Presentation to

Lake Okeechobee Technical Advisory Committee

W. Walker

April 6, 2000

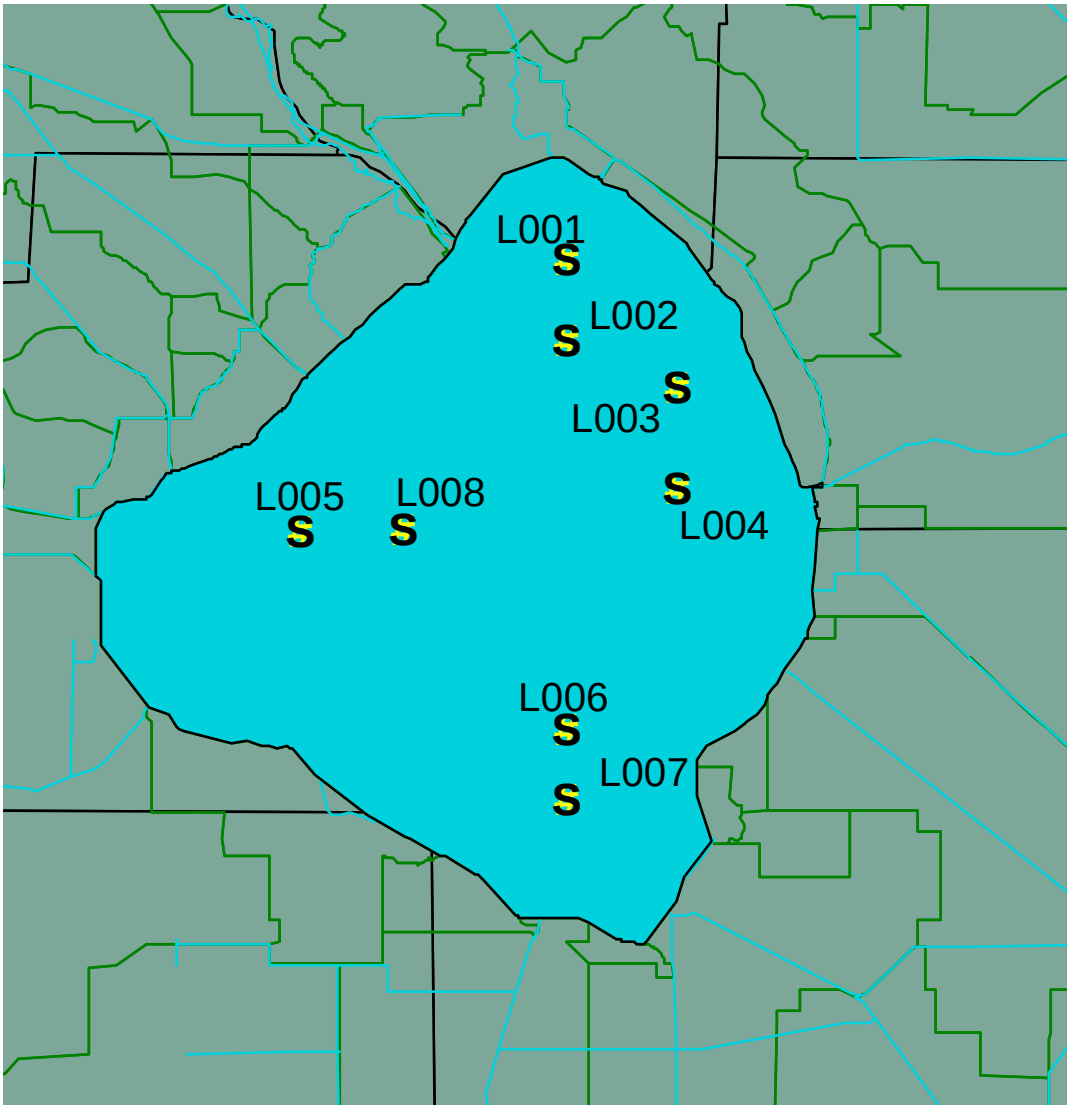
Water Quality Data Analysis

- **Long-Term Trends**
- **Spatial Variations**
- **Bloom Frequency vs. Total P**

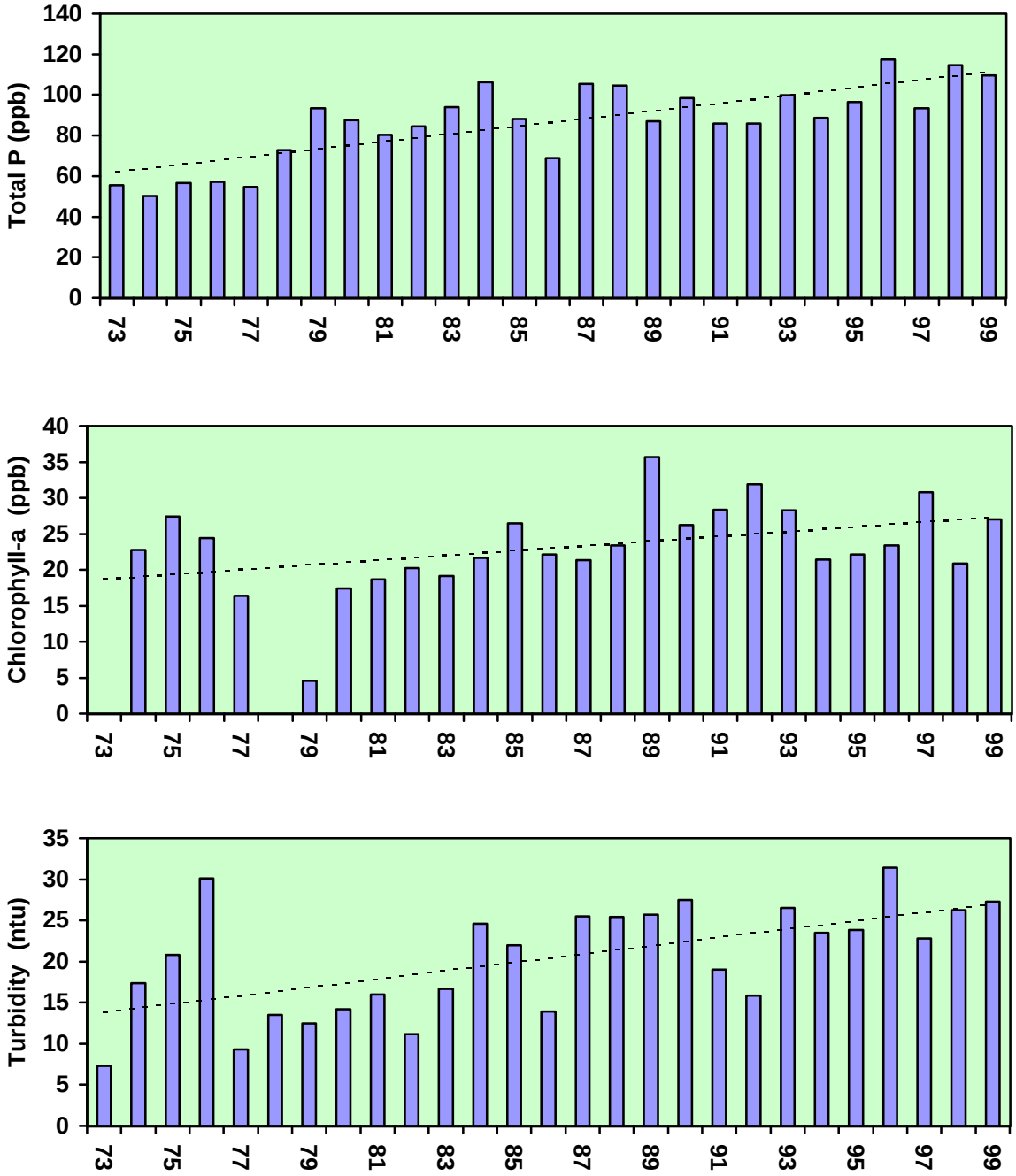
P Mass Balance Modeling

- **Mass-Balance Data Analysis**
- **Model Formulation**
- **Calibration**
- **TMDL Applications**

Long-Term Monitoring Stations

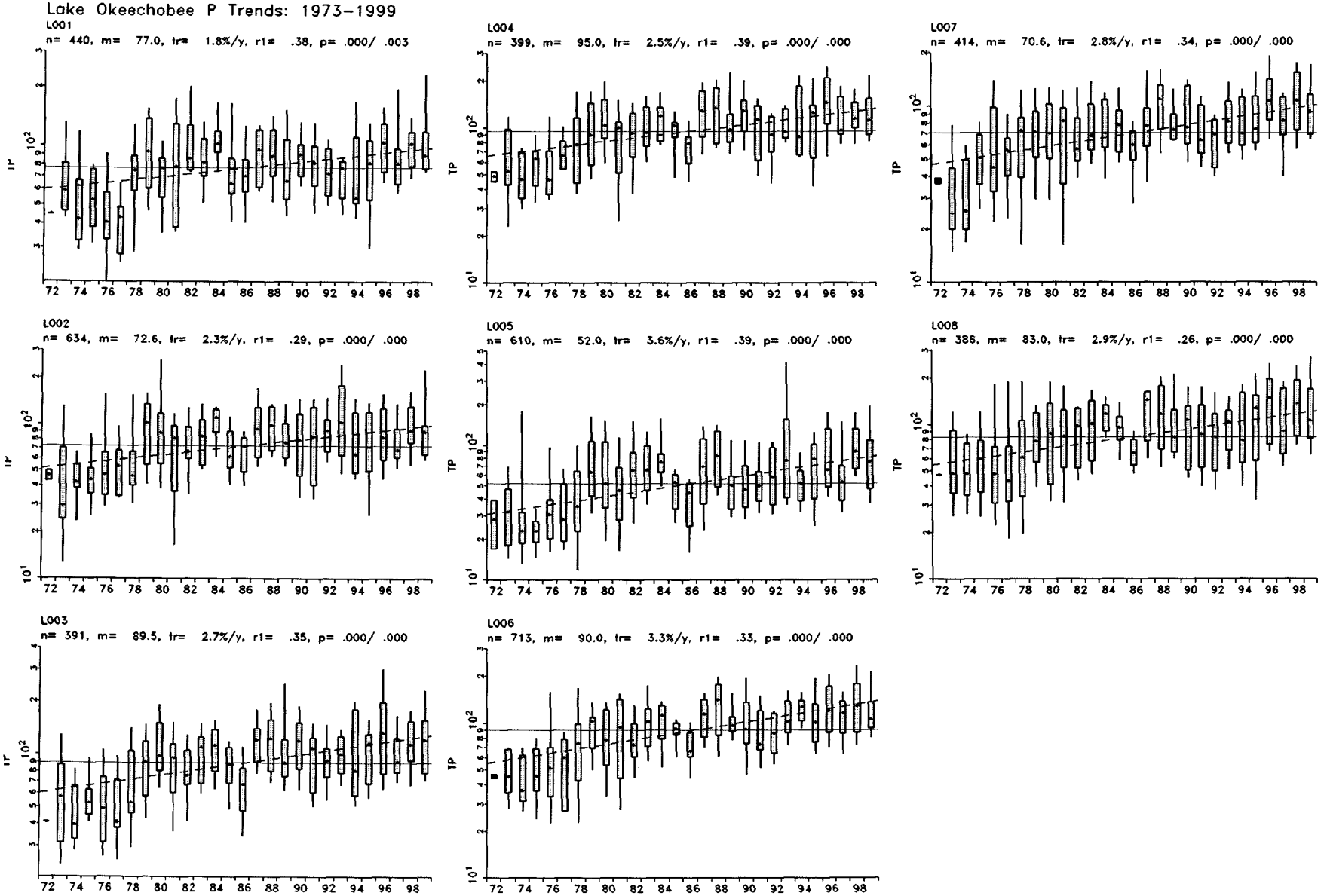


Long-Term Water-Quality Trends at Open-Lake Stations

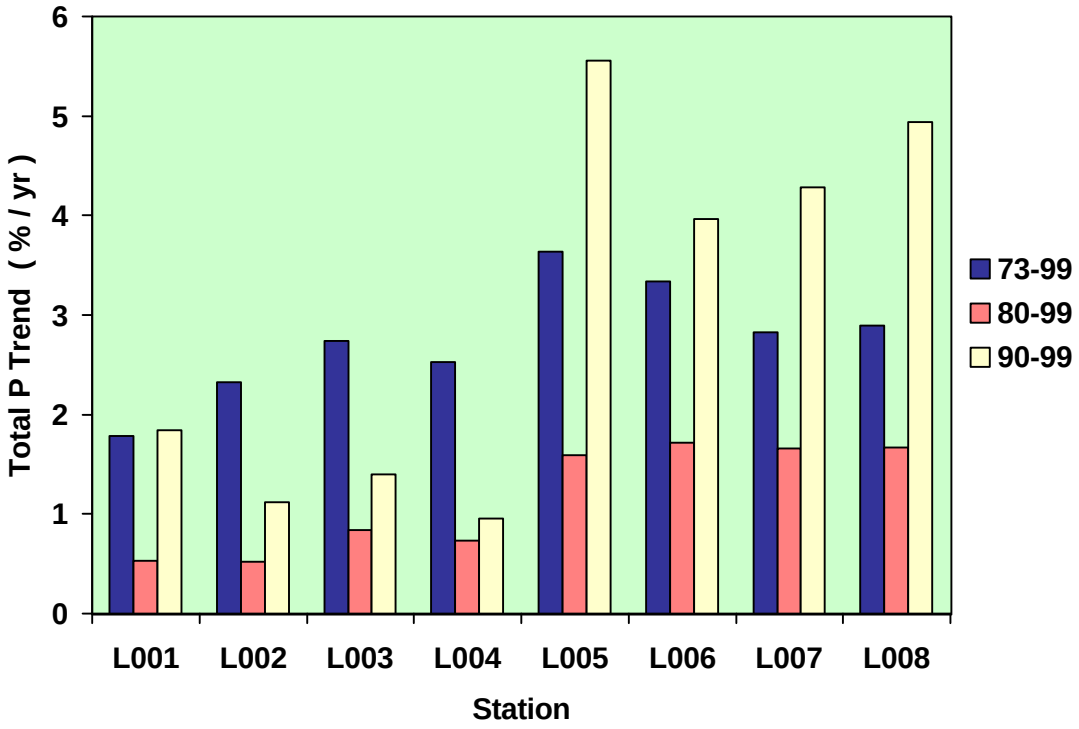


Median Values by Station & Year

Variable:	TP	Chl-a	Turbidity
Trend (%/yr):	2.1%	1.5%	2.3%


Lake Okeechobee P Trends: 1973–1999
L001
n= 440, m= 77.0, tr= 1.8%/y, r1= .38, p= .000/ .003
L004
n= 399, m= 95.0, tr= 2.5%/y, r1= .39, p= .000/ .000
L007
n= 414, m= 70.6, tr= 2.8%/y, r1= .34, p= .000/ .000
L002
n= 634, m= 72.6, tr= 2.3%/y, r1= .29, p= .000/ .000
L005
n= 610, m= 52.0, tr= 3.6%/y, r1= .39, p= .000/ .000
L008
n= 386, m= 83.0, tr= 2.9%/y, r1= .26, p= .000/ .000
L003
n= 391, m= 89.5, tr= 2.7%/y, r1= .35, p= .000/ .000
L006
n= 713, m= 90.0, tr= 3.3%/y, r1= .33, p= .000/ .000
TP
72 74 76 78 80 82 84 86 88 90 92 94 96 98

Long-Term Phosphorus Trends
Lake Okeechobee Open-Lake Stations



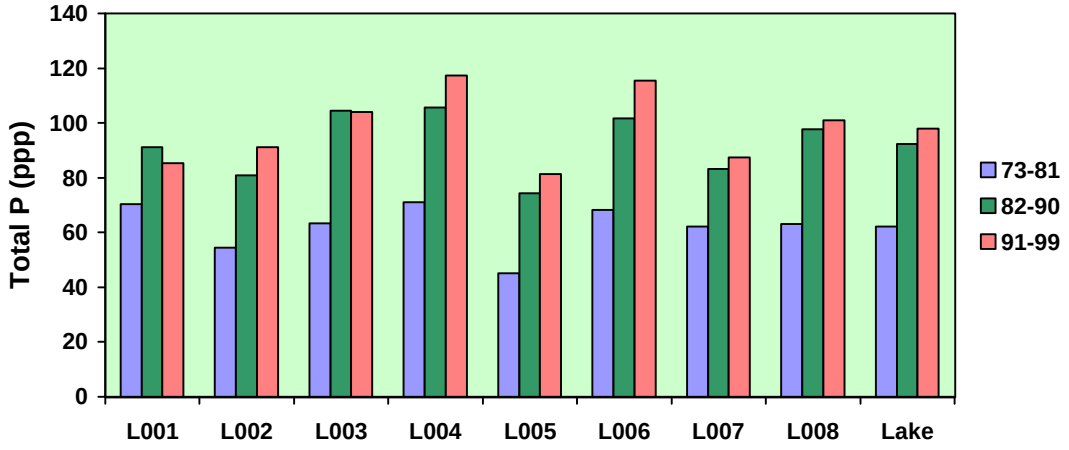
North ---------->South **Central**

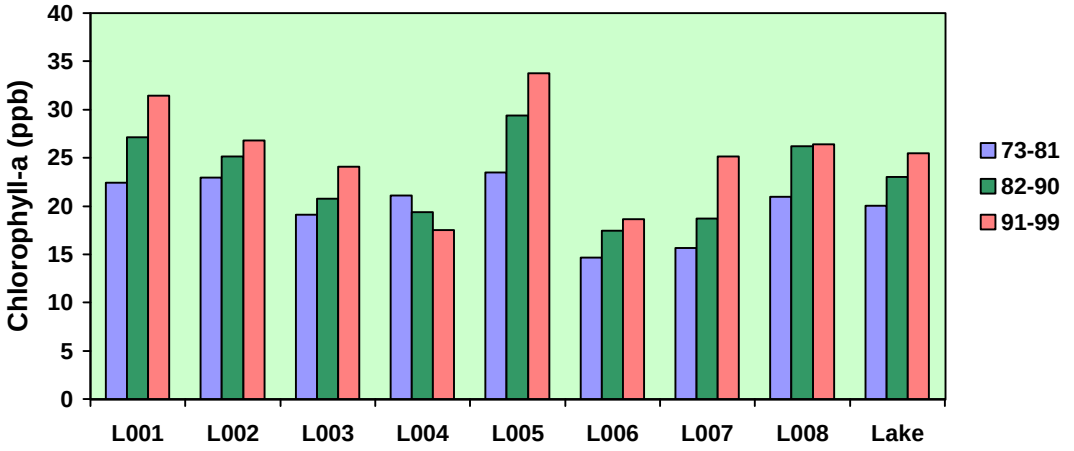
Trend (%/yr)

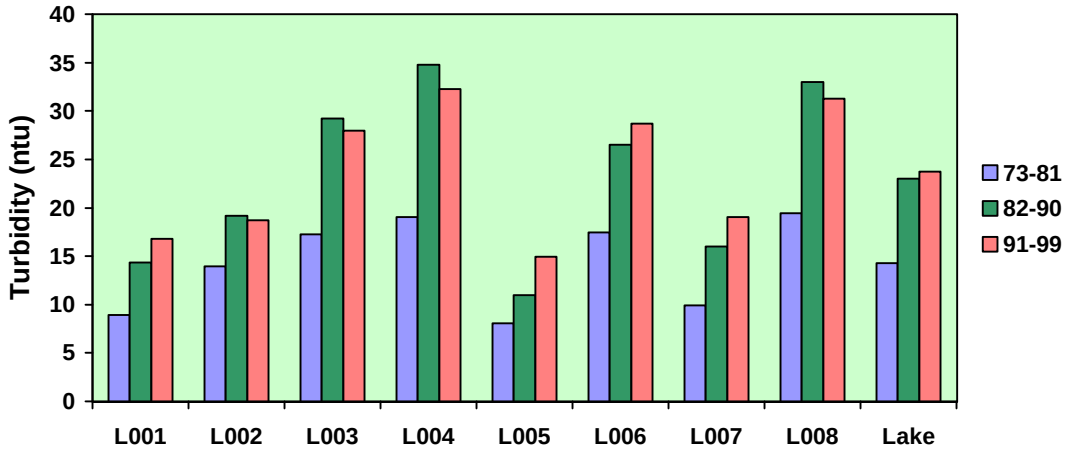
Station	73-99		80-99		90-99	
L001	1.8	*	0.5		1.8	
L002	2.3	*	0.5		1.1	
L003	2.7	*	0.8		1.4	
L004	2.5	*	0.7		1.0	
L005	3.6	*	1.6		5.6	*
L006	3.3	*	1.7	*	4.0	*
L007	2.8	*	1.7	*	4.3	*
L008	2.9	*	1.7	*	4.9	*

* significant at p < .05, seasonal kendall test

Spatial & Temporal Water Quality Variations at Open Lake Stations



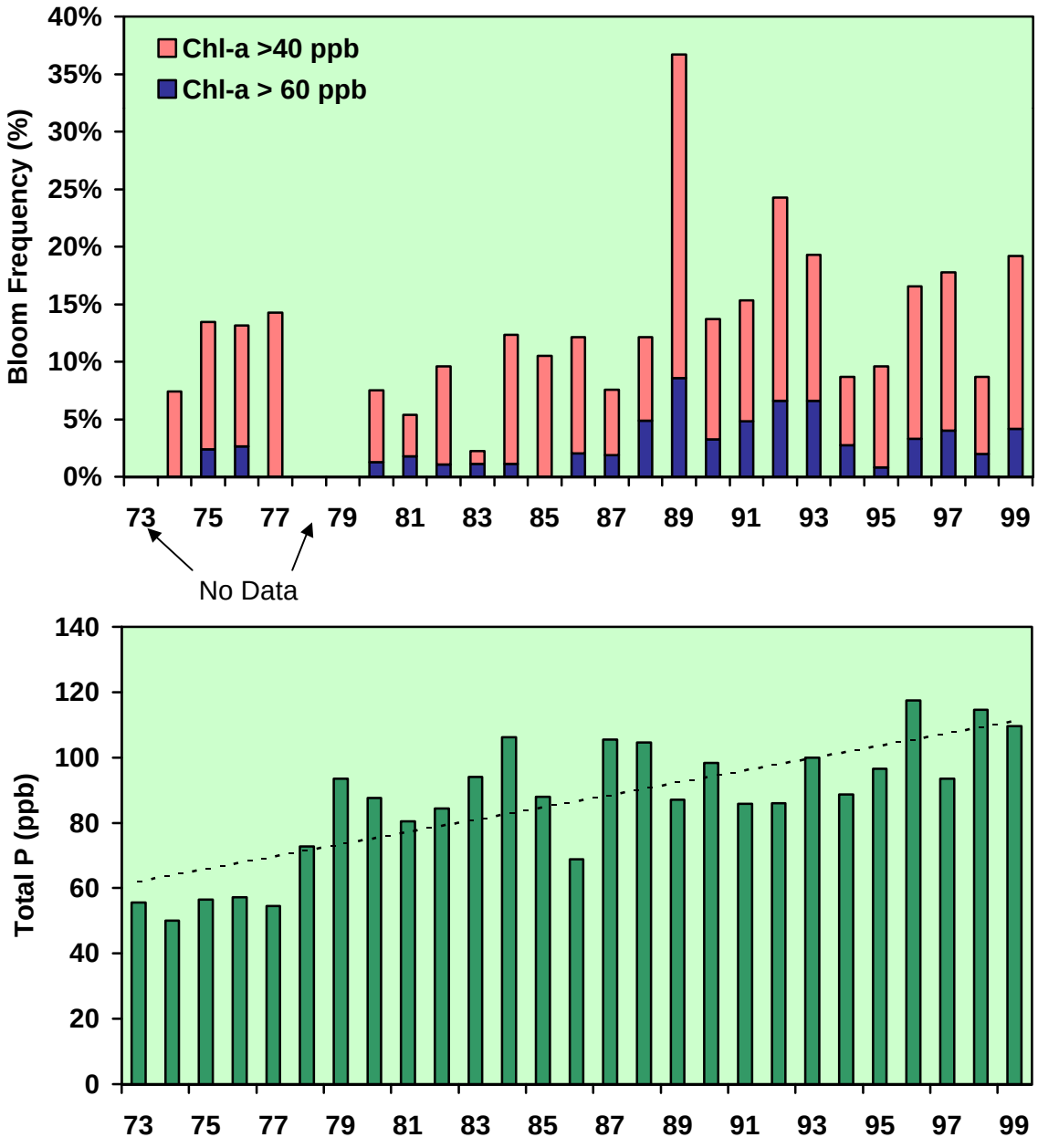




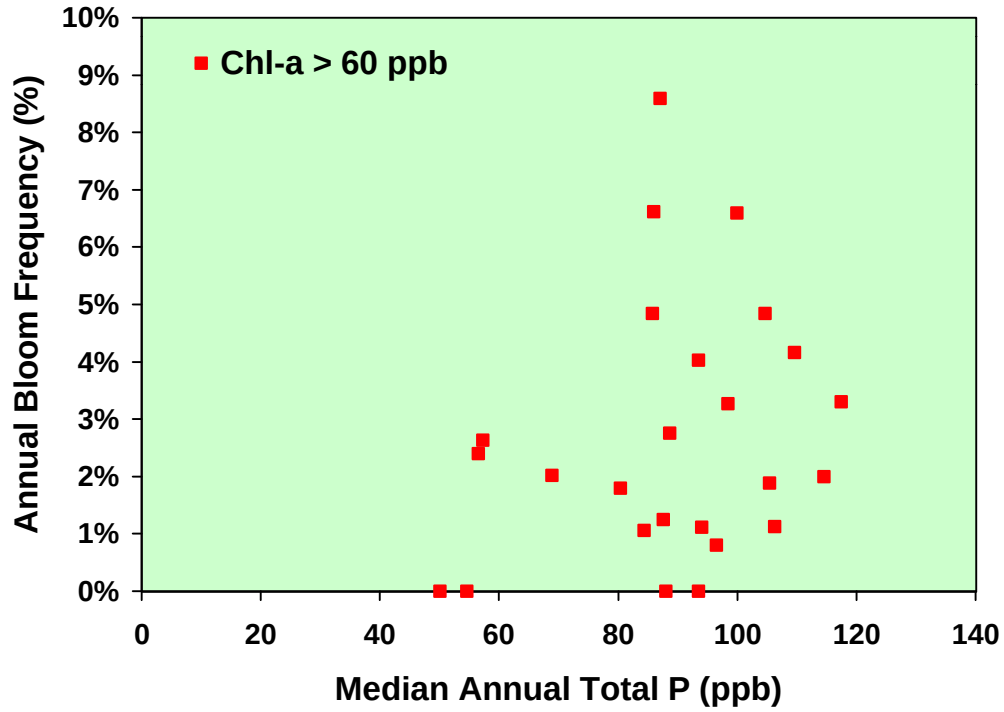
North ---------- West --- South -- West Central

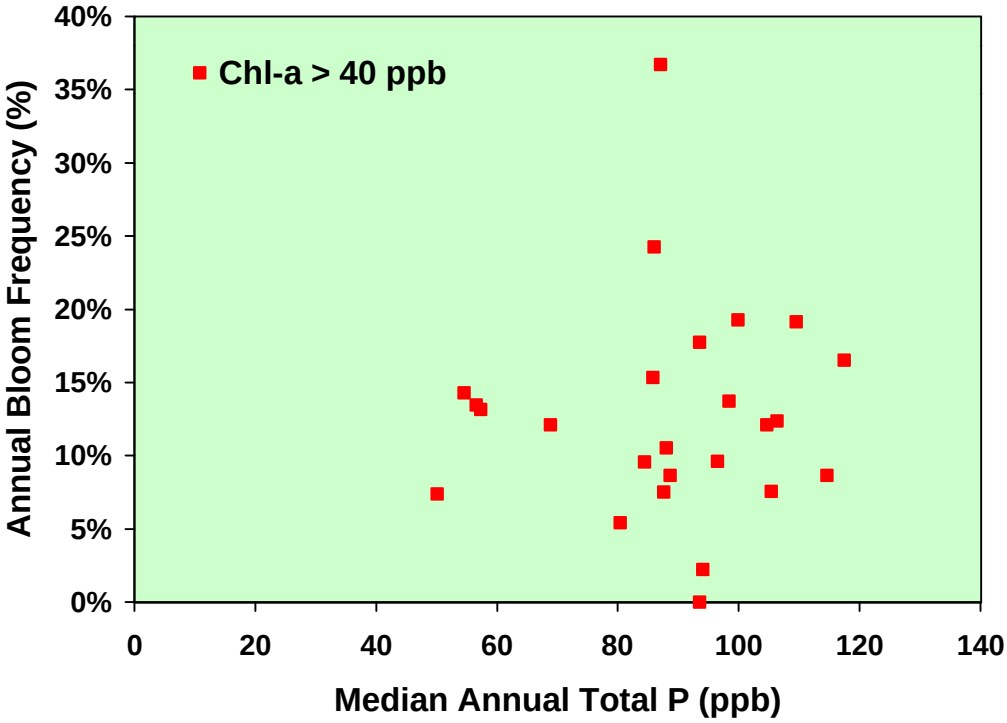
Median Concentrations vs. Station & Time Interval

Long-Term Trends in Algal Bloom Frequency & Total P

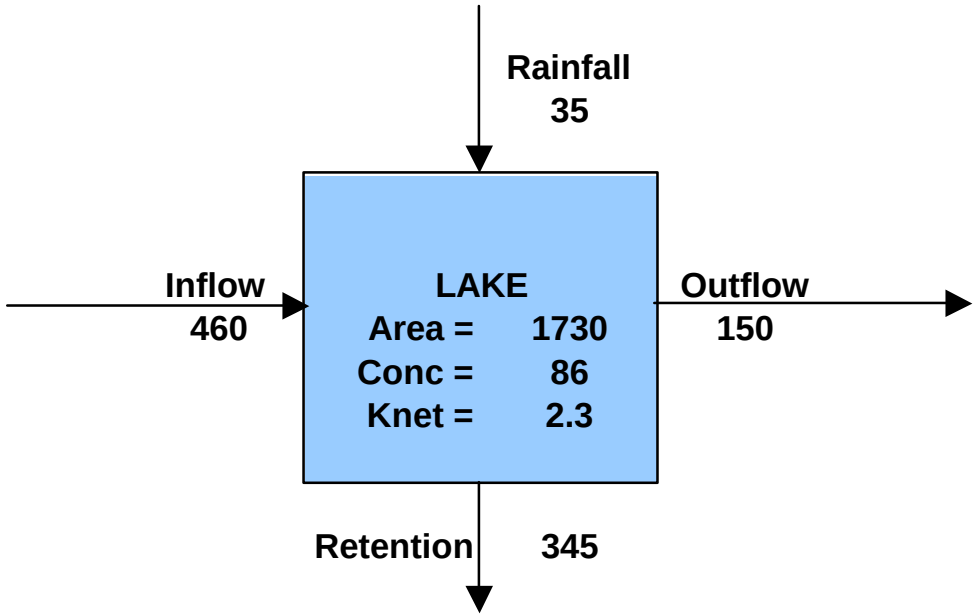


Algal Bloom Frequencies vs. Total P in Open Lake

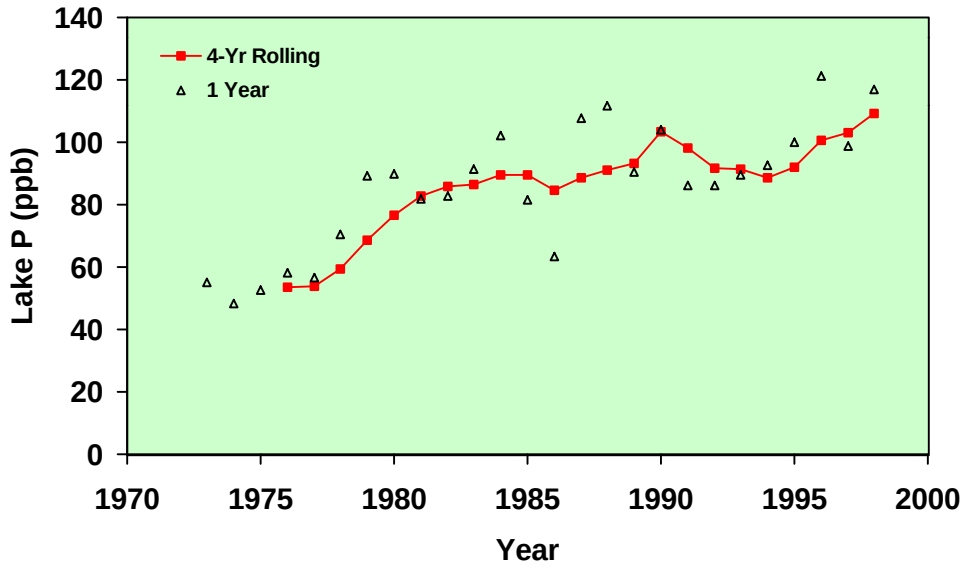


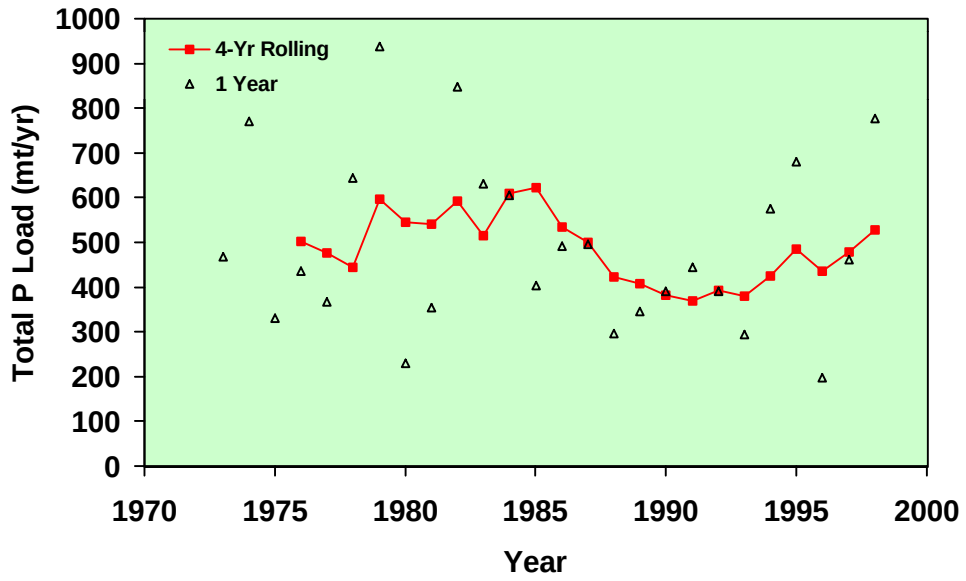


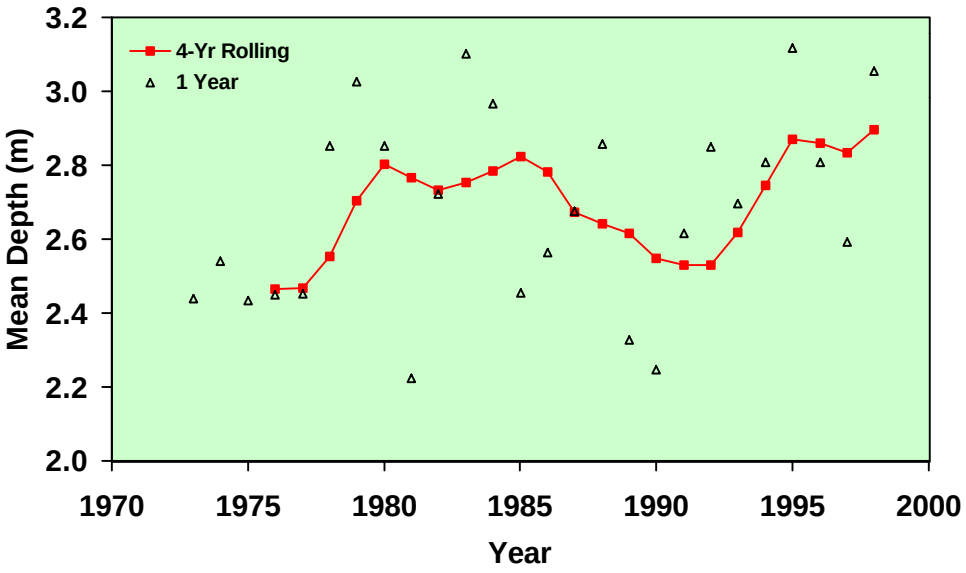
Phosphorus Mass Balance
1973-1998 Average

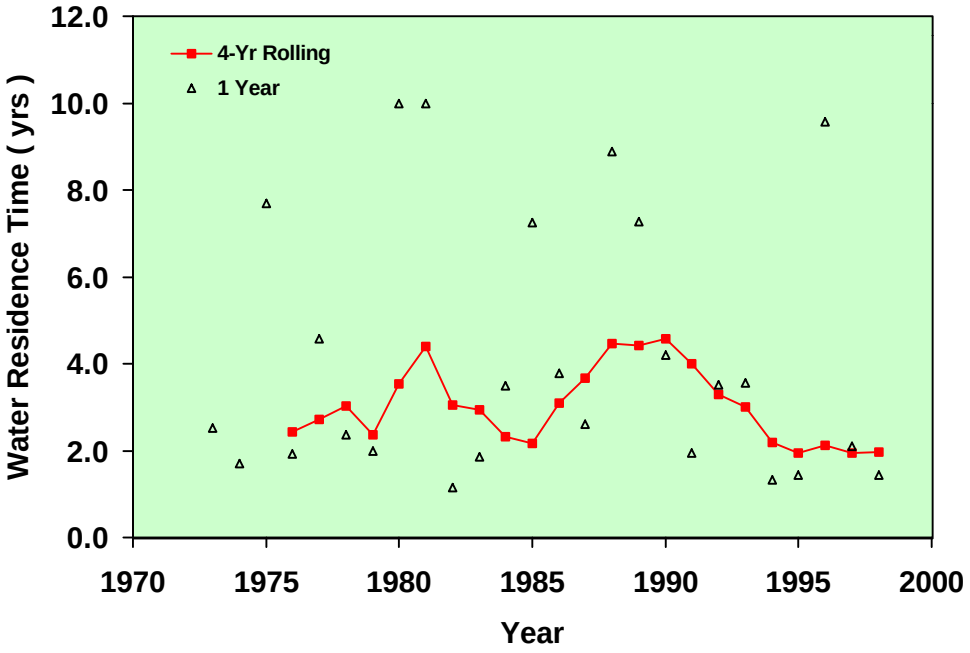


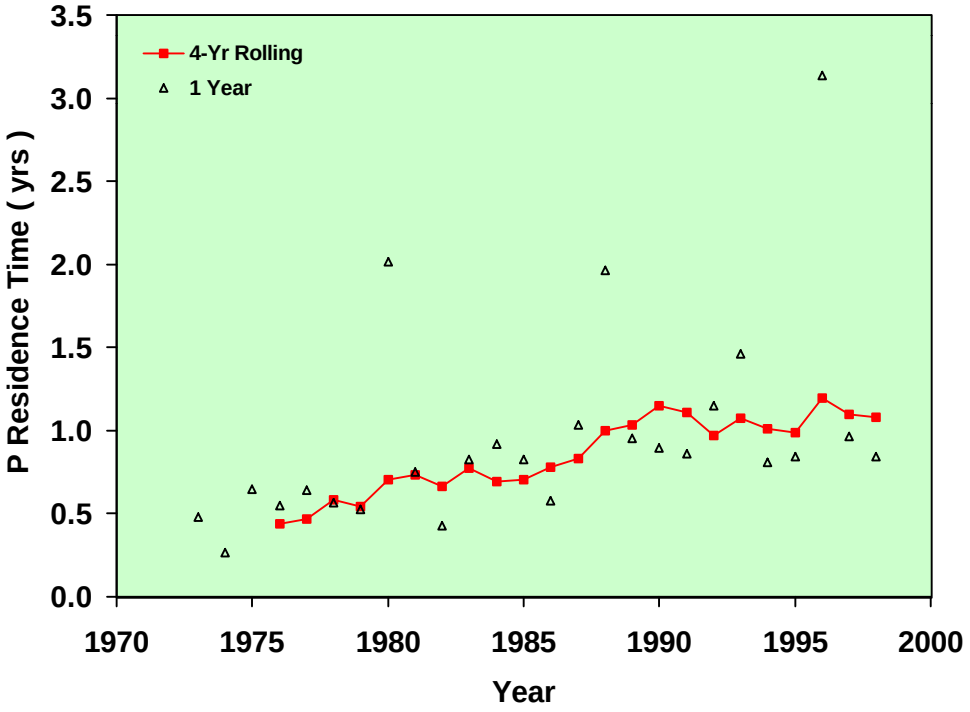
Phosphorus Fluxes in metric tons / year
Areas in 1000 acres
Concentrations in ppb
Settling Rates in m/yr


4-Yr Rolling
1 Year
Lake P (ppb)
140
120
100
80
60
40
20
0
1970
1975
1980
1985
1990
1995
2000
Year

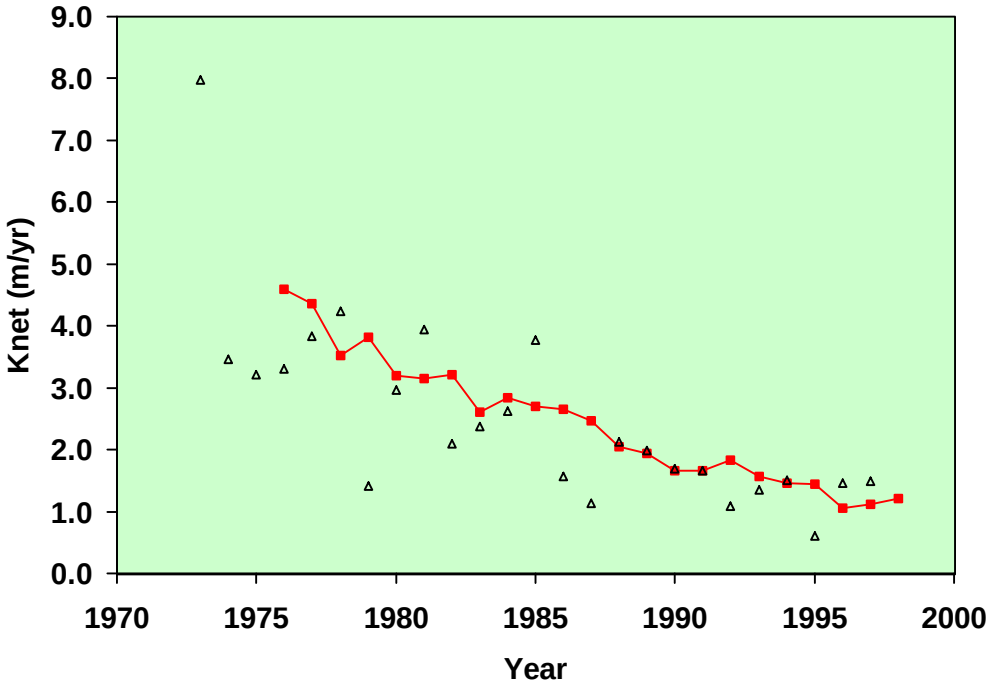

4-Yr Rolling
1 Year
Total P Load (mt/yr)
1000
900
800
700
600
500
400
300
200
100
0
1970
1975
1980
1985
1990
1995
2000
Year

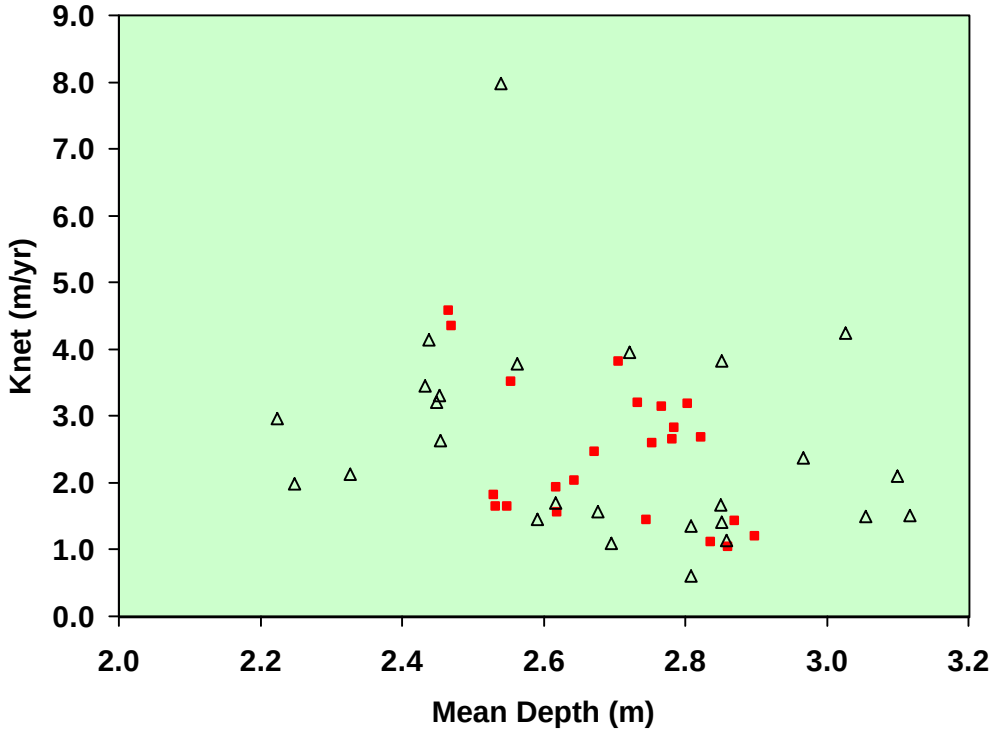

4-Yr Rolling
1 Year
Mean Depth (m)
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1970
1975
1980
1985
1990
1995
2000
Year


4-Yr Rolling
1 Year
Water Residence Time (yrs)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1970
1975
1980
1985
1990
1995
2000
Year

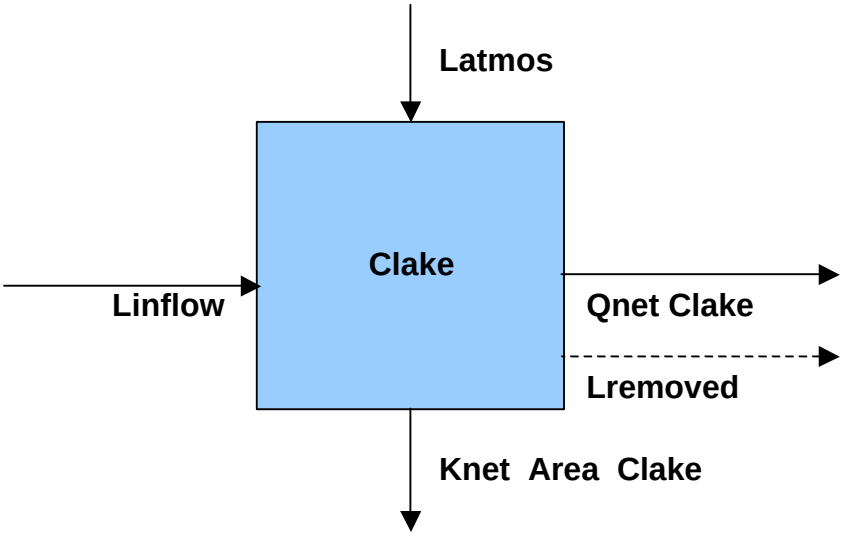

4-Yr Rolling
1 Year
P Residence Time (yrs)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1970
1975
1980
1985
1990
1995
2000
Year

Net Settling Rate **1 Year & 4-Year Rolling Averages**





Lake Okeechobee Steady-State P Balance Model



Water Balance:

$$Qnet = Qout + dV/dt = Qin + Qprec - Qevap$$

Mass Balance:

$$Linflow + Latmos - Lremoved = Qnet\ Clake + Knet\ Area\ Clake$$

TMDL Calculation:

$$TMDL = Qnet\ Ctarget + Knet\ Area\ Ctarget$$
$$= Linflow + Latmos - Lremoved$$
$$Linflow = TMDL - Latmos + Lremoved$$

Model Calibration to 4-Year Rolling Averages, 1973 - 1998:

$Knet = 4.76\ exp\ [\ -.063\ (\ Year - 1975\ )\ ]$ $R^2 = 0.97$

$Clake = Total\ Load\ /\ (\ Qnet + Knet\ Area\ )$ $R^2 = 0.90$

Hydrologic Conditions for TMDL Calculations (1973-1998 Means):

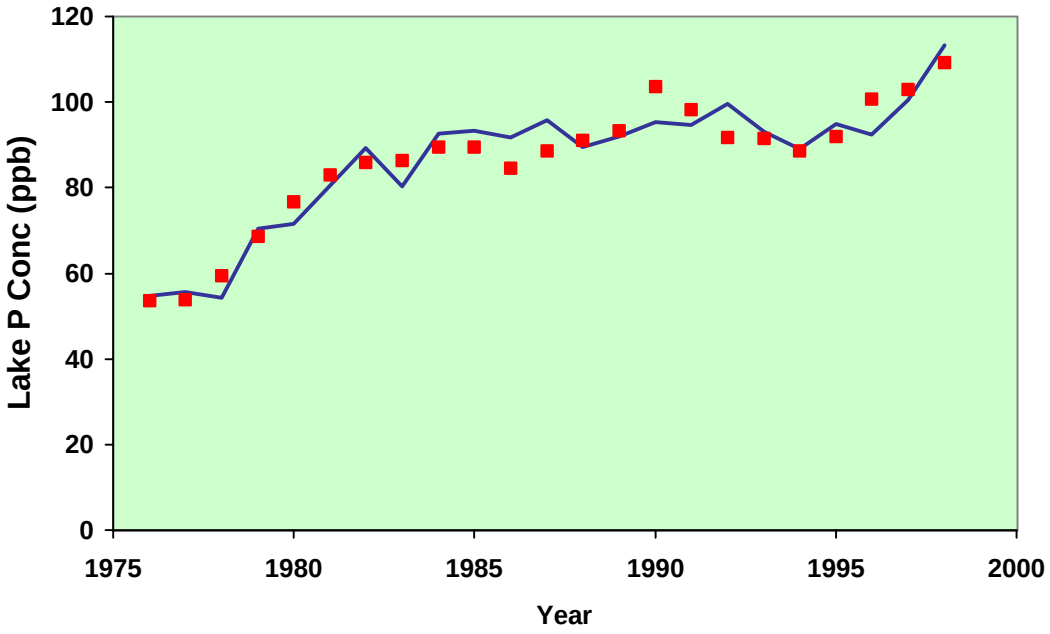
Qnet = 1751 hm^3/yr

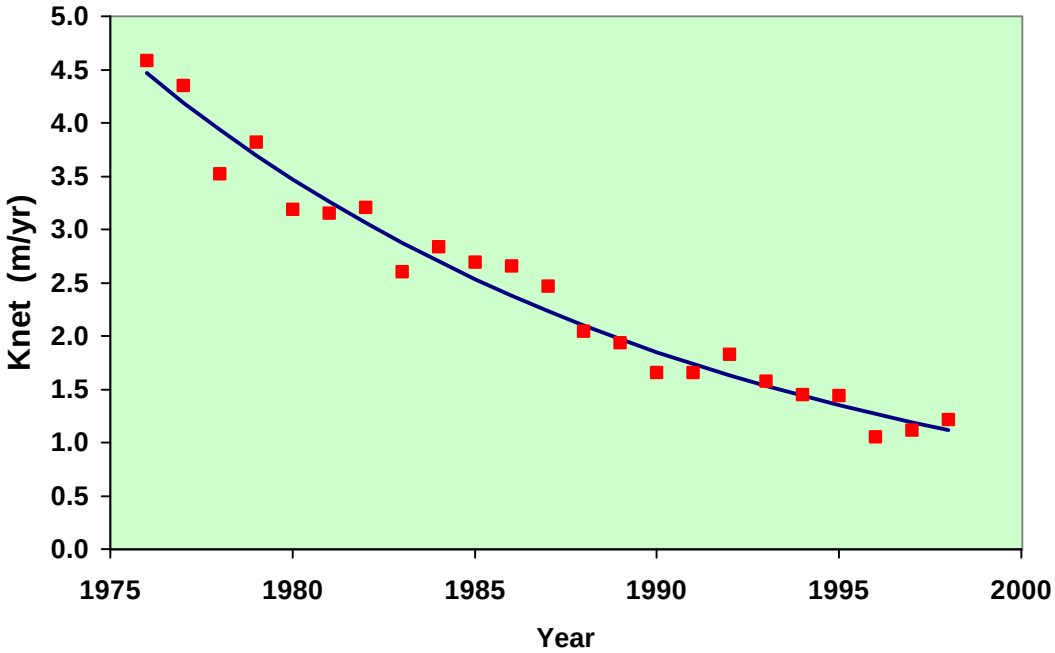
Area = 1730 km2

Lake Okeechobee Phosphorus Balance Model
Four-year Rolling Averages

Model: Knet = 4.76 exp [-.063 (Year - 1975)] R^2 = 0.97

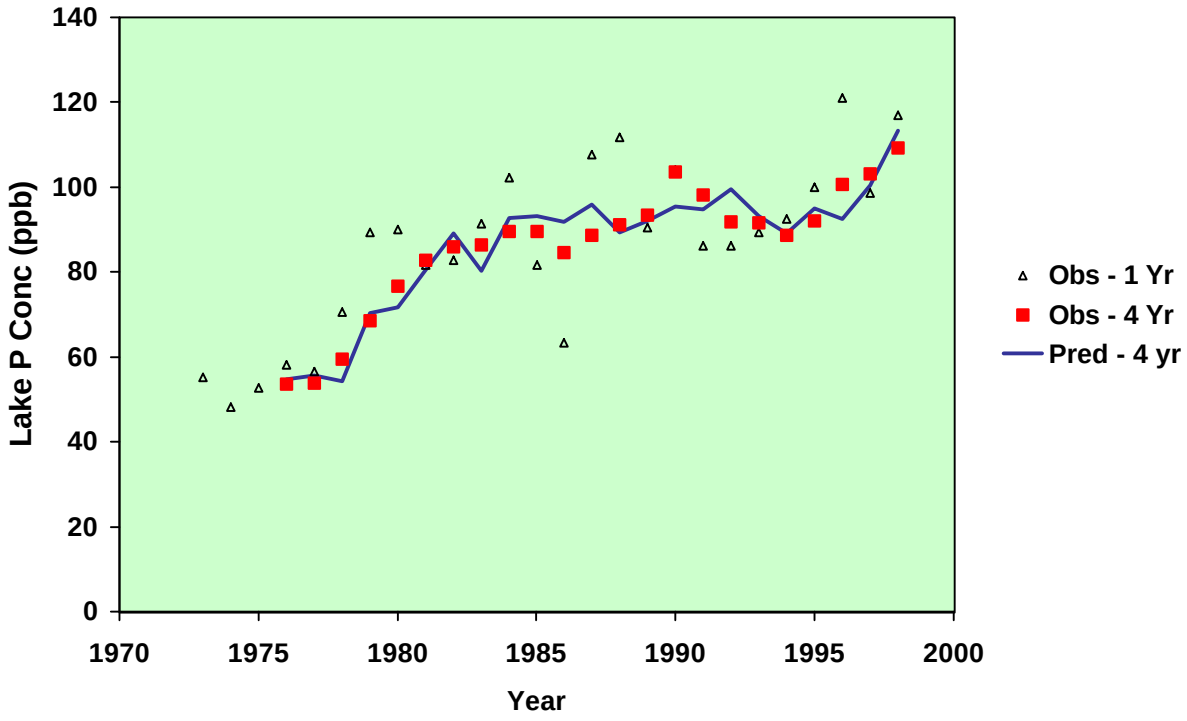
Clake = Total Load / (Qnet + Knet Area) R^2 = 0.90

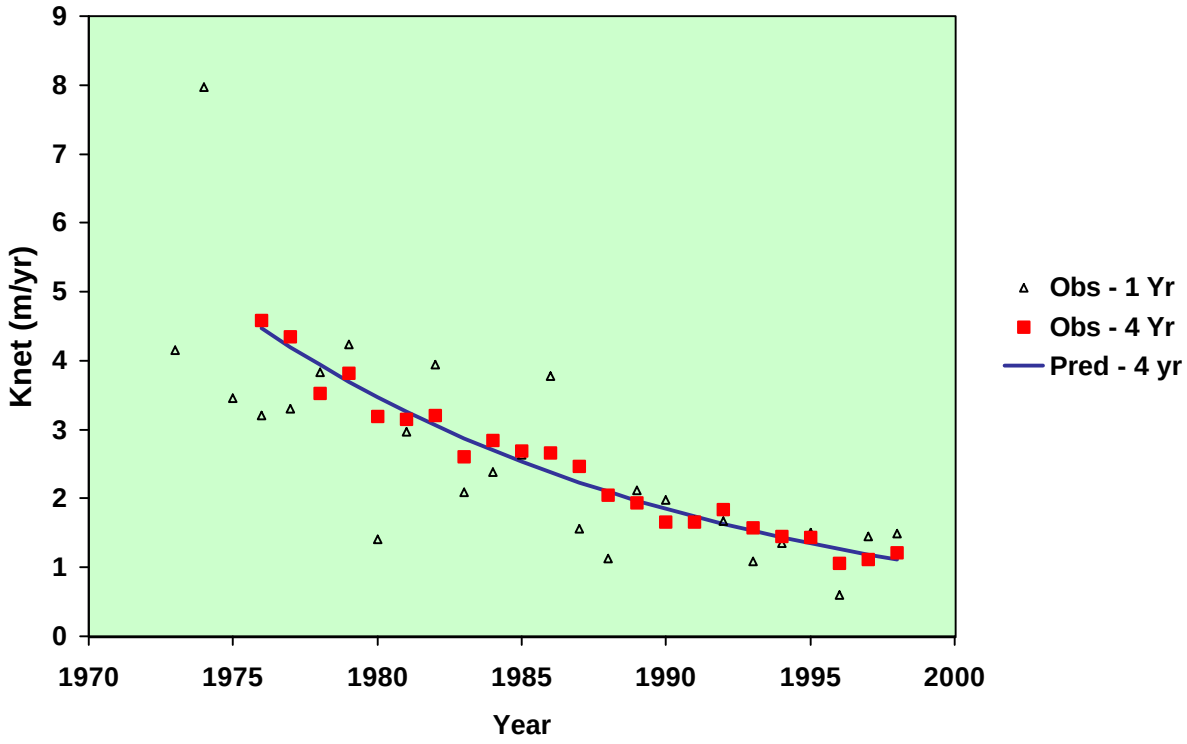




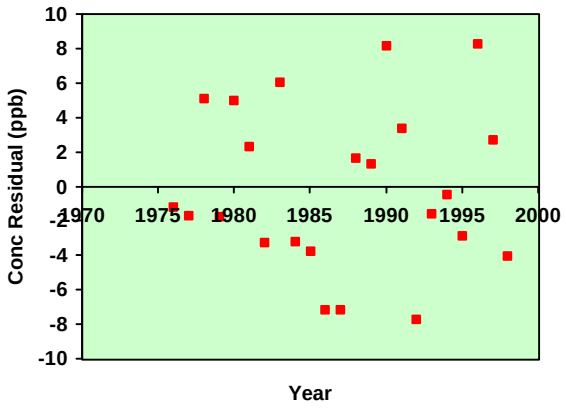
Lake Okeechobee Phosphorus Balance Model

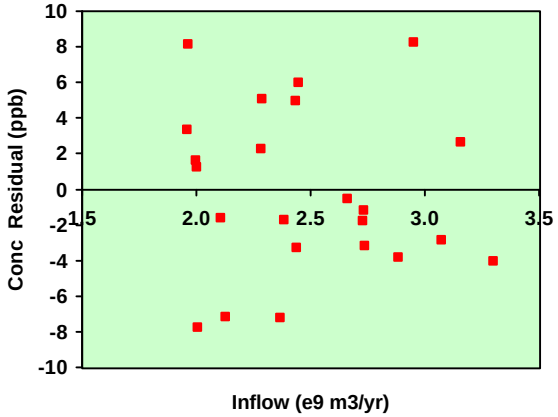
One-Year & Four-Year Rolling Averages

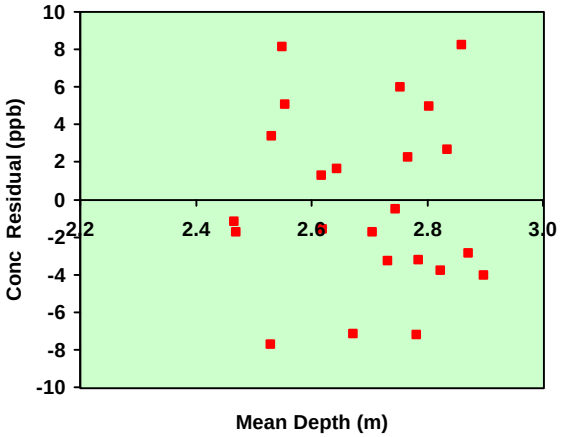


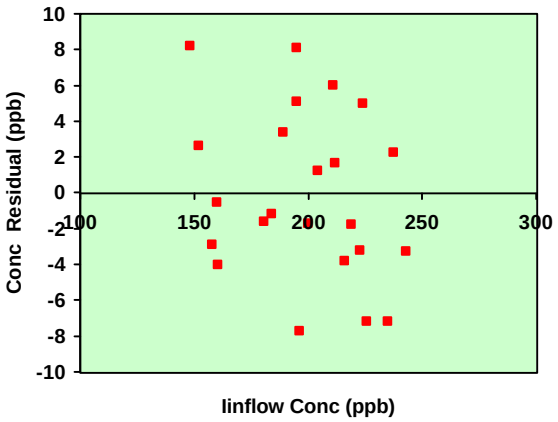


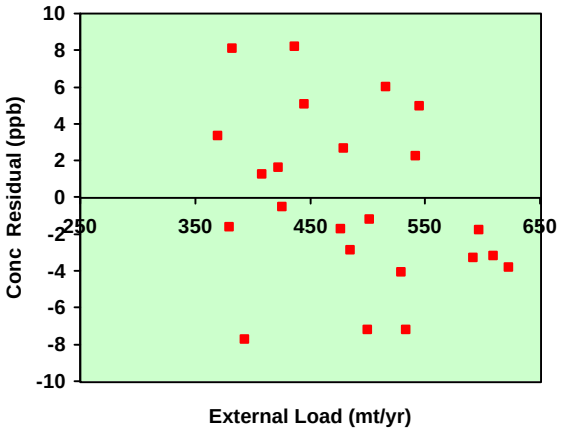
Residuals Plots **Observed - Predicted Concs** **4-Year Rolling Averages**

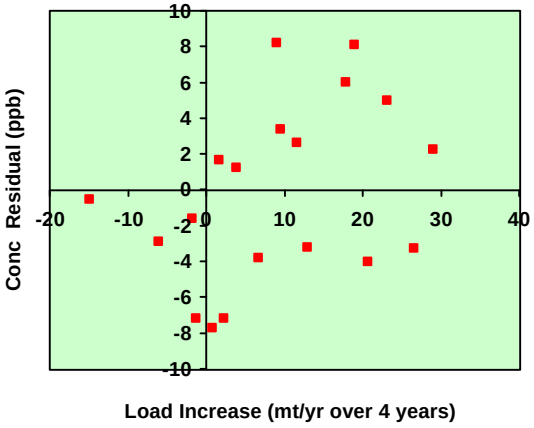




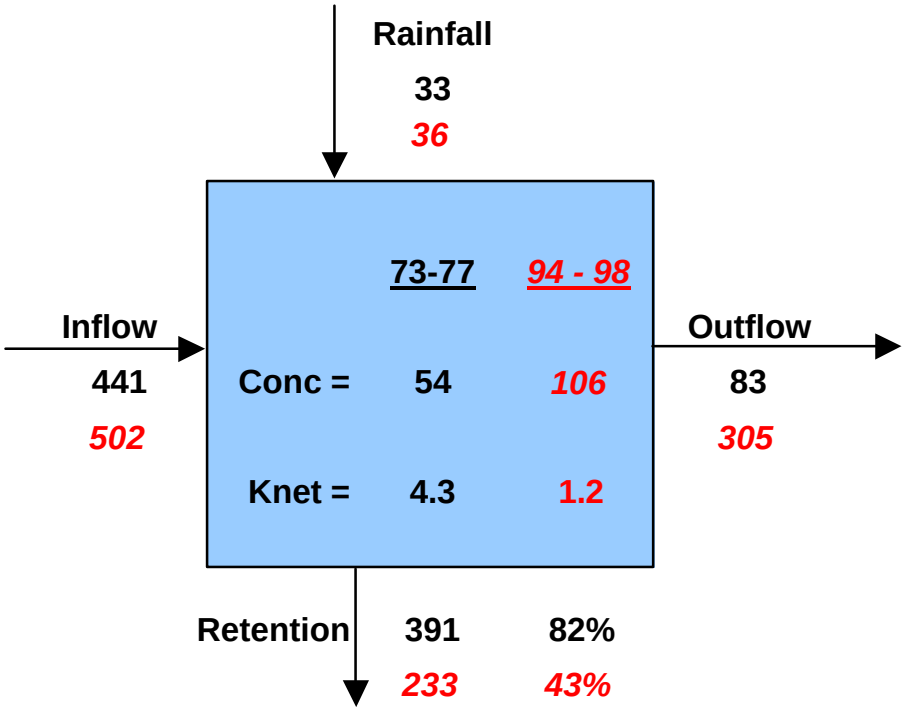








Phosphorus Mass Balances
Historical Conditions



Phosphorus Loads in metric tons / year

Concentrations in ppb

Settling Rates in m/yr

Lake Okeechobee P Balance Results

Net Settling Rate Decreasing @ ~ 6% / year

- From 4.3 m/yr in 1973-1977 to 1.2 m/yr in 1994-1998
- Model residuals independent of depth, flow, & load
- Explains 90% of variance in 4-yr rolling average conc
- Implied time scales of sediment response:

Half-life (50% Response)	11 years
90% Response	36 years

Potential Causal Factors:

- Gradual accumulation & recycling of P
- Decrease in lake area caused by dike
- Decrease in calcium levels (?)
- Recycling aggravated by increased water depths
  - wave action - resuspension
  - intermittent stratification &O2 loss (?)
  - increased light-limitation of algal growth
  - loss of rooted vegetation
  - increased horizontal transport

Reversible?

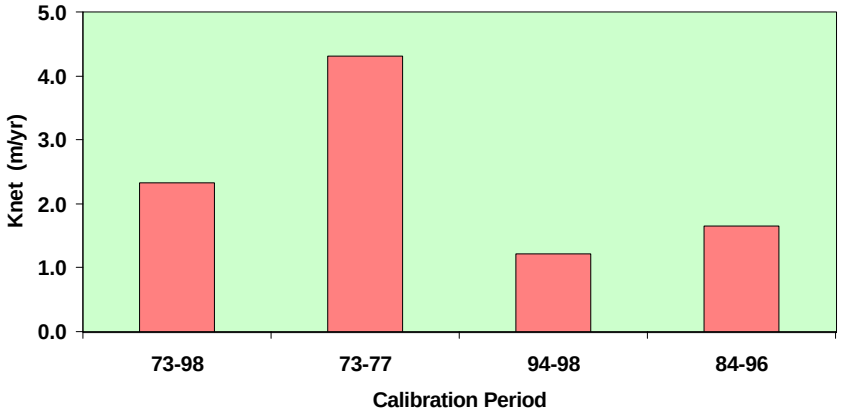
- Decrease external P load
- Decrease water depth
- Remove sediment
- Re-establish vegetation

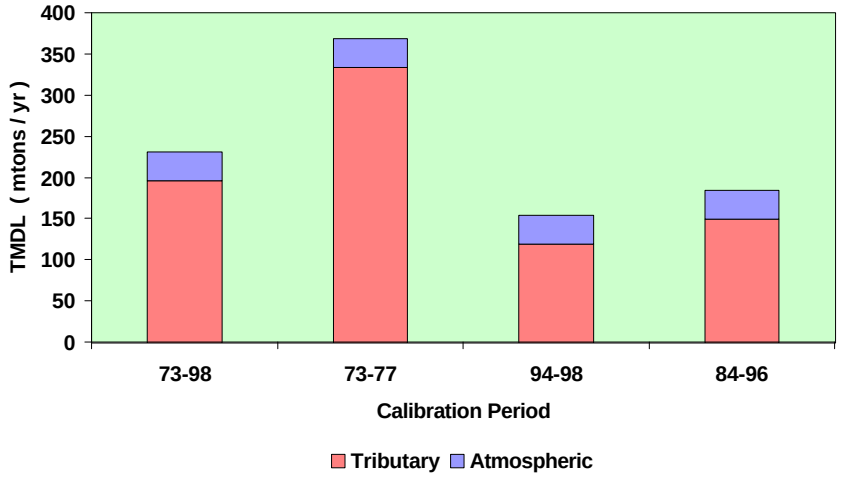
Conservative Assumption for TMDL Calculation:

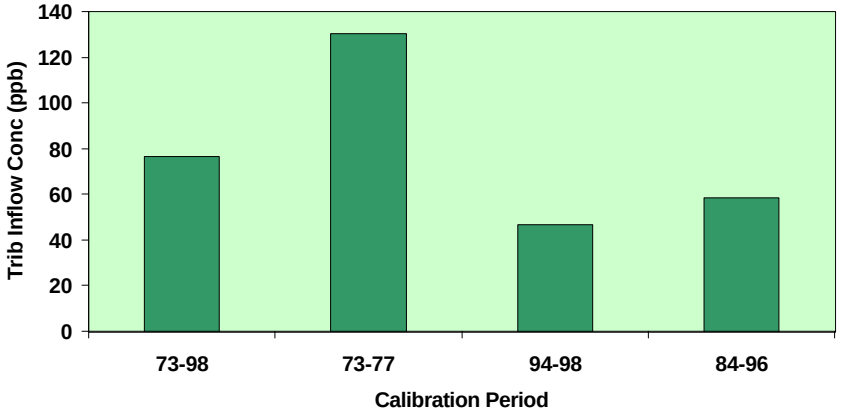
- Use 1994-1998 settling rate
- Steady-State Settling Rate may be lower
- Effect of changes in water level?

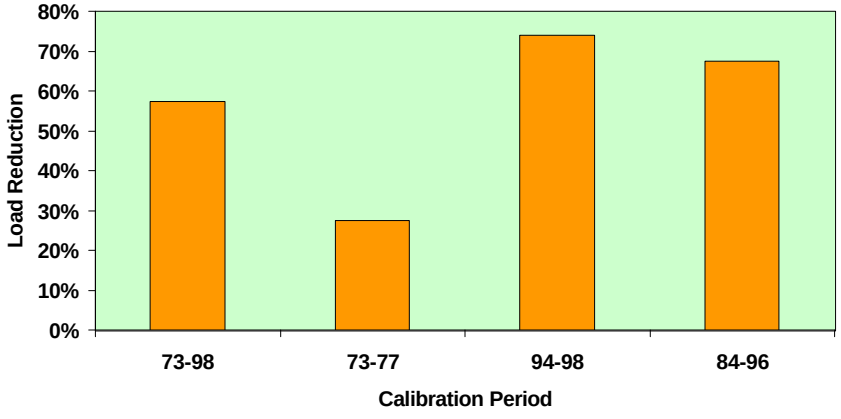
Lake Okeechobee TMDL Calculation

		Calibration Period			
Variable	**Units**	**73-98**	**73-77**	**94-98**	**84-96**
Knet	m/yr	2.32	4.31	1.22	1.65
Design Conditions (1973 - 1999) Means					
Qnet	hm3/yr	1750.6	1750.6	1750.6	1750.6
Qin	hm3/yr	2564.5	2564.5	2564.5	2564.5
Area	km2	1729.8	1729.8	1729.8	1729.8
Volume	e9m3	4.7	4.7	4.7	4.7
Zmean	m	2.70	2.70	2.70	2.70
Qs	m/yr	1.01	1.01	1.01	1.01
Atmos P Load	mg/m2-yr	20	20	20	20
Atmos P Load	mt/yr	34.6	34.6	34.6	34.6
Historical Linflow	mt/yr	460.2	460.2	460.2	460.2
TMDL Calculations					
Lake Target Conc	ppb	40.0	40.0	40.0	40.0
Ltotal = TMDL	mt/yr	230.9	368.3	154.1	184.2
Latmos	mt/yr	34.60	34.6	34.6	34.6
Linflow	mt/yr	196.3	333.7	119.5	149.6
Cinflow	ppb	76.5	130.1	46.6	58.3
Loutflow	mt/yr	70.0	70.0	70.0	70.0
Load Reduction	mt/yr	263.9	126.5	340.7	310.6
Load Reduction	%	57%	27%	74%	67%
P Retention	mt/yr	161	298	84	114
WC P Res Time	years	0.81	0.51	1.21	1.01


5.0
4.0
3.0
2.0
1.0
0.0
Knet (m/yr)
73-98
73-77
94-98
84-96
Calibration Period

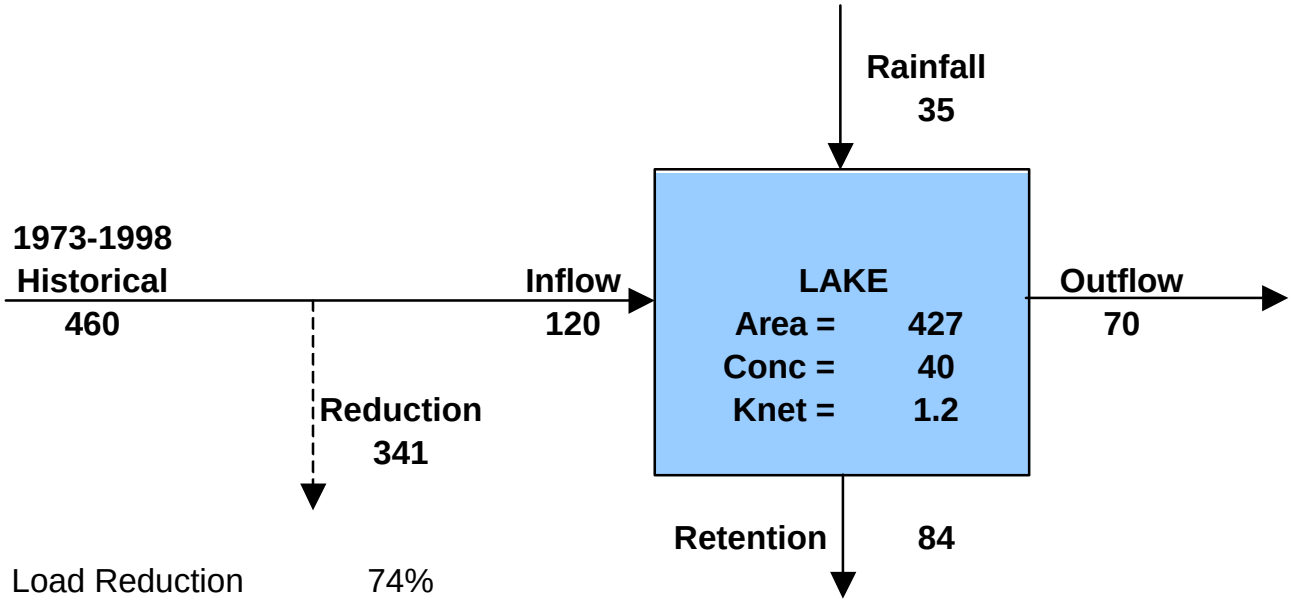

400
350
300
250
200
150
100
50
0
TMDL (mtons / yr)
73-98
73-77
94-98
84-96
Calibration Period
Tributary
Atmospheric


140
120
100
80
60
40
20
0
Trib Inflow Conc (ppb)
73-98
73-77
94-98
84-96
Calibration Period


80%
70%
60%
50%
40%
30%
20%
10%
0%
Load Reduction
73-98
73-77
94-98
84-96
Calibration Period

Phosphorus Mass Balance

TMDL - E X A M P L E



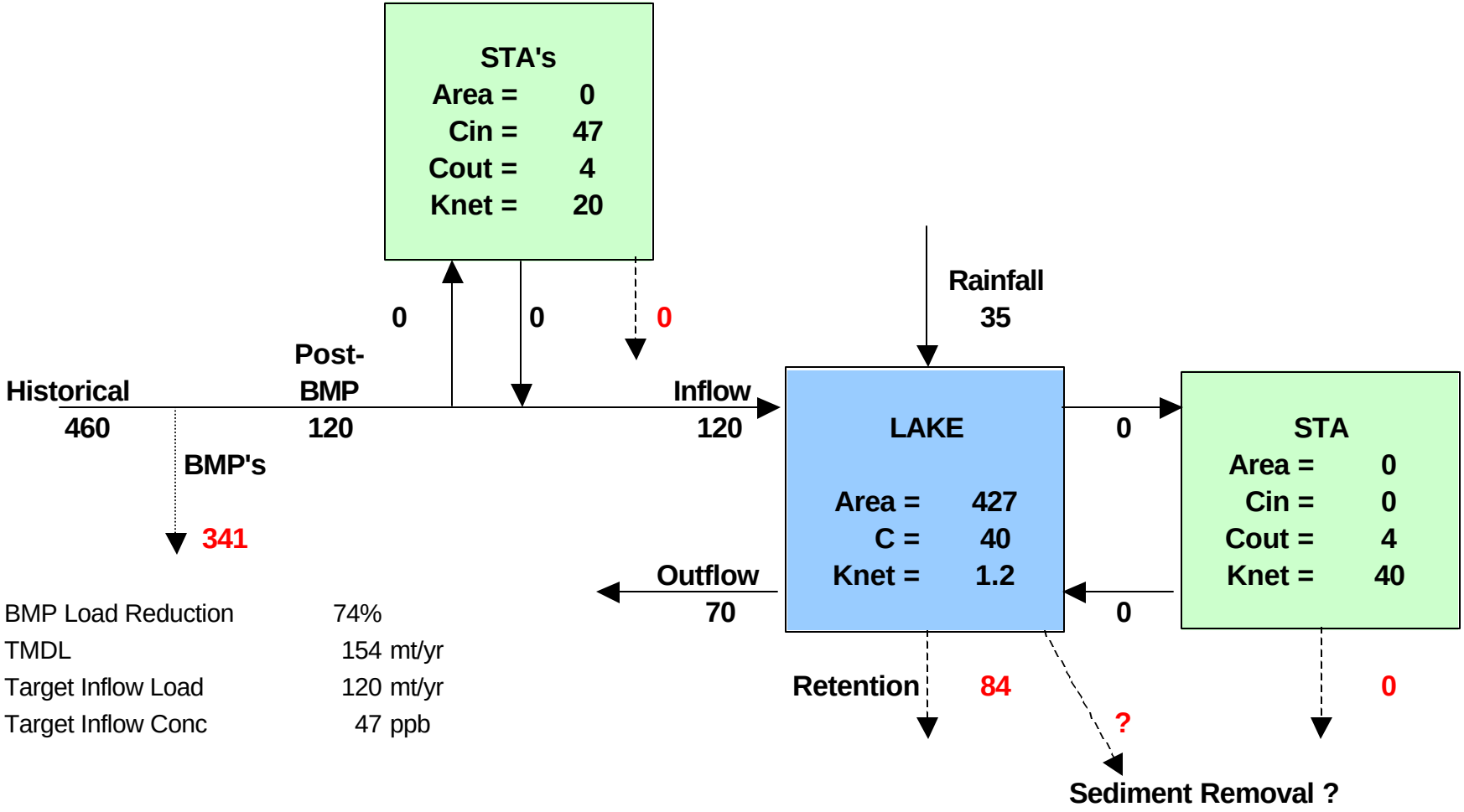
Load Reduction	74%	
TMDL	154	mt/yr
Target Inflow Load	120	mt/yr
Target Inflow Conc	47	ppb

Phosphorus Fluxes in metric tons / year, Areas in 1000 Acres, Concentrations in ppb

Settling Rate in m/yr, Calibrated to 1994-1998 Data

Phosphorus Mass Balance

TMDL with Controls - Example 1

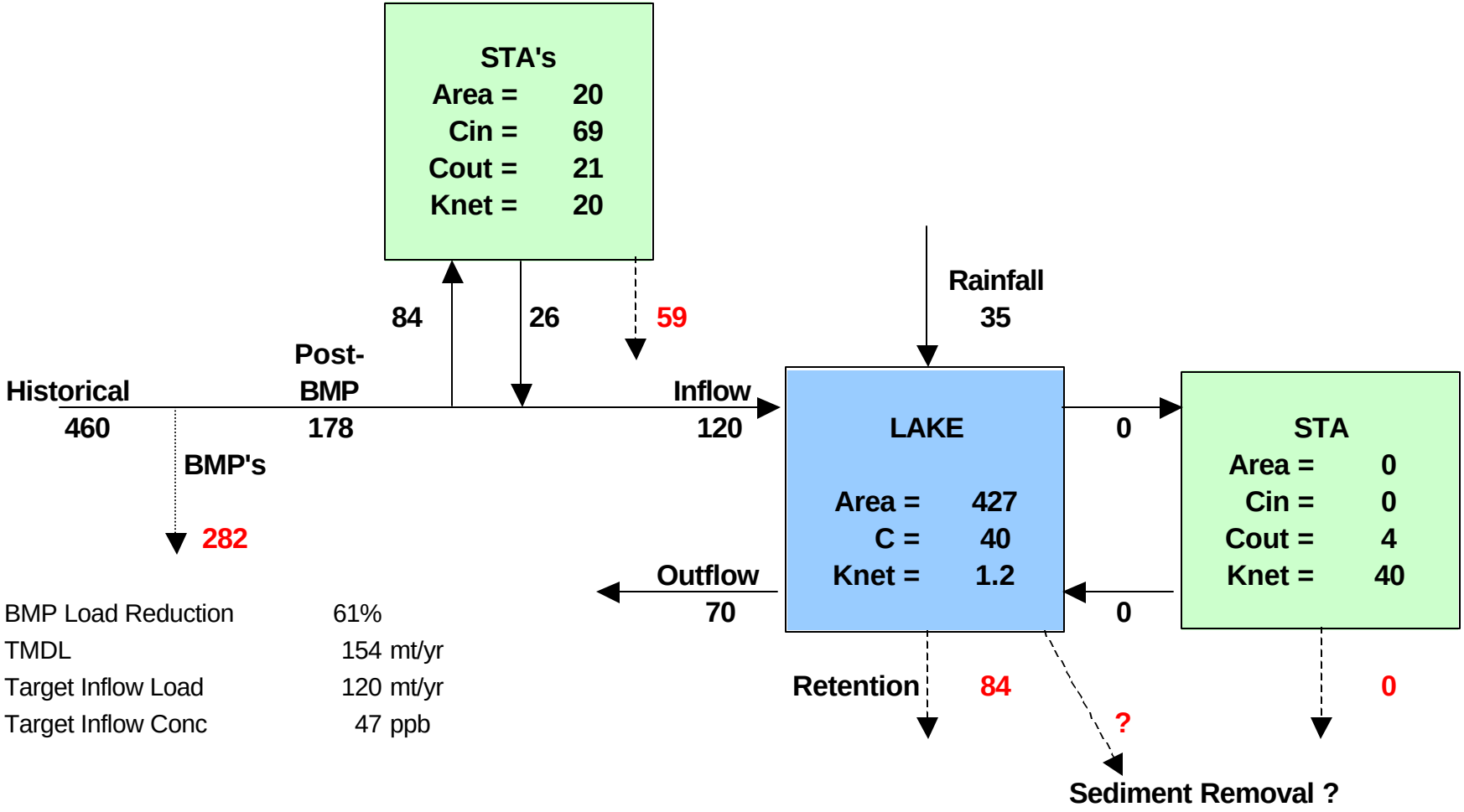


BMP Load Reduction	74%	
TMDL	154	mt/yr
Target Inflow Load	120	mt/yr
Target Inflow Conc	47	ppb

P Loads in metric tons / year, Areas in 1000 acres, Concentrations in ppb, Settling Rates in m/yr

Phosphorus Mass Balance

TMDL with Controls - Example 2

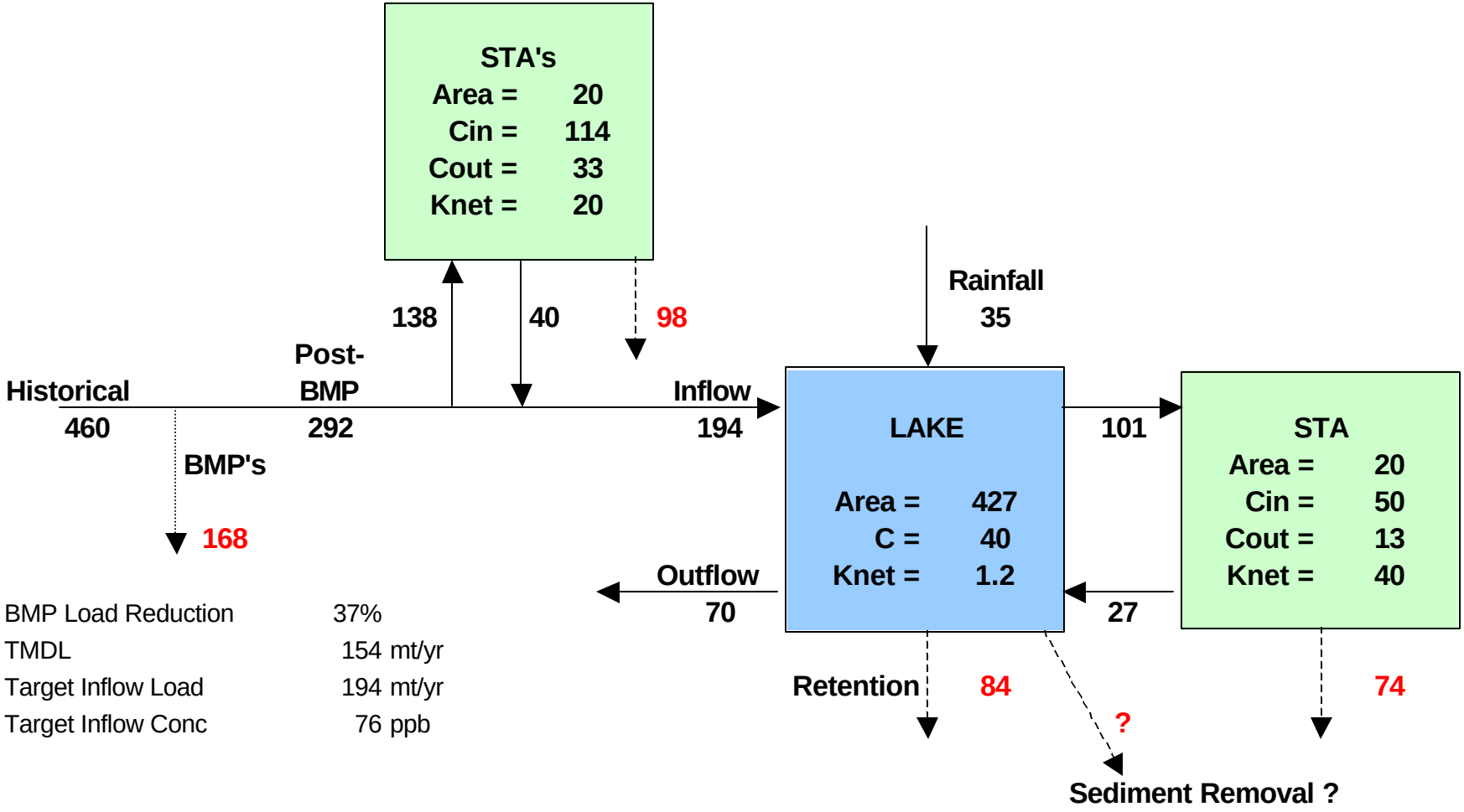


BMP Load Reduction	61%	
TMDL	154	mt/yr
Target Inflow Load	120	mt/yr
Target Inflow Conc	47	ppb

P Loads in metric tons / year, Areas in 1000 acres, Concentrations in ppb, Settling Rates in m/yr

Phosphorus Mass Balance

TMDL with Controls - Example 3



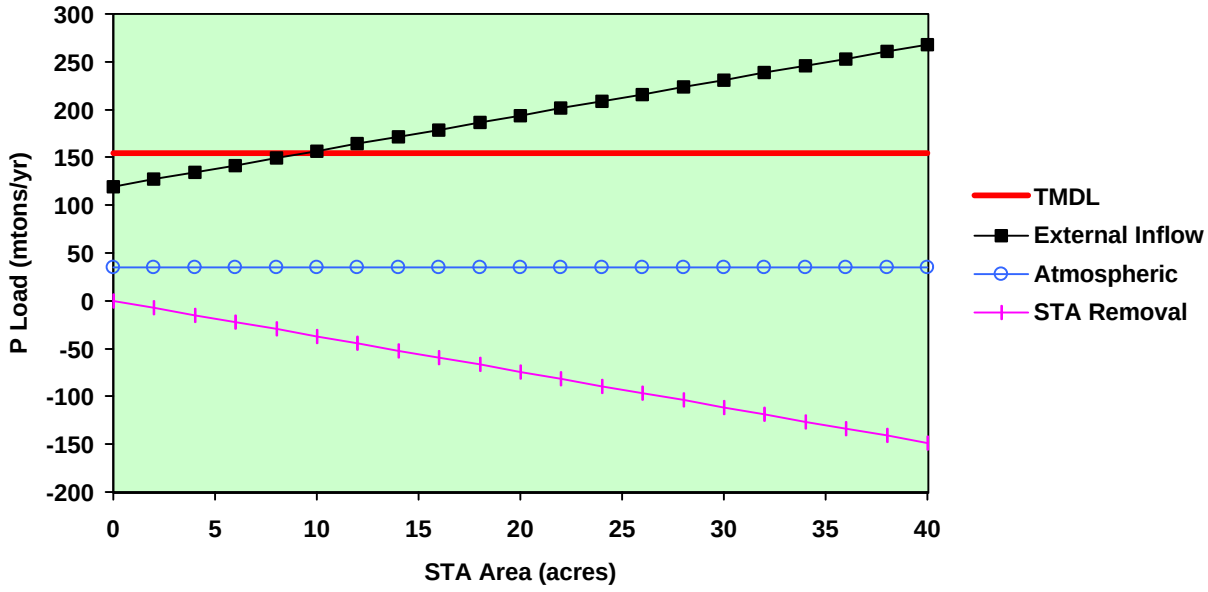
BMP Load Reduction	37%	
TMDL	154	mt/yr
Target Inflow Load	194	mt/yr
Target Inflow Conc	76	ppb

P Loads in metric tons / year, Areas in 1000 acres, Concentrations in ppb,

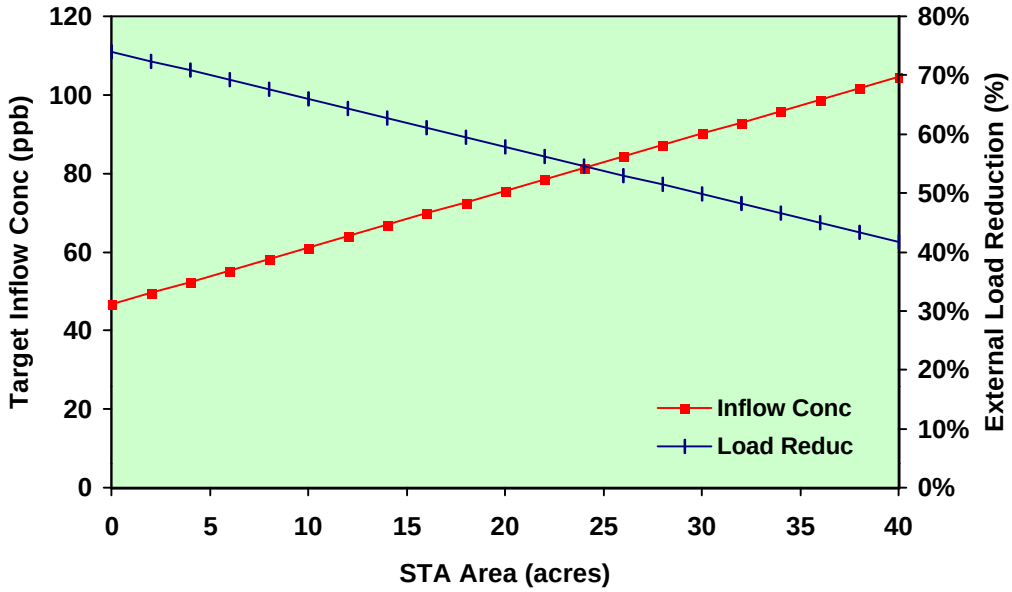
Load Allocations with Parallel STA

TMDL = External Load + Atmospheric Load - Load Removed by STA

TMDL Components:



External Load Requirements:



Sensitivity of TMDL Calculation to Atmospheric Loads

Calibration Period: 94-98

Variable	Units	Assumed	Previous Studies
Atmospheric Load	mg/m2-yr	20.0	43.3
Atmospheric Load	mt/yr	34.6	75.0
Average Rainfall	m/yr	1.07	1.07
Bulk Concentration	ppb	18.7	40.5

Atm Load mg/m2-yr	Knet m/yr	Conc R^2 --	TMDL mt/yr	L Reduc %	Linflow mt/yr	Cinflow ppb
	1.22	0.90	154	74%	120	47
10	1.12	0.89	148	72%	130	51
20	1.22	0.90	154	74%	120	47
30	1.31	0.90	161	76%	109	42
40	1.40	0.90	167	79%	98	38
50	1.50	0.90	174	81%	87	34
60	1.59	0.90	180	83%	76	30
70	1.69	0.90	187	86%	66	26