Experience in Developing Phosphorus TMDL's for Shallow Lakes

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

Environmental Engineer

Concord, Massachusetts

wwwalker@shore.net

http:/www.shore.net/~wwwalker

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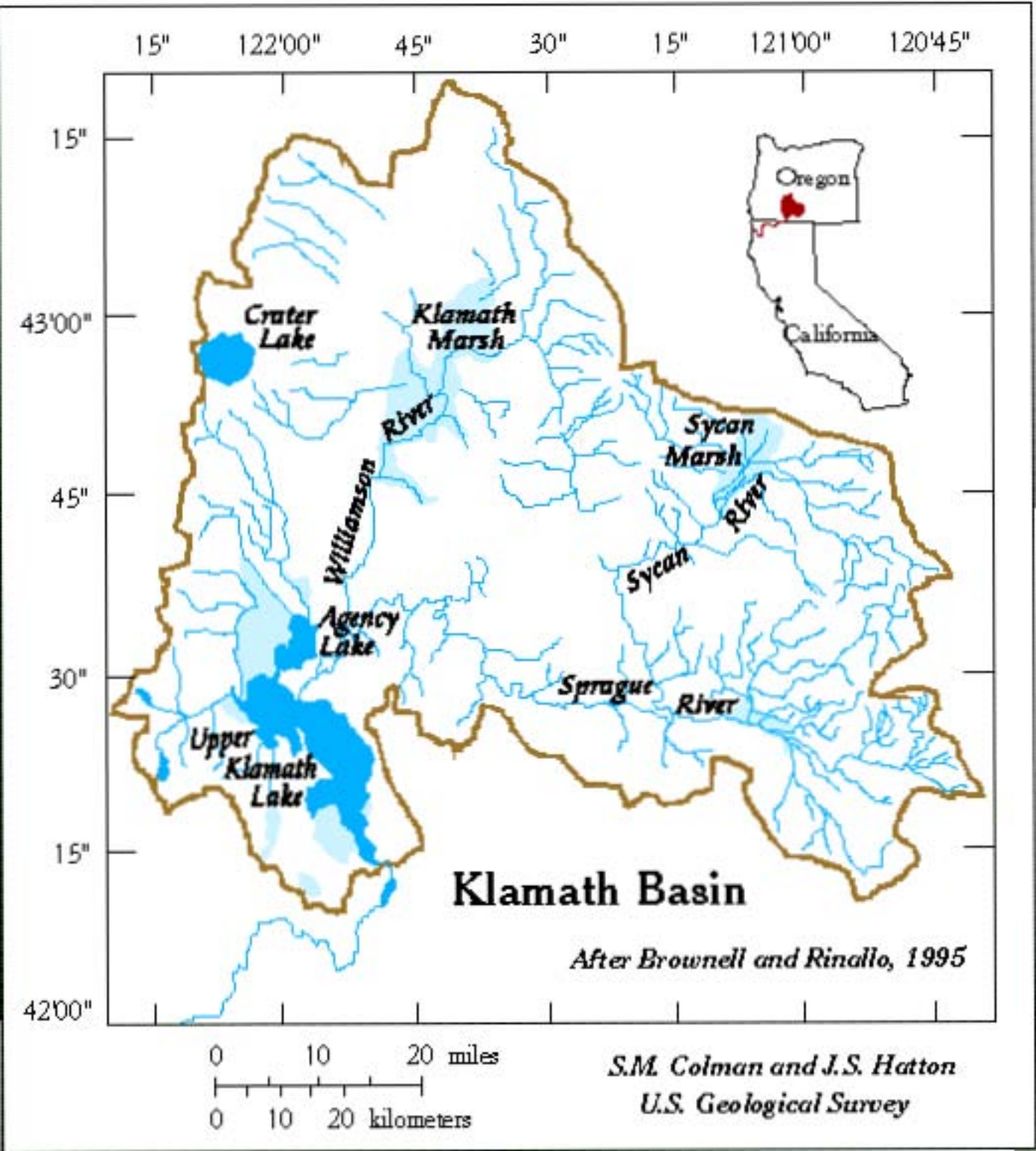
Basic Concepts

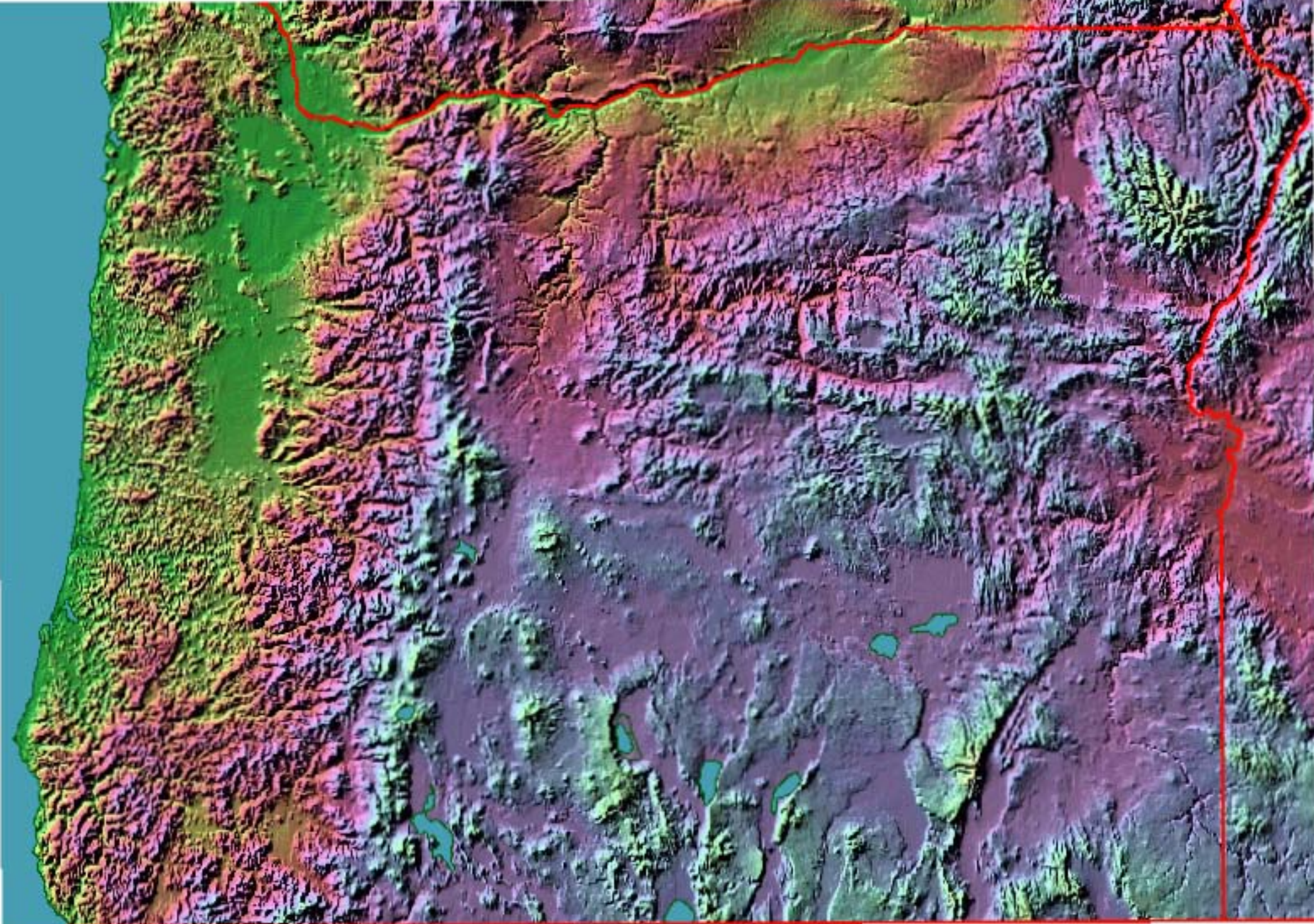
Case Studies

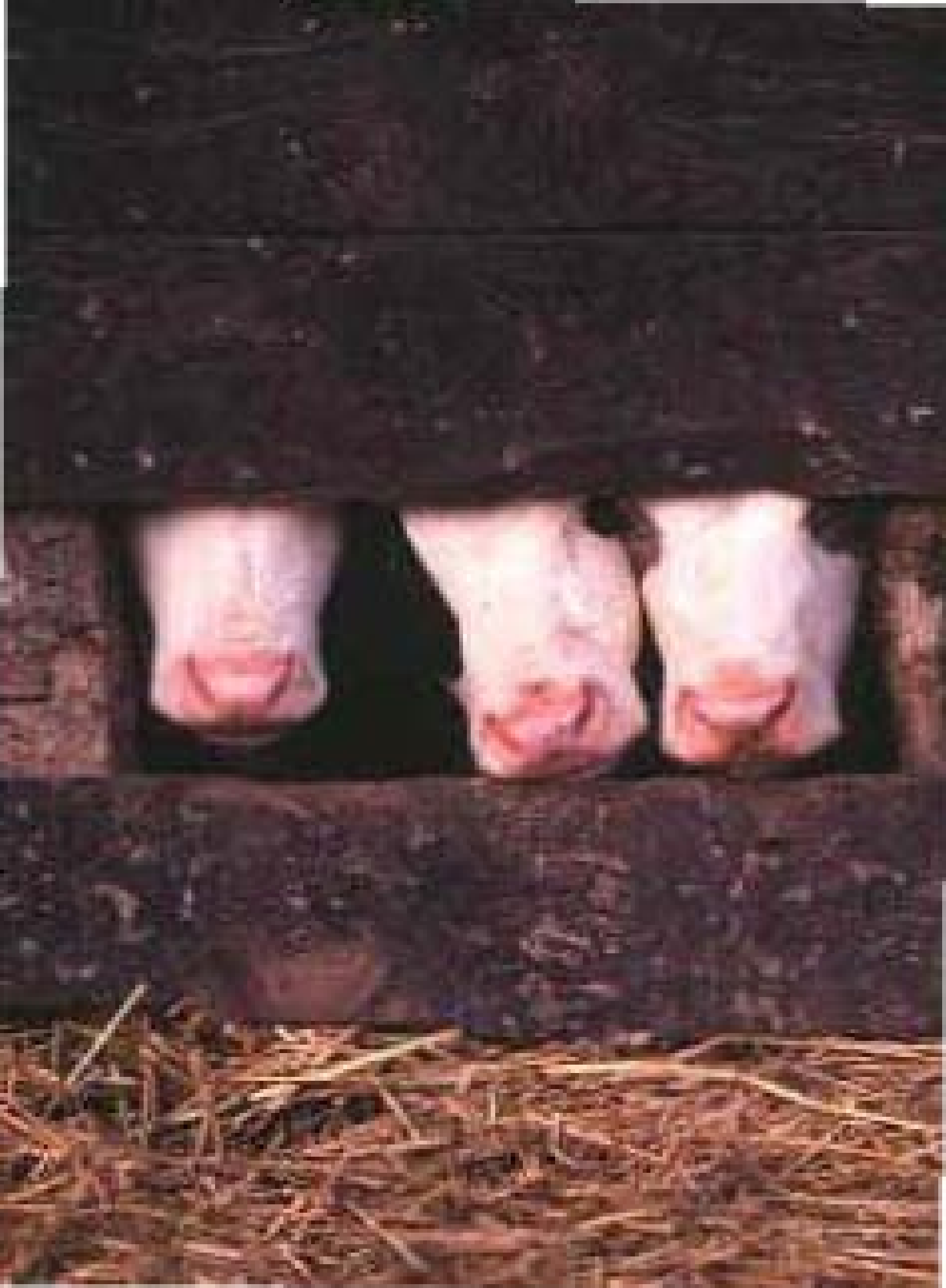
Lake Okeechobee, Florida

Upper Klamath Lake, Oregon

??? Total Maximum Daily Load ???


15"
122°00"
45"
30"
15"
121°00"
120°45"
15"
43°00"
45"
30"
15"
42°00"
Oregon
California
Crater Lake
Klamath Marsh
Williamson River
Sycan Marsh
Sycan River
Agency Lake
Upper Klamath Lake
Sprague River
Klamath Basin
After Brownell and Rinallo, 1995
0 10 20 miles
0 10 20 kilometers
S.M. Colman and J.S. Hatton
U.S. Geological Survey





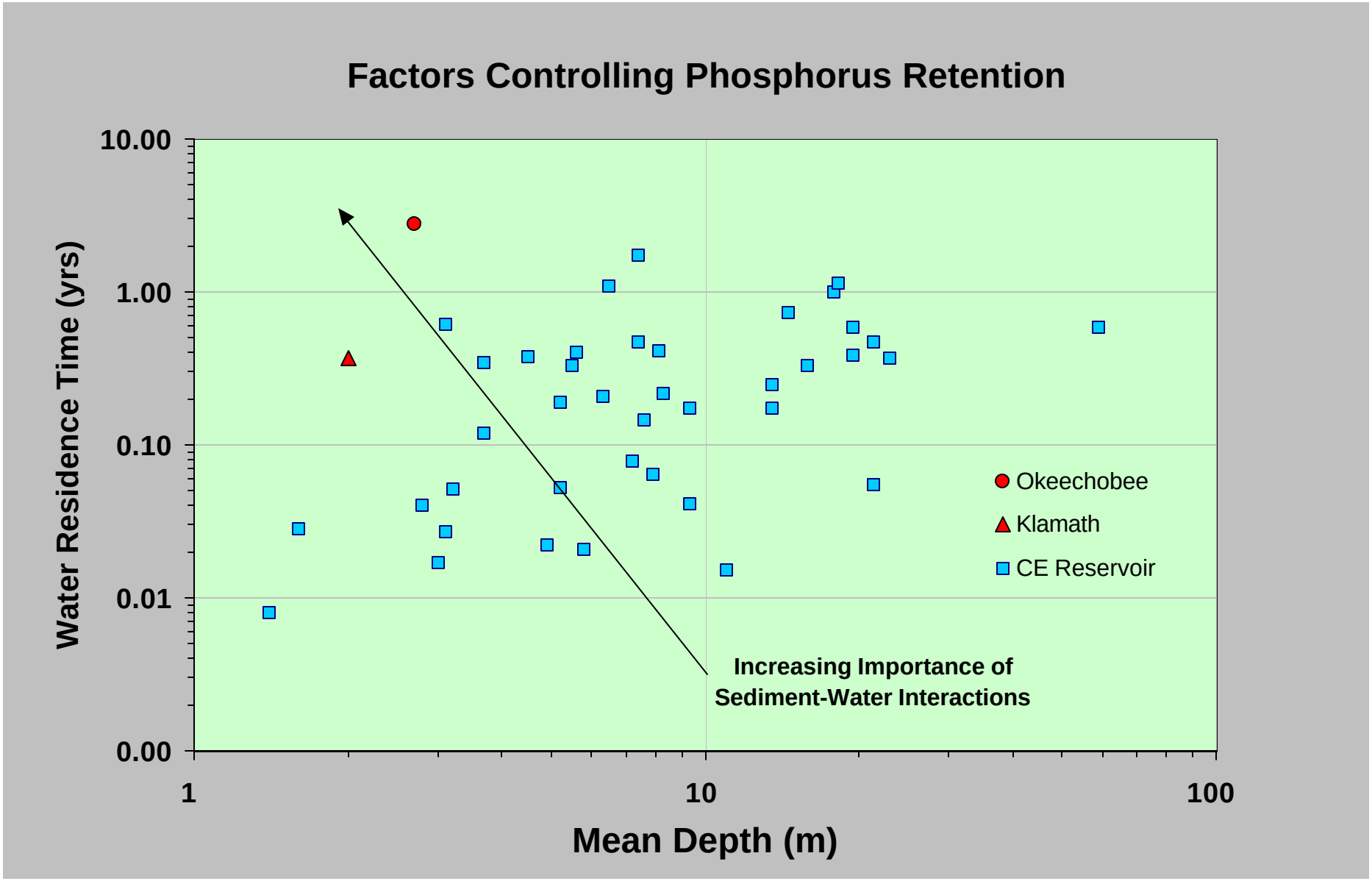
Water Quality Comparisons

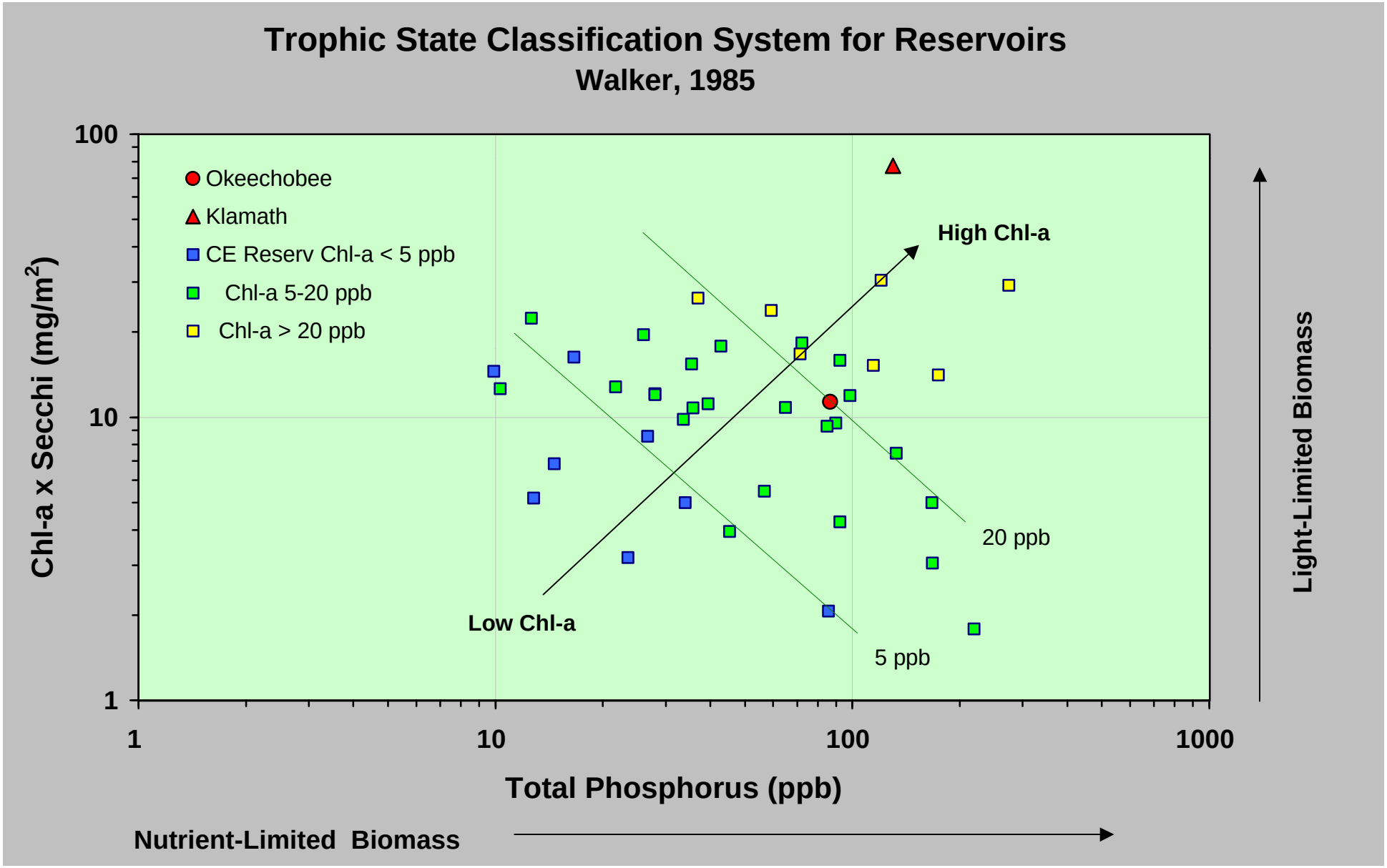
Variable	Units	Okeechobee*	Klamath
Period of Record	years	27	10
Total P	ppb	87	158
Total N	ppb	1590	1735
Chlorophyll-a	ppb	23	88
Freq. Chl-a > 40 ppb	%	12%	61%
Freq. Chl-a > 100 ppb	%	0.3%	38%
Secchi Depth	m	0.50	0.88
Mean Depth / Secchi	-	5.4	2.3
Mean pH	-	8.2	8.7
Freq. pH > 9	-	1%	38%
Calcium	ppm	41	< 2
Alkalinity	ppm	146	50

* Pelagic Zone

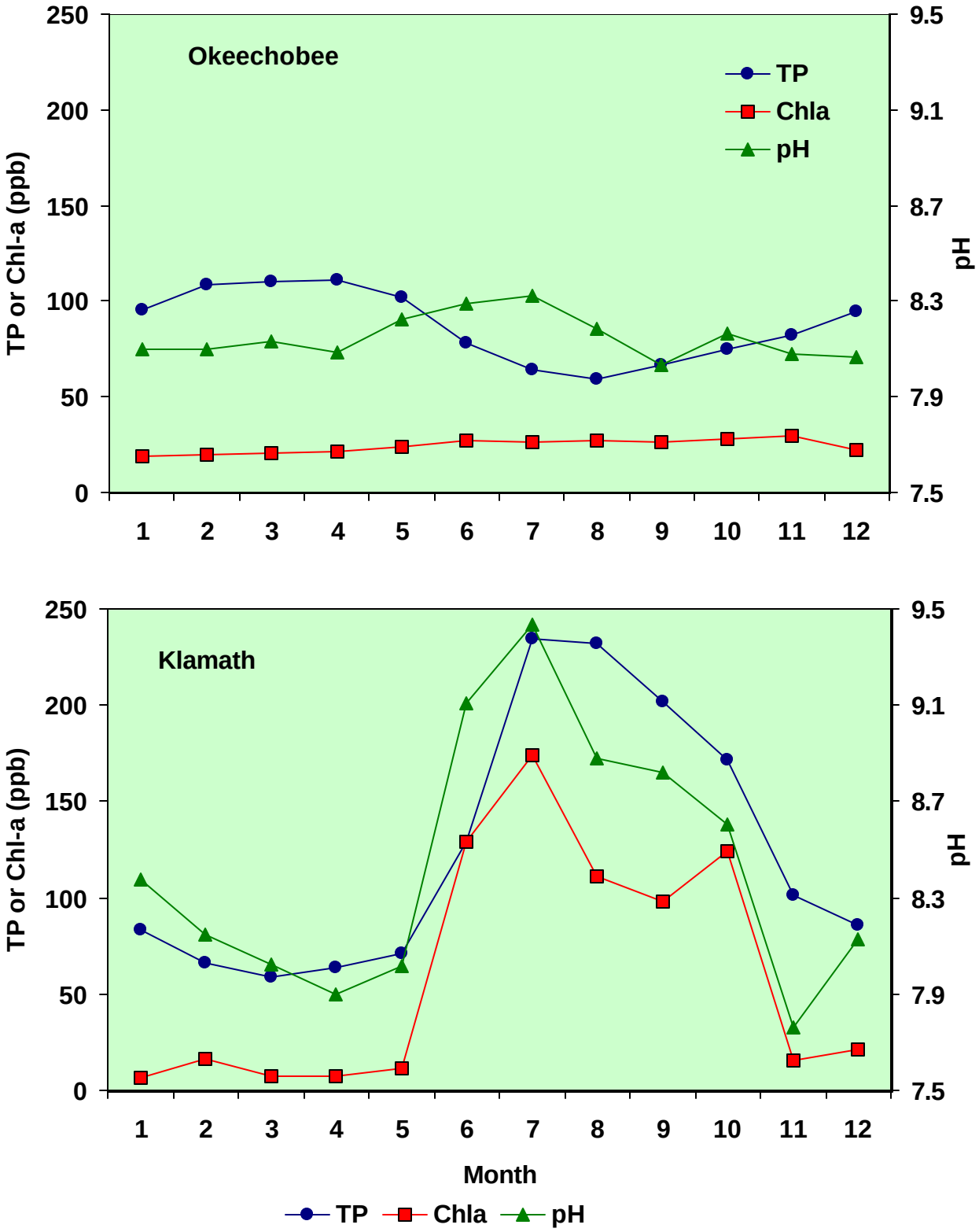
Morphometric & Hydrologic Features

Feature	Units	Okeechobee	Klamath
Watershed Area	km^2	11,914	9,758
Surface Area	km^2	1,732	271
Mean Depth	m	2.7	2.0
Net Water Load	m/yr	1.0	5.4
Hyd. Residence Time	years	2.8	0.4
Evap. / Total Outflow	%	65%	15%

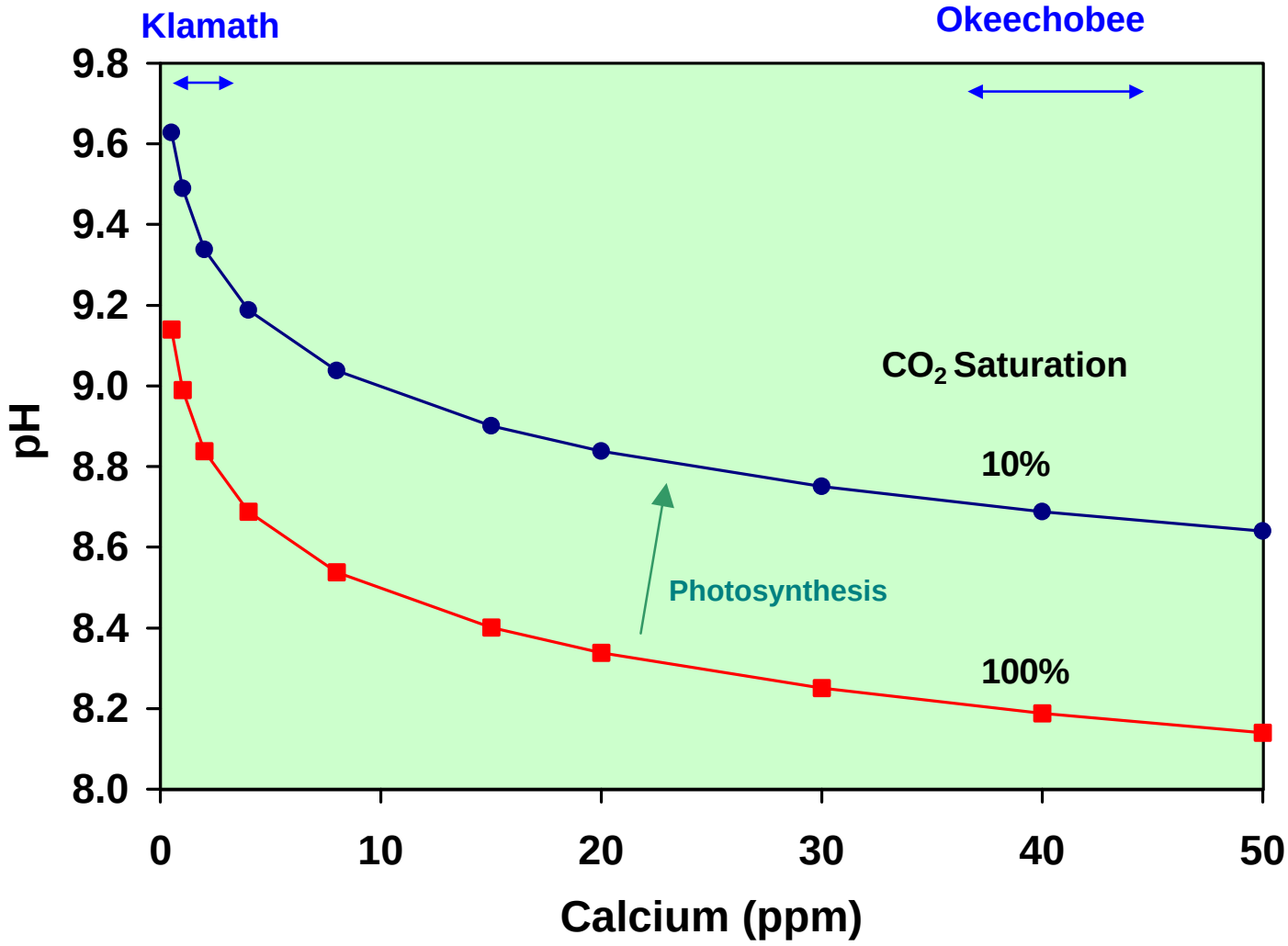

Factors Controlling Phosphorus Retention
Water Residence Time (yrs)
10.00
1.00
0.10
0.01
0.00
1
10
100
Mean Depth (m)
Okeechobee
Klamath
CE Reservoir
Increasing Importance of
Sediment-Water Interactions


Trophic State Classification System for Reservoirs
Walker, 1985
Okeechobee
Klamath
CE Reserv Chl-a < 5 ppb
Chl-a 5-20 ppb
Chl-a > 20 ppb
High Chl-a
Low Chl-a
20 ppb
5 ppb
Chl-a x Secchi (mg/m2)
100
10
1
1
10
100
1000
Total Phosphorus (ppb)
Light-Limited Biomass
Nutrient-Limited Biomass

Seasonal Variations in Total P, Chl-a, & pH

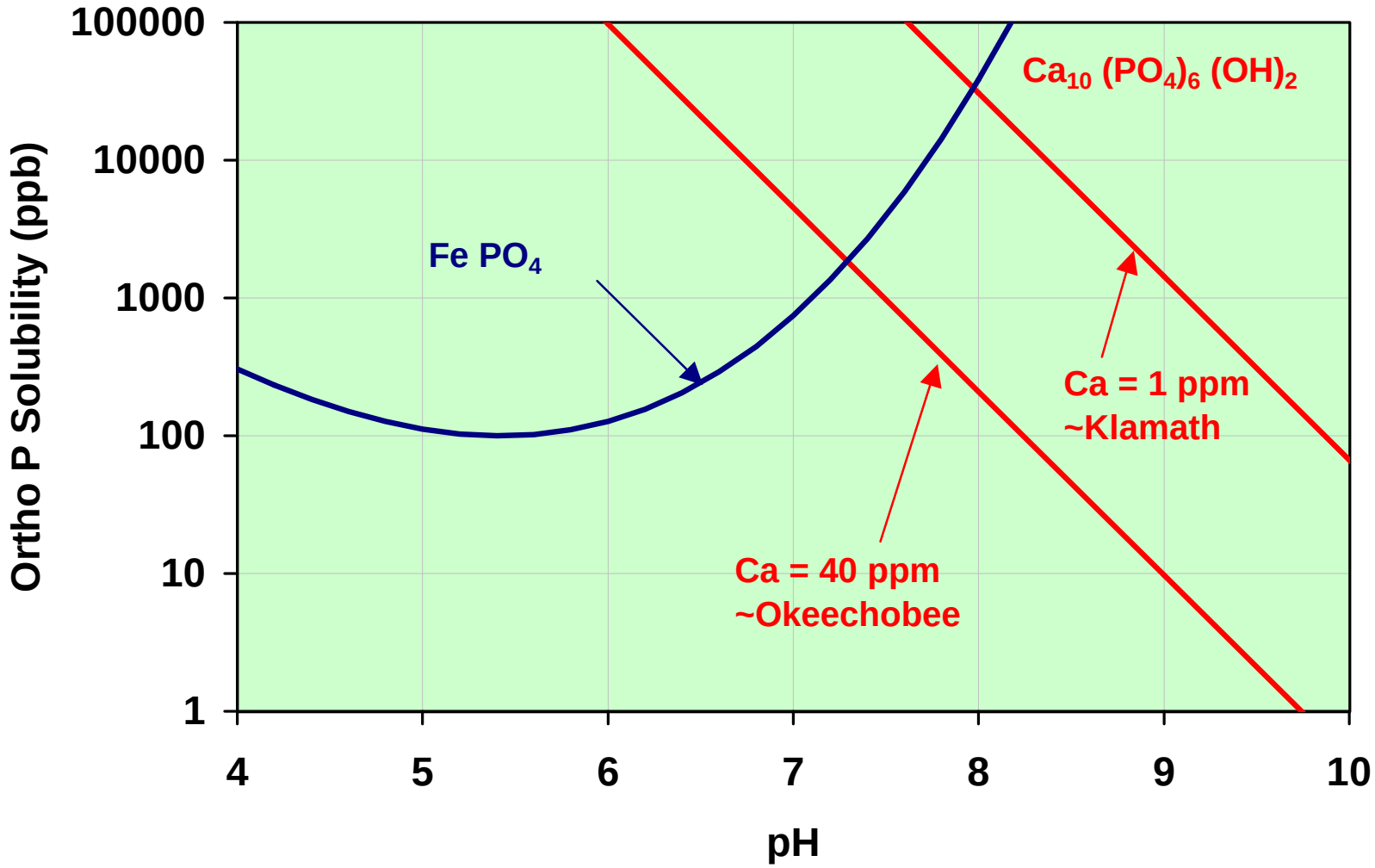


pH vs. Calcium & Dissolved Carbon Dioxide

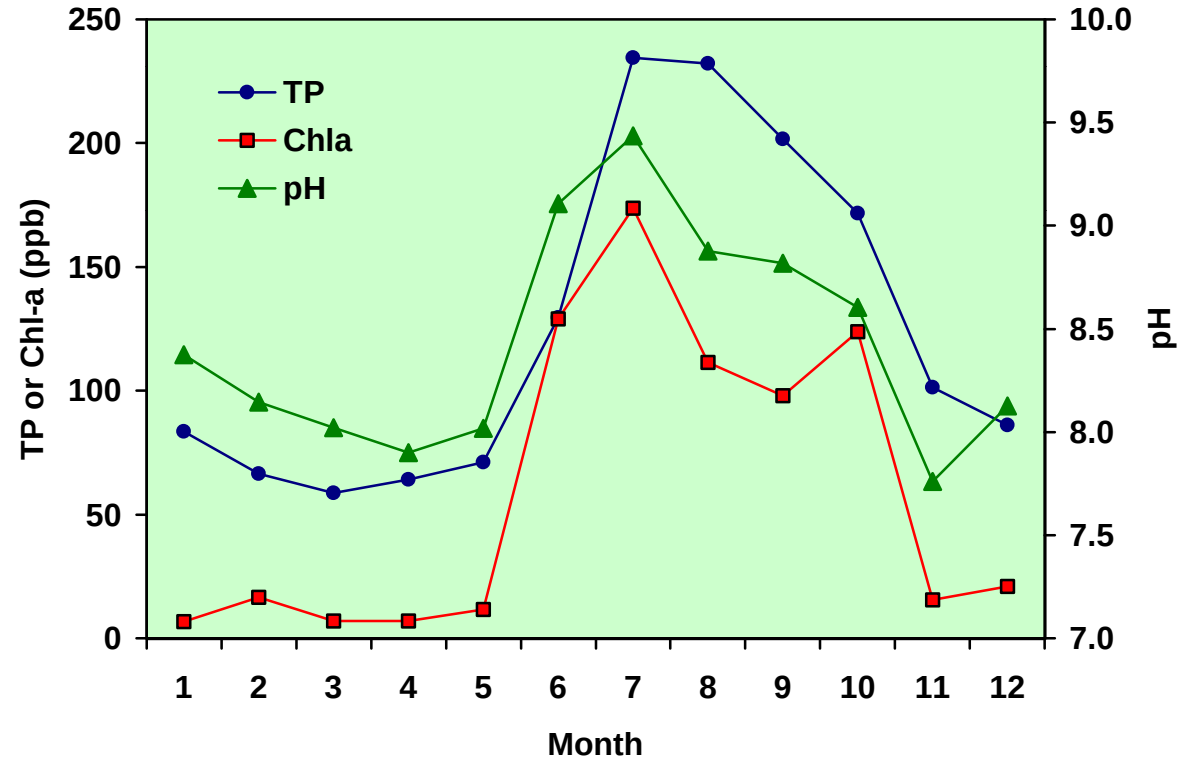


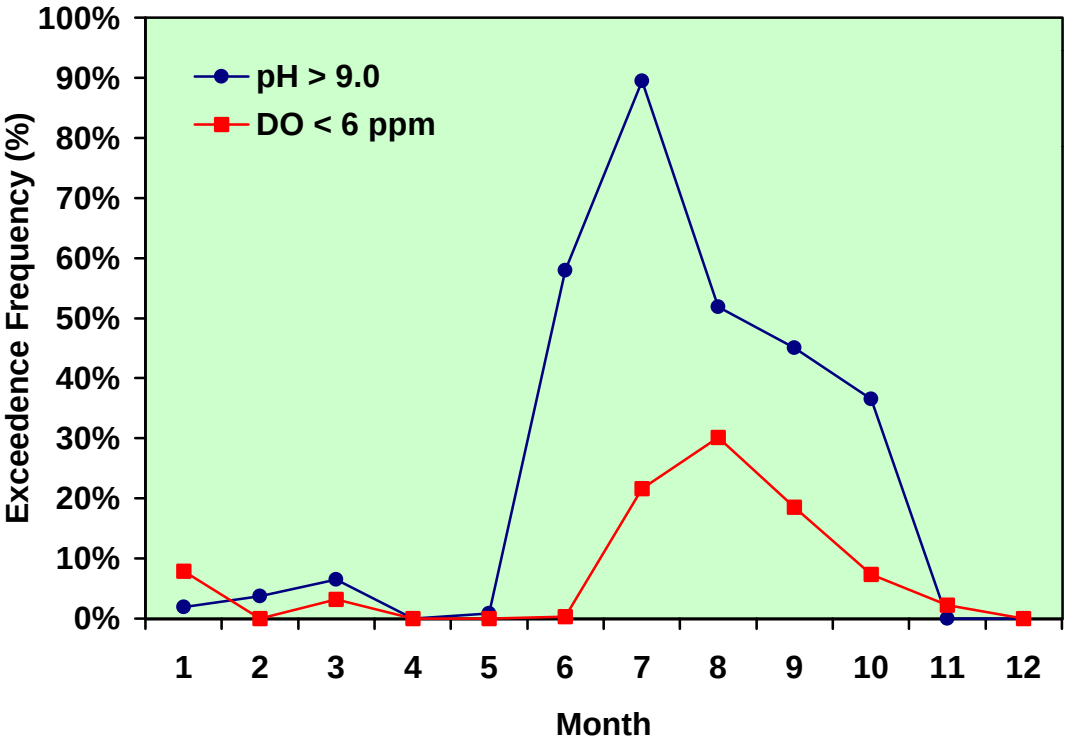
Temp = 25 deg C

Iron & Calcium Controls on Ortho P Solubility

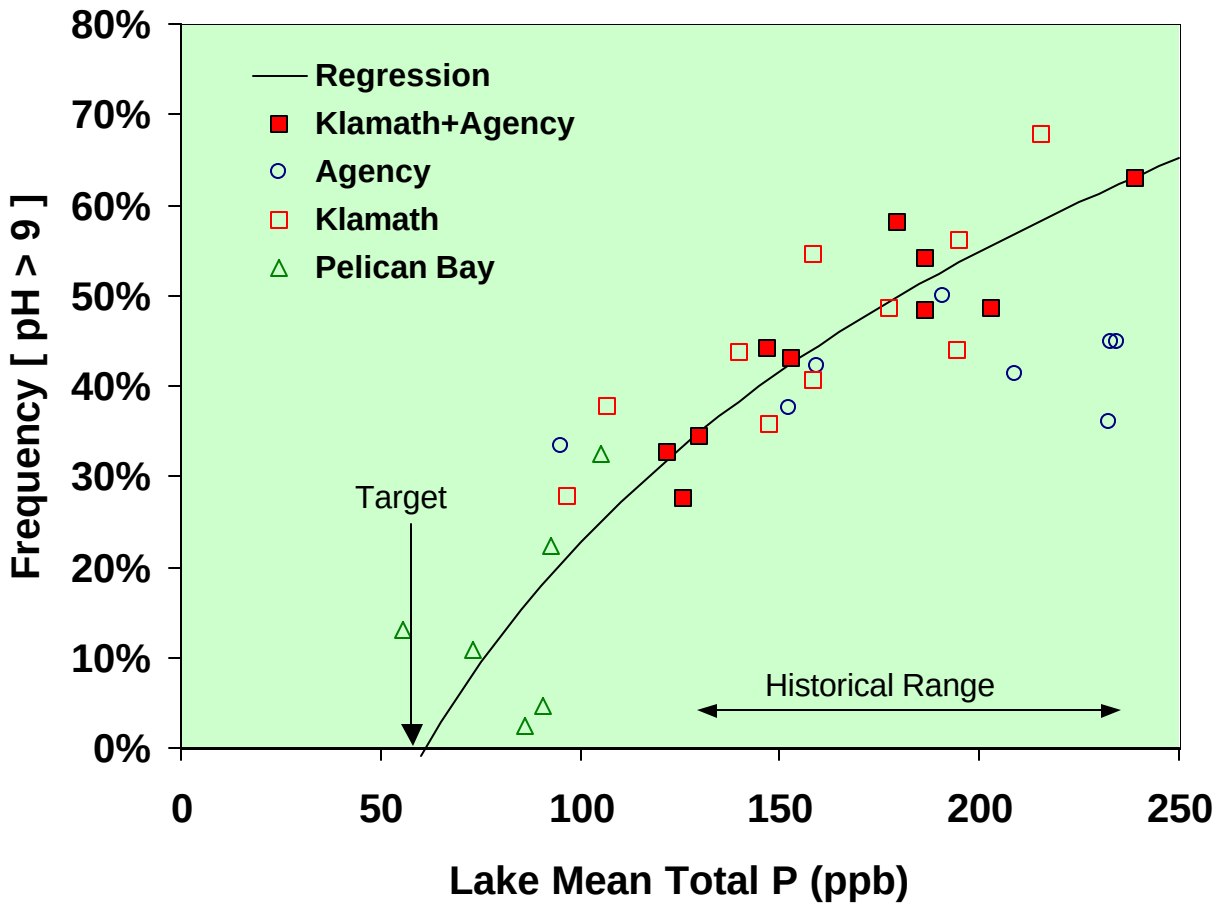


Seasonal Variations - Upper Klamath Lake



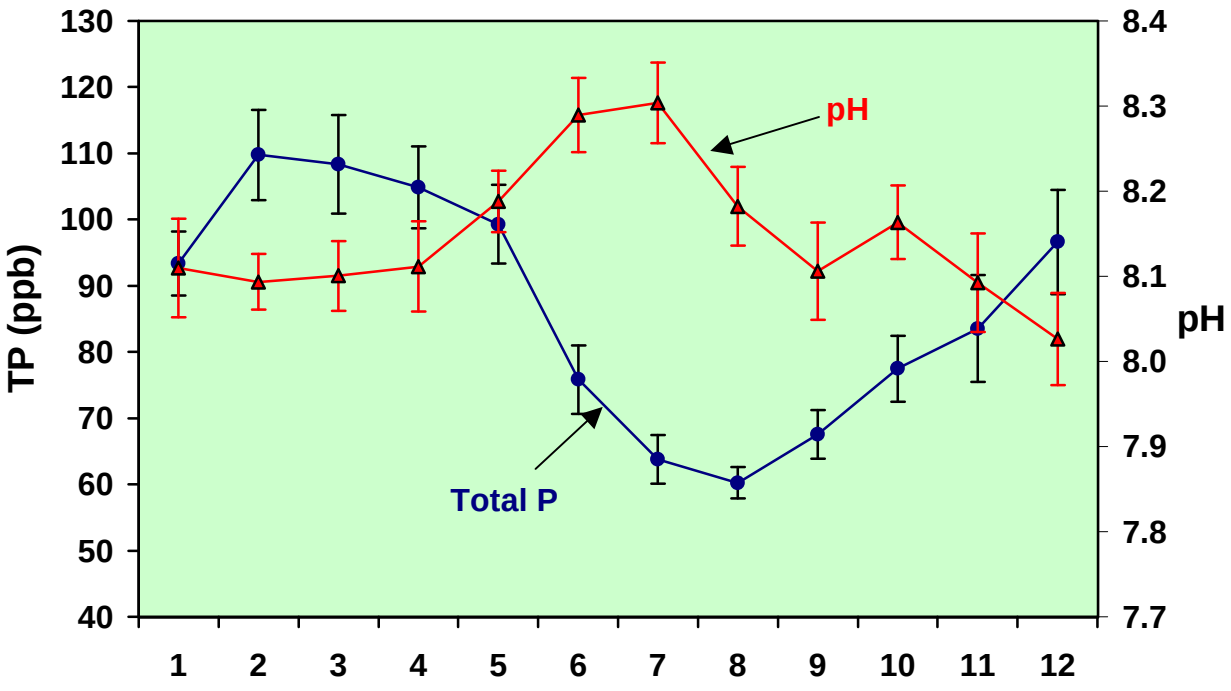


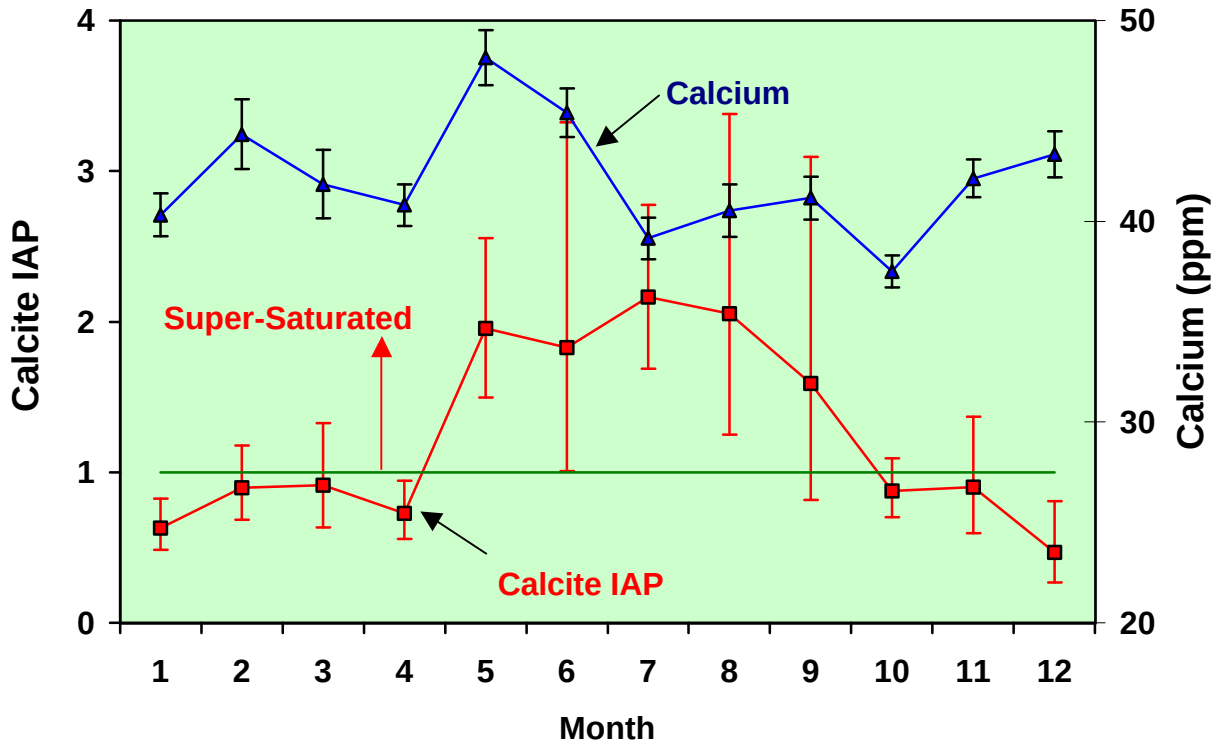
Derivation of Phosphorus Target for Upper Klamath Lake for Compliance with pH Standard



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

Seasonal Variations in Total P, Calcium, pH, & Calcite IAP





Phosphorus T M D L 's for Lakes

Watershed Mass Balance:

TMDL = S LAs + S WLAs + Background + MOS

TMDL	S LAs	S WLAs	Background	MOS
Total Maximum Daily Load	Non-Point Sources	Point Sources	Natural or Unregulated	Margin of Safety

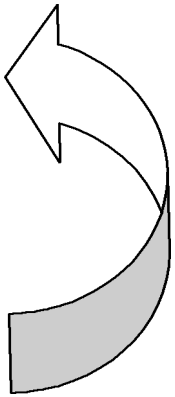
Lake Mass Balance:

$$TMDL = Q_O\ P^* + K_{NET}\ A\ P^* + L_I$$

Input	Flushing	Net Retention	"Internal Load"

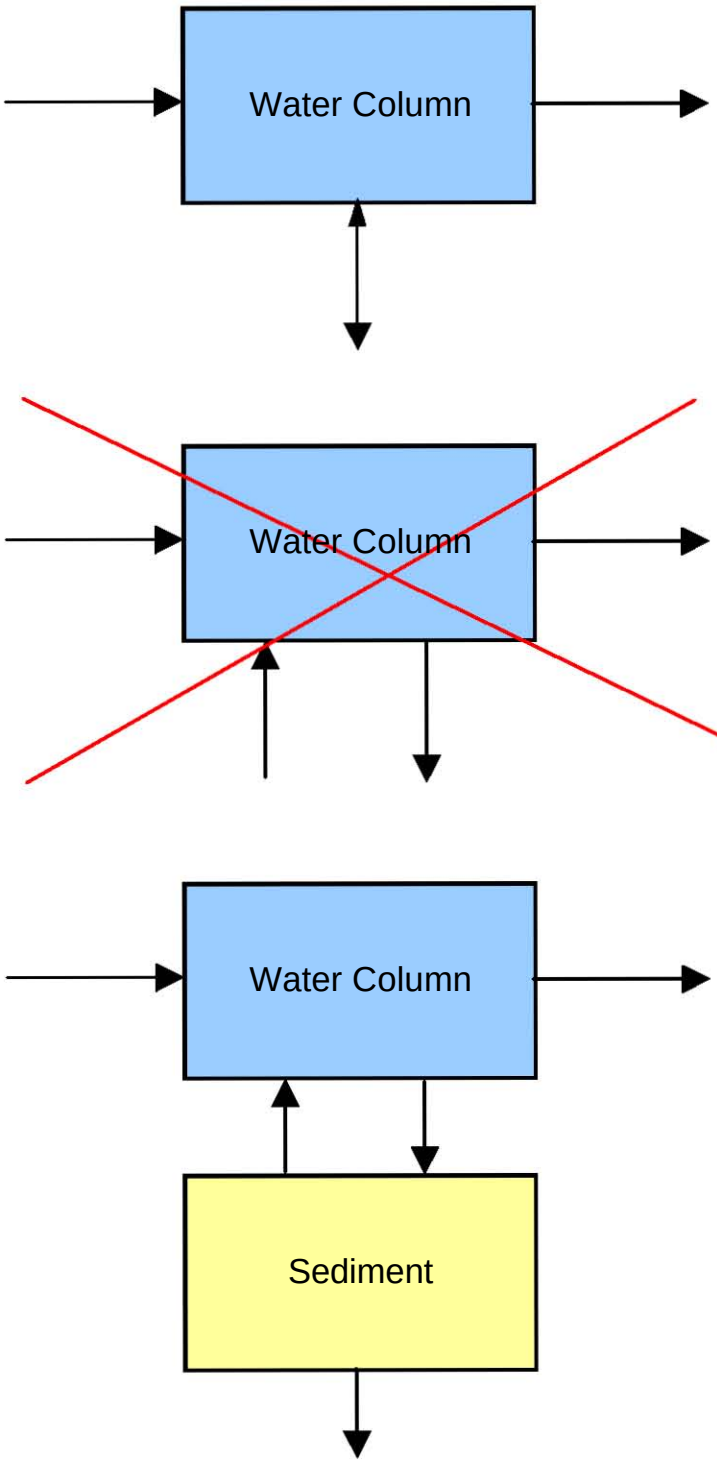
Decisions:

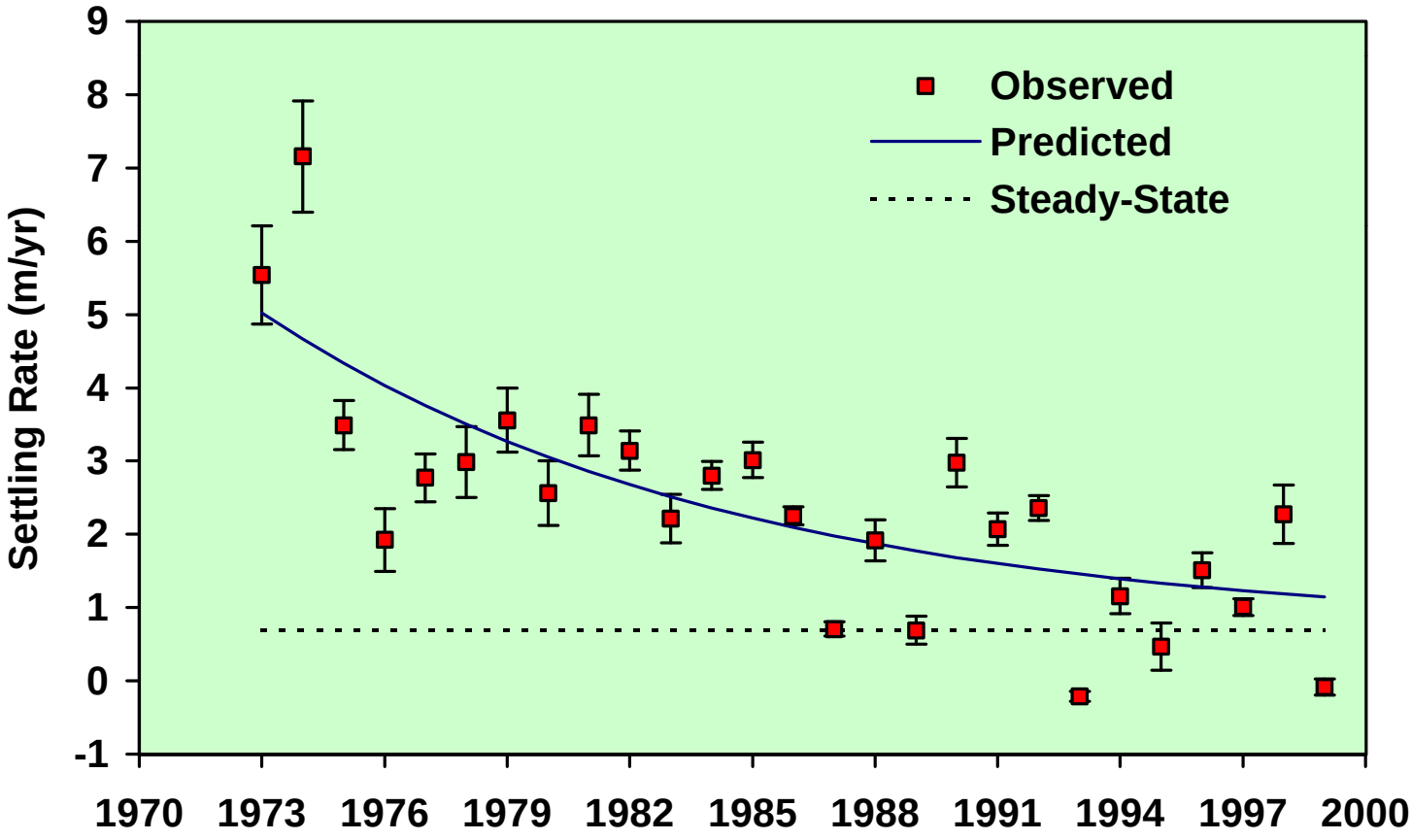
Water Quality Objectives
Phosphorus Target (P*)
Spatial & Temporal Scales
Model Development
Control Technologies
Allocations
Implementation Schedule

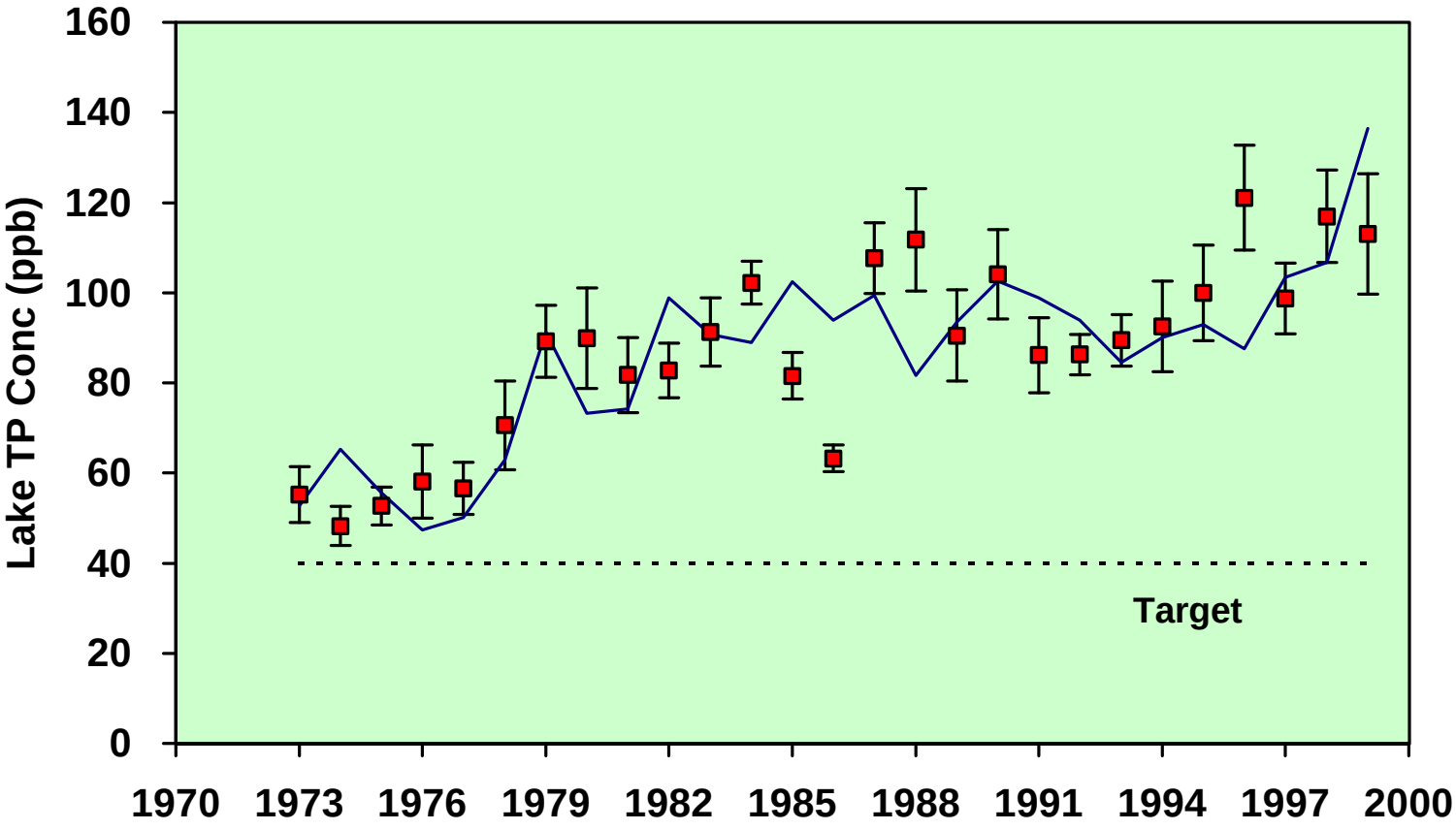


~ 5 years

Alternative Mass Balance Models

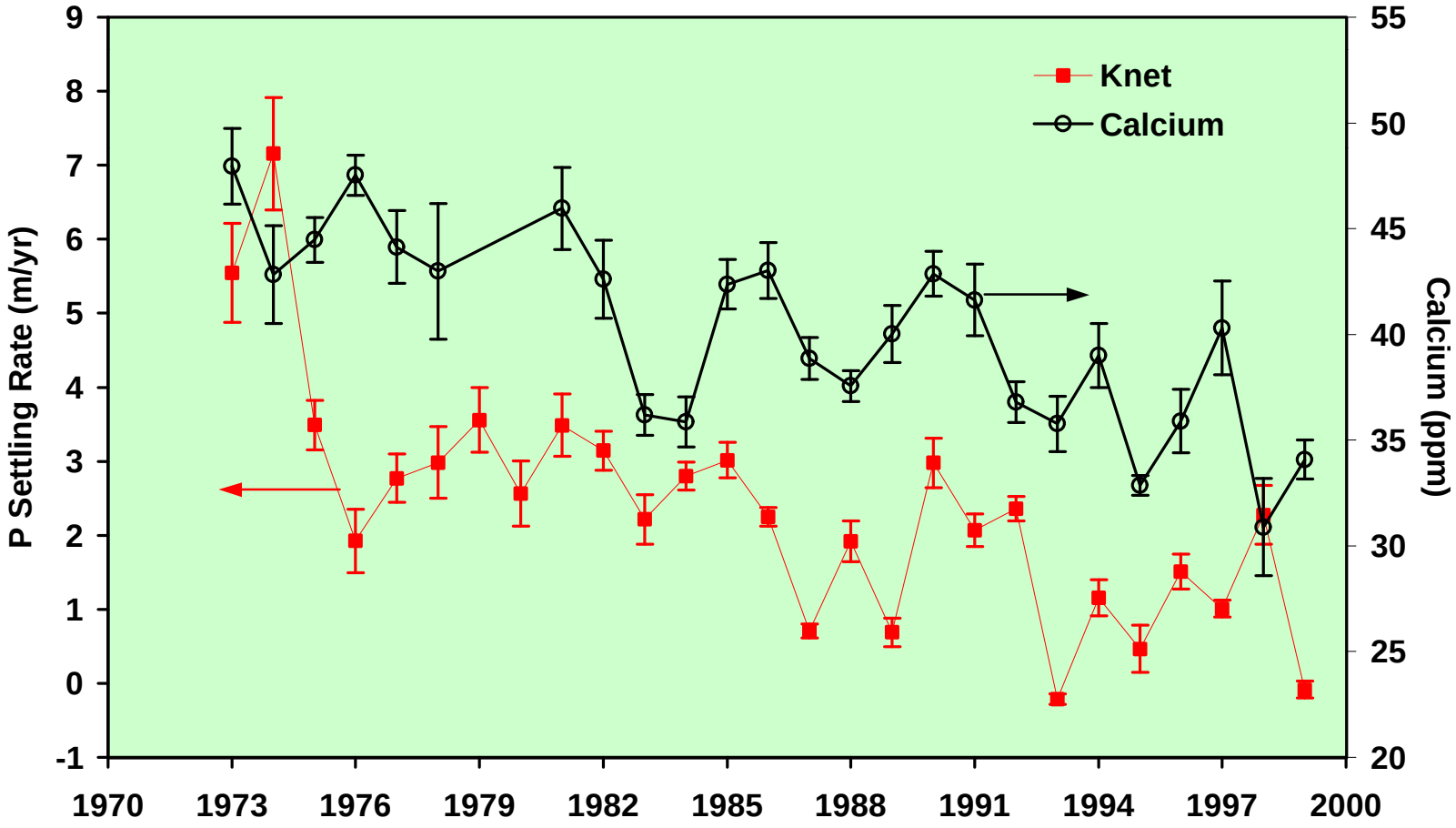



Settling Rate (m/yr)
9
8
7
6
5
4
3
2
1
0
-1
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
Observed
Predicted
Steady-State

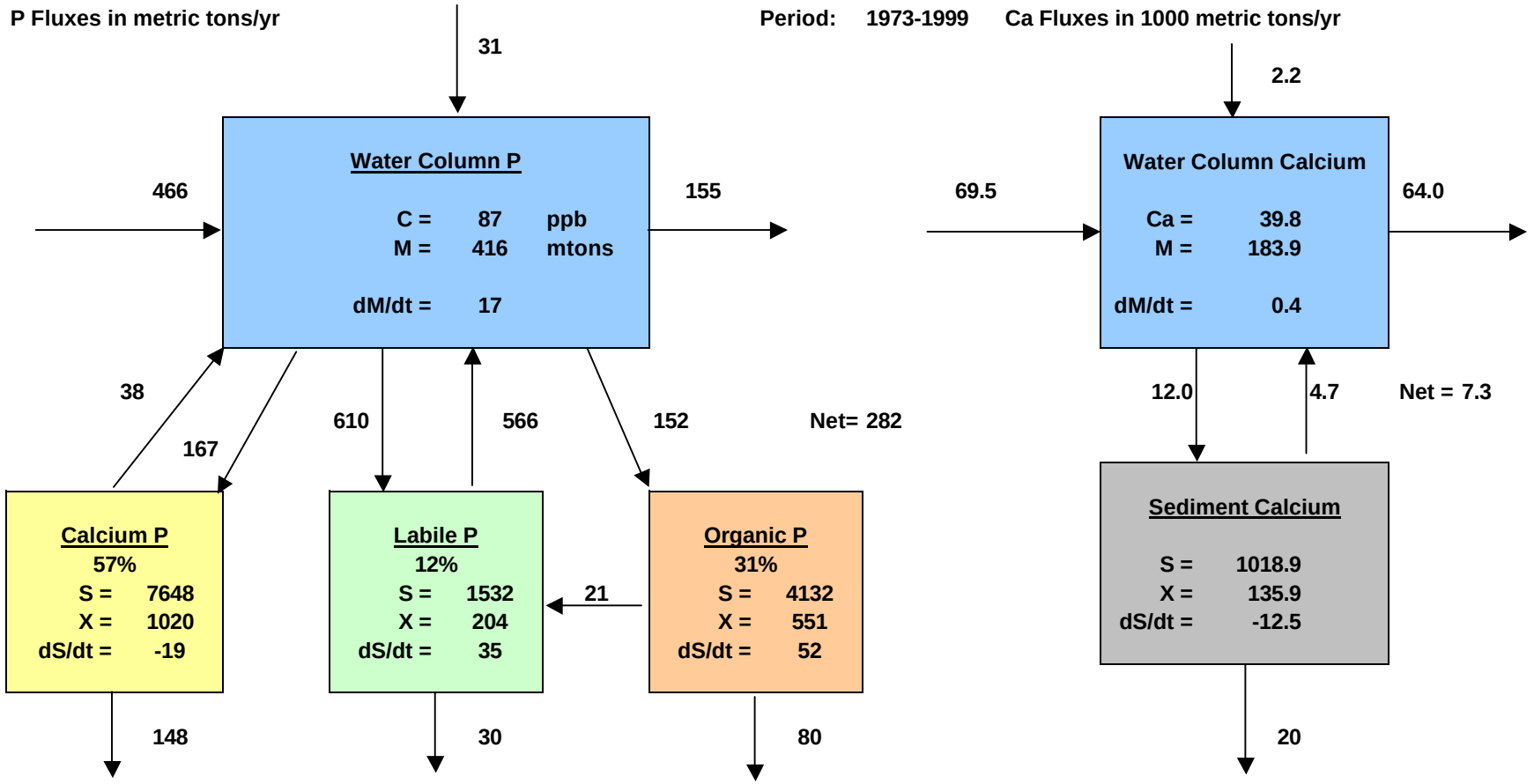


Mass Balance: $\frac{dM}{dt} = L - Q\,C - K_{NET}\,A\,C$

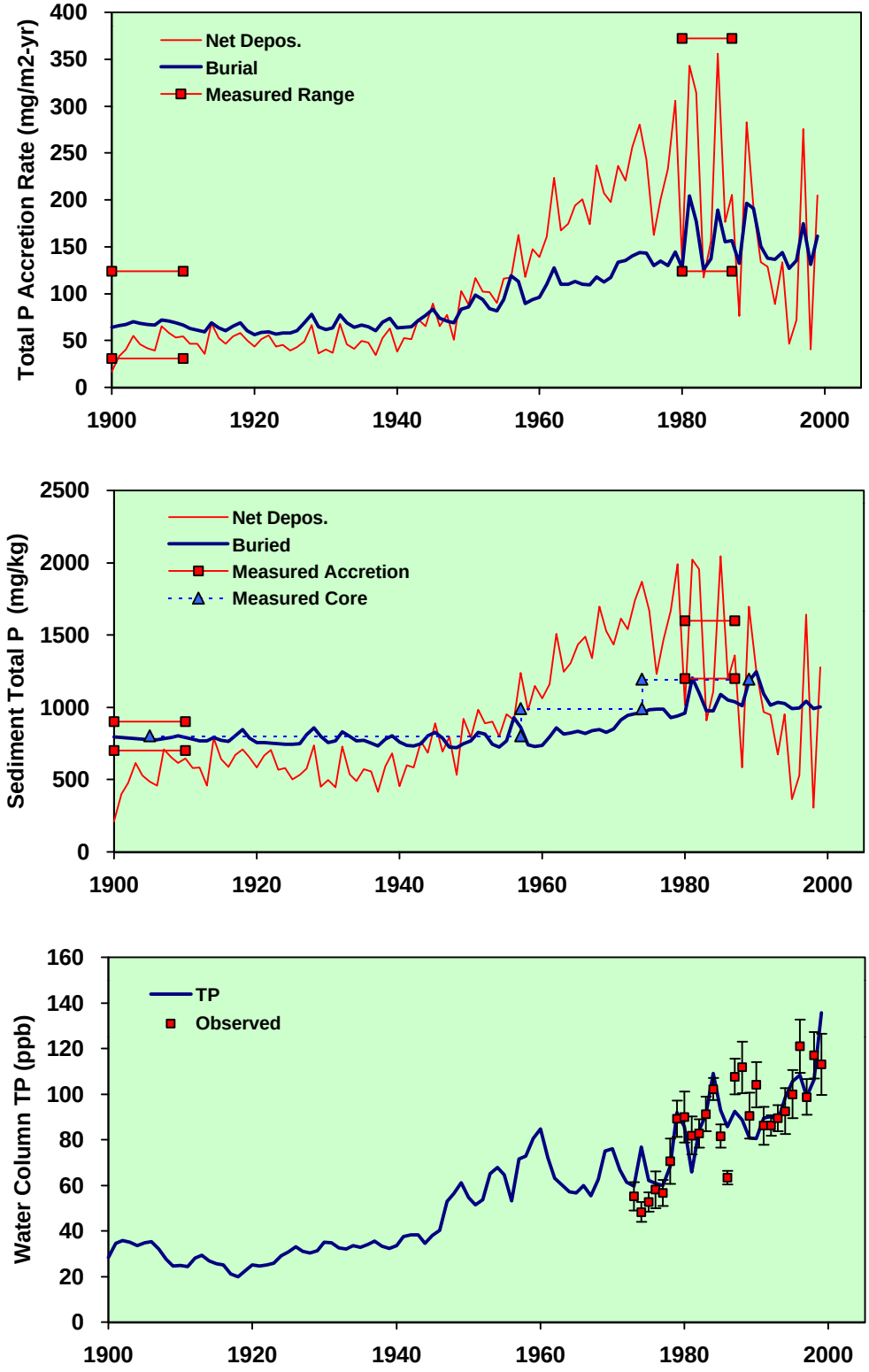
Phosphorus Settling Rate & Calcium Concentration



Phosphorus & Calcium Balances

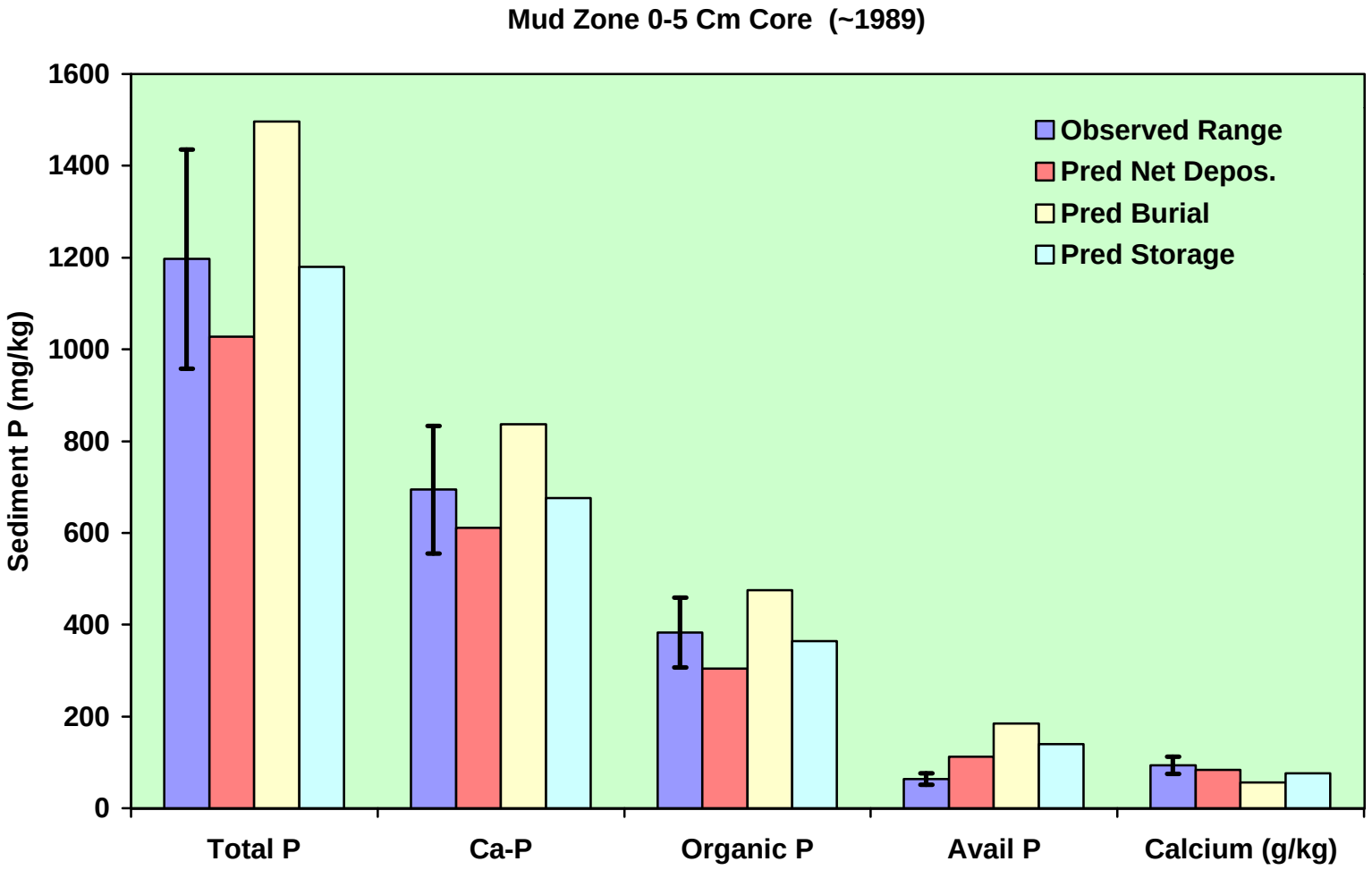


Observed & Predicted Sediment & Water-Column Phosphorus



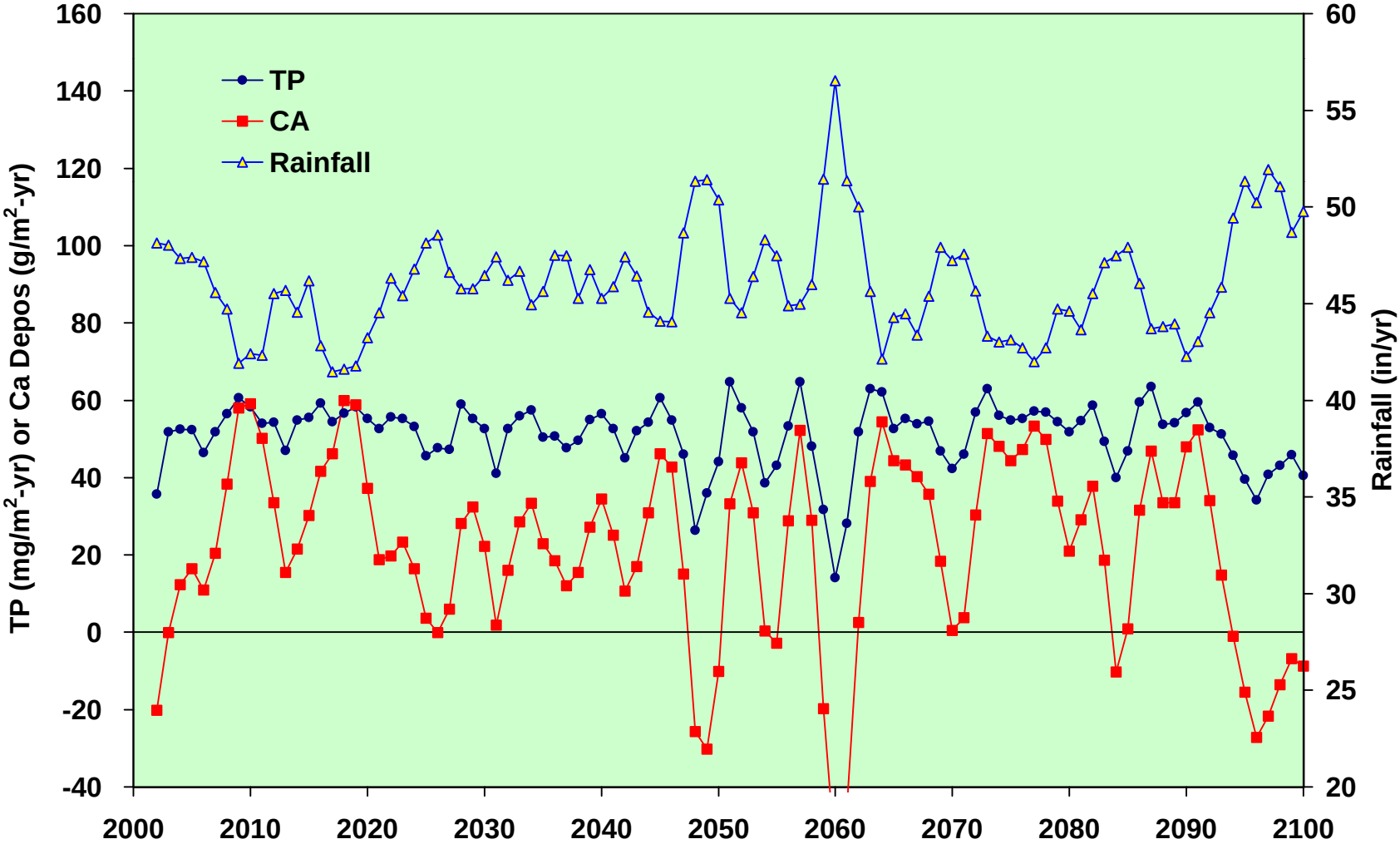
R^2 = 0.60 SE = 13.0 ppb

Observed & Predicted Sediment Composition



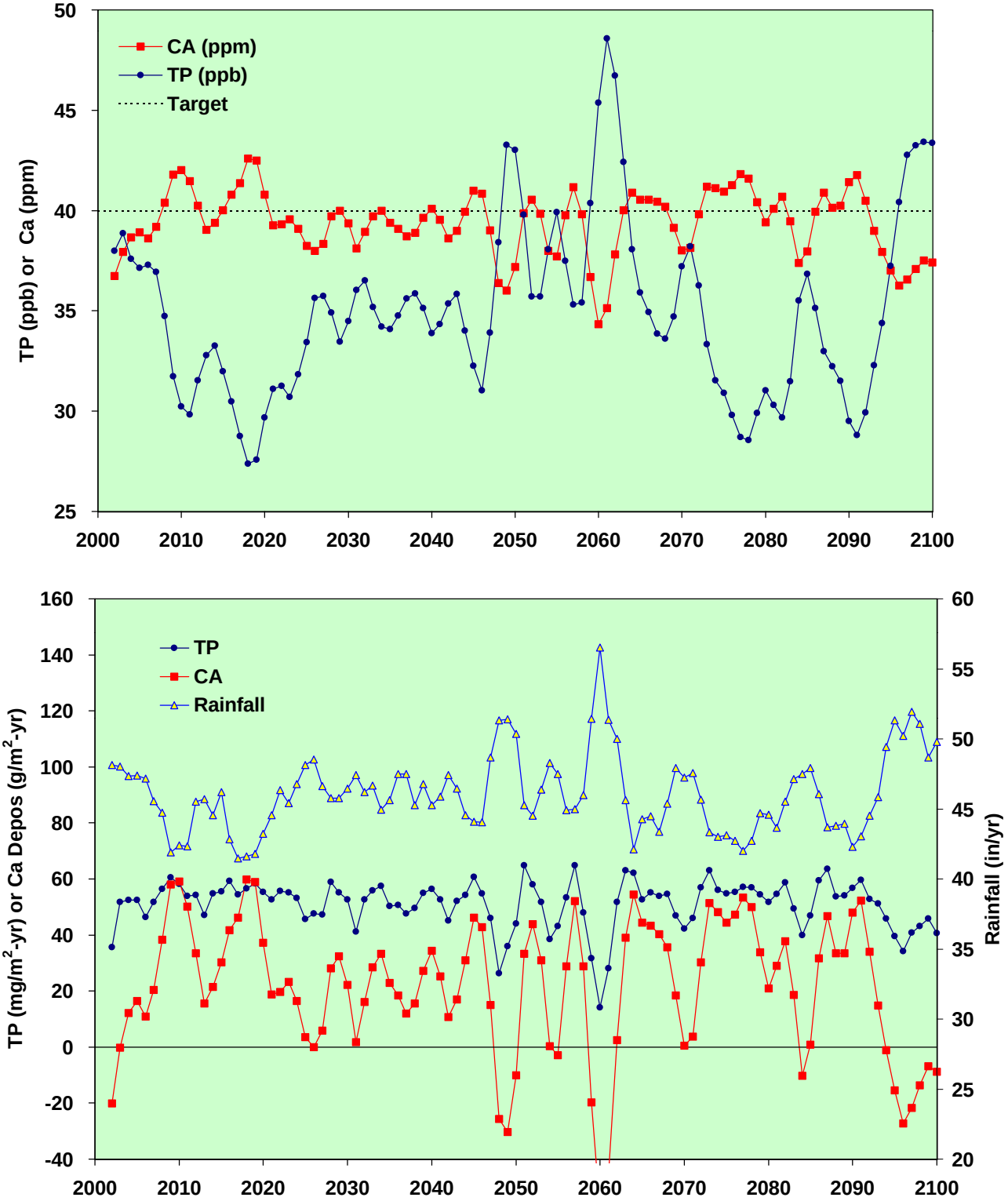
Observed values from 0-5 cm core collected in 1989 by Olila et al (1995) at Station K8 in mud zone; +/- 2 standard errors
Model available P pool compared with measured NH4CL-P + NaOH-P + Loose Organic P.
Predicted composition of active storage, net deposition from water column, & burial from storage over time interval represented by core.

Rain-Driven Variations in Calcium & Phosphorus Deposition



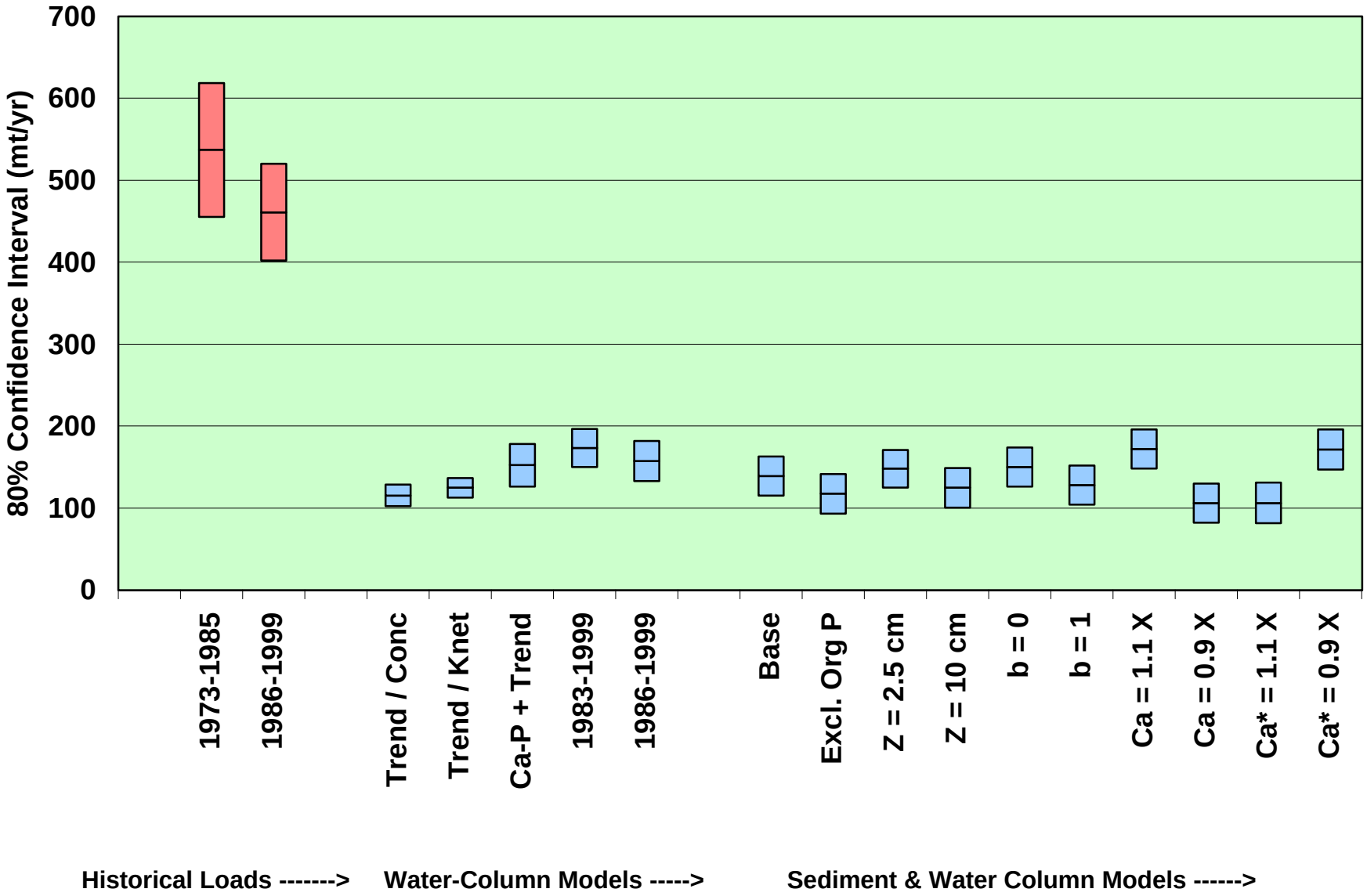
Three-Year rolling averages using simulated hydrology based upon 1900-1999 rainfall record & TMDL Conditions

Rain-Driven Variations in Calcium & Phosphorus Under TMDL Conditions



Three-Year rolling averages using simulated hydrology based upon 1900-1999 rainfall record

Lake Okeechobee Historical P Loads vs. Alternative TMDL Estimates



Phosphorus Concentrations & Loads

Feature	Units	Okeechobee	Klamath
Historical Conditions			
Lake P Conc	ppb	87	158
Inflow P Conc	ppb	194	120
Total P Load	mg/m^2-yr	288	656
Anthropogenic Load	%	74%	40%
Retention Coef.	%	57%	14%
TMDL Conditions			
Lake P Target	ppb	40	? 50 - 70 ?
Basis for Target	-	Algal Blooms	pH, DO, Blooms
TMDL	mg/m^2-yr	70 - 90	200 - 400
Load Reduction	%	65 - 80%	40 - 60%
Inflow Conc	ppb	45 - 65	40 - 60