APPENDIX A7 - MASS BALANCES DRAFT 7/25/2006

1. INTRODUCTION

The development and structure of a mass-balance modeling framework for Onondaga Lake is described in previous lake monitoring reports (Ecologic, 2005). The framework facilitates computation and analysis of mass balances for nutrients and other water-quality components using hydrologic and water quality data collected in the Lake and its tributaries since 1986. Results provide a basis for:

(1) Estimating the magnitude and precision of loads from each source;
(2) Assessing long-term trends in load and inflow concentration from each source and source category (point, nonpoint, total);
(3) Evaluating the adequacy of the monitoring program, based upon the precision of loads computed from concentration and flow data;
(4) Developing and periodic updating of an empirical nutrient loading model that predicts eutrophication-related water quality conditions (as measured by nutrient concentrations, chlorophyll-a, algal bloom frequency, transparency, and hypolimnetic oxygen depletion) as a function of yearly nutrient loads, inflows, and lake morphometry (Ecologic, 2000;2001).
(5) Developing simple input/output models for other constituents; and
(6) Developing data summaries to support integration and interpretation of monitoring results in each yearly AMP report.

This appendix updates the mass-balance framework to include through 2005. Computations are linked directly to the AMP long-term water quality and hydrologic database (Figure A7-1), as described by Ecologic et al (2005). Recent mass balances for key water quality components are summarized. Long-term trends in total loads (point, nonpoint), inflow concentrations, and outflow concentrations are documented.

In addition, the empirical eutrophication model network is updated to reflect data through 2005. This network was initially developed based upon data thru 1999 (Ecologic, 2000) and subsequently updated to include data thru 2000 (Ecologic, 2001). Phosphorus and nitrogen balances are linked to empirical models for predicting eutrophication-related water quality variables (chlorophyll-a, transparency, organic nitrogen, oxygen depletion). Models for predicting the frequency of algal blooms (daily chlorophyll-a concentrations > 15 or 30 ppb) as a function of seasonal average chlorophyll-a concentrations are recalibrated for use in the empirical model framework, as well as in the detailed mechanistic lake model being developed by QEA et al (2006) for OCDWEP. This linkage provides a basis for predicting summer-average lake concentrations and bloom frequencies to reductions in external phosphorus loads potentially resulting from future implementation of point-source and nonpoint-source control measures.

2. LONG-TERM TRENDS

Yearly variations in precipitation and lake inflow volume are summarized in Figure A7-2. Over the 1990-2005 period, yearly runoff from the Onondaga Lake watershed varied from 31 to 75 cm and was strongly correlated with precipitation ($r^2 = 0.82$). Runoff was 62 cm in 2005, as compared with a 16-year mean of 52 cm. Precipitation was 102 cm in 2005, as compared with a 16-year mean of 97 cm.

The following figures show long-term trends in each water quality component over the 1990-2005 period:

Figure A7-3	Total Inflow & Outflow Concentrations
Figure A7-4	Total Inflow & Outflow Loads
Figure A7-5	Total NonPoint & Total Metro Loads

The time series start in 1990 because that was the first year in which total phosphorus measurements were made in the lake tributaries. For the first year in recorded history, loads from Metro (sum of bypass and treated discharge) in 2005 were lower than the total non-point loads in the cases of 5-Day BOD, Ammonia N, Nitrite N, Total Kjeldahl N, Soluble Reactive P, Total Dissolved P, and Total P. (Figure A7-5). The 2005 Metro loads for these constituents were also lower than those measured in 1990-2004. This pattern reflects treatment plant improvements. Nitrate loads from Metro in 2004-2005 increased relative to the non-point loads because of increased nitrification in the treatment process.

Ten-year (1996-2005) trends in concentration and load for each mass-balance term and water quality component are summarized in Table A7-1. Trends are tested using a linear regression of flow-weighted-mean concentration or load against year. Trend slopes that are significantly different from zero ($p < .10$ for a two-tailed hypothesis or $p < 0.05$ for a one-tailed hypothesis) are listed. A ten-year rolling window has been consistently used for trend analysis in yearly AMP reports. With a longer period, results would be strongly influenced by historical data that are not representative of current conditions with respect to municipal and industrial wastewater inputs. With a shorter period, results would be increasingly influenced by short-term variations in hydrology and other random factors.

For total inflows, decreasing trends in concentration and/or load are indicated for BOD-5, Ammonia N, Total Kjeldahl N, Nitrite N, Total N, Total & Filtered Organic Carbon, and Total P. An increasing trend in Nitrate N load reflects increased nitrification of the Metro effluent. Increases in Chloride and Sodium loads (4-5 %/yr) were also observed.

For total non-point inflows, decreasing trends in concentration and/or load are indicated for BOD-5, Ammonia N, Kjeldahl N, Total N, Soluble Reactive P, and Total P. These indicate that lake improvements over this period reflect reductions in both point and non-point loads. However, trend analyses for 1996-2005 are strongly influenced by the unusually high non-point loads (from Ley & Onondaga Creeks) in 1996. Nonpoint loads in phosphorus and nitrogen species were relatively stable after that (FigureA7-5).

For the lake outflow (12 foot samples considered most representative), significant decreasing trends in concentration and/or load are indicated for BOD-5, Ammonia N, Total Kjeldahl N, Nitrite Nitrogen, Total Nitrogen, and Total P. Outflow trends are generally consistent with trends in point and non-point loads inflows and improving water quality conditions attributed primarily to Metro improvements.

3. MASS BALANCES

Five-year average (2001-2005) mass balances for the following constituents are summarized in the following tables:

Table A7-2	Chloride
Table A7-3	Total Phosphorus
Table A7-4	Soluble Reactive Phosphorus
Table A7-5	Total Nitrogen
Table A7-6	Ammonia Nitrogen

Since chloride is expected to be conservative, the chloride balance provides a basis for testing the accuracy and completeness of the data and methods used to develop the mass balances. Outflow loads computed from 12-foot outlet samples exceeded inflow loads by 5% ± 2% or 10,287 ± 4,374 metric tons/year in 2001-2005 (Table A7-2). Excess loads (outflow-inflow) in chloride and sodium were lower in 2005 than in most previous years (Figure A7-4). The inflow and outflow load time series for these constituents appear to be converging. Excess loads may be attributed to application of road deicing salts in ungauged portions of the watershed, salt springs contributing directly to the lake, and/or over-estimation of lake outflow volumes.

4. EUTROPHICATION MODEL

4.1 Introduction

This section describes refinements and updates to the empirical eutrophication model framework, as described in previous reports (Ecologic, 2000, 2001) and depicted in

Figure A7-6. Data from the last 5 water years (2001-2005) are used for model calibration. Hindcasts of 1991-2000 data are used for model testing. While the previous analysis also included data from 1986-1990, phosphorus loads in those years were estimated from total inorganic phosphorus data and lake total phosphorus were relatively infrequent. Model calibrations to that period would be of limited accuracy and relevance to current conditions.

4.2 Data Set Development

Average phosphorus and nitrogen balances for the calibration period (2001-2005) are listed in Tables A7-3 and A7-5, respectively. Yearly loads and observed lake data used in model calibration and testing are listed in Table A7-7. The model is driven by water and mass balances formulated on a water year basis (October 1–September 30). Daily loads and flows are extracted from the AMP long-term database and summarized in a water year basis.

The seasonal dynamics of the lake TP concentrations have been considered in selecting an averaging period for the lake responses. TP and SRP concentrations generally tend to decline from April to June and increase in late September or October as the thermocline erodes. An averaging period of June thru August is used to reflect the summer stratified period and limit the effects of lake mixing events on the surface concentrations. It also corresponds to the averaging period typically used to assess lake condition relative to the state’s guidance value for Total P (20 ppb) .

Average lake nutrient concentrations in each summer are computed using June-August samples collected at the Lake South station between 0 and 3 meters. Summer means and standard errors are computed from the time series of daily means; i.e., the data are averaged first across depths on each date, then across dates in each year.

Chlorophyll-a concentrations are based upon photic zone samples (1999-2005), epilimnion composites (1993-1998), and 0-3 meter average grab samples (1991-1992). Based upon paired data from 1999-2005, photic zone chlorophyll-a values exceed epilimnetic composites by an average of 9.6%. Accordingly, the 1993-1998 epilimnetic values have been increased by 9.6% for consistency with the 1999-2005 values. No adjustment has been to the 1991-1992 grab data.

Aerial hypolimnetic oxygen depletion rates have been computed from oxygen and temperature profiles collected at 0.5 or 1.0 meter increments, as extracted from the AMP long-term water quality database. The rate reflects oxygen consumption below the thermocline between the first sampling date with thermal stratification and the last date prior to development of anoxic conditions (hypolimnetic mean < 2 ppm). Rates could not be computed for 1993 and 1994 because profile data prior to the onset of anoxia were not available. The areal rate is computed as the product of the mean hypolimnetic depth and the decrease in volume-averaged concentration divided by the number of days between sampling events. Rates have been computed for three assumed average thermocline levels (6, 9, 12 m), as summarized in Table A7-7.

4.3 Phosphorus Trends and Averaging Interval

Figure A7-7 shows total phosphorus (TP) and soluble reactive phosphorus (SRP) concentrations in the upper (0 – 6 m) and lower (9 – 12 m) layers at the lake south station between 1990 and 2005. Declining trends in both TP and SRP are most evident in the bottom layer, where concentrations tend to peak in late summer and then decline as the thermocline erodes and bottom waters become entrained in the upper layer. Peak TP concentrations in the bottom layer declined from 0.6 – 0.9 mg/L in 1990-1998 to 0.3 – 0.5 mg/L in 1999-2005. Peak SRP concentrations in the bottom layer declined from 0.4 – 0.8 mg/L in 1990-1998 to 0.3 – 0.4 mg/L in 1999-2005. The late summer increase in upper layer TP and SRP concentrations were lowest in 2005, when the peak bottom water concentrations were also lowest.

The bottom panel of Figure A7-7 shows TP time series for the Lake South (0 -6 m), Lake North (0-6 m) and the lake outlet (12 ft, assumed to be representative of flow leaving the lake in the mass balance calculations). Generally, there is good agreement among these stations. Seasonal minimum concentrations were lowest in 1998-2002 and 2005, when external P loads to the lake were also lowest (Figures A7-4, A7-5).

The declining trends in inflow, lake surface, and lake bottom concentrations may influence the calibration of the phosphorus balance model, which assumes that the lake is at steady state with respect to the inflow loads in any given year. The peak fall overturn concentrations declined from ~0.3 to ~0.1 ppm between 1995 and 2005 (Fig A-8, bottom panel), which corresponds to an average trend of -1.3 metric tons / year in the phosphorus stored in the lake, assuming a total lake volume (128 x10^6 m^3). This is approximately 2% of the average inflow load and 3% of the average outflow load over the 2001-2005 period (Table A7-3). It is unlikely, therefore, that the long-term declining trend would have much influence on the model calibrations, except possibly in years when sharp TP declines were observed (e.g., 2004-2005).

Depletion of surface SRP concentrations in the summer is a sign that algal productivity is limited by phosphorus. Summer SRP concentrations in the upper layer were frequently at or below the detection in 1998-2005, with exception of 2004, when loads from Metro were high relative to the other years (Figure A7-5). Figure A7-9 plots summer mean SRP vs. TP concentrations for each year Analytical detection limits varied from 1 to 3 ppb over this period. To allow comparison across years, the SRP concentrations have been constrained to a minimum value of 3 ppb before computing the summer averages. In the last decade, SRP concentrations generally averaged 3 ppb or less in years when the TP concentration averaged less than 40 ppb.

4.4 Model Structure and Calibration

The model structure (Figure A7-6) consists of the following components:

- Yearly flow-weighted-mean outflow TP and TN concentrations are predicted from inflow loads and flows using a simple first-order settling velocity model (Vollenweider, 1969). The effective settling rates (19.9 and 30.6 m/yr, respectively) are calibrated to 2001-2005 data.

- Summer lake TP and TN concentrations are assumed to be a fixed percentage of the yearly flow-weighted-mean outflow concentrations. The percentages (57% and 124%, respectively) are calibrated to 2001-2005 data.

- Chlorophyll-a is predicted from summer TP using the Jones & Bachman (1976) regression equation, without recalibration to Onondaga Lake data.

- Other trophic response variables (Secchi Depth, organic nitrogen, utilized phosphorus (TP - SRP), and HOD rates) rates are predicted from the predicted chlorophyll-a concentrations using empirical models derived from other lake and reservoir datasets, as extracted from the BATHTUB model (Walker, 1985; 2004). With the exception of Secchi depth, the models are not recalibrated.

- Bloom frequencies (% of daily chlorophyll-a concentrations exceeding 15 or 30 ppb, the adopted AMP metrics) are computed from predicted mean chlorophyll-a concentrations using a log-normal frequency distribution model (Walker, 1984; 2004), with the temporal coefficient of variation (CV = 0.67) calibrated to 2001-2005 lake data.

- Frequencies of Secchi Depths less than 2 meters and 1.2 meters (equivalent to the NYSDEC guidance value for swimming (4 feet), the adopted AMP metric) are also predicted with a log-normal distribution model with CV = 0.34, again calibrated to 2001-2005 lake data.

Updated model equations coefficients and equations are listed in Table A7-8. Observed and predicted time series for primary variables in the model network are shown in Figure A7-9.

Calibrated to 2001-2005 data, the phosphorus balance model performs reasonably well in the previous years used for model testing (1991-2000). The nitrogen balance mode tends to under-predict observed outflow and lake TN concentrations in the 1991-2000 pre-calibration period. This may reflect the drastic shift in inflow load speciation from reduced to oxidized forms associated with nitrification of the Metro discharge. A simple first-order model that ignores nitrogen speciation does not appear to be sufficient.

Effects of phosphorus releases from the lake bottom sediments are not directly considered in the model, but are embedded in the calibrated net settling rate. Non-steady state responses attributed to phosphorus releases from bottom sediments following reductions would be reflected in the model residual time series (observed – predicted lake P concentrations). Reasonable agreement between observed and predicted lake and outlet P time series over this period with significant reductions in external load (Figure A7-9) suggests that effects of net phosphorus releases from bottom sediments are small relative to external loads. There is no evidence of a lagged response to changes in external P loads, as would be expected if net reflux of P from historical sediments were an important source.

Aside from SRP depletion, another pattern consistent with the increased importance of phosphorus limitation is the convergence of observed and predicted chlorophyll-a concentrations in recent years (1999-2005, Figure A7-9)), since the predicted values are based upon the Jones-Bachman regression model derived from other phosphorus-limited lakes. The model generally over-predicts observed chlorophyll-a concentrations in earlier years (1991-1998), when TP and SRP concentrations were higher and less likely to have limited algal growth (Figure A7-7). Similar convergence of the observed and predicted lake responses in later years is evident for other trophic indicators (transparency, bloom frequency, organic N, TP – SRP, and HOD rate).

It is possible that under-prediction of HOD rates reflects external sources of oxygen demand (Metro discharge, CSO's) that would not be typical of the lakes used in calibrating the HOD vs. Chl-a regression model (Walker, 1985). The convergence of the observed and predicted HOD rates in recent years would be expected with Metro and CSO improvements (reduced BOD loads) and increased trend towards phosphorus limitation of algal growth.

Calibration of the bloom frequency model to observed chlorophyll-a data is shown in Figure A7-10 Observed and predicted frequencies of daily-mean chlorophyll-a concentrations exceeding 15, 20, 30, and 40 ppb are plotted against the observed summer (June-August) mean values. Predicted values are based upon a log-normal frequency distribution with a temporal coefficient of variation (CV = 0.67) calibrated to 2001-2005 data. Analogous results for Secchi interval frequencies are shown in Figure A7-11 (CV = 0.39).

Temporal variability in chlorophyll-a and transparency between June and August generally decreased over the 1991-2005 period (Figure A7-12). Shifting the seasonal window forward by one month (July - September) generally eliminates these trends. This pattern appears to reflect the absence of spring and early summer clearing events in recent years, in turn linked to shifts in lake ecology (increased alewife and decreased daphnia populations). Calibrated (2001-2005) CV's for chlorophyll-a are 0.67 for June-August and 0.55 for July-September. Calibrated CV's for Secchi depth are 0.34 for June-August and 0.29 for July-September. These alternative averaging periods and calibrations can be used in linking the bloom frequency models to the mechanistic lake model under development (QEA et al, 2006).

4.5 MODEL IMPLEMENTATION

The model application workbook has been revised to reflect the updated calibration (Table A7-9). Predictions are driven by lake outflow volume, inflow total phosphorus load, and inflow total nitrogen load, each referenced to a specified hydrologic period of record.

The predicted response of each trophic state indicator to variations in phosphorus load is shown in Figure A7-13 . Results are for average 2001-2005 hydrologic conditions (outflow volume = 485 hm^3/yr). The 80% prediction interval (10th, 50th,90th percentiles) for an individual year is shown for each response variable. These intervals reflect the combined influences of sampling variations (uncertainty in loads and measured responses) and model error.

The following table summarizes projected lake responses to various management scenarios involving combinations of Metro effluent P levels & nonpoint source load reductions, using 2001-2005 average flows and loads as a base case:

	TP Load	Inflow Conc (ppb)		Lake P Conc (ppb)			Frequencies	
Scenario	mt/yr	Metro	NonPoint	Mean	Low	High	Chla > 15	Secchi < 1.2
Existing	59.2	358	64	47	32	68	64%	7%
Existing	59.2	358	64	47	32	68	64%	7%
April 2006	36.8	120	64	29	20	42	22%	2%
April 2006 + 20% NPS	31.9	120	51	25	17	37	13%	1%
Dec 2012	27.4	20	64	22	15	32	7%	1%
Dec 2012 + 20% NPS	22.5	20	51	18	12	26	3%	1%
Metro Diversion	25.6	0	64	23	16	34	9%	1%
Diversion + 20% NPS	20.6	0	51	19	13	27	3%	1%
Background	8.1	0	20	7	5	11	0%	0%

Lake P levels approach the 20 ppb criterion for management scenarios involving control of Metro load (either by diversion or by achieving the 2012 effluent P level of 20 ppb) and ~20% reduction in nonpoint load. These projections differ only slightly from those derived from the previous calibration of the model (Ecologic, 2001).

5 . REFERENCES

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Appendix 7 - Mass Balances

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Table A7-1: 10-Year Trends in Load & Flow-Wtd-Mean Concentration

Load Trends (% / yr) **Period: 1996 to 2005**

Term	ALK	BOD5	CA	CL	NA	NH3N	NO2N	NO3N	TKN	TN	SIO2	TIC	TOC	TOC_F	SRP	TP	TSS
Metro		-6%		4%	4%	-21%	-10%	17%	-18%	-5%			-7%	-8%			
Bypass								9%									
Allied	13%		12%	14%	15%			14%				13%					15%
Crucible	-4%	-5%			-5%		-15%	-16%	-5%	-13%			-6%	-6%			
Harbor/Hiawatha	5%		4%	6%	7%	-7%		7%		6%	4%	5%					
Ley/Park	3%		3%	5%	5%		-7%					4%					
Ninemile/Rt48		5%									5%	5%					
Onond./Kirkpatrick	4%		4%	7%	7%							4%			-18%		
Harbor/Velasko	5%	8%	4%	6%	9%	-7%		7%		6%	4%	5%	8%				
Onondaga/Dorwin	4%	7%		3%	4%	-8%			6%			4%					
Total Gauged				4%	5%	-19%	-8%	11%	-14%								
NonPoint Gauged	4%			3%	5%	-4%						4%					
Ungauged	4%			3%	5%	-4%						4%					
Total NonPoint	4%			3%	5%	-4%						4%					
Total Industrial								-6%		-4%							
Total Municipal		-6%		4%	4%	-21%	-10%	17%	-17%	-5%			-7%	-8%			
Total Inflow				4%	5%	-19%	-8%	11%	-13%								
Total Outflow					3%	-15%	-4%	8%	-11%		7%						
Retention		-8%		-18%	-20%	-26%		21%	-18%					-20%			
Outlet2					4%	-14%		8%	-9%								8%
Outlet12					3%	-15%	-4%	8%	-11%		7%						

Concentration Trends (% / yr) **Period: 1996 to 2005**

Term	ALK	BOD5	CA	CL	NA	NH3N	NO2N	NO3N	TKN	TN	SIO2	TIC	TOC	TOC_F	SRP	TP	TSS
Metro		-7%		4%	3%	-21%	-10%	16%	-18%	-5%			-7%	-8%			
Bypass		-5%	-6%			-8%			-8%	-6%			-12%	-13%		-6%	-4%
Allied					3%	-18%	-8%		-12%	-4%	-5%		-4%	-4%	-7%	-5%	5%
Crucible	2%		2%				-8%	-10%		-7%	4%	3%					
Harbor/Hiawatha						-10%	-7%	2%									
Ley/Park		-13%			3%	-12%	-9%		-11%	-8%					-15%	-8%	
Ninemile/Rt48			-3%	-5%	-3%	-5%	-4%	2%	-3%		1%	1%					
Onond./Kirkpatrick						-5%						1%			-20%	-9%	
Harbor/Velasko		3%	-2%		3%	-11%	-10%	2%		1%							
Onondaga/Dorwin	1%	3%				-11%			3%			1%			-22%		
Total Gauged		-6%				-19%	-10%	8%	-15%	-5%			-4%	-4%		-6%	
NonPoint Gauged		-3%				-7%			-3%			1%			-13%	-6%	
Ungauged		-3%				-7%			-3%			1%			-13%	-6%	
Total NonPoint		-3%				-7%			-3%			1%			-13%	-6%	
Total Industrial	2%			3%	3%						3%	3%					
Total Municipal		-6%		4%	3%	-20%	-10%	15%	-17%	-5%			-7%	-8%			
Total Inflow		-6%				-19%	-10%	7%	-14%	-5%			-3%	-4%		-6%	
Total Outflow		-2%	-1%			-16%	-6%	5%	-12%	-5%						-5%	
Outlet2						-15%		5%	-11%	-3%							5%
Outlet12		-2%	-1%			-16%	-6%	5%	-12%	-5%						-5%	

Trends Significant at $p < .10$ (2-tailed hypothesis), based upon linear regression of yearly values

Table A7-2: Chloride Balance for 2001-2005

Variable: **Chloride** **Average for Years:** **2001** **thru** **2005**

						Percent of Total Inflow				Drain.		Export
Term	**Flow 10^6 m3**	**Load mtons**	**Std Error mtons**	**Conc ppm**	**RSE %**	**Sampl per yr**	**Flow %**	**Load %**	**Error %**	**Area km2**	**Runoff cm**	**mtons/ km2**
Metro Effluent	93.24	37438	2082	402	6%	34	18%	19%	37%			
Metro Bypass	2.40	1027	182	428	18%	4	0%	1%	0%			
East Flume	0.68	330	15	486	4%	28	0%	0%	0%			
Crucible	2.15	835	16	389	2%	27	0%	0%	0%			
Harbor Brook	10.76	2950	205	274	7%	30	2%	2%	0%	31.4	34.3	94.1
Ley Creek	40.68	14268	1443	351	10%	31	8%	7%	18%	66.1	61.5	215.9
Ninemile Creek	151.67	52583	819	347	2%	30	30%	27%	6%	298.1	50.9	176.4
Onondaga Creek	172.08	73785	1655	429	2%	31	34%	38%	24%	285.1	60.3	258.8
Nonpoint Gauged	375.19	143586	2353	383	2%	122	73%	74%	47%	680.7	55.1	210.9
Nonpoint Ungauged	25.55	9780	1325	383	14%	0	5%	5%	15%	46.4	55.1	210.9
NonPoint Total	400.74	153366	2700	383	2%	122	78%	79%	63%	727.0	55.1	210.9
Industrial	2.83	1165	22	412	2%	55	1%	1%	0%			
Municipal	95.64	38465	2090	402	5%	38	19%	20%	37%			
Total External	499.21	192997	3414	387	2%	215	98%	100%	100%	727.0	68.7	265.5
Precipitation	11.59	12	1	1	9%	0	2%	0%	0%	11.7	99.1	1.0
Total Inflow	510.80	193008	3414	378	2%	215	100%	100%	100%	738.7	69.1	261.3
Evaporation	8.86						2%			11.7	75.7	
Outflow	501.94	203296	2299	405	1%		98%	105%	45%	738.7	67.9	275.2
Retention	0.00	-10287	4116		40%		0%	-5%				
Alternative Estimates of Lake Output												
Outlet 12 Feet	501.94	203296	2299	405	1%	27	98%	105%	45%	738.7	67.9	275.2
Outlet 2 Feet	501.94	179549	4374	358	2%	27	98%	93%	164%	738.7	67.9	243.0
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	10.03	2367	81	236	3%	30	2%	1%	0%	27.0	37.2	87.8
Downstream - Hiawatha	10.76	2950	205	274	7%	30	2%	2%	0%	31.4	34.3	94.1
Local Inflow	0.73	584	220	801	38%		0%	0%	0%	4.4	16.5	132.5
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	133.42	15765	298	118	2%	33	26%	8%	1%	229.4	58.2	68.7
Downstream - Kirkpatrick	172.08	73785	1655	429	2%	31	34%	38%	24%	285.1	60.3	258.8
Local Inflow	38.65	58020	1682	1501	3%		8%	30%	24%	55.7	69.4	1041.1

Lake Overflow Rate 42.90 m/yr Calib. Settling Rate -2.2 m/yr RSE % = Relative Std. Error of Load & Inflow Conc. Estimates
Lake Residence Time 0.25 years Calib. Retention Coef. -5% Error % = Percent of Variance in Total Inflow Load Estimate

Table A7-3: Total Phosphorus Balance for 2001-2005

Variable: **Total Phosphorus** **Average for Years:** **2001** **thru** **2005**

							Percent of Total Inflow			Drain.		Export
Term	**Flow 10^6 m3**	**Load kg**	**Std Error kg**	**Conc ppb**	**RSE %**	**Sampl per yr**	**Flow %**	**Load %**	**Error %**	**Area km2**	**Runoff cm**	**kg / km2**
Metro Effluent	93.24	31084	351	333	1%	362	18%	51%	5%			
Metro Bypass	2.40	2565	86	1067	3%	42	0%	4%	0%			
East Flume	0.68	103	6	151	6%	28	0%	0%	0%			
Crucible	2.15	269	9	125	3%	28	0%	0%	0%			
Harbor Brook	10.76	855	119	79	14%	30	2%	1%	1%	31.4	34.3	27.2
Ley Creek	40.68	3768	408	93	11%	31	8%	6%	7%	66.1	61.5	57.0
Ninemile Creek	151.67	8374	517	55	6%	30	30%	14%	11%	298.1	50.9	28.1
Onondaga Creek	172.08	11558	1373	67	12%	31	34%	19%	75%	285.1	60.3	40.5
Nonpoint Gauged	375.19	24555	1527	65	6%	122	73%	41%	92%	680.7	55.1	36.1
Nonpoint Ungauged	25.55	1672	249	65	15%	0	5%	3%	2%	46.4	55.1	36.1
NonPoint Total	400.74	26227	1547	65	6%	122	78%	43%	95%	727.0	55.1	36.1
Industrial	2.83	372	11	132	3%	55	1%	1%	0%			
Municipal	95.64	33648	361	352	1%	404	19%	56%	5%			
Total External	499.21	60247	1589	121	3%	581	98%	99%	100%	727.0	68.7	82.9
Precipitation	11.59	348	31	30	9%	0	2%	1%	0%	11.7	99.1	29.7
Total Inflow	510.80	60595	1589	119	3%	581	100%	100%	100%	738.7	69.1	82.0
Evaporation	8.86						2%			11.7	75.7	
Outflow	501.94	40911	1163	82	3%		98%	68%	54%	738.7	67.9	55.4
Retention	0.00	19683	1969		10%		0%	32%				
Alternative Estimates of Lake Output												
Outlet 12 Feet	501.94	40911	1163	82	3%	27	98%	68%	54%	738.7	67.9	55.4
Outlet 2 Feet	501.94	39116	1211	78	3%	27	98%	65%	58%	738.7	67.9	52.9
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	10.03	404	141	40	35%	30	2%	1%	1%	27.0	37.2	15.0
Downstream - Hiawatha	10.76	855	119	79	14%	30	2%	1%	1%	31.4	34.3	27.2
Local Inflow	0.73	450	184	618	41%		0%	1%	1%	4.4	16.5	102.2
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	133.42	8557	1472	64	17%	33	26%	14%	86%	229.4	58.2	37.3
Downstream - Kirkpatrick	172.08	11558	1373	67	12%	31	34%	19%	75%	285.1	60.3	40.5
Local Inflow	38.65	3001	2013	78	67%		8%	5%	160%	55.7	69.4	53.9

Lake Overflow Rate 42.90 m/yr Calib. Settling Rate 20.6 m/yr RSE % = Relative Std. Error of Load & Inflow Conc. Estimates
Lake Residence Time 0.25 years Calib. Retention Coef. 32% Error % = Percent of Variance in Total Inflow Load Estimate

Table A7-4: Soluble Reactive P Balance for 2001-2005

Variable: **Soluble Reactive P** **Average for Years:** **2001** **thru** **2005**

							Percent of Total Inflow			Drain.		Export
Term	**Flow 10^6 m3**	**Load kg**	**Std Error kg**	**Conc ppb**	**RSE %**	**Sampl per yr**	**Flow %**	**Load %**	**Error %**	**Area km2**	**Runoff cm**	**kg / km2**
Metro Effluent	93.24	9296	797	100	9%	29	18%	67%	74%			
Metro Bypass	2.40	607	398	253	66%	4	0%	4%	18%			
East Flume	0.68	42	4	62	11%	28	0%	0%	0%			
Crucible	2.15	103	6	48	5%	27	0%	1%	0%			
Harbor Brook	10.76	300	37	28	12%	30	2%	2%	0%	31.4	34.3	9.6
Ley Creek	40.68	624	36	15	6%	31	8%	4%	0%	66.1	61.5	9.4
Ninemile Creek	151.67	1163	155	8	13%	30	30%	8%	3%	298.1	50.9	3.9
Onondaga Creek	172.08	1347	189	8	14%	31	34%	10%	4%	285.1	60.3	4.7
Nonpoint Gauged	375.19	3435	250	9	7%	122	73%	25%	7%	680.7	55.1	5.0
Nonpoint Ungauged	25.55	234	36	9	15%	0	5%	2%	0%	46.4	55.1	5.0
NonPoint Total	400.74	3669	253	9	7%	122	78%	26%	7%	727.0	55.1	5.0
Industrial	2.83	145	7	51	5%	55	1%	1%	0%			
Municipal	95.64	9903	891	104	9%	33	19%	71%	93%			
Total External	499.21	13716	926	27	7%	210	98%	99%	100%	727.0	68.7	18.9
Precipitation	11.59	174	16	15	9%	0	2%	1%	0%	11.7	99.1	14.9
Total Inflow	510.80	13890	926	27	7%	210	100%	100%	100%	738.7	69.1	18.8
Evaporation	8.86						2%			11.7	75.7	
Outflow	501.94	23337	2121	46	9%		98%	168%	524%	738.7	67.9	31.6
Retention	0.00	-9447	2314		24%		0%	-68%				
Alternative Estimates of Lake Output												
Outlet 12 Feet	501.94	23337	2121	46	9%	27	98%	168%	524%	738.7	67.9	31.6
Outlet 2 Feet	501.94	20662	1313	41	6%	27	98%	149%	201%	738.7	67.9	28.0
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	10.03	86	14	9	17%	30	2%	1%	0%	27.0	37.2	3.2
Downstream - Hiawatha	10.76	300	37	28	12%	30	2%	2%	0%	31.4	34.3	9.6
Local Inflow	0.73	214	40	294	19%		0%	2%	0%	4.4	16.5	48.6
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	133.42	645	101	5	16%	32	26%	5%	1%	229.4	58.2	2.8
Downstream - Kirkpatrick	172.08	1347	189	8	14%	31	34%	10%	4%	285.1	60.3	4.7
Local Inflow	38.65	702	214	18	31%		8%	5%	5%	55.7	69.4	12.6

Lake Overflow Rate 42.90 m/yr Calib. Settling Rate -17.4 m/yr RSE % = Relative Std. Error of Load & Inflow Conc. Estimates
Lake Residence Time 0.25 years Calib. Retention Coef. -68% Error % = Percent of Variance in Total Inflow Load Estimate

Table A7-5: Total Nitrogen Balance for 2001-2005

Variable: **Total Nitrogen** **Average for Years:** **2001** **thru** **2005**

						Percent of Total Inflow				**Drain.**		**Export**
Term	**Flow 10^6 m3**	**Load kg**	**Std Error kg**	**Conc ppb**	**RSE %**	**Sampl per yr**	**Flow %**	**Load %**	**Error %**	**Area km2**	**Runoff cm**	**kg/ km2**
Metro Effluent	93.24	1120648	25213	12019	2%	89	18%	61%	81%			
Metro Bypass	2.40	29442	1170	12254	4%	4	0%	2%	0%			
East Flume	0.68	4002	111	5893	3%	27	0%	0%	0%			
Crucible	2.15	3167	148	1475	5%	27	0%	0%	0%			
Harbor Brook	10.76	23242	780	2160	3%	28	2%	1%	0%	31.4	34.3	741.0
Ley Creek	40.68	56304	2587	1384	5%	27	8%	3%	1%	66.1	61.5	851.8
Ninemile Creek	151.67	268130	7201	1768	3%	27	30%	15%	7%	298.1	50.9	899.5
Onondaga Creek	172.08	275942	7059	1604	3%	28	34%	15%	6%	285.1	60.3	967.8
Nonpoint Gauged	375.19	623618	10440	1662	2%	109	73%	34%	14%	680.7	55.1	916.2
Nonpoint Ungauged	25.55	42476	5823	1662	14%	0	5%	2%	4%	46.4	55.1	916.2
NonPoint Total	400.74	666094	11954	1662	2%	109	78%	36%	18%	727.0	55.1	916.2
Industrial	2.83	7169	184	2537	3%	55	1%	0%	0%			
Municipal	95.64	1150090	25241	12025	2%	94	19%	62%	81%			
Total External	499.21	1823353	27929	3653	2%	257	98%	99%	100%	727.0	68.7	2507.9
Precipitation	11.59	22021	1975	1900	9%	0	2%	1%	0%	11.7	99.1	1882.1
Total Inflow	510.80	1845374	27998	3613	2%	257	100%	100%	100%	738.7	69.1	2498.0
Evaporation	8.86						2%			11.7	75.7	
Outflow	501.94	1350111	24755	2690	2%		98%	73%	78%	738.7	67.9	1827.6
Retention	0.00	495263	37373		8%		0%	27%				
Alternative Estimates of Lake Output												
Outlet 12 Feet	501.94	1350111	24755	2690	2%	26	98%	73%	78%	738.7	67.9	1827.6
Outlet 2 Feet	501.94	1241850	25955	2474	2%	26	98%	67%	86%	738.7	67.9	1681.0
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	10.03	21505	1009	2144	5%	27	2%	1%	0%	27.0	37.2	797.7
Downstream - Hiawatha	10.76	23242	780	2160	3%	28	2%	1%	0%	31.4	34.3	741.0
Local Inflow	0.73	1737	1276	2384	73%		0%	0%	0%	4.4	16.5	394.2
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	133.42	206546	6659	1548	3%	29	26%	11%	6%	229.4	58.2	900.4
Downstream - Kirkpatrick	172.08	275942	7059	1604	3%	28	34%	15%	6%	285.1	60.3	967.8
Local Inflow	38.65	69397	9705	1795	14%		8%	4%	12%	55.7	69.4	1245.2

Lake Overflow Rate	42.90 m/yr	Calib. Settling Rate	15.7 m/yr	RSE % = Relative Std. Error of Load & Inflow Conc. Estimates
Lake Residence Time	0.25 years	Calib. Retention Coef.	27%	Error % = Percent of Variance in Total Inflow Load Estimate

Table A7-6: Ammonia Nitrogen Balance for 2001-2005

Variable: **Ammonia Nitrogen** **Average for Years:** **2001** **thru** **2005**

							Percent of Total Inflow					
Term	**Flow 10^6 m3**	**Load kg**	**Std Error kg**	**Conc ppb**	**RSE %**	**Sampl per yr**	**Flow %**	**Load %**	**Error %**	**Drain. Area km2**	**Runoff cm**	**Export kg/ km2**
Metro Effluent	93.24	312229	5167	3349	2%	362	18%	78%	59%			
Metro Bypass	2.40	13909	784	5789	6%	42	0%	3%	1%			
East Flume	0.68	348	18	512	5%	28	0%	0%	0%			
Crucible	2.15	379	91	177	24%	28	0%	0%	0%			
Harbor Brook	10.76	1018	96	95	9%	28	2%	0%	0%	31.4	34.3	32.4
Ley Creek	40.68	13082	871	322	7%	27	8%	3%	2%	66.1	61.5	197.9
Ninemile Creek	151.67	38664	3936	255	10%	27	30%	10%	34%	298.1	50.9	129.7
Onondaga Creek	172.08	16115	981	94	6%	28	34%	4%	2%	285.1	60.3	56.5
Nonpoint Gauged	375.19	68879	4150	184	6%	110	73%	17%	38%	680.7	55.1	101.2
Nonpoint Ungauged	25.55	4691	692	184	15%	0	5%	1%	1%	46.4	55.1	101.2
NonPoint Total	400.74	73570	4207	184	6%	110	78%	18%	39%	727.0	55.1	101.2
Industrial	2.83	727	92	257	13%	55	1%	0%	0%			
Municipal	95.64	326139	5227	3410	2%	404	19%	81%	61%			
Total External	499.21	400436	6710	802	2%	569	98%	100%	100%	727.0	68.7	550.8
Precipitation	11.59	1159	104	100	9%	0	2%	0%	0%	11.7	99.1	99.1
Total Inflow	510.80	401595	6711	786	2%	569	100%	100%	100%	738.7	69.1	543.6
Evaporation	8.86						2%			11.7	75.7	
Outflow	501.94	311999	12078	622	4%		98%	78%	324%	738.7	67.9	422.3
Retention	0.00	89595	13817		15%		0%	22%				
Alternative Estimates of Lake Output												
Outlet 12 Feet	501.94	311999	12078	622	4%	27	98%	78%	324%	738.7	67.9	422.3
Outlet 2 Feet	501.94	268529	12111	535	5%	27	98%	67%	326%	738.7	67.9	363.5
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	10.03	595	47	59	8%	28	2%	0%	0%	27.0	37.2	22.1
Downstream - Hiawatha	10.76	1018	96	95	9%	28	2%	0%	0%	31.4	34.3	32.4
Local Inflow	0.73	422	106	580	25%		0%	0%	0%	4.4	16.5	95.9
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	133.42	8114	409	61	5%	30	26%	2%	0%	229.4	58.2	35.4
Downstream - Kirkpatrick	172.08	16115	981	94	6%	28	34%	4%	2%	285.1	60.3	56.5
Local Inflow	38.65	8001	1063	207	13%		8%	2%	3%	55.7	69.4	143.6

Lake Overflow Rate	42.90 m/yr	Calib. Settling Rate	12.3 m/yr	RSE % = Relative Std. Error of Load & Inflow Conc. Estimates
Lake Residence Time	0.25 years	Calib. Retention Coef.	22%	Error % = Percent of Variance in Total Inflow Load Estimate

Table A7-7: Yearly Data Used for Model Calibration & Testing

Phosphorus Balance

	Net	Metro+	Total	Outflow	Inflow P	Outflow			Settling	Lake	
Water	Inflow	Bypass	Load	Load	P Conc	P Conc	HLR	Res Time	Rate	P Conc	SE
Year	hm3	kg	kg	kg	ppb	ppb	m/yr	Yrs	m/yr	ppb	ppb
1991	545	55917	97121	55123	178	101	46.5	0.23	35.5	56.6	4.4
1992	483	70660	108270	49880	224	103	41.3	0.26	48.4	54.7	8.5
1993	572	111985	168103	102535	294	179	48.9	0.22	31.3	137.3	18.9
1994	484	62340	81212	66203	168	137	41.3	0.26	9.4	70.2	12.5
1995	298	48494	62085	49542	209	166	25.4	0.43	6.4	66.0	9.2
1996	488	54461	98479	65066	202	133	41.7	0.26	21.4	73.8	6.9
1997	450	40893	79475	52948	176	118	38.5	0.28	19.3	52.6	6.8
1998	475	41096	69666	39197	147	82	40.6	0.27	31.6	55.8	6.0
1999	315	34248	54752	33412	174	106	26.9	0.41	17.2	62.6	3.8
2000	485	31678	58512	37741	121	78	41.5	0.26	22.8	42.9	3.1
2001	412	22838	47493	31423	115	76	35.3	0.31	18.0	30.4	2.1
2002	422	24957	45607	29530	108	70	36.1	0.30	19.7	41.8	4.5
2003	486	39196	62473	40235	129	83	41.6	0.26	23.0	67.9	1.5
2004	593	52913	87228	55931	147	94	50.7	0.21	28.4	60.3	3.0
2005	513	28094	53055	42727	103	83	43.8	0.25	10.6	34.8	1.1
2001-2005	485	33600	59171	39969	122	82	41.5	0.26	19.9	47.0	7.3

Nitrogen Balance

	Net	Metro+	Total	Outflow	Inflow P	Outflow			Settling	Lake	
Water	Inflow	Bypass	Load	Load	P Conc	N Conc	HLR	Res Time	Rate	N Conc	SE
Year	hm3	kg	kg	kg	ppb	ppb	m/yr	Yrs	m/yr	ppb	ppb
1991	545	1789444	2550107	1745941	4683	3206	46.5	0.23	21.4	4488	197
1992	483	1708103	2407891	1846734	4981	3820	41.3	0.26	12.6	4437	352
1993	572	1928003	2713974	2001518	4742	3497	48.9	0.22	17.4	3802	160
1994	484	1835571	2453120	1942574	5072	4016	41.3	0.26	10.9	4126	233
1995	298	1872663	2203523	1576422	7401	5295	25.4	0.43	10.1	5350	355
1996	488	1906027	2666785	1556101	5470	3192	41.7	0.26	29.7	4038	197
1997	450	1662123	2295919	1541110	5098	3422	38.5	0.28	18.9	3743	225
1998	475	1723598	2330608	1476170	4905	3107	40.6	0.27	23.5	3668	252
1999	315	1285518	1656663	1067617	5265	3393	26.9	0.41	14.8	3524	185
2000	485	1157852	1815076	1030434	3741	2124	41.5	0.26	31.6	2463	81
2001	412	1070750	1630199	1044371	3952	2532	35.3	0.31	19.8	3001	114
2002	422	964925	1469572	1035313	3480	2451	36.1	0.30	15.1	2153	170
2003	486	1143386	1874313	1133392	3855	2331	41.6	0.26	27.2	2612	134
2004	593	1274993	2117068	1049626	3569	1769	50.7	0.21	51.6	2838	13
2005	513	1249244	1927453	928170	3758	1809	43.8	0.25	47.2	2698	91
2001-2005	485	1140660	1803721	1038174	3716	2139	41.5	0.26	30.6	2660	143

Chlorophyll-a Photic Zone or 0-3 m averages

Water	Sample	Mean	Std Dev	SE	CV	Freq > 15	Freq > 20	Freq > 30	Freq > 40	Freq > 60
Year	Dates	ppb	ppb	ppb	-	-	-	-	-	-
1991	17	22.0	21.7	5.3	0.99	47%	35%	29%	12%	6%
1992	13	13.9	9.7	2.7	0.70	54%	15%	8%	0%	0%
1993	6	15.2	22.0	9.0	1.45	17%	17%	17%	17%	0%
1994	7	32.7	45.2	17.1	1.38	43%	43%	43%	43%	14%
1995	7	8.0	4.7	1.8	0.59	0%	0%	0%	0%	0%
1996	6	33.2	33.3	13.6	1.00	67%	67%	50%	17%	17%
1997	7	15.5	14.3	5.4	0.93	57%	14%	14%	14%	0%
1998	10	16.7	8.8	2.8	0.52	40%	20%	10%	0%	0%
1999	13	30.5	20.6	5.7	0.68	77%	69%	62%	31%	8%
2000	13	23.1	18.6	5.2	0.81	62%	54%	31%	15%	0%
2001	13	17.3	17.4	4.8	1.00	31%	23%	23%	15%	0%
2002	14	24.6	16.4	4.4	0.67	64%	57%	21%	21%	0%
2003	13	36.6	31.9	8.8	0.87	69%	62%	54%	31%	15%
2004	28	20.6	10.1	1.9	0.49	57%	50%	14%	7%	0%
2005	26	11.7	3.8	0.7	0.33	23%	0%	0%	0%	0%
2001-2005	19	22.2	15.9	4.7	0.67	49%	38%	23%	15%	3%

Secchi Depth

Water	Sample	Mean	Std Dev	SE	CV	Freq < 1.2	Freq < 2.0	HOD (mg/m^2-day)		
Year	Dates	m	m	m	-	-	-	< 6 m	< 9 m	< 12 m
1991	5	1.62	1.20	0.54	0.74	40%	80%	1602	1484	1333
1992	7	2.14	1.49	0.56	0.70	0%	86%	1966	1795	1521
1993	6	2.62	1.44	0.59	0.55	17%	50%			
1994	7	2.10	0.92	0.35	0.44	29%	29%			
1995	6	2.03	0.68	0.28	0.33	0%	33%	1124	1105	1034
1996	6	1.70	1.07	0.44	0.63	33%	67%	1477	1354	1191
1997	7	3.27	2.30	0.87	0.70	0%	43%	1095	970	873
1998	7	1.94	0.61	0.23	0.32	14%	43%	927	922	899
1999	13	1.71	1.35	0.37	0.79	38%	69%	1699	1455	1196
2000	13	2.15	0.93	0.26	0.43	8%	46%	1769	1565	1307
2001	13	2.76	1.25	0.35	0.45	8%	31%	1146	1073	909
2002	13	2.03	0.78	0.22	0.38	0%	62%	1085	988	876
2003	13	1.39	0.55	0.15	0.39	31%	85%	968	946	860
2004	16	1.66	0.33	0.08	0.20	13%	88%	1160	1186	1073
2005	25	1.89	0.48	0.10	0.25	0%	56%	900	794	644
2001-2005	16	1.9	0.7	0.16	0.34	10%	64%	1052	998	872

Nutrient Species

	Total Org. Carbon		Organic N		Inorganic N		TP - SRP		SRP	
Water	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Year	ppm	ppm	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
1991	6.7	0.59	1081	223	3407	177	53	4.3	3.1	0.1
1992	5.8	0.22	1360	130	3077	242	45	10.5	9.6	4.5
1993	5.6	0.21	956	99	2847	209	105	10.6	32.0	10.3
1994	4.8	0.53	1023	151	3103	181	58	14.0	11.9	3.9
1995	4.9	0.47	1131	173	4219	230	53	5.8	12.6	5.5
1996	6.2	0.34	1015	174	3023	190	65	5.9	8.6	2.3
1997	4.7	0.09	932	70	2810	189	44	3.1	8.5	4.4
1998	4.7	0.15	570	93	3098	198	51	5.7	4.5	1.1
1999	4.7	0.21	924	161	2600	218	56	4.8	6.2	2.1
2000	4.5	0.12	671	25	1792	82	38	3.9	5.2	1.4
2001	4.2	0.14	685	58	2316	142	27	2.1	3.0	0.0
2002	4.4	0.12	740	48	1413	198	39	4.5	3.0	0.0
2003	5.3	0.36	930	67	1682	129	63	1.6	4.7	1.1
2004	5.8	0.20	672	18	2166	6	48	2.4	12.4	3.2
2005	4.5	0.12	611	17	2086	90	32	1.1	3.1	0.0
2001-2005	4.8	0.31	728	55	1932	167	42	6.4	5.2	1.82

SE = Standard Error of Mean

Table A7-8: Model Equations & Coefficients

Predicted Trophic Response Variables:

Po = Water Year Flow-Wtd-Mean Outflow Total P (ppb)
* P = Mean Total P (ppb)
No = Water Year Flow-Wtd-Mean Outflow Total N (ppb)
* N = Mean Total N (ppb)
* B = Mean Chlorophyll-a (ppb)
* S = Mean Secchi Depth (m)
HOD = Hypolimnetic Oxygen Depletion Rate (mg/m^2-day)
* TON = Total Organic Nitrogen (ppb)
* TP-SRP Total Phosphorus - Soluble Reactive P (ppb)

* June-August, 0-3 meters, Lake South Station

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 = 19.9 m/yr
Calibrated to 2001-2005

Period	2001-2005	1991-2005
Residual CV	0.11	0.21
R^2	0.07	0.53

Lake Surface Total P:

Reference: Walker (1978), Sas (1989)
$P = F_P P_O$
F_P = 0.57 Calibrated to 2001-2005

Period	2001-2005	1991-2005
Residual CV	0.24	0.21
R^2	0.52	0.73

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 = 30.6 m/yr
Calibrated to 2001-2005

Period	2001-2005	1991-2005
Residual CV	0.22	0.26
R^2	0.00	0.32

Lake Summer Total N:

$N = F_N \, No$
F_N = 1.24 Calibrated to 2001-2005

Period	2001-2005	1991-2005
Residual CV	0.08	0.15
R^2	0.50	0.66

Lake Photic Zone Chlorophyll-a:

Reference: Jones & Bachman (1976)
$B = 0.081 \, P^{1.46}$ not recalibrated

Period	2001-2005
Residual CV	0.44
R^2	0.00

Algal Bloom Frequencies:

Reference: Walker (1984)
F_X = $1 - \text{Normal} [(\ln(X) - \ln(B) - 0.5 S_B^2) / S_B]$
Normal Cumulative Normal Frequency Distribution
X = Bloom Criterion (15, 20, 30 or 40 ppb)
F_X = Frequency of Chl-a > X
S_B = Standard Deviation of ln (Chl-a)
$S_B = [\ln (1 + C_B^2)]^{1/2}$
C_B = Within-Year Temporal CV = 0.67
Calibrated to 2001-2005 data

Lake Secchi Depth:

Reference: BATHTUB, Walker (1985; 2004)
$S = 1 / (a + b B)$
Calibrated to 2001-2005
a = 0.328 1/m
b = 0.010 m^2/mg

Period	2001-2005
Residual CV	0.23
R^2	0.26

Secchi Interval Frequencies:

Reference: Walker (1984)
F_Y = $\text{Normal} [(\ln(Y) - \ln(S) - 0.5 S_S^2) / S_S]$
Normal Cumulative Normal Frequency Distribution
F_Y = Frequency of Secchi < Y
Y = Secchi Criterion (1.2 or 2 m)
S_S = Standard Deviation of ln (Secchi)
$S_S = [\ln (1 + C_S^2)]^{1/2}$
C_S = Within-Year Temporal CV = 0.34
Calibrated to 1996-2005

Lake Summer Total P - SRP:

Reference: BATHTUB, Walker (1985; 2004)
TP - SRP = -4.1 + 1.78 B + 23.7a not recalibrated
a = non-algal turbidity from secchi model = 0.328

	2001-2005
Residual CV	0.29
R^2	0.29

Lake Summer Organic Nitrogen:

Reference: BATHTUB, Walker (1985; 2004)
TON = 157 + 22.8 B + 75.3 a not recalibrated
a = non-algal turbidity from secchi model = 0.328

	2001-2005
Residual CV	0.23
R^2	0.00

Hypolimnetic Oxygen Depletion Rate:

Reference: BATHTUB, Walker (1985; 2004)
$HOD = 219 \, B^{0.45}$ not recalibrated

DataSet	2001-2005
Residual CV	0.16
R^2	0.00

Table A7-9: Model Inputs & Outputs

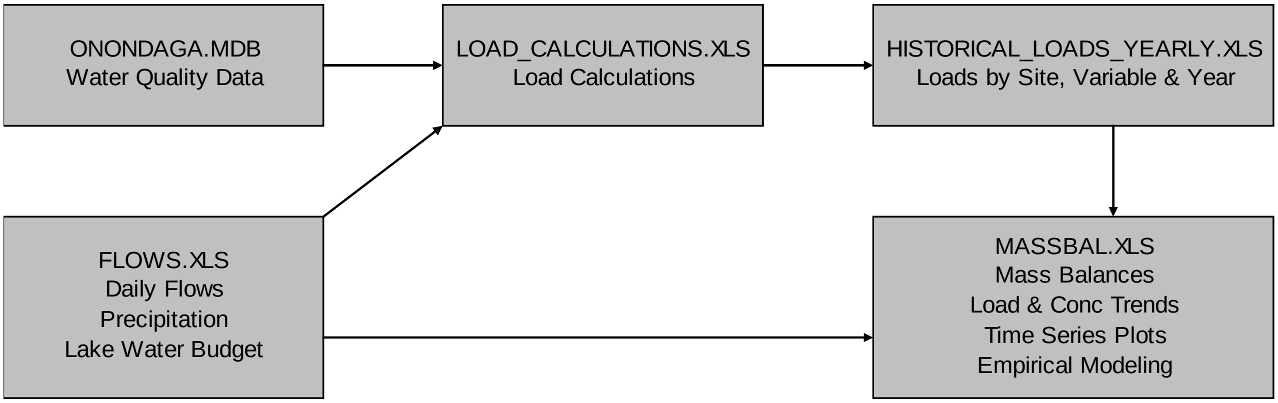
Model Parameters	**Units**	**Value**	**Source**
Lake Area	km^2	11.7	
P Settling Rate	m/yr	19.932	Calibrated to 2001-2005
Epil P / Outflow P	-	0.571	Calibrated to 2001-2005
Outflow P Error CV	-	0.106	
Lake P Error CV	-	0.241	
Chla/P Slope	-	1.460	Jones & Bachman, 1976
Chla/P Intercept	-	0.081	Jones & Bachman, 1976
Chl-a Error CV	-	0.440	
Chla Temporal CV	-	0.671	Calibrated to 2001-2005
Non-Algal Turbidity	1/m	0.328	Calibrated to 2001-2005
Secchi/Chla Slope	m^2/mg	0.010	Calibrated to 2001-2005
Secchi Error CV	-	0.231	
Secchi Temporal CV	-	0.336	Calibrated to 2001-2005
HOD Intercept	-	218.8	Walker, 1985, 2004
HOD Slope		0.450	Walker, 1985, 2004
HOD Error CV		0.163	
Spring DO Conc	ppm	12.0	
Hypol. Depth	m	7.02	Below 9 meters depth
Stratified Period	days	183.0	
Total N Setting Rate	m/yr	30.59	Calibrated to 2001-2005
Outflow N CV		0.22	
Epil N / Outflow N		1.24	Calibrated to 2001-2005
Epil N Error CV		0.08	
Organic N Slope		22.80	Walker, 1985, 2004
Organic N Intercept		181.72	Walker, 1985, 2004
Organic N Error CV		0.23	
TP-OP Intercept		3.68	Walker, 1985, 2004
TP-OP Slope		1.78	Walker, 1985, 2004
TP-OP Error CV		0.29	

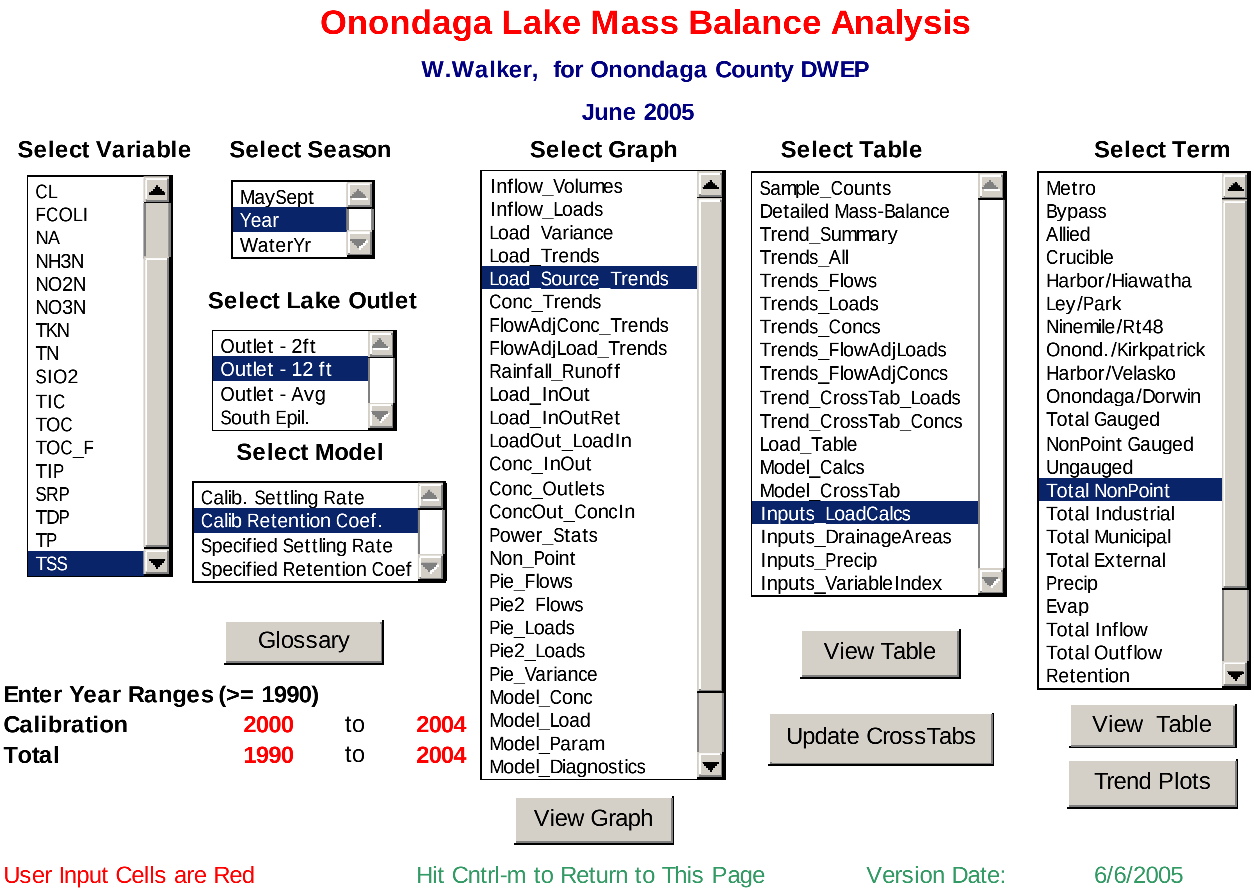
Loading Scenario			
Net Inflow Volume	hm^3/yr	485	2001-2005 Mean
Inflow P Load	kg/yr	59171	""
Inflow N Load	kg/yr	1803721	""

Output Variable	**Units**	**Mean**	**Low**	**High**	**2001-2005 Observed**
Outflow P Conc	ppb	82	70	97	82
Lake P Conc	ppb	47	32	68	47
Outflow N Conc	ppb	2139	1529	2992	2139
Lake N Conc	ppb	2660	2336	3028	2660
Mean Chl-a	ppb	22	11	44	22
Algal Bloom Frequencies					
>	15	64%	23%	93%	49%
>	20	46%	11%	84%	38%
>	30	22%	3%	63%	23%
>	40	11%	1%	44%	15%
Mean Secchi Depth	m	2.0	2.5	1.5	1.9
Secchi Interval Frequencies					
<	1.2	7%	2%	32%	10%
<	2	54%	28%	86%	64%
Oxygen Depletion Rate	mg/m^2-day	888	692	1140	998
Days of O$_2$ Supply	days	95	122	74	
Anoxic Period	days	88	61	109	
Organic N	ppb	694	489	985	728
Total P - SRP	ppb	44	28	68	42

Figure A7-1

Mass Balance Computations Integrated with AMP Long-Term Database





Onondaga Lake Mass Balance Analysis

W.Walker, for Onondaga County DWEP

June 2005

Enter Year Ranges (>= 1990)

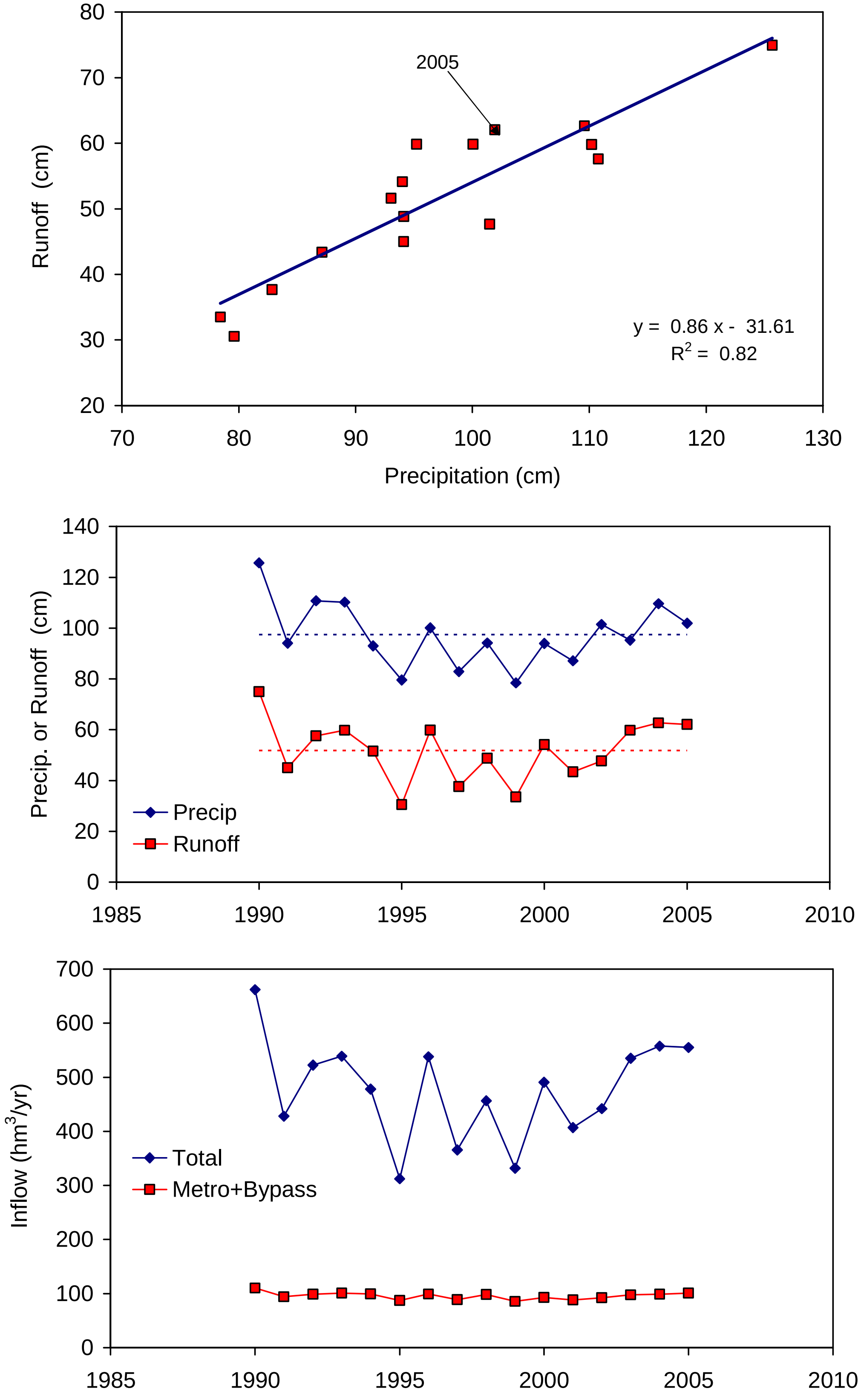
Calibration	2000	to	2004
Total	1990	to	2004

User Input Cells are Red

Hit Cntrl-m to Return to This Page

Version Date: 6/6/2005

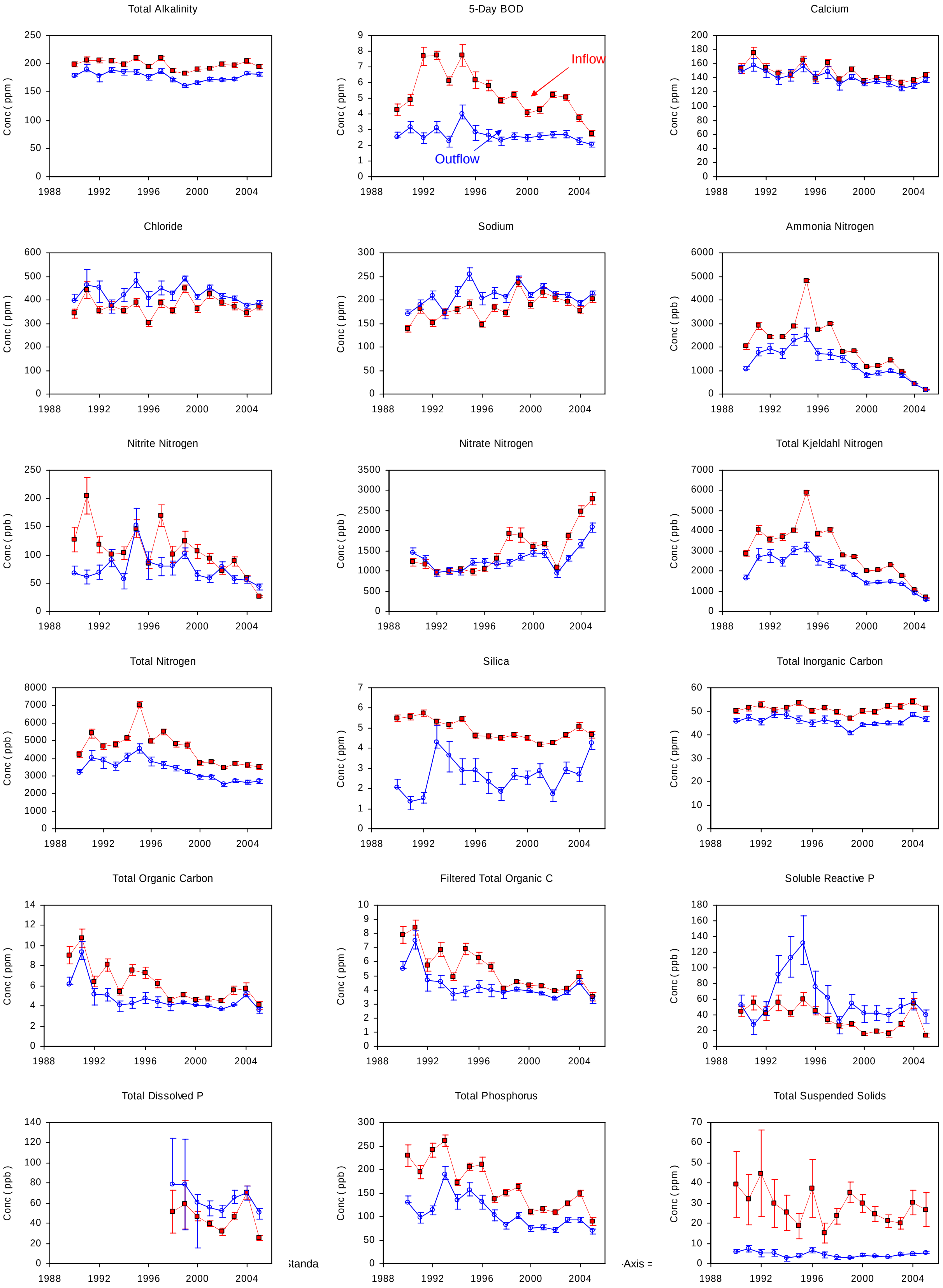
Figure A7-2
Precipitation, Runoff, & Lake Inflow Volumes



X Axis: Calendar Year

Figure A7-3
Long-Term Trends in Total Inflow & Outflow Concentrations

Squares = Inflow, Circles = Outflow   Error Bars = +/- 1 Standard Error   Dotted Lines = Linear Trends   X-Axis = Calendar Year



A7-4
Long-Term Trends in Total Inflow & Outflow Loads

Squares = Inflow, Circles = Outflow   Error Bars = +/- 1 Standard Error   Dotted Lines = Linear Trends   X-Axis = Calendar Year

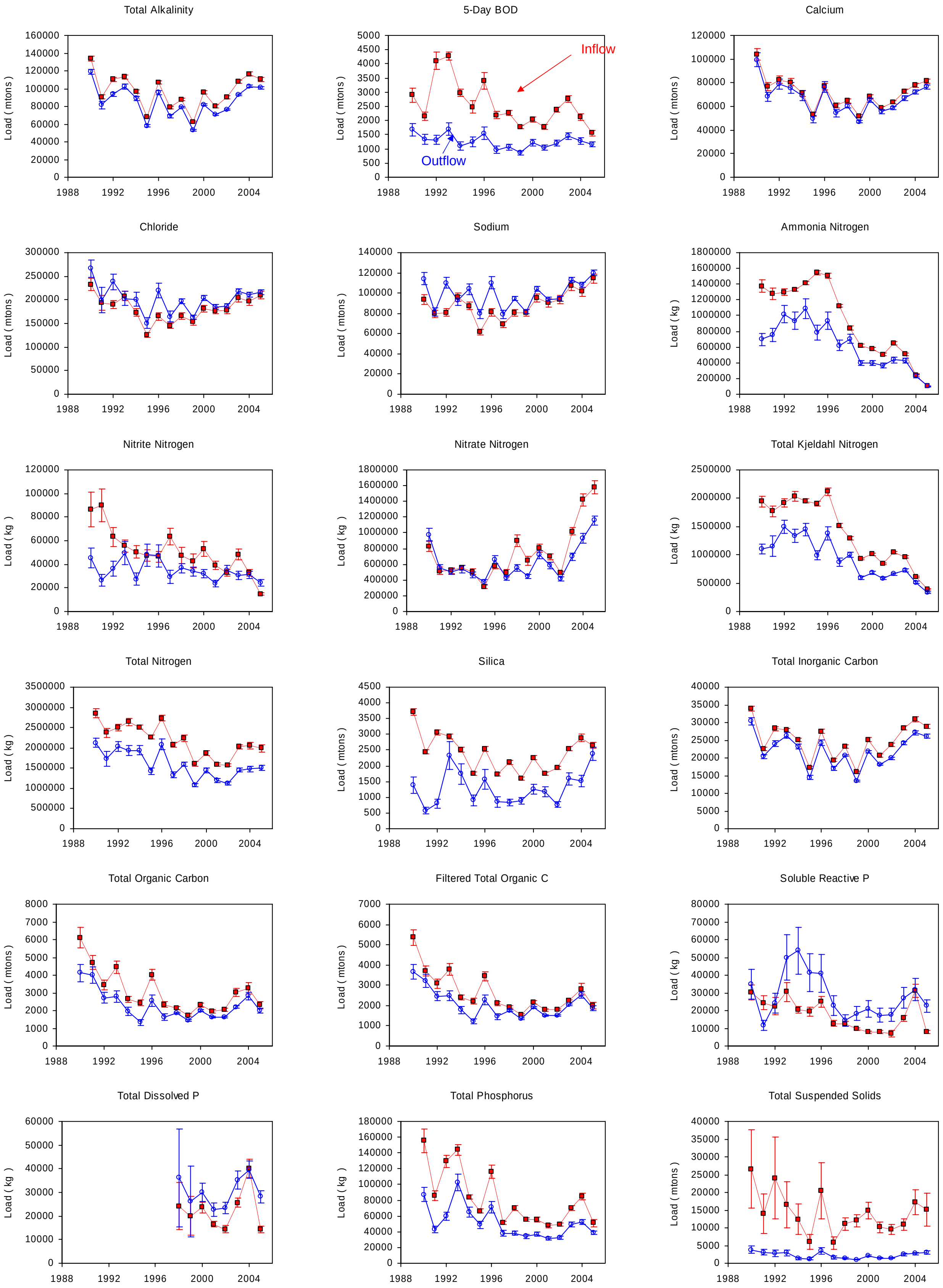
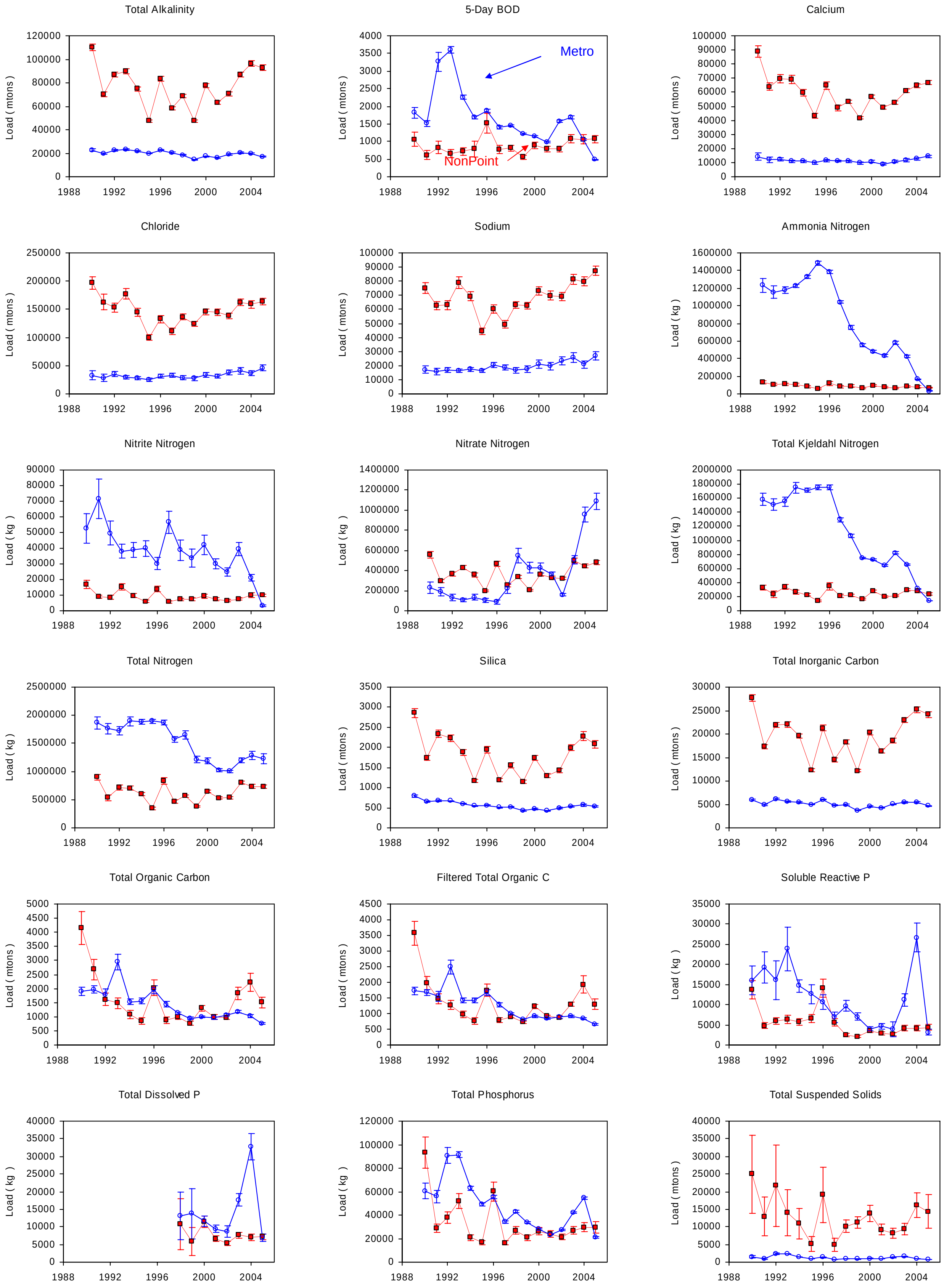


Figure A7-5
Long-Term Trends in NonPoint & Metro Loads

Squares = NonPoint Sources, Circles = Metro + Bypass Error Bars = +/- 1 Standard Error Dotted Lines = Linear Trends X-Axis = Calendar Year



Total Alkalinity

5-Day BOD

Calcium

Chloride

Sodium

Ammonia Nitrogen

Nitrite Nitrogen

Nitrate Nitrogen

Total Kjeldahl Nitrogen

Total Nitrogen

Silica

Total Inorganic Carbon

Total Organic Carbon

Filtered Total Organic C

Soluble Reactive P

Total Dissolved P

Total Phosphorus

Total Suspended Solids

Figure A7-6

Empirical Eutrophication Model Network

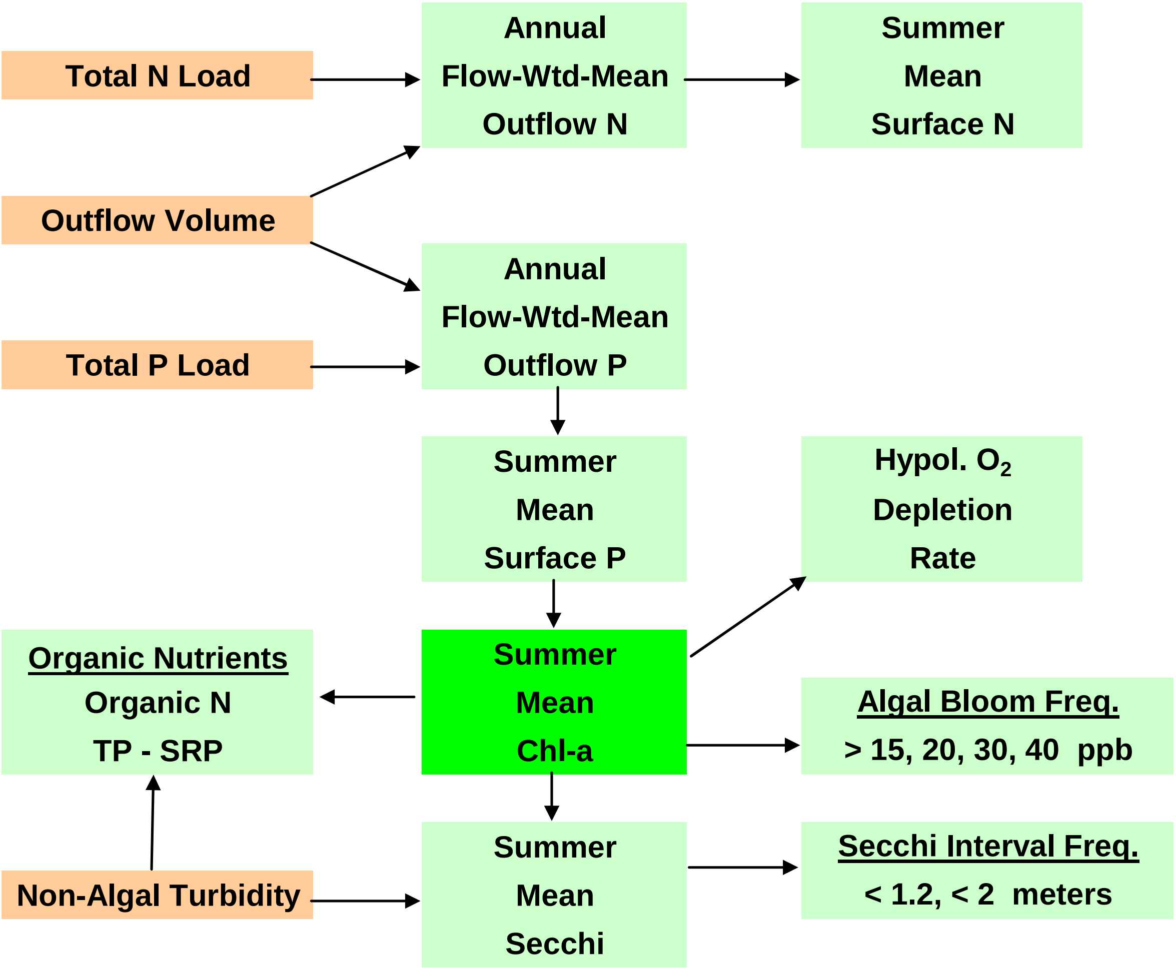
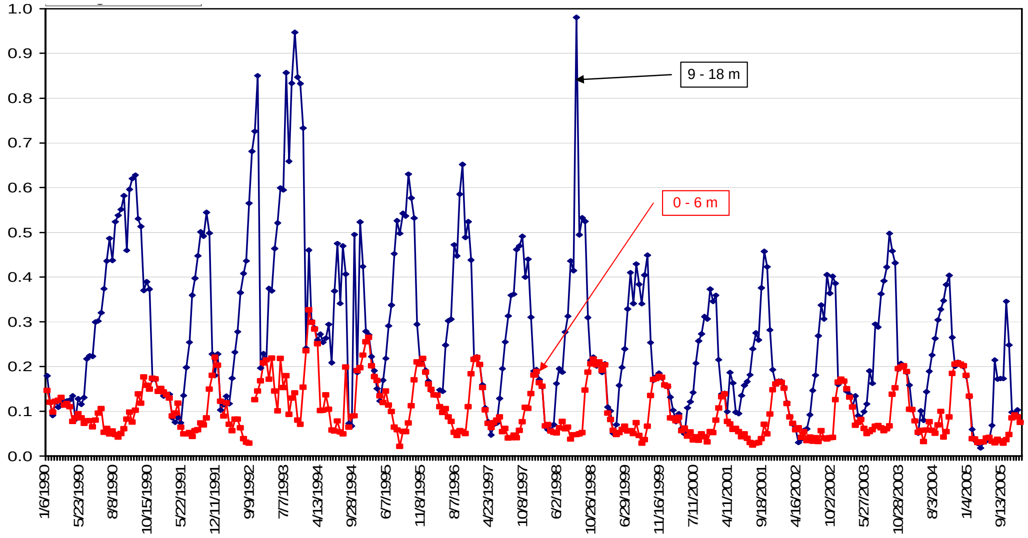
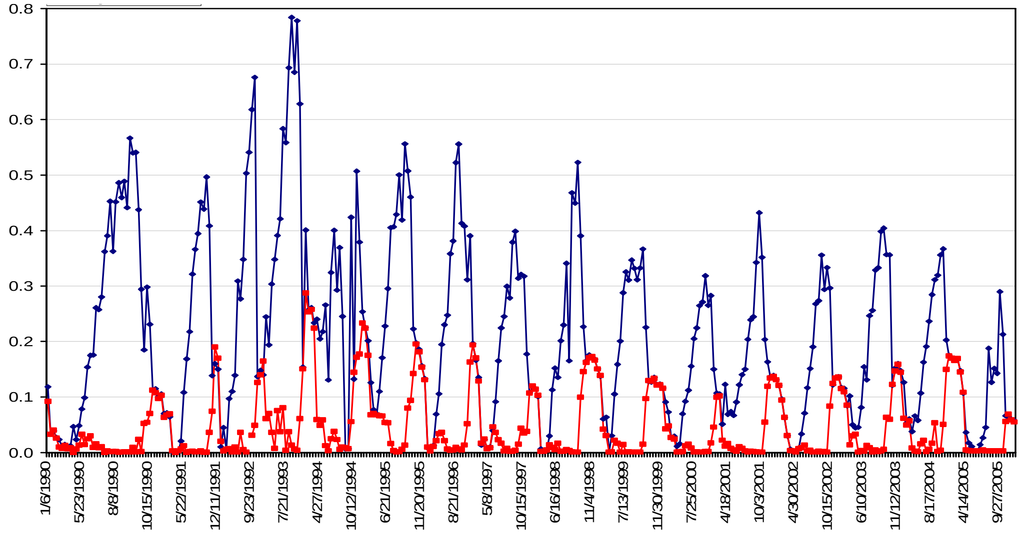


Figure A7-7
Lake & Outlet Phosphorus Time Series

Total Phosphorus (ppm) Lake South 0 - 6 m vs. 9 - 18 m



Soluble Reactive Phosphorus (ppm) Lake South 0 - 6 m vs. 9 - 18 m



Lake South (0 - 6 m), Lake North (0 - 6 m), Outlet (12 ft)

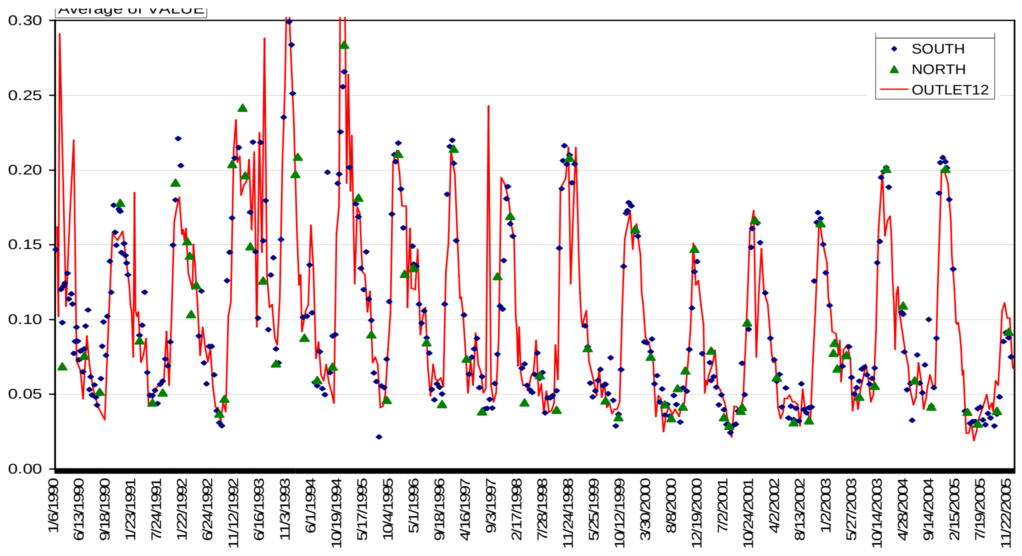


Figure A7-8
Soluble Reactive P vs. Total P Concentrations

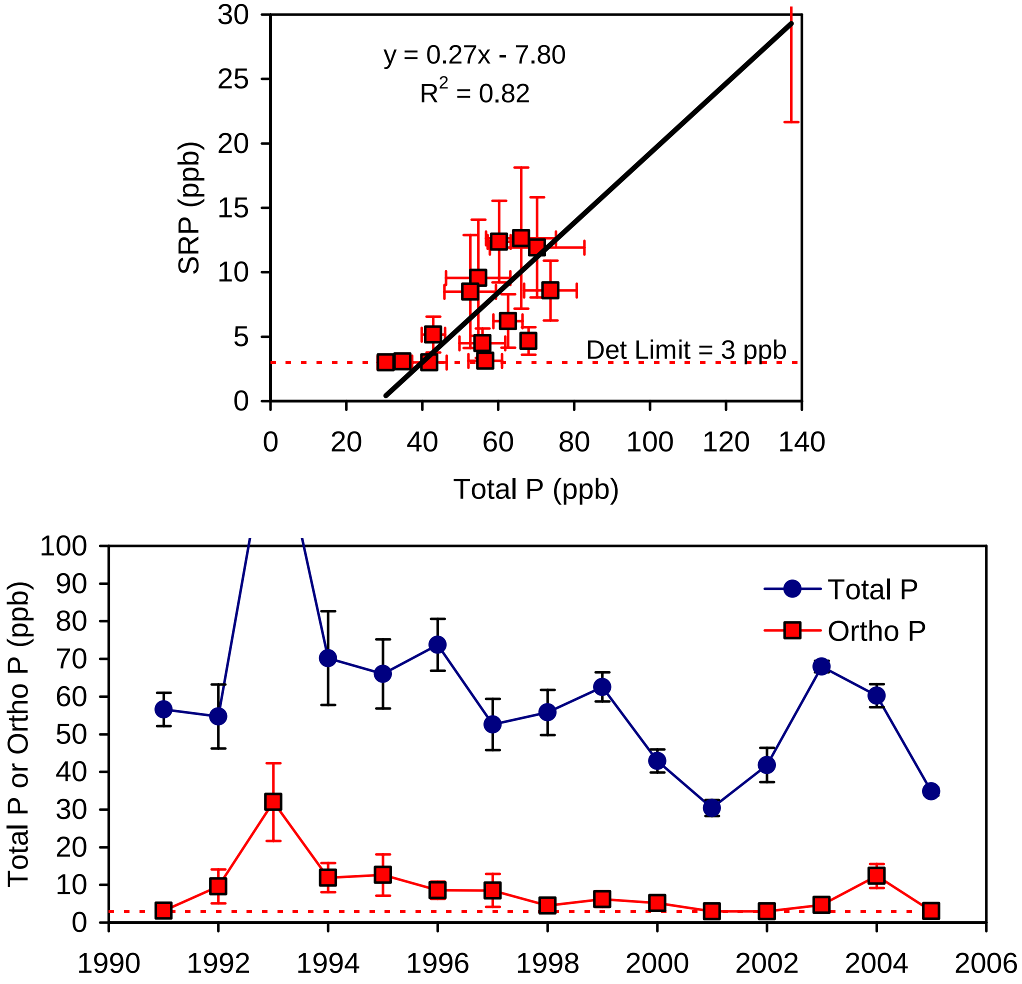
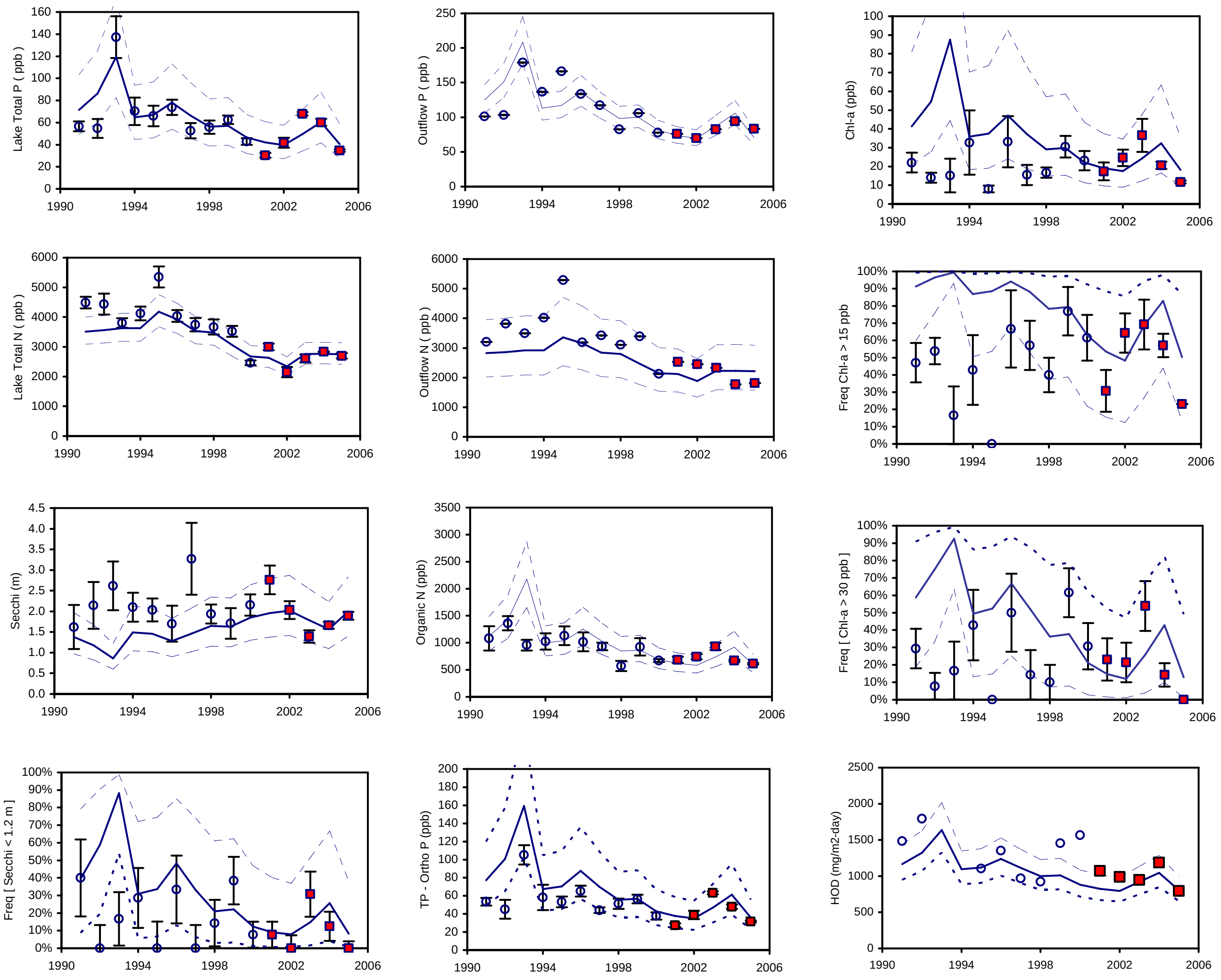


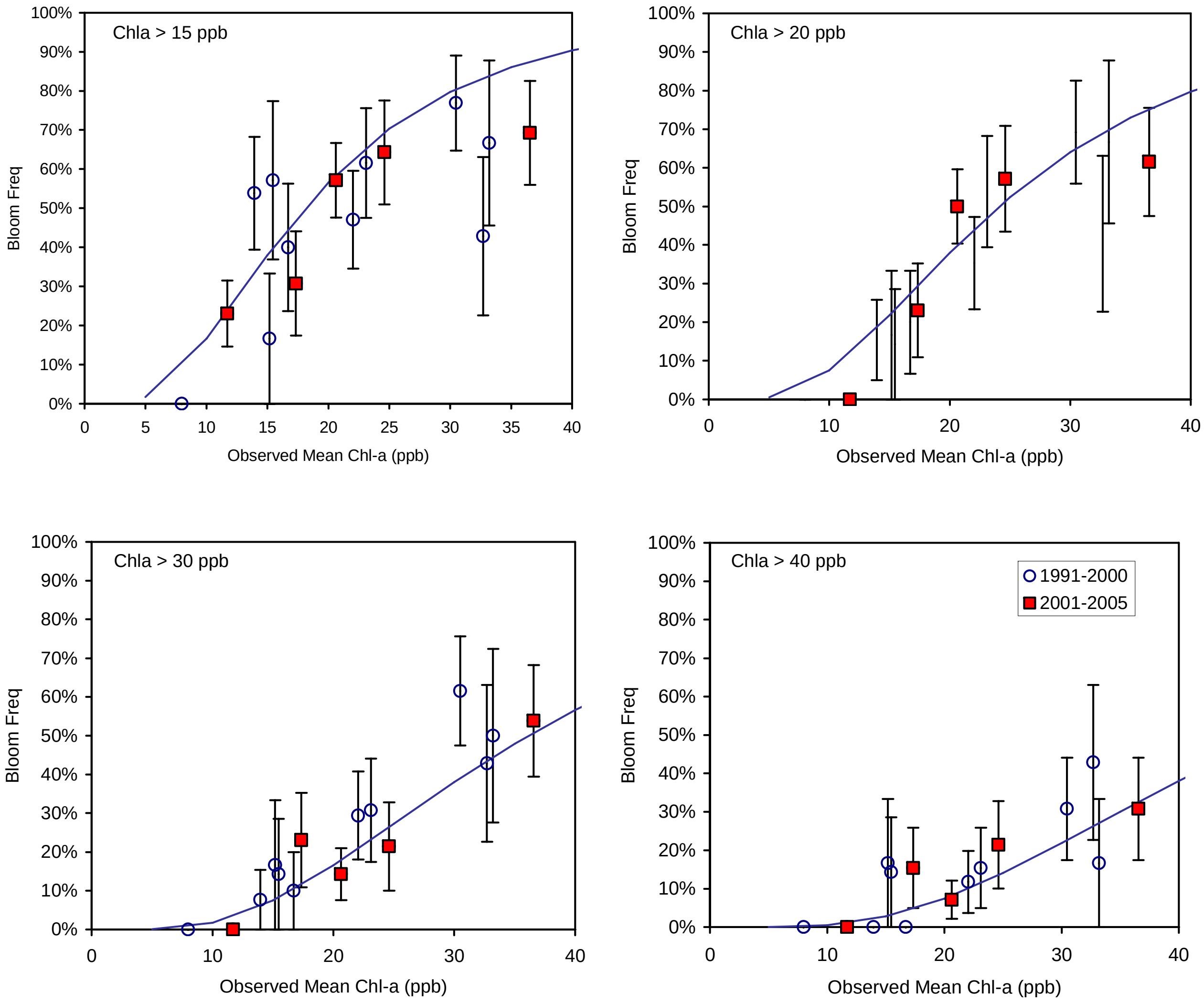
Figure A7-9
Observed and Predicted Time Series



Square Symbols = Calibration Period; Observed Means +/- 1 Std Error

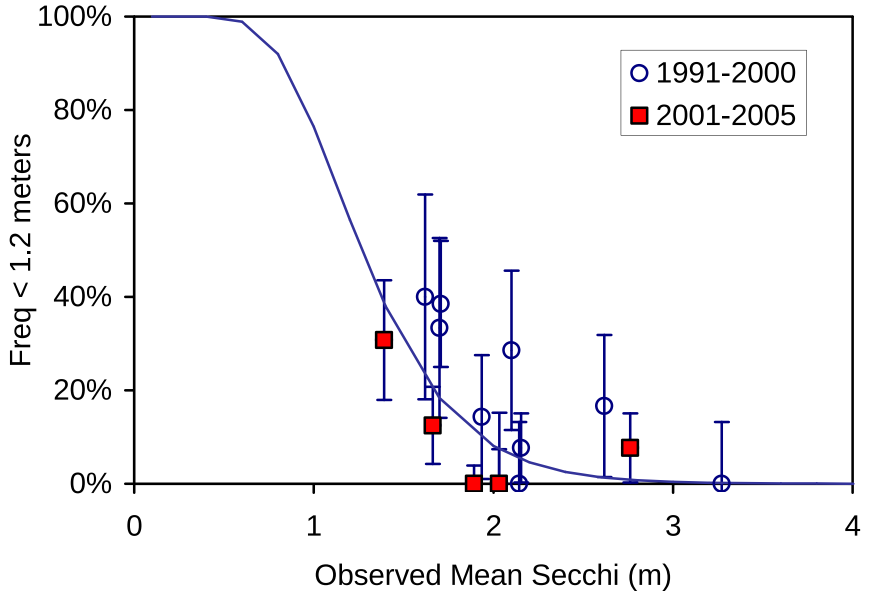
Lines = 80% Prediction Intervals

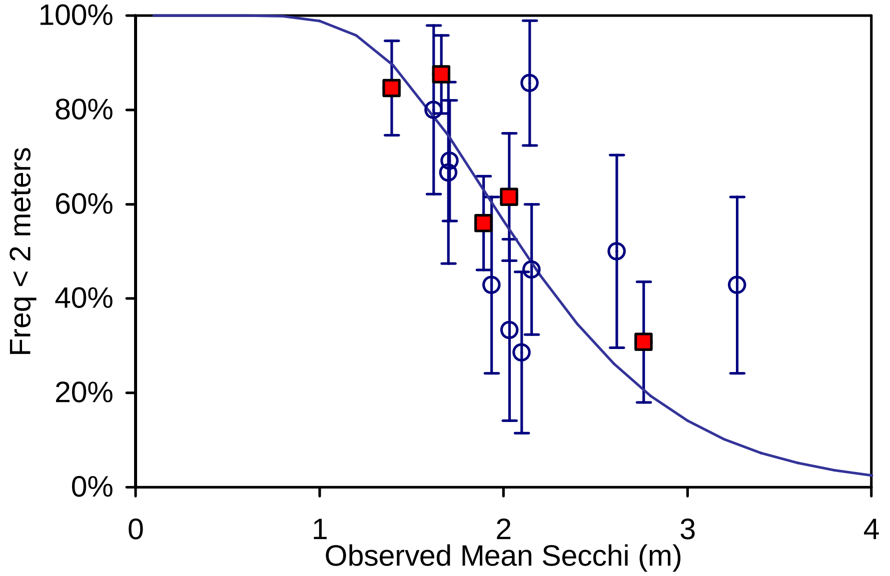
Figure A7-10
Algal Bloom Frequencies vs. Observed Mean Chlorophyll-a



Model: Log-Normal Frequency Distribution, CV = 0.67 Months: 6 thru 8

Figure A7-11
Secchi Interval Frequencies vs. Mean Secchi Depth

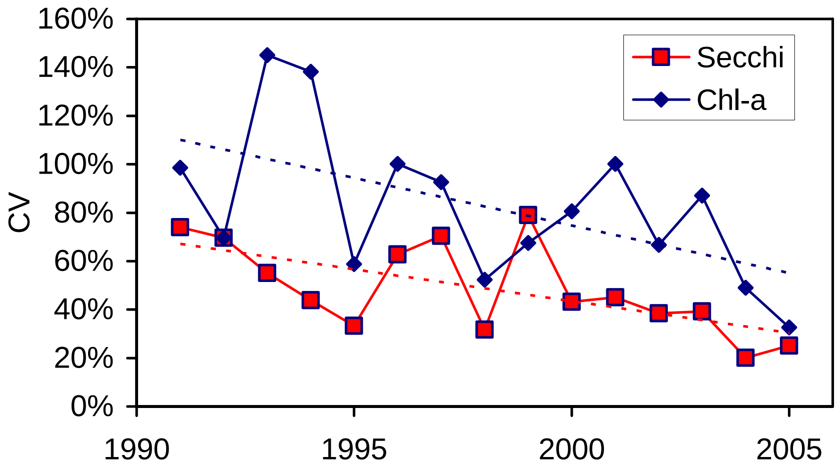




Model:	Log-Normal Frequency Distribution,		CV =	0.34
Months:	6	thru	8	

Figure A7-12
Trends in Chlorophyll-a and Secchi Depth Variability

June- August Averaging Period

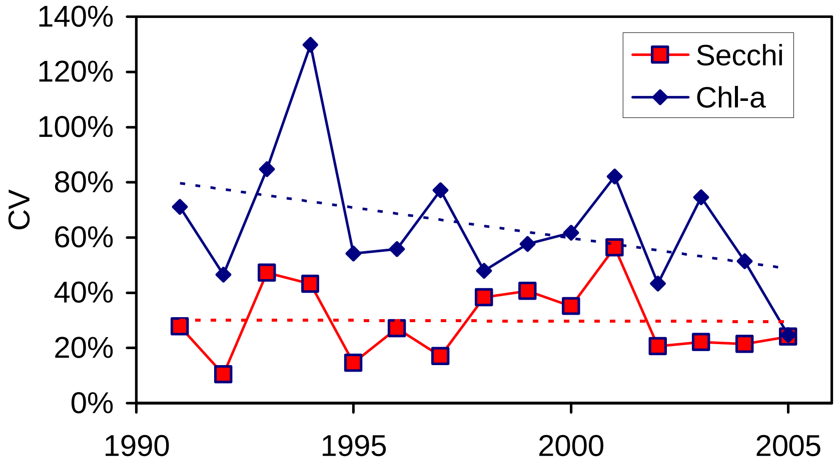


Months: 6 thru 8

CV = Coefficient of Variation = Standard Deviation / Mean

	Chl-a	Secchi
Mean CV (2001-2005)	0.67	0.34

July - September Averaging Period

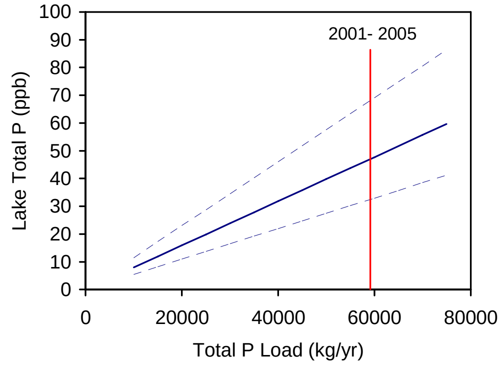


Months: 7 thru 9

CV = Coefficient of Variation = Standard Deviation / Mean

	Chl-a	Secchi
Mean CV (2001-2005)	0.55	0.29

Figure A7-13
Predicted Responses to Reductions in Phosphorus Load



Predicted Lake Responses to Reductions in Phosphorus Load

Base Conditions (2001-2005):

Average Outflow =	485 hm^3/yr
Total P Load =	59,171 kg/yr

Dashed lines show 80% prediction intervals for individual year
Vertical Line = 2001-2005 Average