Experience in Developing Phosphorus TMDLs for Lakes

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Phosphorus TMDL’s for Lakes
Topics

- Conceptual Model
- Deriving TMDL Goals
- Phosphorus Mass-Balance Models
- Available Software
- Examples
Causal Pathways Linking P Loads to Water Uses

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<th>Water Uses</th>
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Conceptual Model for Lake Phosphorus TMDLs
Phosphorus TMDL's for Lakes

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- Examples

Statistical Basis for Mean Chlorophyll-a Criteria
Frequency of Severe Nuisance Blooms vs. Mean Chl-a

Based upon Log-Normal Frequency Distribution Models Calibrated to Various Datasets
Walker, W., "Statistical Bases for Mean Chlorophyll-a Criteria", Lake & Reservoir Mgt, 1985
Algal Bloom Frequency vs. Total Phosphorus
St. Paul Water Supply

Development of a Chlorophyll-a Goal for Lake Pepin, Minnesota

Algal Bloom Frequencies vs. Mean Chl-a in Different Years
Algal Bloom Frequencies vs. Mean Chl-a
Onondaga Lake, New York

Near-Shore Bloom Frequencies vs. Pelagic Mean TP
Lake Okeechobee, Florida

Havens & Walker, Lake & Reservoir Mgt, 2002
Total P Standard Based upon Transparency
Platte Lake, Michigan

Y-Axis = Frequency of Secchi Depths < 10 feet

Freq. Secchi < 4 ft vs. Predicted TP
Onondaga Lake, New York
Derivation of P Target for Compliance with pH Standard
Upper Klamath Lake, Oregon

Data from Marsh Transects along P Gradient in Water Cons. Area 2A
Impact = Significant Change from Reference Sites
South Florida Water Mgt Dist. & Florida Dept of Env. Protection, 2002

Derivation of TP Criterion for Everglades Marsh
Percent of Biological Indicators Impacted vs. Mean TP
DO, Macroinvert., Periphyton, Algal Mats, Open Water, Macrophytes

Data from Marsh Transects along P Gradient in Water Cons. Area 2A
Impact = Significant Change from Reference Sites
South Florida Water Mgt Dist. & Florida Dept of Env. Protection, 2002
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Watershed Mass Balance:

\[ \text{TMDL} = \sum \text{LA}_s + \sum \text{WL}_s + \text{Background} + \text{MOS} \]

- Total Maximum Daily Load
- Non-Point Sources
- Point Sources
- Natural or Unregulated
- Margin of Safety
  - Anthropogenic
  - Discharge Permit
  - Undev. Watershed
  - Atmospheric
  - uncertainty variability

Lake Mass Balance:

\[ \text{TMDL} = Q_s P^* + U P^*_n \]

- Input
- Flushing
- Net Retention

\[ \text{--- Expected Long-Term-Average Load to Lake ---} \]
Phosphorus Mass Balance Models for TMDL Applications

One-Box

Water

One Box / Internal Load
Not Recommended

Two-Box

Water

Water

"Internal Load"

Sediment

Three-Box

Epilimion

Hypolimion

Sediment

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- Phosphorus Mass-Balance Models
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BATHTUB Software (Windows Version)
U.S. Army Corps - Fall, 2003

BATHTUB Main Menu
**BATHTUB Segmentation Schemes**

- Single Lake or Reservoir Well-Mixed
- Spatially Segmented Multiple Arms
- Impoundments In Series
- Alternative Loading Scenarios

**BATHTUB - Load Response Analysis**

Bloom Frequency vs. Total P Load

![Graph showing Bloom Frequency vs. Total P Load](image)
Phosphorus TMDL's for Lakes

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Final Report

Estimation of a Phosphorus TMDL for Lake Okeechobee

prepared for
Florida Department of Environmental Protection
&
U.S. Department of the Interior

by
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December 27, 2000
Long-Term Trends in Bloom Frequency & Total P in Pelagic Zone of Lake Okeechobee

Near-Shore Bloom Frequencies vs. Pelagic Mean TP
Lake Okeechobee, Florida

Havens & Walker, Lake & Reservoir Mgt, 2002
Decline in Net Settling Rate
Loss of Assimilative Capacity
- Sediment Enrichment
- Decrease in Calcium Loads

Lake P Goal = 40 ppb

Coupled Water Column & Sediment Model for Lake Okeechobee

Water Column
M = Total P Mass
C = Total P Conc

Calcium P
S_C
K_S S_C

Labile P
S_L
K_S S_L

Organic P
S_O
K_S S_O

L_X

Q_0 C

Y_C F_C C A
K_2 C (1-f_2) A
K_R S_L
K_S C f_2 A
K_D S_D
Long-Term Simulation of Lake Okeechobee TP Levels

Lake TP Conc (ppb)

Observed
Predicted
Goal

1900 1920 1940 1960 1980 2000 2020 2040

Confidence Intervals for TMDL's Compared with Historical Phosphorus Loads

Historical Loads  Water-Column Models  Sediment & Water Column Models
Development of a Phosphorus TMDL for Upper Klamath Lake, Oregon

prepared for

Oregon Department of Environmental Quality
2146 4th Street, Suite 104
Bend, Oregon 97701

By

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Seasonal Variations - Upper Klamath Lake

- TP
- Chla
- pH

Month:
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12

Seasonal Variations - Upper Klamath Lake

- pH > 8.0
- DO < 6 ppm

Month:
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12

Model Structure

- Hydrology
- TP Load
- Solar Radiation
  - Depth
  - Water Temperature
  - Julian Day
- Non-Algal P
- Algal P / Chla
- pH
- Sediments
- Burial
- Phosphorus Flux
- Control Pathway
Observed & Predicted Values - Upper Klamath Lake Model

Chlorophyll-a (ppb)

Water Quality Standard

pH Violation Frequency vs. Average Inflow P Concentration
Upper Klamath Lake

R = P% Model Prediction for Total and Reduction of P%
Spring P = March-May Average
Freq [pH > 9] = June-July Average
Inflow P = Flow-Weighted Mean Inflow Concentration of Watershed Inflows Oct-Feb Water Year
Evaluation of Phosphorus Standards for Cherry Creek Reservoir

presentation before Colorado Water Quality Commission

William W. Walker, Jr., Ph. D.
Environmental Engineer

September 11, 2000
Algal Bloom Frequencies vs. Mean Chlorophyll-a
Cherry Creek Reservoir, Colorado

Y Axis: Percent of Days in July - September with Chl-a Exceeding 10, 20, or 30 ppb

Algae Visible > 10 ppb
Nuisance Bloom > 20 ppb
Severe Nuisance > 30 ppb

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
0 5 10 15 20 25 30
July-Sept. Mean Chlorophyll-a (ppb)

Algae Visible > 10 ppb
"Goal" Mean Chl-a < 15 ppb

Linkage of Models Used to Forecast
Cherry Creek Reservoir Chlorophyll-a Levels

Management Scenario
Uncertainty
Climate
Watershed Model
Runoff & P Load
Depth & Area
P Balance Model
Reservoir Total P
Chla- Model
Reservoir Chl-a

Summer Mean CH-a
Standard Error ~ 34%
Risk Frequency of Years with July-Sept Mean Chl-a > 15 ppb
Mean Average Risk or Frequency over 10 Years (1989-1998)
Max Risk in Highest Runoff Year (1998)

Risk of Exceeding 15 ppb Mean Chl-a vs. Alternative Total P Standards
Cherry Creek Reservoir, Colorado

Based upon Simulation of 1989-1998 Hydrologic Record
Risk Frequency of Years with July-Sept Mean Chl-a > 15 ppb
Mean Average Risk or Frequency over 10 Years (1989-1998)
Max Risk in Highest Runoff Year (1998)