Quantifying *Variability* & Uncertainty in Phosphorus TMDL's for Lakes

Reservoirs Too!

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Quantifying Variability & Uncertainty Benefits

Estimates Probability of Achieving Goal

Provides Rational Basis for MOS

Helps to Define Lake Goal

- **Numerical Value "Target" or "Limit"?**
- **Spatial & Temporal Averaging**
- **Compliance Rate (% of Years Achieving Goal)**

Identifies Important Sources of Uncertainty

Provides Incentive for Continued Data Collection & Modeling

- **More Data --?-> Lower MOS --?--> Higher Load Alloc**

Quantifying Variability & Uncertainty Difficulties

Limited Guidance Provided in TMDL Regulations

Frequency Concepts Rarely Built into WQ Standards

Load Allocations Sensitive to Assumptions:

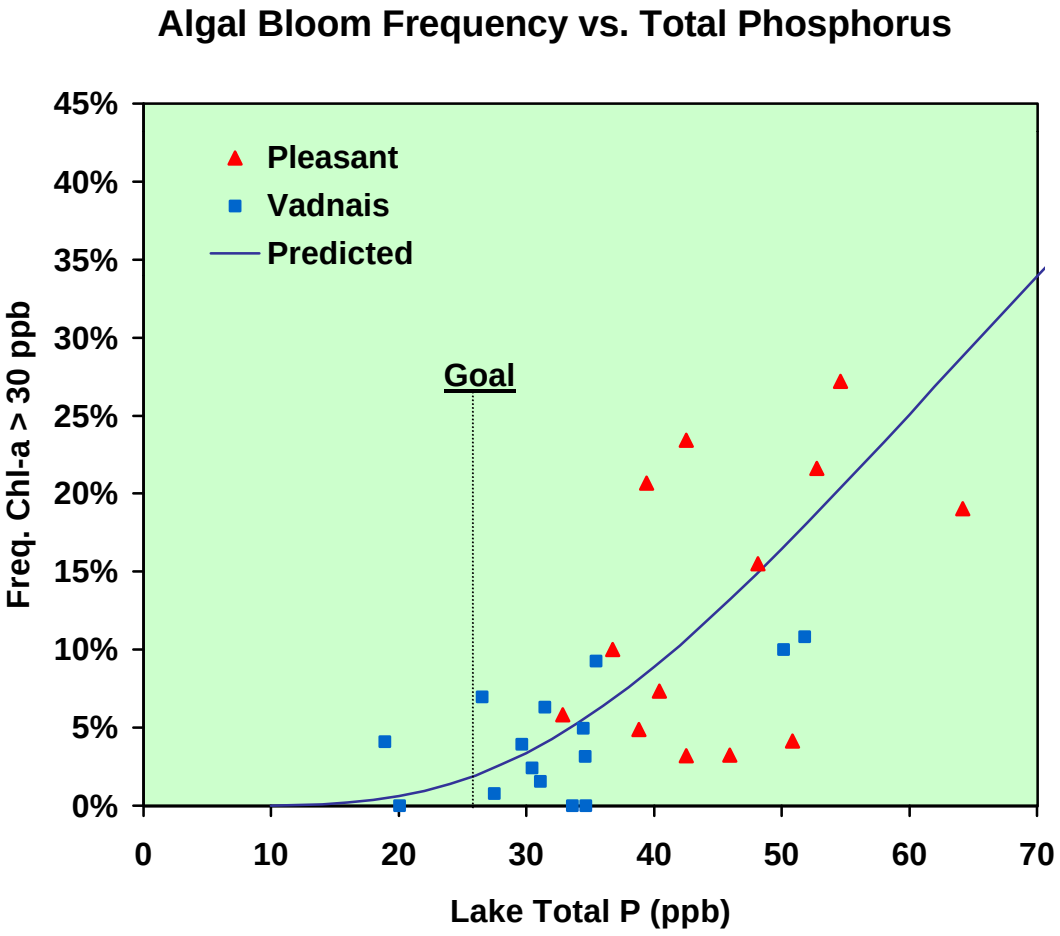
- **Compliance Rate (e.g., % of yrs <= target)**
- **Confidence Level (~probability of success)**

Uncertainty/Variability Costs (MOS) Can Be Large

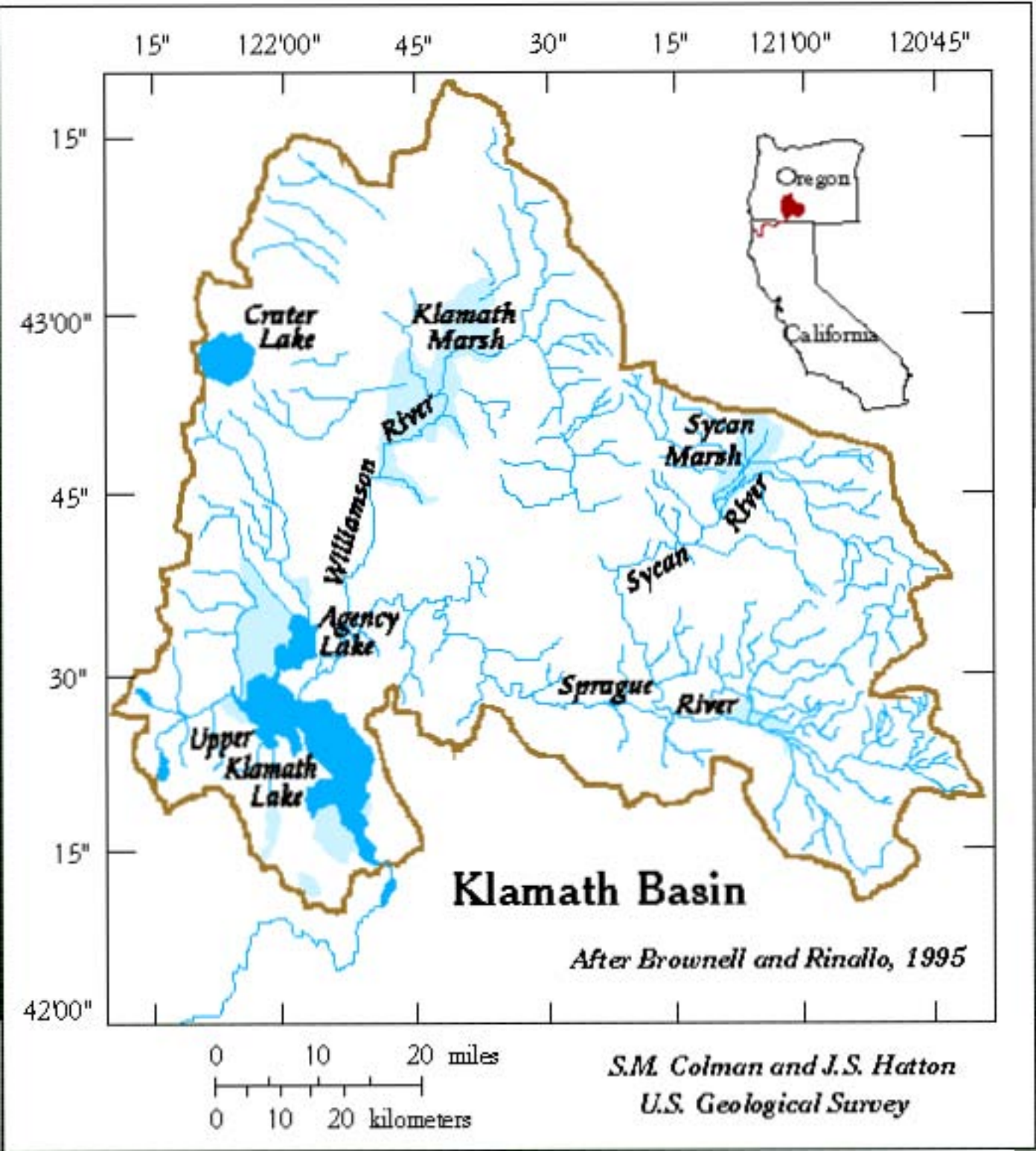
Can Backfire & Retard Restoration Efforts

Technical Complexity

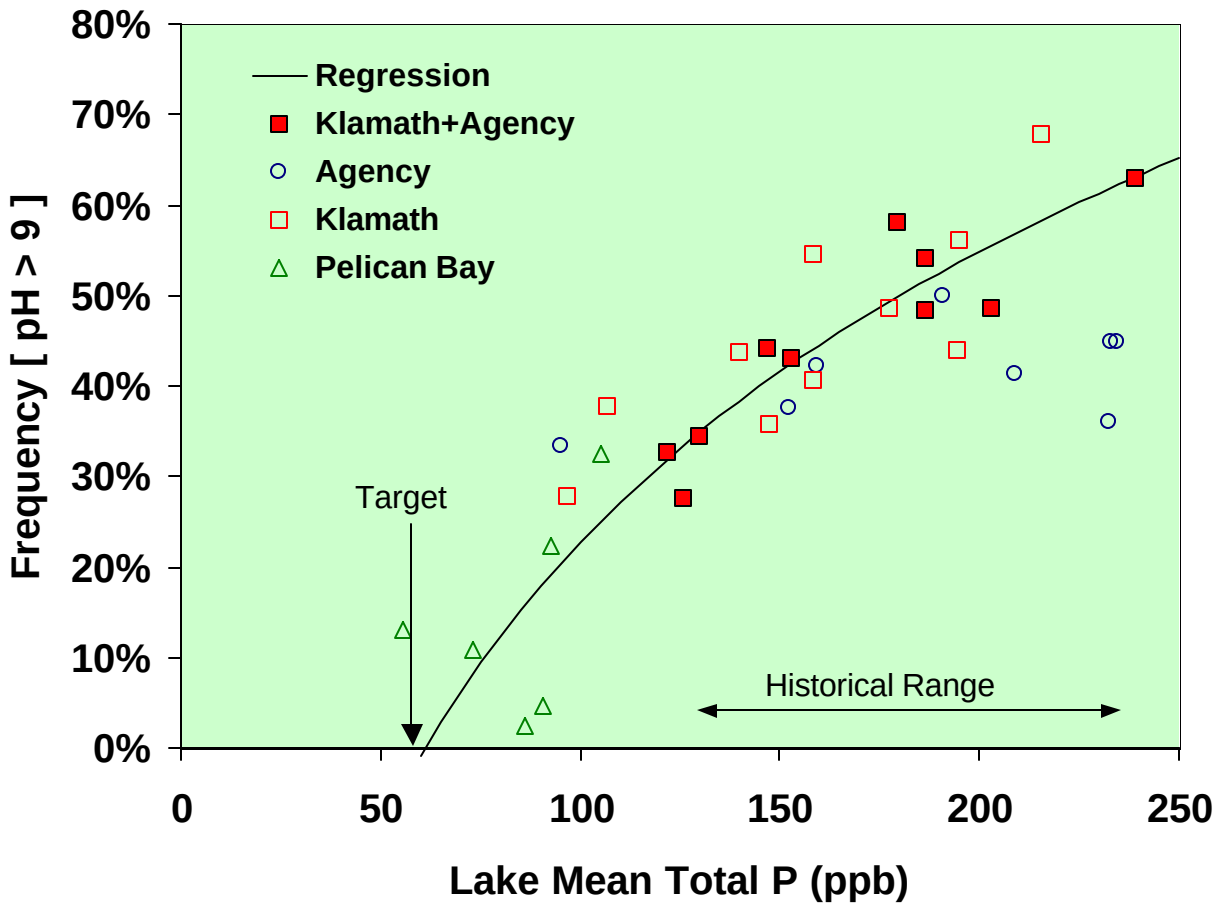
Uncertainty Estimates are Uncertain



Bloom Frequencies from daily samples at Vadnais Intake & Pleasant Gatehouse
Total Phosphorus concentrations measured in Lake Epilimnion (0- 6 m)
April-September Means for Each Year


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

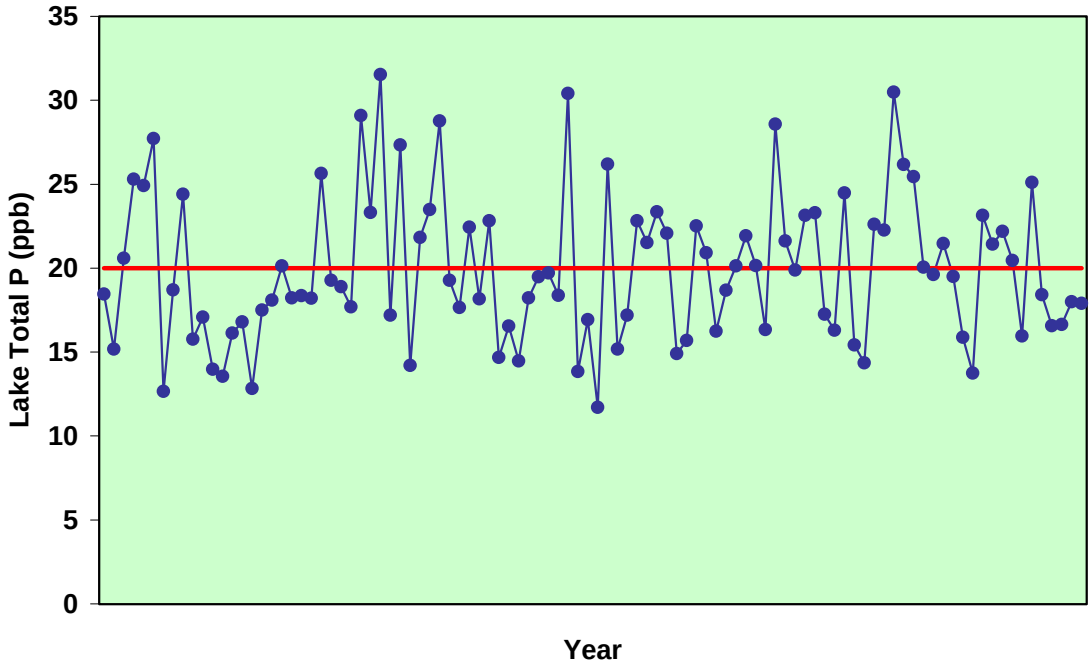
Derivation of Phosphorus Target for Upper Klamath Lake for Compliance with pH Standard



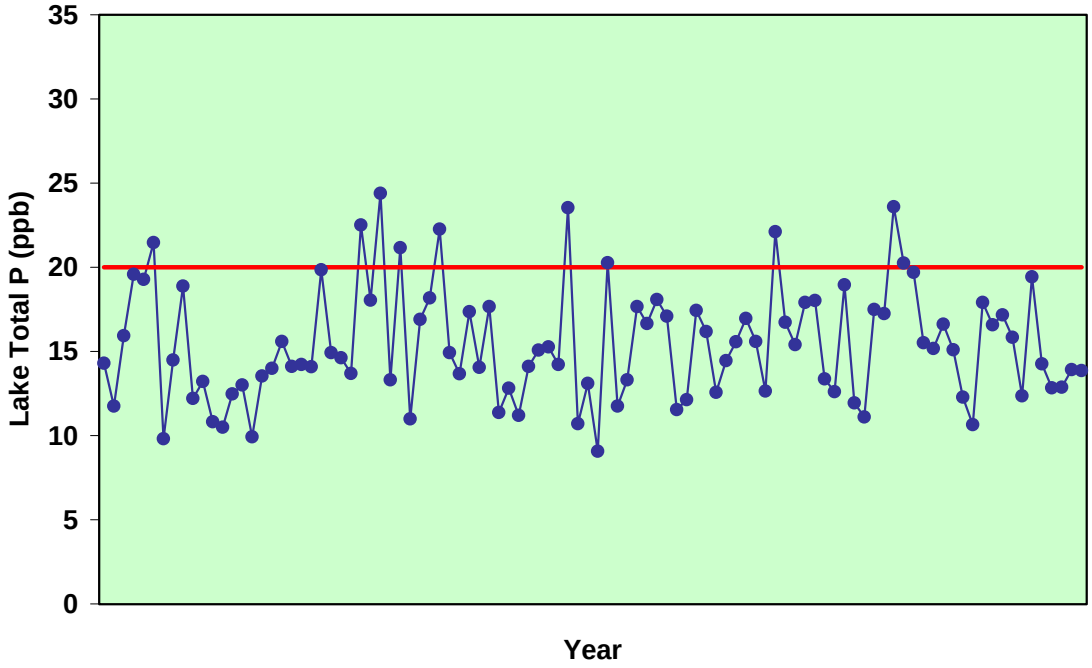
Yearly Means by Lake Region, April-October DRAFT
Frequency = % of Measurements (All Stations & Depths) Exceeding pH 9

Alternative Interpretations of a 20 ppb Lake P Goal

Case 1: **Long-Term Mean < 20 ppb**
TMDL = 100 kg/yr



Case 2: **Yearly Mean < 20 ppb in 90% of Years**
Long-Term Mean = 15.5 ppb
TMDL = 77 kg/yr



TMDL Equations
Long-Term-Average Mass Balances

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
	Anthropogenic	*< Discharge Permit*	*Undev. Watershed*	*uncertainty*
			Atmospheric	*variability*

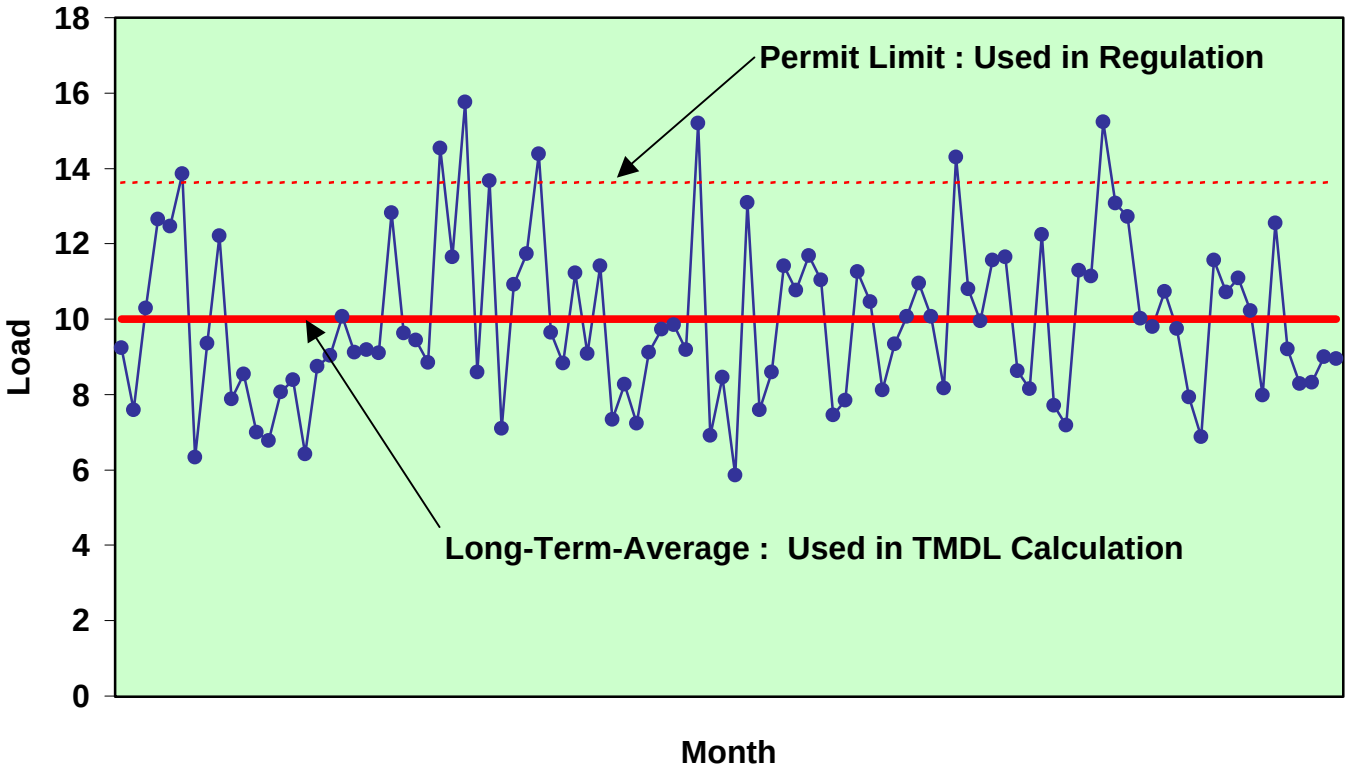
<--- Expected Long-Term-Average Load to Lake --->

Lake Mass Balance:

TMDL = Q_S P* + U P*

TMDL	Q_S P*	U P*
Input	Flushing	Net Retention

Consideration of Point-Source Variability



Arith Mean	10	Long-Term Average Load Used in TMDL Mass Balance
Permit Limit	14	Permit Value not to be Exceeded in >5% of Months
Model: Log-Normal Distribution with CV =	0.2	

MOS Alternatives

Conservative Water Quality Criteria/Standard

Conservative Phosphorus Goal

Conservative Modeling Assumptions

Conservative Effluent Limits / Discharge Permits

Conservative Facility Designs

Conservative Growth Projections

Shell Game

Modeling Variability & Uncertainty
Stochastic Approach

Predicted Long-Term-Average Lake P Conc:

$$P_M = L_M / (U + Q_S)$$

Accounting for Uncertainty:

$$P_{MU} = P_M \exp (d_u)$$

d_u = *random error term, mean = 0, std dev =* s_u

s_u ~ *0.1 - 0.5*

Accounting for Uncertainty & Variability:

$$P_{MUY} = P_M \exp (d_u + d_y)$$

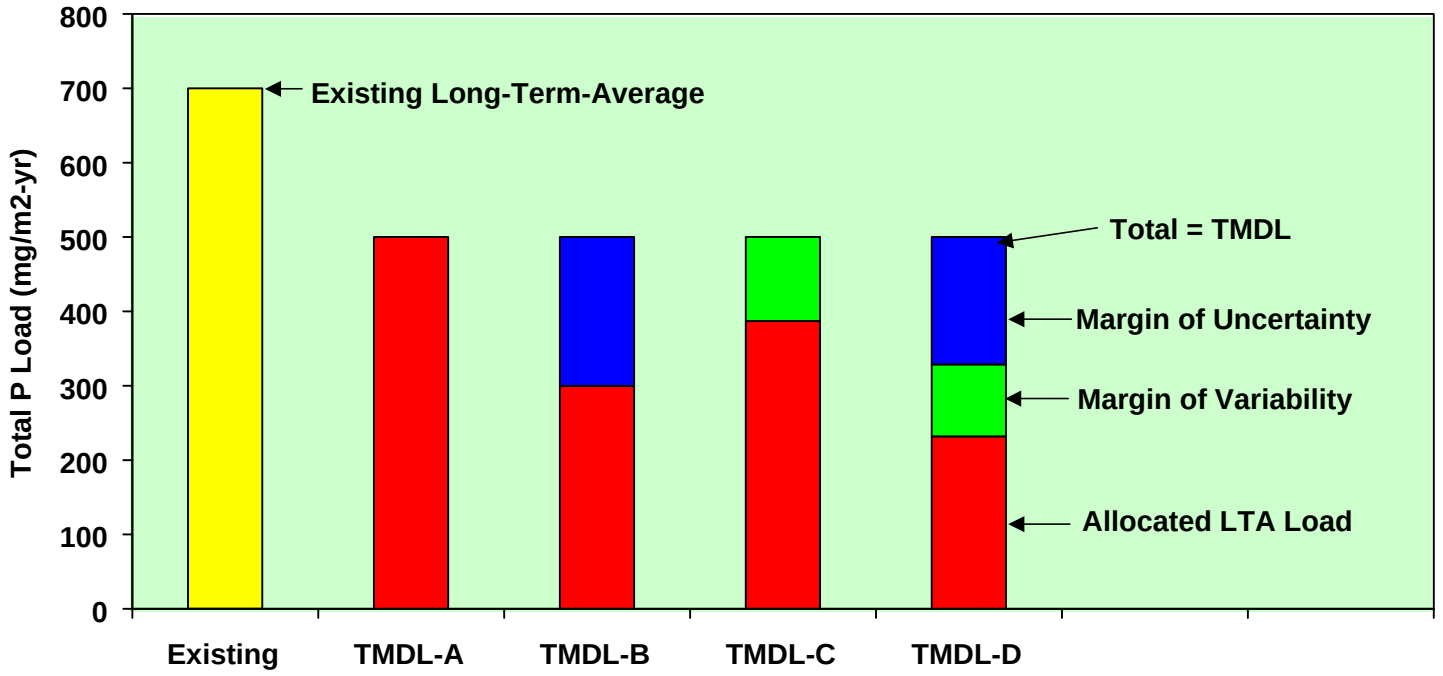
d_y = *random yr-to-yr variation, mean = 0, std dev =* s_y

s_y ~ *0.1 - 0.3*

TMDL Calculation Spreadsheet

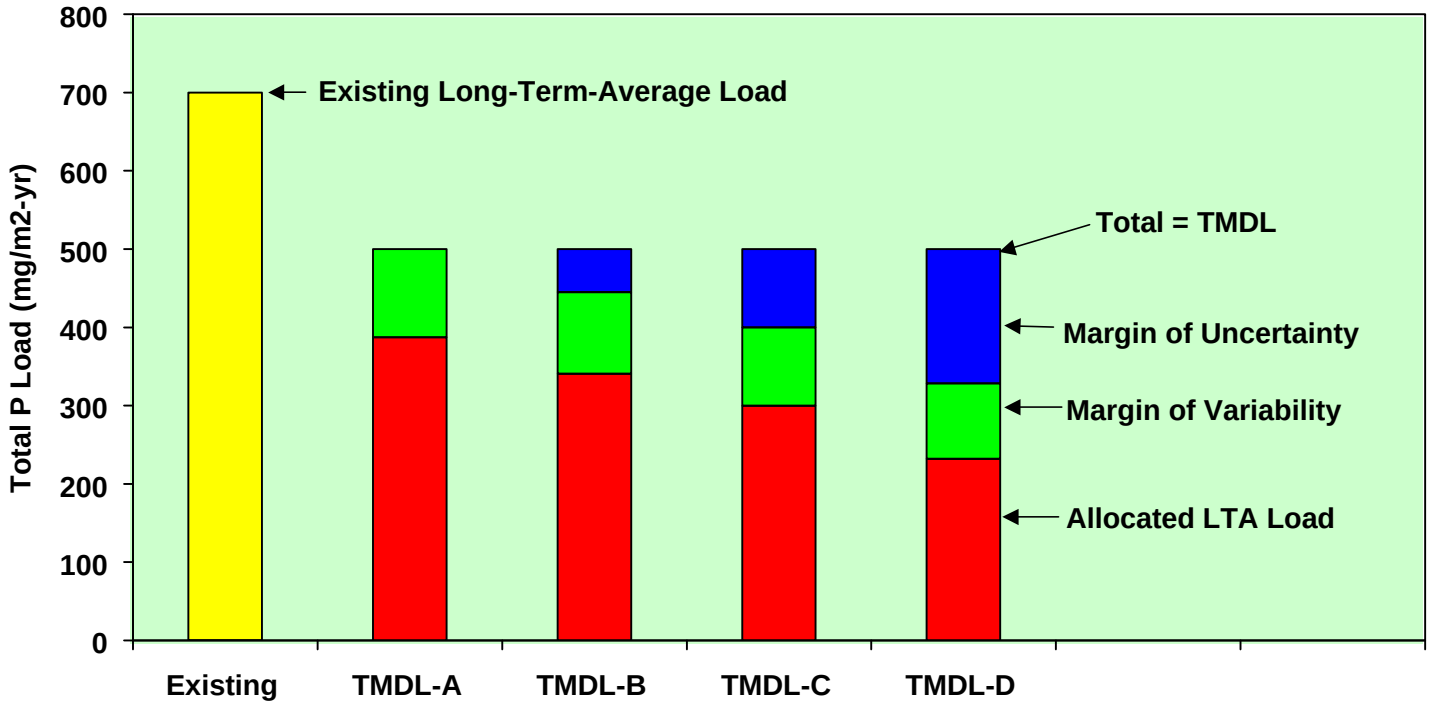
Variable	Units	Value	Equation	Notes
Input Values:				
Existing Load	mg/m^2-yr	1000	Lo	long-term-average load
Net Settling Rate	m/yr	10	U	from model calibration
Water Load	m/yr	10	Qs	outflow / surface area
Target Lake P	ppb	25	P*	for compliance with wq standards
Confidence Level	%	90%	p1	= 100 - max risk of not achieving objective
Compliance Frequency	%	80%	p2	expected percent of years achieving target
Model Error Std Dev	-	0.3	Su	accounts for modelling uncertainty
Year-to-Year Std Dev	-	0.1	Sy	accounts for temporal variability in lake p
Output Values:				
Normal Deviate (p1)		1.282	Zu = Normal (1-p1)	normal deviate with tail probability 1-p1
Uncertainty Factor		0.681	Fu = exp (- Zu Su)	
Normal Deviate (p2)		0.842	Zy = Normal (1-p2)	normal deviate with tail probability 1-p2
Variability Factor		0.919	Fy = exp (- Zy Sy)	
MOU Fraction		0.8	f = (1 - Fu) / (2 - Fu - Fy)	fraction of MOS assigned to MOU
TMDL	mg/m^2-yr	500	TMDL = (Qs + U) P*	
Allocated Load	mg/m^2-yr	313	La = TMDL Fu Fy	long-term-average allocated load
Margin of Safety	mg/m^2-yr	187	MOS = TMDL - La	or MOS = MOU + MOV
Margin of Uncertainty	mg/m^2-yr	149	MOU = f MOS	portion of MOS attributed to uncertainty
Margin of Variability	mg/m^2-yr	38	MOV = MOS - MOU	portion of MOS attributed to variability
Uncertainty Cost		30%	MOU / TMDL	MOU as fraction of TMDL
Variability Cost		8%	MOV / TMDL	MOV as fraction of TMDL
Required Load Reduction		69%	1 - La / Lo	

TMDL Sensitivity to Compliance Frequency & Confidence Level



Lake P Target	LT-Avg	LT-Avg	10-Yr Max	10-Yr Max
Uncertainty Considered	No	Yes	No	Yes
Variability Considered	No	No	Yes	Yes
Confidence Level -->MOU	50%	90%	50%	90%
Compliance Freq --> MOV	50%	50%	90%	90%
Model Error Std Dev	0.4	0.4	0.4	0.4
Temporal Std Dev	0.2	0.2	0.2	0.2
Allocated LTA Load	500	299	387	232
Load Reduction	29%	57%	45%	67%

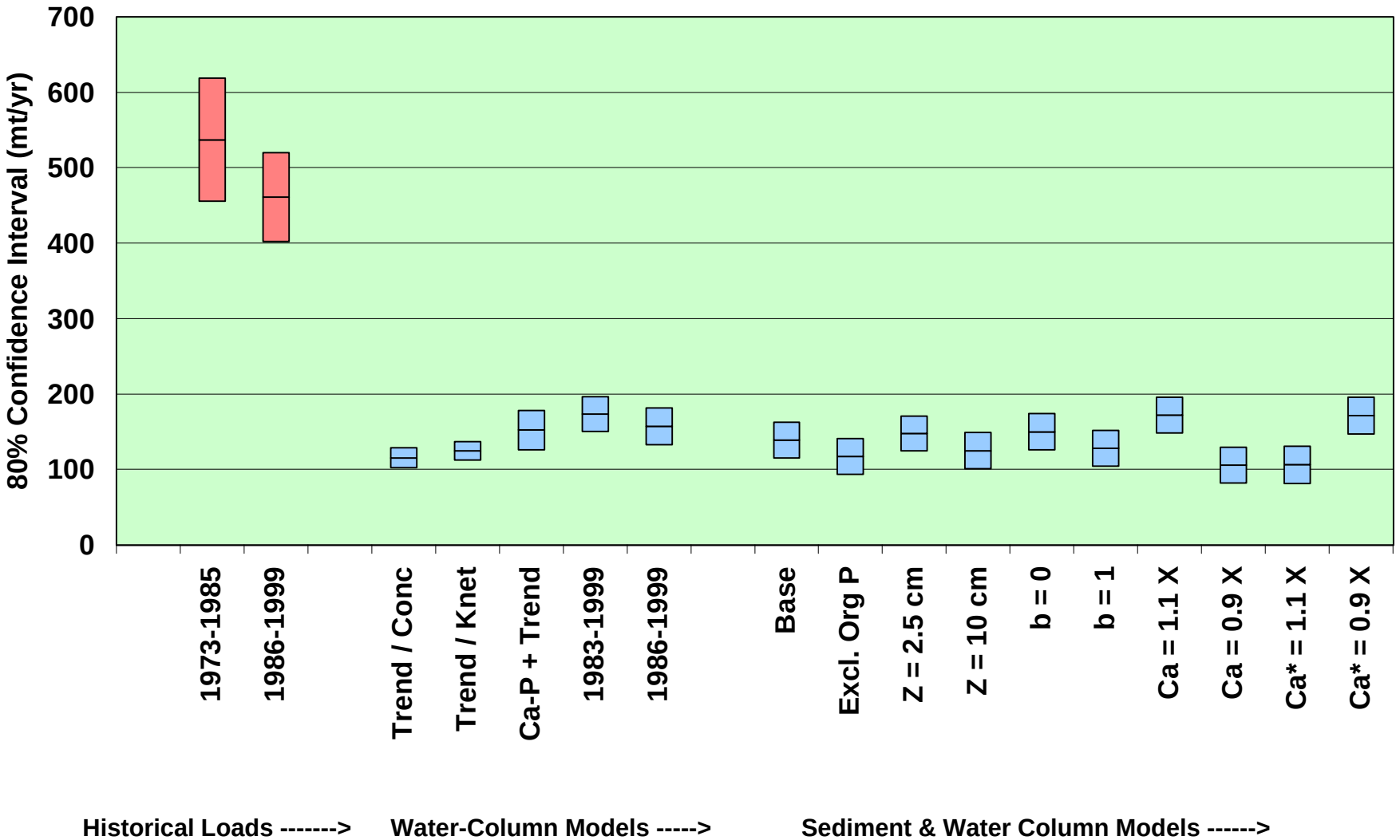
TMDL Sensitivity to Model Uncertainty



	Increasing Model Uncertainty ---------->			
Model Error Std Dev	**0.0**	**0.1**	**0.2**	**0.4**
Temporal Std Dev	**0.2**	**0.2**	**0.2**	**0.2**
Allocated LTA Load	**387**	**340**	**299**	**232**
Load Reduction	**45%**	**51%**	**57%**	**67%**
Uncertainty Cost	**0%**	**11%**	**20%**	**34%**

TMDL Allocations for Confidence Level = 90%, Compliance Freq = 90%

Figure 29
Confidence Intervals for TMDL's Compared with Historical Phosphorus Loads



Iterative TMDL Process

Define Management/Use Objectives

Identify Water Quality Standards

Monitor & Model

Estimate TMDL's

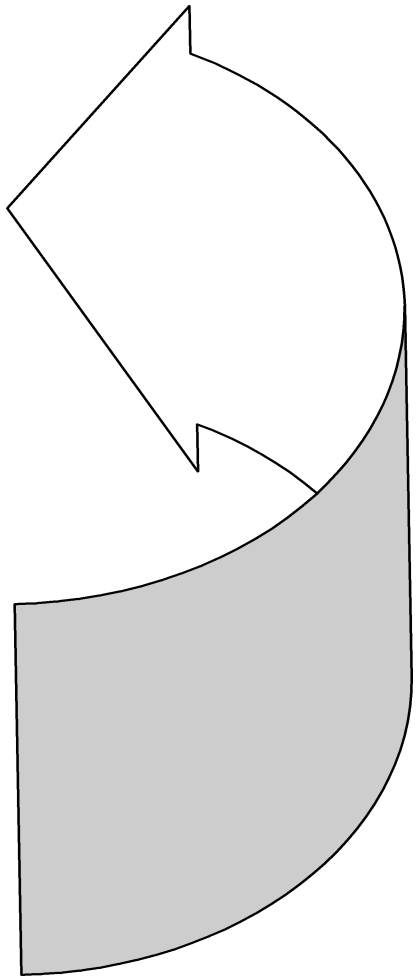
Evaluate Controls

Develop Load Allocations

Implement Controls

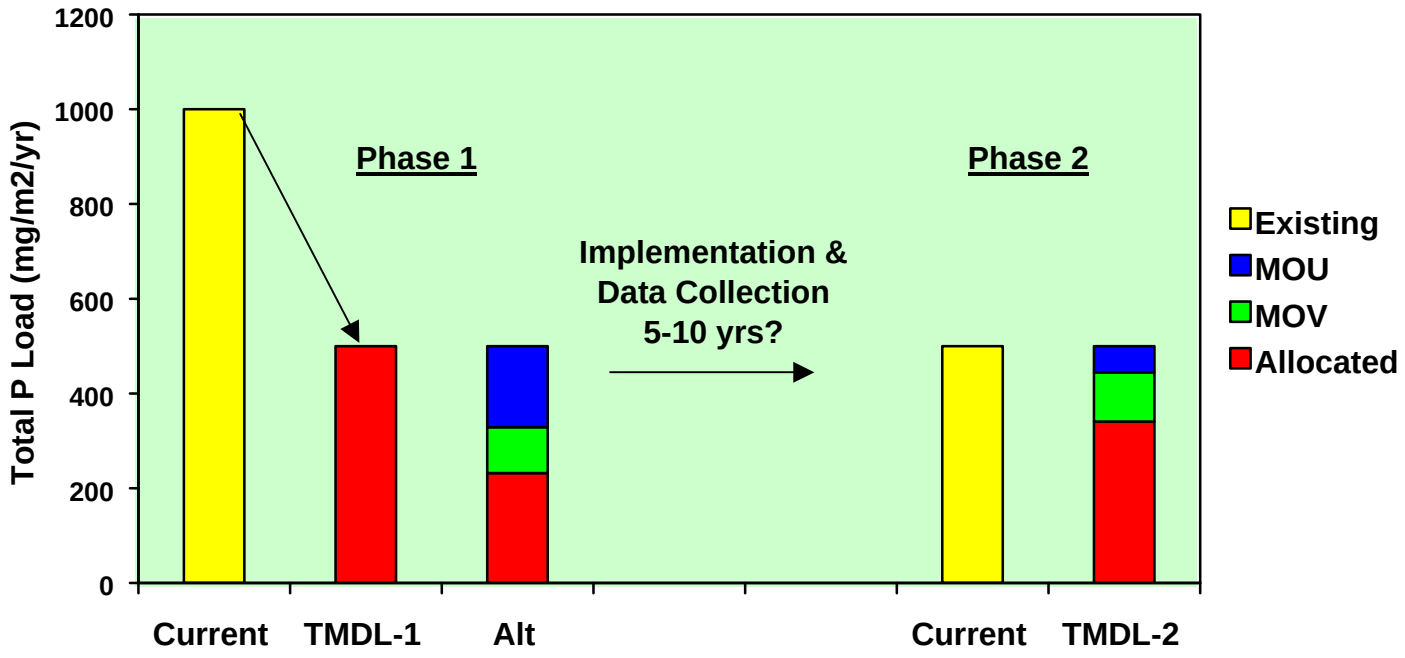
Monitor Results

Objectives Achieved ?



~ 5-10 years?

Phased Approach to T M D L Implementation



Confidence Level	50%	90%		90%
Compliance Freq	50%	90%	Uncertainty Reduction	90%
Model Error Std Dev	0.4	0.4	→	0.1
Temporal Std Dev	0.2	0.2		0.2
Allocated Load	500	232		340
Cum Load Reduction	50%	77%		66%