Chapter 12: Mass-Balance Modeling

1999 Annual Report, Onondaga Lake Ambient Monitoring Program

W. Walker for Onondaga County DD&S

Draft - August 2000

Mass-Balance Framework

Database Updates

Nutrient Mass Balances

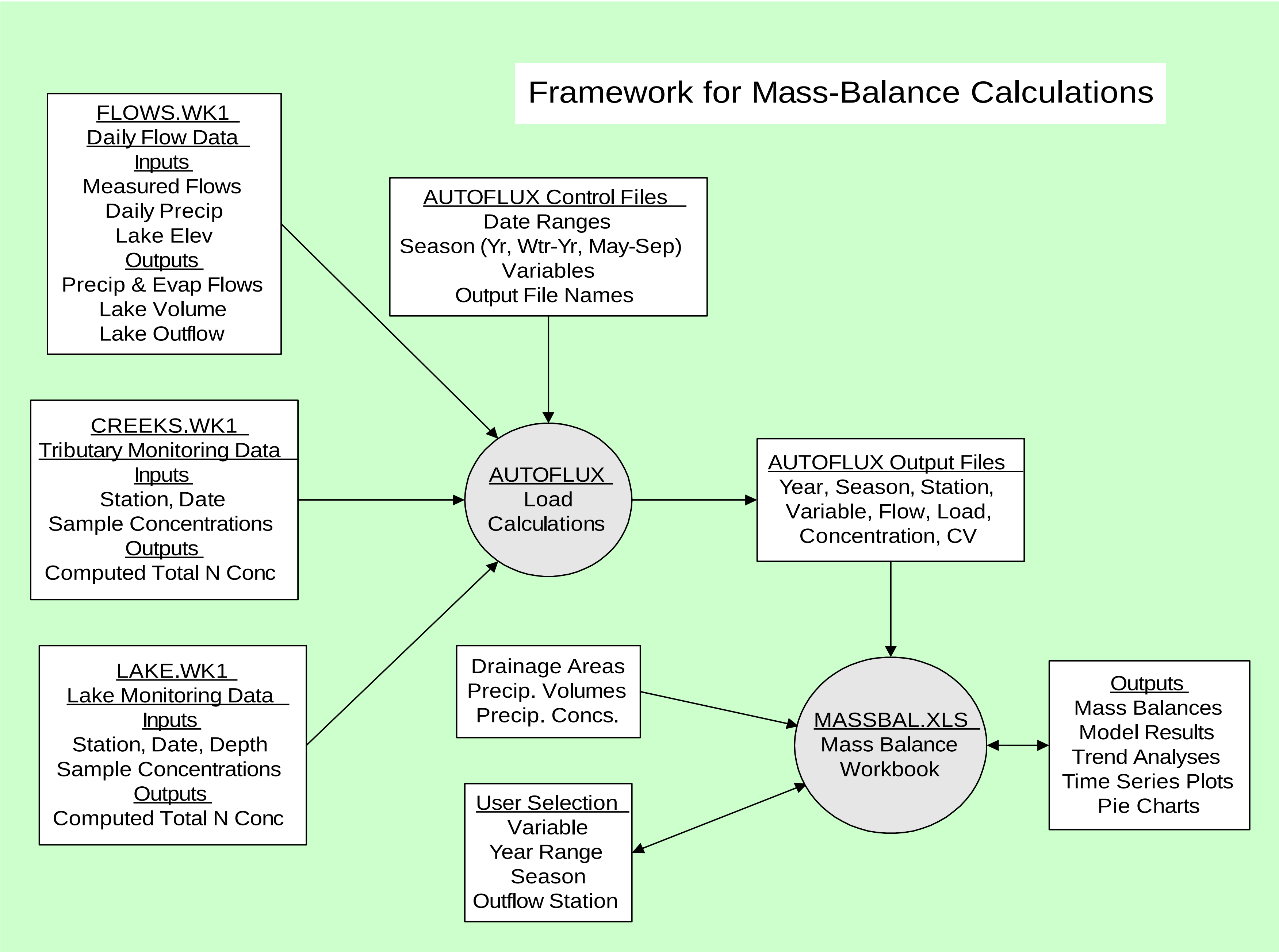
- **Total Phosphorus**
- **Total Nitrogen**

Trophic Response Models

- **Chlorophyll-a**
- **Algal Bloom Frequencies**
- **Secchi Depth**
- **Secchi Interval Frequencies**
- **Hypolimnetic Oxygen Depletion Rate**

Model Implementation

Conclusions & Recommendations


Framework for Mass-Balance Calculations
FLOWS.WK1
Daily Flow Data
Inputs
Measured Flows
Daily Precip
Lake Elev
Outputs
Precip & Evap Flows
Lake Volume
Lake Outflow
AUTOFLUX Control Files
Date Ranges
Season (Yr, Wtr-Yr, May-Sep)
Variables
Output File Names
CREEKS.WK1
Tributary Monitoring Data
Inputs
Station, Date
Sample Concentrations
Outputs
Computed Total N Conc
AUTOFLUX
Load
Calculations
AUTOFLUX Output Files
Year, Season, Station,
Variable, Flow, Load,
Concentration, CV
LAKE.WK1
Lake Monitoring Data
Inputs
Station, Date, Depth
Sample Concentrations
Outputs
Computed Total N Conc
Drainage Areas
Precip. Volumes
Precip. Concs.
MASSBAL.XLS
Mass Balance
Workbook
Outputs
Mass Balances
Model Results
Trend Analyses
Time Series Plots
Pie Charts
User Selection
Variable
Year Range
Season
Outflow Station

Onondaga Lake Mass Balance Analysis

W.Walker, for Onondaga County D&S, July 2000

Select Variable

ALK
BOD5
CA
CL
FCOLI
NA
NH3N
NO2N
NO3N
ORTHOP_F
TIC
TIP
TKN
TN
TOC
TP
TSS

Select Season

MaySept
Year
WaterYr

Select Lake Outlet

Outlet - 2ft
Outlet - 12 ft
Outlet - Avg
South Epil.

Select Model

Calib. Settling Rate
Calib Retention Coef.
Specified Settling Rate
Specified Retention Coef

Glossary

Enter Year Ranges (>= 1986)

Calibration	1995	to	1999
Total	1986	to	1999

OK

Select Graph

Inflow_Volumes
Inflow_Loads
Load_Variance
Load_Trends
Load_Source_Trends
Conc_Trends
FlowAdjConc_Trends
FlowAdjLoad_Trends
Load_InOut
Load_InOutRet
LoadOut_LoadIn
Conc_InOut
Conc_Outlets
ConcOut_ConcIn
Non_Point
Pie_Flows
Pie2_Flows
Pie_Loads
Pie2_Loads
Pie_Variance
Model_Conc
Model_Load
Model_Param
Model_Diagnostics
Model_Epil

View Graph

Select Table

Sample_Counts
Detailed Mass-Balance
Trend_Summary
Trends_All
Trends_Flows
Trends_Loads
Trends_Concs
Trends_FlowAdjLoads
Trends_FlowAdjConcs
Trend_CrossTab_Loads
Trend_CrossTab_Concs
Model_Calcs
Model_CrossTab
Inputs_AUTOFLUX
Inputs_DrainageAreas
Inputs_Precip
Inputs_VariableIndex

View Table

Update CrossTabs

Select Term

Allied
Crucible
Harbor/Hiawatha
Ley/Park
Ninemile/Rt48
Onond./Kirkpatrick
Harbor/Velasko
Onondaga/Dorwin
Total Gauged
NonPoint Gauged
Ungauged
Total NonPoint
Total Industrial
Total Municipal
Total External
Precip
Evap
Total Inflow
Total Outflow
Retention
Outlet2
Outlet12

View Table

Trend Plots

User Input Cells are Red

Hit Cntrl-m to Return to This Page

Version Date: 8/9/00

Variable: **Total Phosphorus** **Average for Years:** 1995 thru 1999 **Season:** WaterYr

Term	Flow 10^6 m3	Load kg	Std Error kg	Conc ppb	RSE %	Samp. Count	Percent of Total Inflow Flow %	Percent of Total Inflow Load %	Percent of Total Inflow Error %	Drain. Area km2	Runoff cm	Export kg / km2
Metro Effluent	90.02	40619	502	451	1%	348	22%	59%	7%			
Metro Bypass	1.70	2521	94	1487	4%	42	0%	4%	0%			
East Flume	0.30	66	2	220	3%	26	0%	0%	0%			
Crucible	0.63	43	2	68	6%	27	0%	0%	0%			
Harbor Brook	7.76	460	45	59	10%	27	2%	1%	0%	29.3	26.5	15.7
Ley Creek	32.27	4266	677	132	16%	26	8%	6%	13%	77.5	41.6	55.0
Ninemile Creek	117.57	7815	1085	66	14%	26	29%	11%	33%	298.1	39.4	26.2
Onondaga Creek	131.35	11359	1288	86	11%	28	32%	17%	46%	285.1	46.1	39.8
Nonpoint Gauged	288.94	23901	1816	83	8%	108	71%	35%	92%	690.0	41.9	34.6
Nonpoint Ungauged	15.51	1283	203	83	16%	0	4%	2%	1%	37.0	41.9	34.6
NonPoint Total	304.45	25183	1827	83	7%	108	75%	37%	93%	727.0	41.9	34.6
Industrial	0.93	109	3	117	3%	53	0%	0%	0%			
Municipal	91.71	43140	511	470	1%	390	22%	63%	7%			
Total External	397.09	68432	1897	172	3%	550	97%	100%	100%	727.0	54.6	94.1
Precipitation	10.69	321	29	30	9%	0	3%	0%	0%	11.7	91.3	27.4
Total Inflow	407.77	68752	1897	169	3%	550	100%	100%	100%	738.7	55.2	93.1
Evaporation	8.86						2%			11.7	75.7	
Outflow	398.92	41148	1970	103	5%		98%	60%	108%	738.7	54.0	55.7
Retention	0.00	27604	2735		10%		0%	40%				
Alternative Estimates of Lake Output												
Outlet 12 Feet	398.92	46698	1980	117	4%	24	98%	68%	109%	738.7	54.0	63.2
Outlet 2 Feet	398.92	41148	1970	103	5%	24	98%	60%	108%	738.7	54.0	55.7
Outlet Average	398.92	43923	1975	110	4%	24	98%	64%	108%	738.7	54.0	59.5
Lake Epil	398.92	45338	2333	114	5%	20	98%	66%	151%	738.7	54.0	61.4
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	25.9	#N/A	#N/A
Downstream - Hiawatha	7.76	460	45	59	10%	27	2%	1%	0%	29.3	26.5	15.7
Local Inflow	#N/A	#N/A	#N/A	#N/A	#N/A		#N/A	#N/A	#N/A	3.4	#N/A	#N/A
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	101.57	6463	786	64	12%	28	25%	9%	17%	229.4	44.3	28.2
Downstream - Kirkpatrick	131.35	11359	1288	86	11%	28	32%	17%	46%	285.1	46.1	39.8
Local Inflow	29.77	4897	1509	164	31%		7%	7%	63%	55.7	53.4	87.9

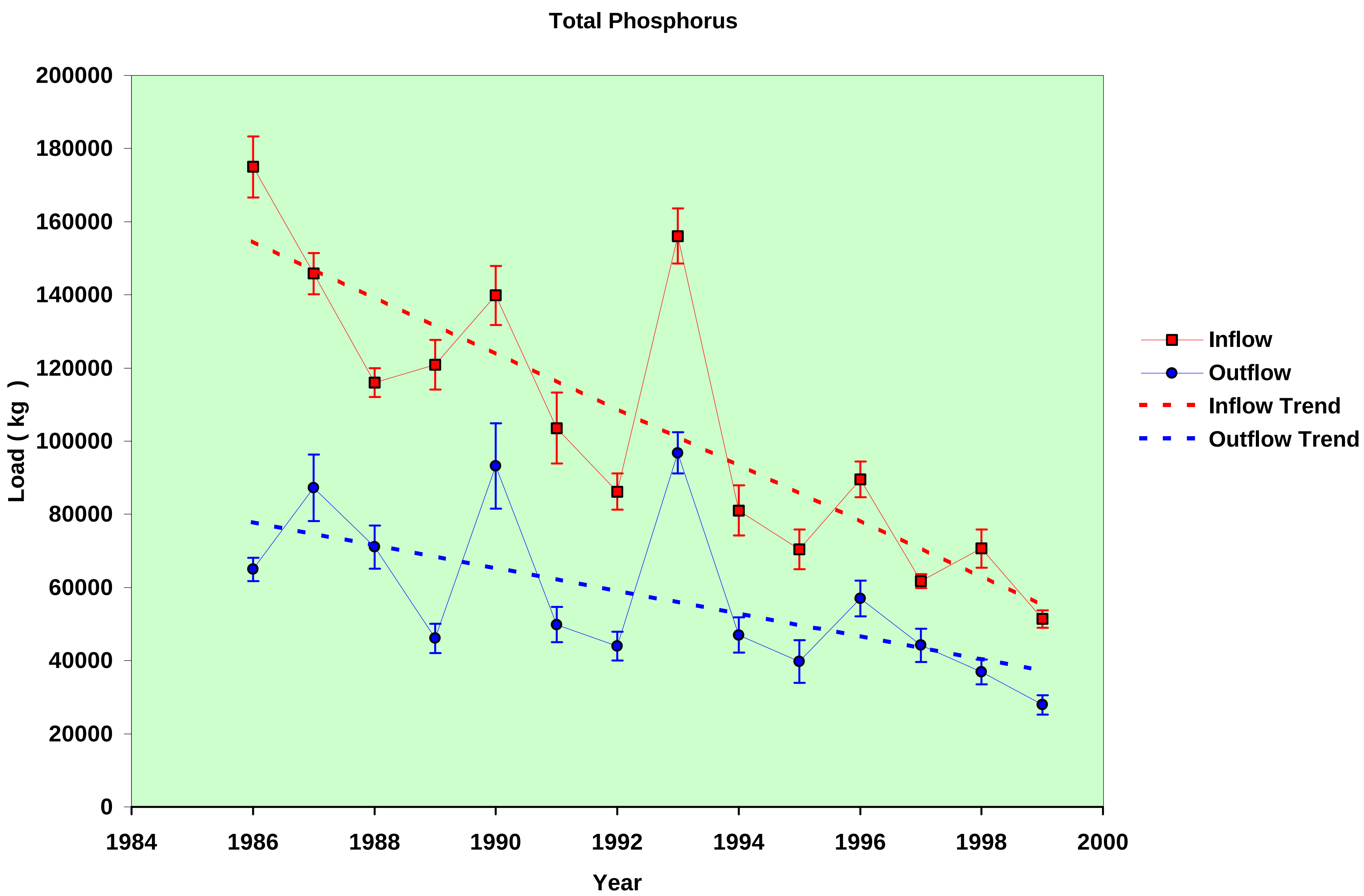
Lake Overflow Rate	34.10 m/yr	Calib. Settling Rate	22.9 m/yr	RSE % = Relative Std. Error of Load & Inflow Conc. Estimates
Lake Residence Time	0.32 years	Calib. Retention Coef.	40%	Error % = Percent of Variance in Total Inflow Load Estimate

Yearly Total Phosphorus Balances

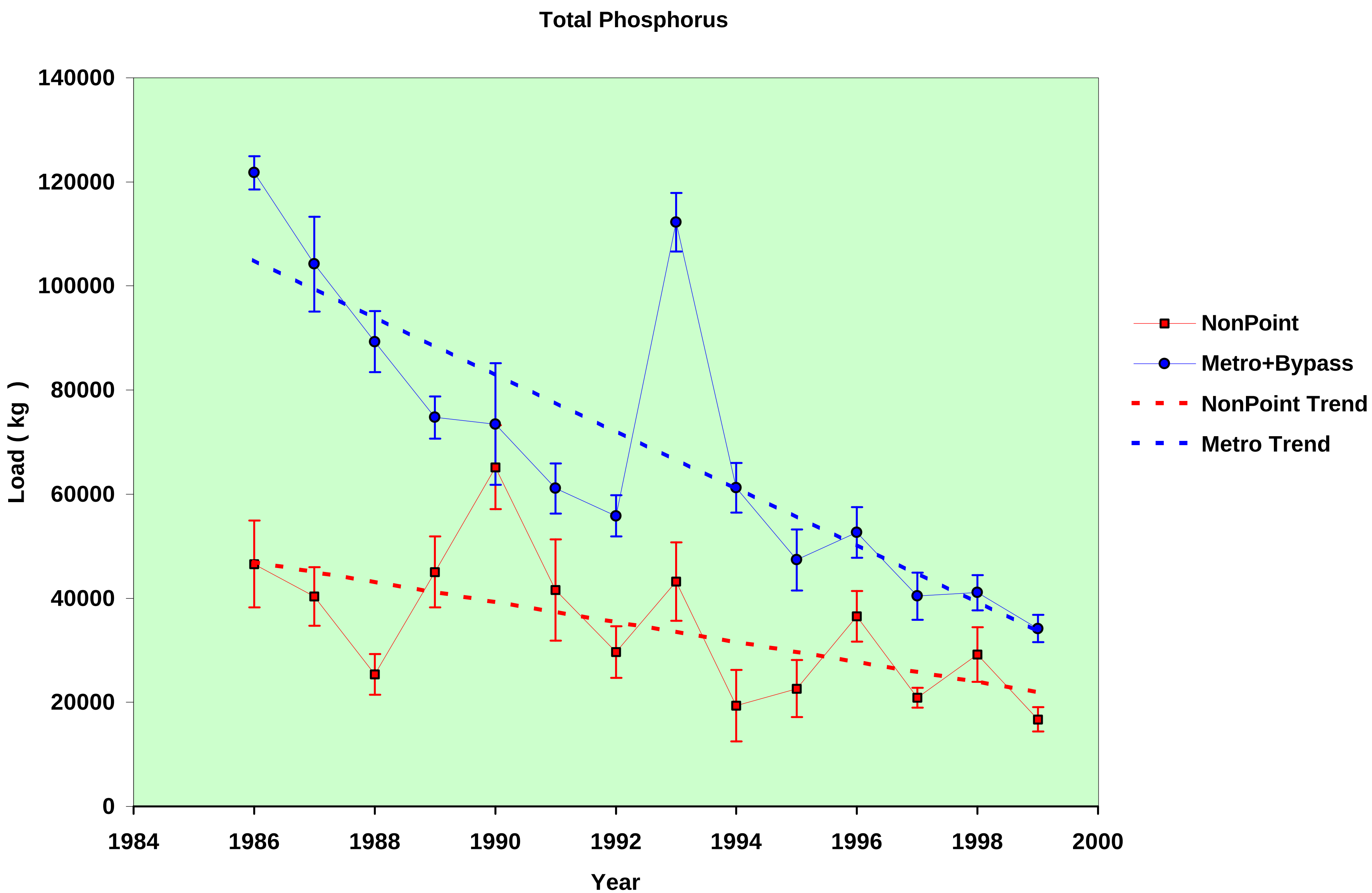
Water Years 1986-1999

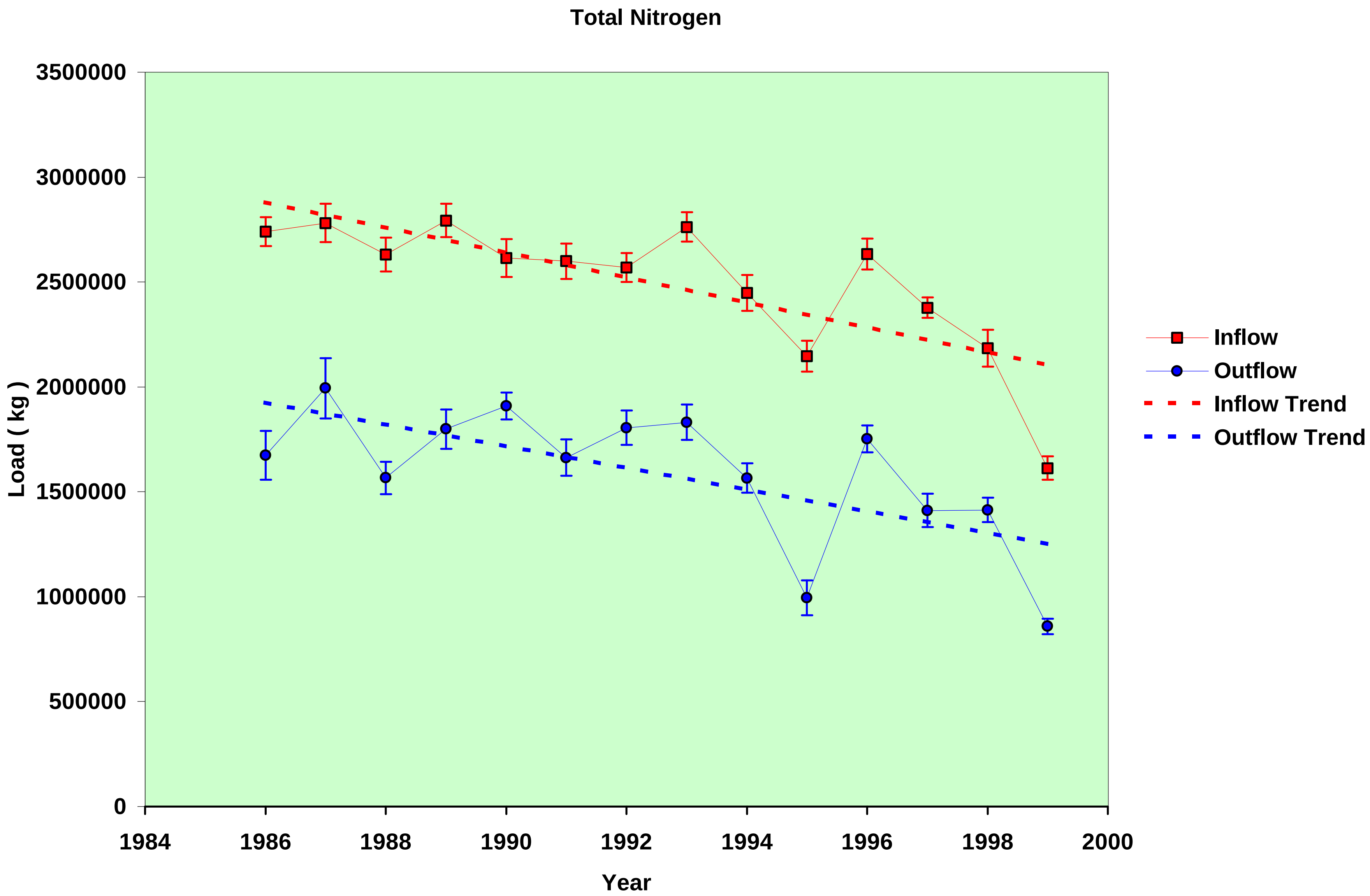
Water	Outflow	Inflow Load		Metro+Bypass Load		Inflow Conc	Outflow Conc @ 2 ft		Lake South Epil. June-Sept, 0-6 m Concentration	
Year	106 m3	kg	RSE%	kg	RSE%	ppb	ppb	RSE%	ppb	RSE%
1986	483.5	174968	5%	121740	6%	362	134	5%	136	5%
1987	440.5	145808	4%	104222	4%	331	198	10%	120	4%
1988	341.8	116002	3%	89279	4%	339	208	8%	127	5%
1989	426.7	120874	6%	74729	5%	283	108	9%	96	11%
1990	602.3	139838	6%	73460	9%	232	155	13%	88	14%
1991	536.7	103589	9%	61088	12%	193	93	10%	61	9%
1992	476.1	86216	6%	55830	7%	181	92	9%	62	18%
1993	563.7	156070	5%	112279	6%	277	172	6%	132	12%
1994	478.2	81034	8%	61232	10%	169	98	10%	87	11%
1995	296.7	70431	8%	47372	3%	237	134	15%	72	13%
1996	474.2	89570	5%	52661	3%	189	120	9%	68	10%
1997	444.9	61725	3%	40422	2%	139	99	10%	60	10%
1998	466.2	70668	7%	41068	2%	152	79	9%	55	8%
1999	312.5	51366	5%	34174	2%	164	89	9%	54	10%
95-99	398.9	68752	6%	43140	3%	172	103	11%	62	10%

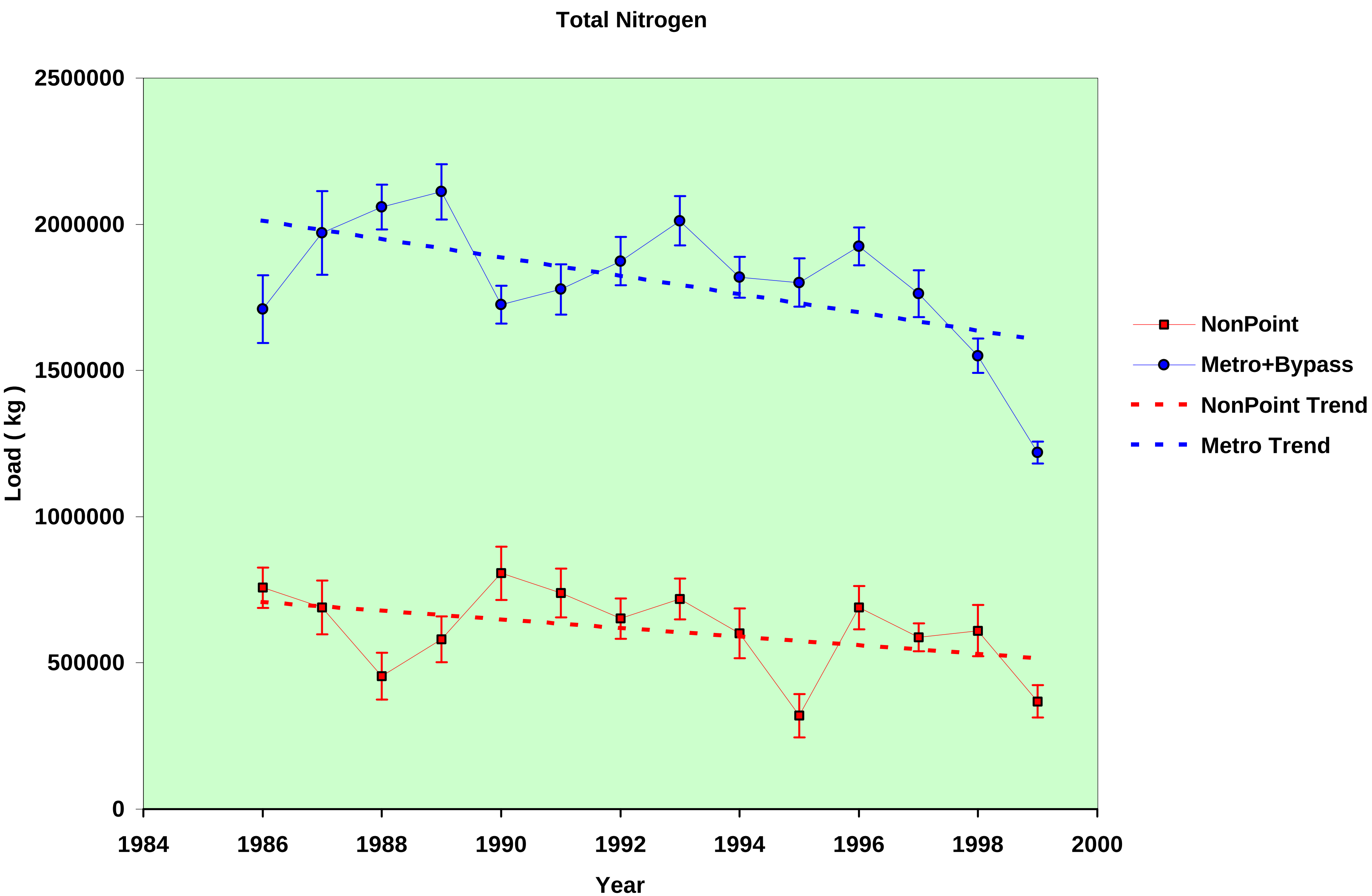
RSE = relative standard error = standard error / mean

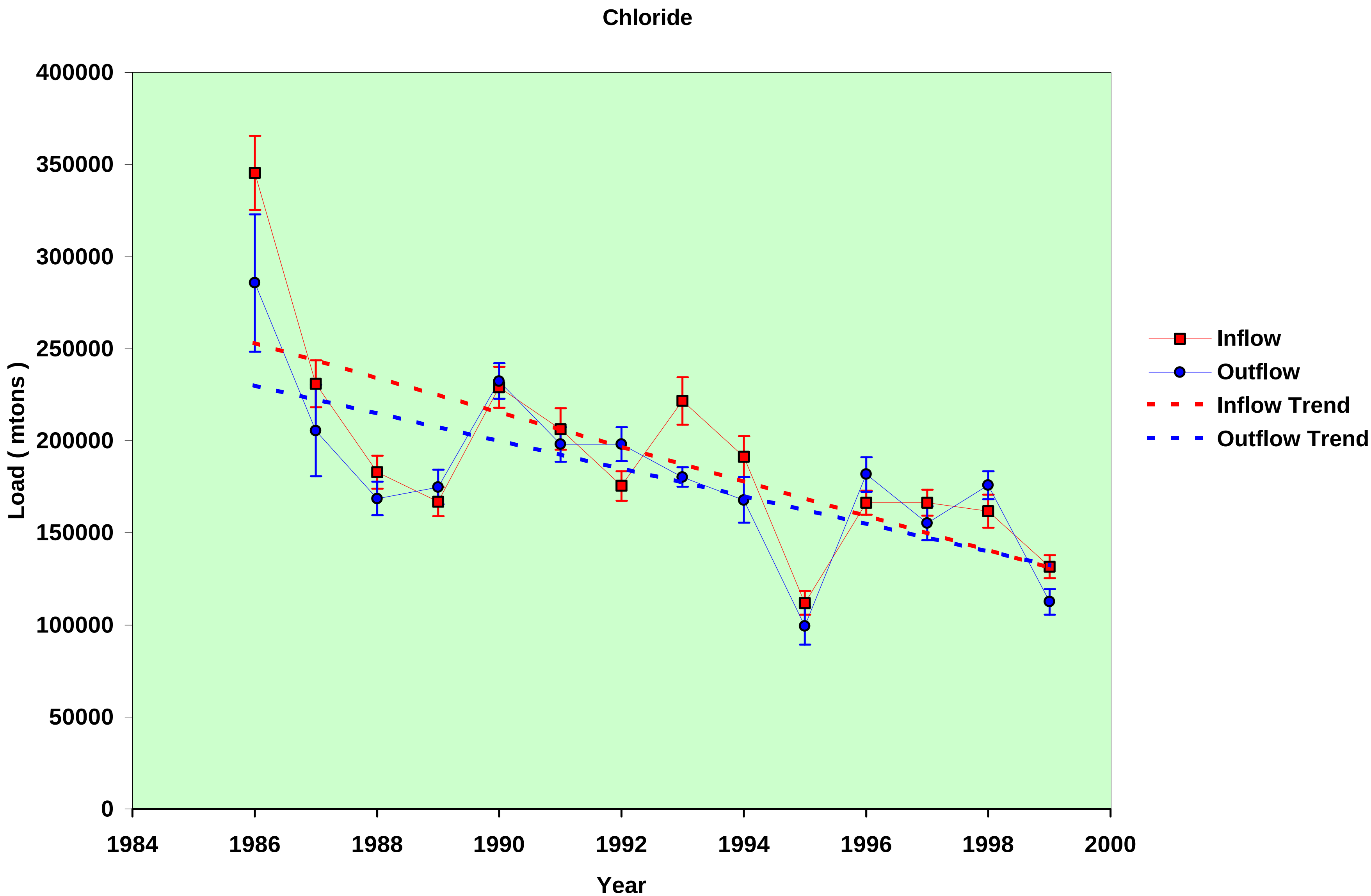


Total Phosphorus
Load (kg)
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year
Inflow
Outflow
Inflow Trend
Outflow Trend

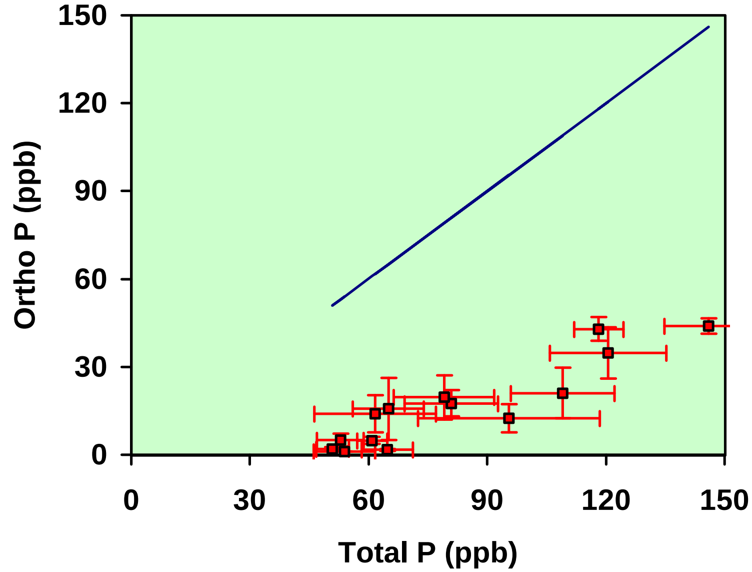

Total Phosphorus
Load (kg)
140000
120000
100000
80000
60000
40000
20000
0
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year
NonPoint
Metro+Bypass
NonPoint Trend
Metro Trend

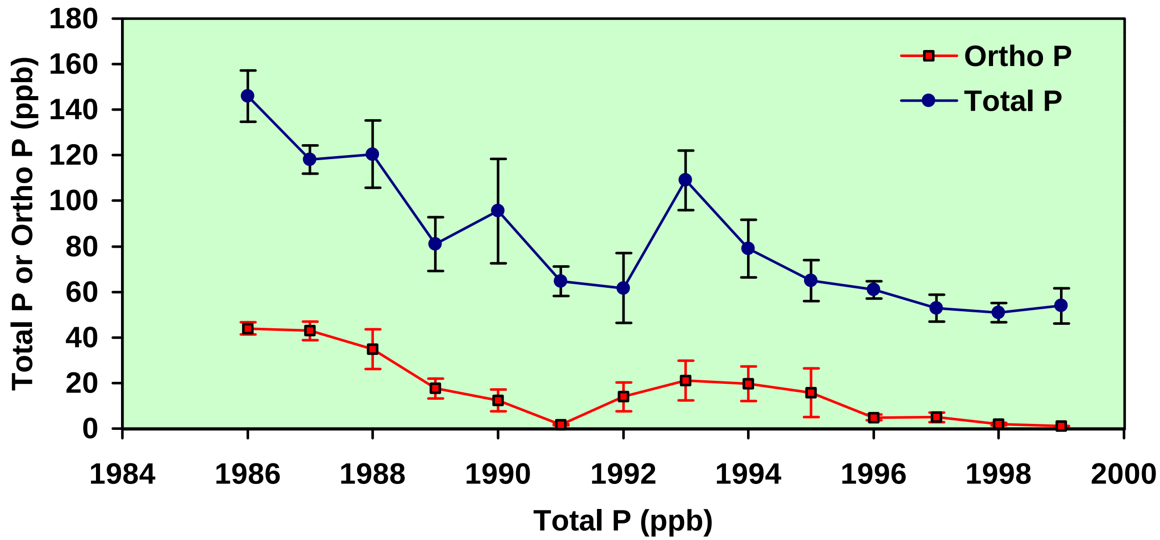

Total Nitrogen
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
Load (kg)
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year
Inflow
Outflow
Inflow Trend
Outflow Trend


Total Nitrogen
2500000
2000000
1500000
1000000
500000
0
Load (kg)
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year
NonPoint
Metro+Bypass
NonPoint Trend
Metro Trend


Chloride
Load (mtons)
400000
350000
300000
250000
200000
150000
100000
50000
0
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year
Inflow
Outflow
Inflow Trend
Outflow Trend

Ortho P vs. Total P Concentrations



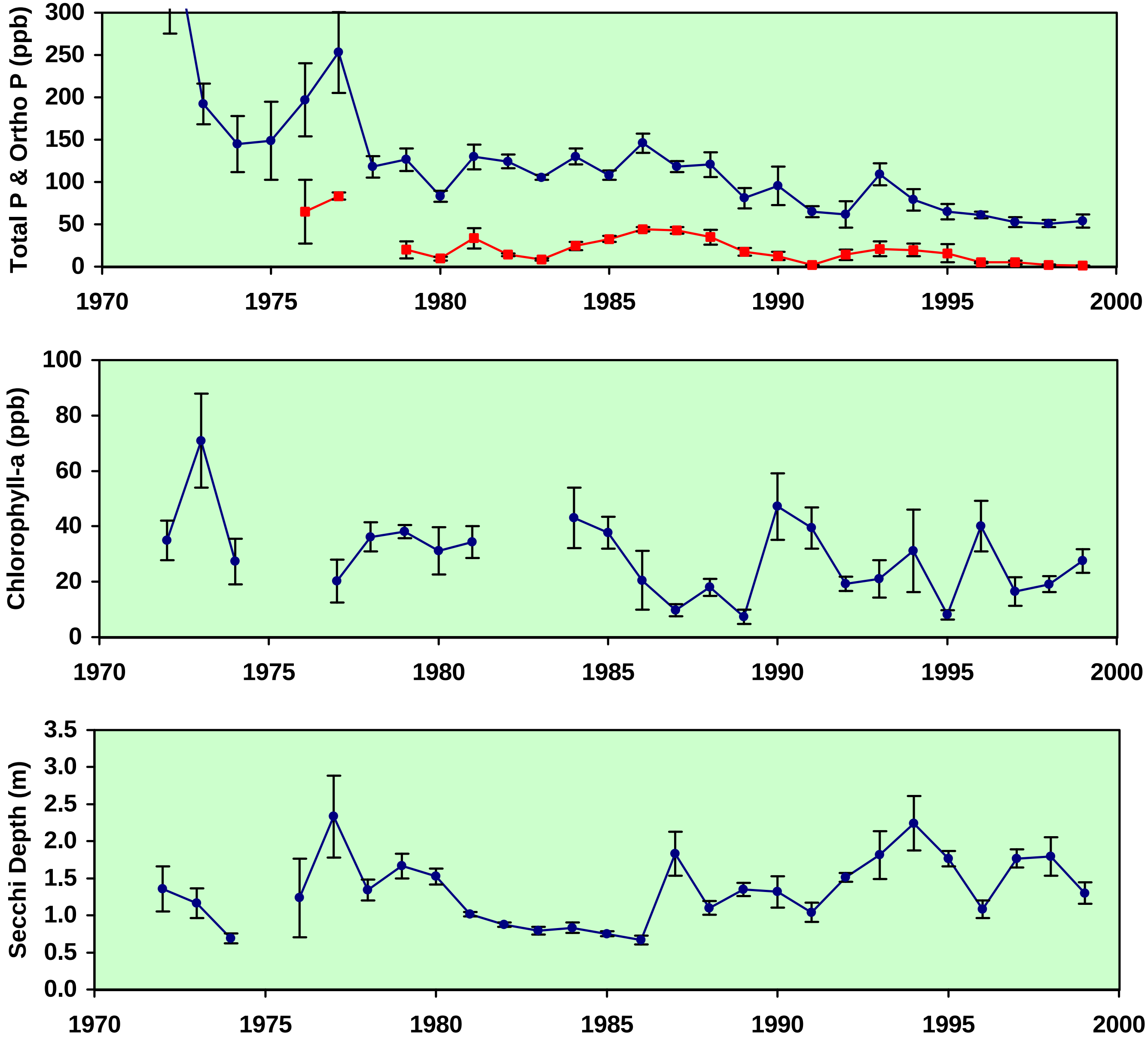


July-September Means, 0-3 meters, Lake South Station

Error bars show mean +/- 1 standard error

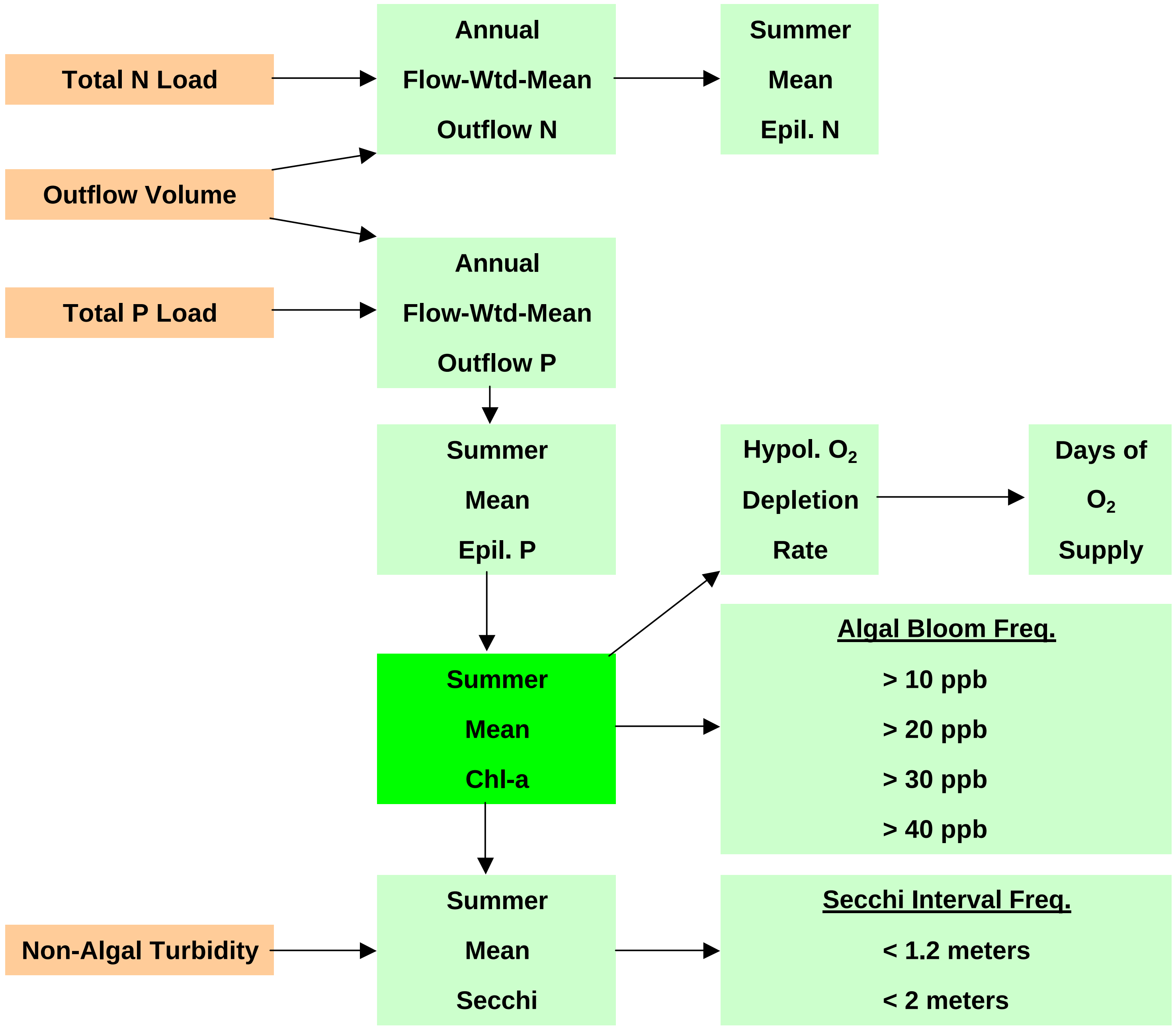
P Limited ? ----->

Long-Term Variations in Lake Trophic State Indicators



July-September Means, 0-3 meters, Lake South

Eutrophication Model Network for Onondaga Lake



Empirical Eutrophication Models

Trophic responses assumed to be consistent with data from other P-limited lakes

Primary Uses:

- **Interpreting lake monitoring data**
- **Projecting responses to variations in external P load**
  - **Trophic State**
  - **Nuisance Algal Blooms**
  - **WQ criteria & standards (TP, Secchi, DO)**
- **Contrast with mechanistic model(s)**

Strengths:

- **Simple / Robust**
- **Easy to calibrate, apply, understand**
- **Uncertainty quantifiable**

Limitations:

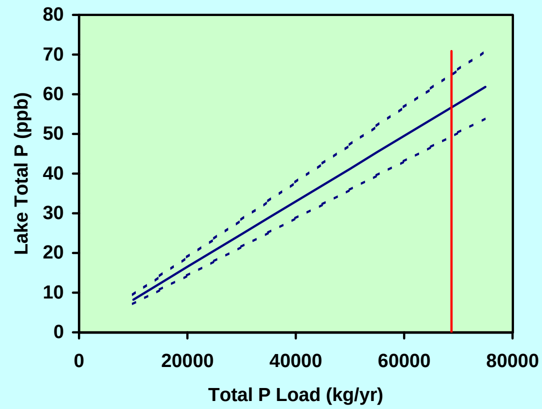
- **Limited scope & resolution**
- **Limited range of management questions**
- **N & P cycles uncoupled**
- **Insensitive to forms & timing of P input**
- **Under-estimates sensitivity to reductions in Metro P Load ?**

Onondaga Lake Empirical Eutrophication Model

Model Parameters	**Units**	**Input Value**
Lake Area	km^2	11.7
P Settling Rate	m/yr	22.873
Epil P / Outflow P	-	0.550
Outflow P Error CV	-	0.112
Lake P Error CV	-	0.089
Chla/P Slope	-	1.460
Chla/P Intercept	-	0.076
Chl-a Error CV	-	0.241
Chla Temporal CV	-	0.600
Non-Algal Turbidity	1/m	0.381
Secchi/Chla Slope	m^2/mg	0.016
Secchi Error CV	-	0.193
Secchi Temporal CV	-	0.320
HOD Intercept	-	42.400
HOD Slope		0.940
HOD Error CV		0.230
Spring DO Conc	ppm	12.000
Hypol. Depth	m	8.340
Stratified Period	days	183.000

Scenario			
Outflow Volume	hm^3/yr	399	1995-1999 Average
Inflow Load	kg/yr	68752	1995-1999 Average

Predicted Reponses		**Units**	**Mean**	**Low (10%)**	**High (90%)**
Outflow P Conc		ppb	103	87	123
Lake P Conc		ppb	57	49	65
Mean Chlorophyll-a		ppb	28	19	40
Algal Bloom Frequencies					
	>	10	0.94	0.81	0.99
	>	20	0.62	0.36	0.83
	>	30	0.33	0.14	0.59
	>	40	0.17	0.05	0.39
Mean Secchi Depth		m	1.34	1.61	1.08
Secchi Interval Frequencies					
	<	1.2	0.42	0.22	0.69
	<	2	0.92	0.80	0.98
Oxygen Depletion Rate		mg/m^2-day	1887	1326	2686
Days of O2 Supply		days	53	75	37
Anoxic Period		days	130	108	146

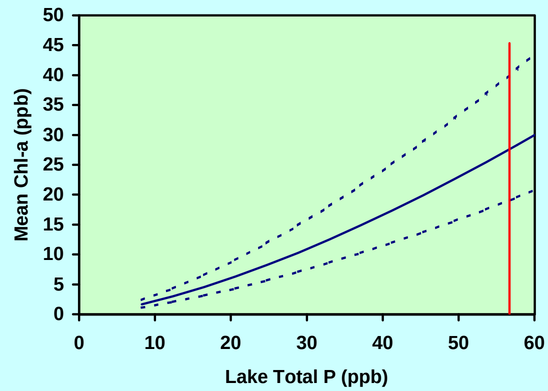


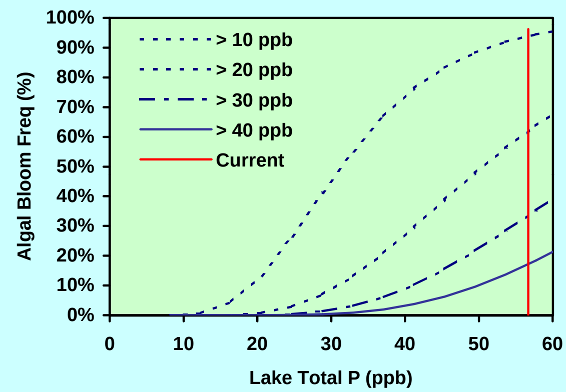
Predicted Lake Responses to Reductions in Phosphorus Load

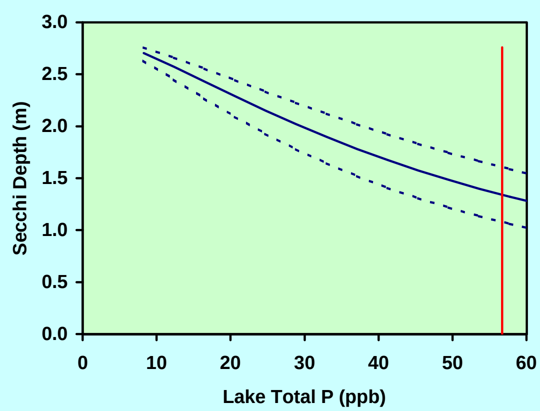
Average Outflow = 399 hm^3/yr

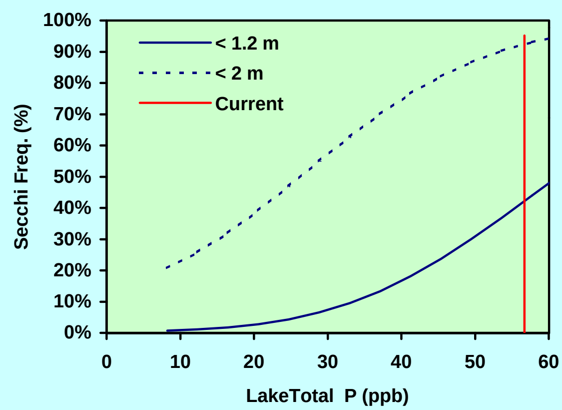
Total P Load = 68752 kg/yr

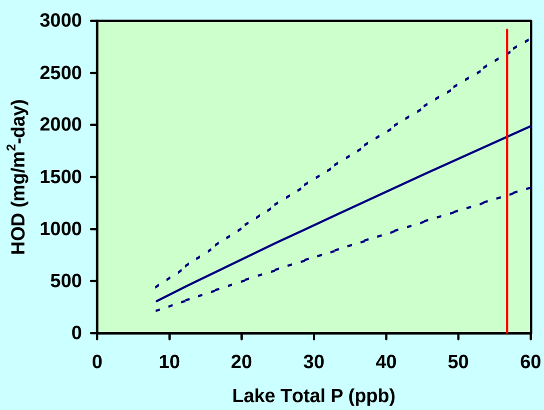
Dashed lines show 80% prediction intervals

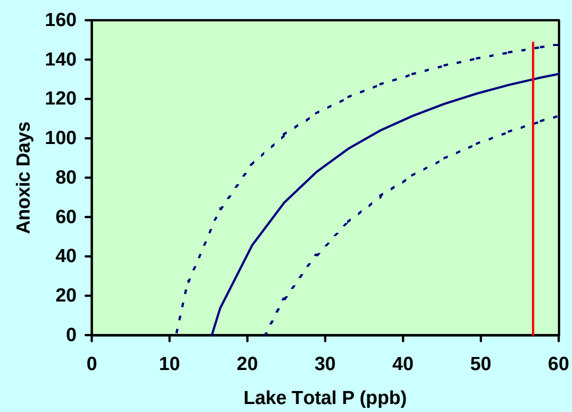




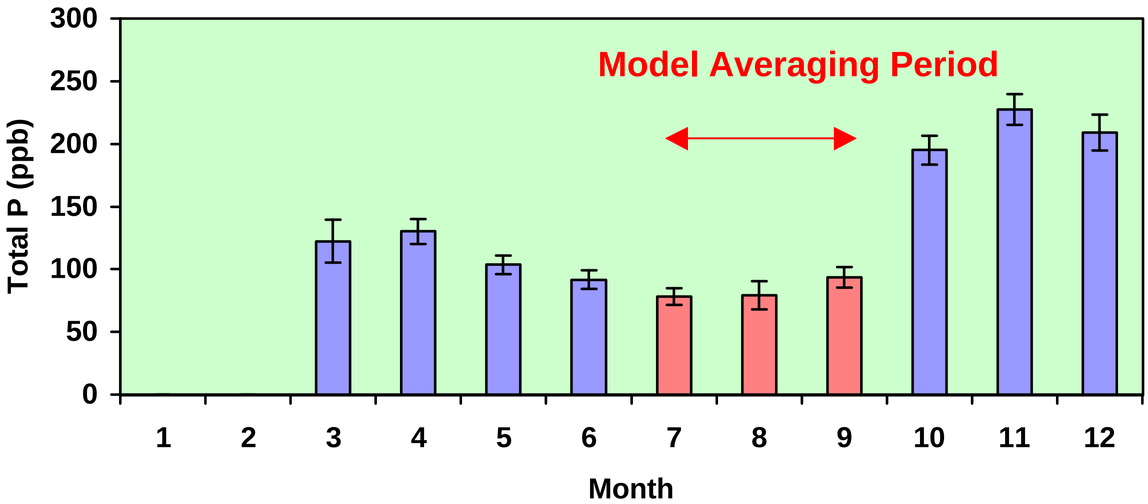


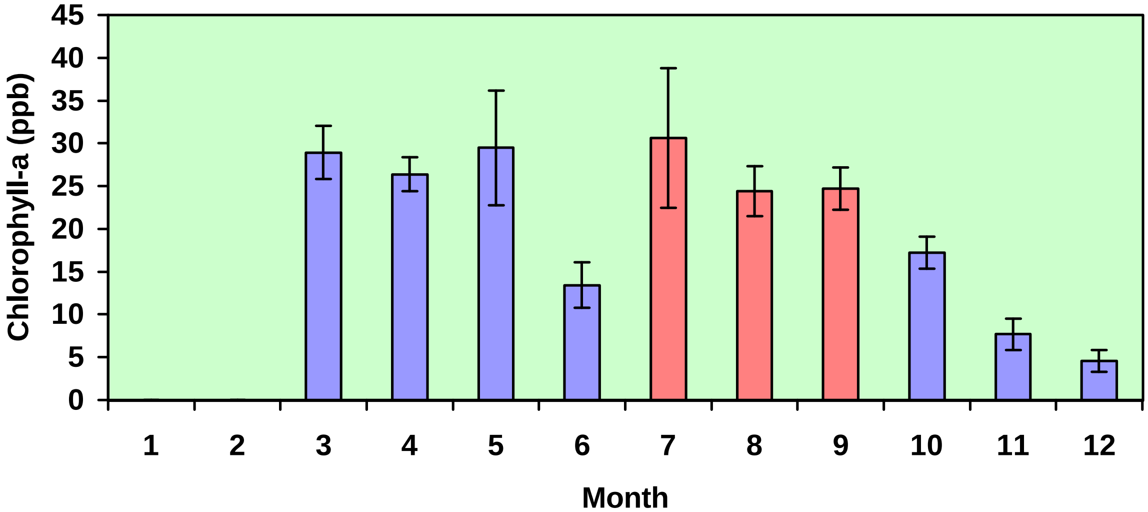


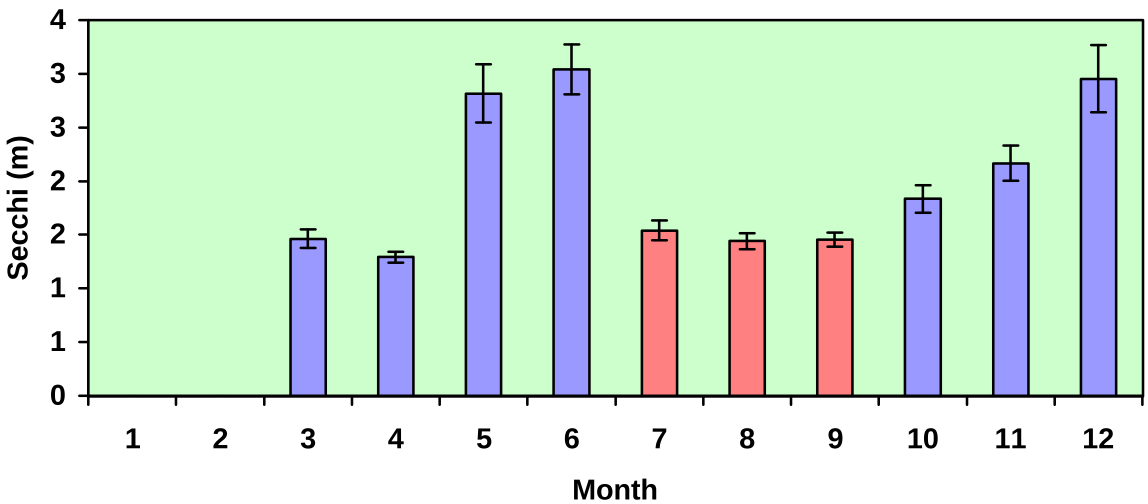




Season Variations in Trophic State Indicators

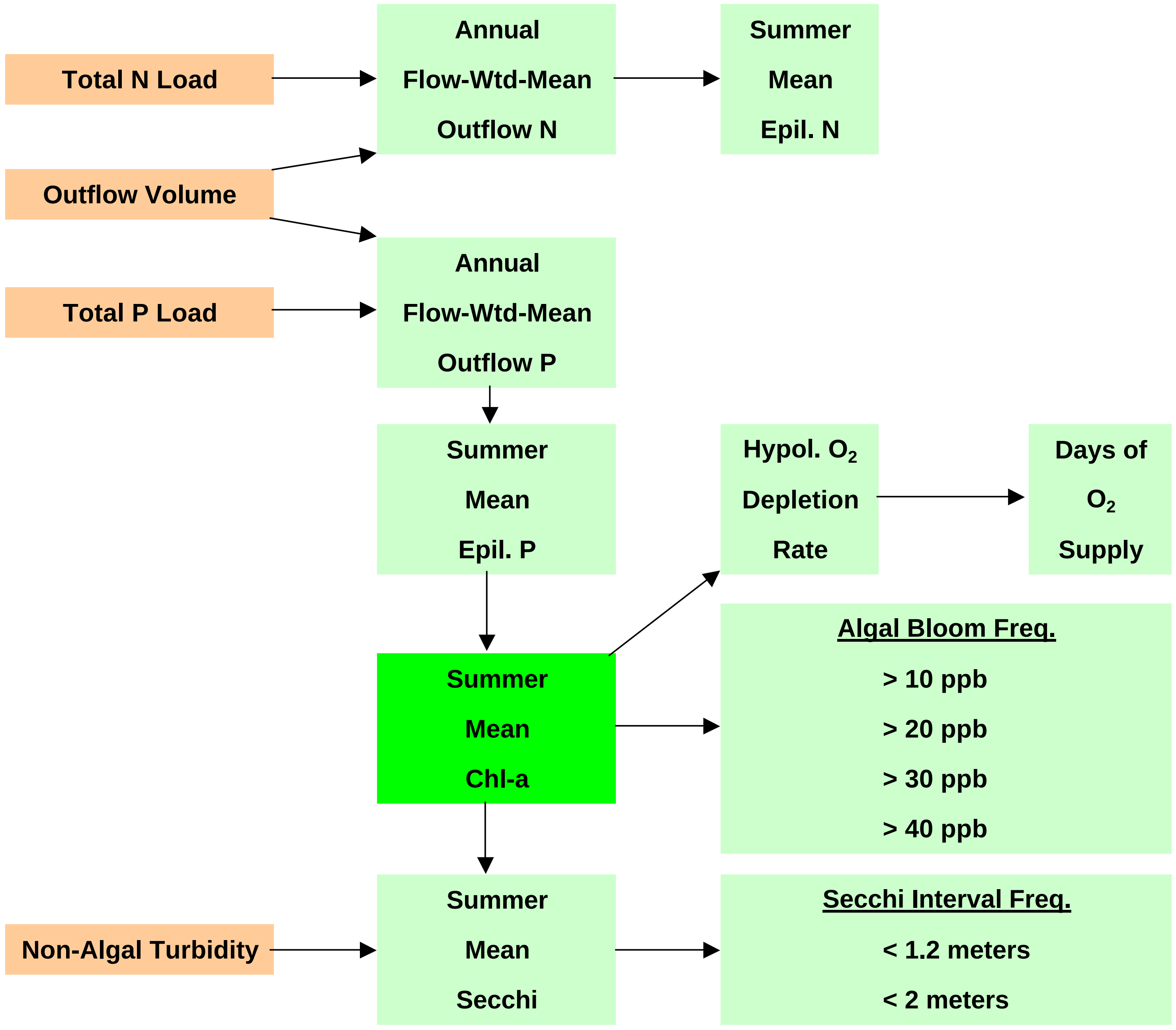






Means +/- 1 Standard Error, 1986-1999, 0-3 meters, Lake South

Eutrophication Model Network for Onondaga Lake



Onondaga Lake Empirical Model Network

Predicted Trophic Response Variables:

Po =	Water Year Flow-Wtd-Mean Outflow Total P (ppb)
P =	July-Sept Surface (0-3 m) Mean Total P (ppb)
No =	Water Year Flow-Wtd-Mean Outflow Total N (ppb)
N =	July-Sept Surface (0-3 m) Mean Total N (ppb)
B =	June-Sept Epilimnetic Mean Chlorophyll-a (ppb)
S =	June-Sept Mean Secchi Depth (m)
HOD =	Hypolimnetic Oxygen Depletion Rate (mg/m^2-day)

Lake Outflow Total P:

Reference: Vollenweider (1969) , Chapra (1975), Sas (1989)

$P_O = W_P / (Q_O + U_P A)$

W_P = Inflow P Load (kg/yr)

Q_O = Outflow = External Inflow + Precip - ET (hm^3/yr)

A = Lake Surface Area = 11.7 km^2

U_P = P Settling Rate = 22.9 m/yr

Calibrated to 1995-1999

Period	95-99	86-99
Residual CV	0.11	0.28
R^2	0.73	0.25

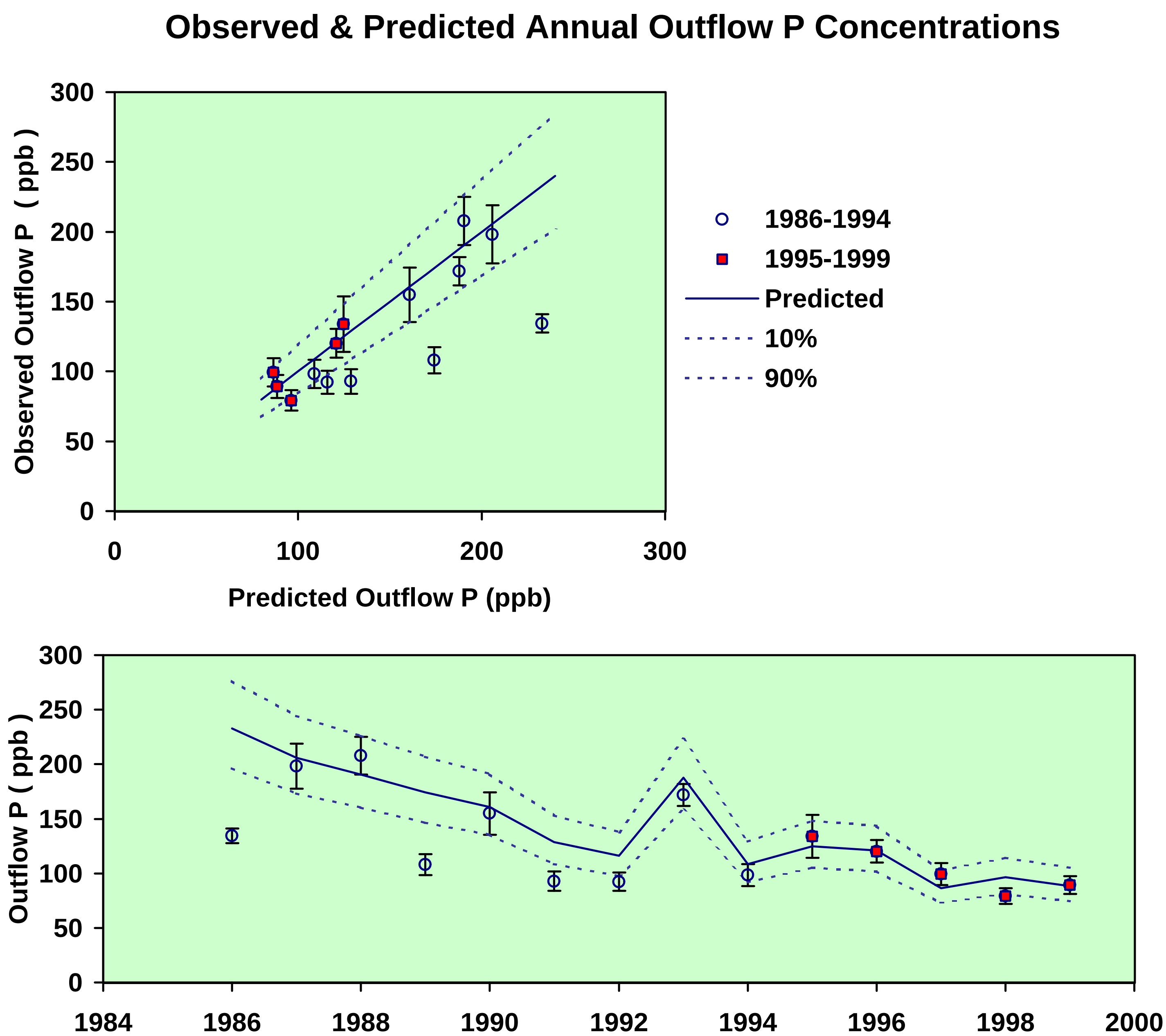
Lake South Epilimnetic Total P:

Reference: Walker (1978), Sas (1989)

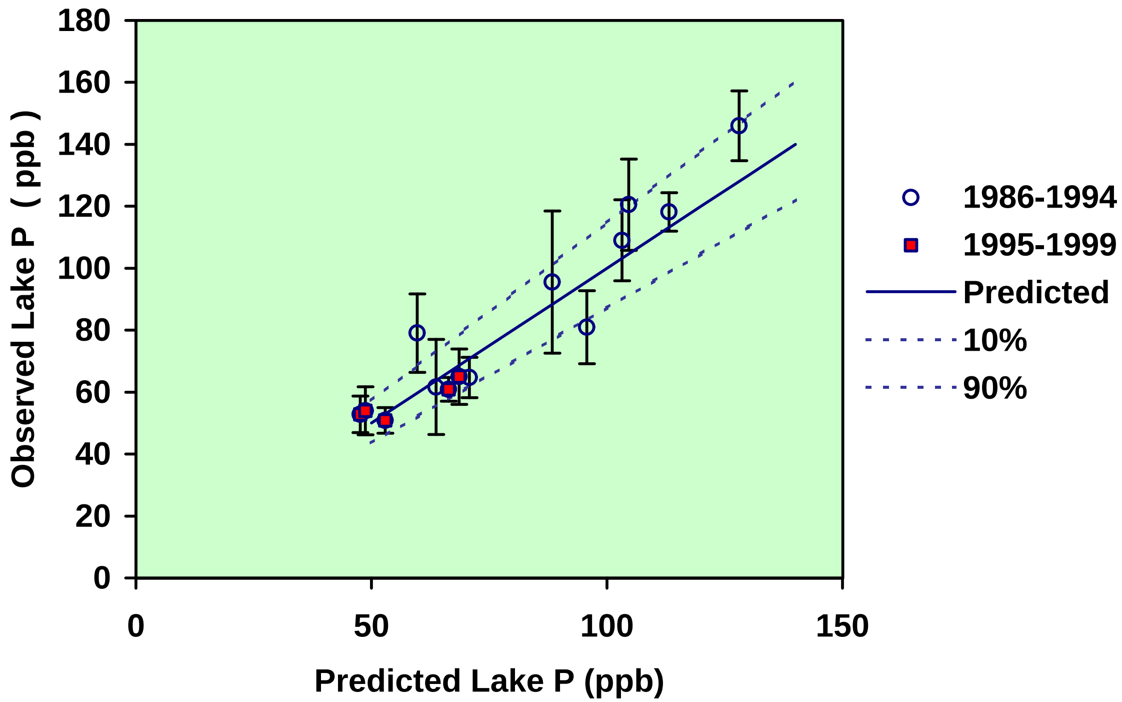
$P = F_P P_O$

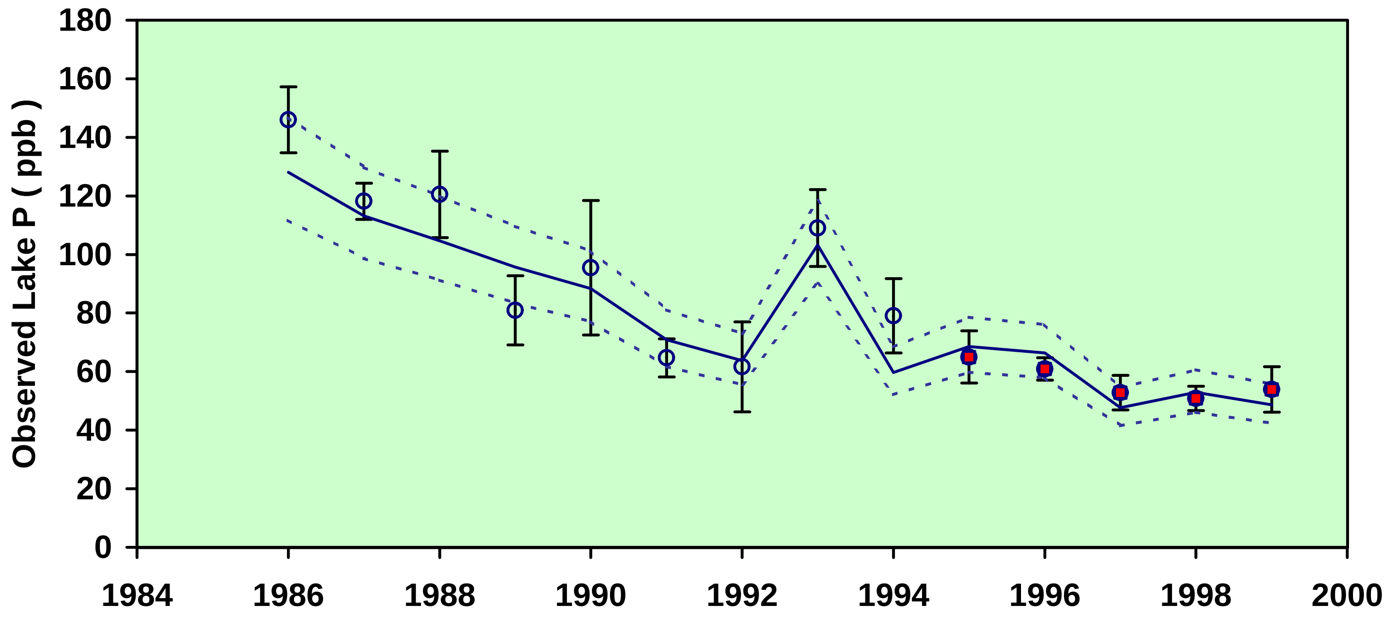
F_P = 0.55 Calibrated to 1995-1999

Period	95-99	86-99
Residual CV	0.09	0.13
R^2	0.29	0.88


Observed & Predicted Annual Outflow P Concentrations
Observed Outflow P (ppb)
300
250
200
150
100
50
0
0
100
200
300
Predicted Outflow P (ppb)
1986-1994
1995-1999
Predicted
10%
90%
Outflow P (ppb)
1984
1986
1988
1990
1992
1994
1996
1998
2000

Observed & Predicted Summer Epilimnetic P Concentrations





Onondaga Lake Empirical Model Network

Lake Outflow Total N:

$N_O = W_N / (Q_O + U_N A)$

W_N = Inflow N Load (kg/yr)

U_N = N Settling Rate = 24.0 m/yr

Calibrated to 1995-1999

Period	95-99	86-99
Residual CV	0.07	0.08
R^2	0.61	0.75

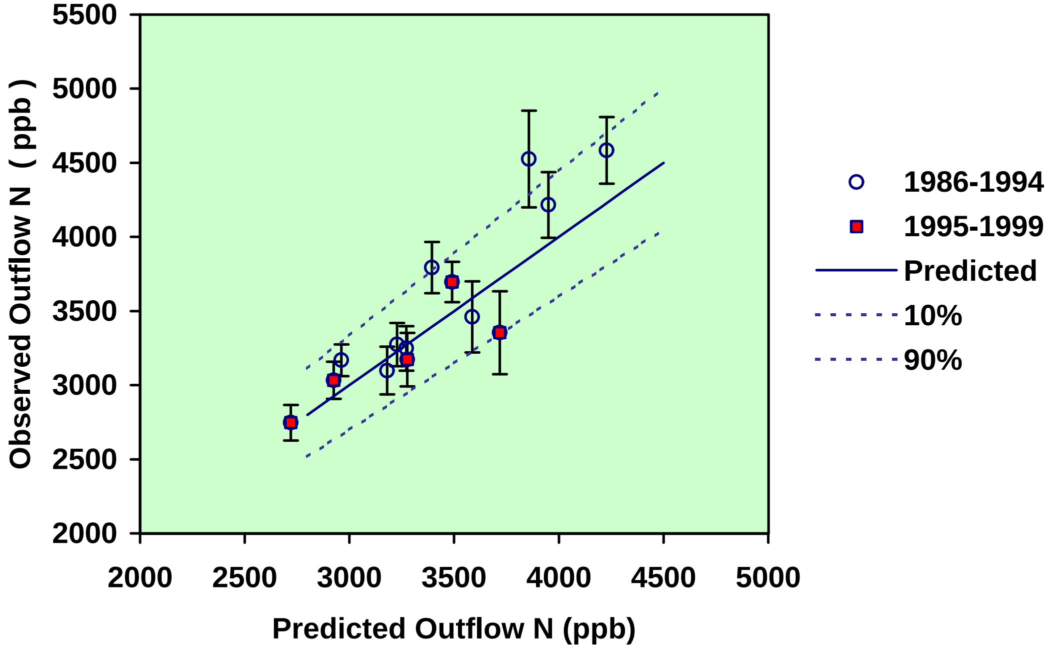
Lake South Epilimnetic Total N:

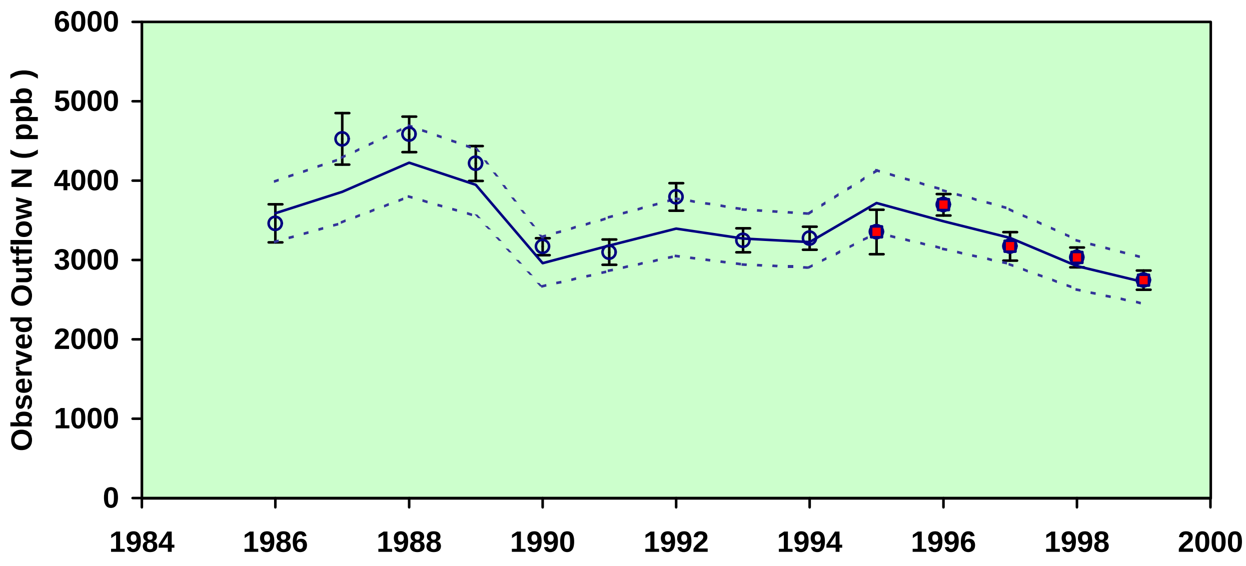
$N = F_N \; No$

F_N = 1.15 Calibrated to 1995-1999

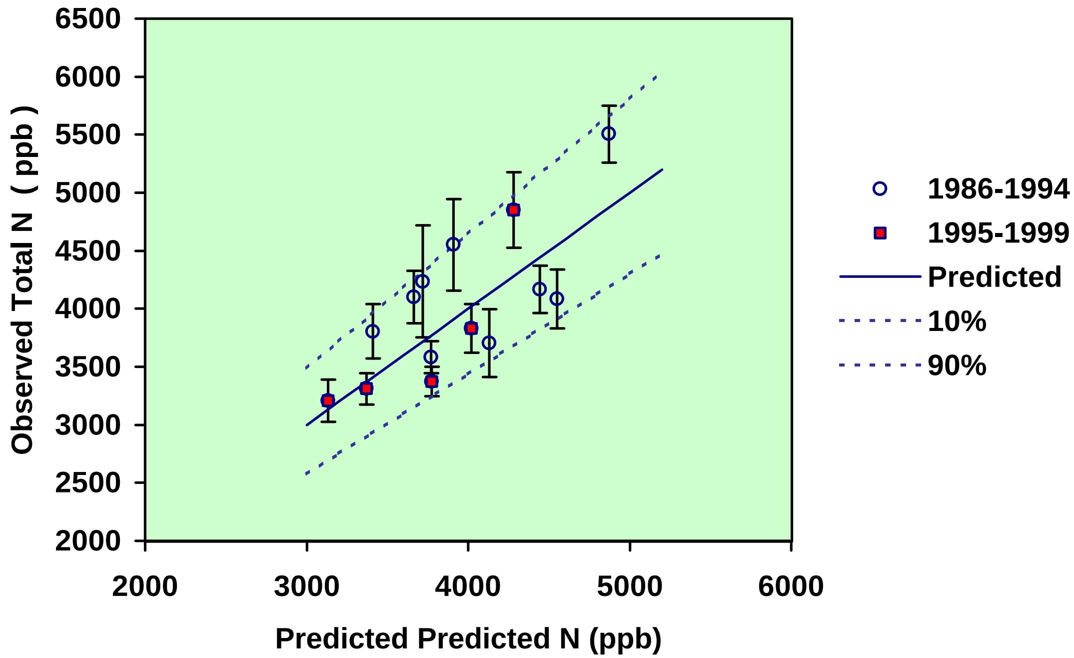
Period	95-99	86-99
Residual CV	0.10	0.11
R^2	0.71	0.53

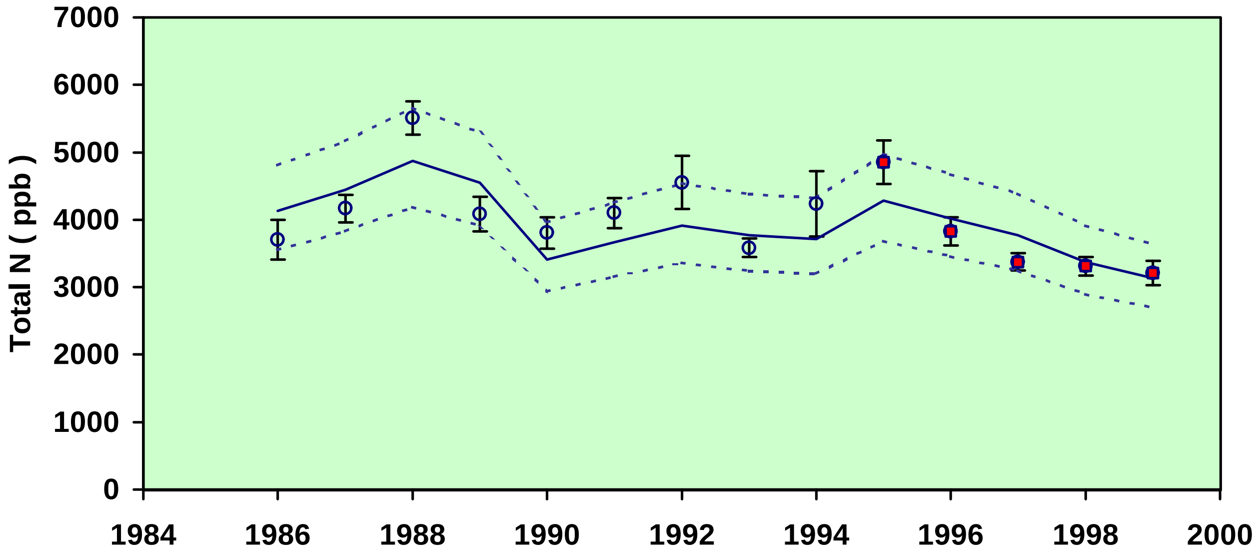
Observed & Predicted Annual Outflow N Concentrations



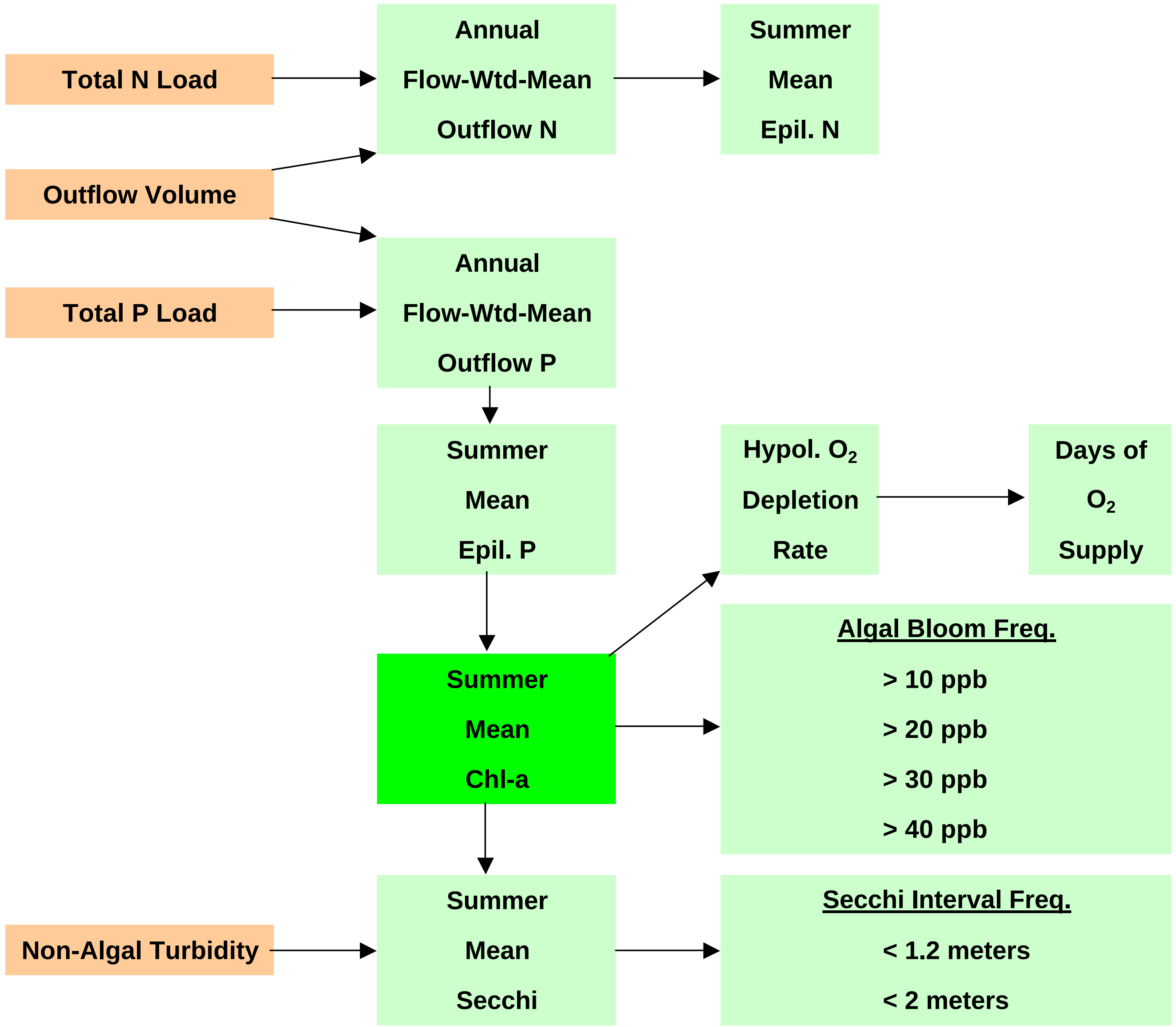


Observed & Predicted Summer Total N Concentrations





Eutrophication Model Network for Onondaga Lake



Onondaga Lake Empirical Model Network

Lake South Chlorophyll-a:

Reference: Jones & Bachman (1976)

$B = k \, P^{1.46}$

k = 0.076 calibrated to 1996-1999 Data

DataSet	J& B	96-99
Residual CV	-	0.24
R^2	0.90	0.66

Algal Bloom Frequencies:

Reference: Walker (1984)

F_X = $1 - \text{Normal}\left[\left(\ln(X) - \ln(B) - 0.5\, S_B^2 \right) / S_B \right]$

S_B = $\left[\ln \left(1 + C_B^2 \right) \right]^{1/2}$

X = Bloom Criterion (10, 20, 30 or 40 ppb)

F_X = Frequency of Chl-a > X

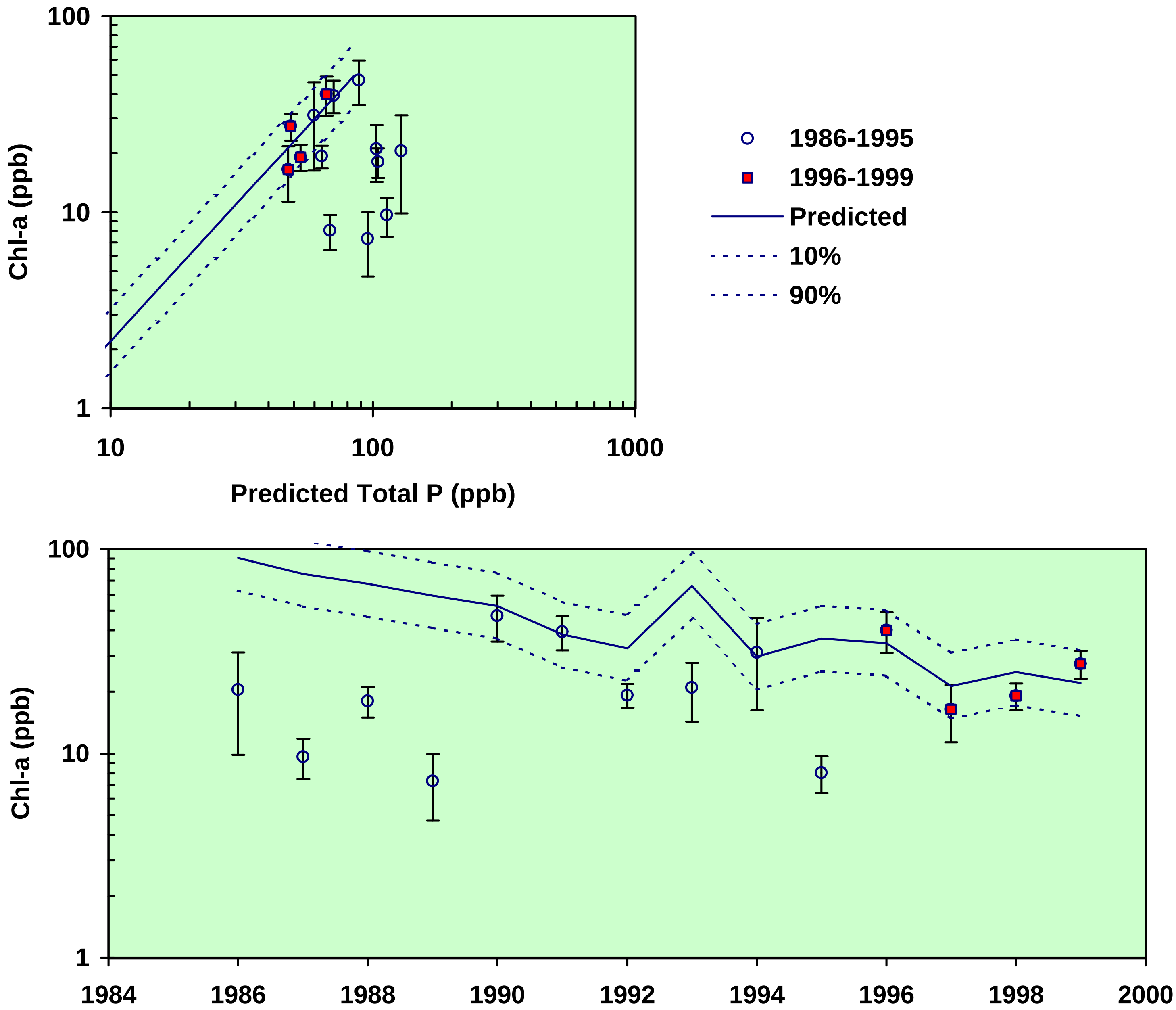
Normal Cumulative Normal Frequency Distribution

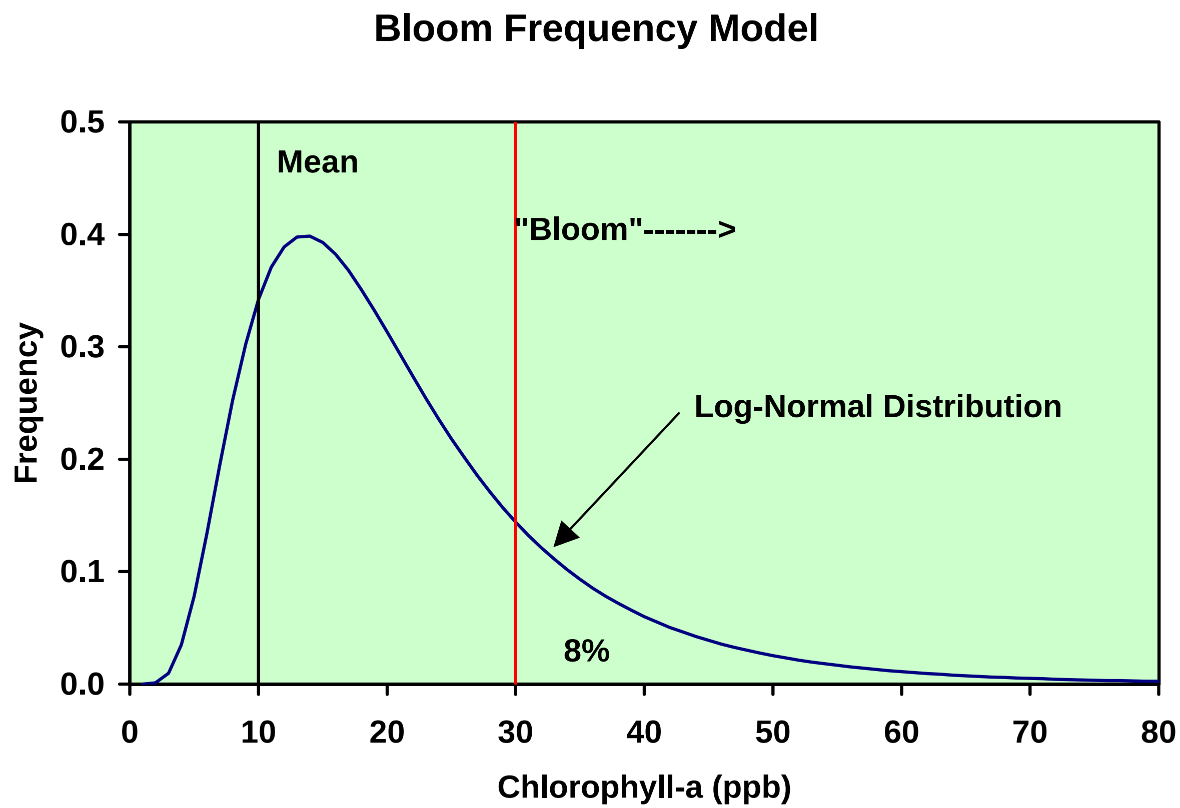
S_B = Standard Deviation of ln (Chl-a)

C_B = Within-Year Temporal CV = 0.600

Calibrated to 1986-1999 Data

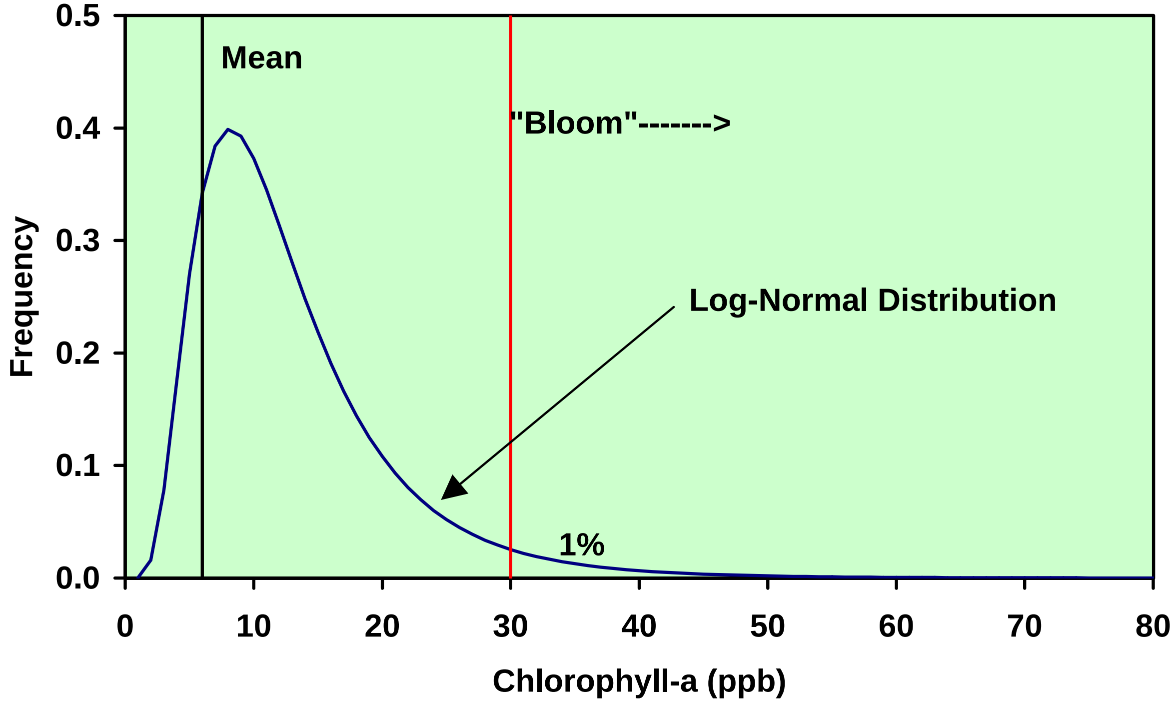
Observed & Predicted Mean Chlorophyll-a





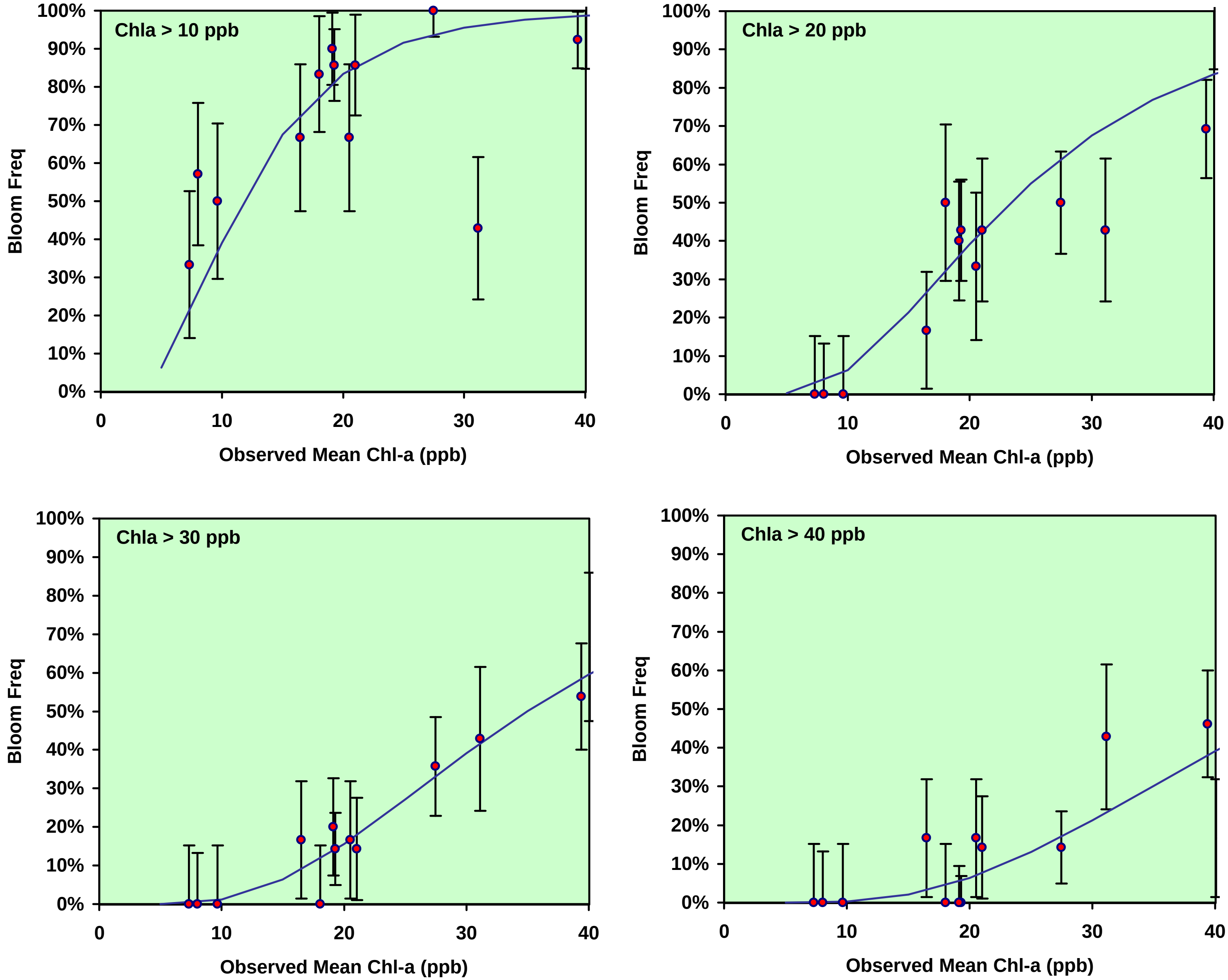
Mean =	10	ppb	Bloom Criterion =	30	ppb
CV =	0.6		Bloom Freq =	7.7%	

Bloom Frequency Model

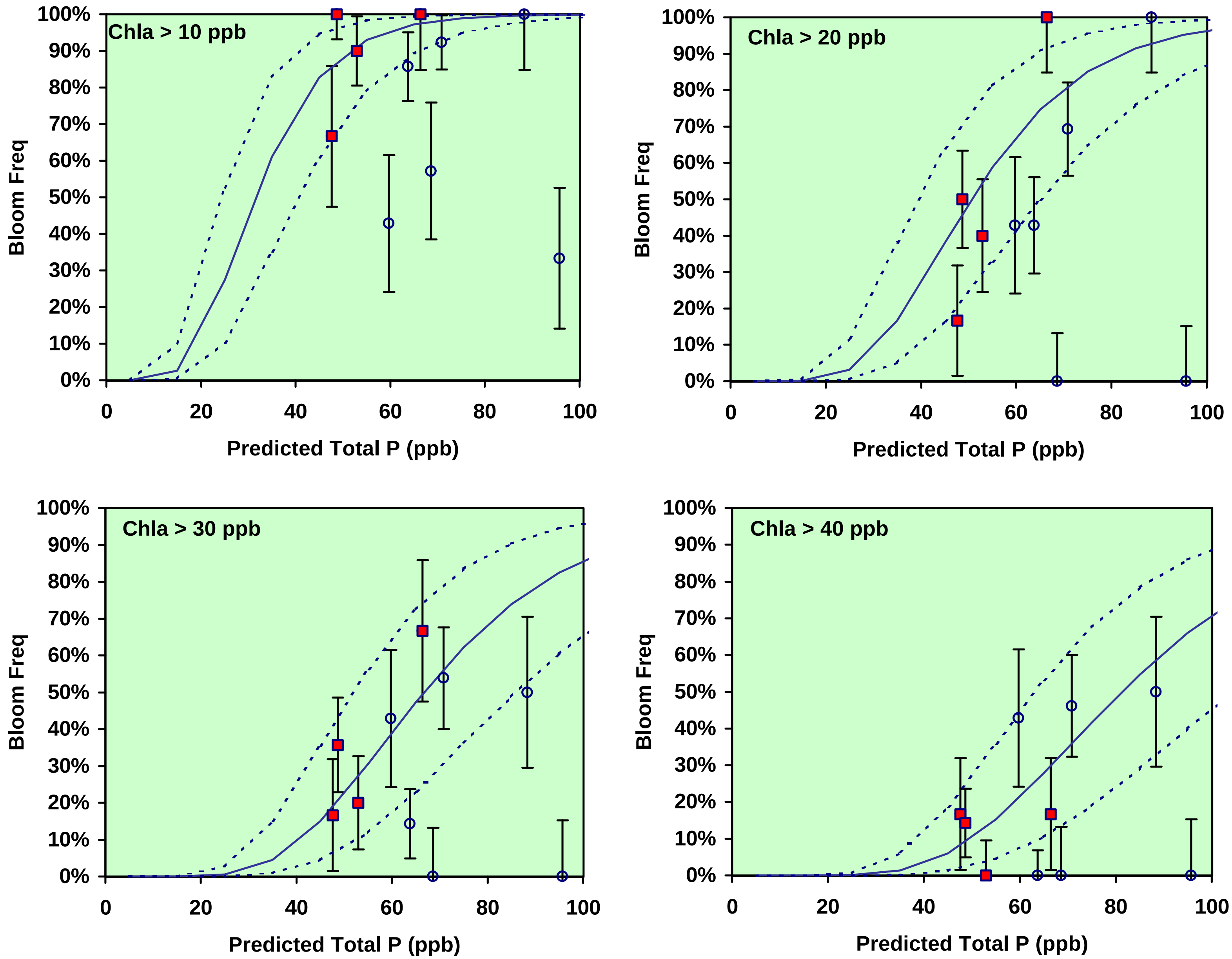


Mean =	6	ppb	Bloom Criterion =	30	ppb
CV =	0.6		Bloom Freq =	0.9%	

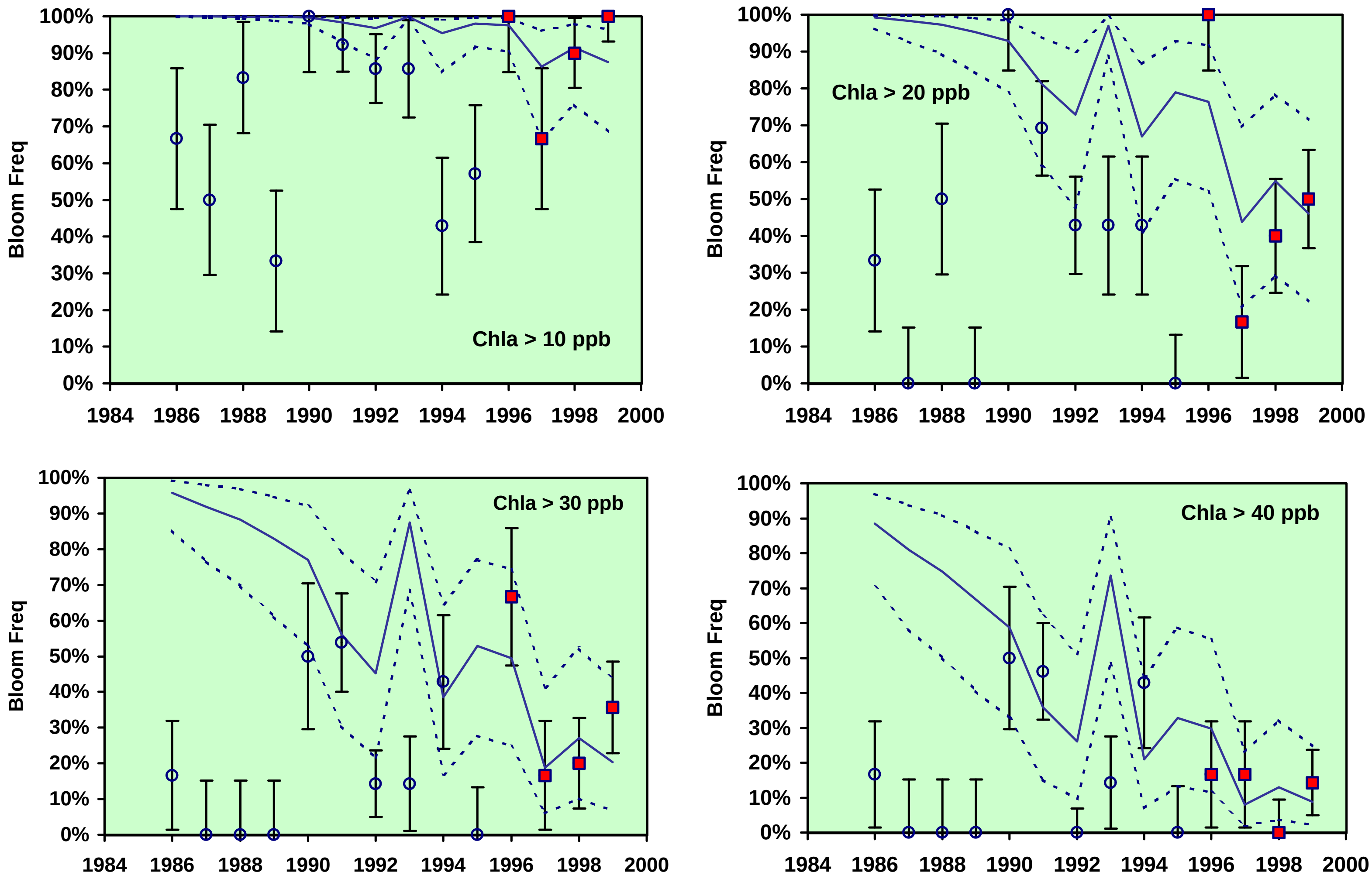
Algal Bloom Frequencies vs. Observed Mean Chlorophyll-a



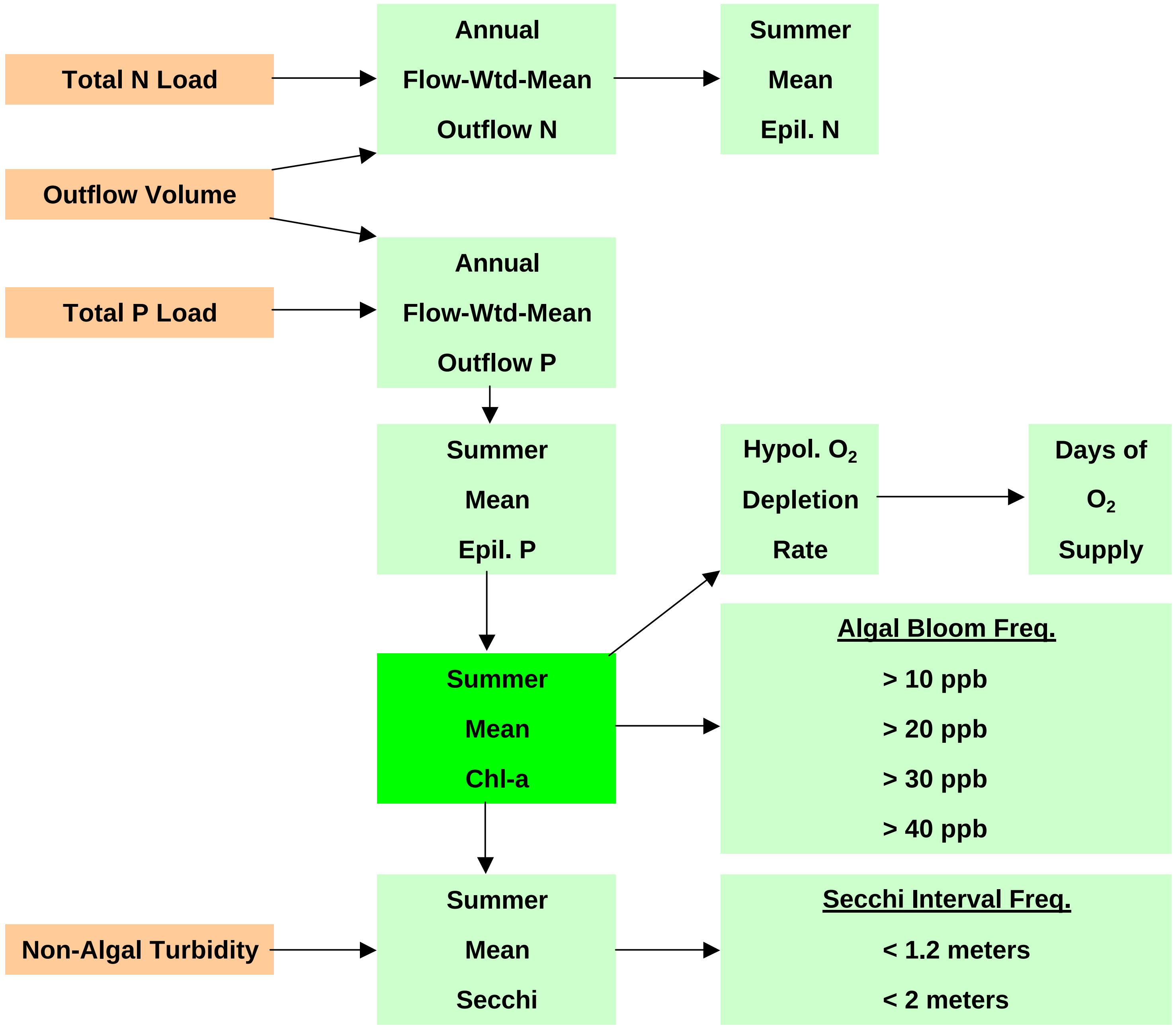
Algal Bloom Frequencies vs. Predicted Total Phosphorus



Algal Bloom Frequencies vs. Year



Eutrophication Model Network for Onondaga Lake



Onondaga Lake Empirical Model Network

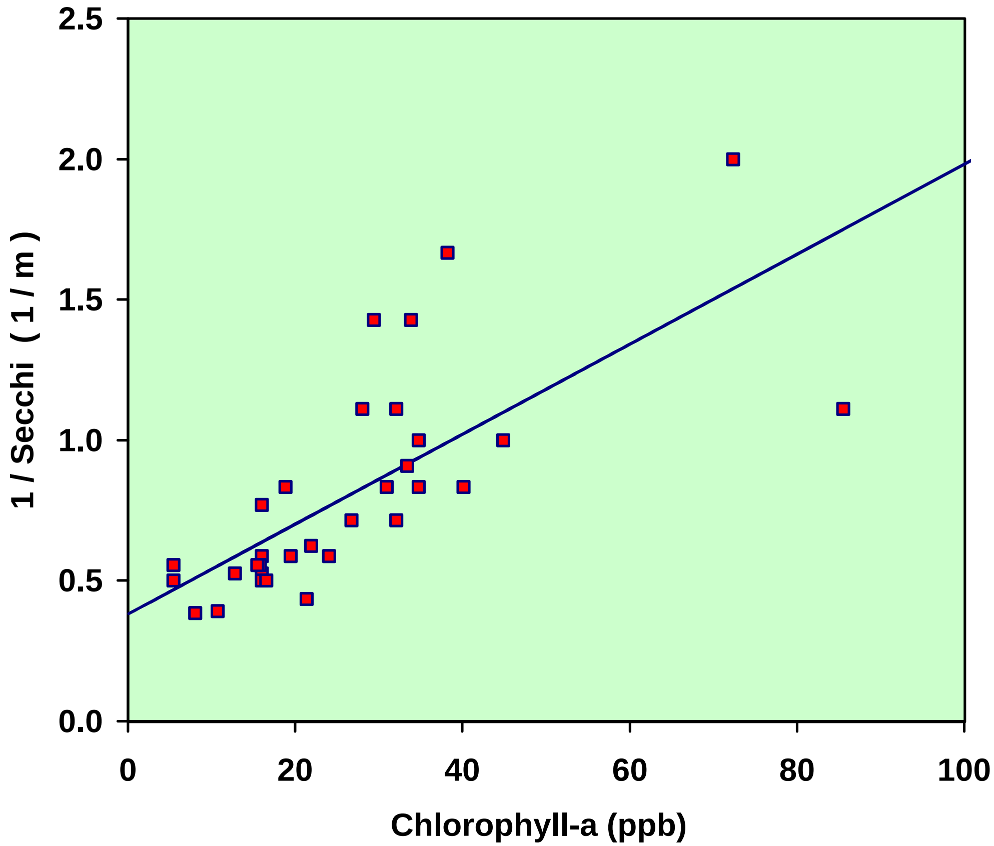
Lake South Secchi Depth:

Reference:	Walker (1985,1996)			
S =	$\exp(S_S^2) / (a + b\ B)$			
Calibrated to Sample Dates, 1996-1999				
a =	0.381	1/m		
b =	0.016	m^2/mg		
		From Predicted Chla		
Period			96-99	86-99
Residual CV			0.19	0.40
R^2			0.39	0.00

Secchi Interval Frequencies:

Reference:	Walker (1984)		
F_Y =	Normal [($\ln(Y) - \ln(S) - 0.5\ S_S^2$) / S_S]		
S_S =	$[\ln(1 + C_S^2)]^{1/2}$	=	0.31
C_S =	0.32	Calibrated to 1986-1999 Data	
Y =	Secchi Criterion (1.2 or 2 m)		
F_Y =	Frequency of Secchi < Y		
S_S =	Standard Deviation of ln (Secchi) =		
C_S =	Within-Year Temporal CV of Secchi Depth		

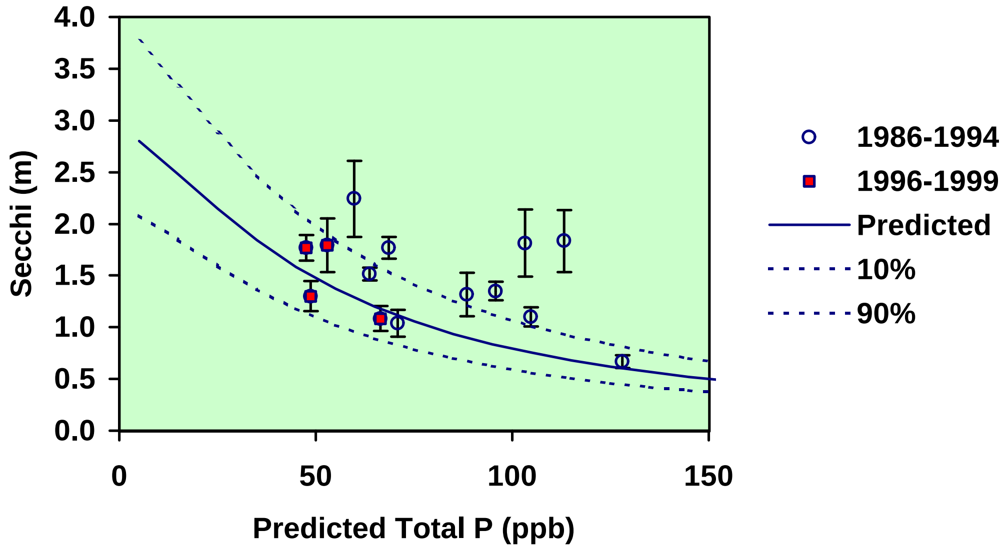
Calibration of Secchi Depth Model

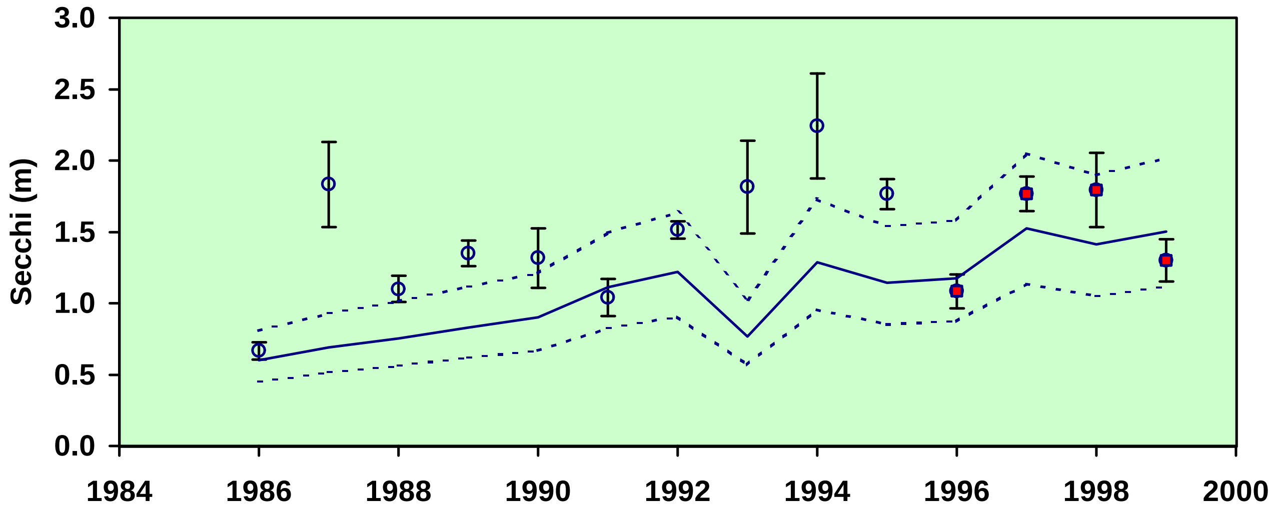


Lake South Epilimnion Samples, 0-3 m, July-September, 1996-1999
Regression:

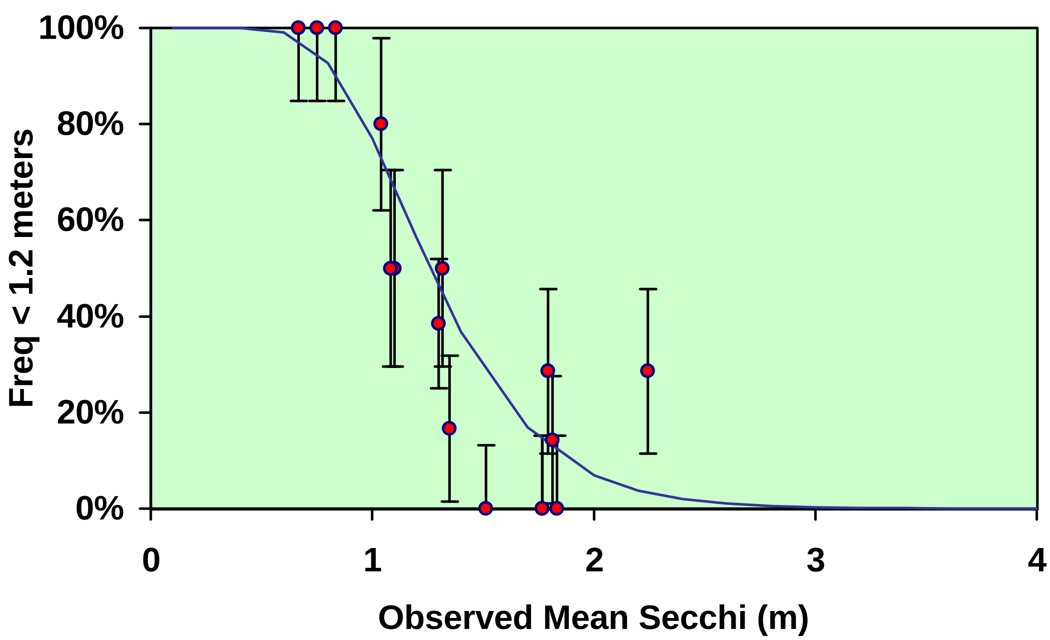
Y =	0.381	+	0.016	X
R^2 =	0.53	SE =	0.27	

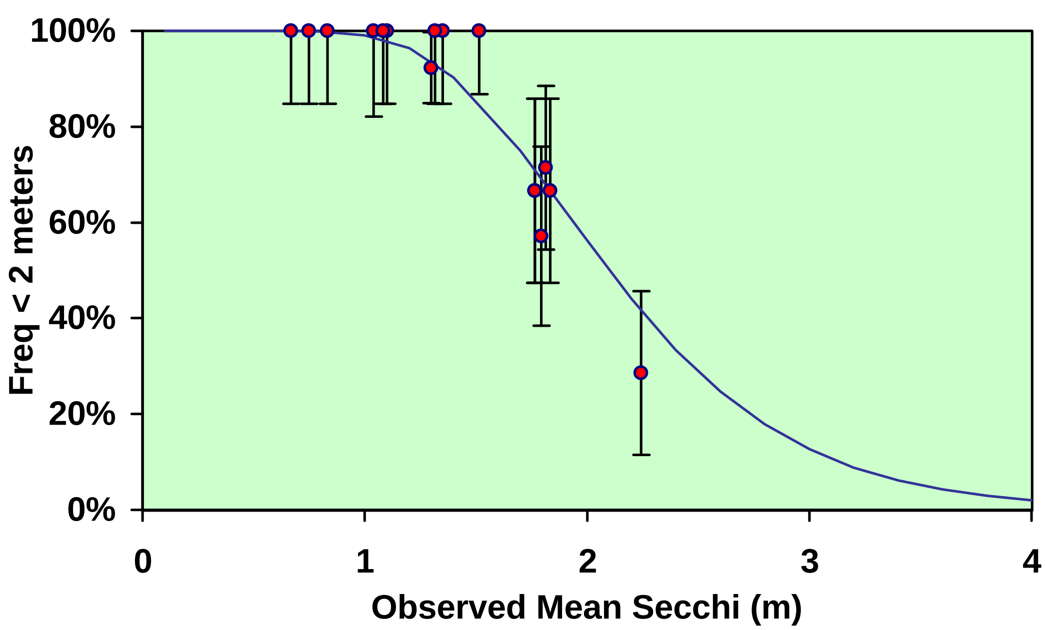
Observed & Predicted Secchi Depth



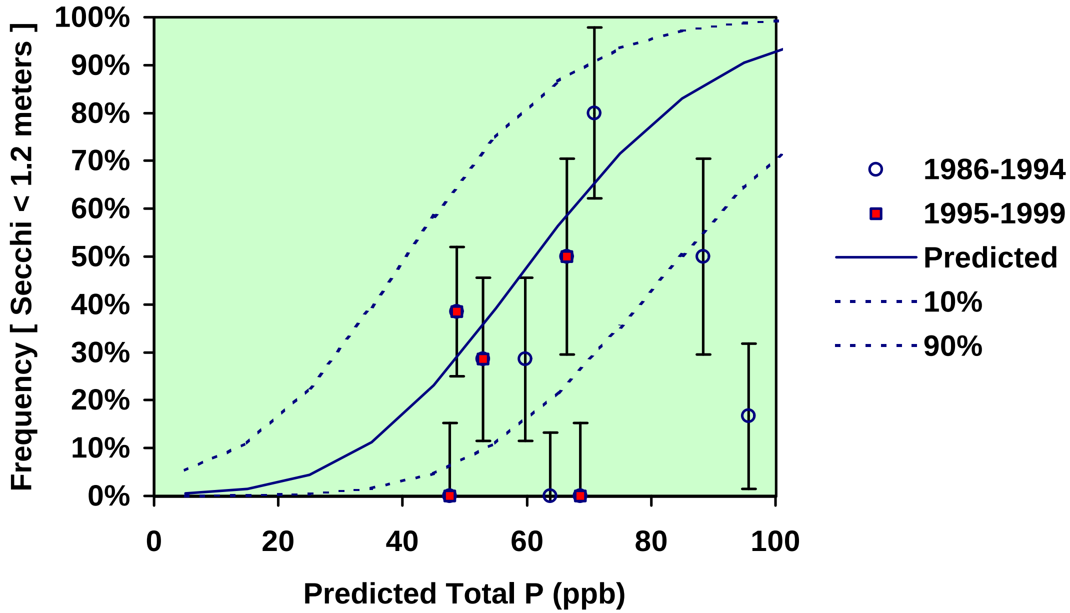


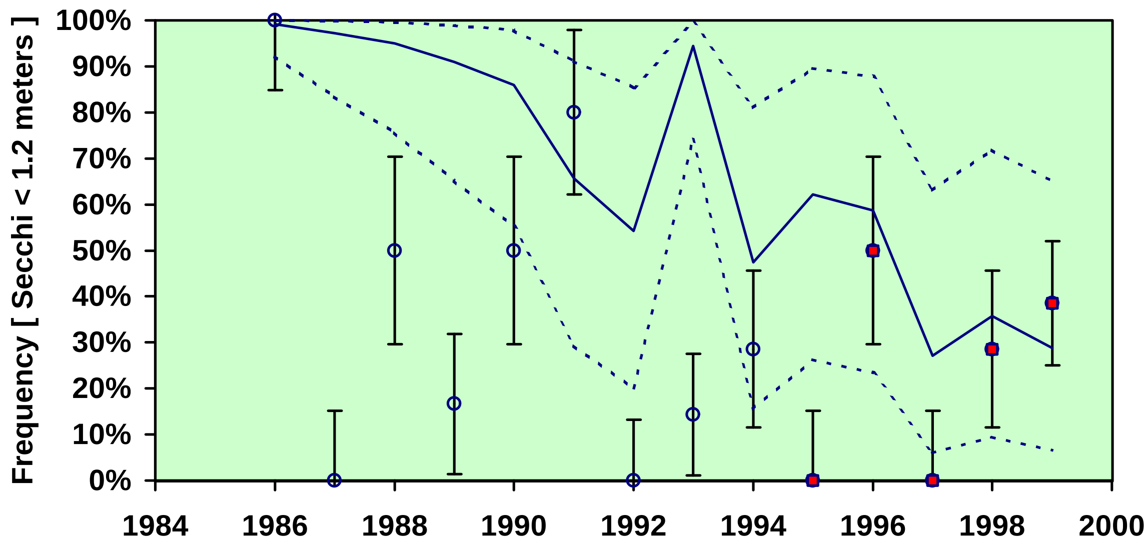
Secchi Interval Frequencies vs. Mean Secchi



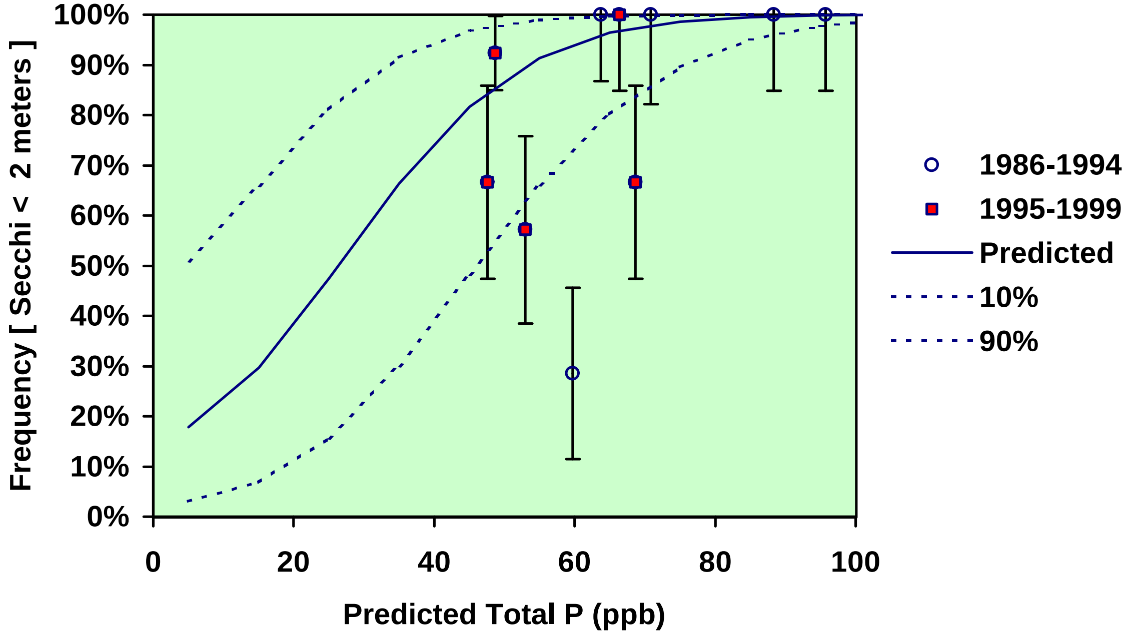


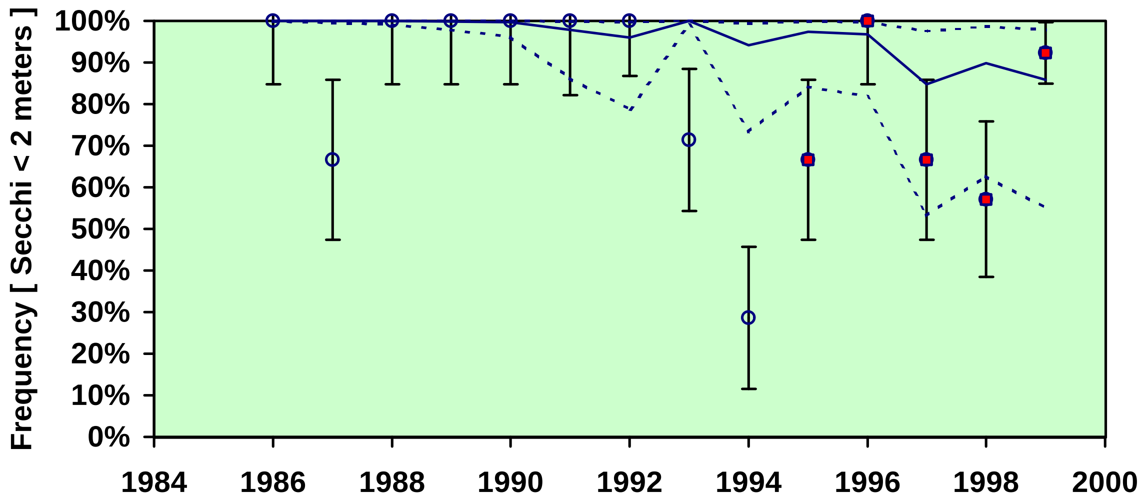
Observed & Predicted Frequency of Secchi < 1.2 meters



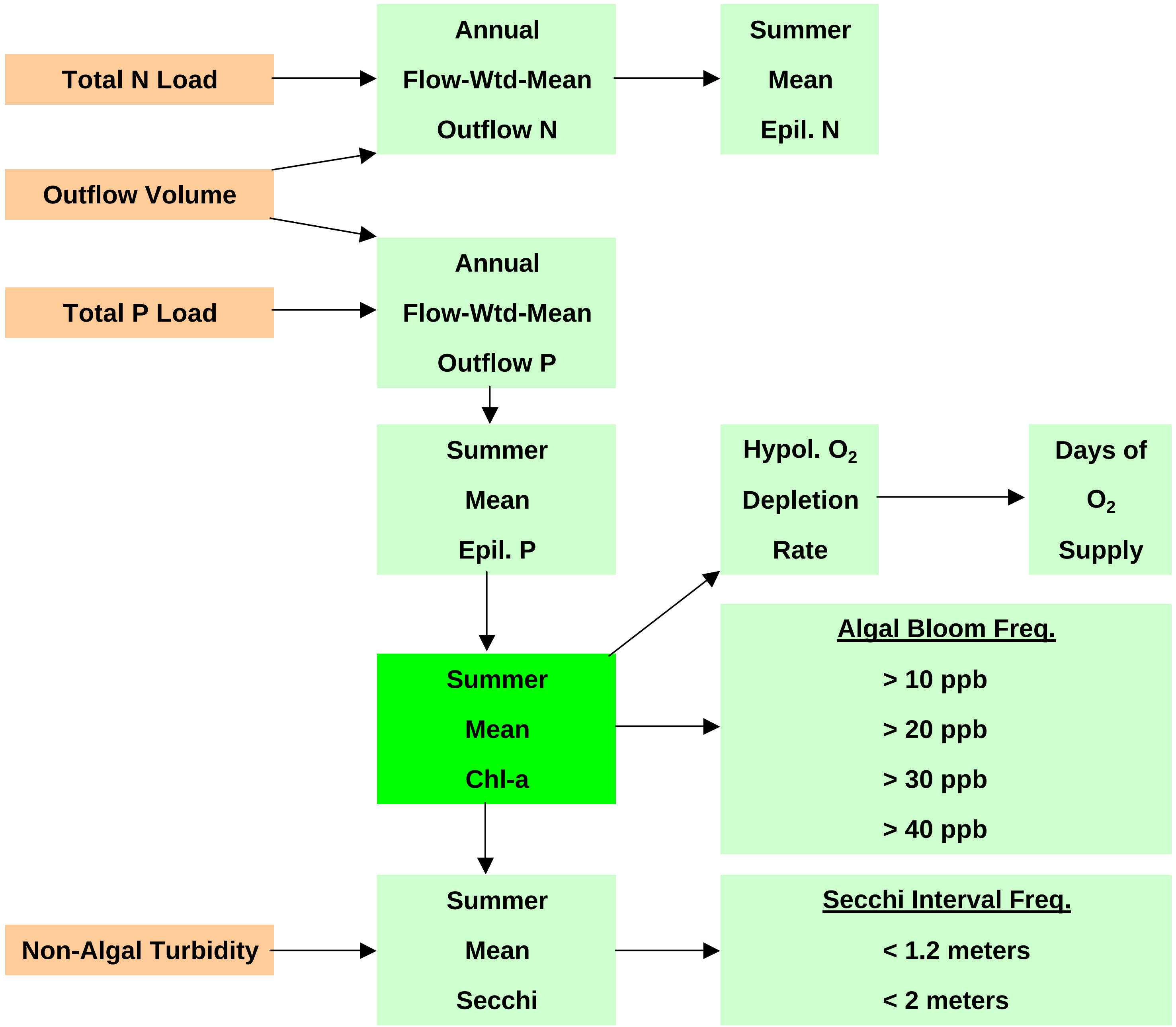


Observed & Predicted Frequency of Secchi < 2 meters





Eutrophication Model Network for Onondaga Lake



Onondaga Lake Empirical Model Network

Hypolimnetic Oxygen Depletion Rate:

Reference: Walker (1979)

$\text{Log HOD} = -0.58 + 0.0204\ I + 4.55 \log Z - 2.04 (\text{Log } Z)^2$

I = Phosphorus Trophic Index = -15.6 + 46.1 log P

Z = Mean Depth = 10.90 m

$\text{HOD} = 42.3\ P^{0.94}$ not recalibrated

DataSet	Walker(1979)	96-99
Residual CV	0.23	0.21
R^2	0.91	0.00

Days of Oxygen Supply in Hypolimnion:

Reference: Walker (1979)

$T_{DO} = 1000\ DO_S\ Z_H\ /\ \text{HOD}$

$T_{ANOXIC} = T_{STRAT} - T_{DO}$

T_{DO} = Oxygen Supply at Spring Turnover (days)

T_{ANOXIC} = Duration of Anoxic Period (days)

DO_S = Oxygen at Spring Turnover = 12 ppm

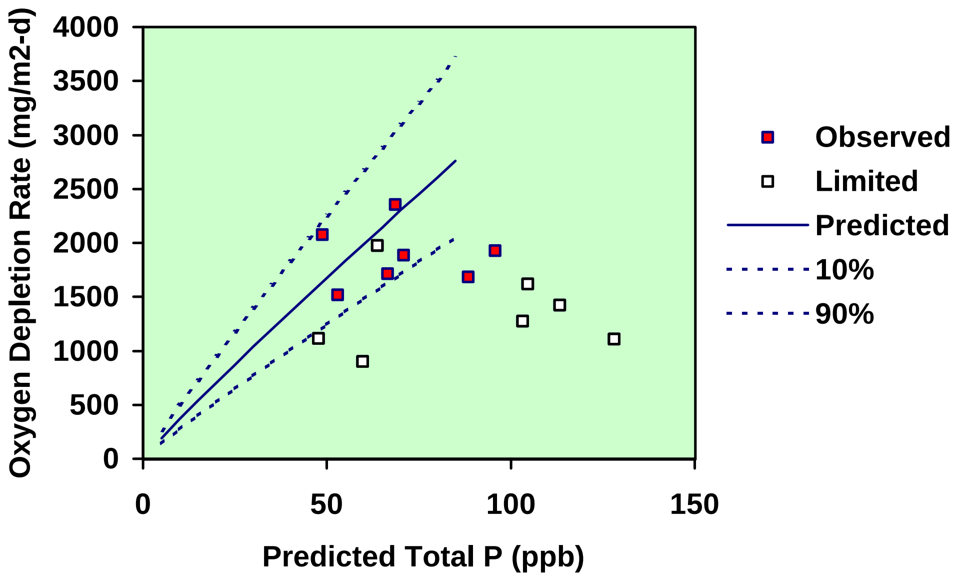
Z_H = Mean Hypolimnetic Depth = 8.34 meters

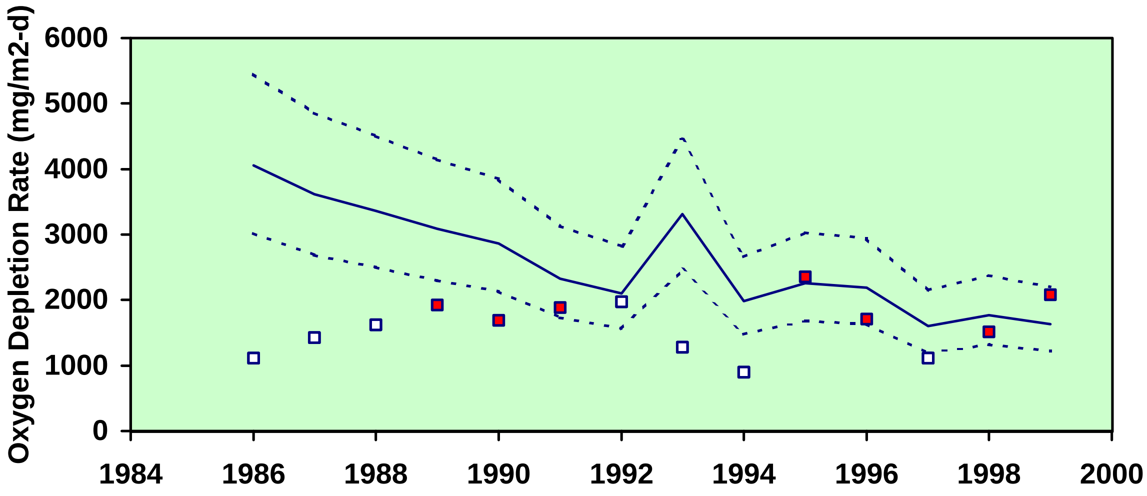
for 6-meter Thermocline Depth

T_{STRAT} = Duration of Stratified Period = 183 days

April 15 - October 15

Observed & Predicted Hypolimnetic Oxygen Depletion Rates





Limited = observed value limited by incomplete spring turnover or partial depletion of oxygen;

Model & Measurement Errors

Period	Residual Standard Error Calibration Pd 1995-1999	 Entire Pd 1986-1999	Measurement Error*
Inflow P	*N/A*	*N/A*	6%
Outflow P	11%	28%	11%
Lake P	9%	13%	11%
Outflow N	7%	8%	5%
Lake N	10%	11%	5%
Mean Chla	24%	*N/A*	21%
Mean Secchi	19%	*N/A*	10%
HOD	21%	*N/A*	

* Average Relative Standard Error of Observed Mean, 1995-1999

Onondaga Lake Empirical Eutrophication Model

Model Parameters	**Units**	**Input Value**
Lake Area	km^2	11.7
P Settling Rate	m/yr	22.873
Epil P / Outflow P	-	0.550
Outflow P Error CV	-	0.112
Lake P Error CV	-	0.089
Chla/P Slope	-	1.460
Chla/P Intercept	-	0.076
Chl-a Error CV	-	0.241
Chla Temporal CV	-	0.600
Non-Algal Turbidity	1/m	0.381
Secchi/Chla Slope	m^2/mg	0.016
Secchi Error CV	-	0.193
Secchi Temporal CV	-	0.320
HOD Intercept	-	42.400
HOD Slope		0.940
HOD Error CV		0.230
Spring DO Conc	ppm	12.000
Hypol. Depth	m	8.340
Stratified Period	days	183.000

Scenario			
Outflow Volume	hm^3/yr	399	1995-1999 Average
Inflow Load	kg/yr	68752	1995-1999 Average

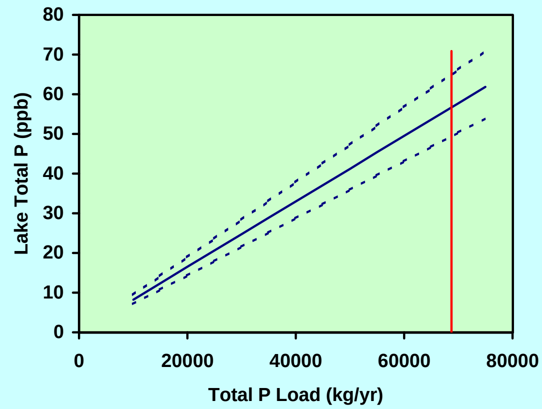
Predicted Reponses		**Units**	**Mean**	**Low (10%)**	**High (90%)**
Outflow P Conc		ppb	103	87	123
Lake P Conc		ppb	57	49	65
Mean Chlorophyll-a		ppb	28	19	40
Algal Bloom Frequencies					
	>	10	0.94	0.81	0.99
	>	20	0.62	0.36	0.83
	>	30	0.33	0.14	0.59
	>	40	0.17	0.05	0.39
Mean Secchi Depth		m	1.34	1.61	1.08
Secchi Interval Frequencies					
	<	1.2	0.42	0.22	0.69
	<	2	0.92	0.80	0.98
Oxygen Depletion Rate		mg/m^2-day	1887	1326	2686
Days of O2 Supply		days	53	75	37
Anoxic Period		days	130	108	146

Evaluation of a Hypothetical Phosphorus Load Scenario

Control Program:

	Percent Reduction vs. 1995-1999	
	Flow	**Conc**
NonPoint Sources	0%	20%
Industrial Sources	0%	0%
Municipal Sources	0%	50%

Lake Mass Balances		Hypothetical Case			Calibration: 1995-1999		
		Flow	**Load**	**Conc**	**Flow**	**Load**	**Conc**
Source		**10^6 m3**	**kg**	**ppb**	**10^6 m3**	**kg**	**ppb**
NonPoint		304	20147	66	304	25183	83
Industrial		1	109	117	1	109	117
Municipal		92	21570	235	92	43140	470
Precipitation		11	321	30	11	321	30
Total Inflow		408	42146	103	408	68752	169
Evaporation		9			9		
Outflow		399	25224	63	399	41148	103
Retention			16922		0	27604	
Predicted Water Quality		**Mean**	**10%**	**90%**	**Mean**	**10%**	**90%**
Outflow P	**ppb**	63	53	75	103	87	123
Summer Epil. P	**ppb**	35	30	40	57	49	65
Mean Chlorophyll-a	**ppb**	13.5	9.3	19.6	27.6	19.1	39.9
Algal Bloom Frequencies							
>	**10**	60%	34%	82%	94%	81%	99%
>	**20**	16%	5%	38%	62%	36%	83%
>	**30**	4%	1%	15%	33%	14%	59%
>	**40**	1%	0%	6%	17%	5%	39%
Mean Secchi Depth	**m**	1.8	2.1	1.6	1.3	1.6	1.1
Secchi Interval Frequencies							
<	**1.2**	11%	5%	23%	42%	22%	69%
<	**2**	66%	51%	81%	92%	80%	98%
Oxygen Depletion Rate	**mg/m2-day**	1191	837	1696	1887	1326	2686
Days of O2 Supply	**days**	84	120	59	53	75	37
Anoxic Period	**days**	99	63	124	130	108	146

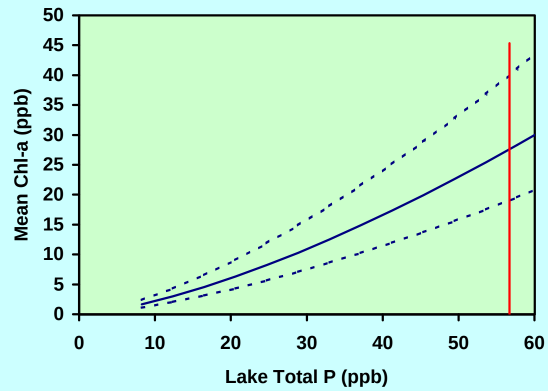


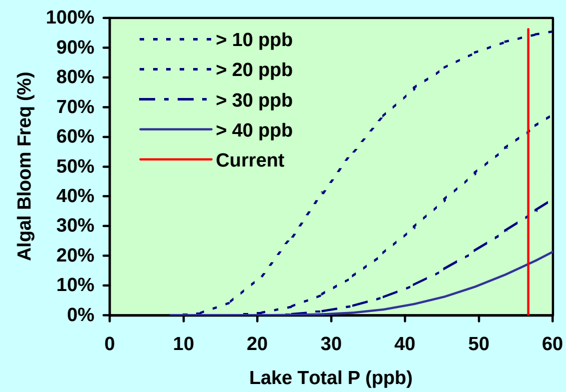
Predicted Lake Responses to Reductions in Phosphorus Load

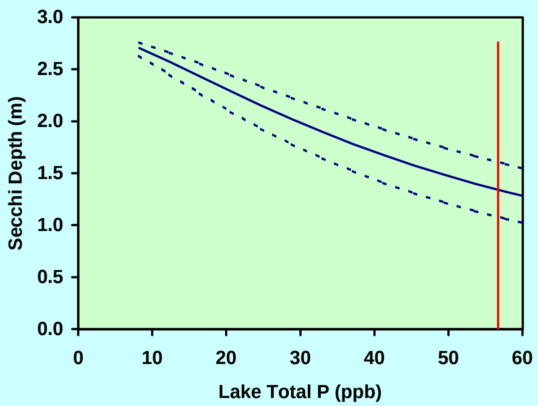
Average Outflow = 399 hm^3/yr

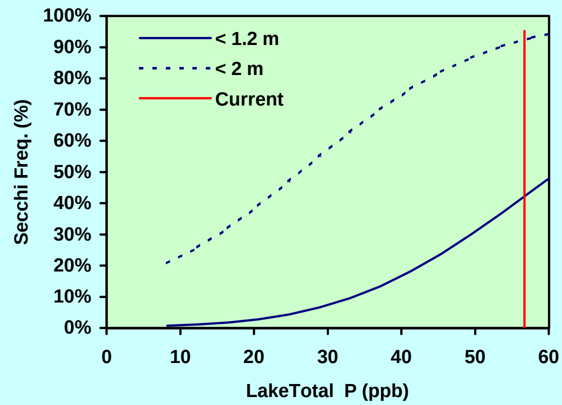
Total P Load = 68752 kg/yr

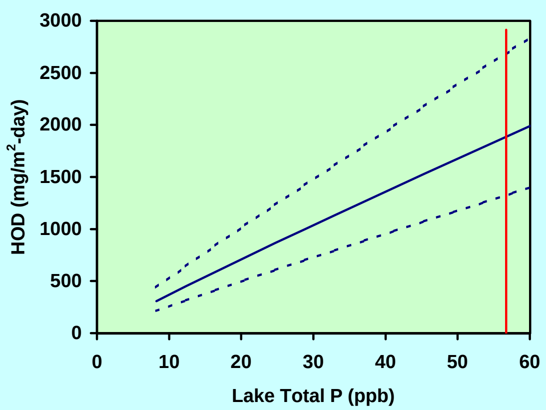
Dashed lines show 80% prediction intervals

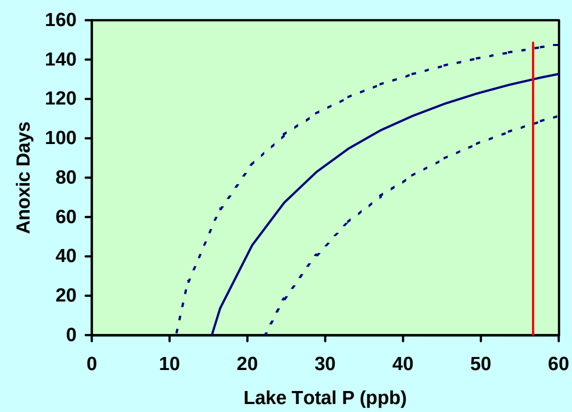












Conclusions

Historically, Lake P levels responded quickly to reductions in external load.

Rapid response suggests that P levels are controlled more by recent external loads than by recycling of historical loads from bottom sediments. The latter may become important with further reductions in external load.

Limited response of trophic state to historical reductions in external P load attributed to algal growth limitation by factors other than P.

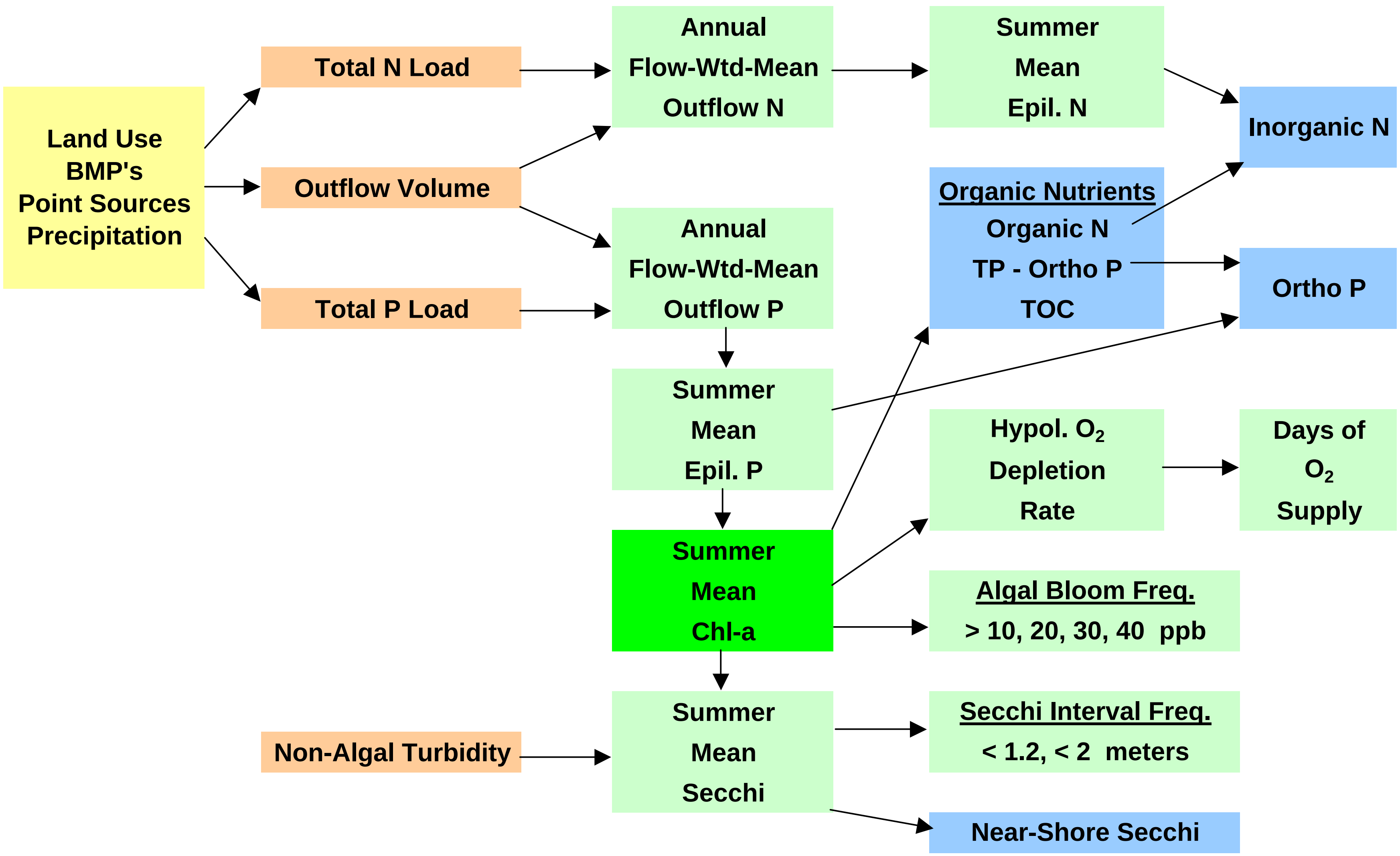
Phosphorus approached growth-limiting levels in 1996-1999:

- Cumulative effects of historical reductions in external loads
- Reductions in Lake Ortho P levels
- Convergence of TSI's with predictions of empirical models calibrated to other phosphorus-limited lakes

TSI's likely to be more responsive to future reductions in external P load.

Residual standard errors are less than or equal to typical values derived from other lake & reservoir data sets.

Expanded Eutrophication Model Network for Onondaga Lake



Recommendations

Use models to track progress relative to lake goals.

Recalibrate & refine models models every 2-3 years.

Perform error analysis to partition measurement error, model error, & year-to-year variations; couple with AMP Statistical Framework.

Couple with simple watershed model relating P loads to land use & BMP's

Add organic nutrient forms (P, N, C) & near-shore transparency.

Modify to account for different responses to point vs. nonpoint loads.

Integrate & compare data from other regional lakes.

Develop interactive software to evaluate alternative management scenarios under a range of hydrologic conditions.

Modify to generate daily loads & monthly mass balances.

Couple with Seneca River Model.

Consider parallel development of a mechanistic lake model.