Evaluation of Water Quality Controls in St. Paul Water Utility Watersheds

Analysis of 1984-1999 Monitoring Data

prepared for

Board of Water Commisioners
St. Paul, Minnesota

by

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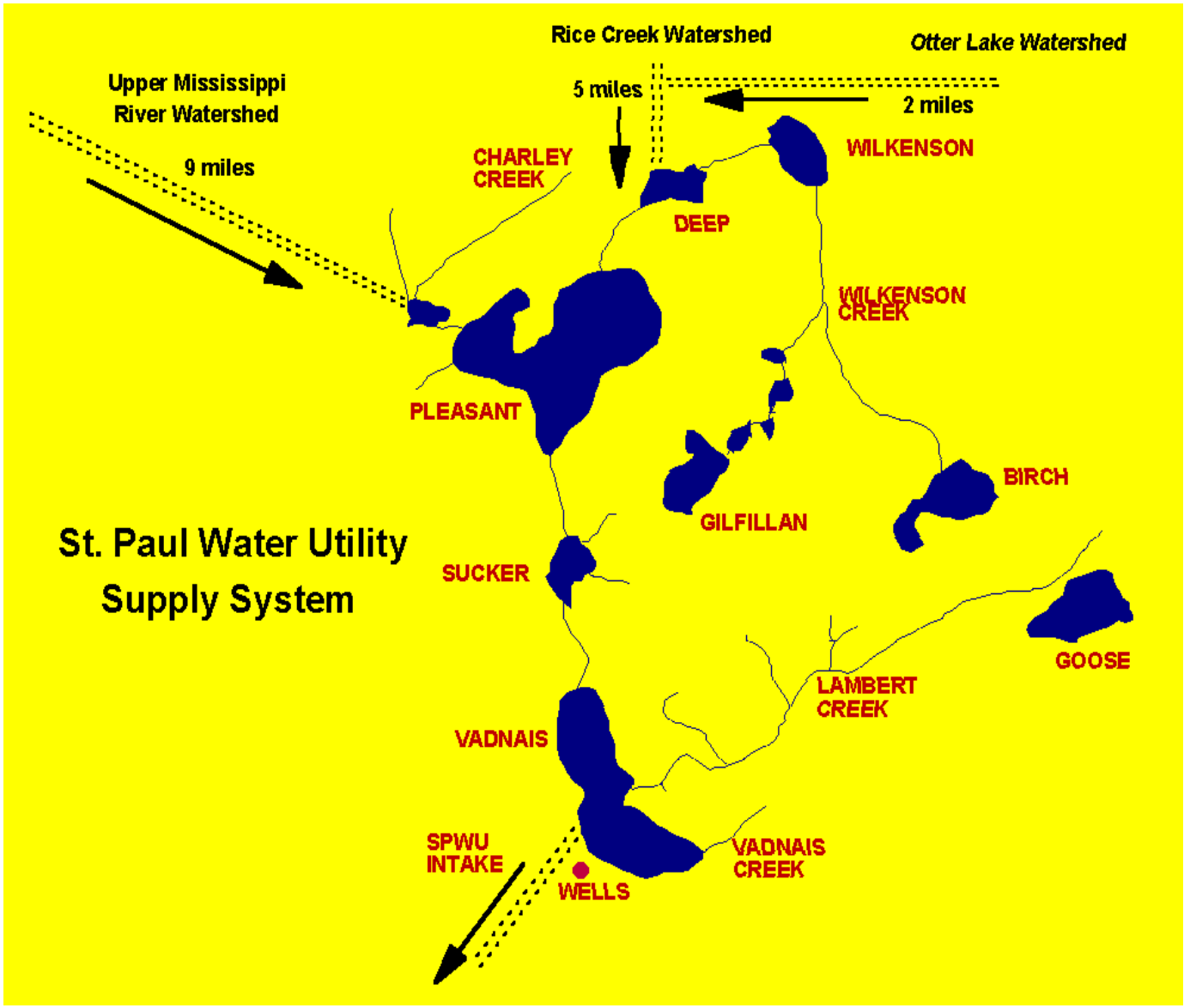
Analysis of 1984-1999 Monitoring Data

- Project History
- Objectives
- Conceptual Model
- Diagnostic Study Design
- Control Program
- Monitoring Results
- Conclusions
- Recommendations


Rice Creek Watershed
Otter Lake Watershed
Upper Mississippi
River Watershed
5 miles
2 miles
9 miles
CHARLEY
CREEK
WILKENSON
DEEP
WILKENSON
CREEK
PLEASANT
BIRCH
GILFILLAN
St. Paul Water Utility
Supply System
SUCKER
GOOSE
LAMBERT
CREEK
VADNAIS
SPWU
INTAKE
VADNAIS
CREEK
WELLS

Objectives
Vadnais Lake Chain Diagnostic Study
SPWU Taste & Odor Control Program
1984 - 1999

- **Characterize basic limnology of supply lakes**

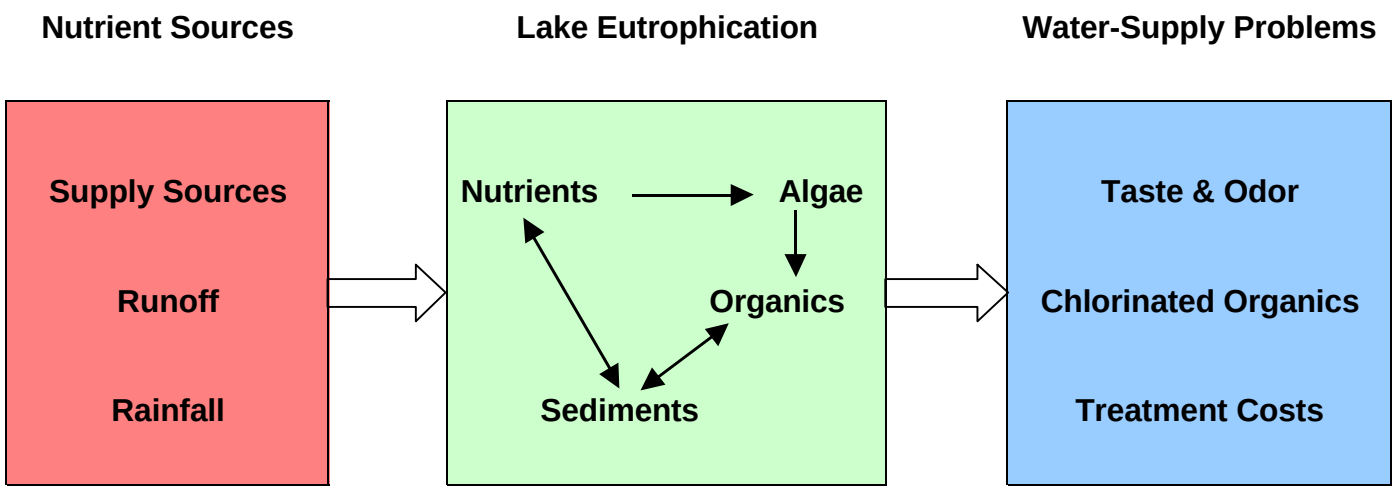
- **Quantify runoff & nutrient loadings from supply sources under existing & future land uses**

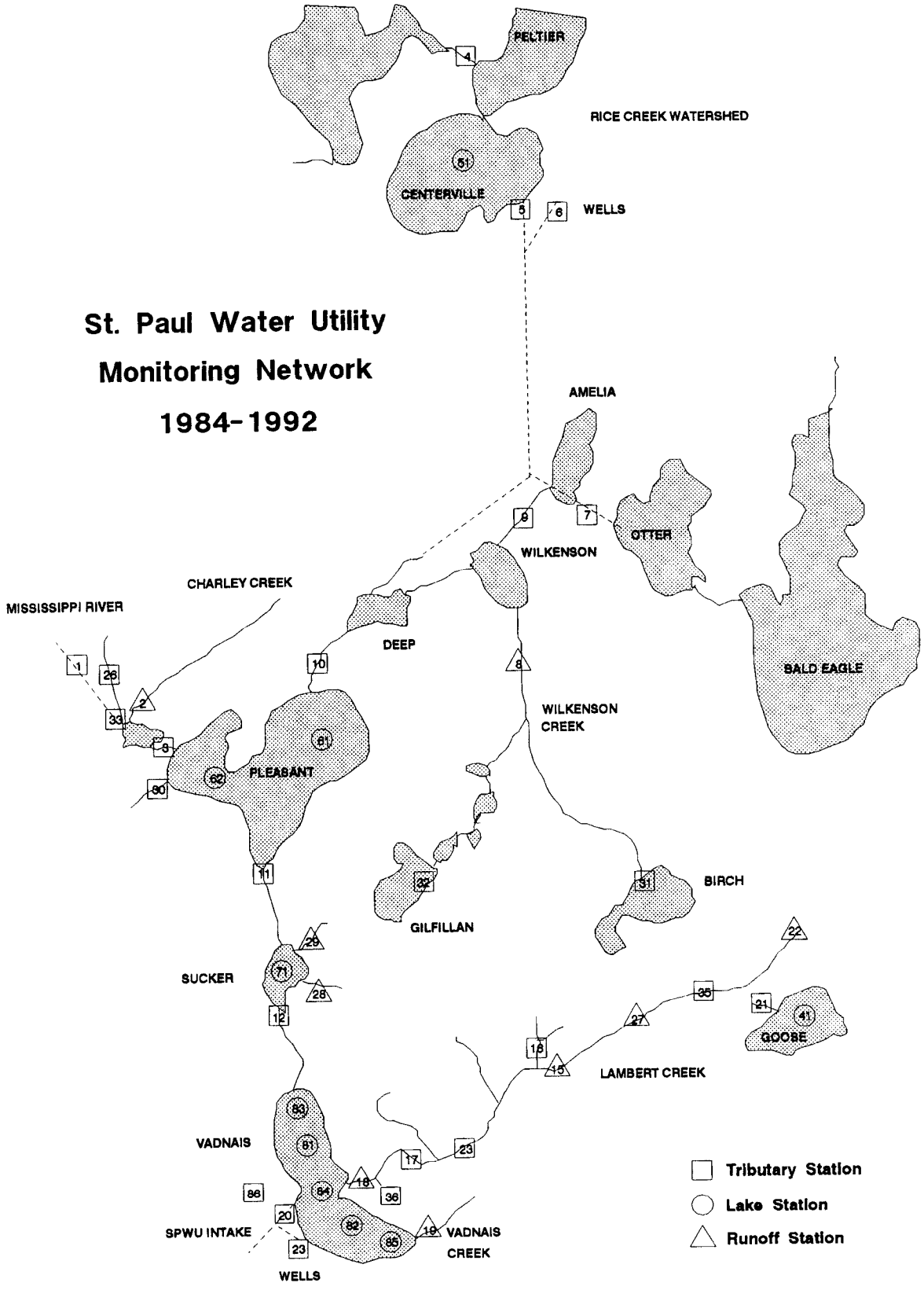
- **Assess cause-effect relationships linking watersheds, diversions, lake water quality, & taste-and-odor episodes**

- **Provide data & models for design & evaluation of control measures**

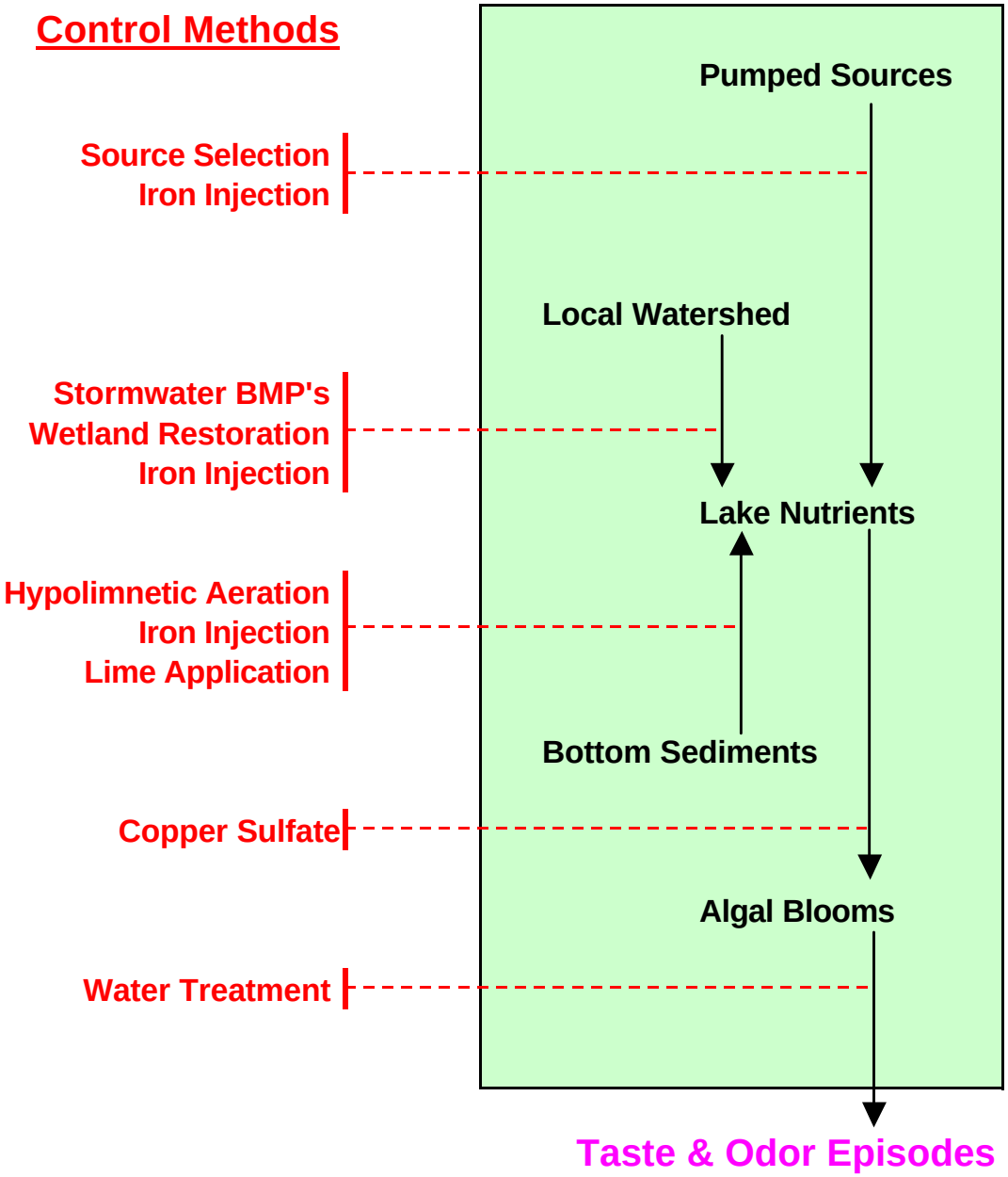
- **Track responses to implementation of controls**

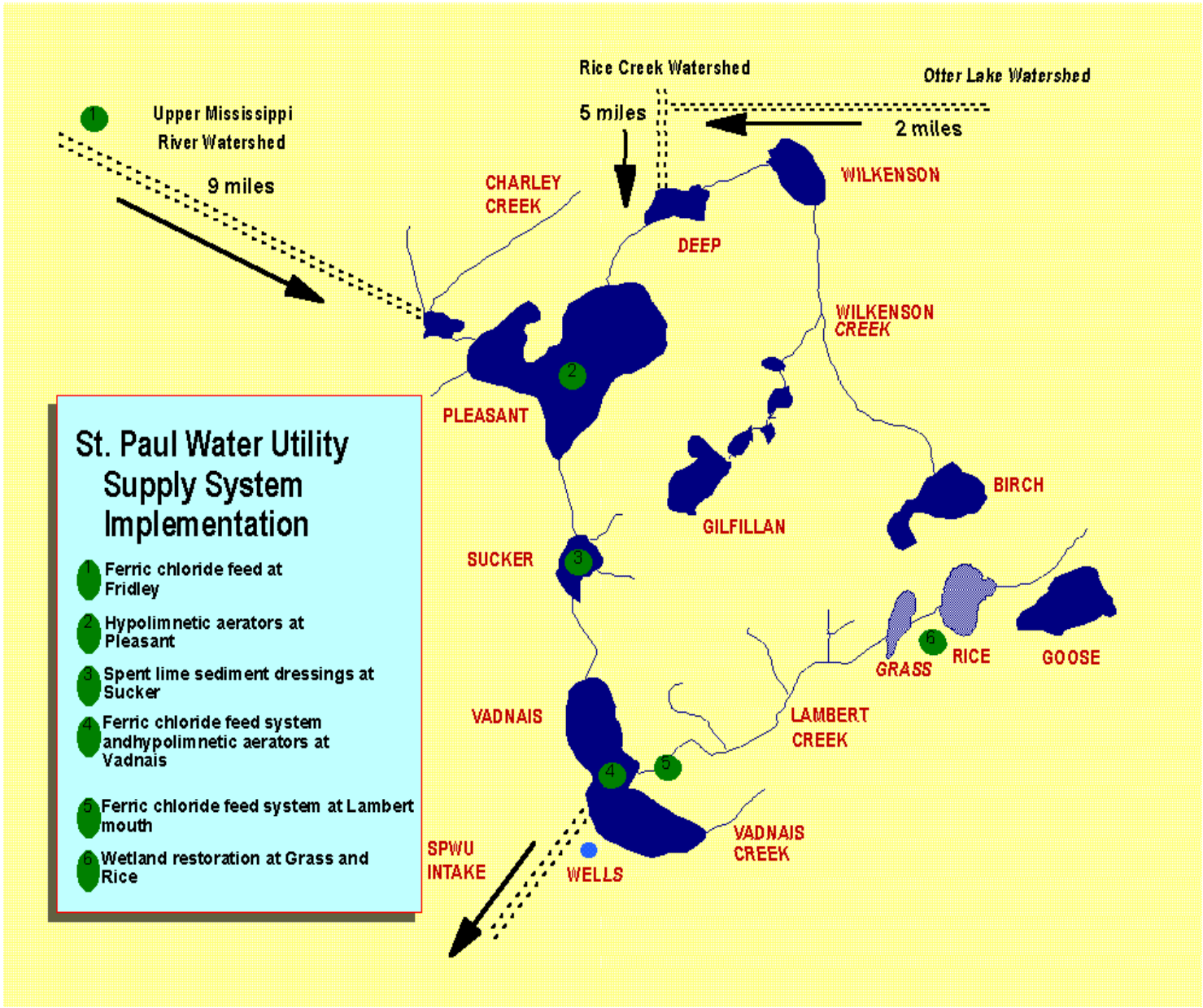
Conceptual Model for Vadnais Lake Diagnostic Study




St. Paul Water Utility
Monitoring Network
1984-1992
PELTIER
4
RICE CREEK WATERSHED
51
CENTERVILLE
5
6
WELLS
AMELIA
9
7
OTTER
WILKENSON
BALD EAGLE
CHARLEY CREEK
MISSISSIPPI RIVER
DEEP
10
8
WILKENSON
CREEK
1
26
2
33
3
61
62
PLEASANT
60
11
32
GILFILLAN
31
BIRCH
29
71
SUCKER
28
12
22
35
21
41
GOOSE
27
18
15
LAMBERT CREEK
83
VADNAIS
81
17
23
16
84
36
86
20
82
85
19
VADNAIS
CREEK
SPWU INTAKE
23
WELLS
Tributary Station
Lake Station
Runoff Station

SPWU Taste & Odor Control Strategy




Rice Creek Watershed
Otter Lake Watershed
5 miles
2 miles
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CHARLEY
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WILKENSON
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SUCKER
3
GRASS
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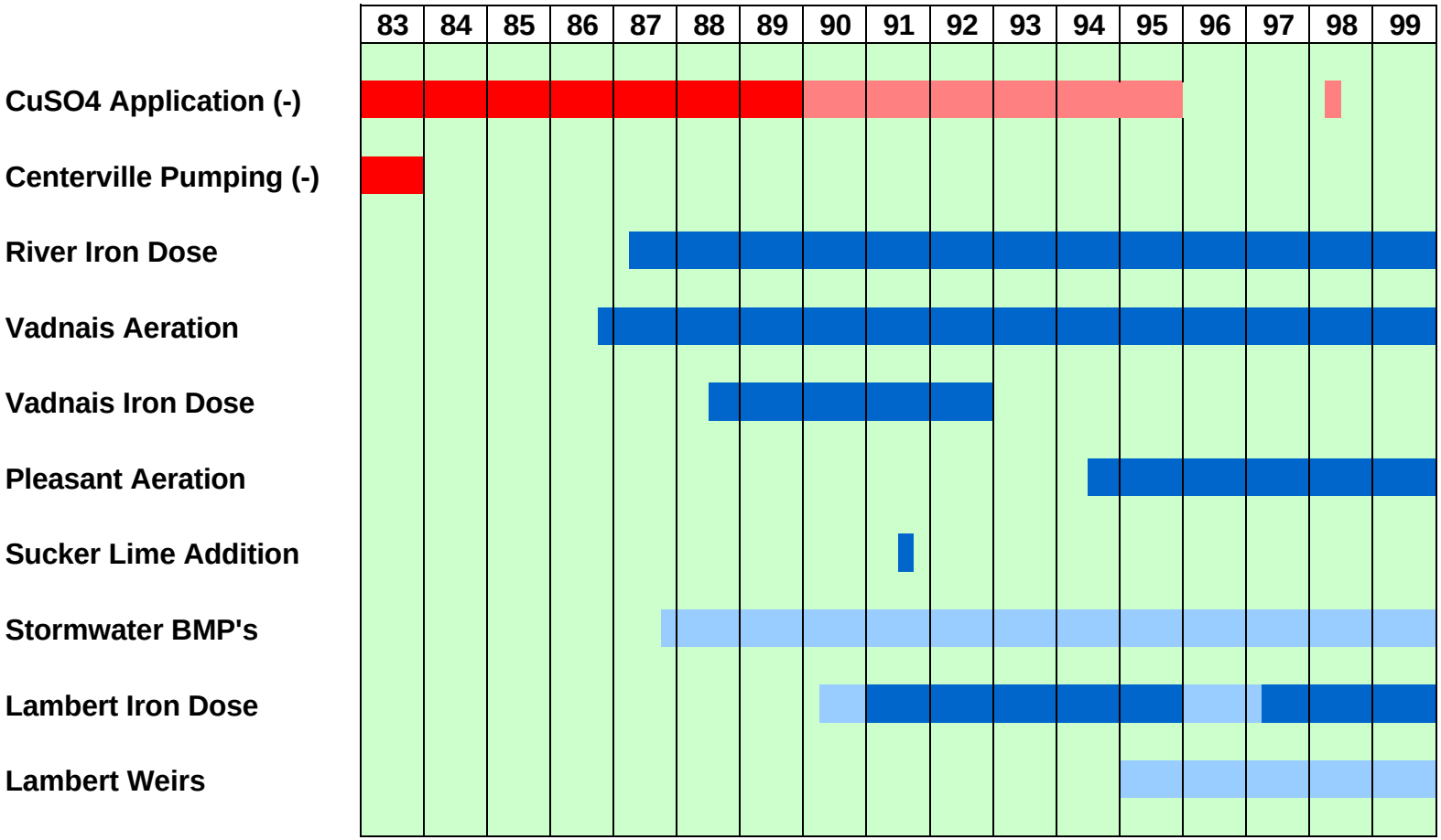
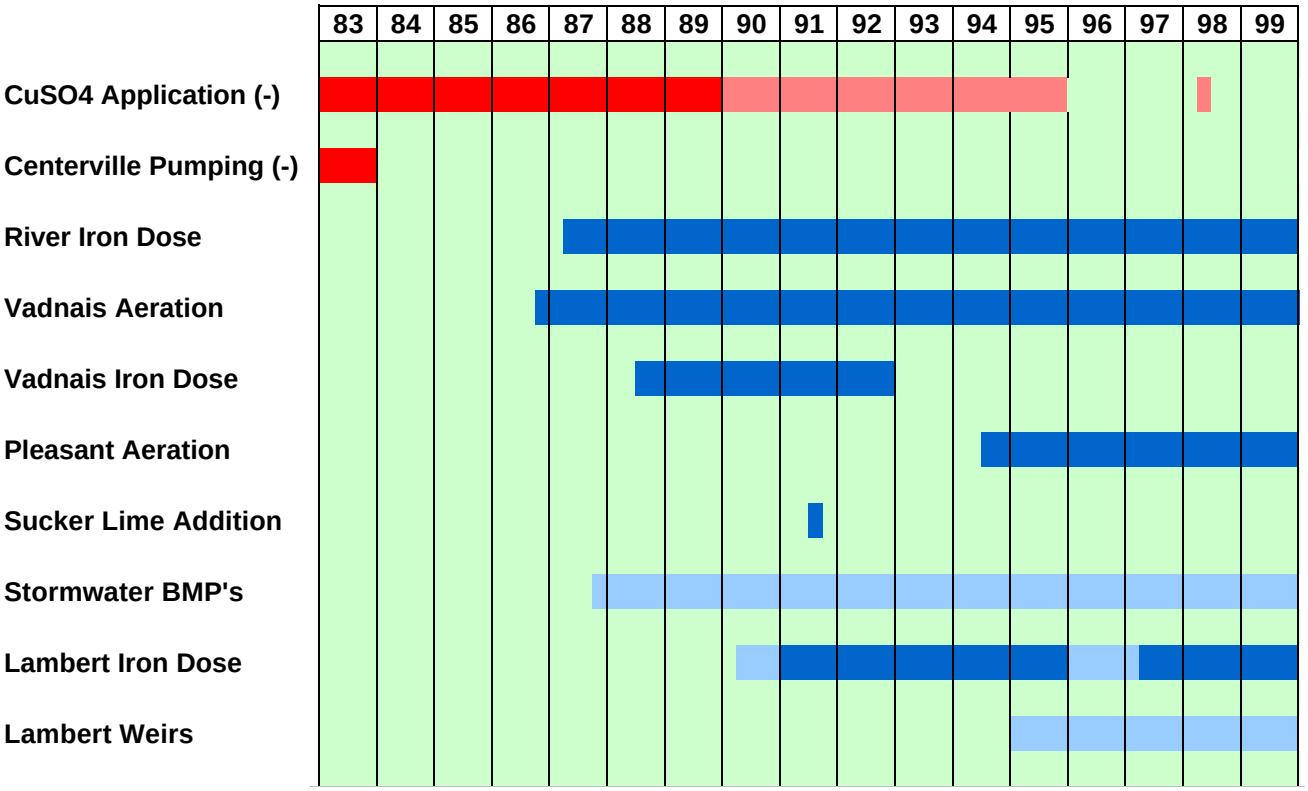
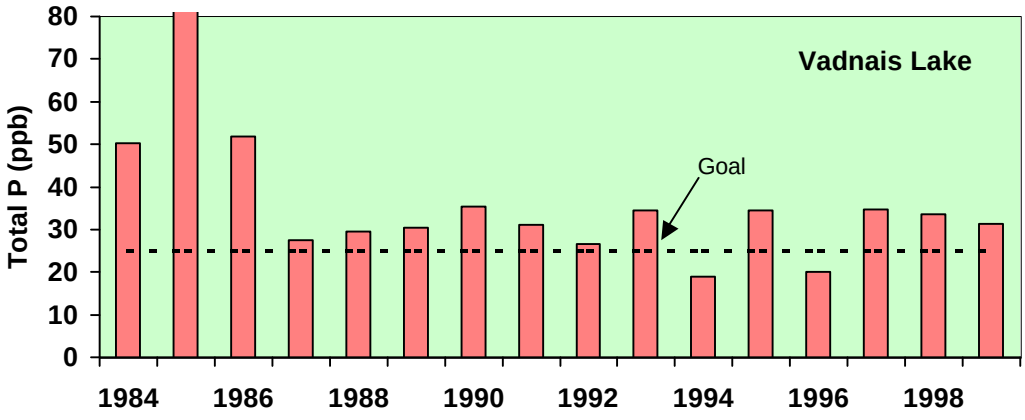
VADNAIS
LAMBERT
CREEK
4
5
VADNAIS
CREEK
SPWU
INTAKE
WELLS
St. Paul Water Utility
Supply System
Implementation
1 Ferric chloride feed at Fridley
2 Hypolimnetic aerators at Pleasant
3 Spent lime sediment dressings at Sucker
4 Ferric chloride feed system andhypolimnetic aerators at Vadnais
5 Ferric chloride feed system at Lambert mouth
6 Wetland restoration at Grass and Rice

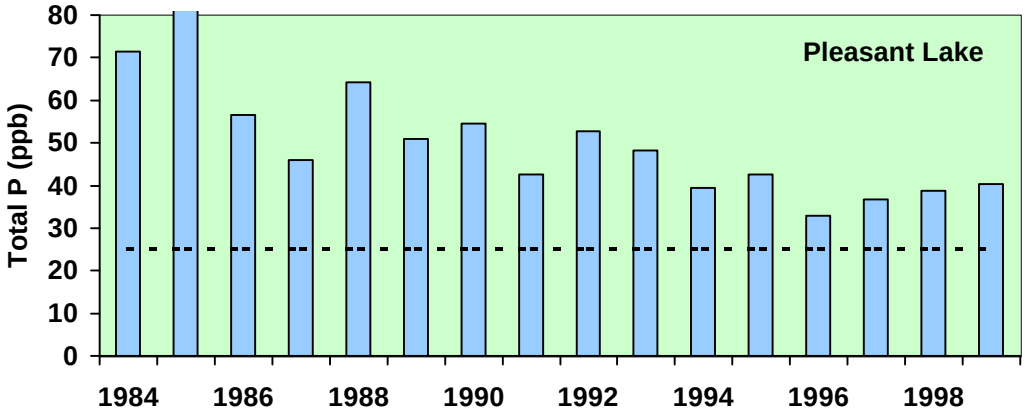
Implementation of Watershed & Lake Controls



Implementation of Watershed & Lake Controls







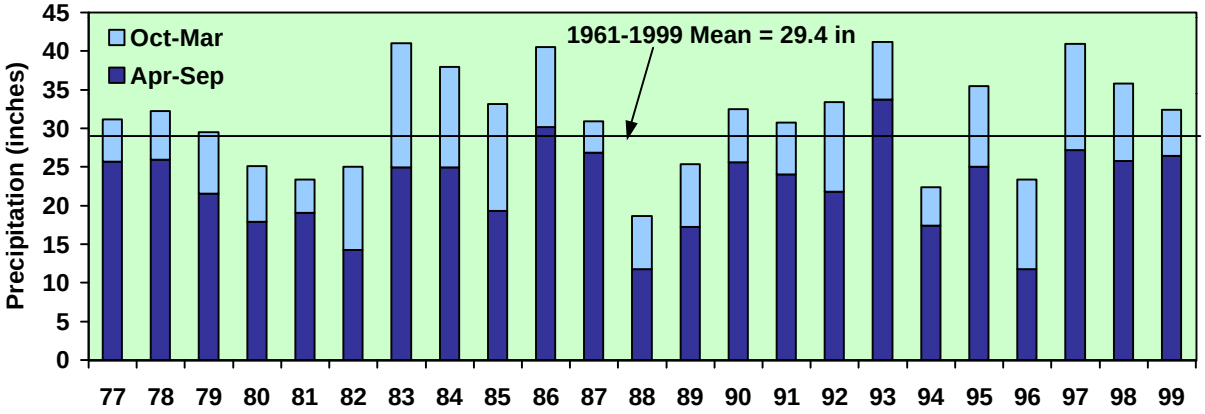
Factors Contributing to Water Quality Improvements Vadnais Lake Chain, 1984-1999

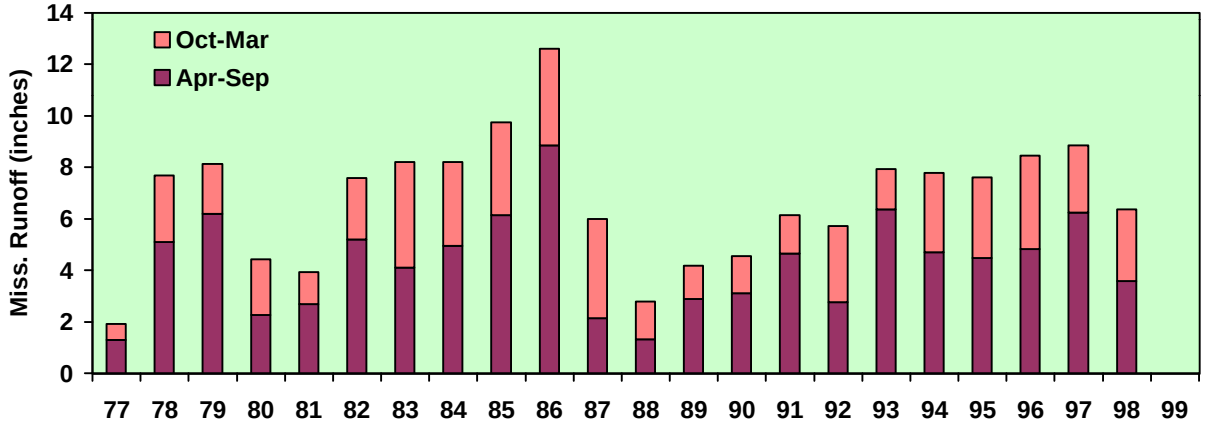
- **Improvements in Mississippi River Water Quality**
  - **Point-Source Controls**
  - **Non-Point Source Controls**

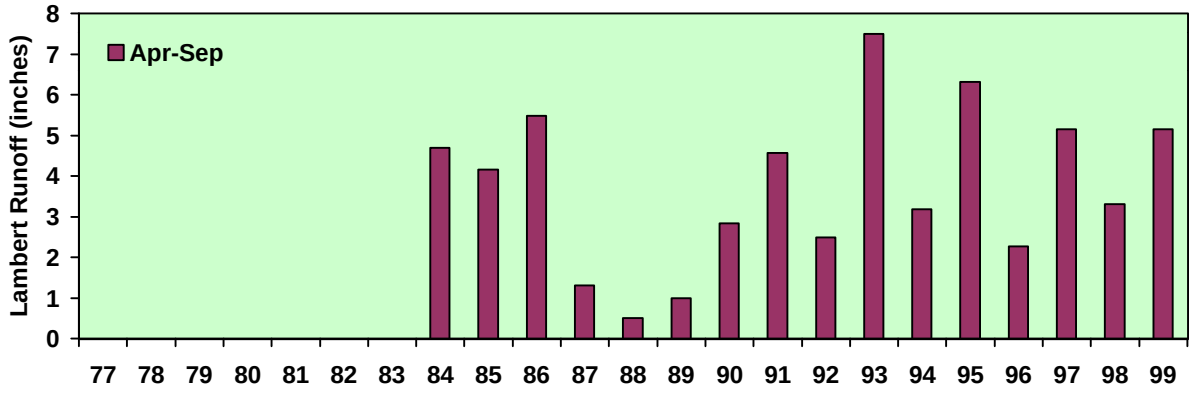
- **SPWU Control Measures**
  - **Source Selection**
  - **Aeration**
  - **Iron Injection**
  - **Stormwater Detention**
  - **Wetland Restoration**

- **Long-Term Climatologic Variations (?)**

Long-Term Variations in Precipitation & Runoff





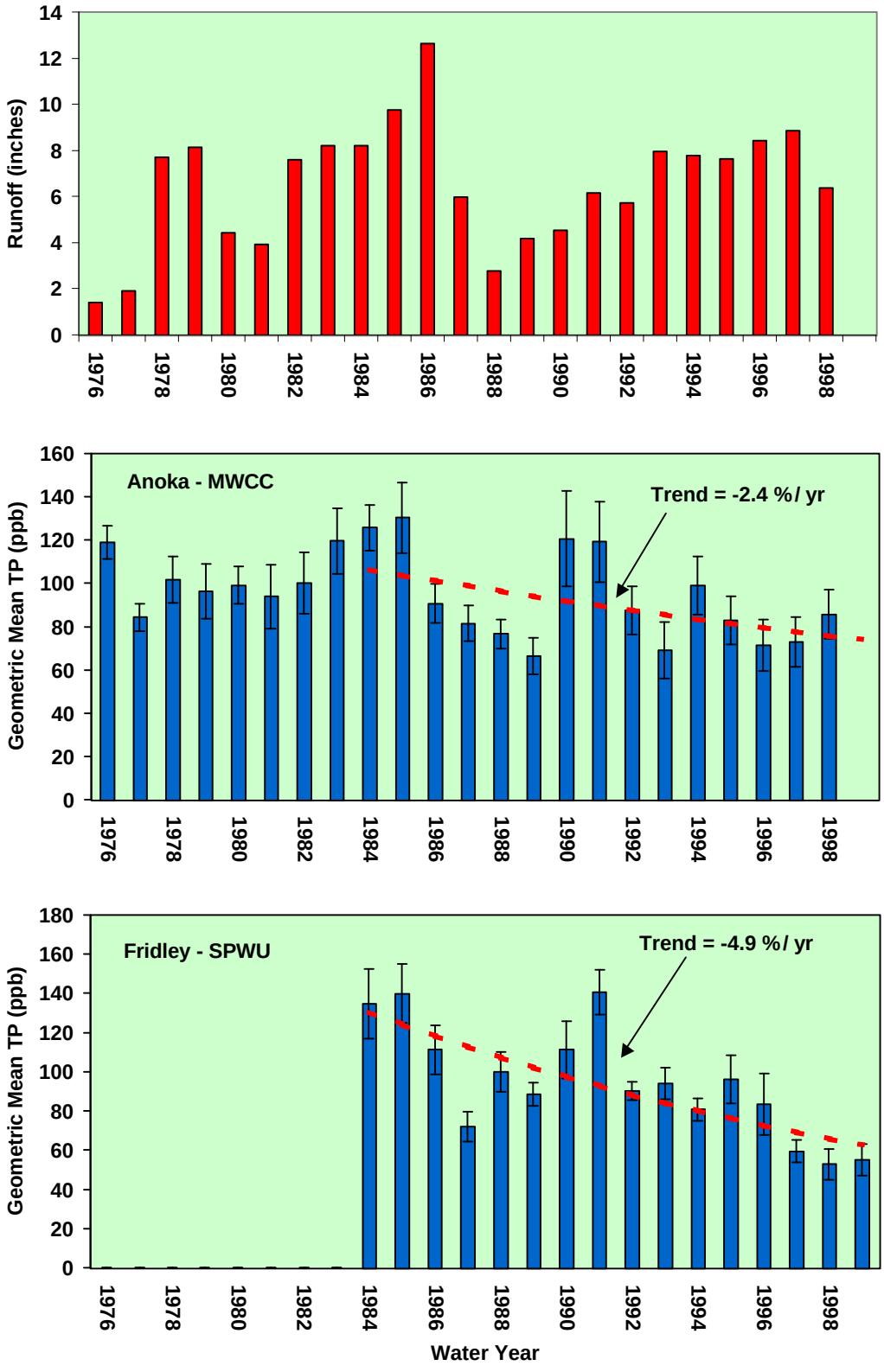


|--------Project Period ---------->

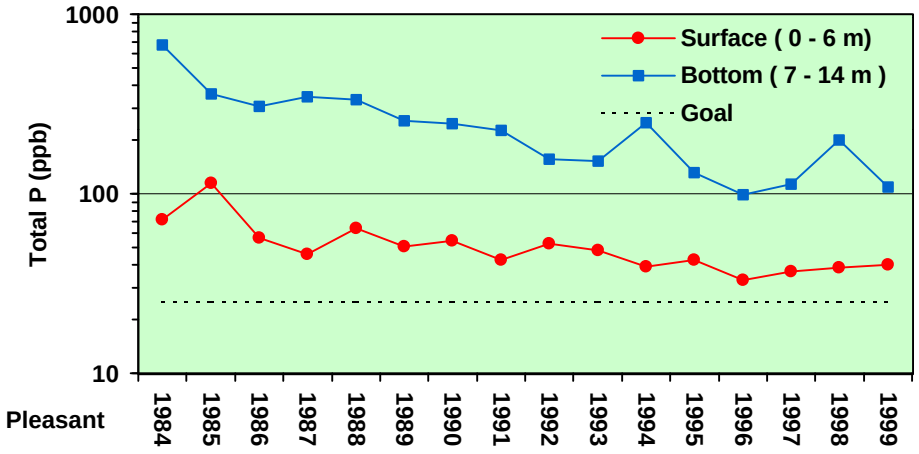
Mississippi River at Anoka
Lambert Creek Mouth

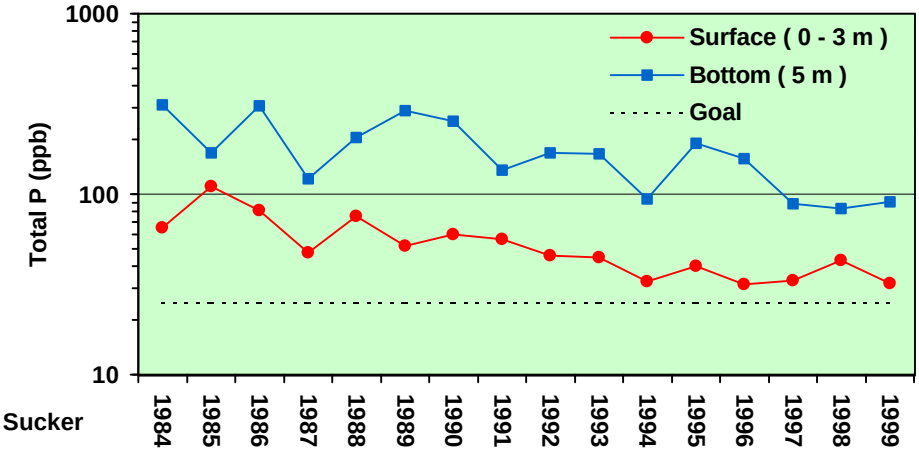
MSP Airport Precipitation

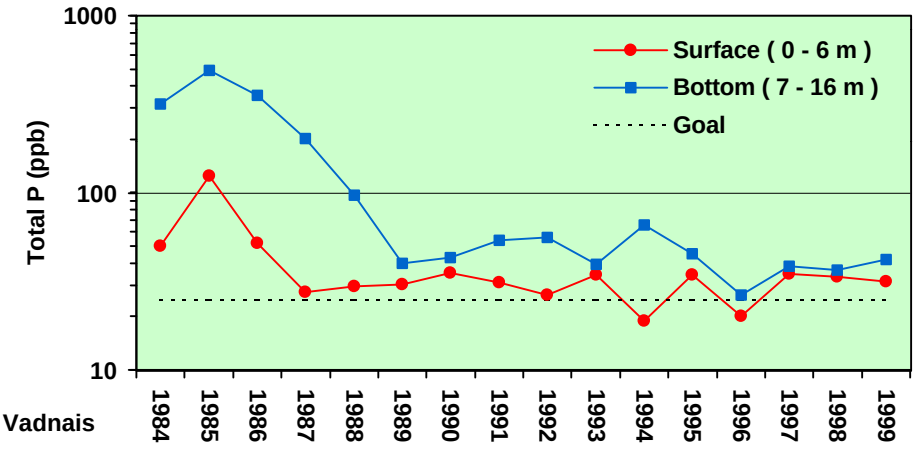
Mississippi River Runoff & Phosphorus Concentrations



Lake Total Phosphorus Time Series

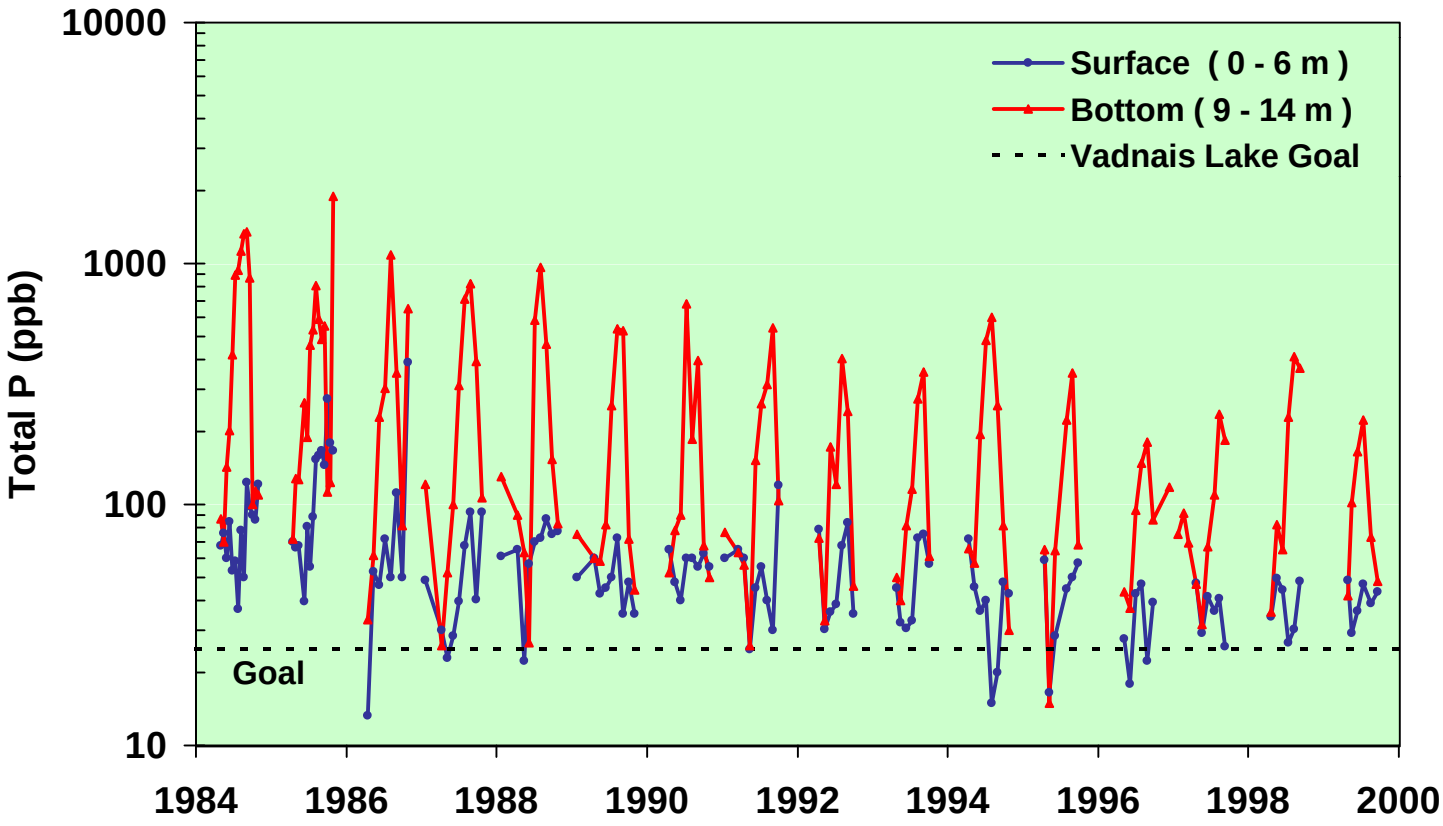






April-September Control Program ---------->

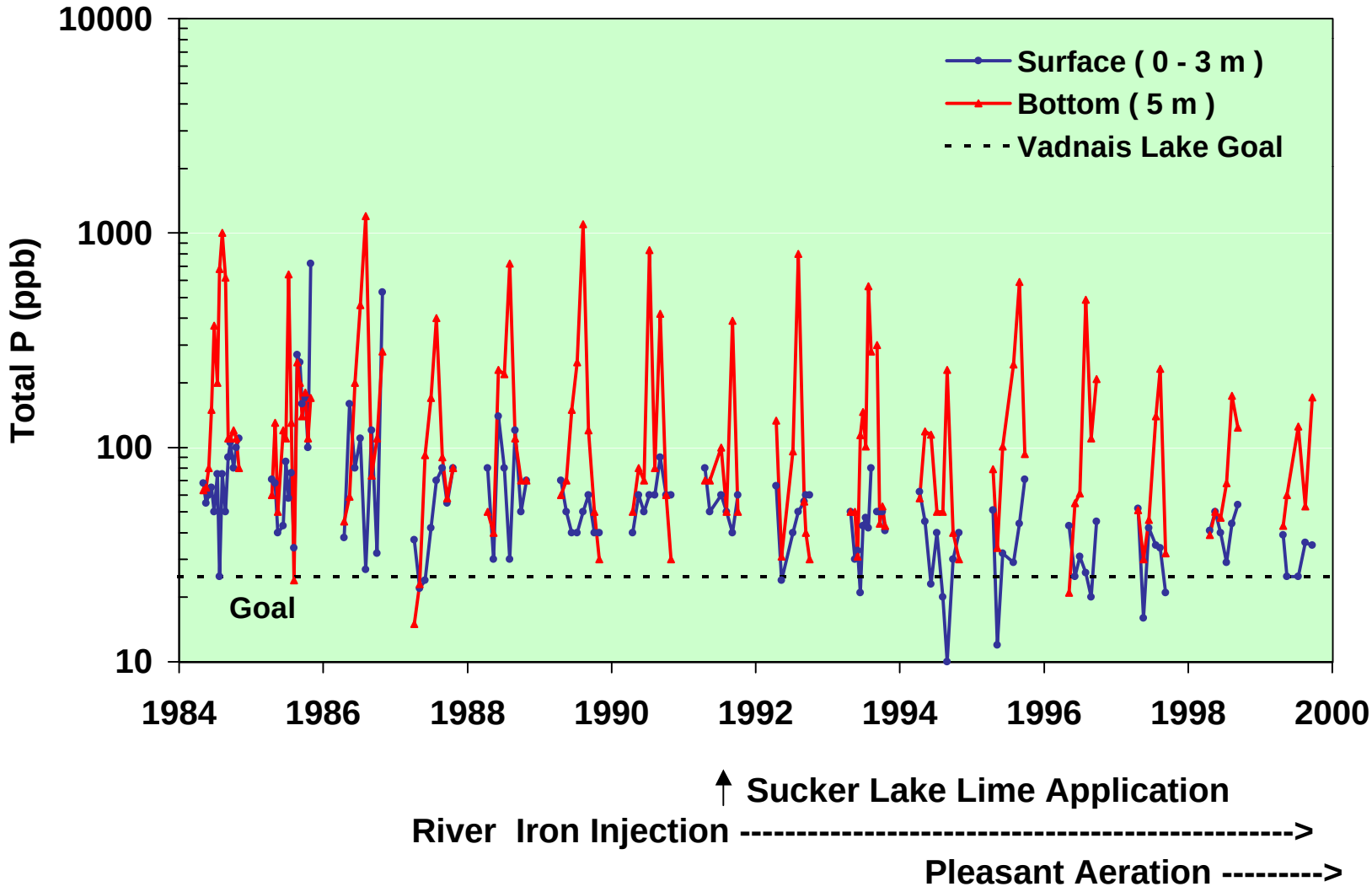
Pleasant Lake Phosphorus Levels



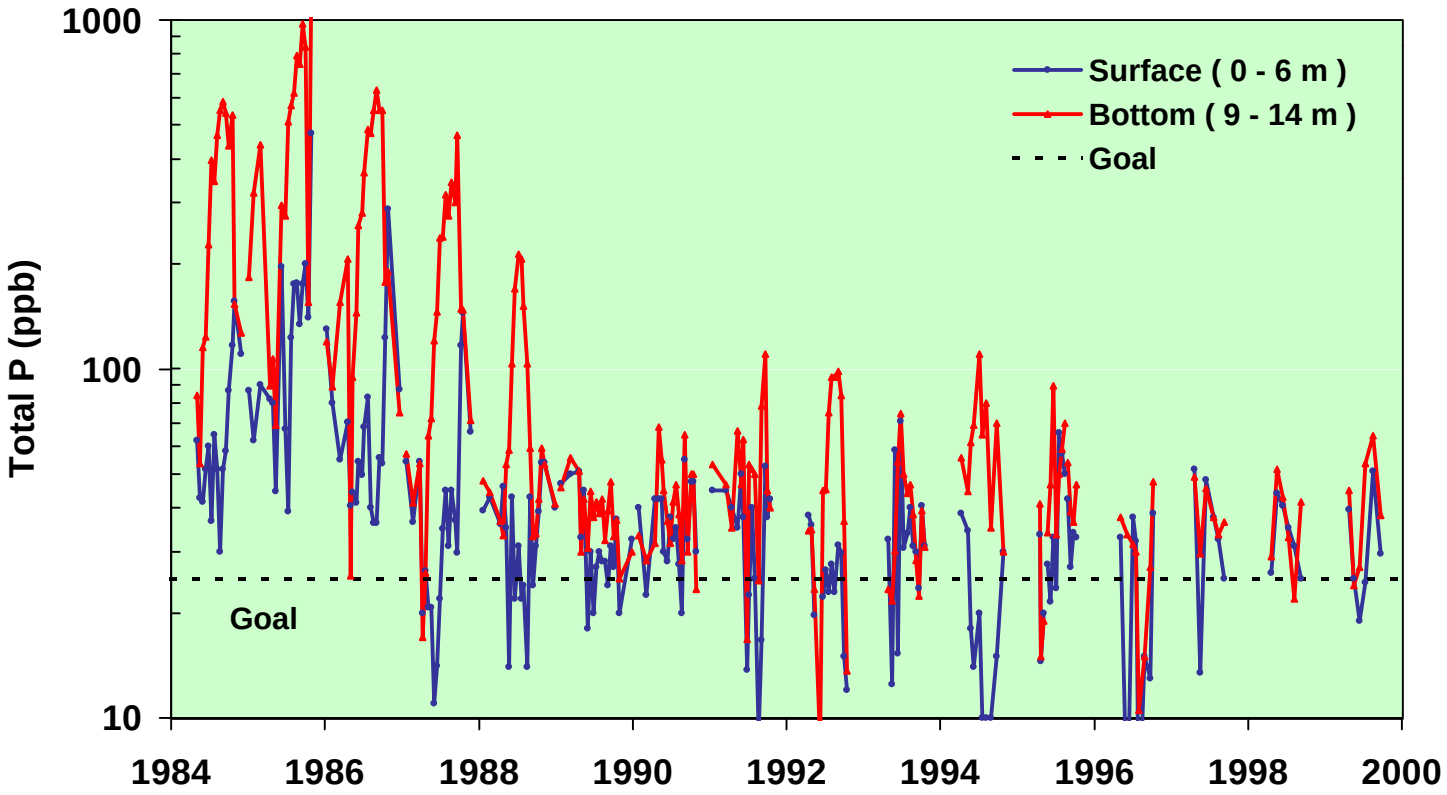
River Iron Injection ---------->

Aeration ---------->

Sucker Lake Phosphorus Levels

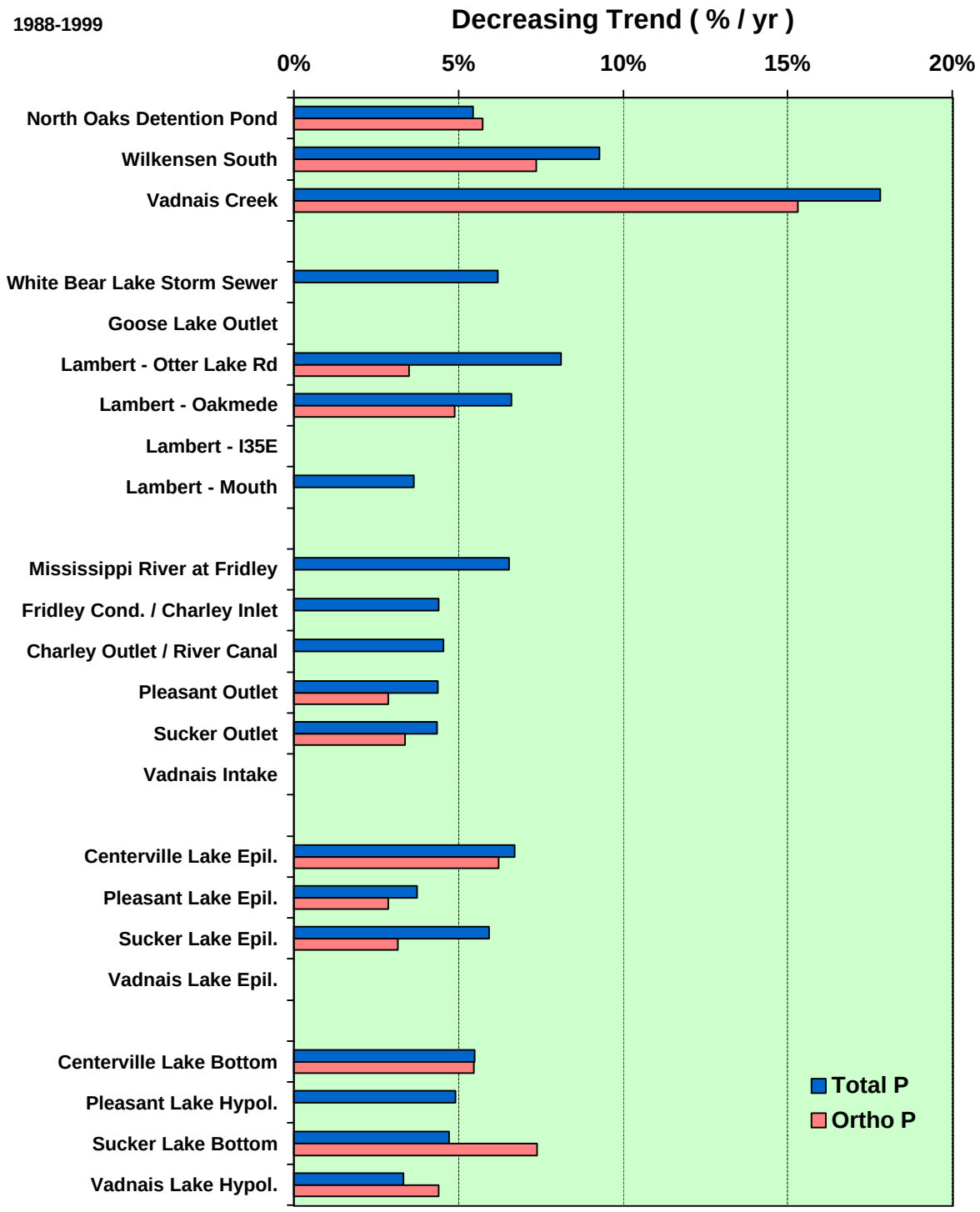


Vadnais Lake Phosphorus Levels



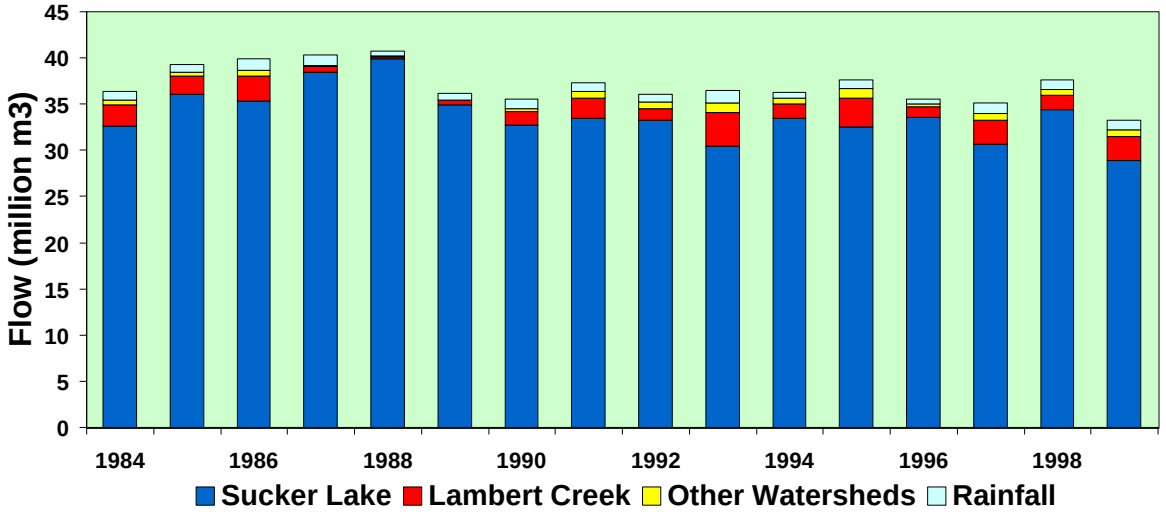
River Iron Injection ---------->
Vadnais Aeration ---------->
Lake Iron Injection -->
Lambert Creek Iron Injection ---------->
Pleasant Aeration ------->
Lambert Wetlands-->

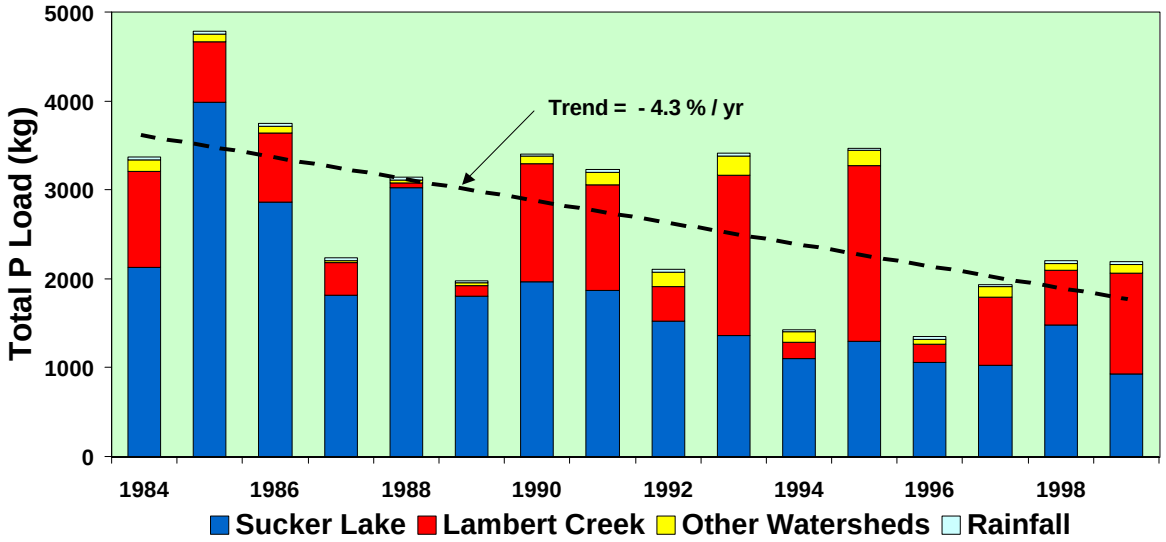
Trends in Total & Ortho Phosphorus, 1988-1999



Trends significant at p < 0.1, 1-Sided Test

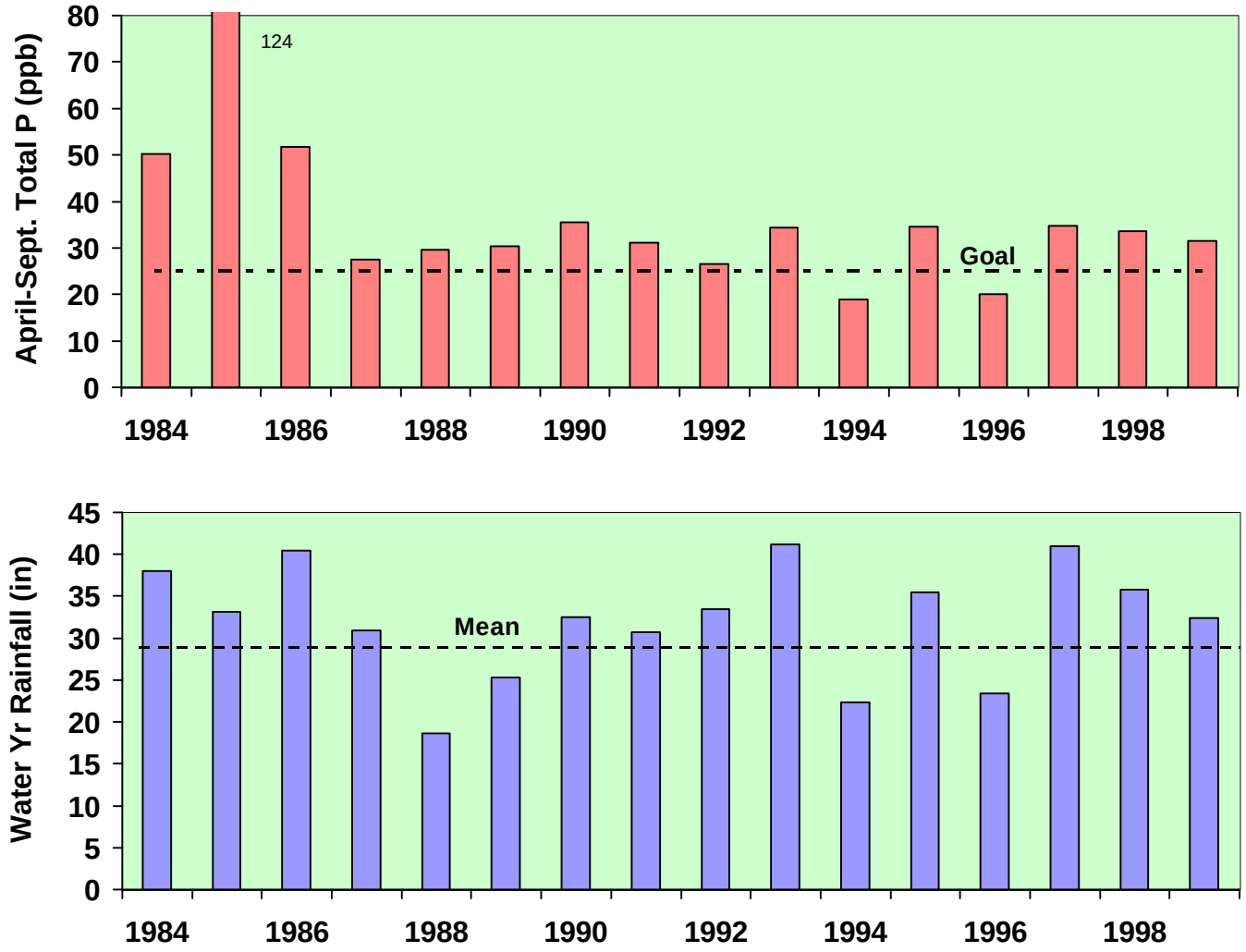
Vadnais Lake Water & Phosphorus Inputs



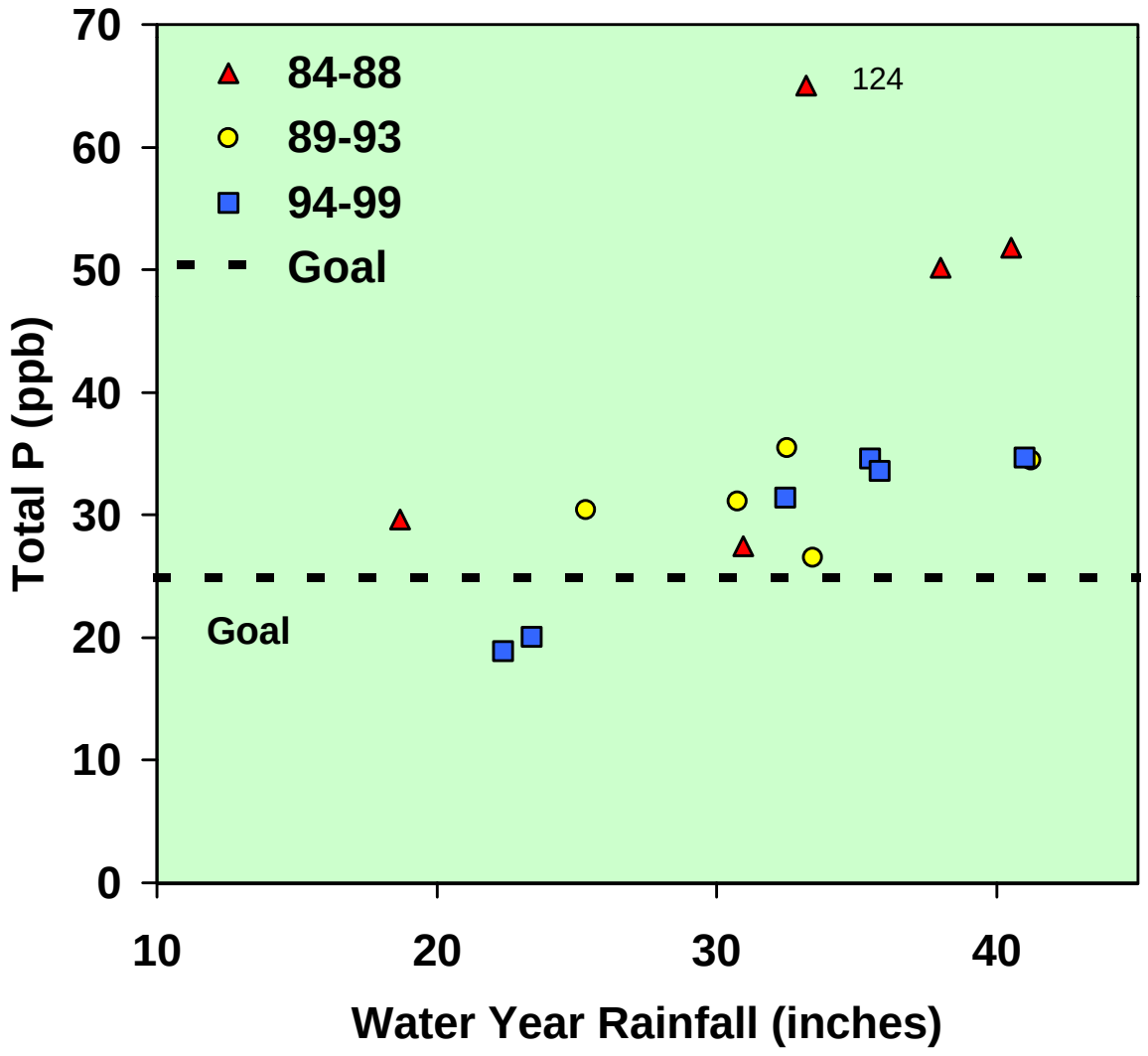


April - September

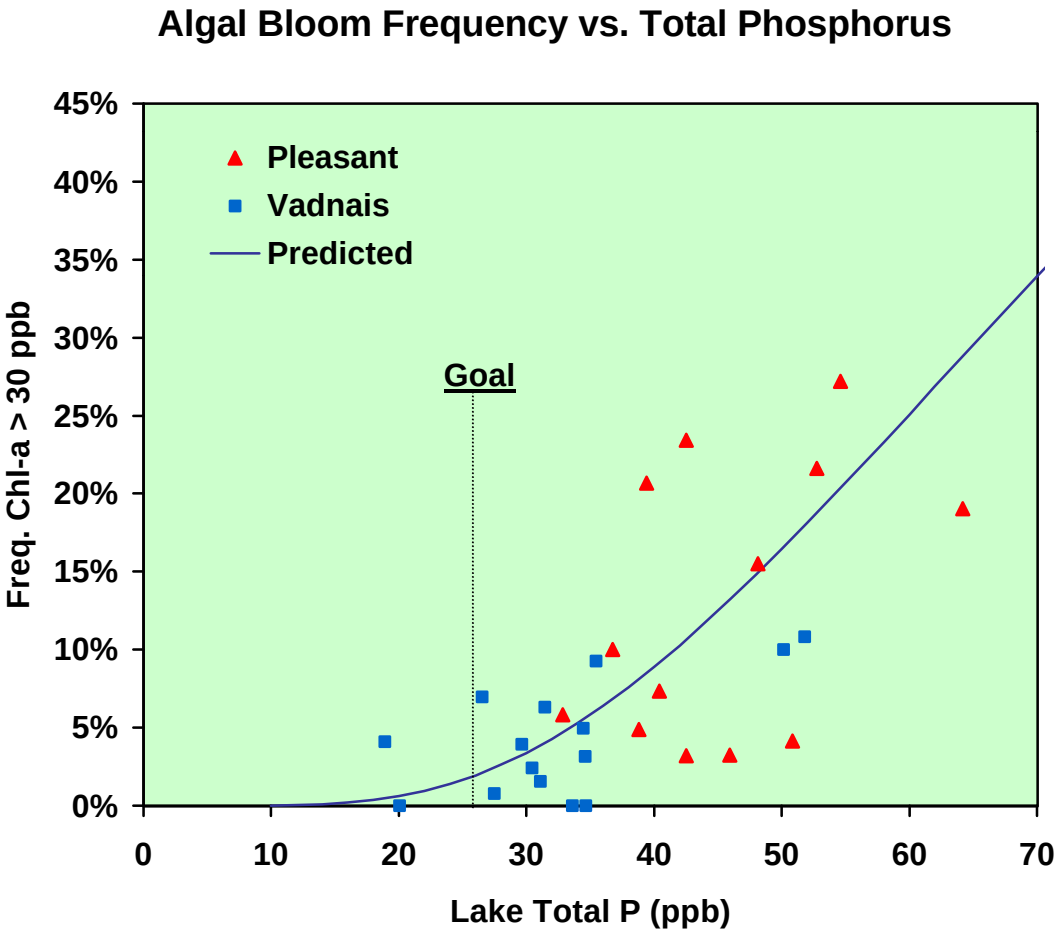
Vadnais Lake Phosphorus Levels & Rainfall



Vadnais Lake Total P Concentration vs. Rainfall

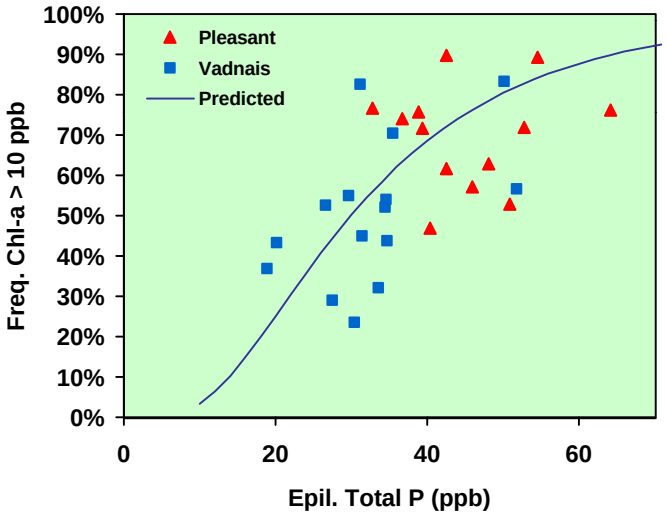


April-September Means, 0 - 6 meters



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

Algal Bloom Frequencies vs. Total Phosphorus



Model:

$B_a = k\ P$

$B_g = B_a / \exp (S^2 / 2)$

$Z^* = \ln (B^* / B_g) / S$

Freq (B > B*) = 1 - NORMSDIST (Z*)

Coefficients:

k = 0.4

S = 0.6

Variables:

P = april-sept. epilimnetic mean total p (ppb)

B_a = arithmetic mean chl-a (ppb)

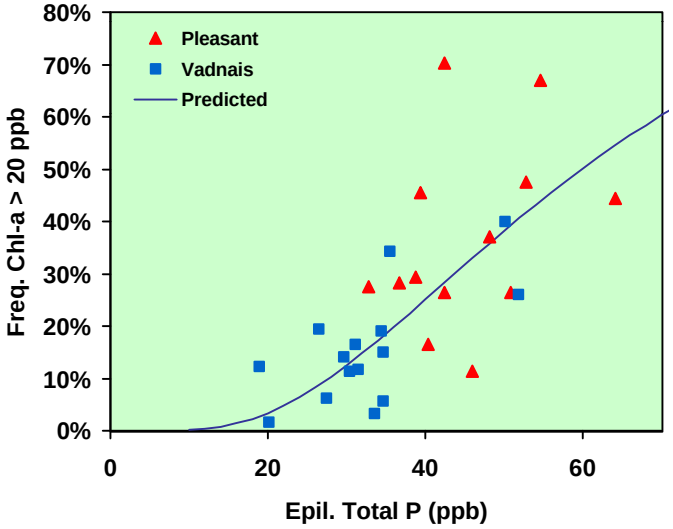
B_g = geometric mean chl-a (ppb)

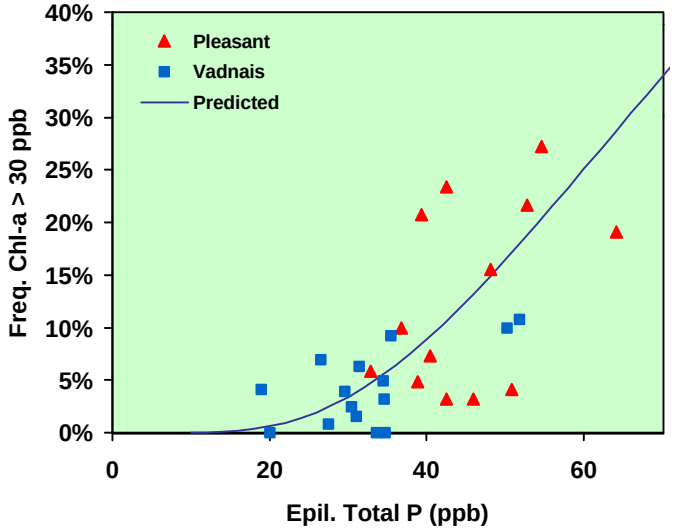
B* = bloom criterion (ppb)

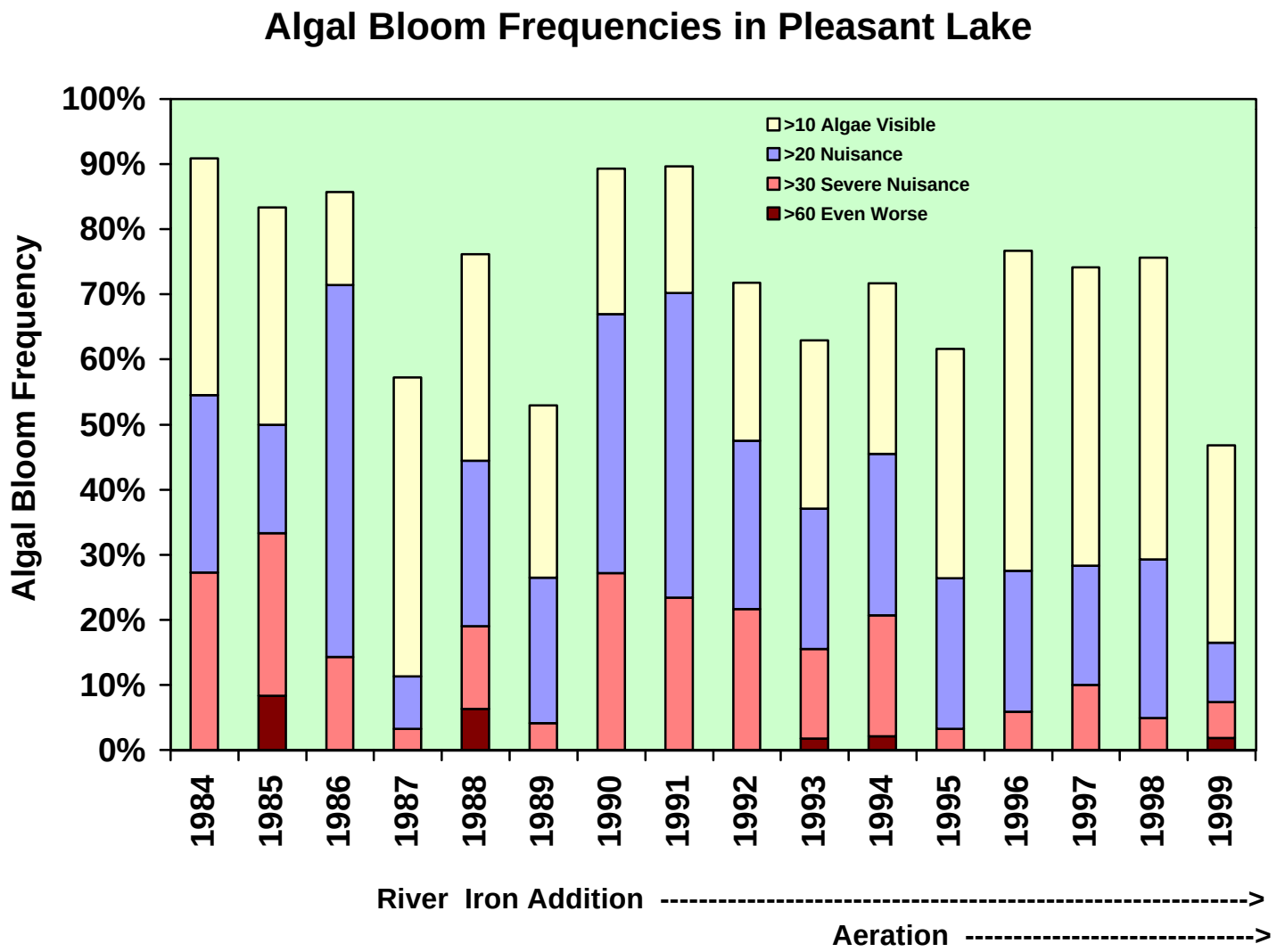
S = standard deviation of ln(Chl-a)

Z* = standard normal deviate

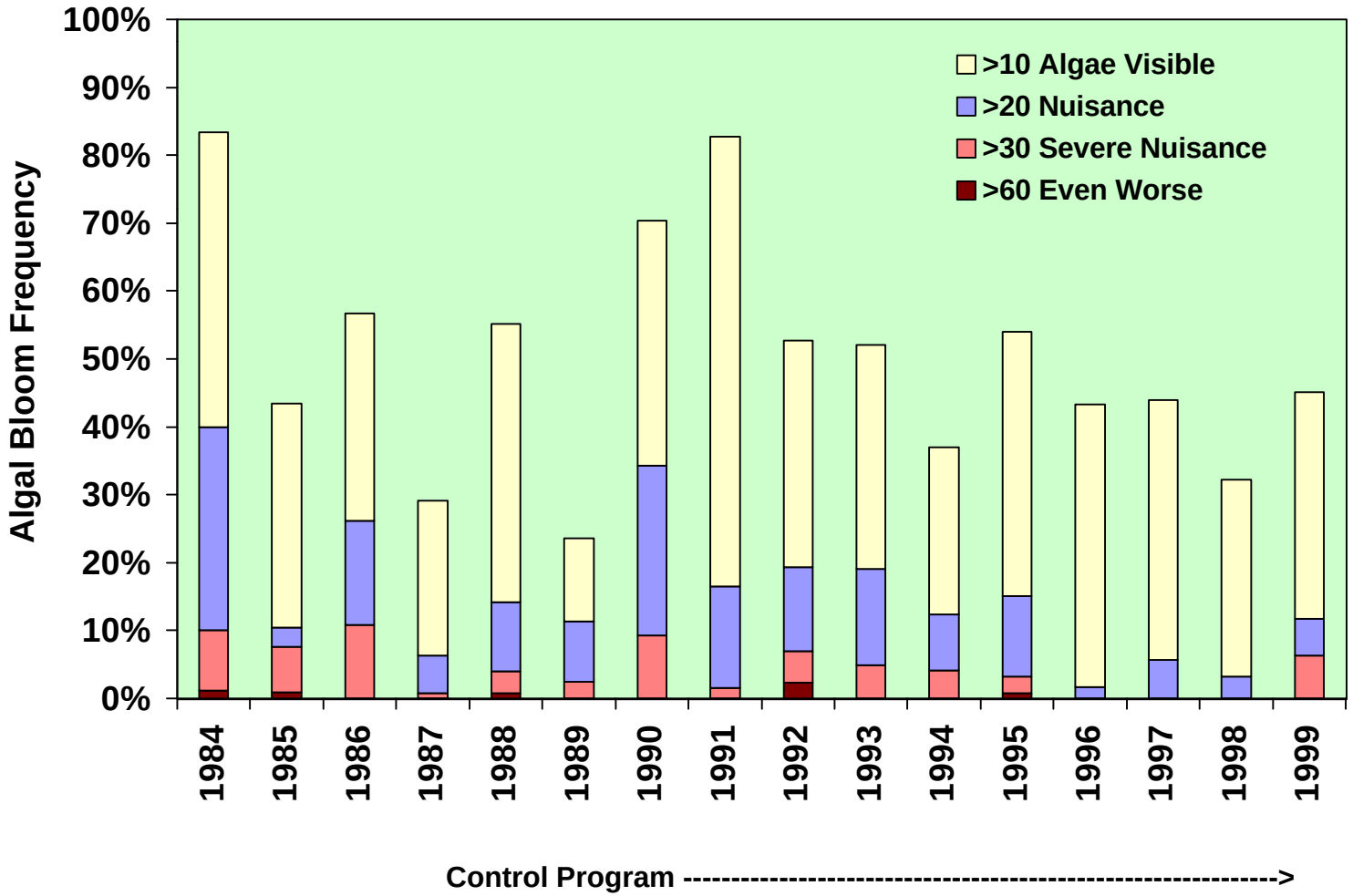
NORMSDIST = cumulative normal distrib. (Excel)






Algal Bloom Frequencies in Pleasant Lake
Algal Bloom Frequency
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
>10 Algae Visible
>20 Nuisance
>30 Severe Nuisance
>60 Even Worse
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
River Iron Addition ---------->
Aeration ---------->
Lake Outflow or Lake Epil. Samples, April-September

Algal Bloom Frequencies in Vadnais Lake



Vadnais Lake Water Quality Goals

Variable	Factor	Goal	84-86 Baseline	95-99 Recent	Change
Total P Concentration	Limit Algal Biomass	< 25 ppb	75	31	-59%
Algal Bloom Frequency	T & O Precursors				
Chlorophyll-a > 20 ppb		Minimize	26%	8%	-69%
Chlorophyll-a > 30 ppb		Minimize	9%	2%	-78%
BlueGreen Algal Count	T & O Precursors				
Frequency > 1000 asu/ml		Minimize	12%	4%	-67%
Threshold Odor No.	Risk of T&O Episode				
Frequency > 5		Minimize	33%	3%	-91%
Total N / P Ratio	Regulates Algal Species	>30	20	41	105%
Silica / Total P Ratio	Regulates Algal Species	>100	61	165	170%
Hypol. Total Fe/ Total P	Regulate P Cycling	>3	0.5	3.8	660%

Summary of Vadnais Lake Data Relative to Program Goals

Variable:	TP	TN/TP	SiO2/TP	Fe/TP	Chla>20	Chla>30	BG>1000	TON>5
Units:	ppb	-	-	-	ppb	ppb	asu/ml	-
Location:	Epil.	Epil.	Epil.	Hypol.	Intake	Intake	Intake	Intake
Goal	< 25	> 30	> 100	> 3	< 1%	< 1 %	< 1 %	< 1%
84	50	19	28	0.4	40%	10%	8%	13%
85	124	14	48	0.4	10%	8%	15%	53%
86	52	28	106	0.7	26%	11%	12%	34%
87	27	33	238	0.5	6%	1%	4%	46%
88	30	29	150	1.0	14%	4%	13%	17%
89	30	31	161	3.7	11%	2%	8%	17%
90	35	32	58	4.3	34%	9%	48%	0%
91	31	41	73	5.5	17%	2%	42%	3%
92	27	46	120	3.3	19%	7%	29%	3%
93	34	28	248	4.1	19%	5%	24%	-
94	19	46	214	2.5	12%	4%	3%	-
95	35	34	77	3.2	15%	3%	5%	-
96	20	69	-	3.0	2%	0%	0%	-
97	35	28	-	3.0	6%	0%	14%	-
98	34	48	-	3.6	3%	0%	0%	-
99	31	27	-	7.6	12%	6%	-	-
84-86	75	20	61	0.5	26%	9%	12%	33%
95-99 (a)	31	41	165	3.8	8%	2%	4%	3%
Increase	-45	21	104	3.3	-17%	-7%	-7%	-30%
% Incr.	-59%	103%	172%	687%	-68%	-76%	-62%	-91%
t	1.81	-2.37	-1.76	-3.98	2.02	4.73	1.84	2.73
p	0.05	0.02	0.08	0.00	0.04	0.00	0.05	0.01

All Values are April-September Means

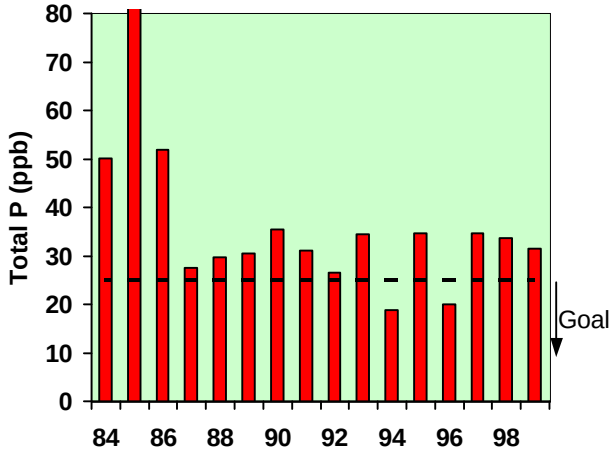
TP	Total Phosphorus
TN/TP	Total Nitrogen to Total P Ratio
SiO2/TP	Reactive Silica to Total P Ratio
Chla>20	Frequency Chlorophyll-a > 20 ppb, Nuisance Algal Bloom
Chla>30	Frequency Chlorophyll-a > 30 ppb, Severe Nuisance Algal Bloom
BG>1000	Frequency of Bluegreen Algal Counts > 1000 asu/ml, Measured At Filtration Plant
TON>5	Frequency of Threshold Odor Number > 5

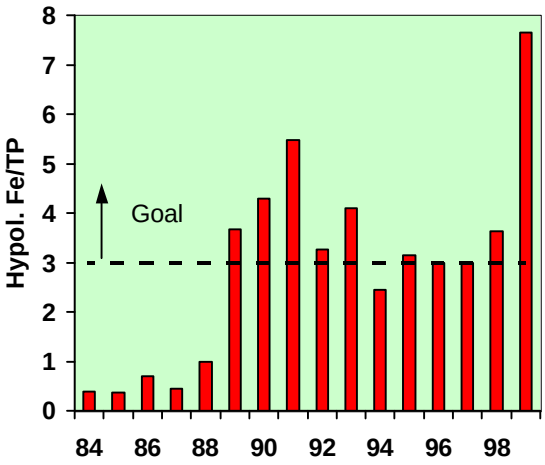
t = t-statistic comparing 84-88 vs. 95-99 means

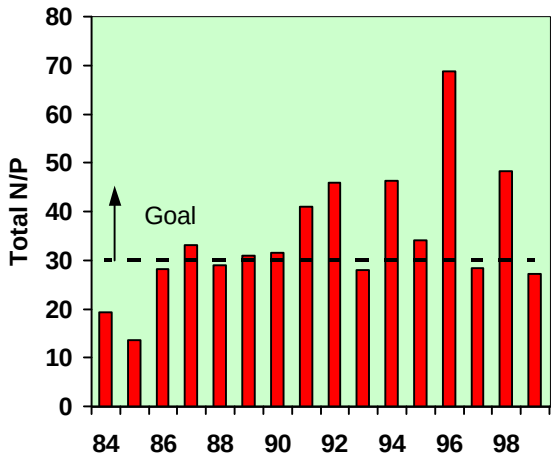
p = significance level, 1-sided test for improvement

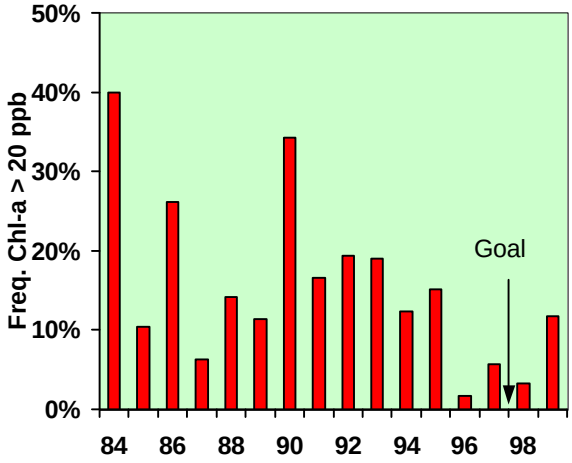
a - 90-95 for SiO2/TP & TON

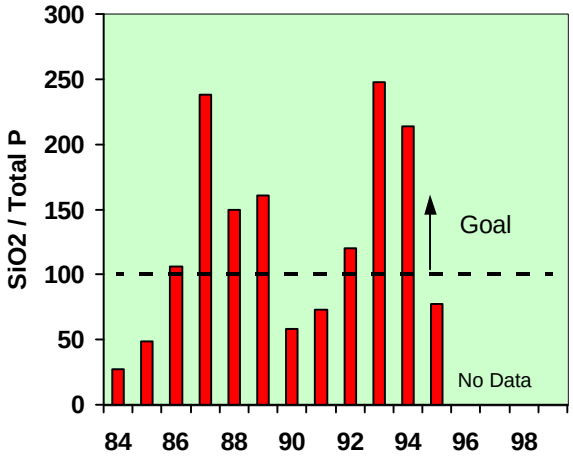
Yearly Variations in Vadnais Lake Water Quality Relative to Program Goals

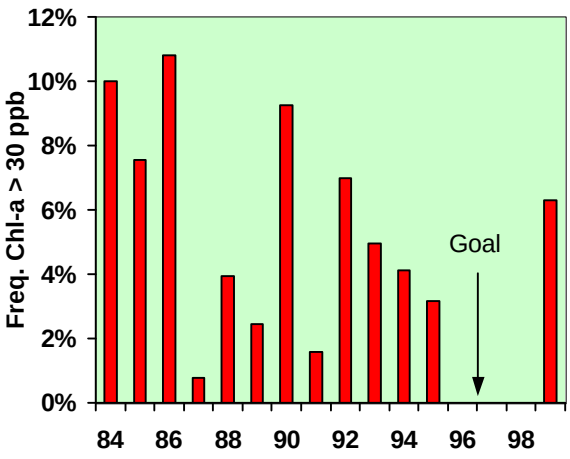




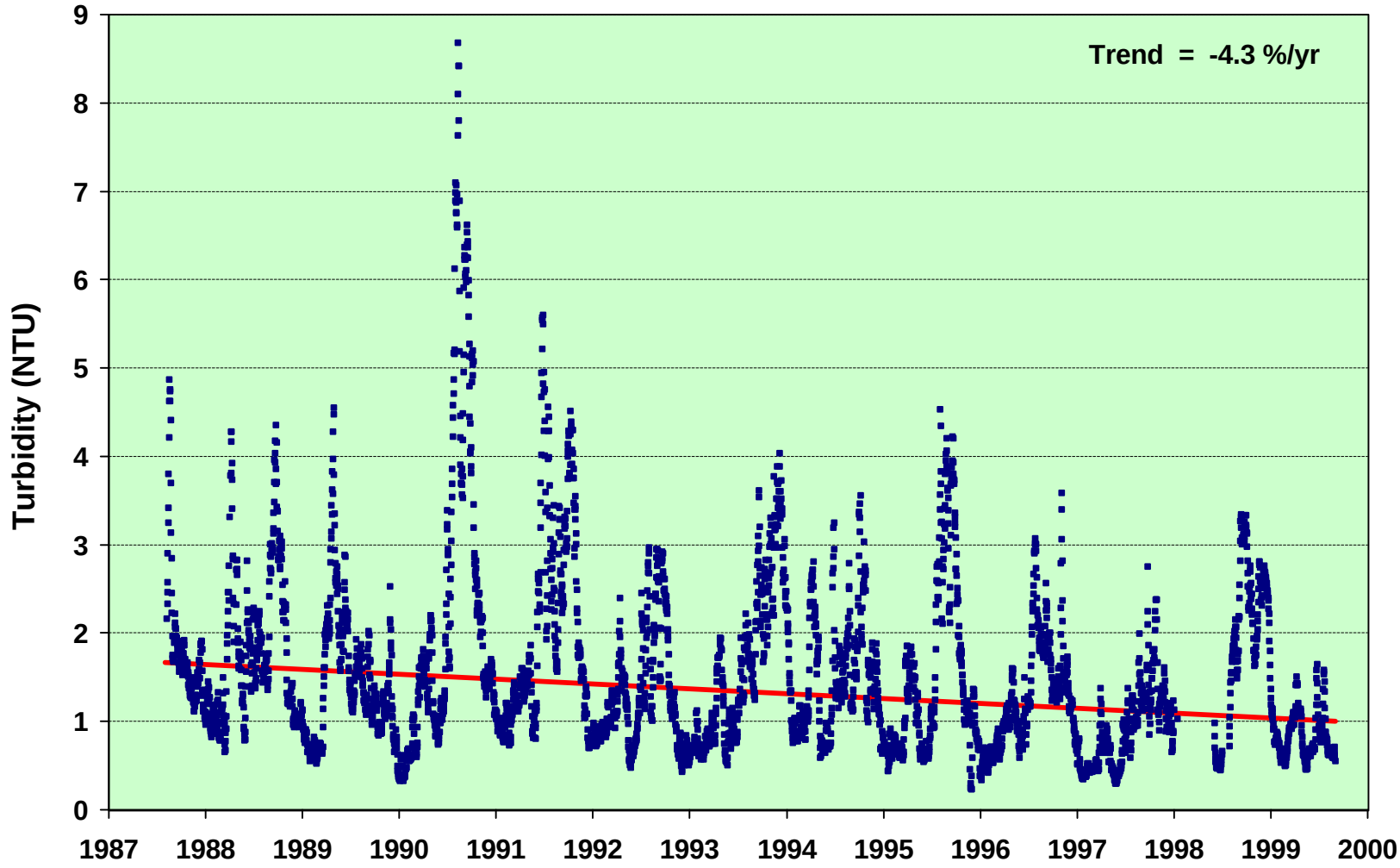






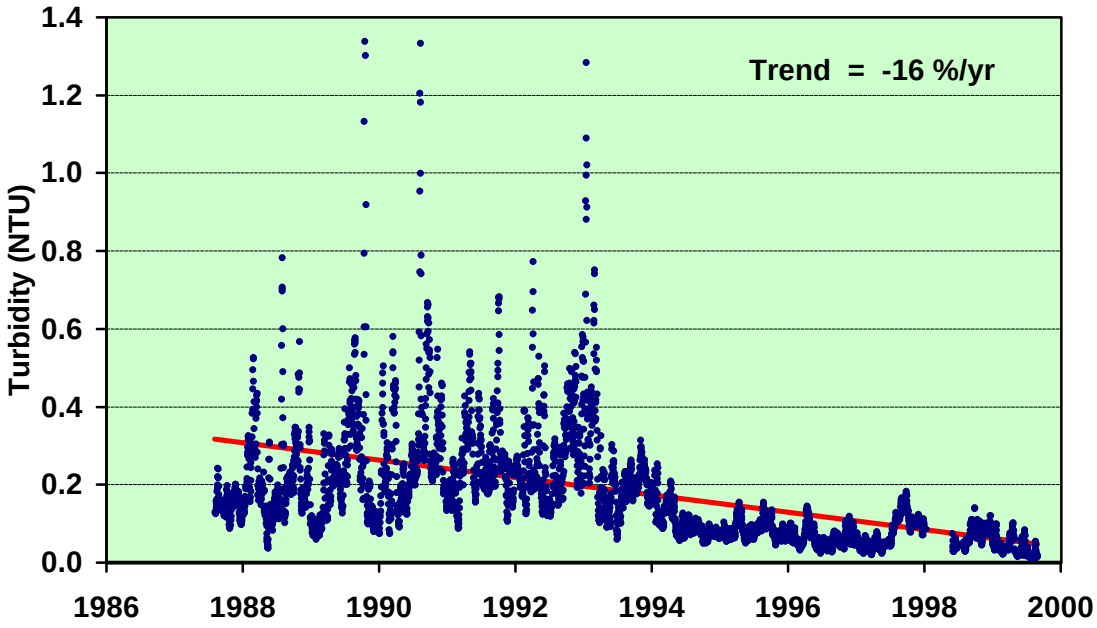


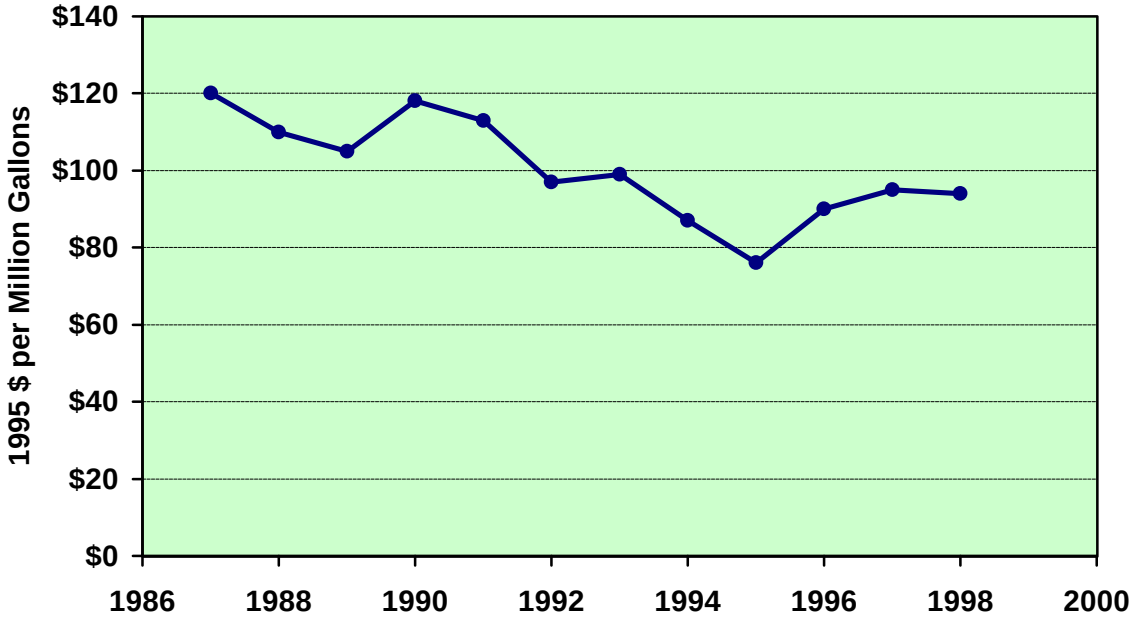
Vadnais Intake Turbidity



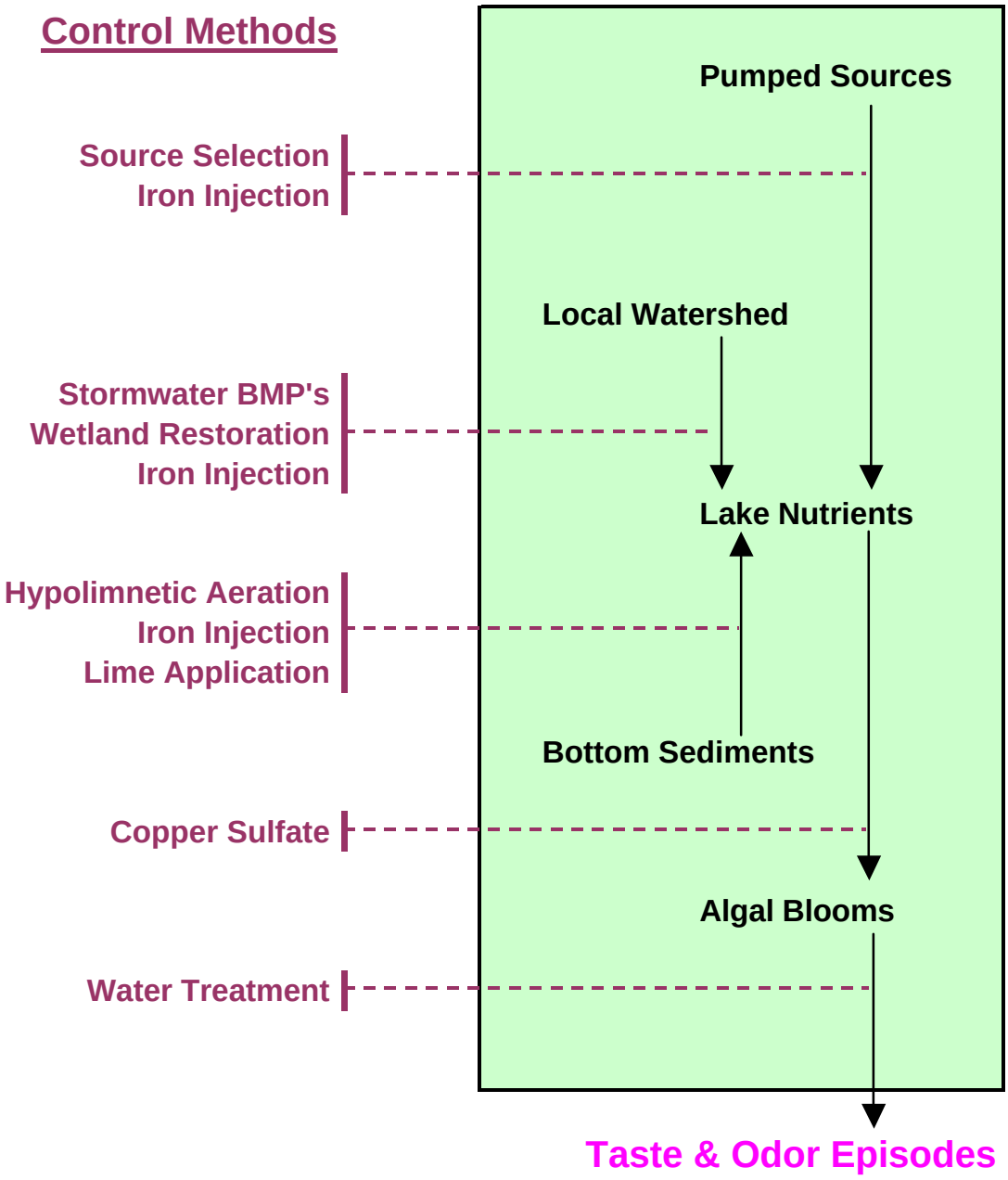
7-Day Rolling Averages

Treated Water Turbidity & Total Chemical Costs

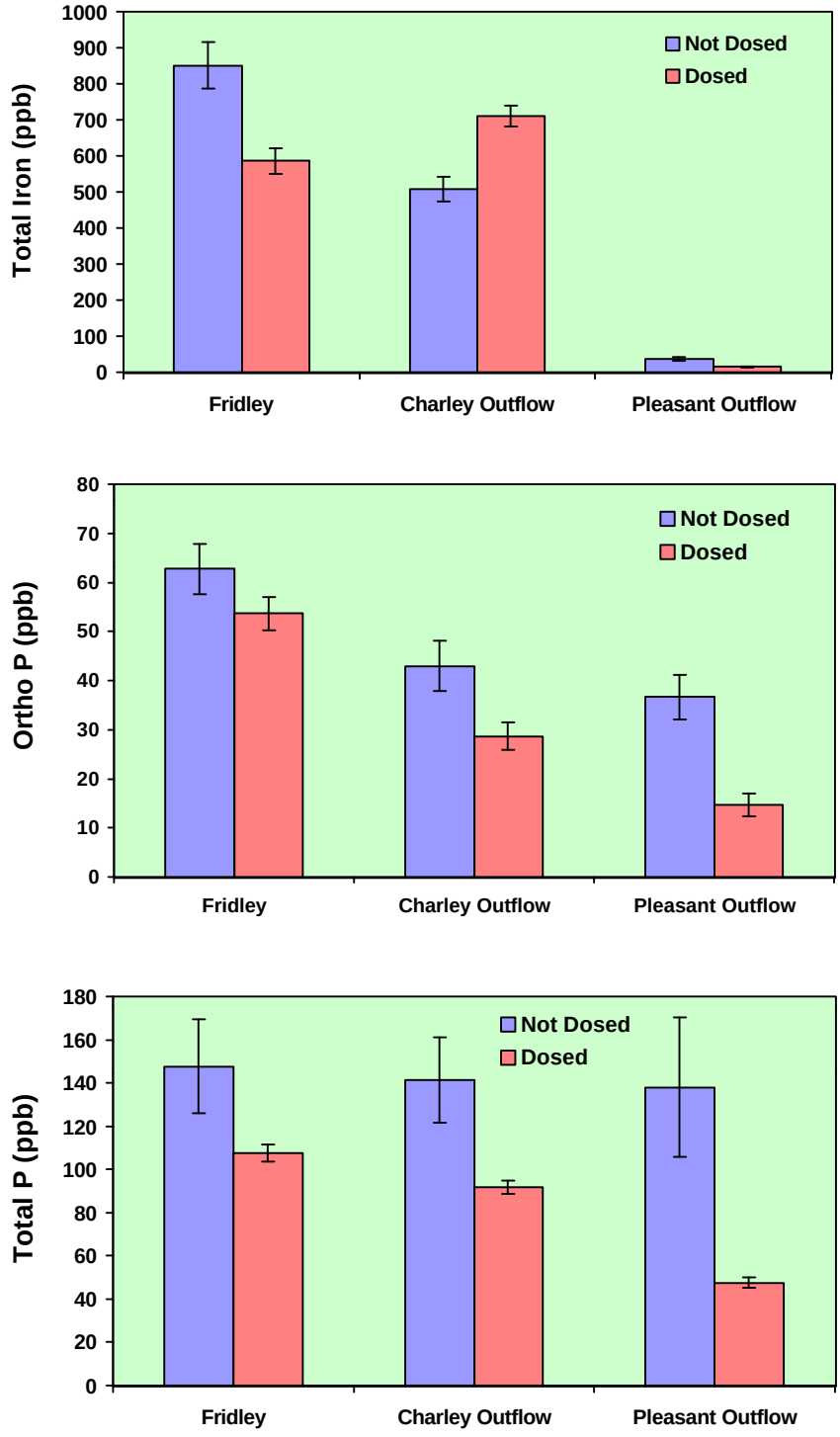




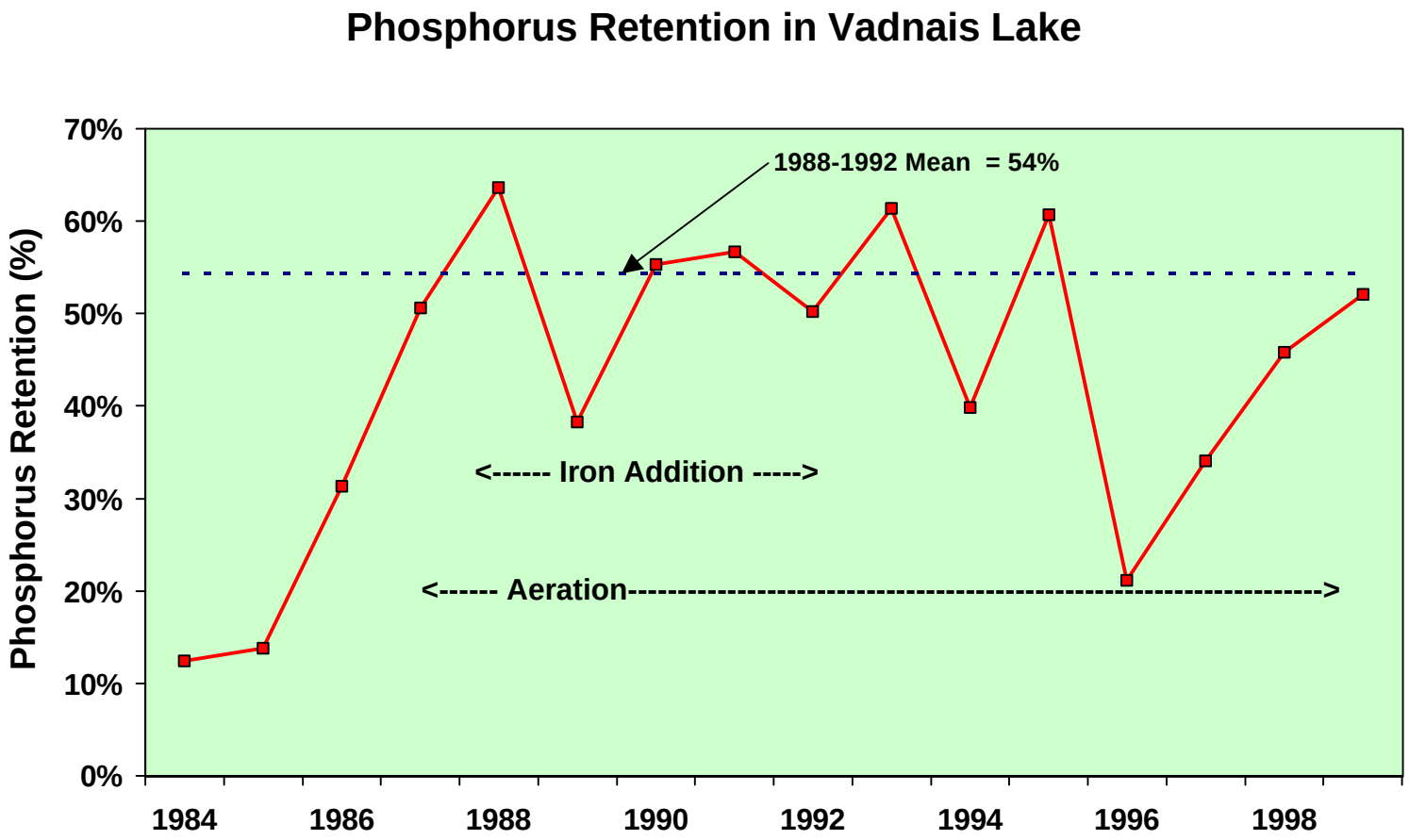
SPWU Taste & Odor Control Strategy

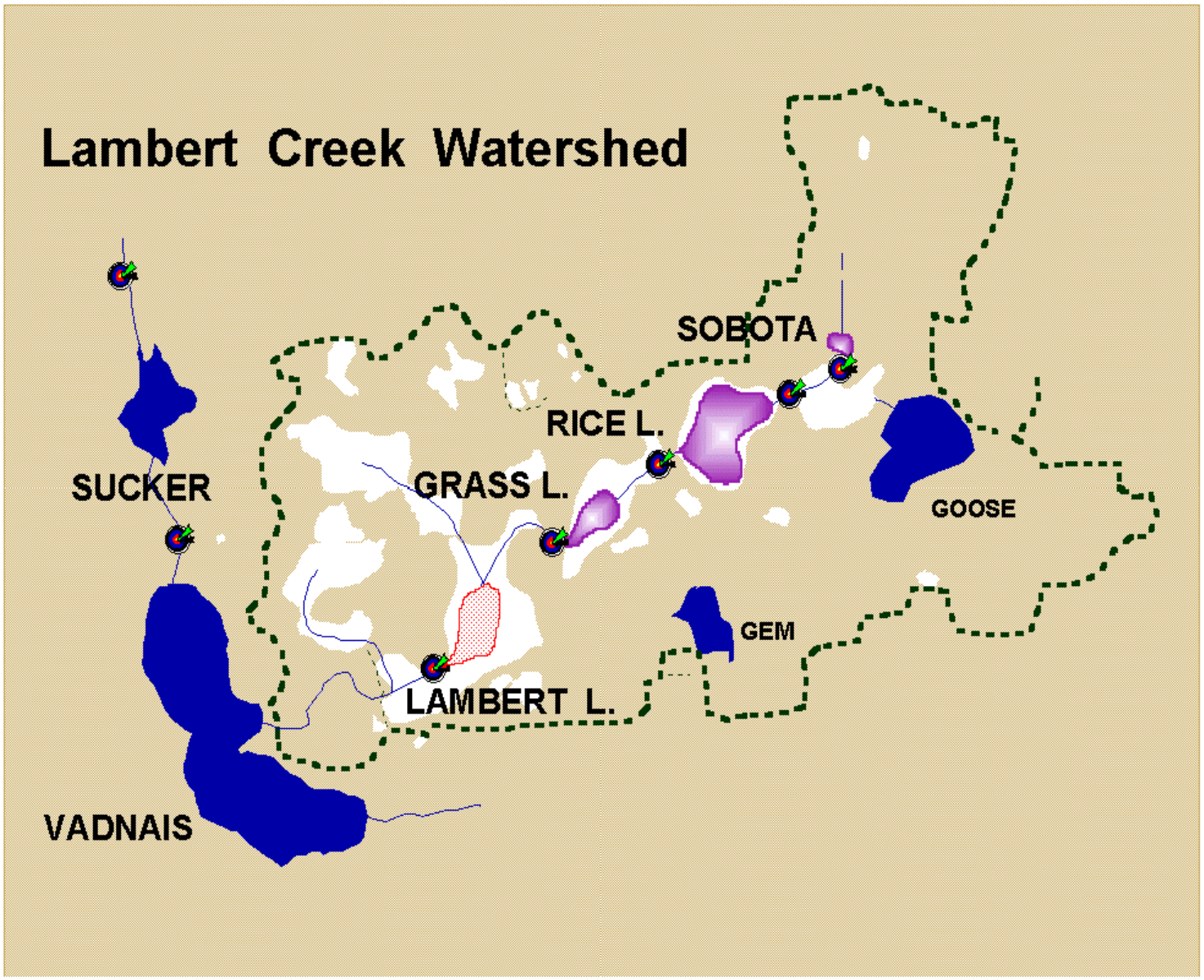


Responses to Ferric Chloride Injection at Fridley Pump Station

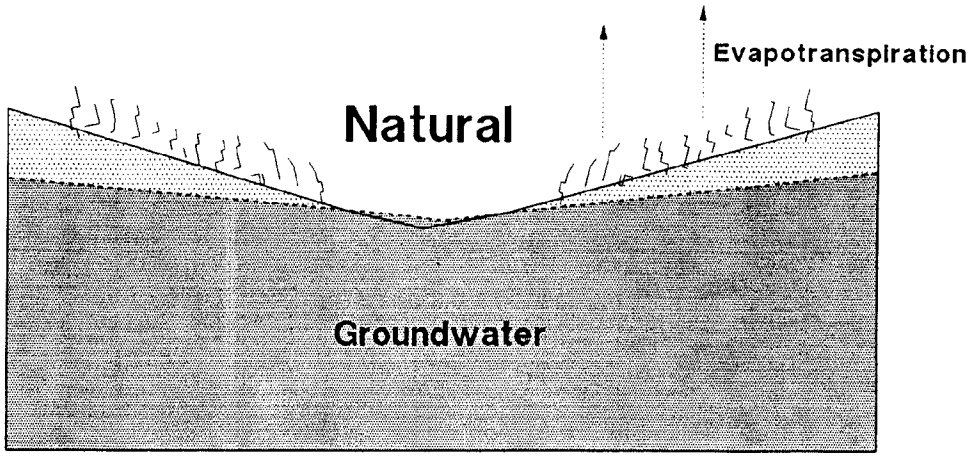


Means +/- 1 Standard Error on days with Fridley pump station operation, April-Sept
Paired samples on dates when concentration at Fridley concentration exceeded 30 ppb.
Dosed/Not Dosed = samples collected in months with/without iron injection at Fridley

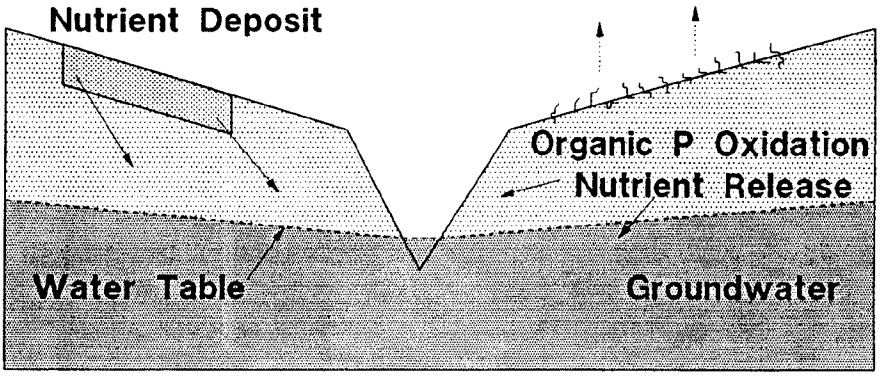

Phosphorus Retention in Vadnais Lake
Phosphorus Retention (%)
70%
60%
50%
40%
30%
20%
10%
0%
1984
1986
1988
1990
1992
1994
1996
1998
1988-1992 Mean = 54%
<------ Iron Addition ----->
<------ Aeration---------->
Percent of total phosphorus retained in Vadnais Lake sediments computed from April-September mass balances
Dashed line shows average retention in years when ferric chloride was injected into hypolimnion (1988-1992)


Lambert Creek Watershed
SOBOTA
RICE L.
GRASS L.
SUCKER
GOOSE
GEM
LAMBERT L.
VADNAIS

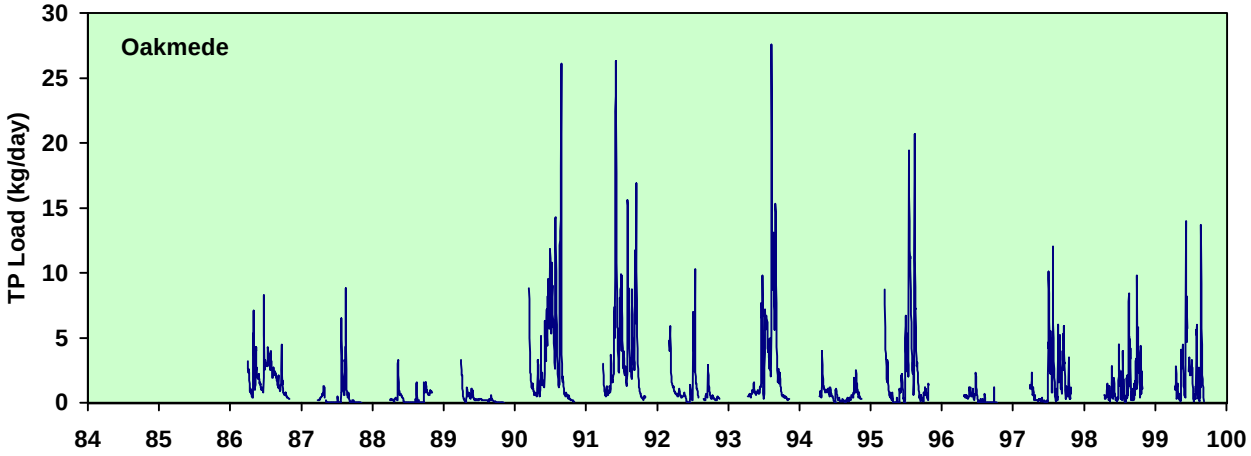
Wetland Cross-Sections

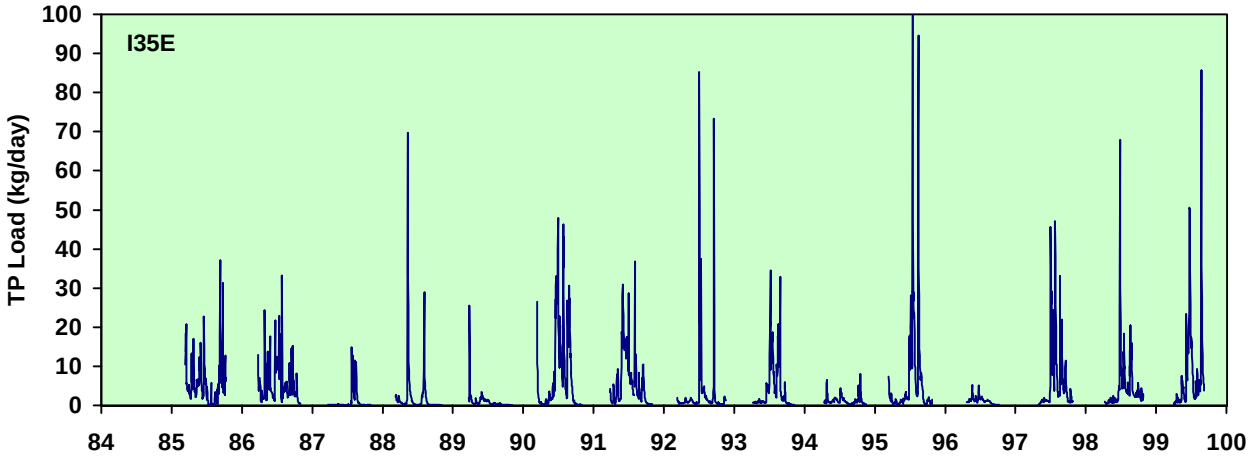


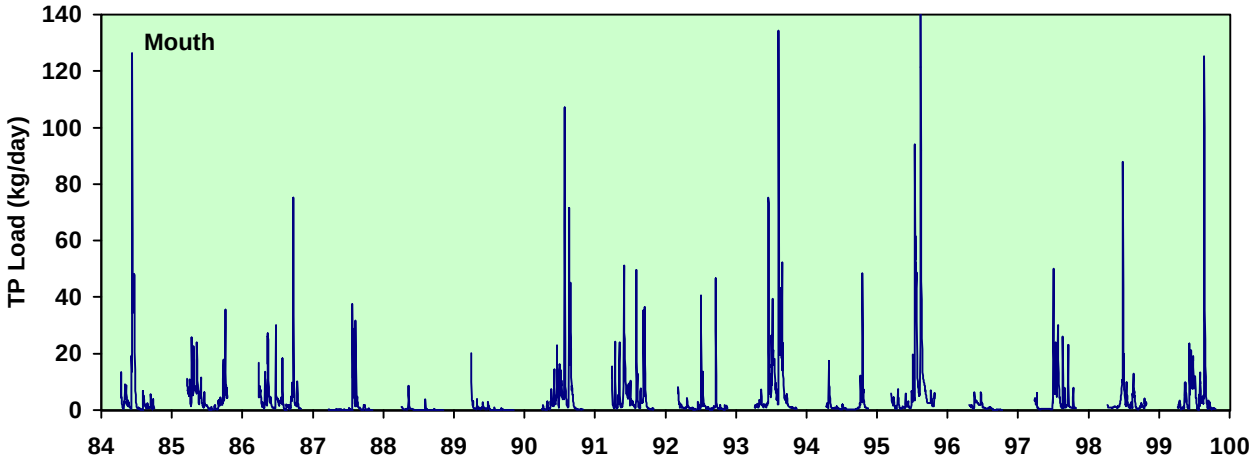
Ditched



Lambert Creek Phosphorus Load Time Series

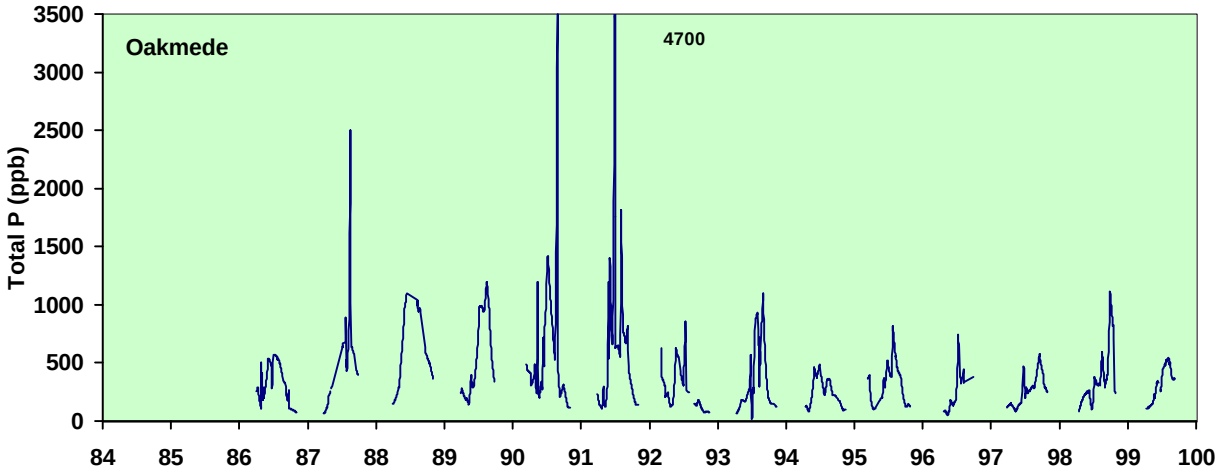


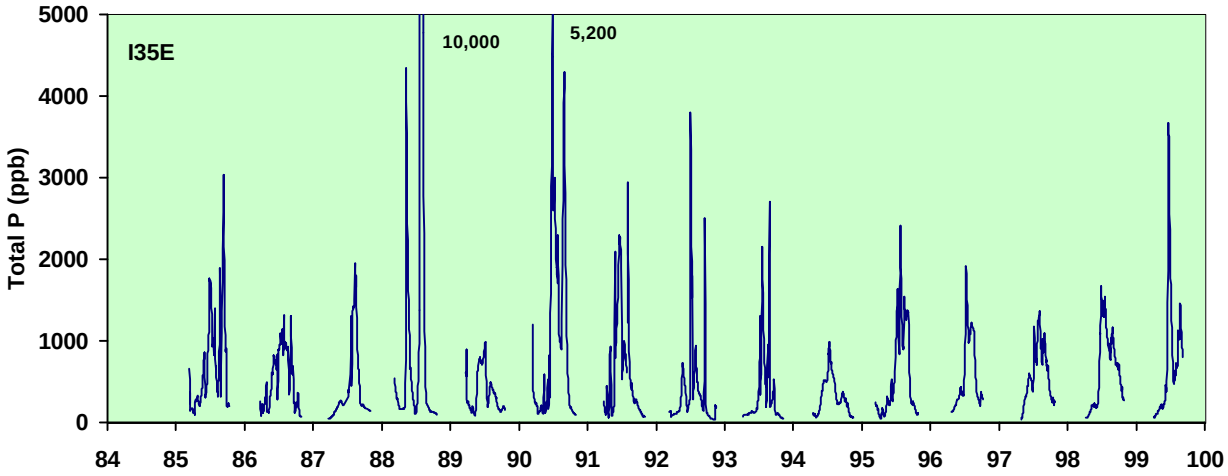


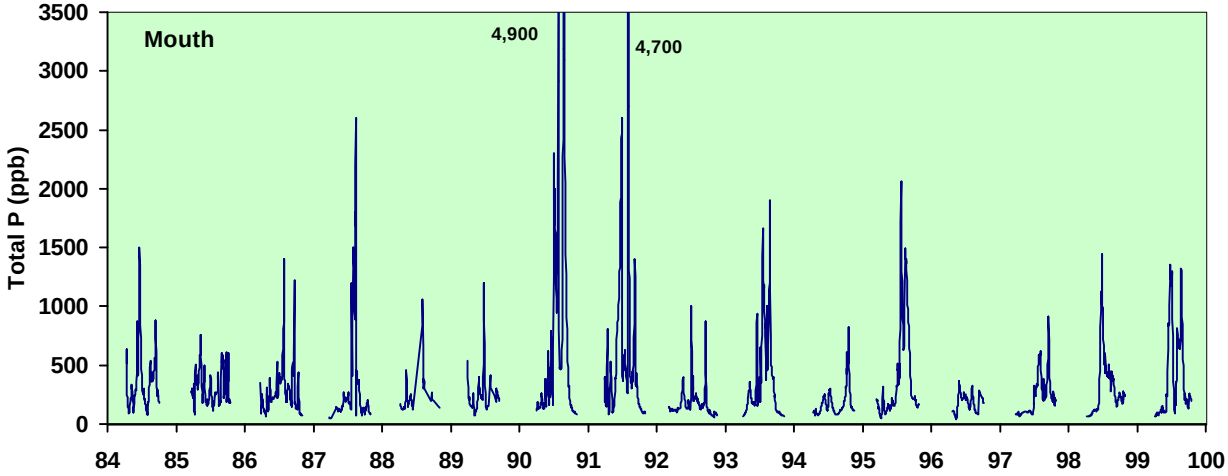


|-------- Weirs Constructed ---------->

Lambert Creek Phosphorus Concentrations

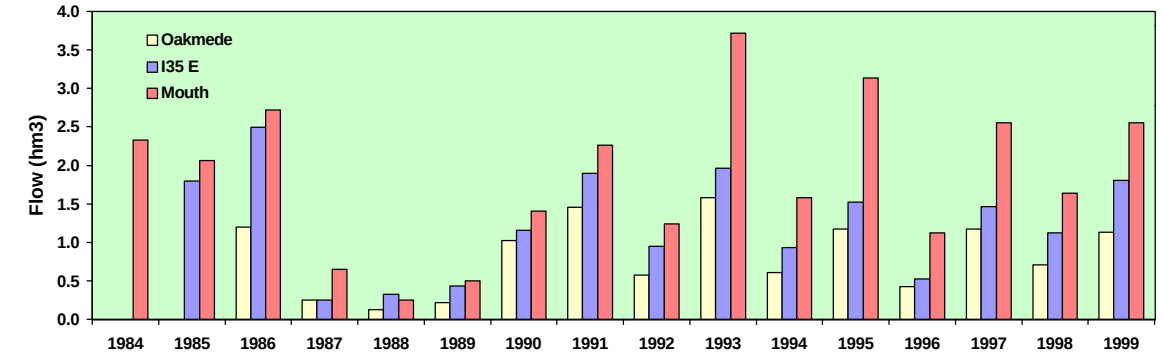


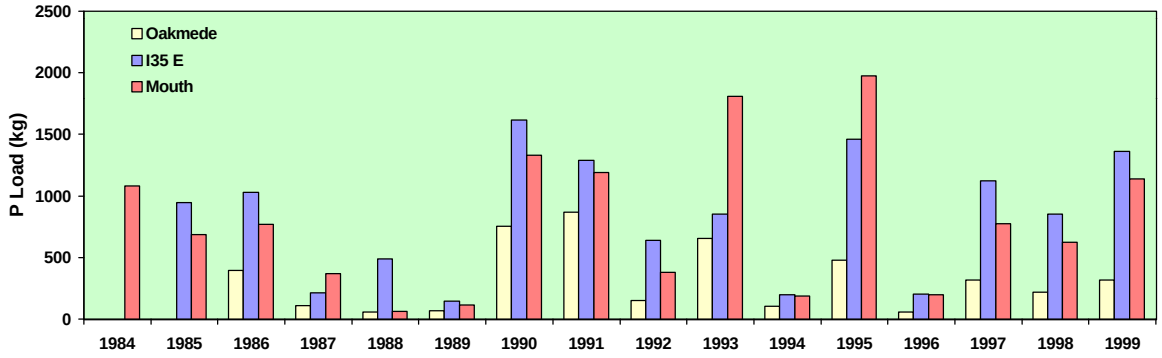


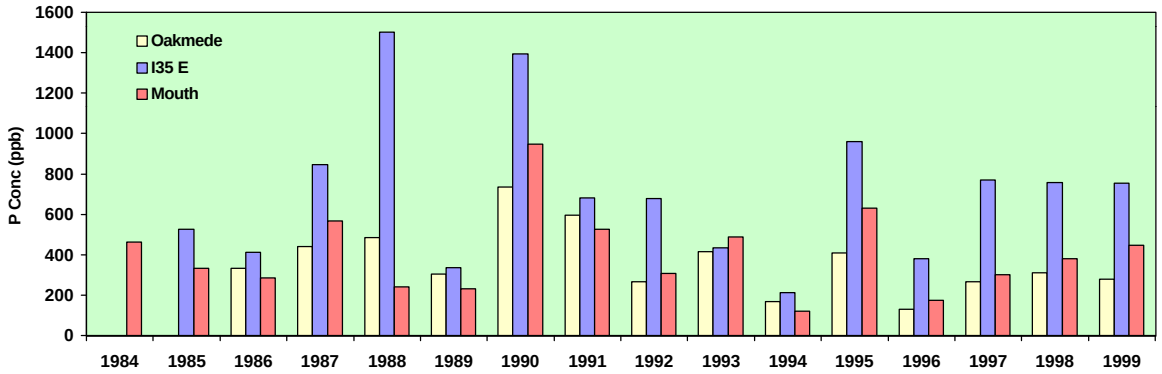


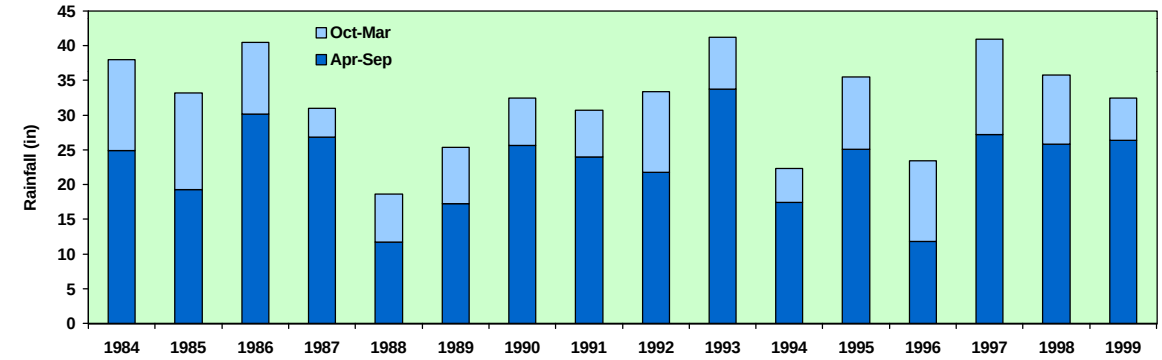
----- Weirs Constructed ---------->

Yearly Flows & P Loads at Lambert Creek Stations



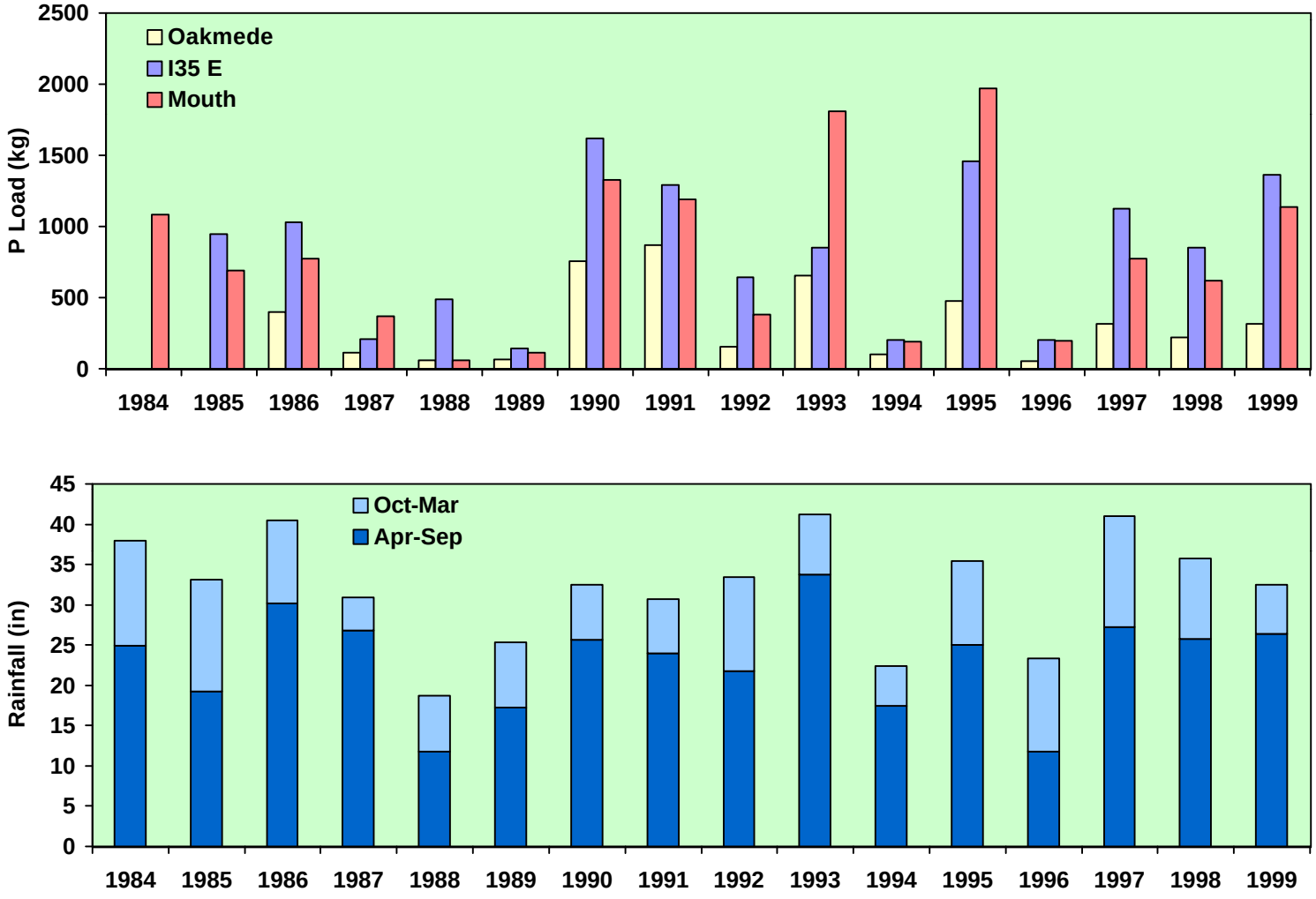






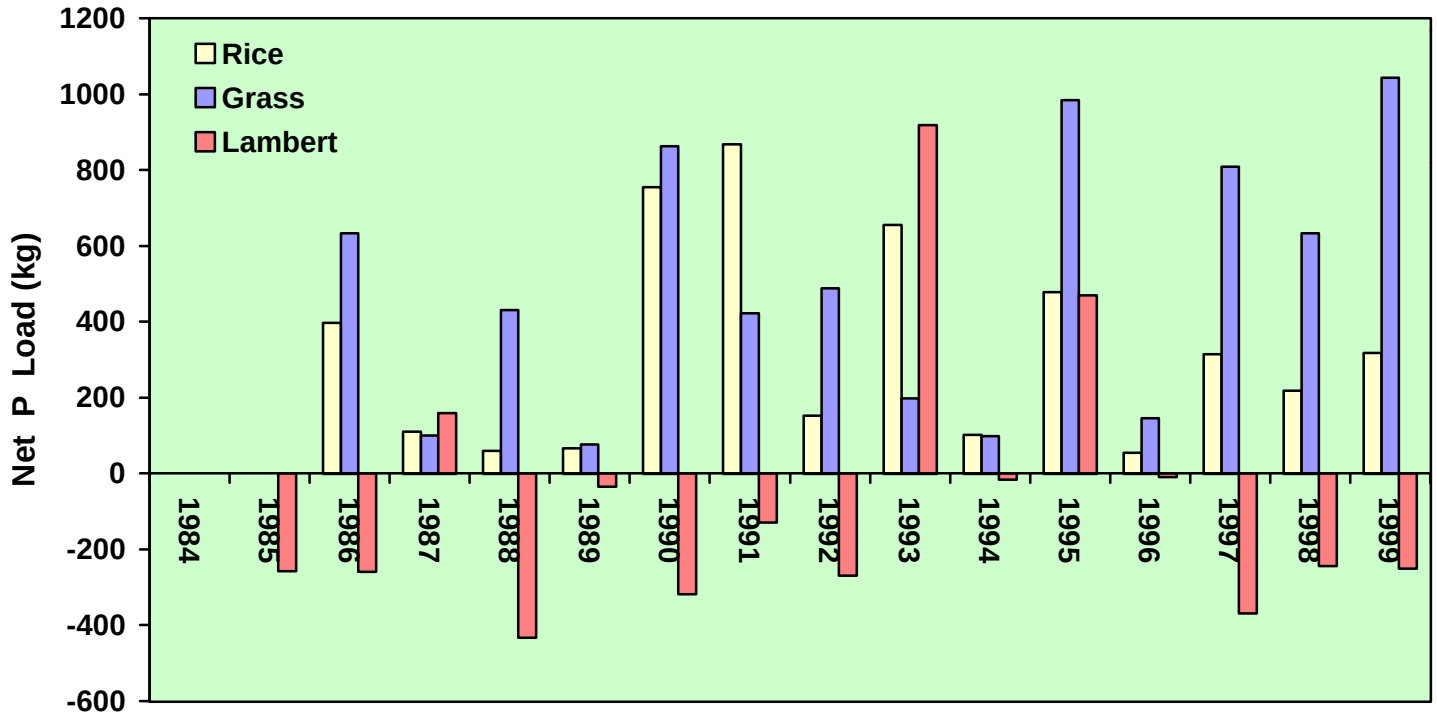
Flows & Loads in April-September of Each Year

Lambert Creek Yearly P Loads & Rainfall



P Loads in April-September of Each Year

Incremental P Loads from Lambert Creek Wetland Basins

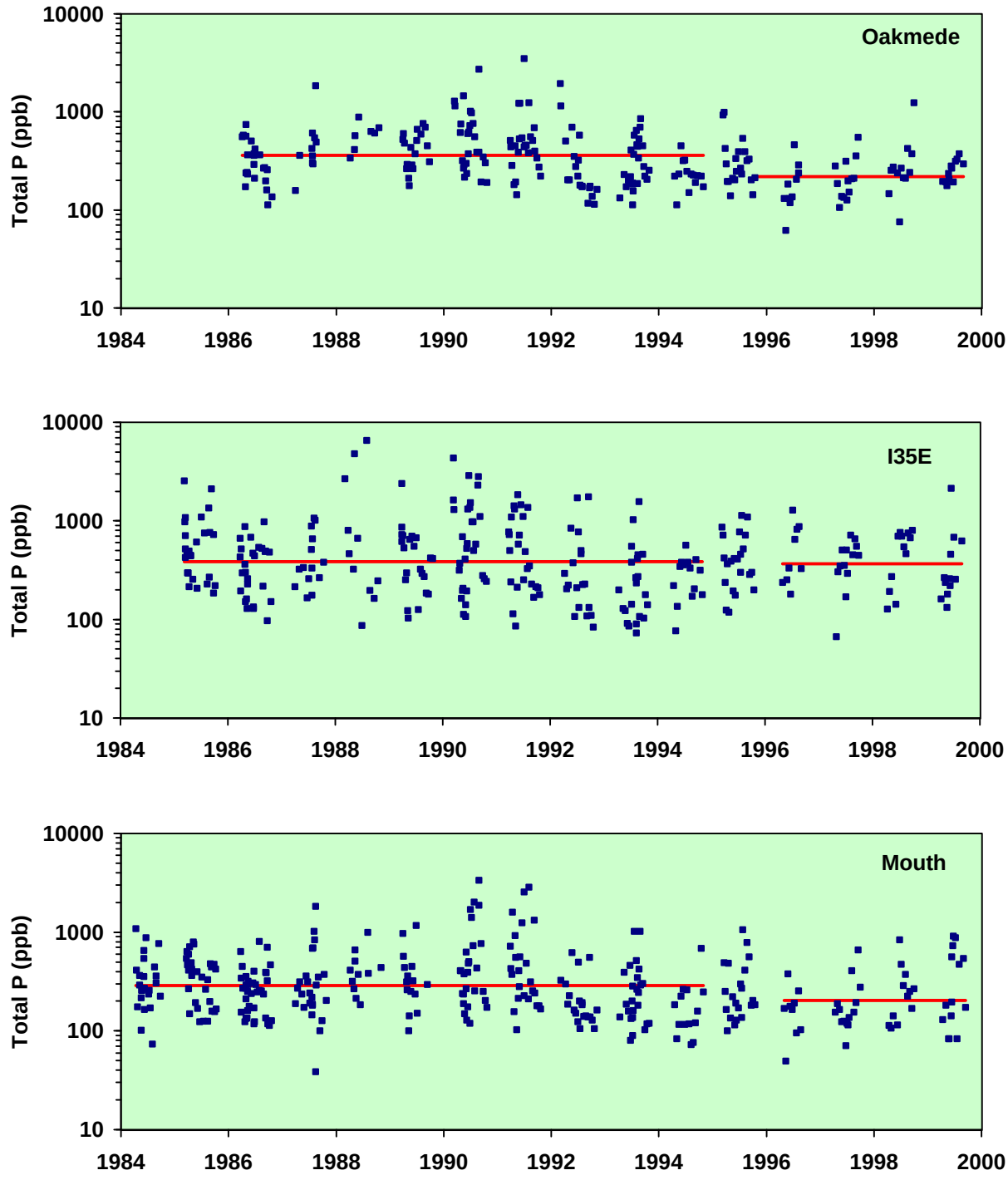


April - September

Weirs Installed ---------->

Rice =	**Total Load Above Oakmede Station**	No Data 1984-1985
Grass =	**Grass Lake = I35E - Oakmede**	No Data 1984-1985
Lambert =	**Lambert Lake = Lambert Mouth - I35E**	No Data 1984

Lambert Creek Total P Concentrations Before & After Weir Installation



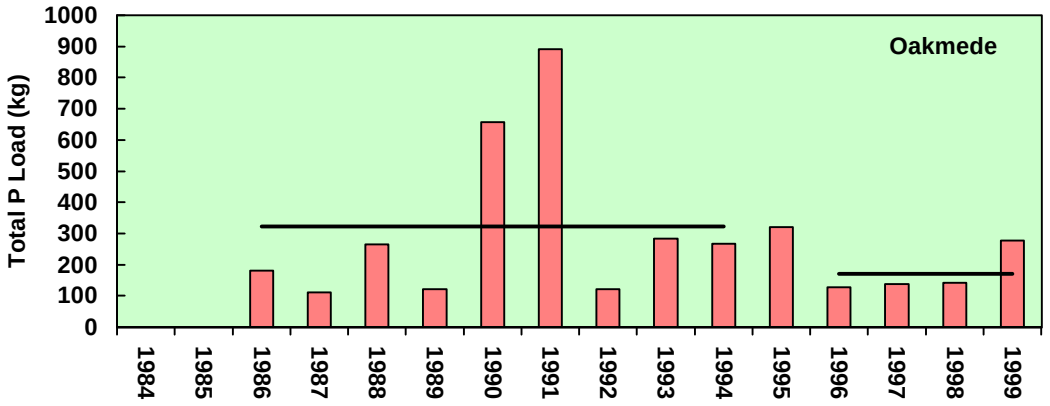
Values Adjusted for Seasonal & Flow Effects

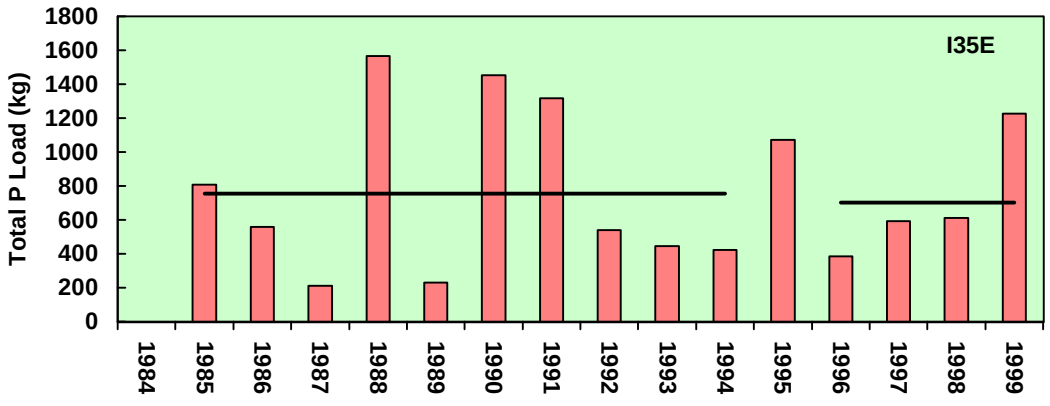
Weirs Installed ---------->

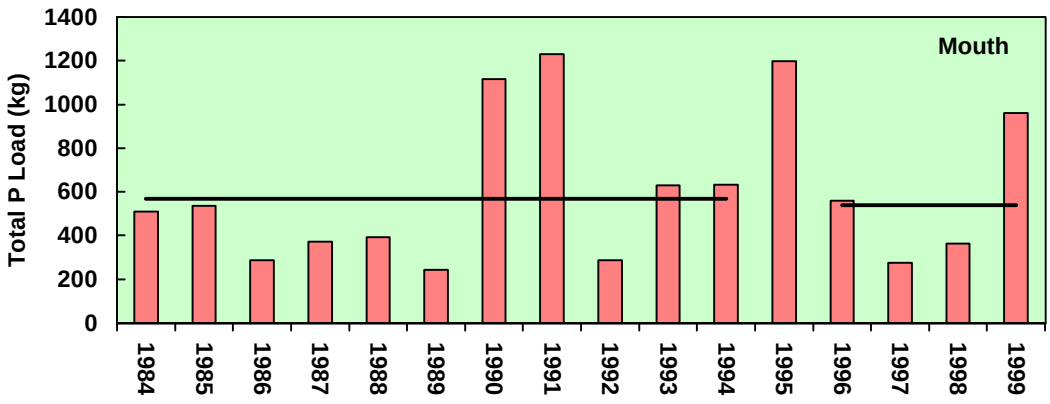
Geometric Means (ppb)

	<= 1994	>=1996	Reduc.	% Reduc	Std Error	Signif.
Oakmede	363	220	143	39%	9%	0.000
I35E	384	366	18	5%	11%	0.328
Mouth	289	203	86	30%	11%	0.001

Lambert Creek Total P Loads Before & After Weir Installation







Weirs Installed--------->

April-September Loads Adjusted for Variations in Water Year Rainfall

Seasonal Load (kg)

	<=1994	>=1996	Reduc	%Reduc.	Std Error	Signif
Oakmede	322	171	151	47%	30%	0.074
I35E	755	703	52	7%	32%	0.418
Mouth	567	540	27	5%	32%	0.442

Lambert Creek Wetland Restoration Projects

- **Rice Lake**
  - **Pool Elevation Raised to Design Levels 1994-1995**
  - **~40-50% TP Reductions Detected**
  - ***--> No Changes Recommended***

- **Grass Lake**
  - **Pool Elevation Raised in 1994-1995**
  - **Permanent Pool Volume ~40% of Design Value**
  - **TP Reductions Not Detected**
  - **Major Phosphorus Source**
  - ***---> Raise Pool to Design Elevation***

- **Lambert Lake**
  - **Phase II Project - Not Implemented**
  - **Pool Elev. Limited by Flooding Constraints**
  - **Hydraulic Analysis Complex**
  - **Phosphorus Sink Under Existing Conditions**
  - ***---> May Be Necessary to Achieve Lake Target***
  - ***---> Reconsider at Later Date***

- **Measured Improvements at Lambert Creek Mouth**
  - **Declining Trends in Concentration**
    - **TP, Ortho P, TN, NO23N**
  - **Decrease in Seasonal Maximum P Conc.**
  - **Reduction in Load Pulse after Dry Period (?)**
  - **Reduction in Mean TP Load Not Detected**

- **Measurement of P Load Reductions Hindered by:**
  - **Short Duration of Post-Implementation Monitoring**
  - **Hydrologic Variability**
  - **Offsetting Load Increases due to Urban Development**
  - **Time Lag in Wetland Response**
  - ***---> Continue Monitoring***

Conclusions

Analysis of 1984-1999 Monitoring Data

- Vadnais Lake Chain Water Quality Generally Improving

Total P, Ortho P, TN / TP Ratio

Algal Boom Frequency, Turbidity, Transparency, Oxygen

- Declining P Trends in Supply Sources

Mississippi River

Sucker & Pleasant Lakes

Lambert Creek (?)

Vadnais Creek

- Vadnais Lake Phosphorus Levels

No Trend over 1988-1999 Period

Average ~30 ppb (vs. 25 ppb goal)

Decreased by ~ 50% vs. 1984-1986 Baseline

Correlated with Rainfall in Recent Years

Increased Sensitivity to Lambert Creek Loads

Limited by Lab Analytical Precision (?)

- Numeric Goals for Vadnais Lake

Achieved: TN /TP , Si / TP, Fe / TP

Approached: TP, Bloom Frequency, Taste & Odor

- Reductions in Treated Water Turbidity & Chemical Costs

Improvements in Intake Water Quality

Improvements in Water Treatment Plant

- Benefits of Existing Controls not Fully Realized

Lag Time in Wetland Response

Lag Time in Lake Response

Recommendations

- **Support Aggressive Management of Watersheds:**
  - **Mississippi River**
  - **Lambert Creek**
  - **Other Local Watersheds**

- **Changes to Control Program:**
  - **Restart Vadnais Lake Iron Injection**
  - **Raise Grass Lake Elevation**
  - **Defer Lambert Lake Project**
  - **Continue Others**

- **Future Evaluations:**
  - **Track Data vs. Goals Yearly**
  - **Re-evaluate Entire Program in ~5 years**

- **Reduce TP Goal from 25 to 20 ppb**

- **Long-Term Monitoring Essential for Management**

- **Refinements to Monitoring Program:**
  - **Improve TP Analytical Method**
  - **Reduce Frequency for N Species**
  - **Sample Upper Watersheds Every 3 Years**
  - **Daily Chl-a at Pleasant & Vadnais Only**