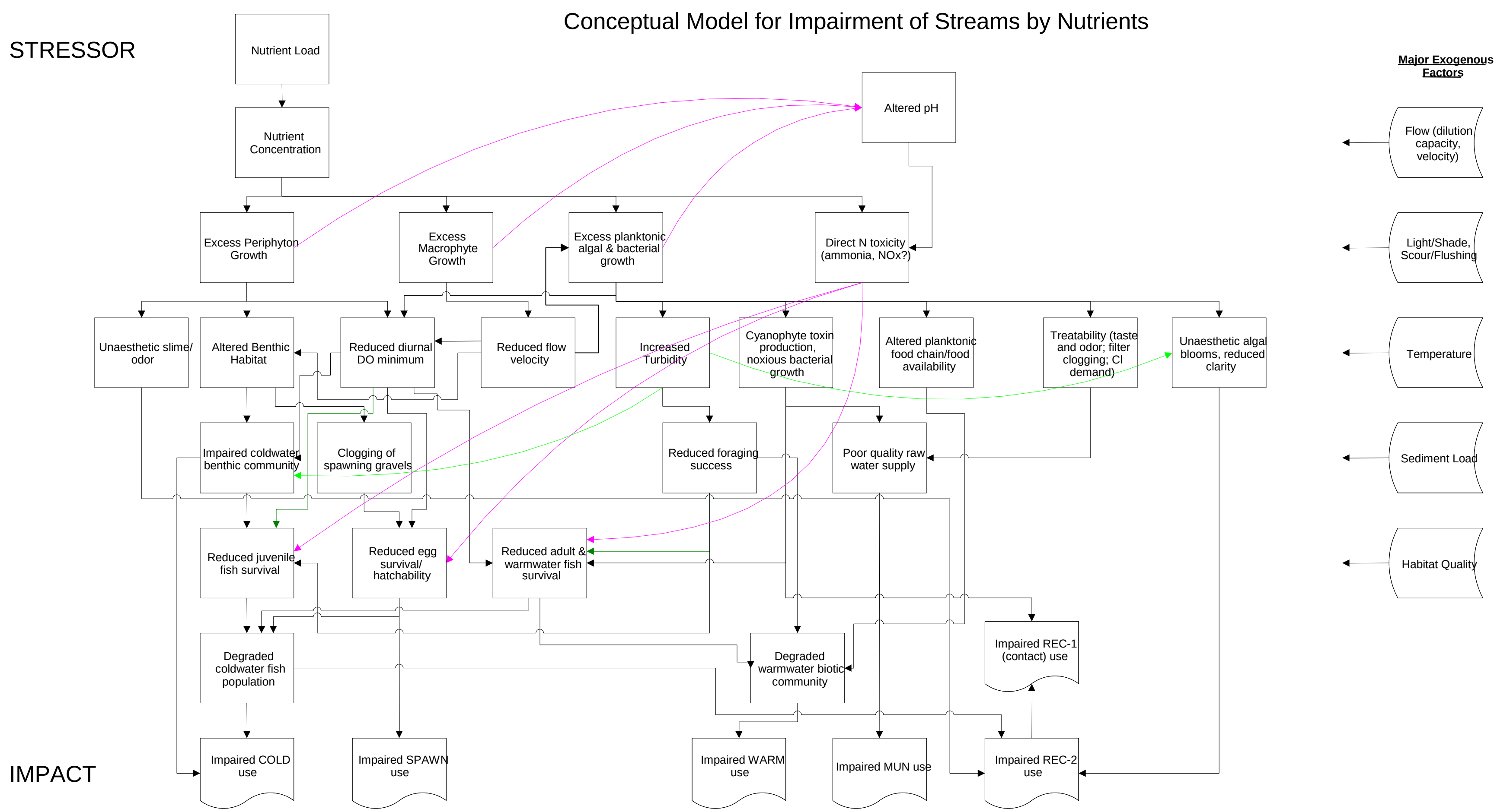


Relationship of Data & Analysis Elements for Development of Nutrient Criteria and TMDLs for a Specific Water Body

Modified Strategy for Developing Criteria

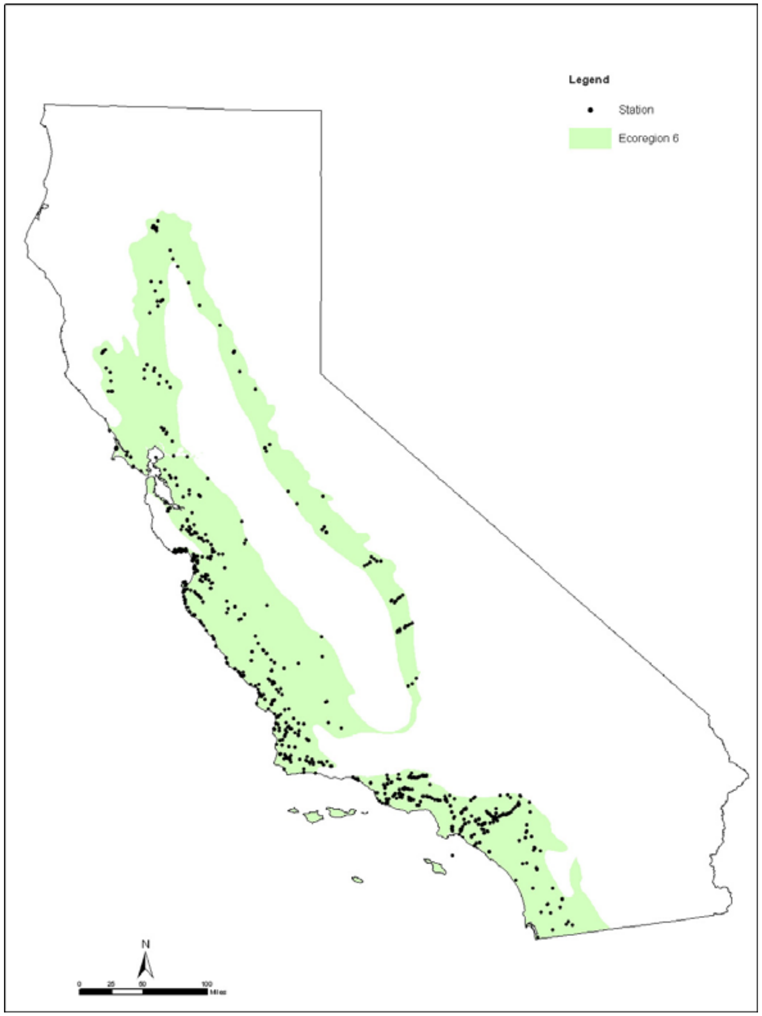
- Focus on a individual ecoregion, not aggregated ecoregion
- Greater emphasis on biological responses to link to protection of beneficial uses
- Use statistical and simulation models to provide better estimates of reference loads
- Models used to estimate biological responses

Conceptual Model of Linkage Between Nutrients and Beneficial Uses for Streams



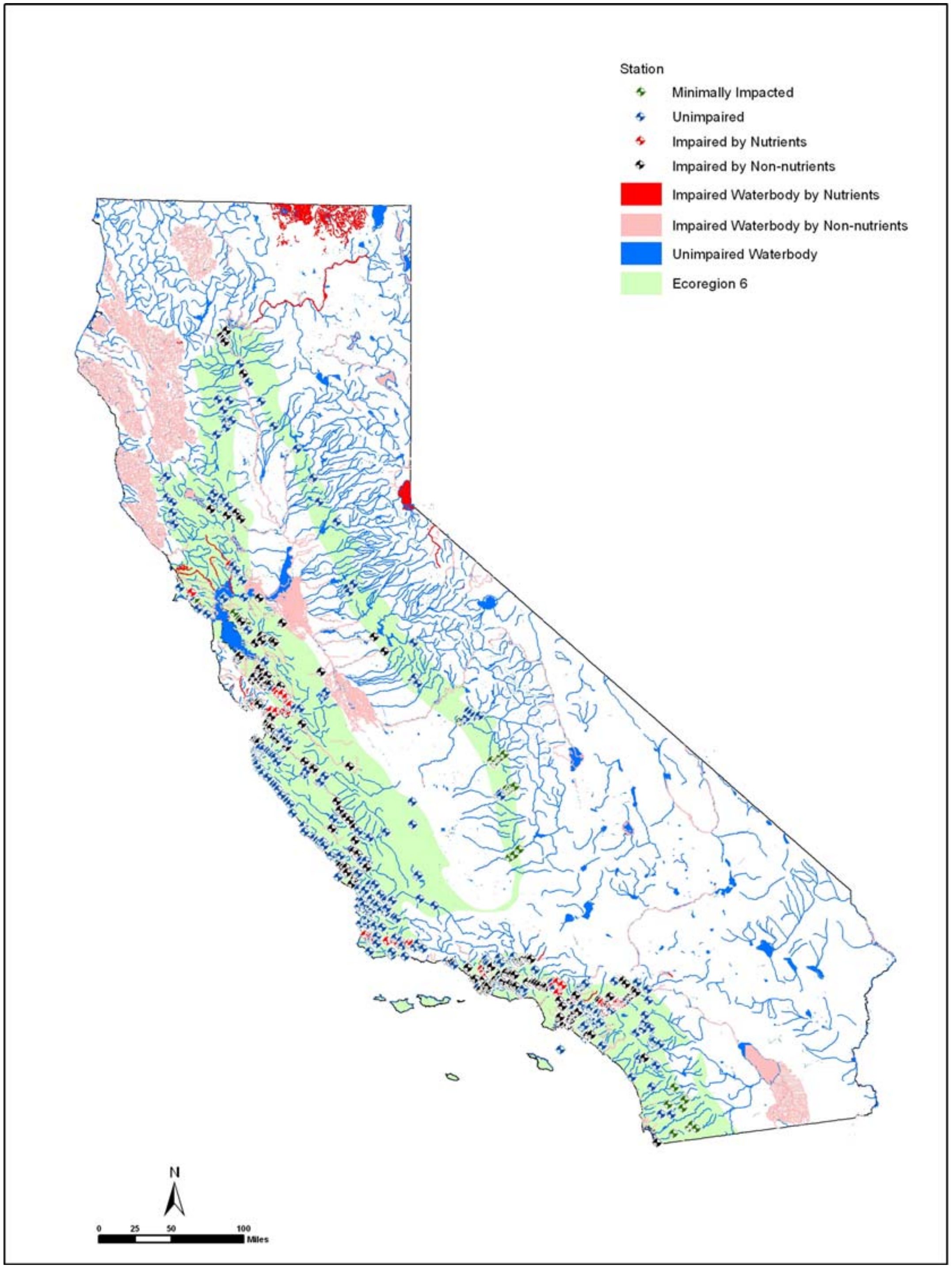
Note: AGR use is assumed not to be impaired by nutrient loads
NAV is insensitive, but could be impacted by macrophytes

Region Selected for Study: California Oak and Chaparral (Ecoregion 6)

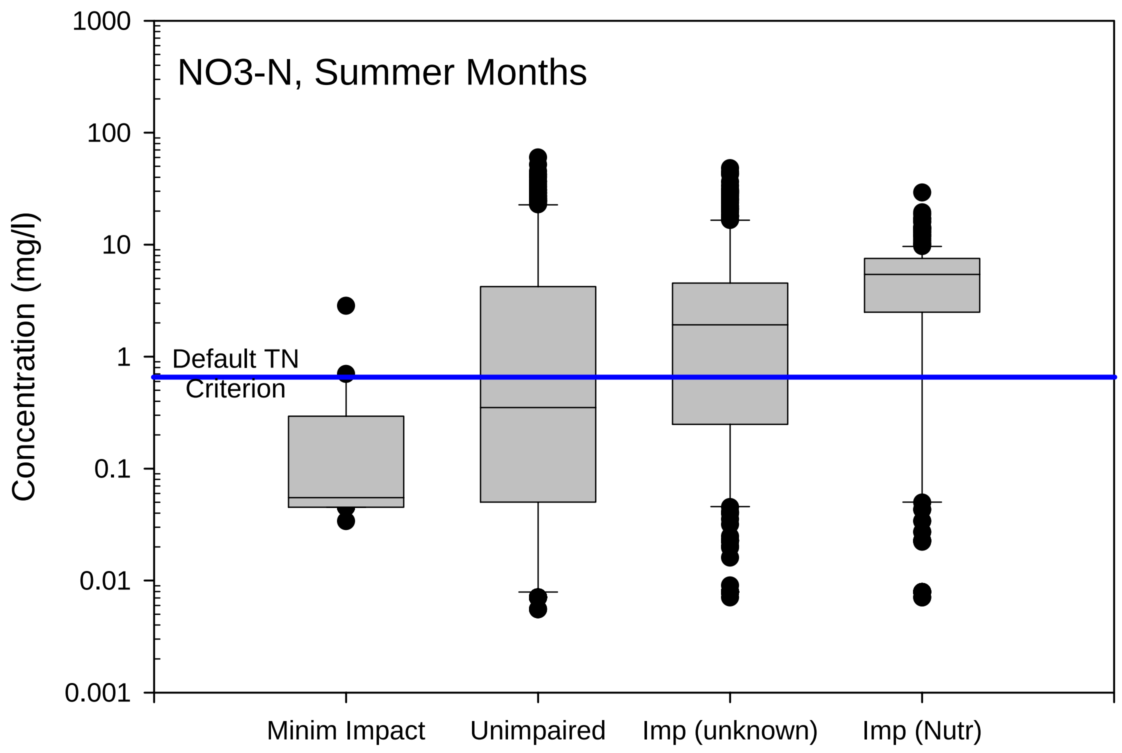


- 680 stations with data
- Stations evenly distributed over ecoregion
- Data obtained from federal, state, and municipal agencies, and research institutions

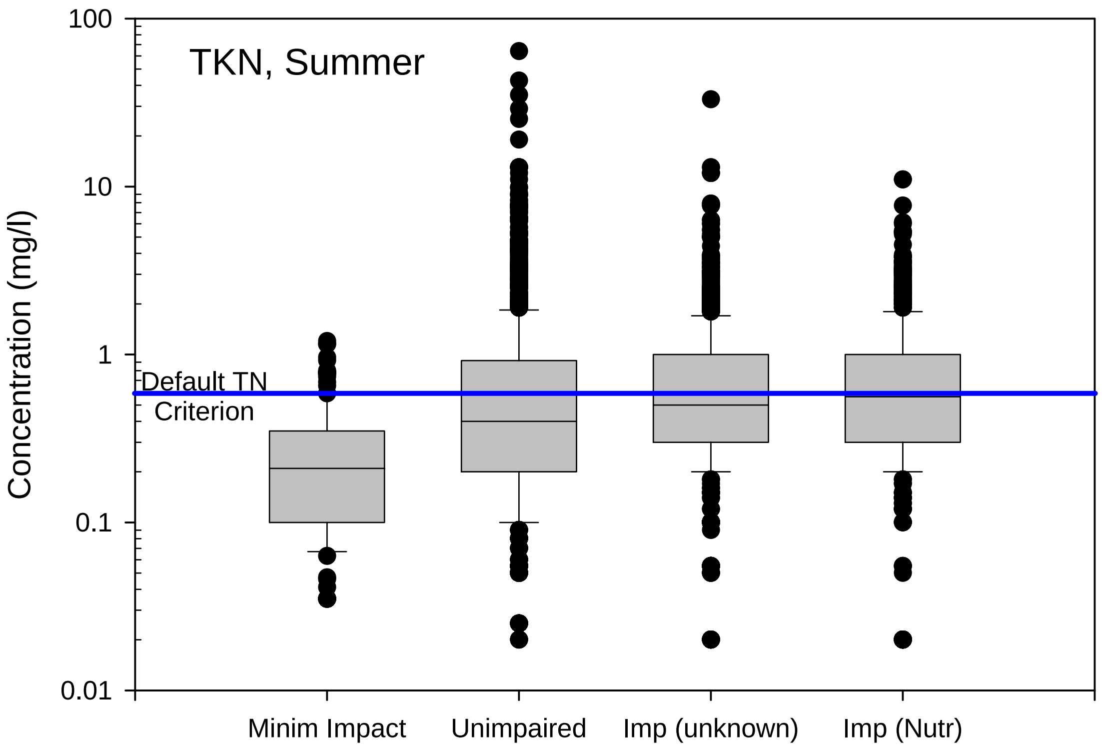
Empirical Data Analysis: Station Classification



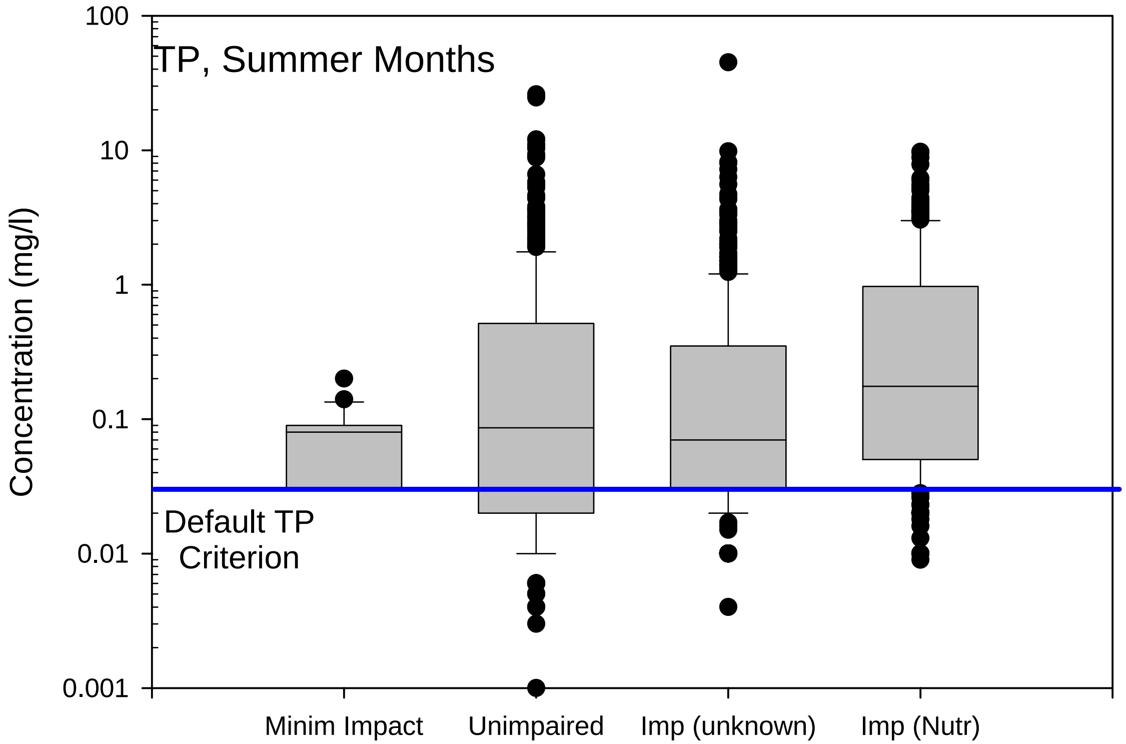
Empirical Data Analysis for Ecoregion 6: NO_3 Levels in Streams by Impairment Classification of Water Body



Empirical Data Analysis for Ecoregion 6: TKN Levels in Streams by Impairment Classification of Water Body



Empirical Data Analysis for Ecoregion 6: TP Levels in Streams by Impairment Classification of Water Body

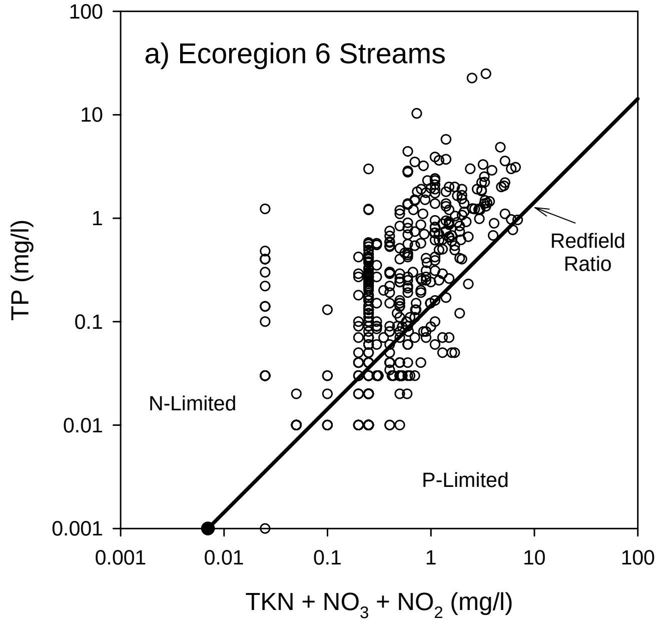


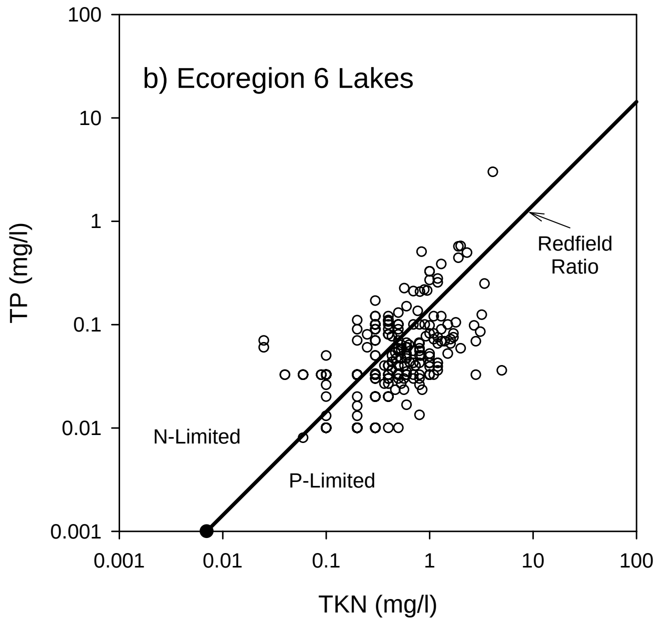
Summary of Nutrient Data for Ecoregion 6

	Lakes-Median Concentrations		
Constituent	**Impaired (mg/l)**	**Unimpaired (mg/l)**	**Minimally Impacted (mg/l)**
NH_3	0.082	0.082	0.010
NO_2	0.010	0.021	0.002
NO_3	0.700	0.100	0.050
PO_4	0.010	0.142	0.017
TKN	0.400	0.500	0.200
TP	0.020	0.033	0.050
	Streams-Median Concentrations		
Constituent	**Impaired (mg/l)**	**Unimpaired (mg/l)**	**Minimally Impacted (mg/l)**
NH_3	0.050	0.020	0.016
NO_2	0.030	0.017	0.002
NO_3	2.918	0.361	0.050
PO_4	0.080	0.080	0.043
TKN	0.630	0.400	0.250
TP	0.080	0.068	0.080

Nitrate appears to the most only significant discriminator between the different types of stations.

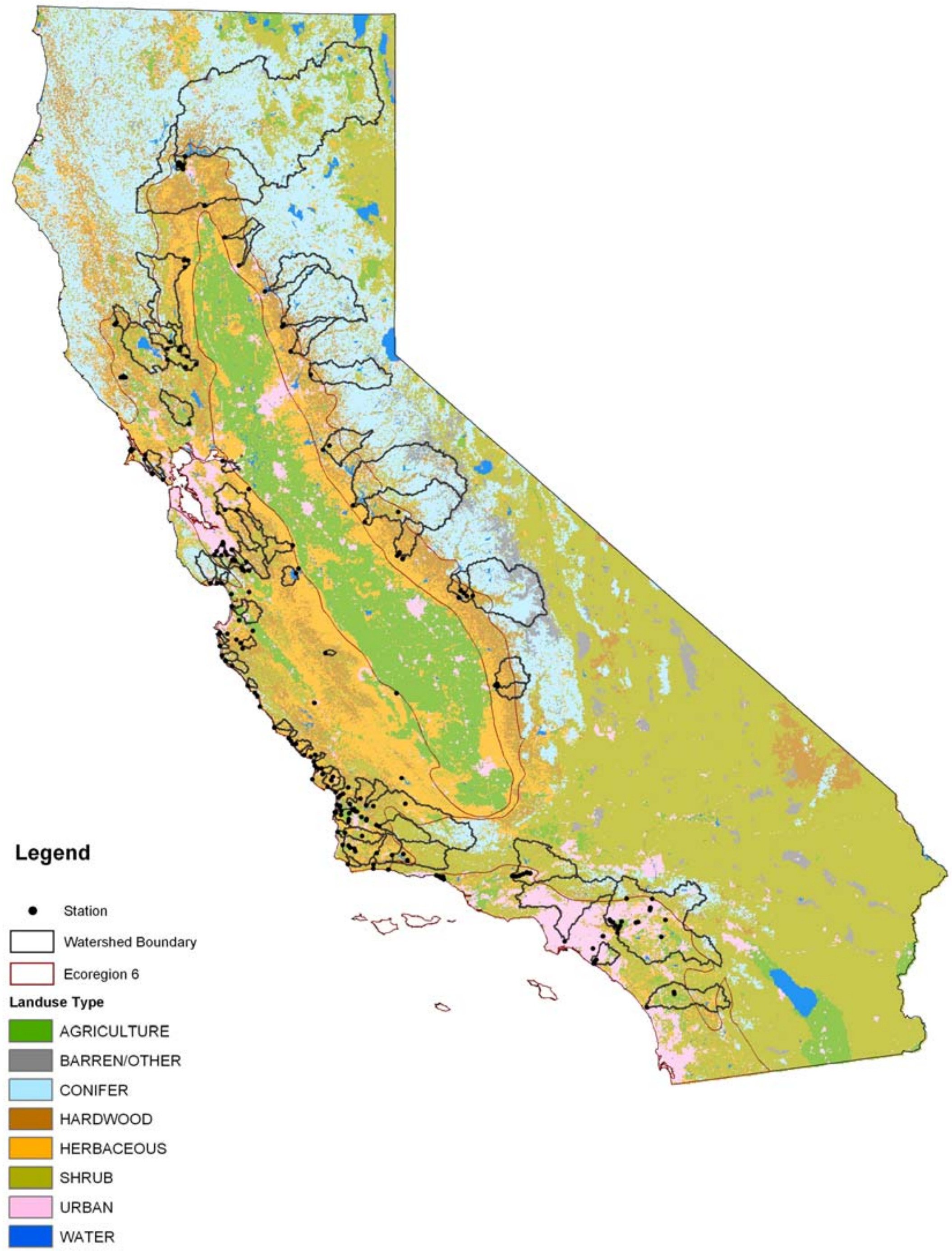
Empirical Data Analysis: TN:TP Ratios





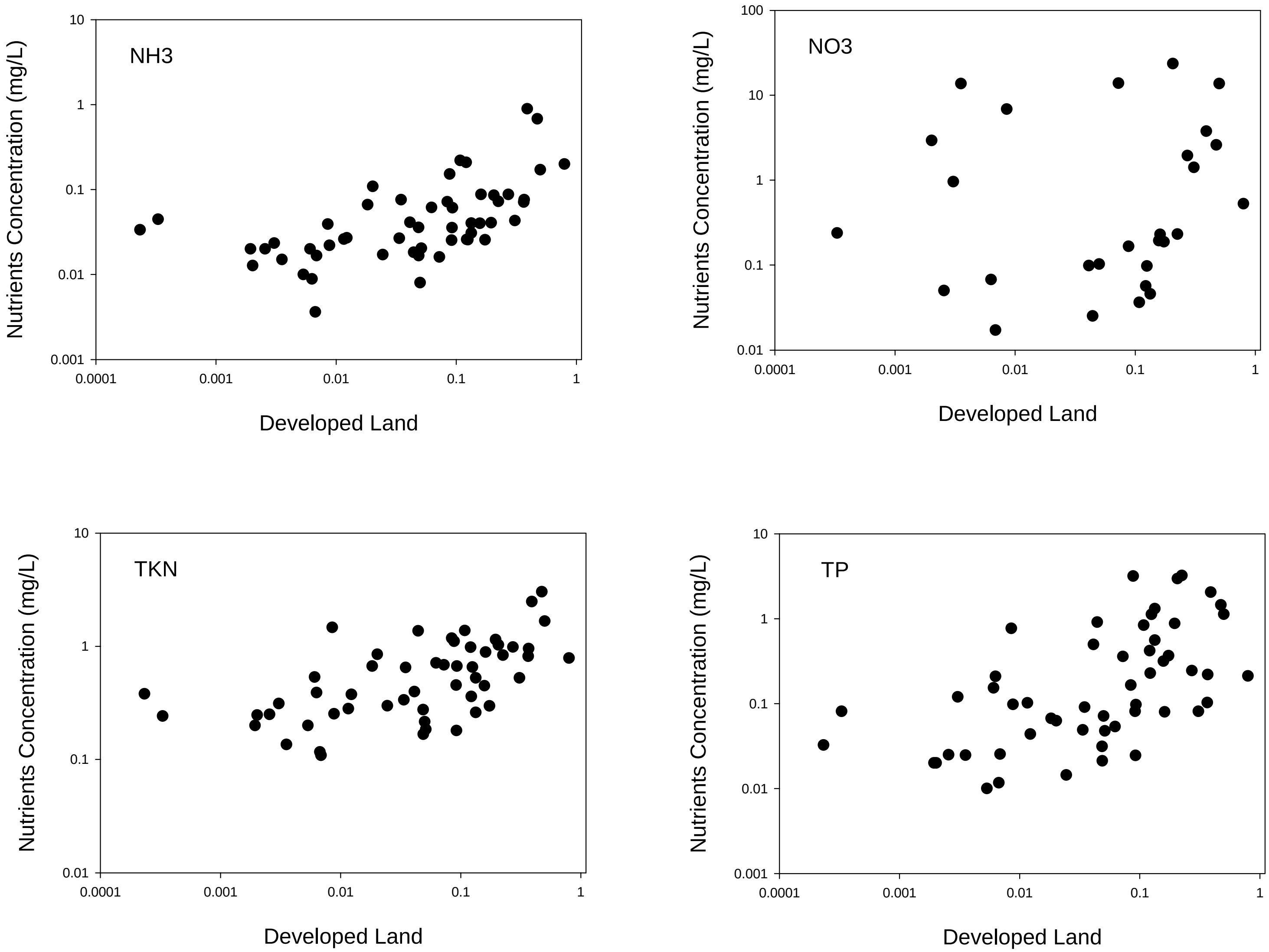
Finding: Nitrogen limitations are very common in Ecoregion 6 streams

Watersheds Associated with Monitoring Stations

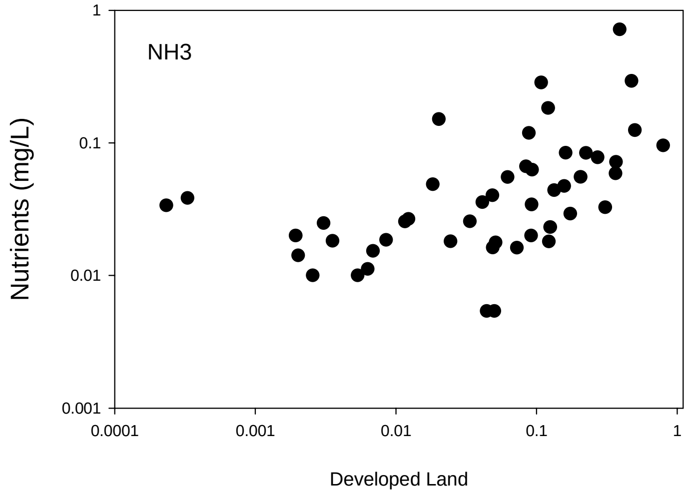


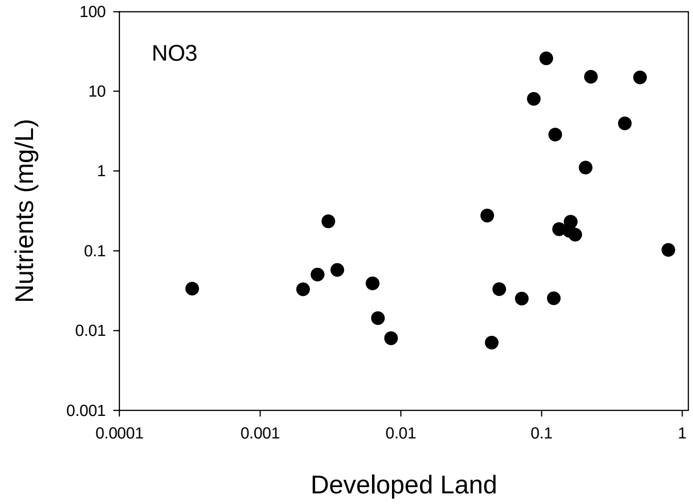
- Watershed for 82 stream stations with enough data were mapped
- Stations evenly distributed over ecoregion
- Data obtained for:
  - Land cover (urban, agriculture, conifer, shrub, etc.)
  - Precipitation
  - Slope
  - Elevation
  - Soil erodibility
  - Soil organic carbon content
  - Soil water conductivity

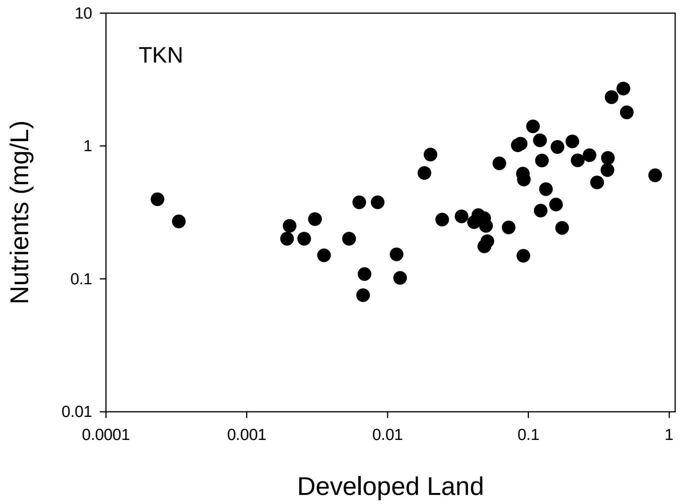
Nutrient Concentrations and Developed Land
Data for Entire Year

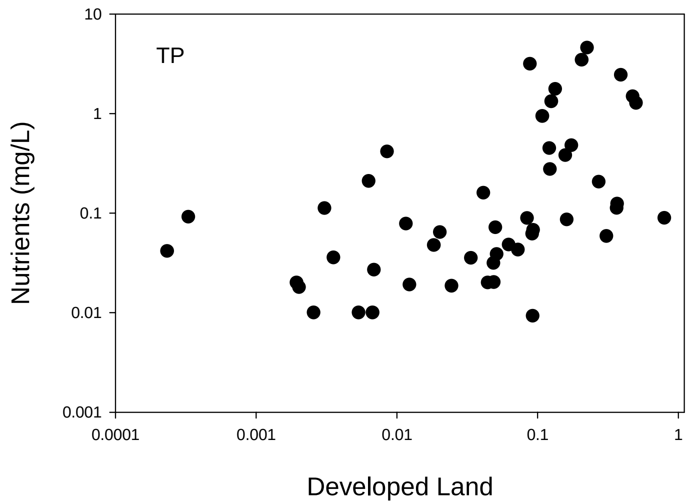


Nutrient Concentrations and Developed Land Data for May Through September

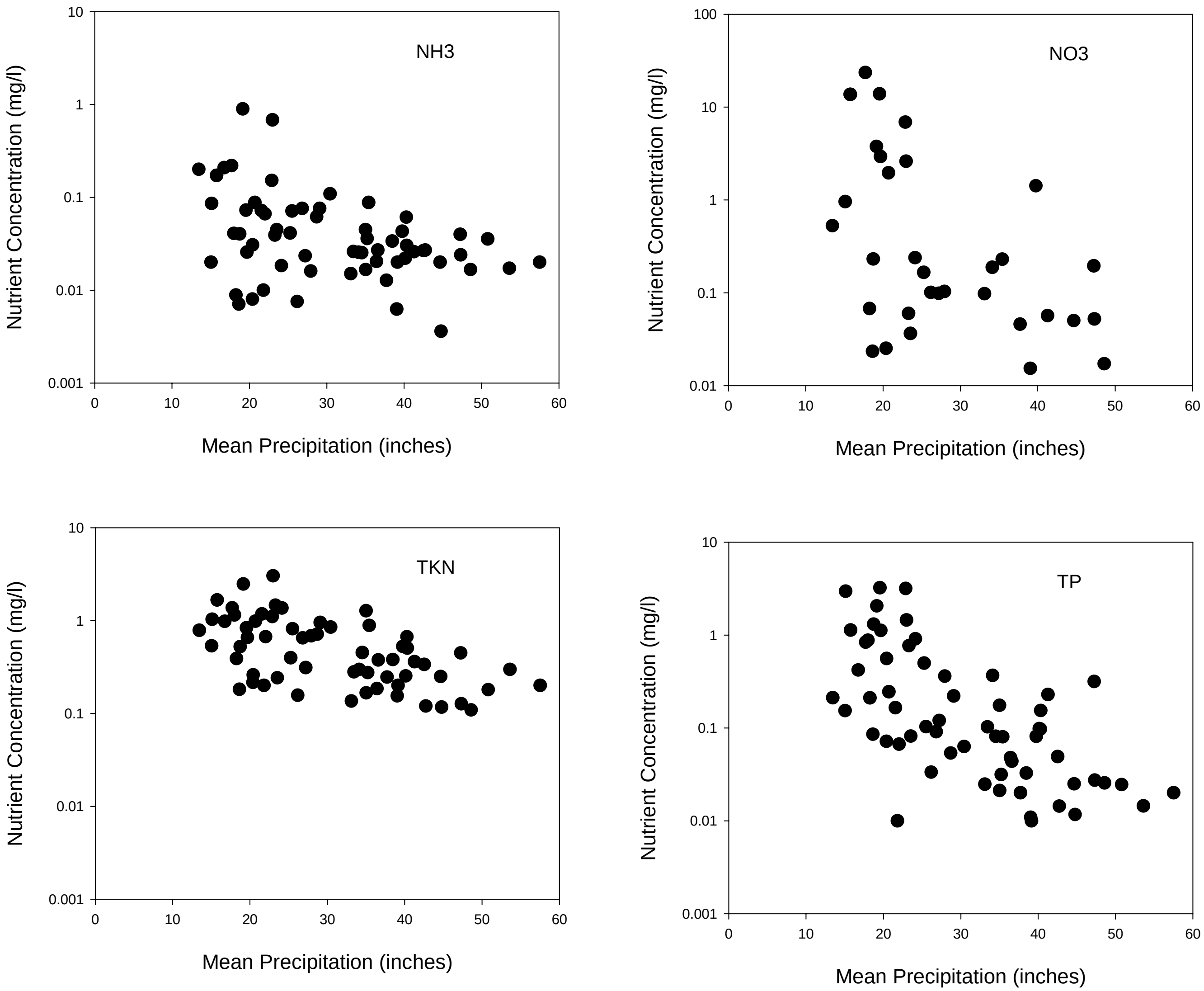






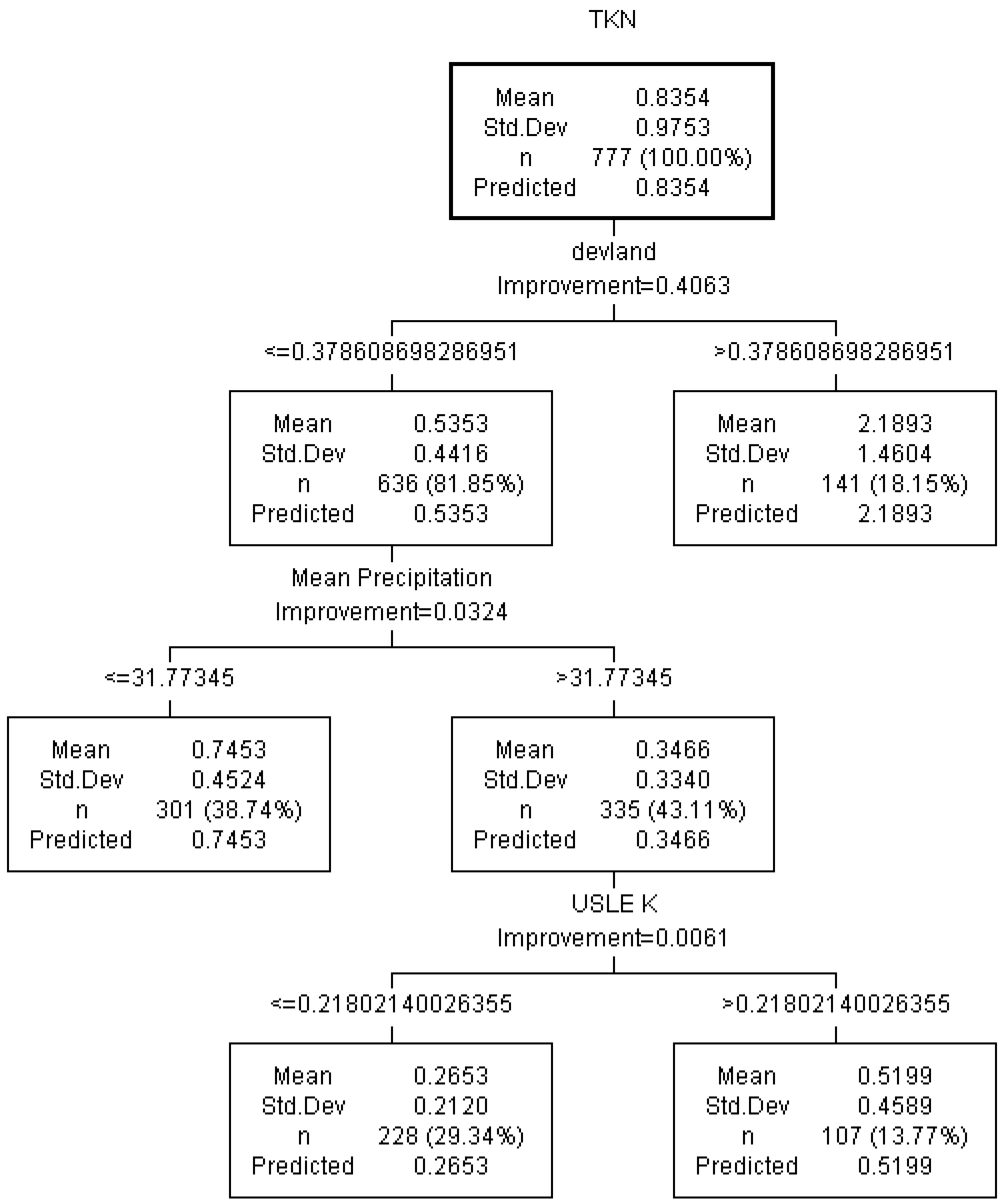


Nutrient Concentrations and Mean Precipitation Data for Entire Year



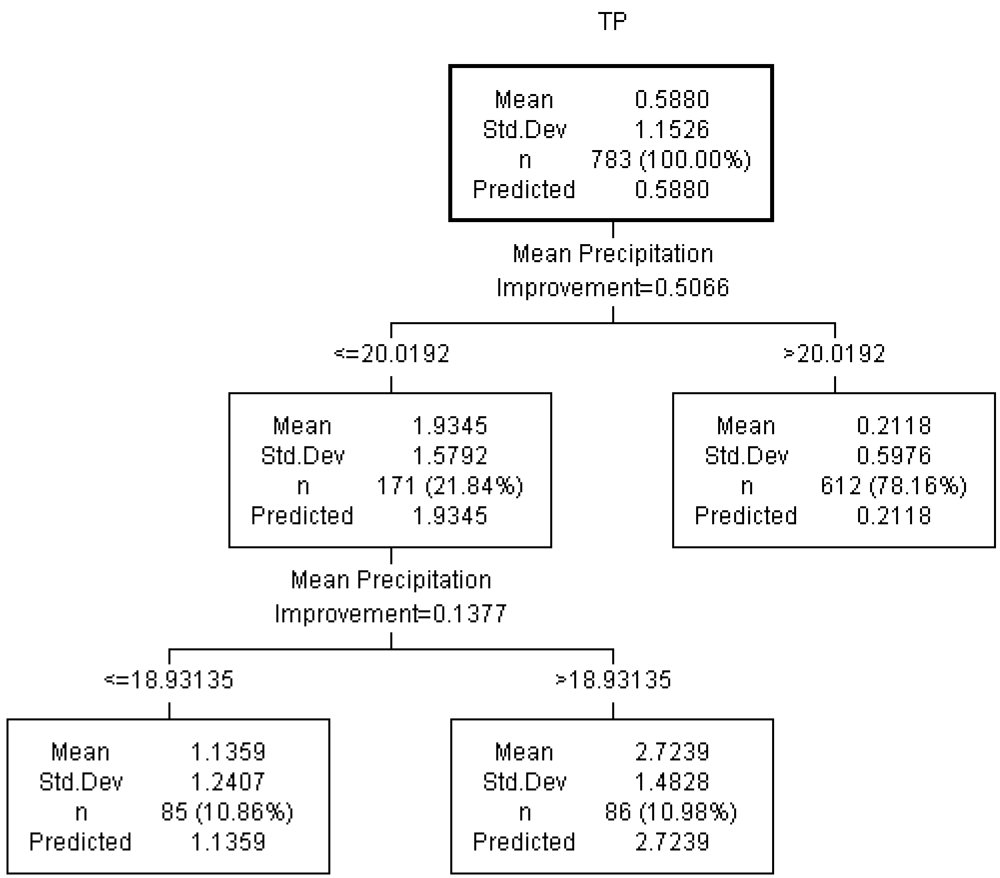
Classification and Regression Tree (CART) Analysis: I

TKN in May through September



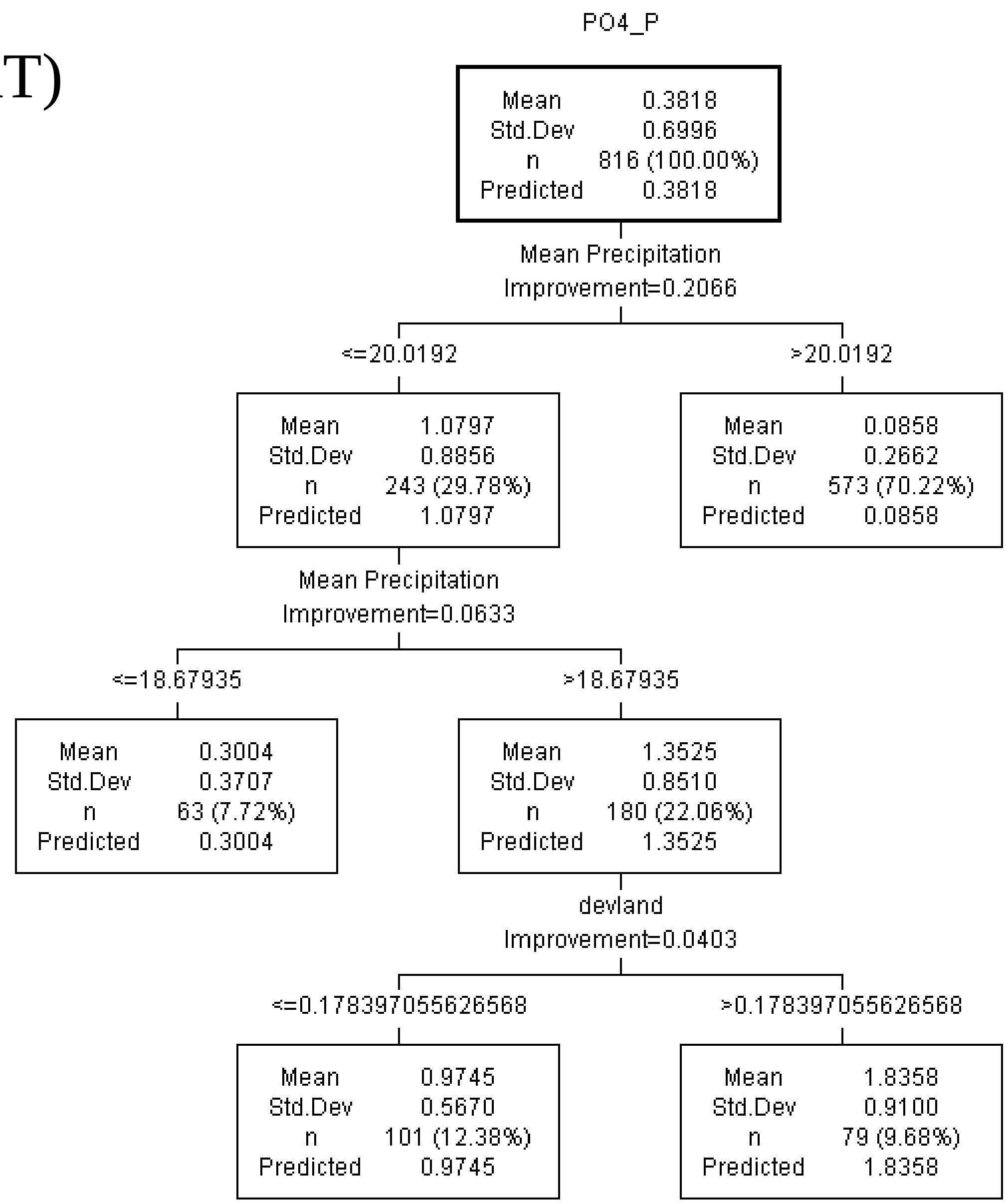
Classification and Regression Tree (CART) Analysis: II

TP in May through September



Classification and Regression Tree (CART) Analysis: III

PO4 in May through September

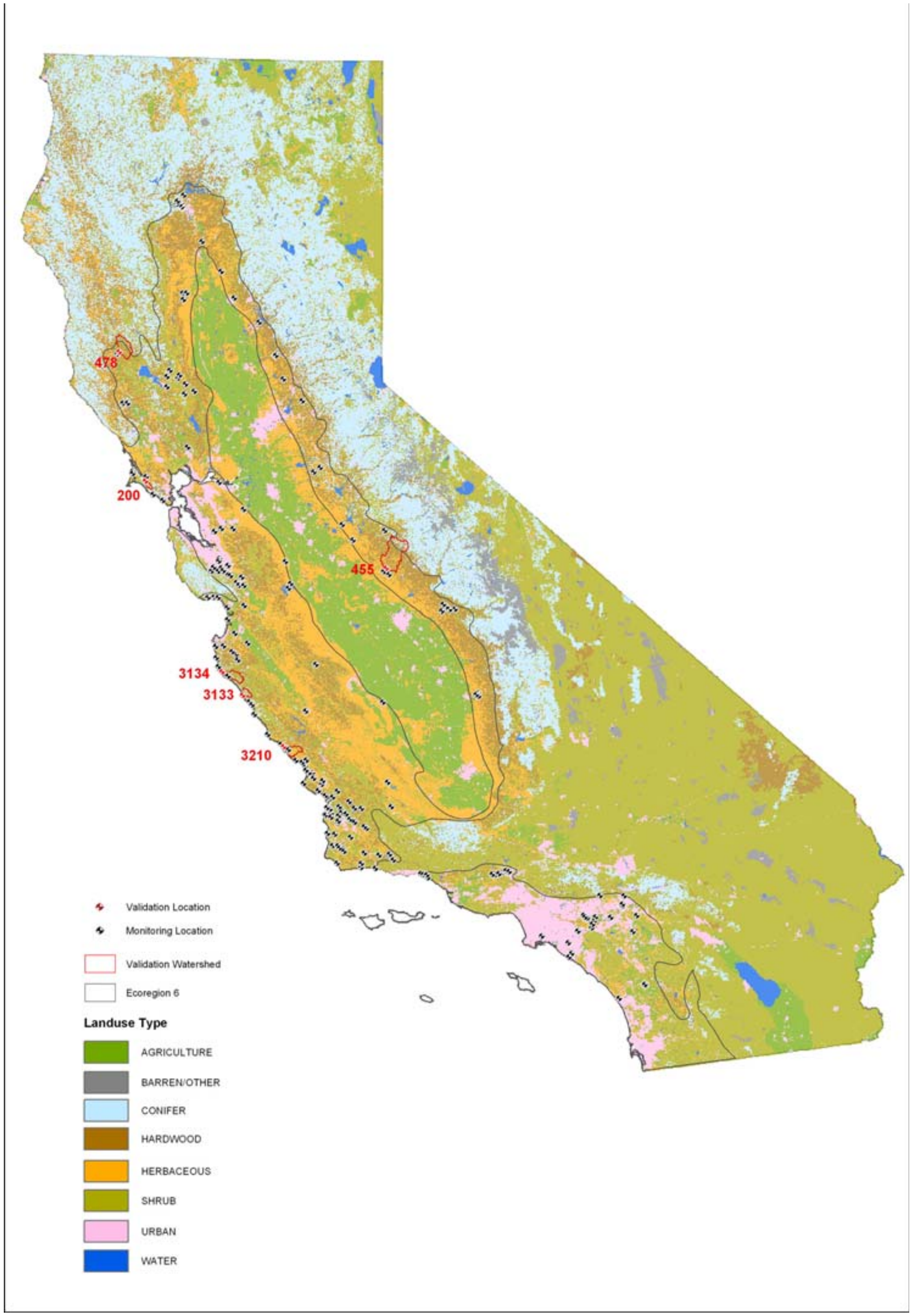


Findings from Data Analysis

- Chemistry data alone is difficult to directly link to impairment, although some land characteristics are good estimators of concentrations (such as the proportion of developed land and precipitation)
- Insufficient, consistently-measured biological data collected over Ecoregion 6
- Limited reference station data on chemistry

Additional Sources of Information

- Estimates of reference loads of nutrients
  - Simulation modeling using SWAT
  - Empirical approaches such USGS-SPARROW
- Estimates of biological responses
  - Lake responses using the BATHUB model
  - Stream responses using
    - Empirical responses (Dodds, Biggs, etc.)
    - Modified version of QUAL2K model
- **Goal:** Develop a more robust basis for reference concentrations, and biological responses to excess nutrients



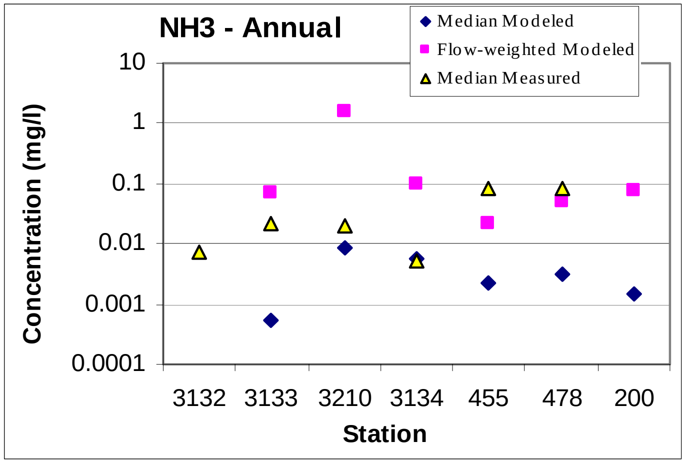
Watershed Modeling Using SWAT

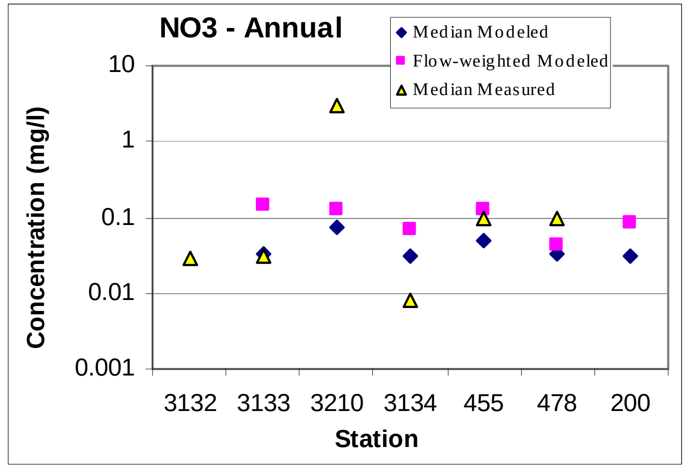
- SWAT (Surface Water Assessment Tool) was used to estimate nutrient loads and concentrations in streams.
- Designed for use without calibration.
- A set of eight, relatively unimpaired watersheds was used for validation testing.
- **Goal:** To identify landscape stratification features as directed by RTAG

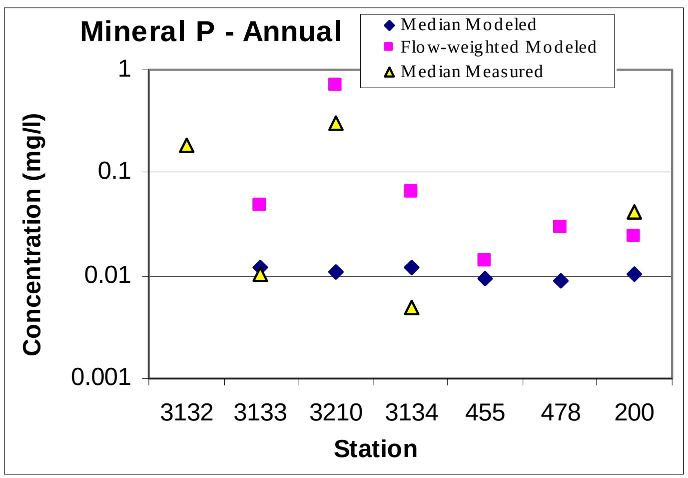
SWAT Validation

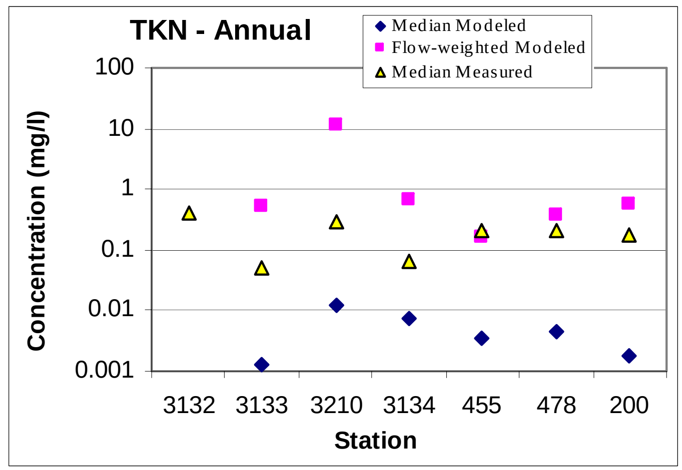
- Data sparse for unimpaired watersheds; potentially unrepresentative
- SWAT expected to perform best on loads, not instantaneous concentration
- Problems encountered in default SWAT parameters for biomass simulation when applied to Ecoregion 6

Comparison of Data and Modeled Values from SWAT









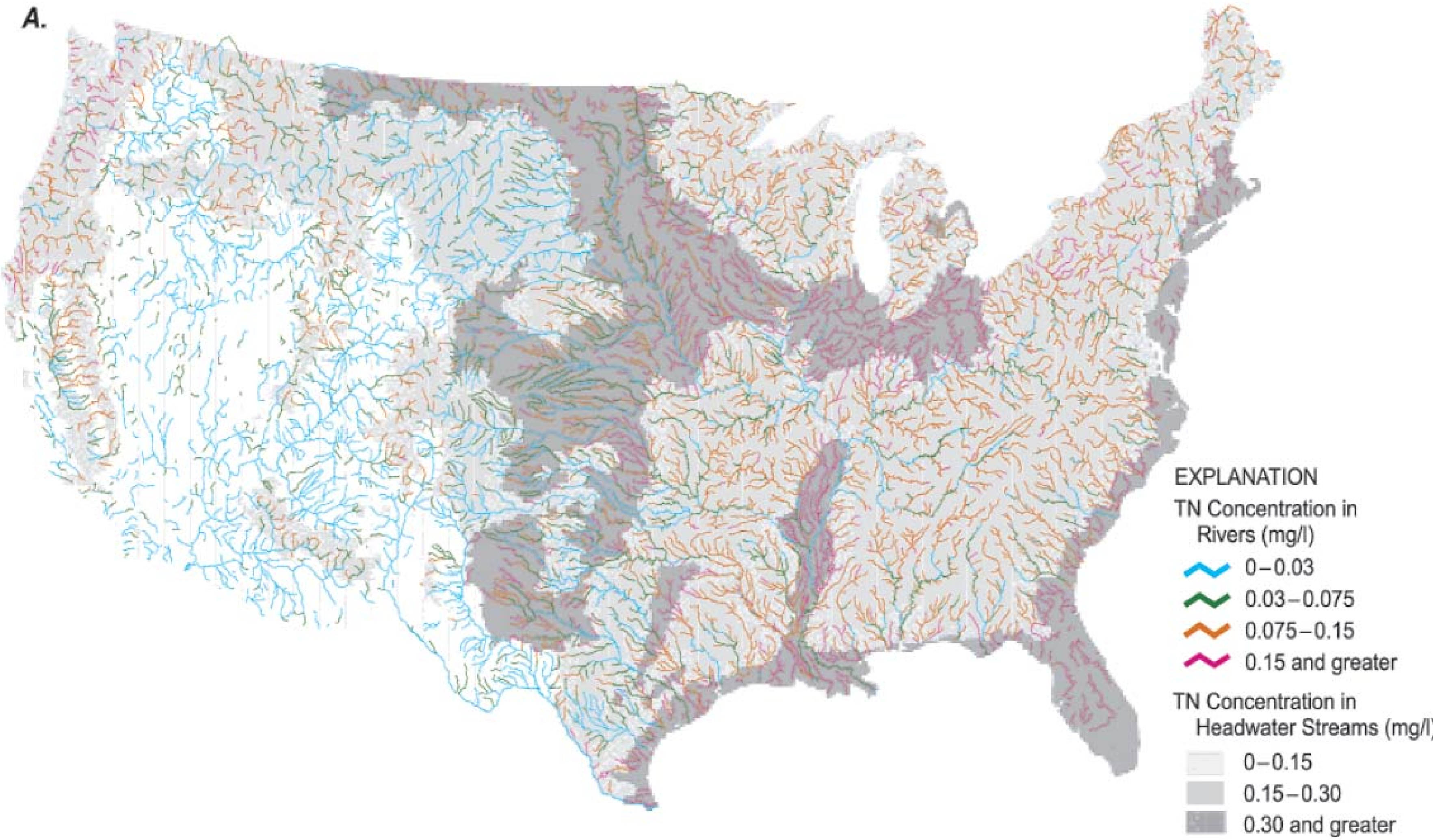
Role of SWAT in California Nutrient Criteria Development

- Validation efforts have been inconclusive
- Without calibration, the model is most appropriate for a qualitative or relative evaluation of nutrient load response to soils, cover, and other factors
- Proper calibration requires monitoring data sets of sufficient size (along with flow) to estimate seasonal and annual loads for comparison to the model
- SWAT continues to be tested further for this study
- Evidence from SWAT that indicates the importance of soils and vegetative cover as stratifying variables

USGS SPARROW Approach

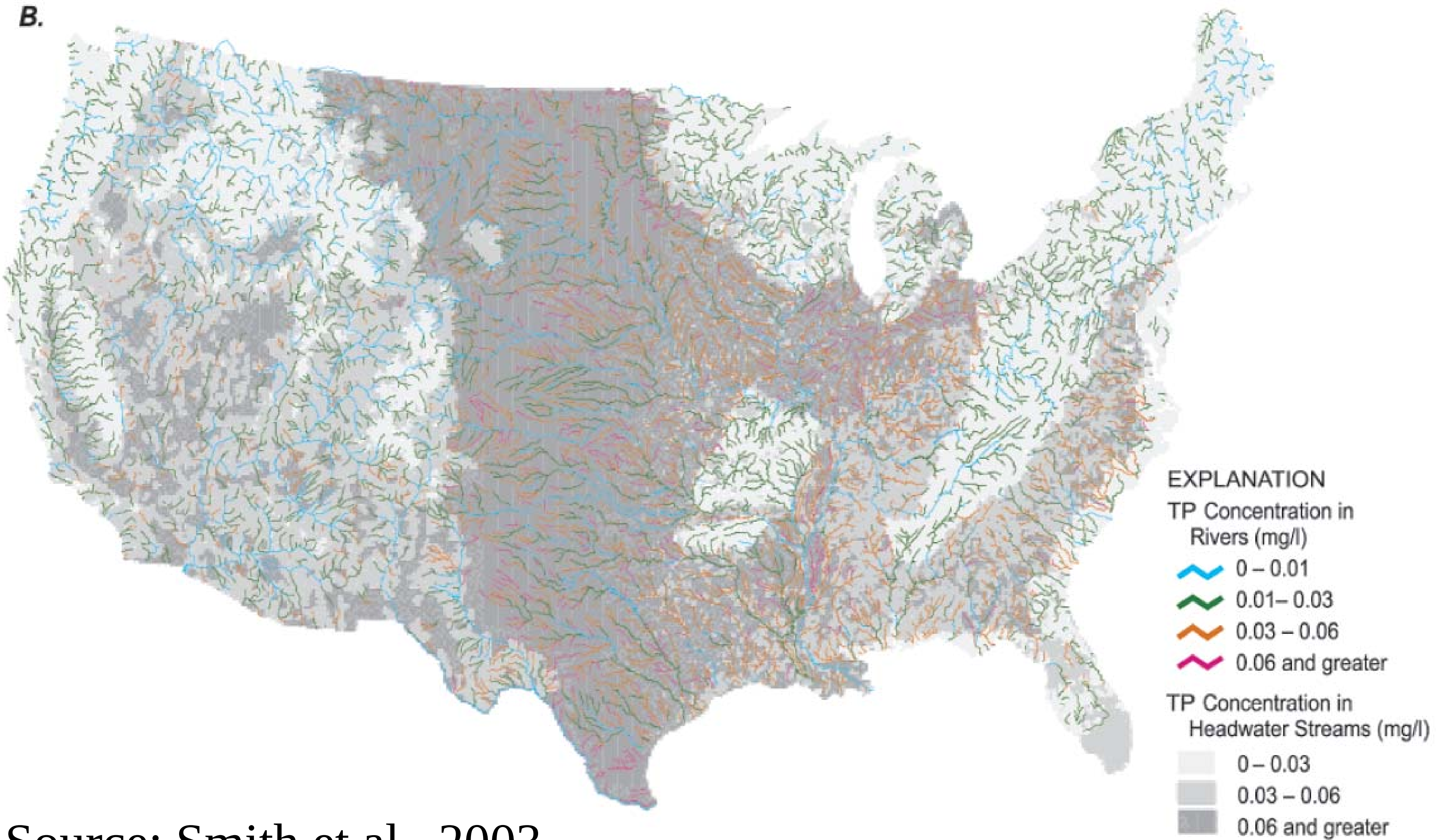
- SPARROW = Spatially Referenced Regression on Watersheds
- A statistical approach to estimate loading rates and concentrations of nutrients in streams based on regressions using NAWQA water quality data
- SPARROW has been used in two modes: for calculating loads and concentrations for current, human-impaired conditions and for estimating natural background loads and concentrations
- By using a subset of water quality stations in the most pristine watersheds, concentrations representing pre-disturbance conditions have been estimated for all RF1 level streams

Predicted Total Nitrogen Concentrations



Source: Smith et al., 2003

Predicted Total Phosphorus Concentrations



Source: Smith et al., 2003

Role of SPARROW in California Nutrient Criteria Development

- We have used SPARROW in conjunction with SWAT-calculated terrestrial loads to estimate downstream concentrations in streams
- Smith et al. (2003) natural background concentrations estimated are also proposed to be used in our framework
- Estimated concentrations have no link to beneficial uses
- Accuracy at the level of ecoregions is unknown – published error statistics lead to large uncertainty bounds
- Underlying data to be made available in June, 2004

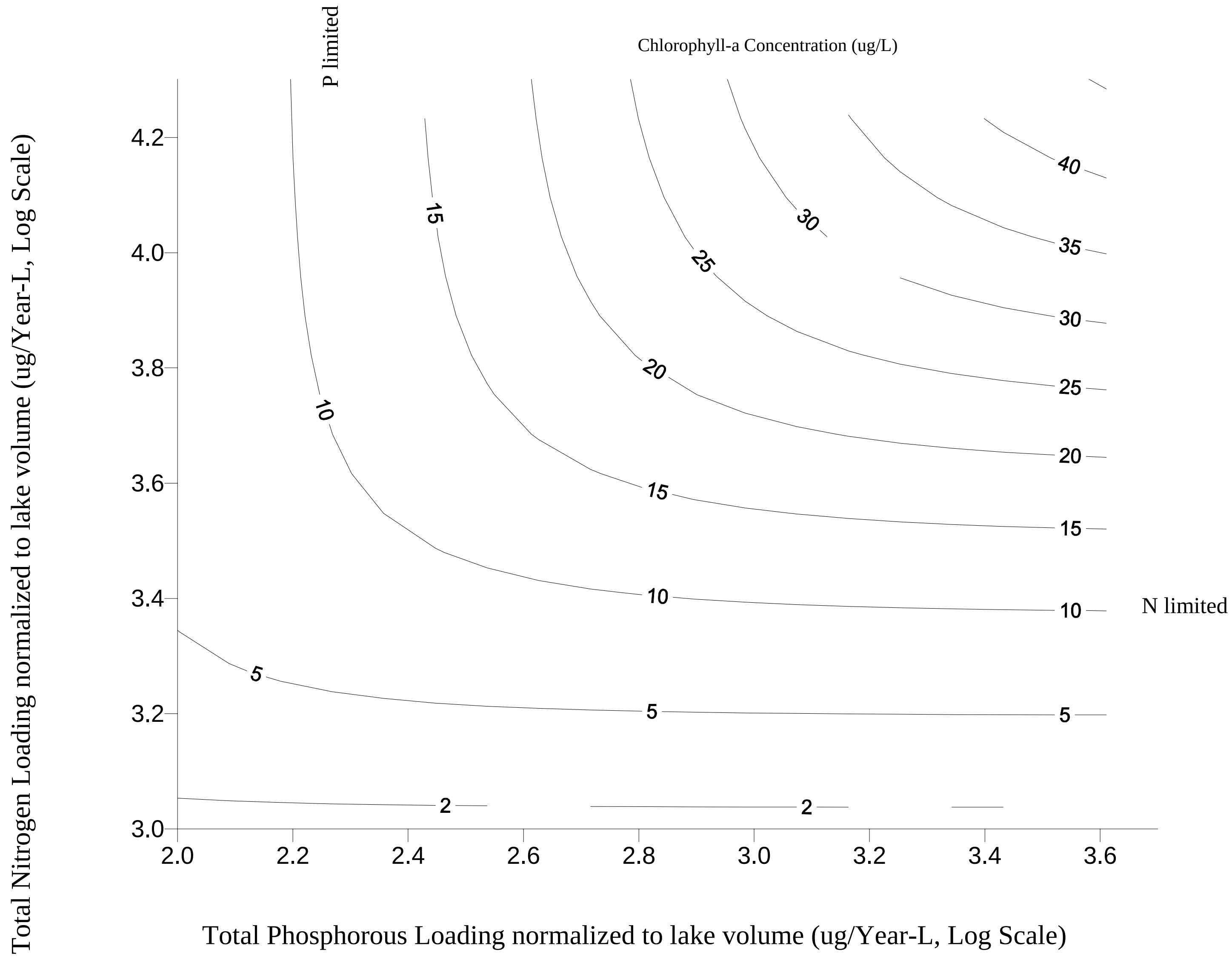
Lake Modeling Using BATHUB

- BATHTUB is a steady-state model that calculates nutrient and chlorophyll-a concentrations, turbidity, and hypolimnetic oxygen depletion based on nutrient loadings, hydrology, lake morphometry, and internal nutrient cycling processes

- BATHTUB was used to establish allowable receiving water nutrient loading as a function of hydraulic residence time and other key variables

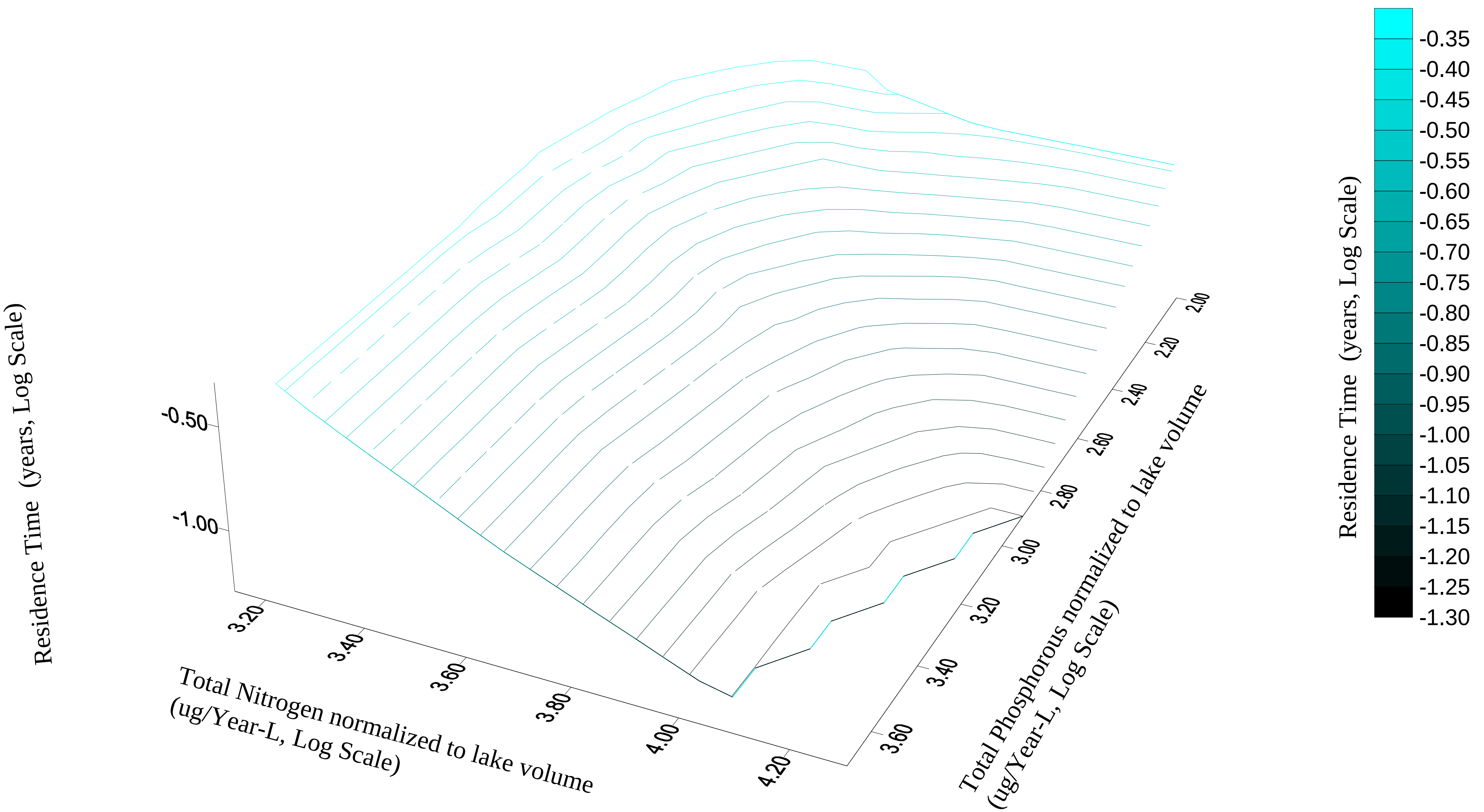
- 3-D loading response surfaces were established with acceptable/unacceptable conditions plotted as a function of residence time, nitrogen load, and phosphorus load

BATHUB Lake Model Results



Lake Chlorophyll-a Concentration versus Phosphorous and Nitrogen Loading (lake volume normalized) for a Residence Time of 0.25 Years and Non-algal turbidity of 1.25 1/m

BATHUB Lake Model Results



Chlorophyll-a Target Concentrations (10 ug/l) versus Phosphorous and Nitrogen Loading (lake volume normalized) for Residence Times from 0.05 to 17 Years and non-algal turbidity of 1.25 1/m

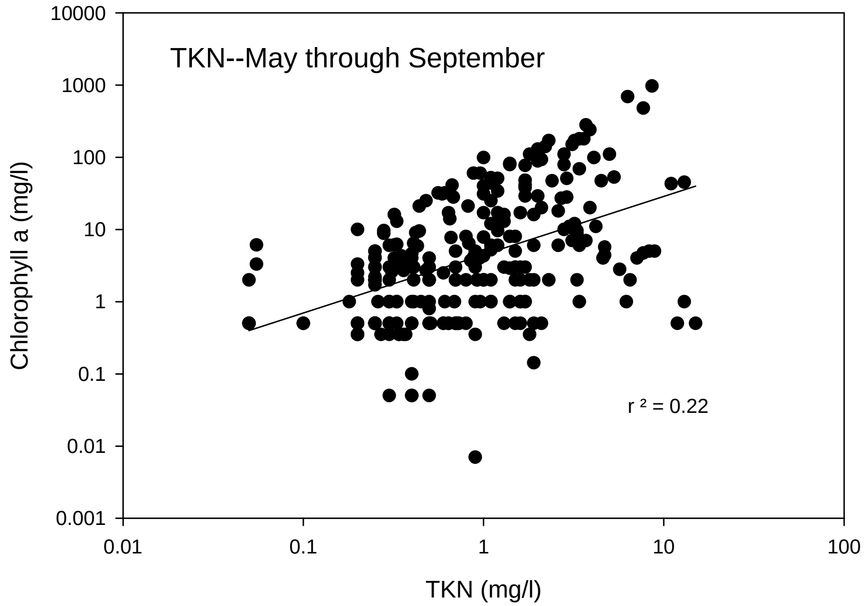
BATHUB Lake Model Summary of Results

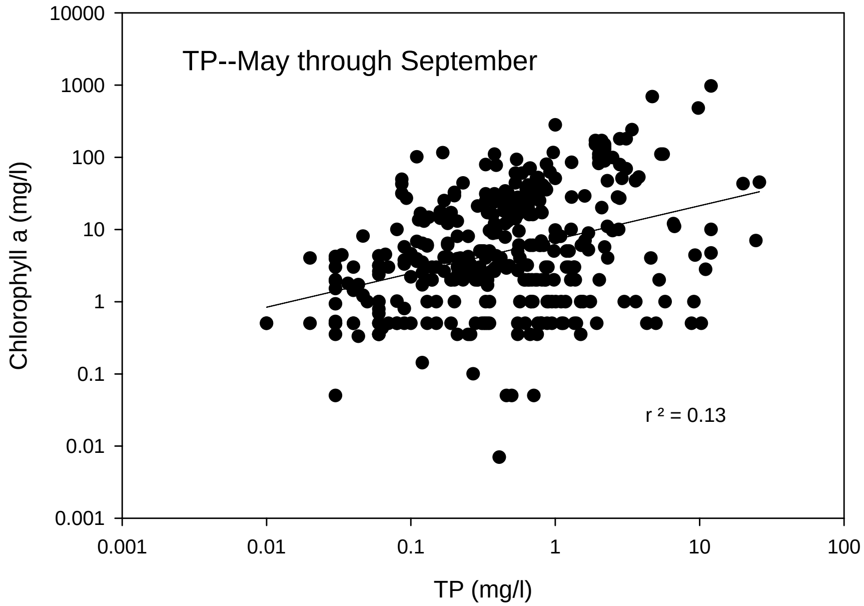
- Phosphorous limited algal growth when nitrogen loadings exceed 5,000 ug/L-year and phosphorous loadings are less than 200 ug/L-year
- Nitrogen limited algal growth when phosphorous loadings exceed 500 ug/L-year and nitrogen loadings are less than 2,000 ug/L-year
- Approximately log-linear inverse relationship between allowable normalized nutrient concentrations and residence times, with allowable normalized nutrient concentrations increasing with decreasing residence time and increasing turbidity values
- Much larger range of nutrient and residence time parameter values exceeds the 10 ug/L target than the 25 or 40 ug/L target values
- Results very sensitive to residence time and moderately sensitive to turbidity over range of Ecoregion 6 values

Empirical Analysis of Stream Response to Nutrients

- Goal is to develop statistical relationships using available data, either from Ecoregion 6 or from larger scale national studies; no mechanistic modeling
- Examples:
  - Global relationship between benthic Chl a and nutrient concentrations (e.g., Dodds, Smith, and Zander, 1997)
  - Periphyton chl-a data for RB-6 and EMAP

Empirical Data Analysis: Planktonic Chl a in Streams

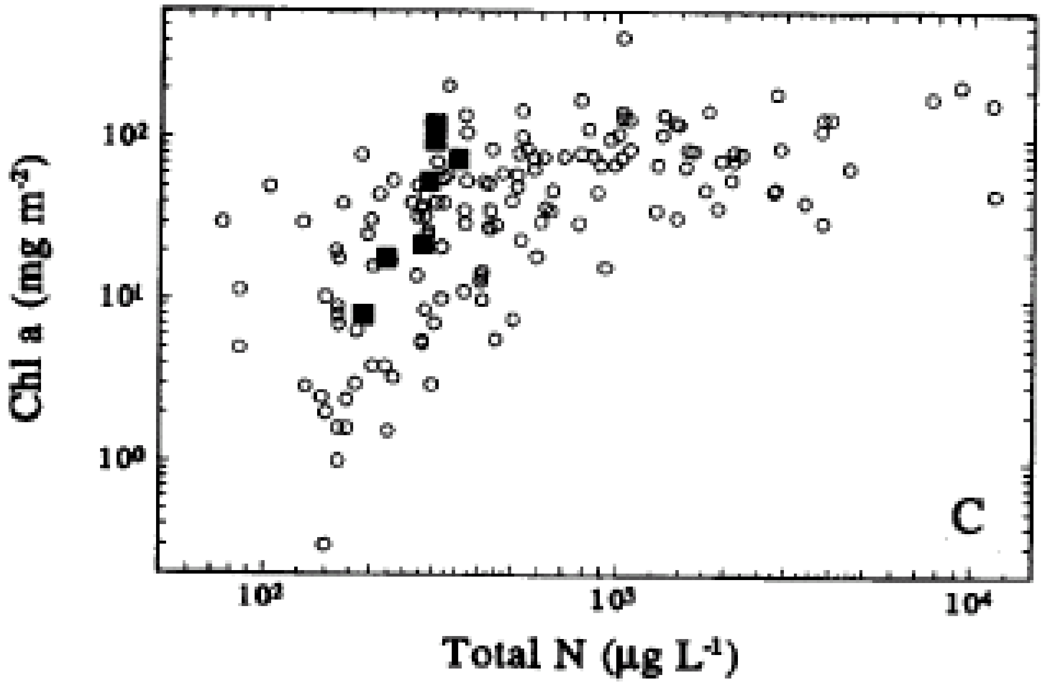




log10(CHL-A) = 0.687 + (0.629 * log10(TKN)) + (0.182 * log10(TP)); $r^2 = 0.23$

log10(CHL-A) = 0.650 + (0.809 * log10(TKN)); $r^2 = 0.22$

Dodds et al. (1997) Relationship Between Benthic Chl-a and Total Nitrogen – US streams



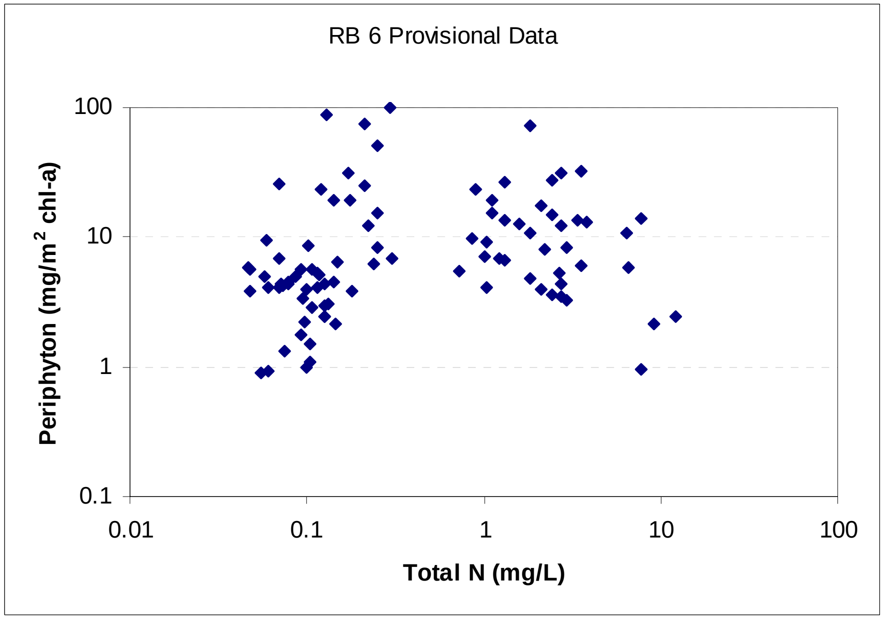
Nutrients define upper bound, not mean of observations

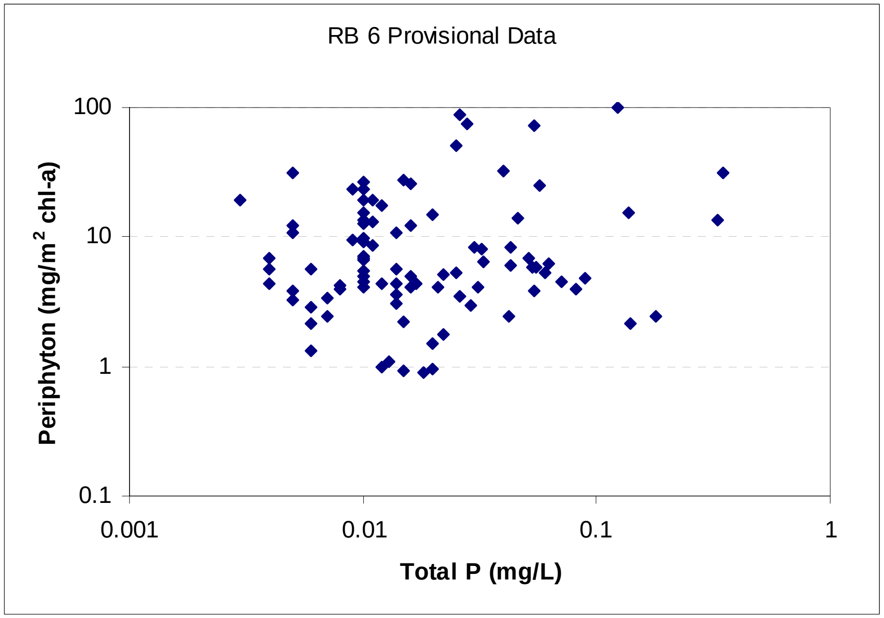
Biggs (2000): Similar results for New Zealand

Boundaries for Stream Trophic Classifications Proposed by Dodds et al. (1998)

Variable	Oligotrophic-Mesotrophic Boundary	Mesotrophic-Eutrophic Boundary
Mean benthic chlorophyll *a* (mg/m^2)	20	70
Maximum benthic chlorophyll *a* (mg/m^2)	60	200
TN (µg/L)	700	1500
TP (µg/L)	25	75

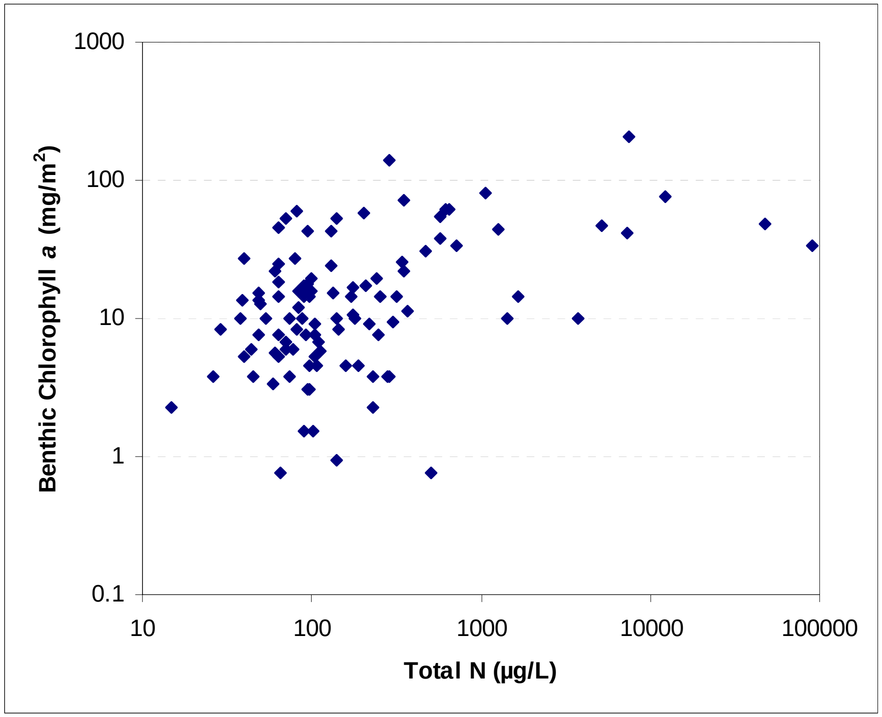
Provisional Data from Regional Board 6

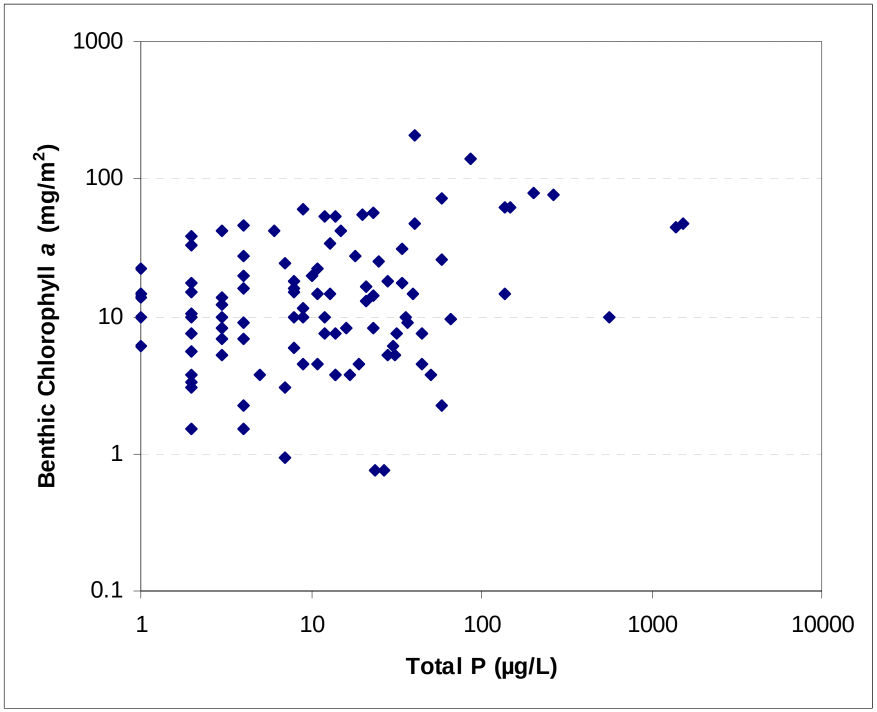




log(mean Chl *a*) = -3.20 + 2.94 log(TN) – 0.512 $(\log(TN))^2$ + 0.0914 log(TP), $r^2 = 0.2$

EMAP Data For California

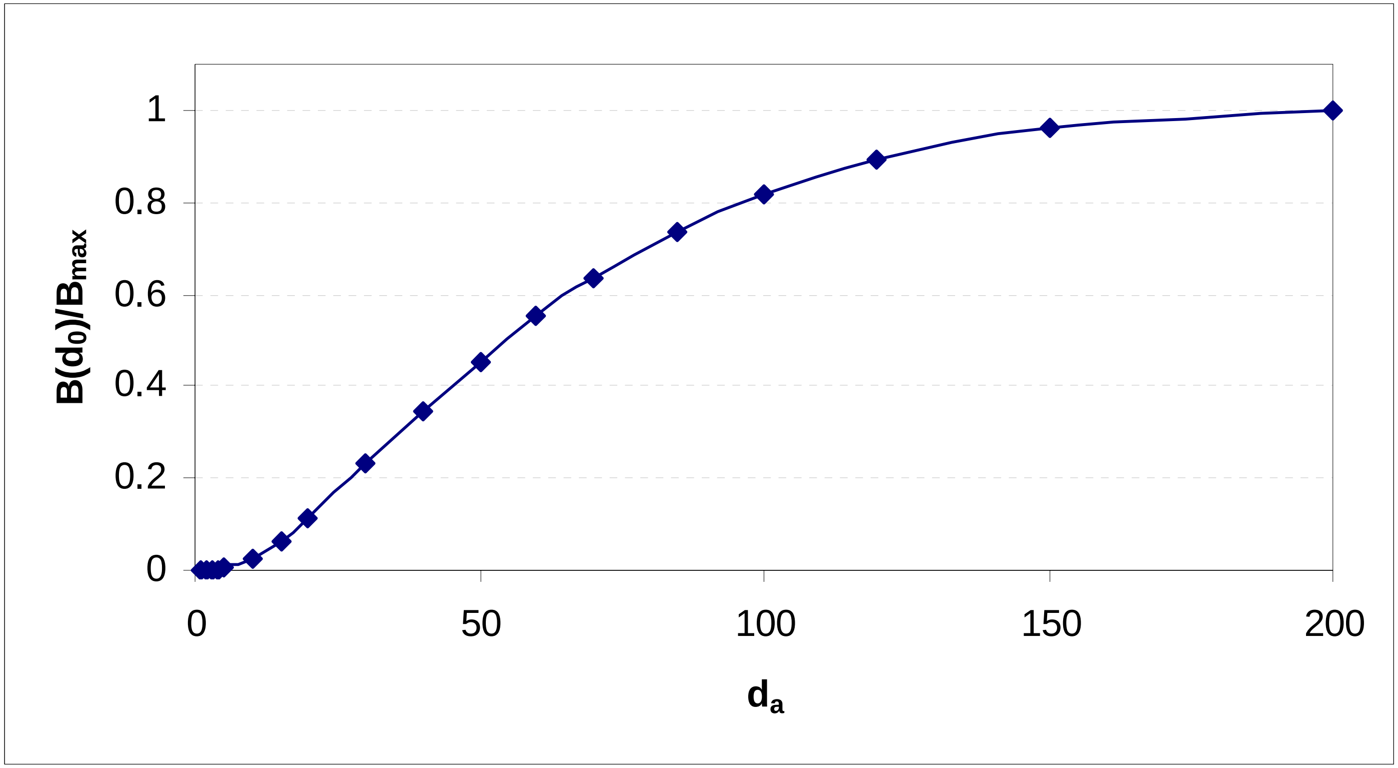




Periphyton Response

- Benthic chlorophyll *a* limited by light availability, scour, and grazing pressure
- Nutrients predict maximum potential, rather than average observed chlorophyll *a*
- Biggs (2000) approach to incorporating scour via days of accrual gave large increase in R^2 (from 32% to 74%).

Fraction of Potential Maximum Periphyton Biomass as a Function of Days of Accrual (Biggs, 2000)



Summary of Empirical Analysis of Stream Biological Reponse

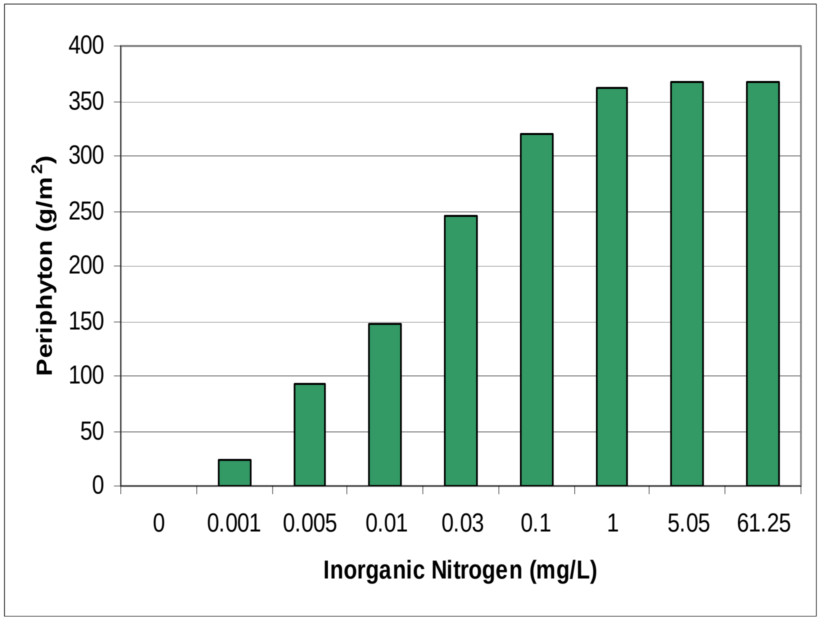
- Both RB-6 and EMAP data showed greater sensitivity to TN than to TP
- Both data sets indicate that the chl-a values lie near the mean values predicted by regression equations in Dodds et al. (2002)
- Nutrients generally explain <50% of chl-a levels, largely as a result of the influence of exogenous factors such as scouring by high flows and/or light limitation

Modeling Stream Response Using QUAL2K

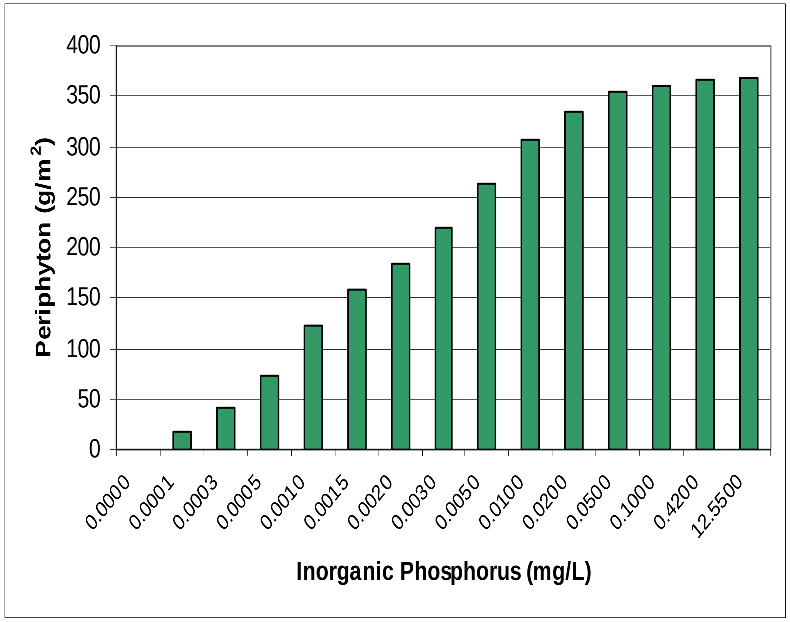
- QUAL2K is a revised version of the QUAL2E water quality model and incorporates benthic algal growth
- In the absence of adequate site-specific data, QUAL2K can be run using reasonable default parameters and can be "tuned" to a Dodds-type model
- Estimated Chl-a values are those that would result in the absence of the constraining factors such as grazing pressure and flood scour

Predicted Maximum Periphyton Biomass (in the absence of light limitation)

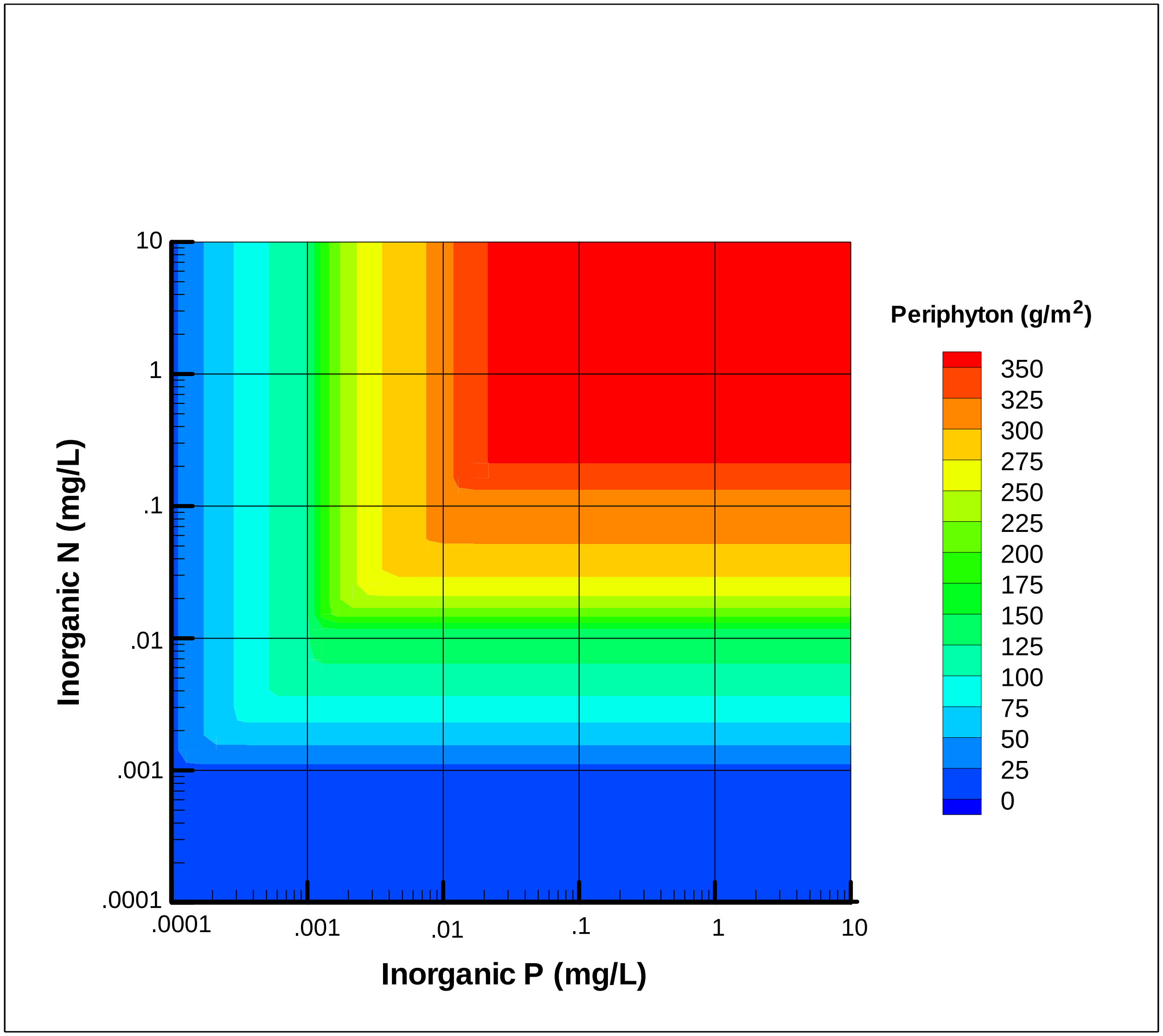
Nitrogen Limited



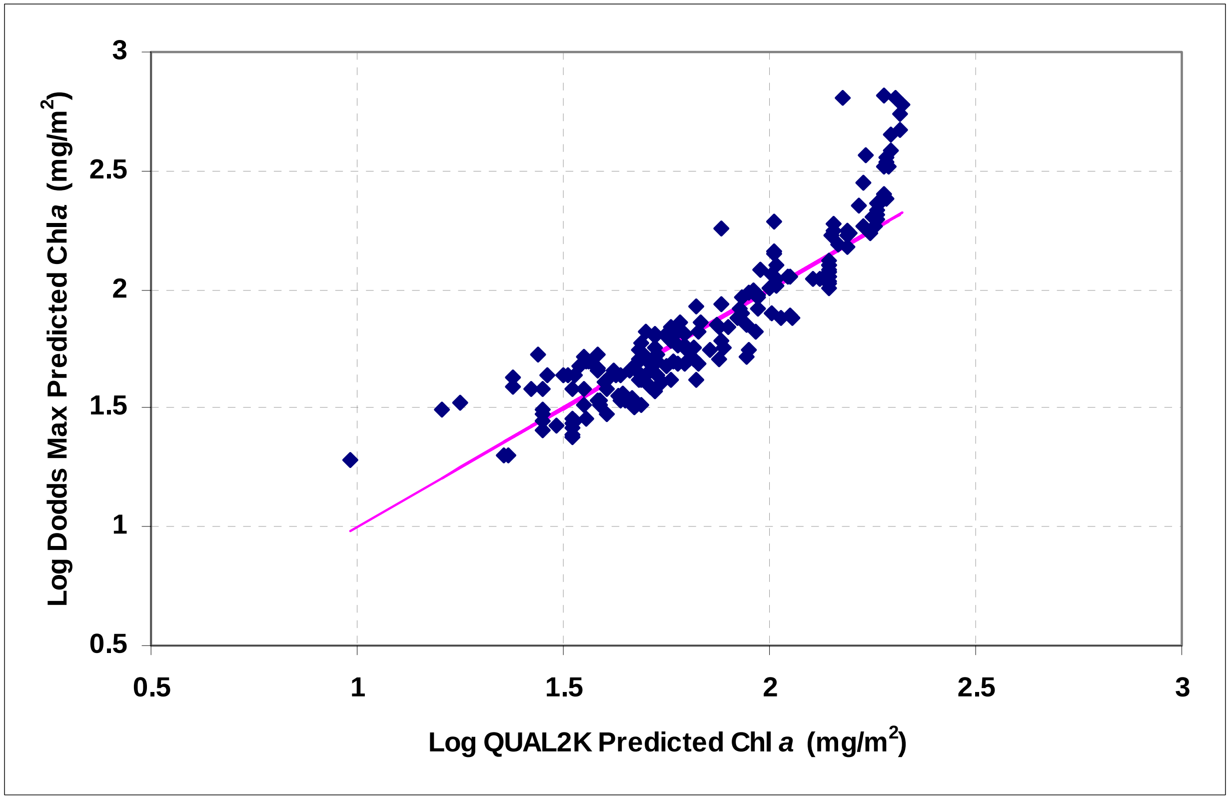
Phosphorus Limited



Response Surface for Maximum Periphyton Biomass



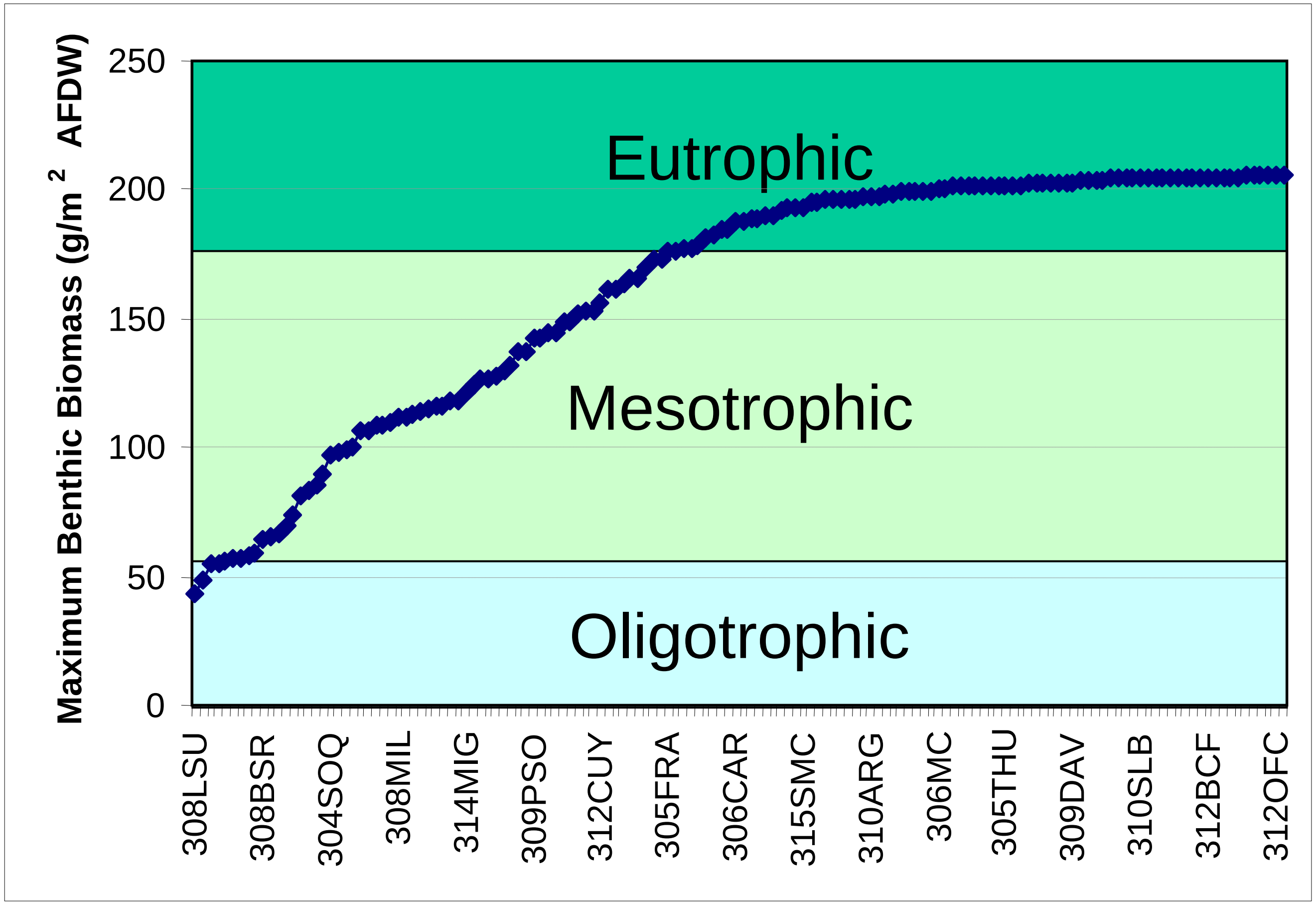
Relating Dodds et al. Data to Model Output



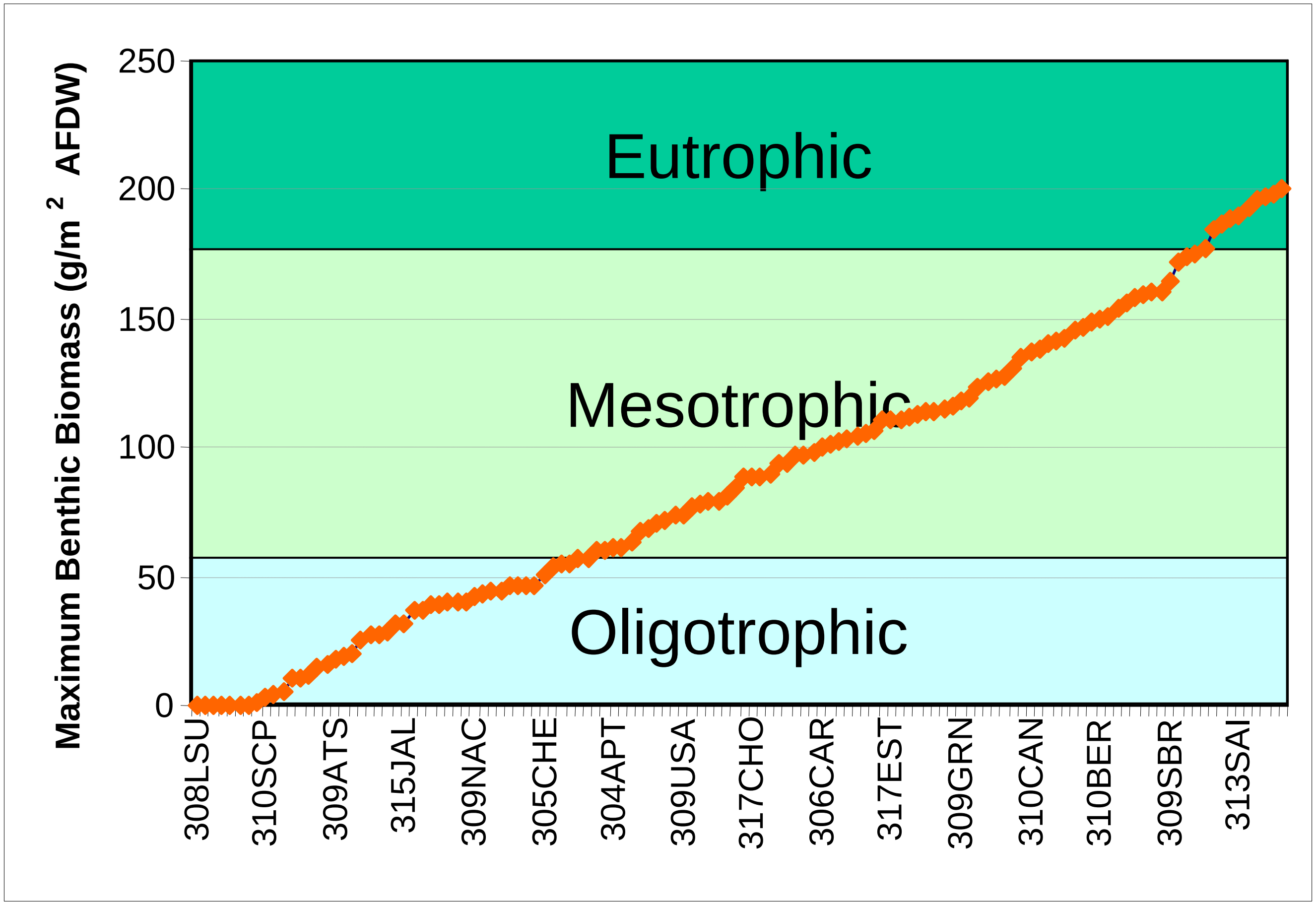
Based on QUAL2K parameters that were adjusted to Dodds et al.'s results

Application of QUAL2K Framework to RB-3 Data

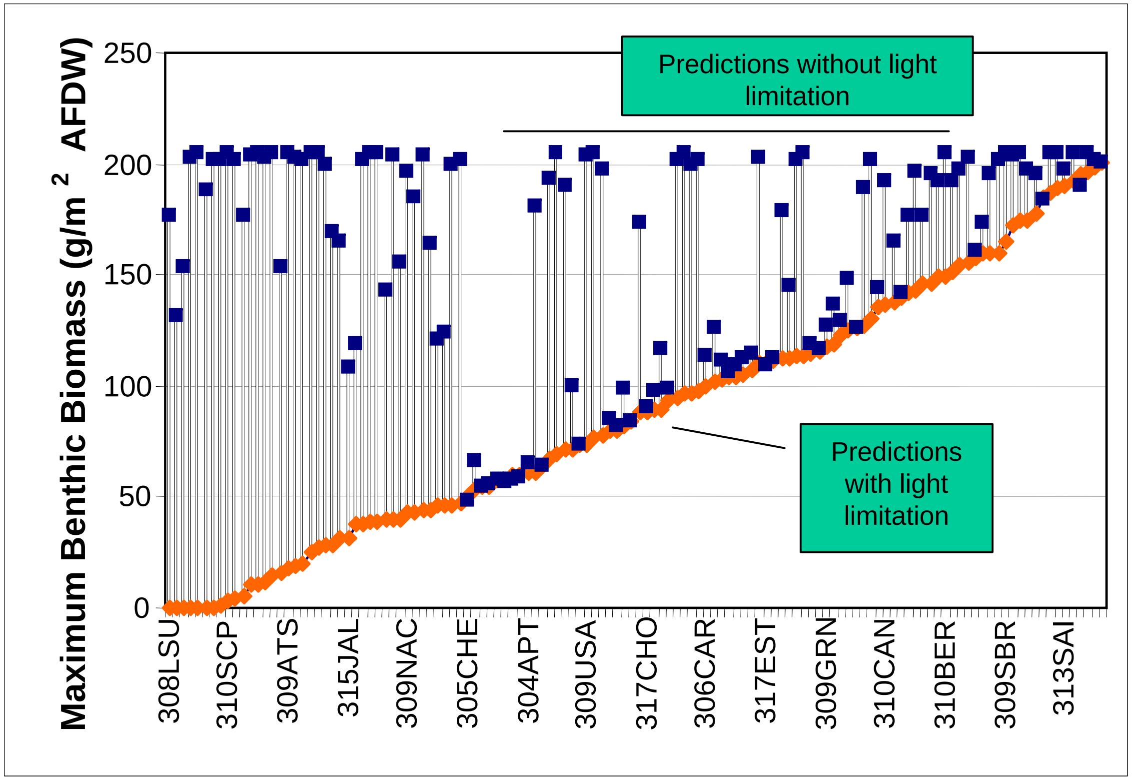
Cumulative Distribution of Maximum Potential Benthic Algal Biomass Predicted by QUAL2K Approach for RB 3 Sites without Considering Light Limitation



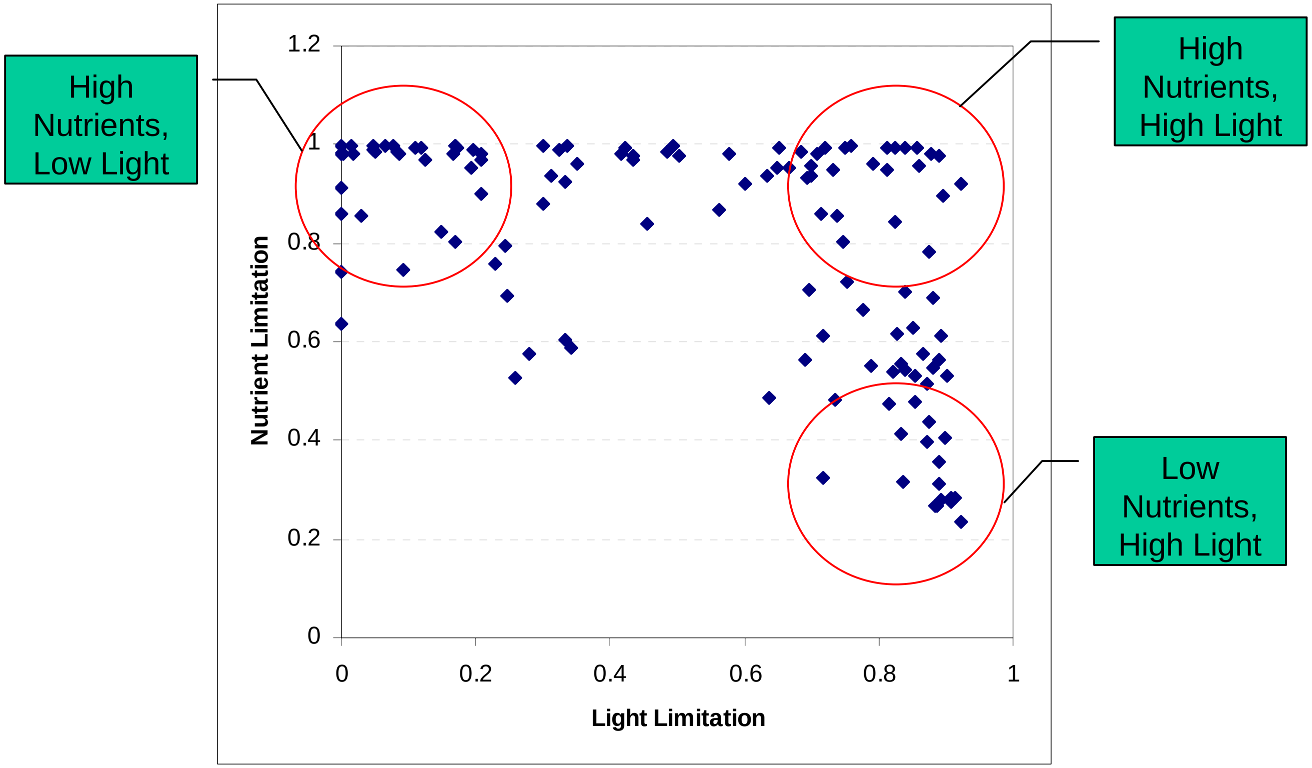
Cumulative Distribution of Maximum Potential Benthic Algal Biomass Predicted by QUAL2K Approach for RB 3 Sites with Light Limitation by Shade and Turbidity



Effects of Light Limitation on Benthic Biomass Predictions



Nutrient and Light Limitation in RB 3 Data Set



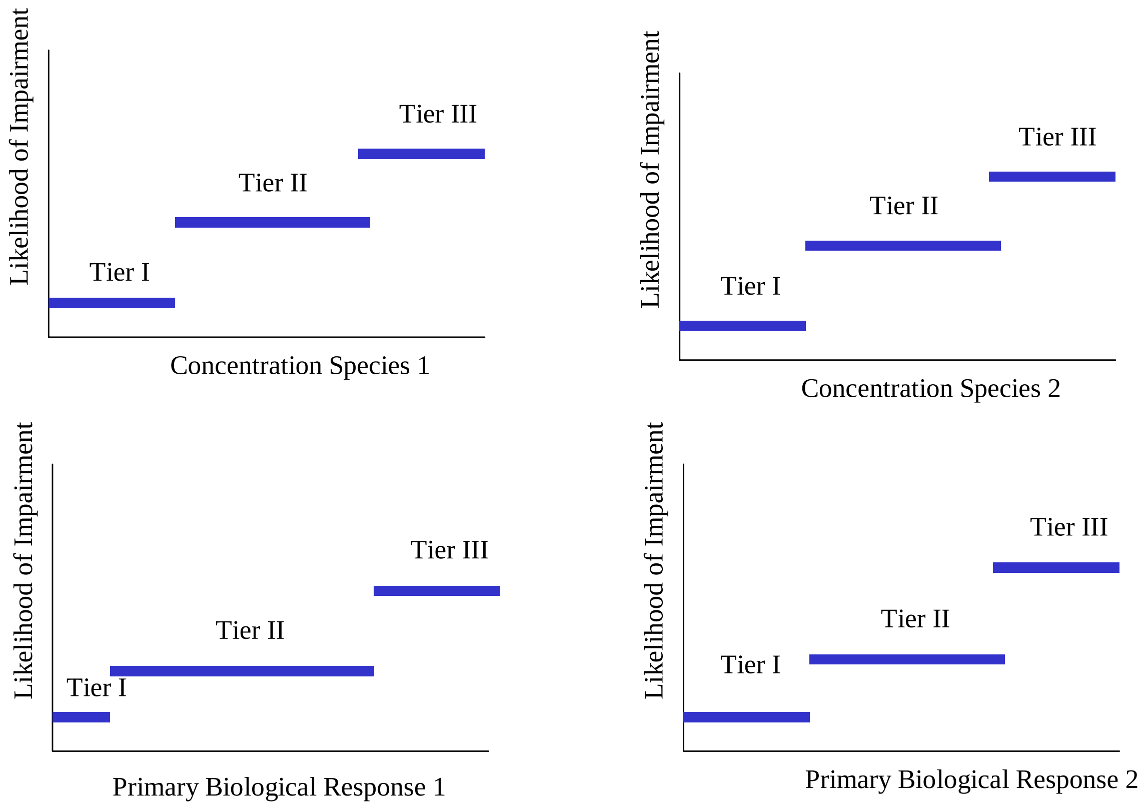
Role of QUAL2K Modeling in California Nutrient Criteria

- Riparian shading/turbidity limitations on light can be incorporated directly
- As structured the model does not directly account for factors such as flood scour, but these can be incorporated using alternative correlations (Biggs)
- QUAL2K be used to provide one line of evidence of likely biological responses in conjunction with data

Phased Approach to Implement Criteria: Phase One Recommendation

- Use combination of data and estimated values to classify water bodies into three categories (a “triad” approach)
  - Nutrient impairment unlikely and/or corresponds to natural background range (Tier I)
  - Nutrient impairment possible and exceeds natural background range (Tier II)
  - Nutrient impairment very likely in the absence of other anthropogenic stressors (Tier III)

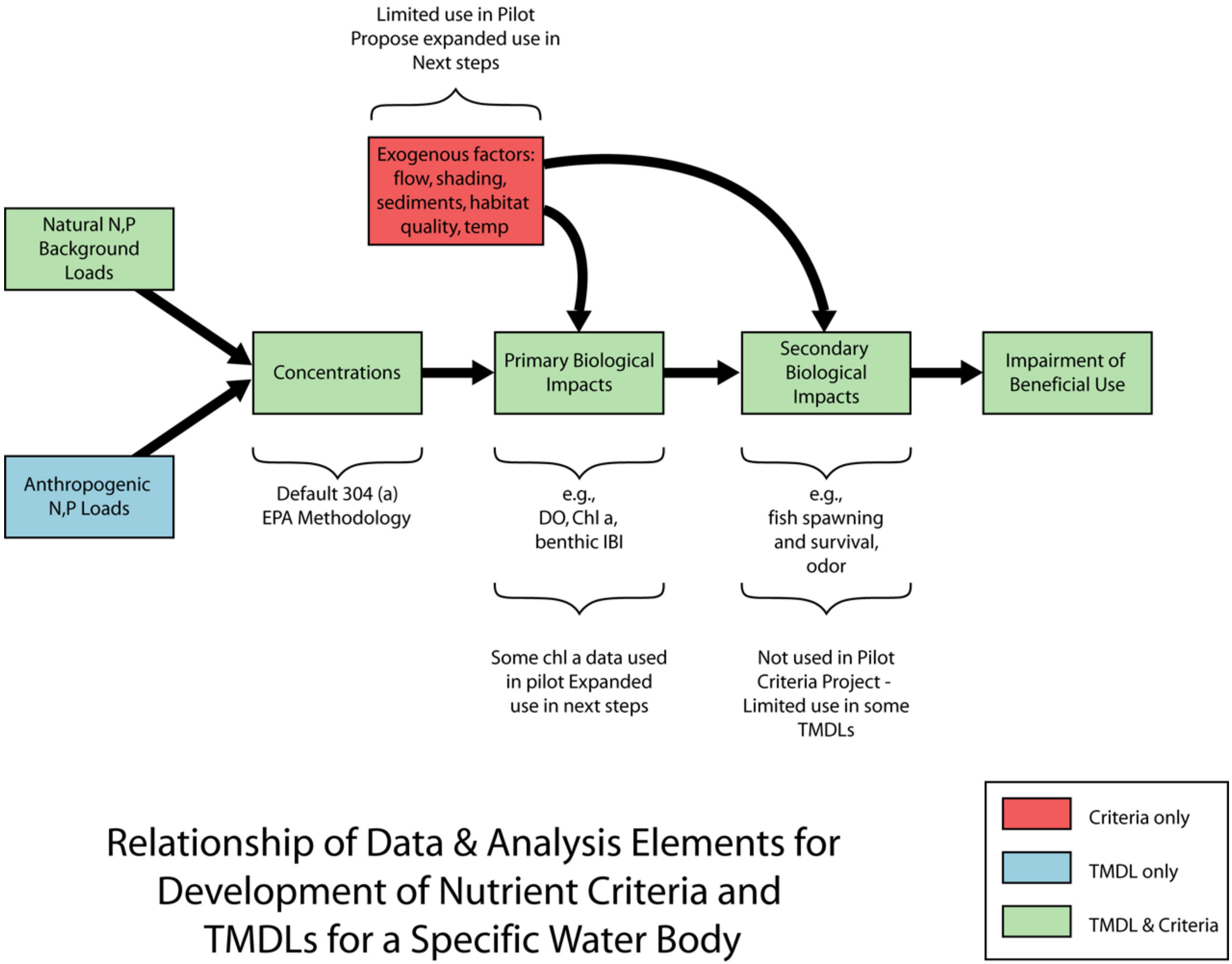
Form of the Standard



- Includes chemical and biological parameters
- All individual criteria must be exceeded before water body is placed in higher tier

Consequences of Classification

- Tier I: No action needed
- Tier II: Further study to determine whether beneficial uses are threatened
  - Site specific factors influencing response
  - Potential anti-degradation analysis
- Tier III: Nutrient load reduction may be needed; possible permit load caps and TMDLs



Relationship of Data & Analysis Elements for Development of Nutrient Criteria and TMDLs for a Specific Water Body

How the Tiered Criteria May Be Used

Tier 2: Mid-Range Concentrations / Low Biological Response • Are physical / chemical factors affecting biological activity? ✓ Evaluate shading, scour, habitat quality, other toxic chemicals.	Tier 3: High Concentrations / High Biological Response • Is this system naturally eutrophic? ✓ Are these conditions consistent with the system’s designated uses? ✓ Evaluate natural background loading (e.g., SPARROW) ✓ Is high biological response caused by degraded physical habitat conditions (e.g., reduced canopy cover)
Tier 1: Low Concentrations / Low Biological Response • No further follow up action is indicated.	Tier 2: Low-Medium Concentrations / High Biological Response • Are these conditions consistent with the system’s Designated Uses? • Are the nutrients tied up in attached biomass? ✓Measure nutrients in periphyton. • Are degraded physical habitat conditions contributing to high biological response? ✓Evaluate shading, scour, and other habitat qualities.

Summary of Approach

- Use available data, make estimates where no data are available
- Use best available information to develop a framework for criteria that recognizes uncertainties
- Leave open the door for improvement in the criteria framework if new chemical or biological data become available

Next Steps

- Continue to refine modeling data analysis tools
- Provide a “Monitoring Needs Report” to SWAMP and collaborators
- Assist with data collection
- Conduct case study using enhanced QUAL2K and BATHTUB tools
- Provide technical support to workgroup to develop language for triad categories -- including background information for NPDES considerations
- Refine ranges for triad categories