Experience in Developing Phosphorus TMDLs for Lakes

William W. Walker, Jr., Ph.D.
Environmental Engineer
Concord, Massachusetts
wwwalker.net

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Chicago

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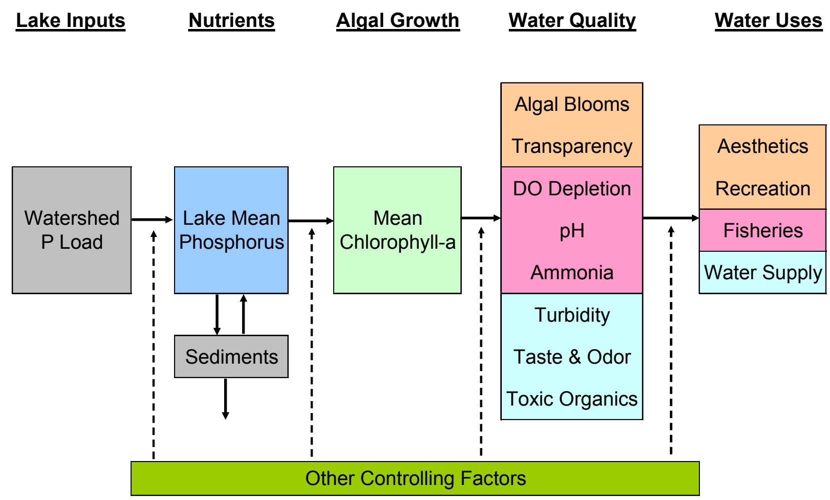
Phosphorus TMDL's for Lakes

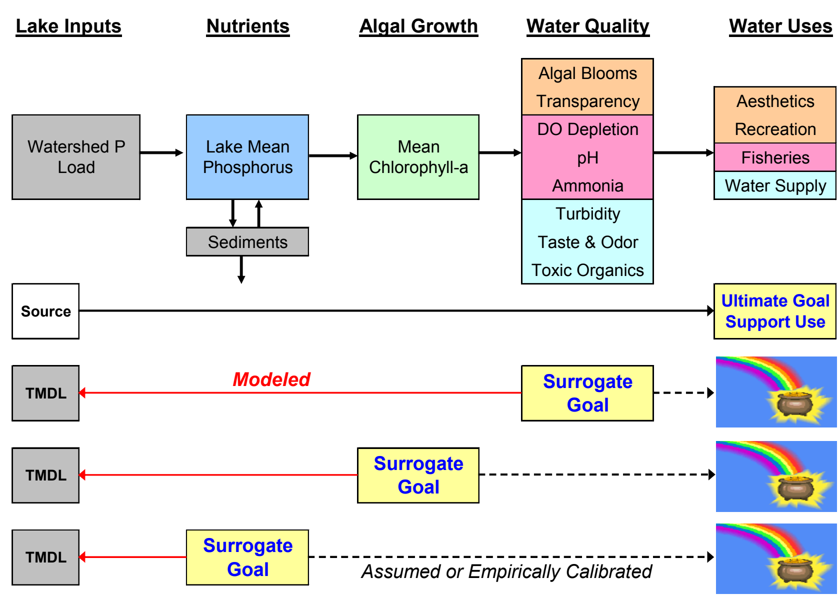
Topics

- Conceptual Model
- Deriving TMDL Goals
- Phosphorus Mass-Balance Models
- Available Software
- Examples

Causal Pathways Linking P Loads to Water Uses



Conceptual Model for Lake Phosphorus TMDLs



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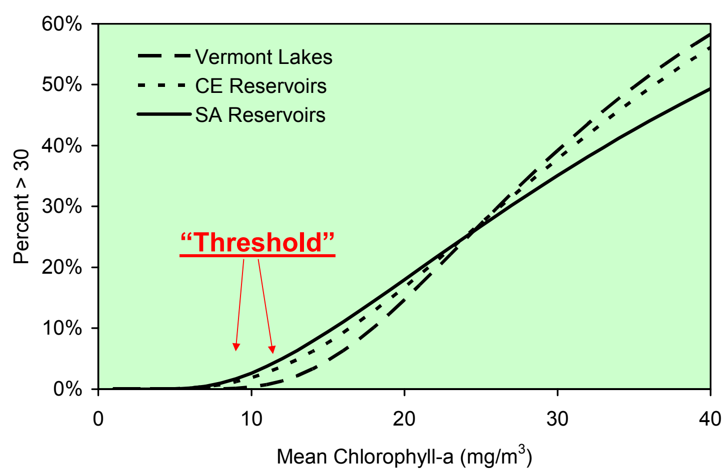
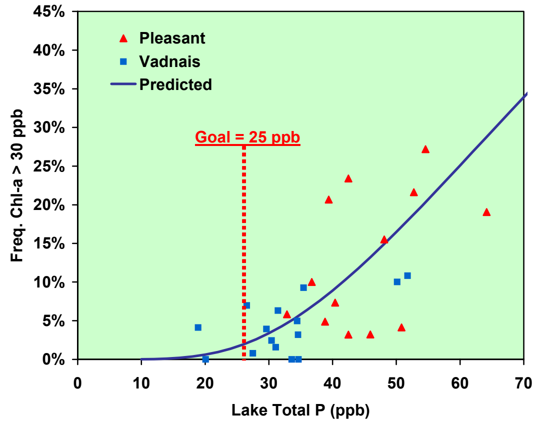
Statistical Basis for Mean Chlorophyll-a Criteria
Frequency of Severe Nuisance Blooms vs. Mean Chl-a

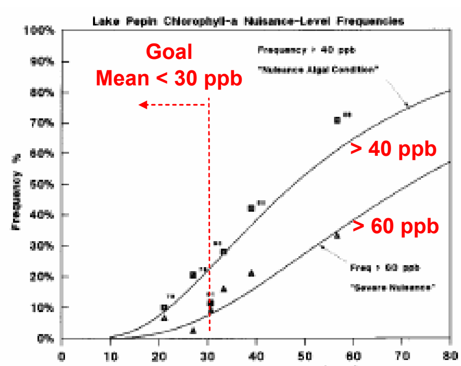


Based upon Log-Normal Frequency Distribution Models Calibrated to Various Datasets
Walker, W., "Statistical Bases for Mean Chlorophyll-a Criteria", Lake & Reservoir Mgt, 1985

Algal Bloom Frequency vs. Total Phosphorus
St. Paul Water Supply



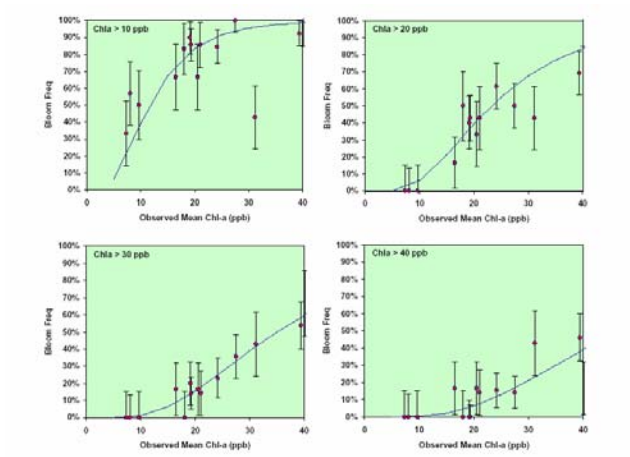
Development of a Chlorophyll-a Goal for Lake Pepin, Minnesota



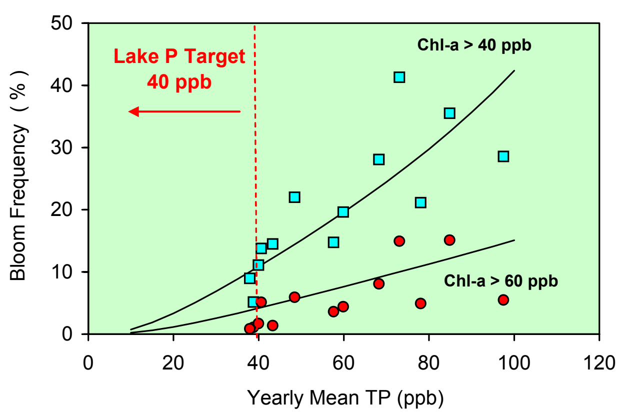
Algal Bloom Frequencies vs. Mean Chl-a in Different Years

Heiskary & Walker, "Establishing a Chlorophyll-a Goal for a Run-of-the River Reservoir"
Lake & Reservoir Management, 1995

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

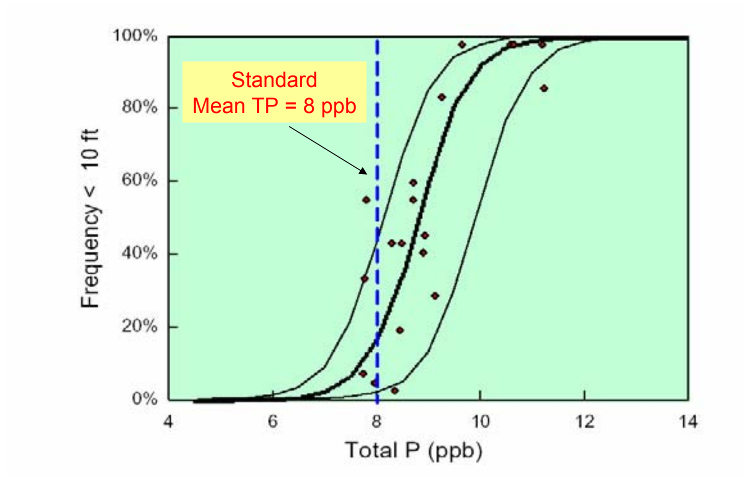


Near-Shore Bloom Frequencies vs. Pelagic Mean TP
Lake Okeechobee, Florida



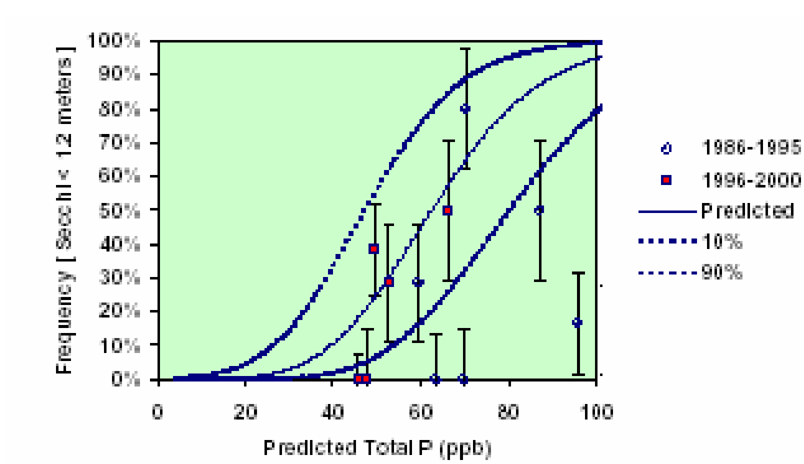
Havens & Walker, Lake & Reservoir Mgt, 2002

Total P Standard Based upon Transparency
Platte Lake, Michigan

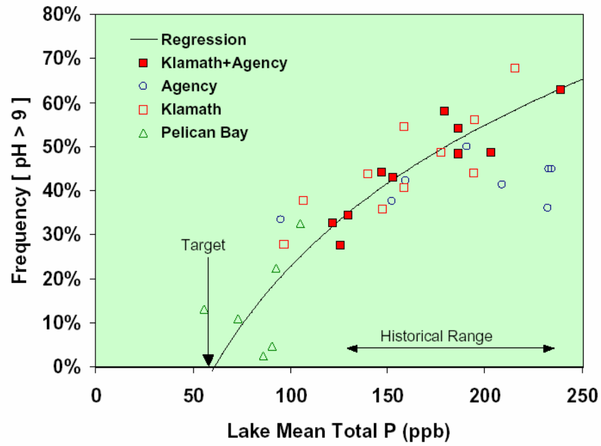


Y-Axis = Frequency of Secchi Depths < 10 feet

Freq. Secchi < 4 ft vs. Predicted TP
Onondaga Lake, New York

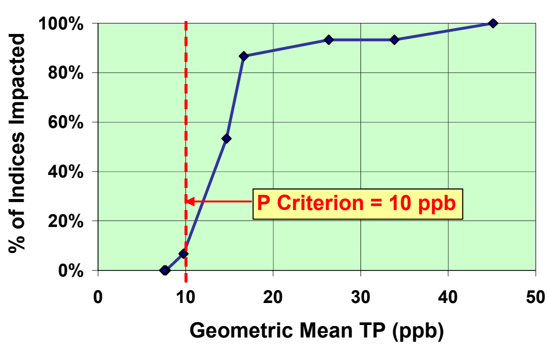


Derivation of P Target for Compliance with pH Standard
Upper Klamath Lake, Oregon



Yearly Means by Lake Region, April-October
Frequency = % of Measurements (All Stations & Depths) Exceeding pH 9

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

Phosphorus TMDL's for Lakes

Topics

- Conceptual Model
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- Phosphorus Mass-Balance Models
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TMDL Equations
Long-Term-Average Mass Balances

Watershed Mass Balance:

TMDL	=	**∑ LAs**	+	**∑ WLAs**	+	**Background**	+	**MOS**
Total Maximum Daily Load		Non-Point Sources		Point Sources		Natural or Unregulated		Margin of Safety
		Anthropogenic		*< Discharge Permit*		*Undev. Watershed* *Atmospheric*		*uncertainty* *variability*

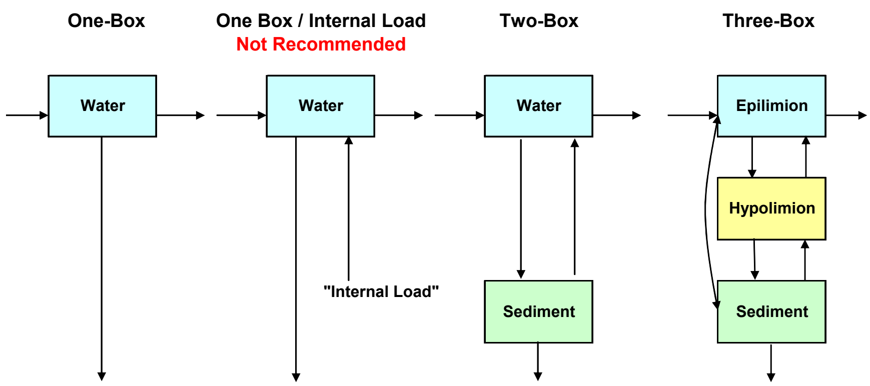
<--- Expected Long-Term-Average Load to Lake --->

Lake Mass Balance:

$$TMDL = Q_S P^* + U P^{*n}$$

TMDL	=	$Q_S P^*$	+	$U P^{*n}$
Input		Flushing		Net Retention

Phosphorus Mass Balance Models for TMDL Applications



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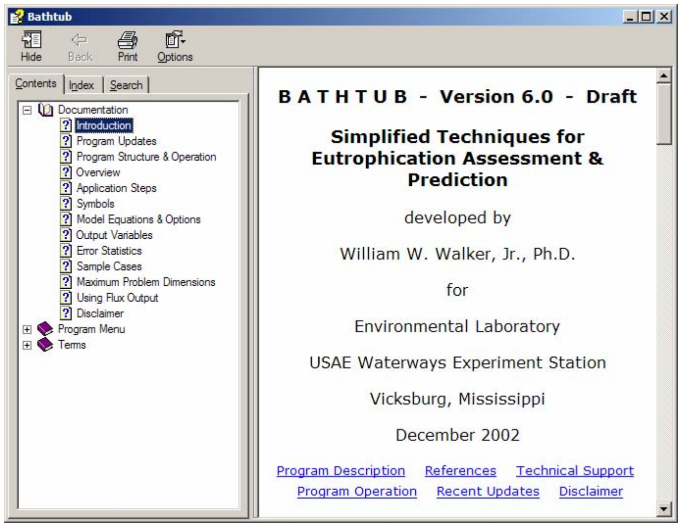
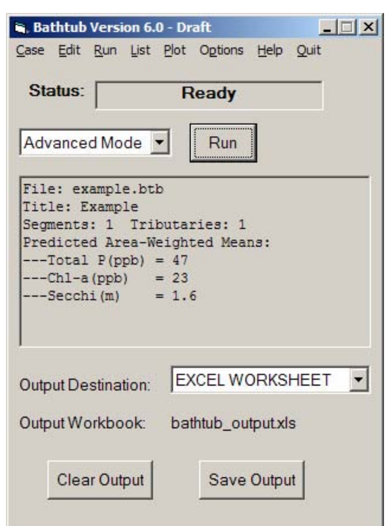
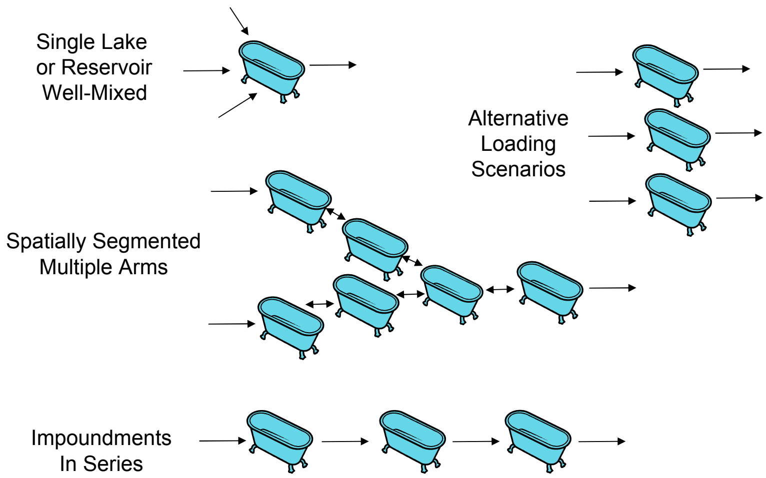
BATHTUB Software (Windows Version)
U.S. Army Corps - Fall, 2003



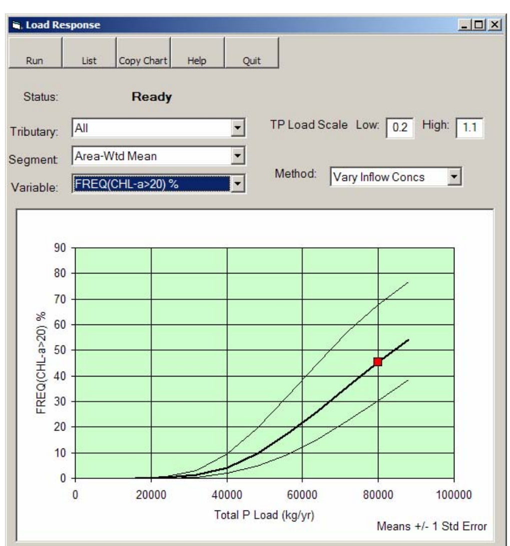
BATHTUB Main Menu



BATHTUB Segmentation Schemes



BATHTUB - Load Response Analysis
Bloom Frequency vs. Total P Load



Phosphorus TMDL's for Lakes

Topics

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- Available Software
- Examples

Final Report

Estimation of a Phosphorus TMDL for Lake Okeechobee

prepared for

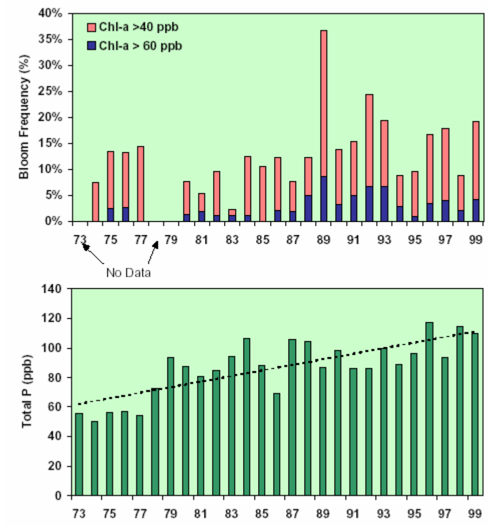
Florida Department of Environmental Protection
&
U.S. Department of the Interior

by

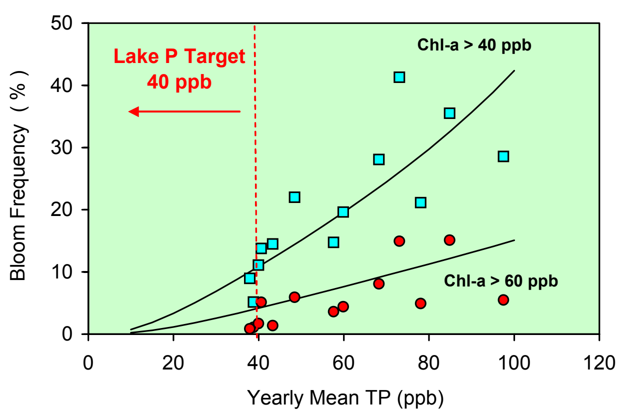
William W. Walker, Jr., Ph.D., Environmental Engineer
1127 Lowell Road, Concord, Massachusetts 01742
Tel: 978-369-8061, Fax: 978-369-4230
wwwalker@shore.net
http://www.shore.net/~wwwalker

December 27, 2000

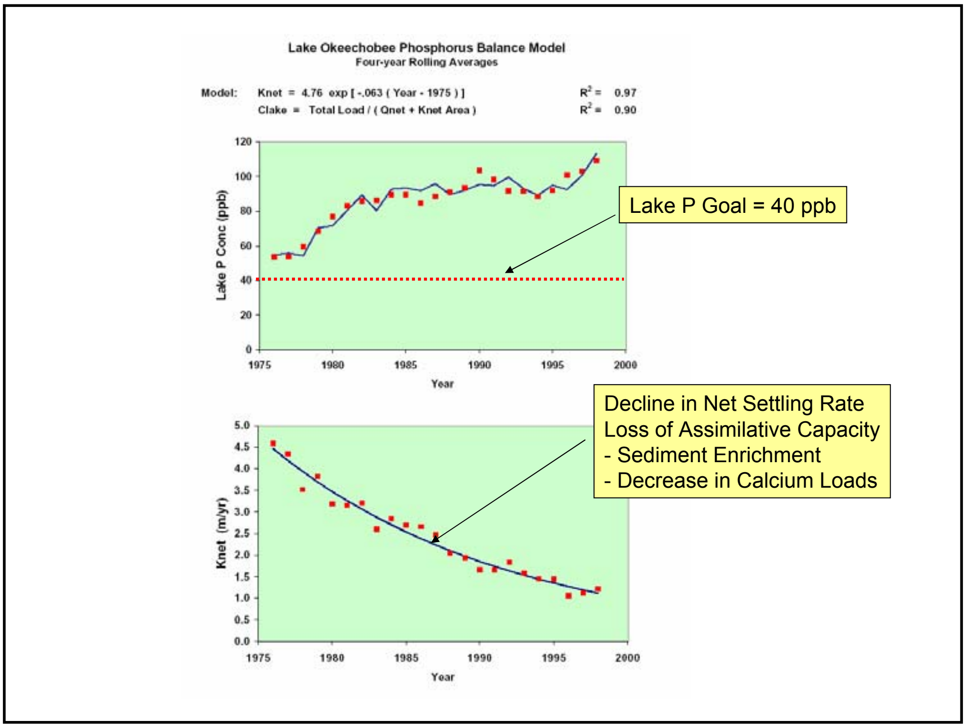
Long-Term Trends in Bloom Frequency & Total P in Pelagic Zone of Lake Okeechobee



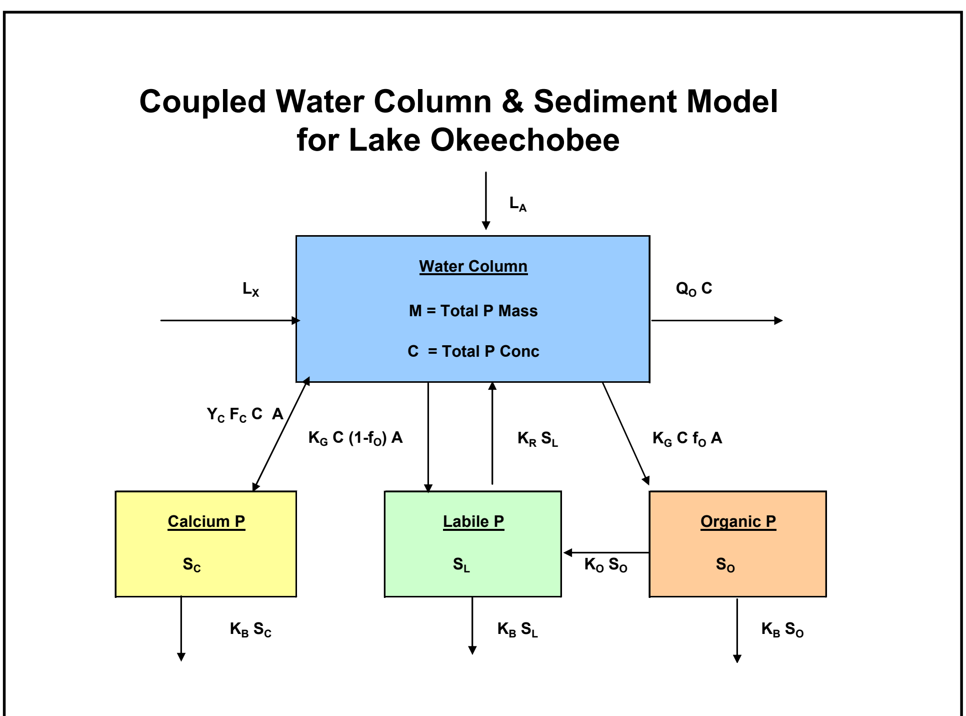
Near-Shore Bloom Frequencies vs. Pelagic Mean TP Lake Okeechobee, Florida



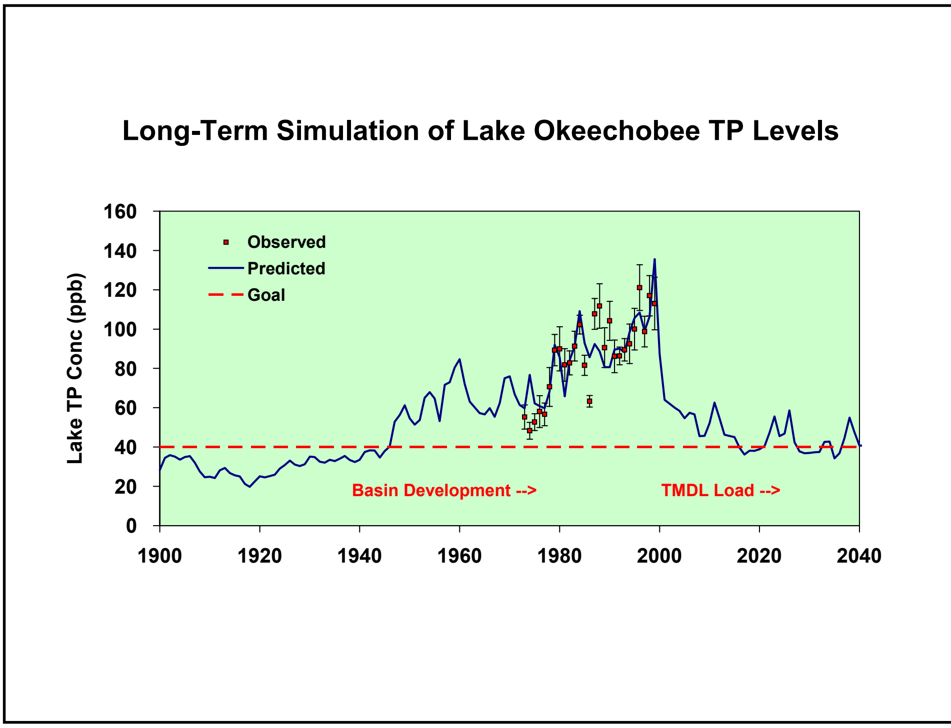
Havens & Walker, Lake & Reservoir Mgt, 2002

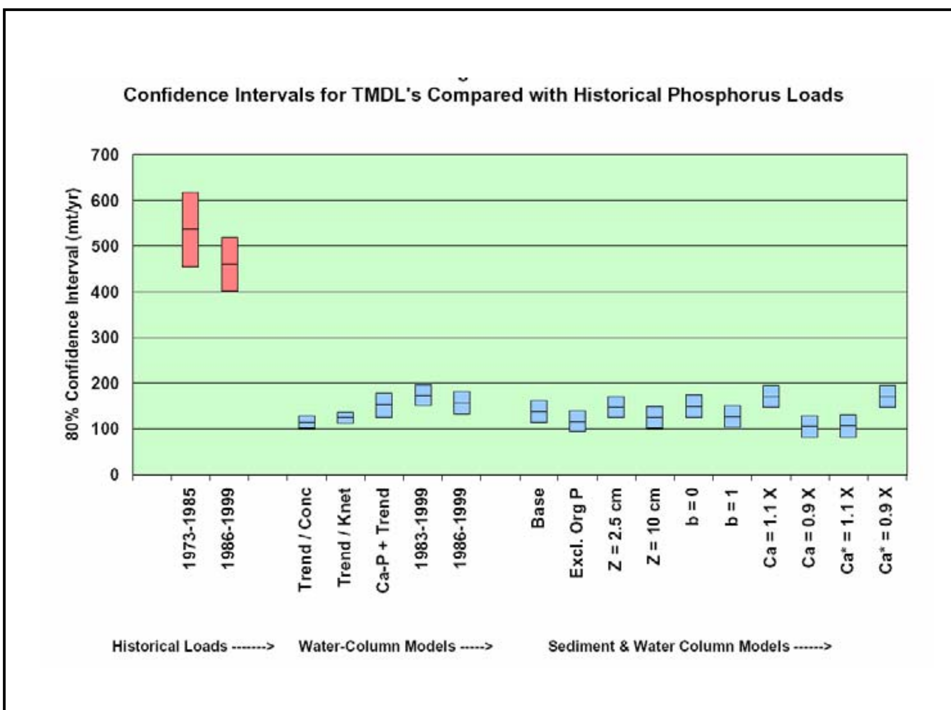


Lake Okeechobee Phosphorus Balance Model
Four-year Rolling Averages
Model: Knet = 4.76 exp [-.063 (Year - 1975)]
Clake = Total Load / (Qnet + Knet Area)
R^2 = 0.97
R^2 = 0.90
Lake P Conc (ppb)
Year
Lake P Goal = 40 ppb
Knet (m/yr)
Year
Decline in Net Settling Rate
Loss of Assimilative Capacity
- Sediment Enrichment
- Decrease in Calcium Loads



Coupled Water Column & Sediment Model
for Lake Okeechobee
L_A
L_X
Water Column
M = Total P Mass
C = Total P Conc
Q_O C
Y_C F_C C A
K_G C (1-f_O) A
K_R S_L
K_G C f_O A
Calcium P
S_C
Labile P
S_L
K_O S_O
Organic P
S_O
K_B S_C
K_B S_L
K_B S_O


Long-Term Simulation of Lake Okeechobee TP Levels
Observed
Predicted
Goal
Lake TP Conc (ppb)
160
140
120
100
80
60
40
20
0
Basin Development -->
TMDL Load -->
1900
1920
1940
1960
1980
2000
2020
2040


Confidence Intervals for TMDL's Compared with Historical Phosphorus Loads
80% Confidence Interval (mt/yr)
700
600
500
400
300
200
100
0
1973-1985
1986-1999
Trend / Conc
Trend / Knet
Ca-P + Trend
1983-1999
1986-1999
Base
Excl. Org P
Z = 2.5 cm
Z = 10 cm
b = 0
b = 1
Ca = 1.1 X
Ca = 0.9 X
Ca* = 1.1 X
Ca* = 0.9 X
Historical Loads ------->
Water-Column Models ----->
Sediment & Water Column Models ------>

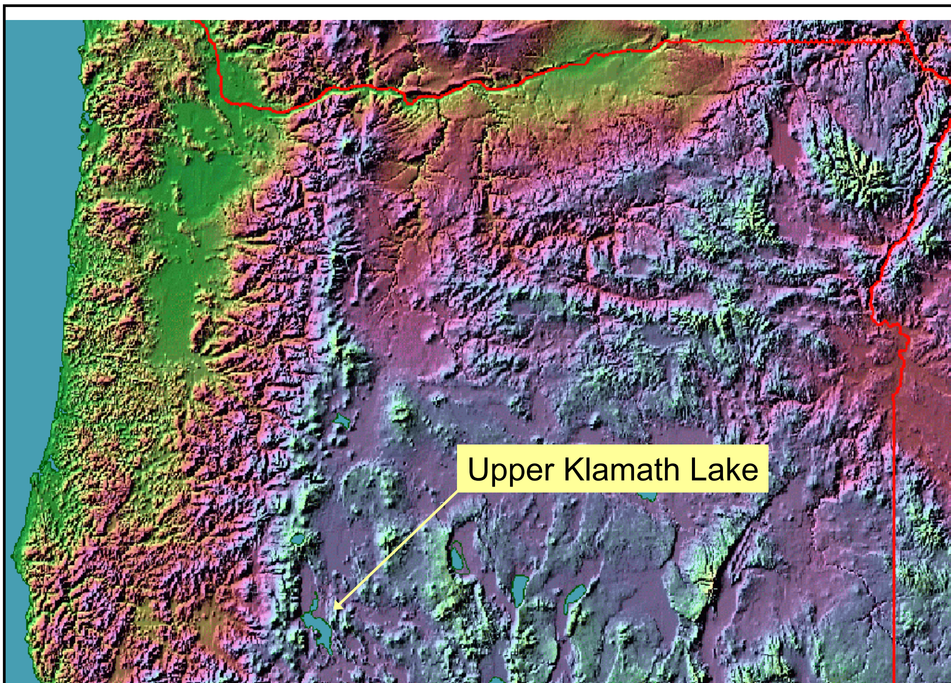
Development of a Phosphorus TMDL for Upper Klamath Lake, Oregon

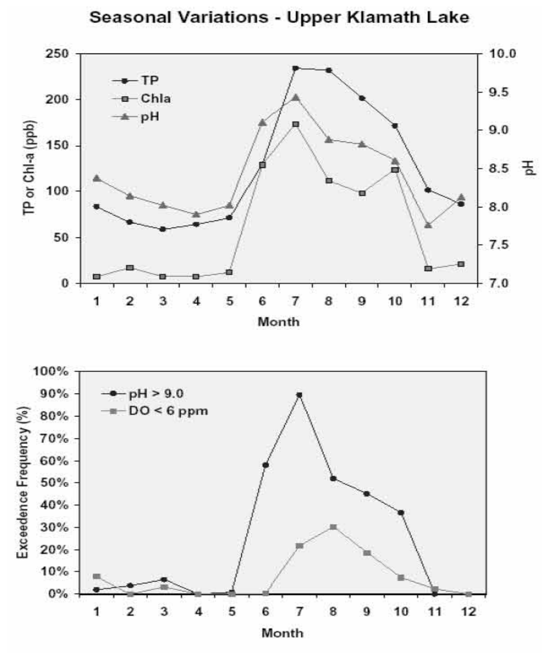
prepared for

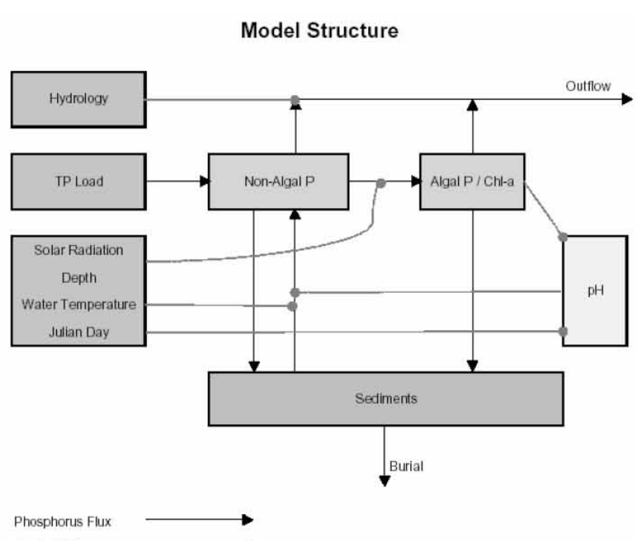
Oregon Department of Environmental Quality
2146 4th Street, Suite 104
Bend, Oregon 97701

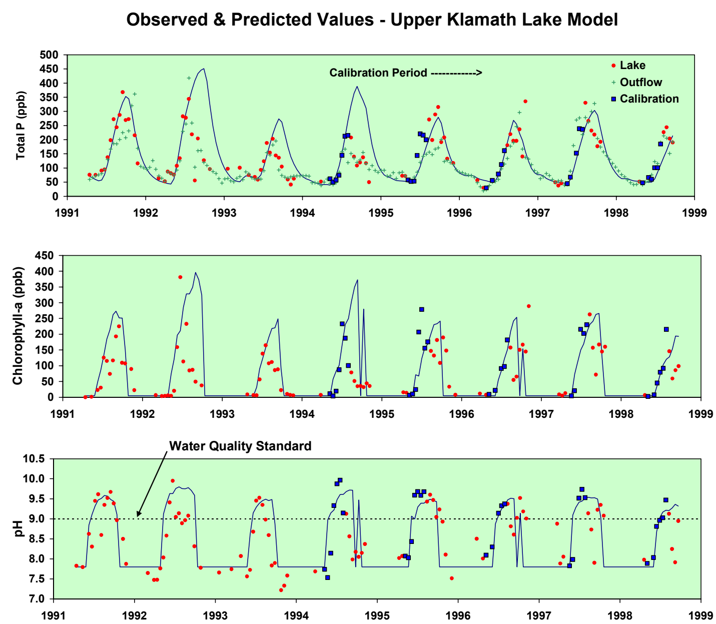
By

William W. Walker, Jr., Ph.D., Environmental Engineer
1127 Lowell Road, Concord, Massachusetts 01742
Tel: 978-369-8061 Fax: 978-369-4230

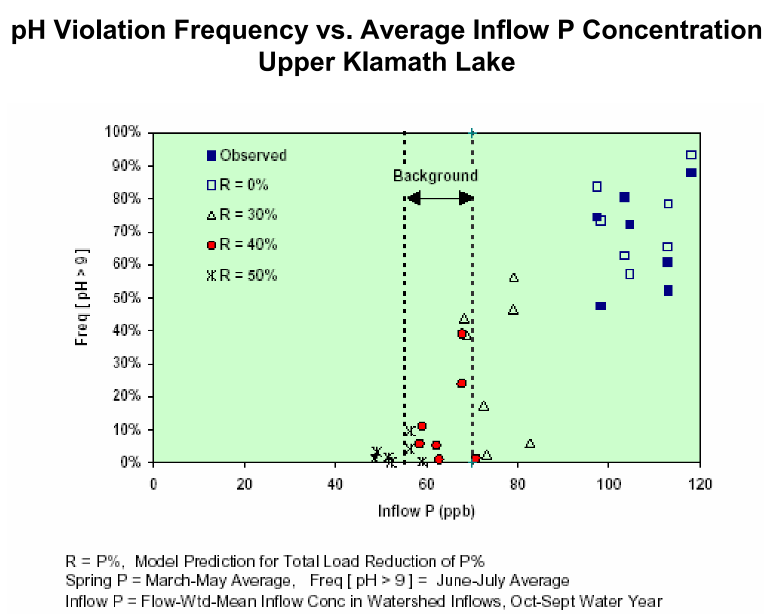



Seasonal Variations - Upper Klamath Lake
TP
Chla
pH
TP or Chl-a (ppb)
pH
Month
pH > 9.0
DO < 6 ppm
Exceedence Frequency (%)
Month


Model Structure
Hydrology
Outflow
TP Load
Non-Algal P
Algal P / Chl-a
Solar Radiation
Depth
Water Temperature
Julian Day
pH
Sediments
Burial
Phosphorus Flux
Control Pathway



Observed & Predicted Values - Upper Klamath Lake Model
Calibration Period ----------->
Lake
Outflow
Calibration
Total P (ppb)
Chlorophyll-a (ppb)
Water Quality Standard
pH
1991
1992
1993
1994
1995
1996
1997
1998
1999



pH Violation Frequency vs. Average Inflow P Concentration
Upper Klamath Lake
Observed
R = 0%
R = 30%
R = 40%
R = 50%
Background
Freq [pH > 9]
Inflow P (ppb)
R = P%, Model Prediction for Total Load Reduction of P%
Spring P = March-May Average, Freq [pH > 9] = June-July Average
Inflow P = Flow-Wtd-Mean Inflow Conc in Watershed Inflows, Oct-Sept Water Year

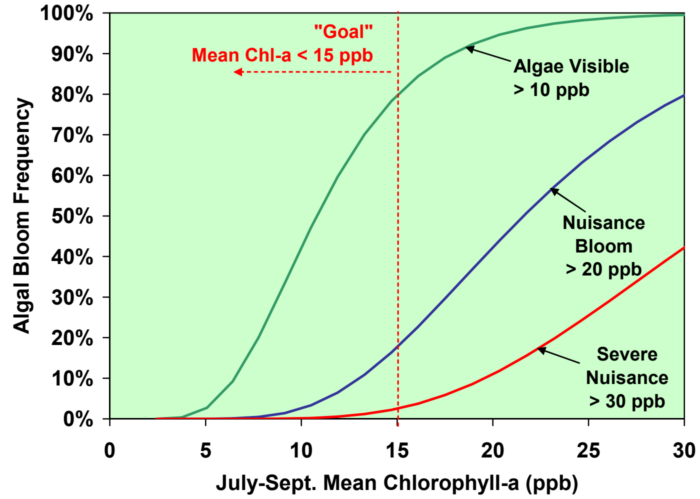
Evaluation of Phosphorus Standards for Cherry Creek Reservoir

presentation before
Colorado Water Quality Commission

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

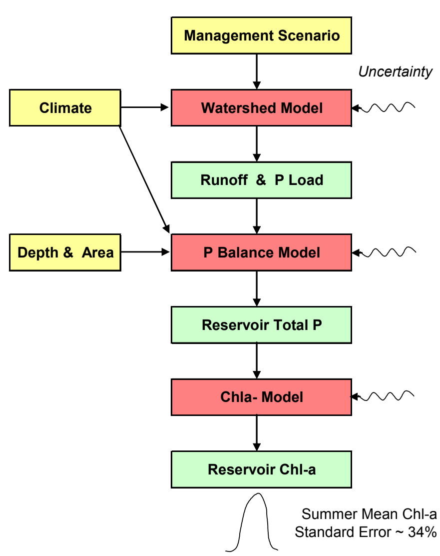
September 11, 2000

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



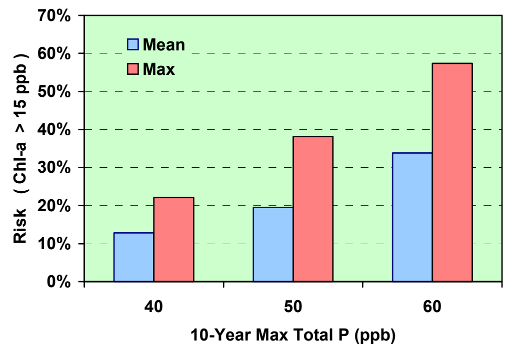
Y Axis: Percent of Days in July - September with Chl-a Exceeding 10, 20, or 30 ppb

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



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)