Developing Nutrient Targets for TMDLs

Biological Thresholds and Predictive Modeling

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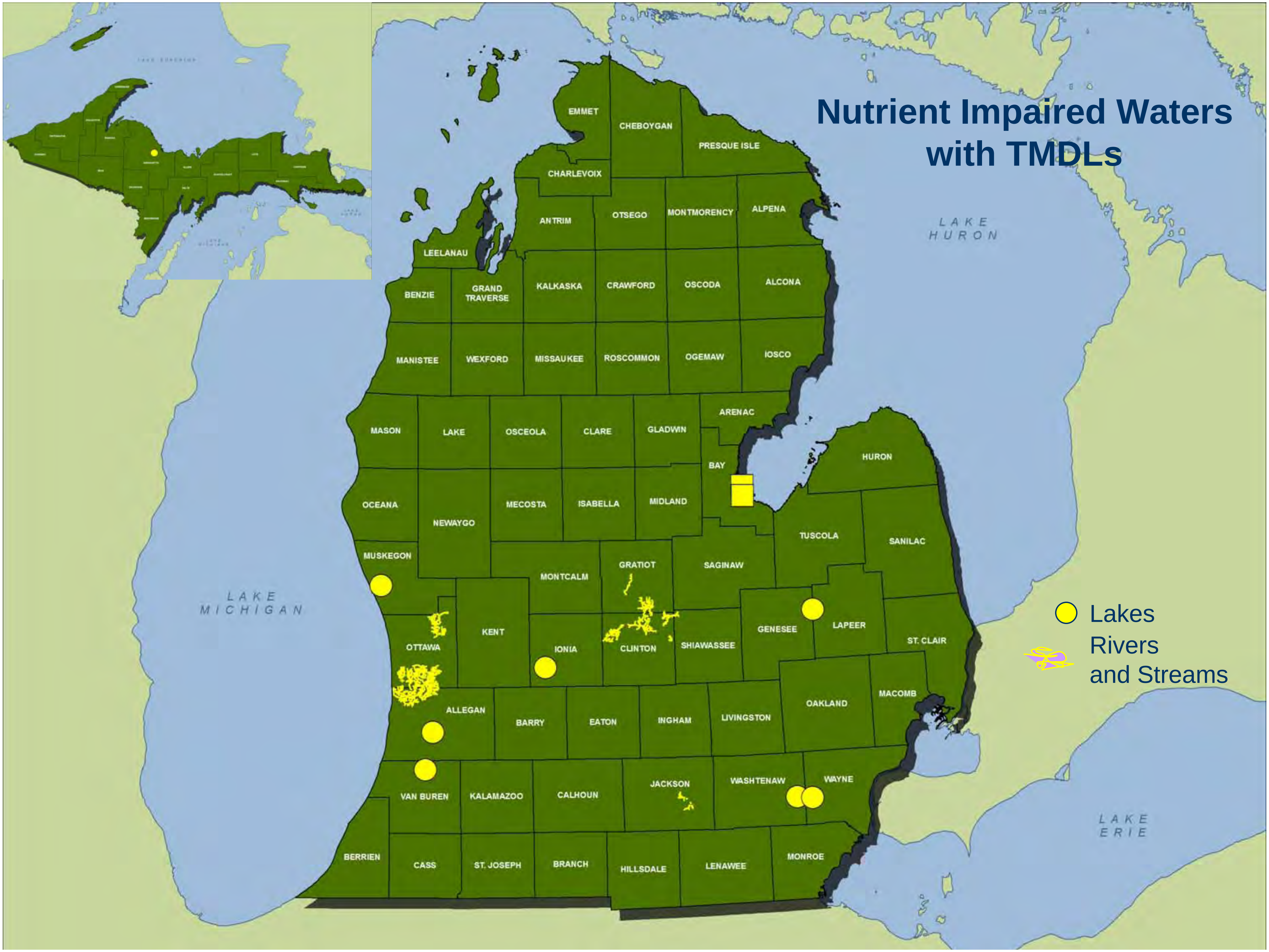
Nutrient Impairment in Michigan Inland Lakes

- 46,000 inland lakes and reservoirs
- 730 inland lakes (SPAL >50 acres)
- Good-excellent water quality
- Supporting: oligotrophic, mesotrophic, or eutrophic
- Not Supporting: hypereutrophic (few)

Nutrient Impairment in Michigan Rivers and Streams

- 76,439 total miles
- 600 miles impaired
- *Cladophora* and/or *Rhizoclonium* >10-inches covering > 25% of a riffle.
- Rooted macrophytes present at densities that impair designated uses
- Presence of bacterial slimes.


Nutrient Impaired Waters
with TMDLs
Lakes
Rivers
and Streams
LAKE HURON
LAKE MICHIGAN
LAKE ERIE
EMMET
CHEBOYGAN
PRESQUE ISLE
CHARLEVOIX
ANTRIM
OTSEGO
MONTMORENCY
ALPENA
LEELANAU
BENZIE
GRAND TRAVERSE
KALKASKA
CRAWFORD
OSCODA
ALCONA
MANISTEE
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
IOSCO
ARENAC
MASON
LAKE
OSCEOLA
CLARE
GLADWIN
BAY
HURON
OCEANA
NEWAYGO
MECOSTA
ISABELLA
MIDLAND
TUSCOLA
SANILAC
MUSKEGON
MONTCALM
GRATIOT
SAGINAW
KENT
OTTAWA
IONIA
CLINTON
SHIAWASSEE
GENESEE
LAPEER
ST. CLAIR
ALLEGAN
BARRY
EATON
INGHAM
LIVINGSTON
OAKLAND
MACOMB
VAN BUREN
KALAMAZOO
CALHOUN
JACKSON
WASHTENAW
WAYNE
BERRIEN
CASS
ST. JOSEPH
BRANCH
HILLSDALE
LENAWEE
MONROE

Problems with Assessing Water bodies as Nutrient Impaired

- No numeric nutrient criteria
- Limited assessment methodology
- Consistency in BPJ
- A single nutrient criterion for a waterbody type is not appropriate

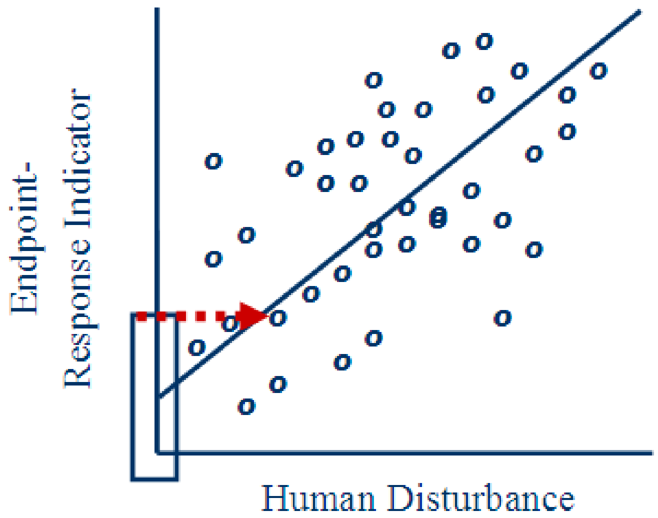
Setting Nutrient Targets (Criteria)

(Soranno et al., 2008)

- Several approaches have been proposed
- Assumption: a given nutrient target or criterion acts as indicator of whether designated uses are being met
- Approaches can be considered either <u>implicit</u> or <u>explicit</u> when measuring “aquatic life” use as “biological integrity”

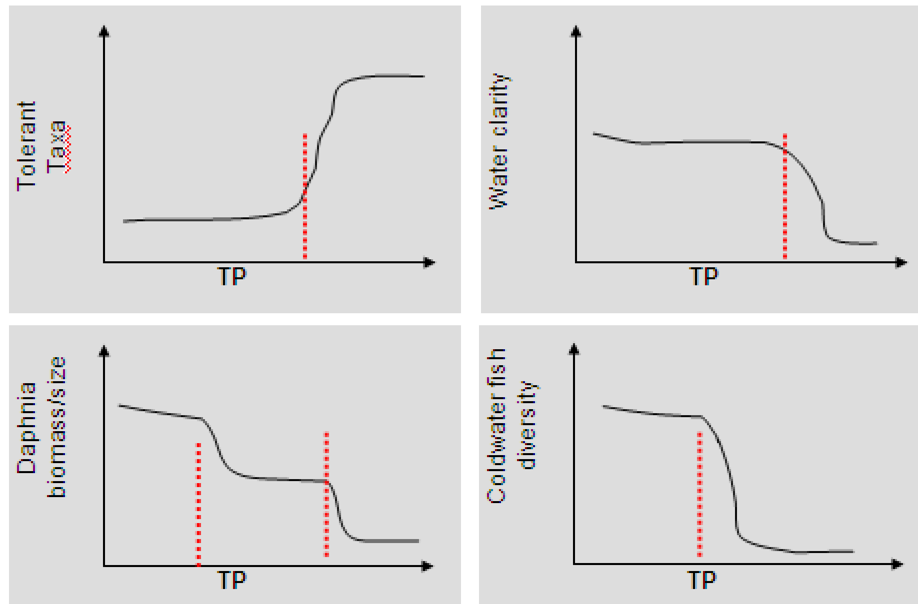
Setting Nutrient Targets,
(Soranno et al., 2008)

- Implicit Approach – biological integrity
  - assumed to be protected at minimal human disturbance levels
  - defined by some human disturbance gradient and associated nutrient value
  - biological integrity not measured



Setting Nutrient Targets,
(Soranno et al., 2008; Stevenson et al., 2004)

- Explicit Approach – biological response
- Changes in biological response are used as surrogate for designated use
- Biological response changes along a nutrient gradient
- Changes can be demonstrated through…
  - Analytical approaches
  - Expert judgment (BPJ)
  - Thresholds (non-linear biological responses along a nutrient gradient)



Integrating Biological Thresholds with Predictive Modeling *(Soranno et al., 2008)*

- Ecosystem – specific framework for developing nutrient targets (criteria) using biological thresholds and predictive modeling (BTPM)

Limnol. Oceanogr., 53(2), 2008, 773–787

A framework for developing ecosystem-specific nutrient criteria: Integrating biological thresholds with predictive modeling

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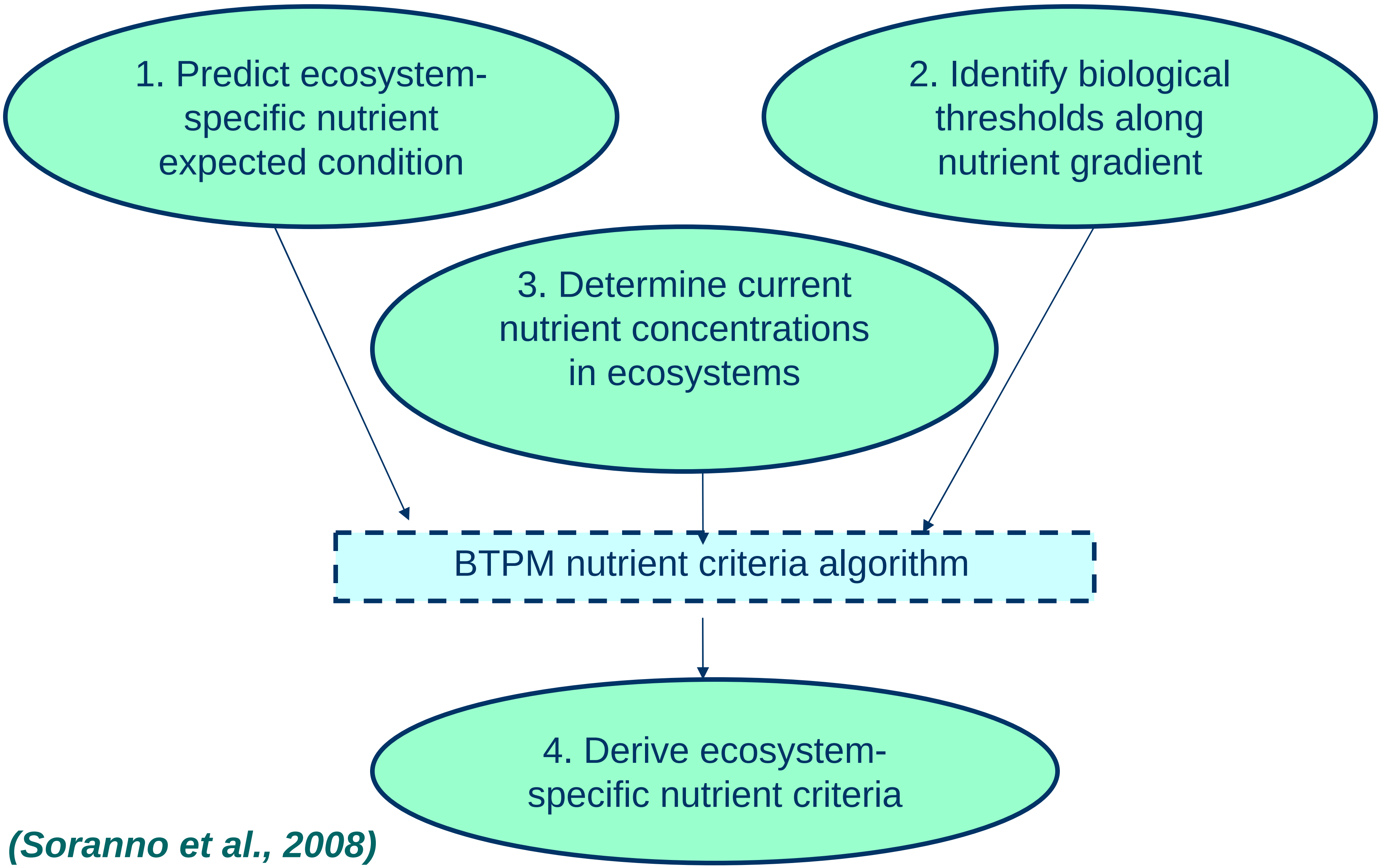
An ecosystem-specific framework for developing nutrient criteria from biological thresholds and predictive modeling (BTPM)



(Soranno et al., 2008)

Application of the BTPM Framework to a Set of Michigan Lakes

1. Predict ecosystem-specific nutrient expected condition

1. **Predict lake-specific expected TP**
   (a) <u>Model lake TP</u> as a function of HGM Features and human LULC (HGM-LU Model)

e.g.
TP = *a*(color) + *b*(lake morph) + *c*(geol) + *d*(LULC)

(b) <u>Predict expected TP</u> for all lakes at zero level of human LULC (EXPo) using the HGM-LU model; add allowance to EXP_O to estimate EXP_A

e.g.
EXP_O = *a*(color)+ *b*(lake morph) + *c*(geol) + *d*(0)
EXP_A = EXP_O + allowance

Figure 2 from Soranno et al., 2008. Limnol. Oceanogr., 53(2), 773-787.

HGM Features and LULC Features

- Lake and Catchment Morphometry
  - Lake area
  - **Mean depth**
  - Maximum depth
  - Shoreline development factor
  - Lake basin slope
  - Catchment area
  - Drainage area
  - Stream length
  - Climate
  - Precipitation
- Bedrock geology
  - % carbonate
  - % clastic
  - % hard rock
  - % salt
  - % iron
- Surficial geology
  - % dune
  - **%outwash**
  - % moraine
  - % exposed bedrock
  - % peat and muck
  - % lacustrine
  - % glacial till
- LULC
  - **% agriculture**
  - **% urban**
  - % forest
  - % upland vegetation
  - % wetland
  - % open water
- Water Chemistry
  - **color**

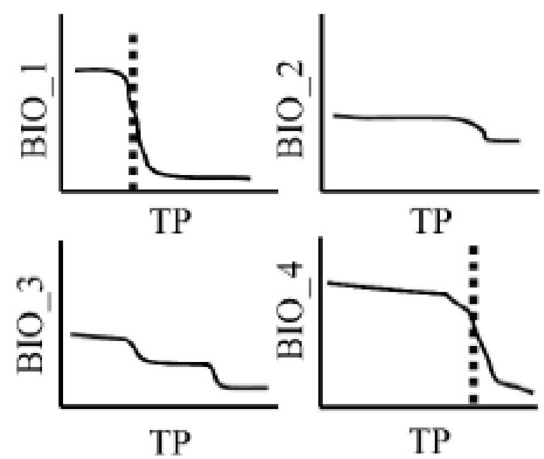
Application of the BTPM Framework to a Set of Michigan Lakes

2. Identify biological thresholds along TP gradient

(a) Quantify the effect of TP on multiple biological responses (BIO_1-4)

(b) select BIO benchmarks (dotted lines) for where there is evidence of an important threshold.

2. Identify biological thresholds along nutrient gradient



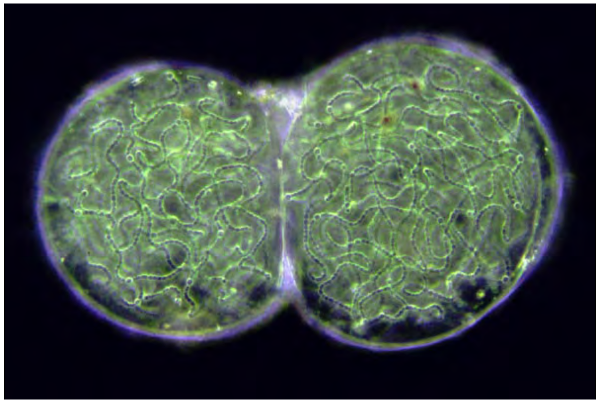
3. Determine current nutrient concentrations in ecosystems

3. Determine current TP and water color in each lake

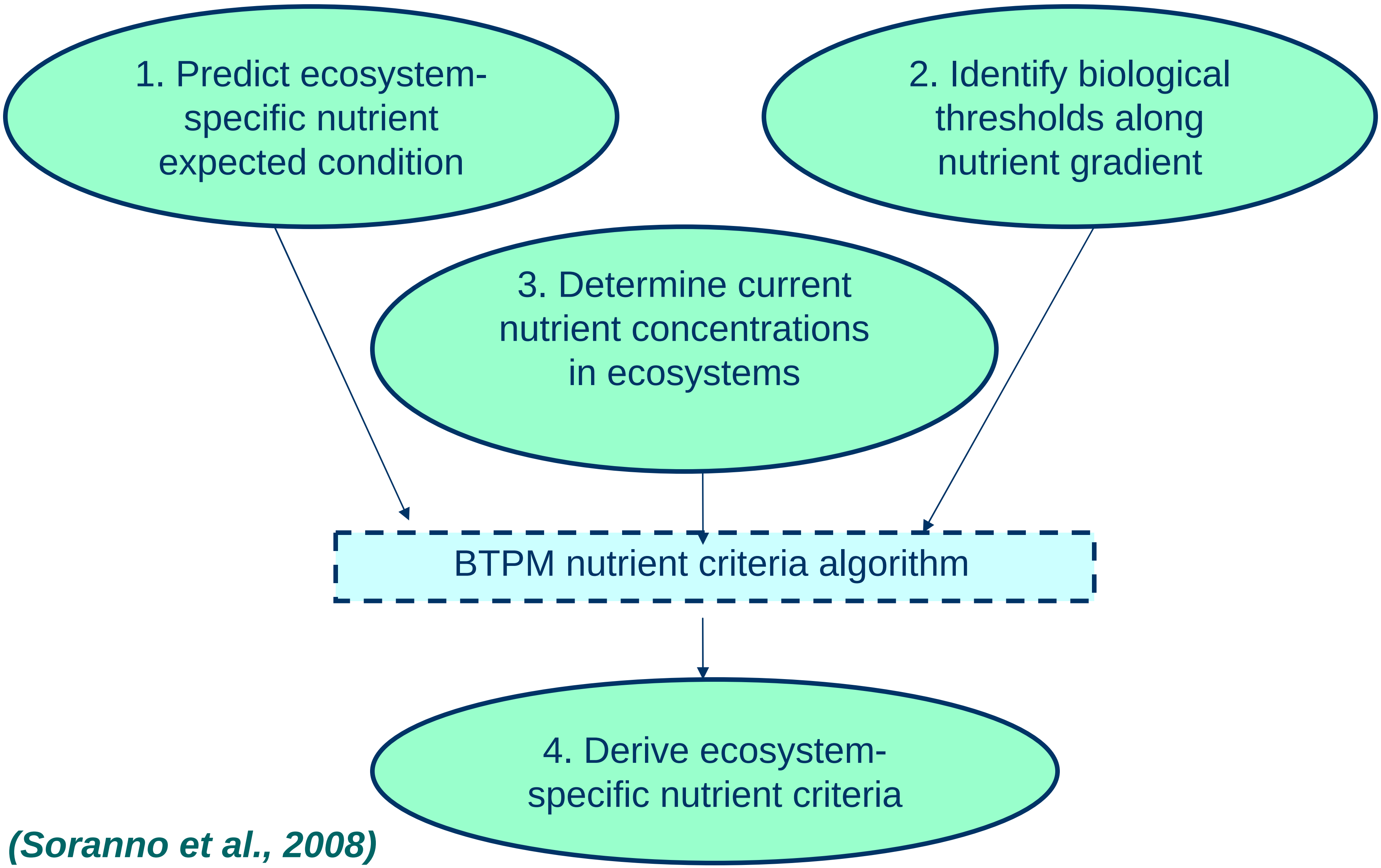
Figure 2 from Soranno et al., 2008. Limnol. Oceanogr., 53(2), 773-787.

Identify Biological Thresholds Along a Nutrient Gradient

- Biological Data:
  - Combined biological response from recent studies (1998 – 2004)
  - Phytoplankton biomass
  - Clarity metrics **Identify biological thresholds along nutrient gradient**
  - Phytoplankton community
  - Toxin metrics
  - Macrophyte cover metrics
- Identified critical thresholds (i.e., major changes in biology)



An ecosystem-specific framework for developing nutrient criteria from biological thresholds and predictive modeling (BTPM)



(Soranno et al., 2008)

4. Derive <u>lake-specific</u> TP criteria using a set of "rules" of the BTPM algorithm by combining the expected TP (EXP_A), the BIO benchmarks (e.g., 8 and 18 ug/l), and the current TP (CUR) to derive lake-specific criteria (CUR).

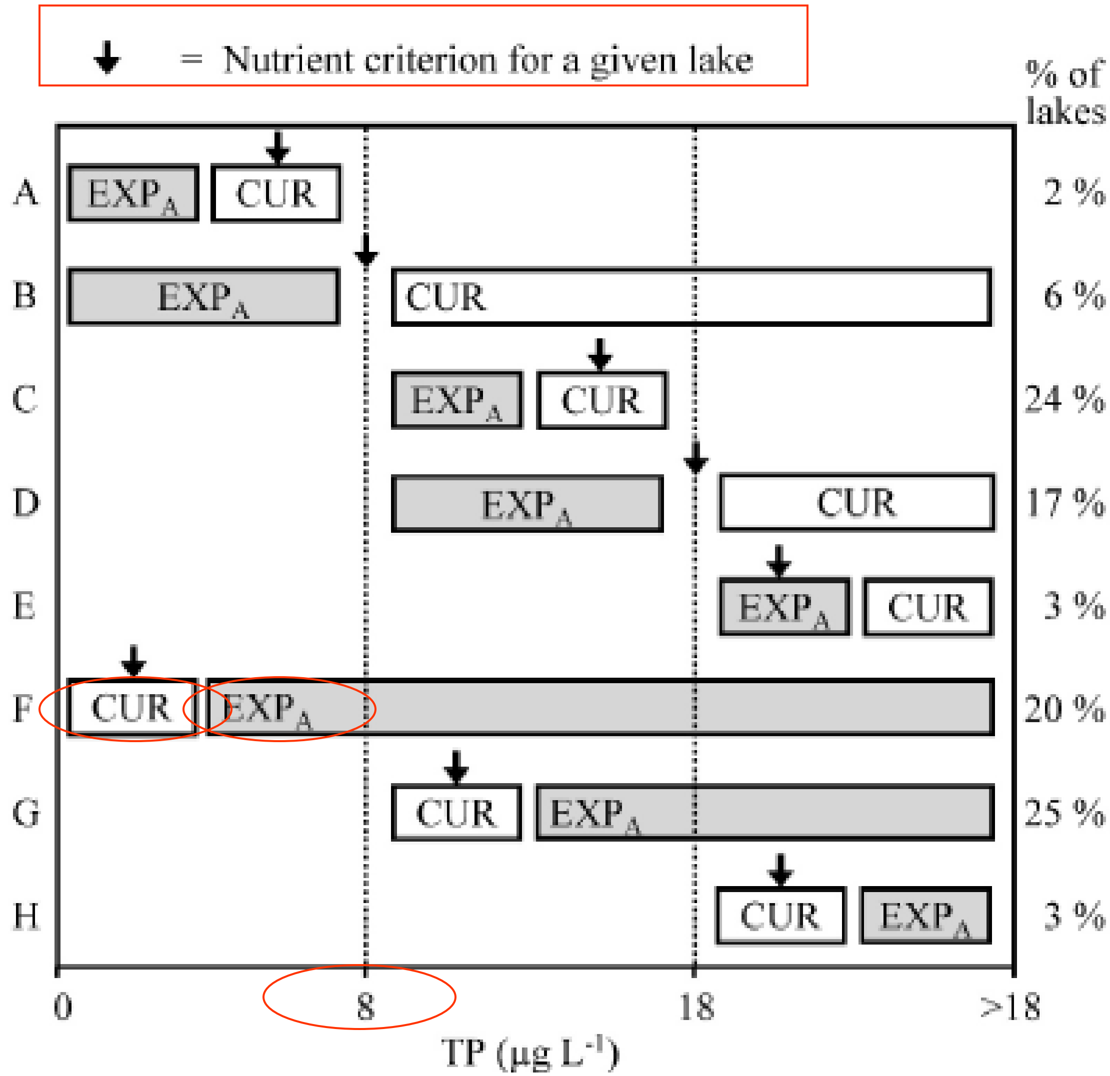
Rules: If……

EXP_A > CUR; CRI = CUR (assures no further degradation) **(e.g., F, G, and H)**

EXP_A < CUR (both in same BIO zone- but not highest one); CRI= CUR (**e.g., A, and C**)

EXP_A < CUR (but in highest BIO zone); CRI = EXP_A **(e.g., E)**

EXP_A (in lower BIO zone than CUR); CRI = next highest BIO) **(e.g., B and D)**



Six Key Assumptions

1. Phosphorus is the main stressor to lakes in Michigan

2. HGM features can be modeled and are important in evaluating the natural variation of phosphorus

3. Benchmarks should be established – sustain desired levels of biological attributes, and which are related to designated uses

Six Key Assumptions

4. Biological responses should include integrative measures of lake biology from pelagic and littoral zones, and water clarity (related to lake biomass through phytoplankton biomass)

5. Human disturbance can be reasonable approximated as the proportion of human LULC in lake catchment

6. Chose the state as a spatial scale to build models since lakes in US are managed at the state level

Thresholds (BIO Benchmarks) Evaluated for Lakes

Zooplankton/foodweb

Cyclopoid biomass
Cladoceran mean length
Daphnia biomass
Zooplankton biomass

←

Lakes

Low TP Thresholds found at around ~8 ug/l for these Response Factors

Clarity/1°Productivity

Chlorophyll *a*
Extinction coefficient
Phytoplankton dry mass

←

Higher TP Thresholds found at around ~18 ug/l and ~27ug/l for these Response Factors

Thresholds (BIO Benchmarks) Evaluated for Streams

Diatoms/1° Productivity

Similarity to reference
Sensitivity
Release from grazing pressure
Invert Taxa (tolerant, intolerant)
Chlorophyll *a*
Cladophera cover

Macroinvertebrates

EPT Metrics
Tolerant Taxa

Fish

Coldwater fish metrics
Warmwater fish metrics
Darter/Sculpin metrics

Streams

Many TP thresholds found at variable concentrations 10 – 80 ug/l

Model Development-Equations for Predicting Expected Condition

Natural Lakes:

LN(TP) = 1.867
- 0.257 x ln(mean depth)
- 0.202 x (outwash)
+ 0.344 x ln(color)

Artificial Lakes:

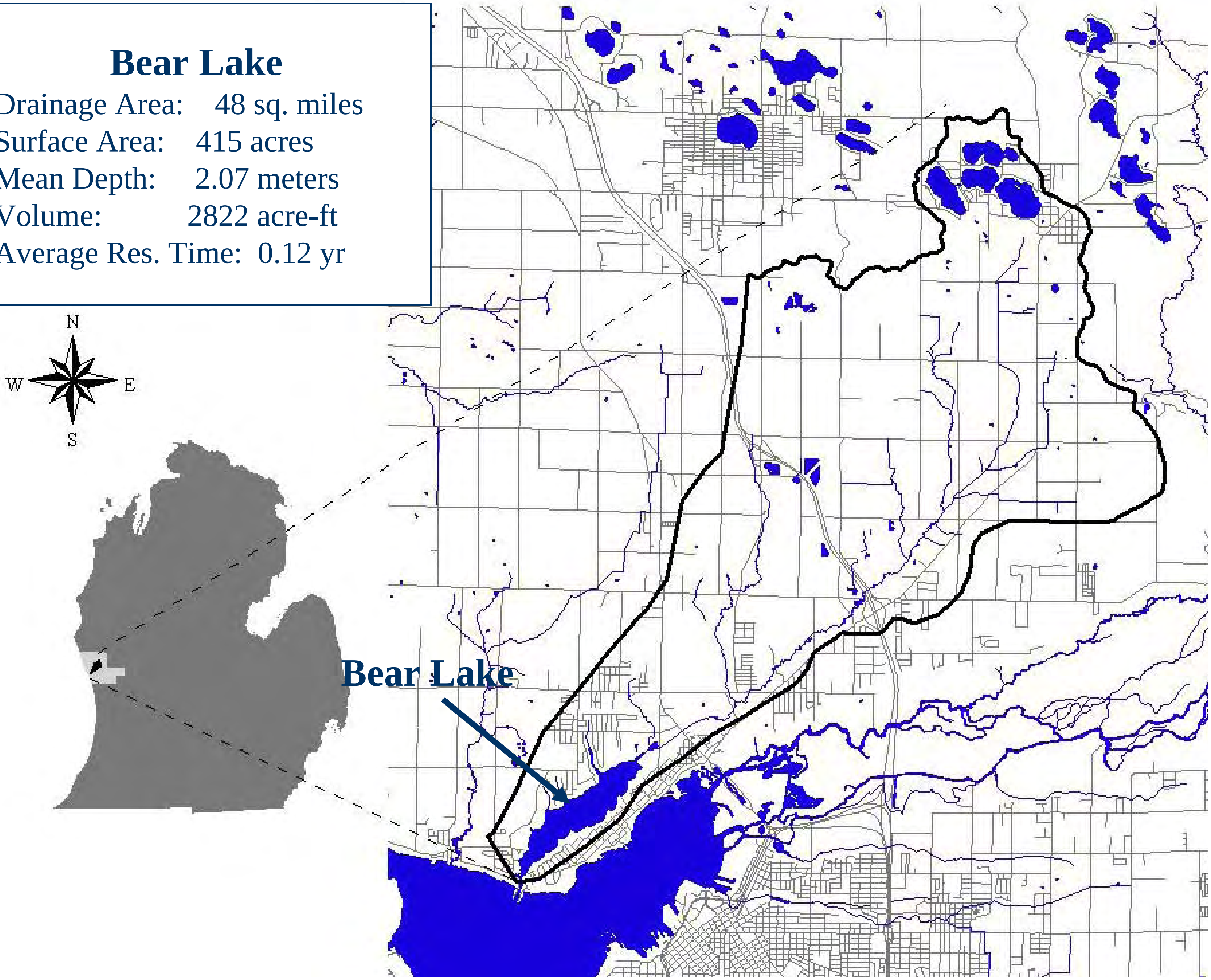
LN(TP) = 1.834
- 0.463 x ln(mean depth)
+ 0.421 x ln(color)

Rivers and Streams:

LN(TP) = 2.058
+ 0.10 x (channel order)
+ 0.318 x (medium substrate)
+ 2.173 x ln(wooded wetlands)

Bear Lake

Drainage Area: 48 sq. miles
Surface Area: 415 acres
Mean Depth: 2.07 meters
Volume: 2822 acre-ft
Average Res. Time: 0.12 yr



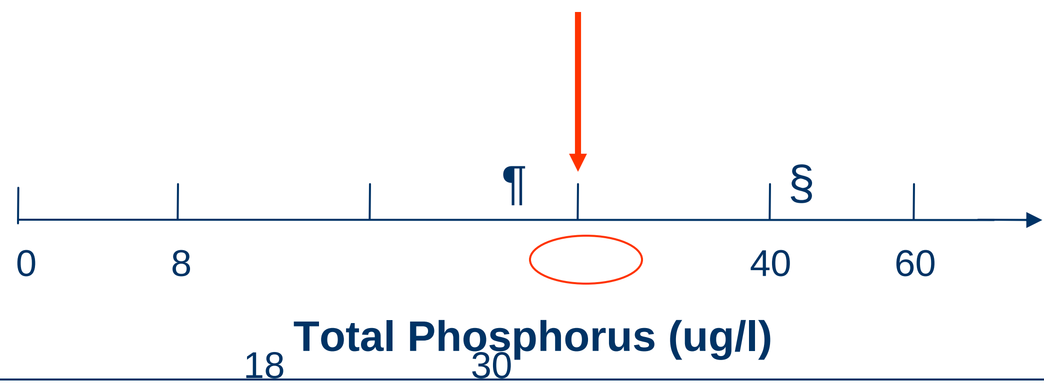
Development of the TMDL

The following steps were used in developing the TMDL for Bear Lake:

1. Determination of a phosphorus concentration target for Bear Lake using BTPM framework
2. Determination of the allowable loading to meet the concentration
3. Determination of phosphorus load reductions necessary to meet the allowable loads

Biological Thresholds and Modeling Framework

Bear Lake



¶ Predicted expected phosphorus concentration (*27 ug/l*)
§ Current phosphorus concentration (*42 ug/l*)
↓ Numeric phosphorus concentration goal (*30 ug/l*)

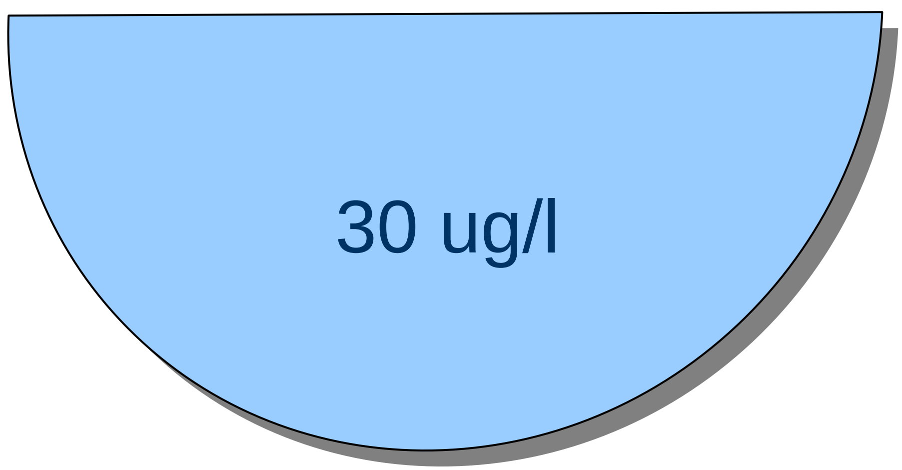
Note: Numeric values along line are biological thresholds

$$\mathbf{TPN = [e^{(1.867 - 0.257(\ln a) - 0.202(b) + 0.344(\ln c))}] * (1.39)}$$

a = arithmetic mean lake depth in meters
b = proportion of surficial geology-outwash within a 500 meter buffer around the lake
c = true color of lake in platinum - cobalt units measured as absorbance during the period July through September

Target Phosphorus Concentration
Bear Lake

Growing Season Concentration
(April to September)
Monthly Average



Walker Model

$$P = \frac{P_a DT}{D_m} \left[\frac{1}{1 + .824DT^{.454}} \right]$$

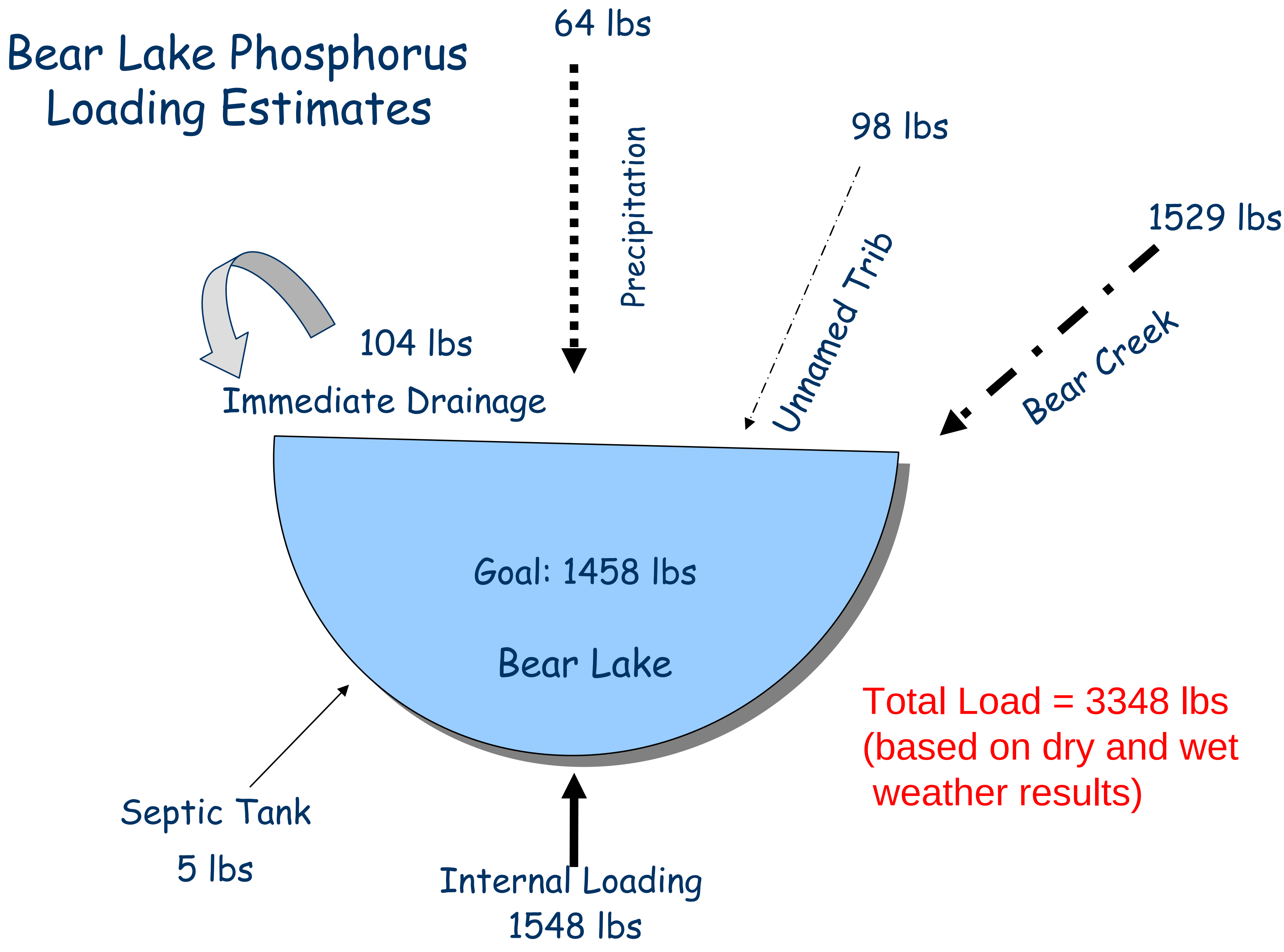
Where:

P = target in-lake phosphorus concentration (mg/l) = 0.03 mg/L

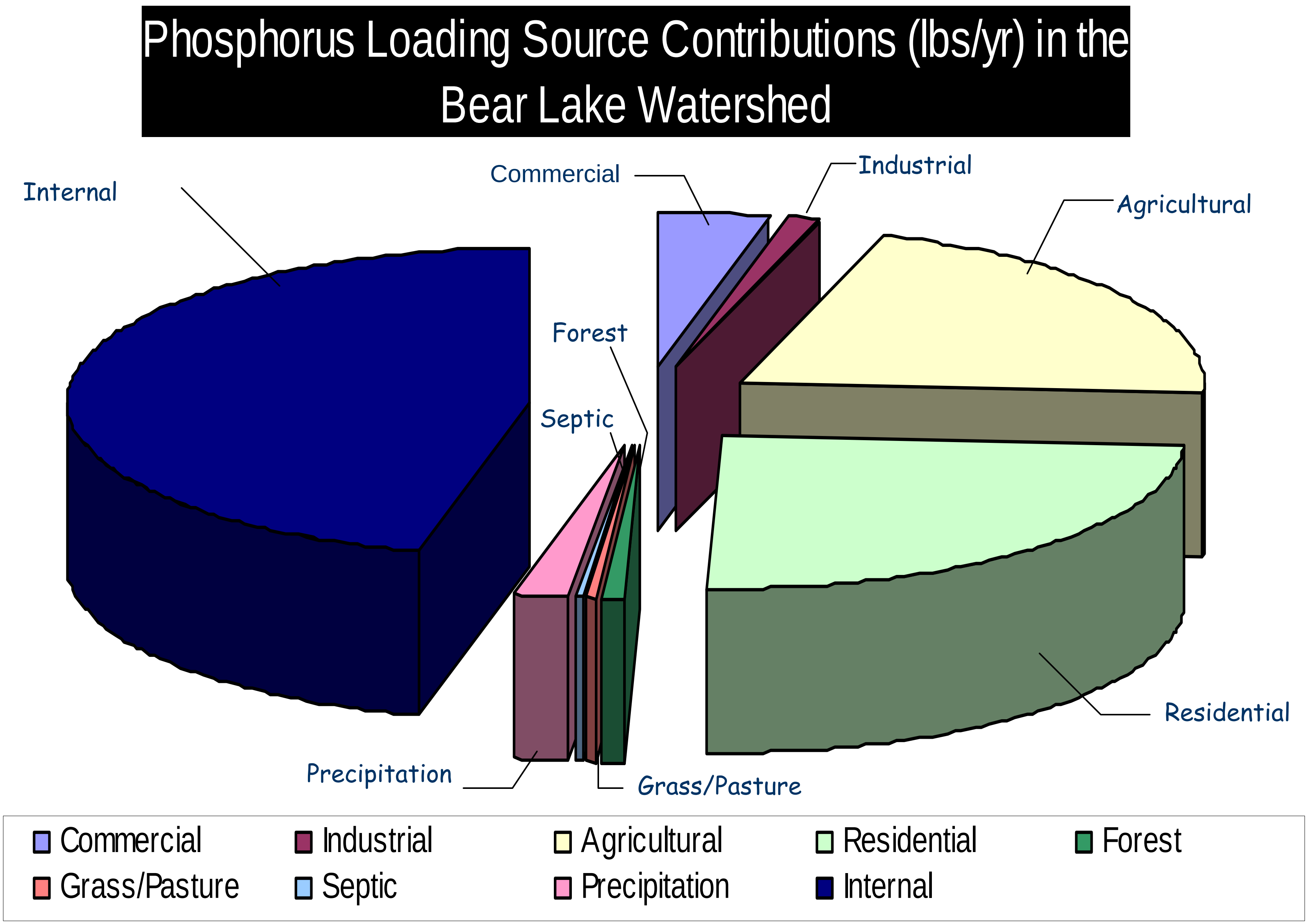
P*a* = annual phosphorus loading (g/m2/year)

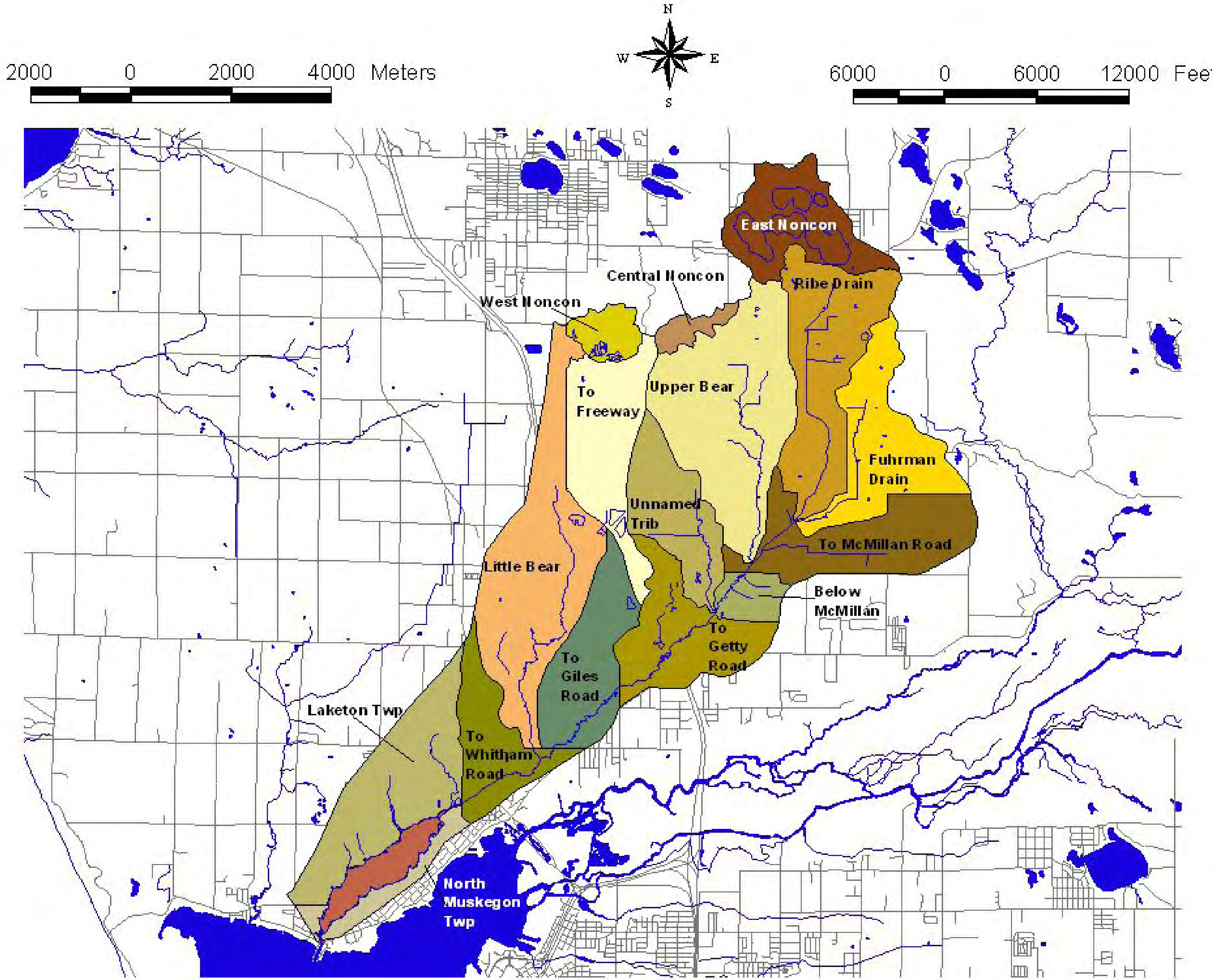
DT = hydraulic detention time (years) = 0.120 years

Dm = mean lake depth (meters) = 2.07 meters



Bear Lake Phosphorus
Loading Estimates
64 lbs
Precipitation
98 lbs
Unnamed Trib
1529 lbs
Bear Creek
104 lbs
Immediate Drainage
Goal: 1458 lbs
Bear Lake
Total Load = 3348 lbs
(based on dry and wet
weather results)
Septic Tank
5 lbs
Internal Loading
1548 lbs


Phosphorus Loading Source Contributions (lbs/yr) in the Bear Lake Watershed
Internal
Commercial
Industrial
Agricultural
Forest
Septic
Residential
Precipitation
Grass/Pasture
Commercial
Industrial
Agricultural
Residential
Forest
Grass/Pasture
Septic
Precipitation
Internal



2000 0 2000 4000 Meters
N
W
E
S
6000 0 6000 12000 Feet
East Noncon
Central Noncon
Ribe Drain
West Noncon
To Freeway
Upper Bear
Fuhrman Drain
Unnamed Trib
To McMillan Road
Little Bear
Below McMillan
To Getty Road
To Giles Road
Laketon Twp
To Whitham Road
North Muskegon Twp

Issues Yet to Resolve

- Natural variation in lake and stream data
- Number of samples that are necessary for assessment and compliance
- “Ground truth” model predictions with current data
- What to do with internal loading?

Contact Information