APPENDIX 4: MASS-BALANCE MODELING - 2001

1. INTRODUCTION

The development and structure of a mass-balance modeling framework for Onondaga Lake is described in previous lake monitoring reports (Ecologic, 2000;2001). 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. Lake water and mass balances are formulated on yearly and seasonal (May-September) time scales. 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, 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 (Chapter ?).

This appendix updates the mass-balance framework to include 1986-2001 data. 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. The potential for upgrading the framework to track flows and loads on a daily basis is also investigated.

2. LONG-TERM TRENDS

Yearly variations in precipitation and lake inflow volume are summarized in Figure 2. Precipitation data are derived from NOAA Local Climatologic Data reports for Hancock Airport in Syracuse. While precipitation has been measured locally by OCDWEP since 2000, the airport data are used because they provide a consistent long-term record. Over the 1986-2001 period, yearly runoff from the Onondaga Lake watershed varied from 30 to 73 cm and was strongly correlated with precipitation ($r^2 = 0.89$). Runoff was 43 cm in 2001, as compared with a 16-year mean of 48 cm.

The following figures show trends in each water quality component over the entire period of record (1986-2000):

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

Ten-year (1992-2001) trends in concentration and load for each mass-balance term and water quality component are summarized in Table 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 alkalinity, BOD, calcium, ammonia nitrogen, Kjeldahl nitrogen, total nitrogen, total organic carbon, total inorganic carbon, soluble reactive phosphorus, total phosphorus, while an increasing trend is indicated for nitrate nitrogen. Decreasing trends in nutrient species and BOD are apparent in Metro loads, but not in the nonpoint loads. For the lake outflow, significant decreasing trends in concentration and/or load are indicated for BOD, calcium, ammonia nitrogen, total Kjeldahl nitrogen, total nitrogen, total organic carbon, total inorganic carbon, soluble reactive phosphorus, and total phosphorus. Outflow trends are generally consistent with inflow trends and improving water quality conditions resulting primarily from Metro improvements over the 1992-2001 period..

3. MASS BALANCES

Five-year average (1997-2001) mass balances for the following constituents are summarized in the following tables:

Table 2	Chloride
Table 3	Total Phosphorus
Table 4	Soluble Reactive Phosphorus
Table 5	Total Nitrogen
Table 6	Ammonia Nitrogen
Table 7	Total Phosphorus (May-September)
Table 8	Soluble Reactive Phosphorus (May-September)

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. When the outflow load is computed using the 2-foot outlet samples, the inflow load exceeds the outflow load by 5%. When the 12-foot outlet samples are used, the outflow loads exceed the inflows load by 14%. Because of hydraulic exchanges with the Seneca River, the 12-foot samples are considered more representative of net discharge from the Lake (Ecologic, 2001). The excess chloride load averaged 24,400 ± 4,400 metric tons/year in 1997-2001 and was fairly consistent from year to year (Figure 4).

Potential additional sources of chloride include runoff from ungauged watersheds, road salt, and hyper-saline groundwater inflows (Ecologic, 2001; Kappel, 1996). Kappel (20002, personal communication) reports aquifer salinity levels in the Onondaga Creek watershed that are ~4 times that of seawater. At the corresponding chloride concentration (~76,000 ppm), a groundwater discharge rate of ~3.6 cfs would be required to explain the apparent excess chloride load. At this point, there is no way of determining whether a discharge of this magnitude is actually occurring. A groundwater discharge of this magnitude would not be likely to have a significant impact on the lake phosphorus budget. For example, if we assume a groundwater P concentration of 50 ppb (probably an over-estimate), the corresponding phosphorus load would be 161 kg/yr, or <0.3% of the estimated total load (Table 3).

Over the 1997-2001 period, the estimated average total phosphorus load was 58,413 ± 1,818 kg/yr, 56% of which was attributed to Metro (Table 2). Decreasing trends in load are apparent within this period (Figure 3). The existing phosphorus balance model (Ecologic, 2001) provides a means for developing preliminary projections of water quality responses likely to result from control of specific phosphorus sources. The model is driven by the yearly total phosphorus load from all sources. One important limitation is that it does not directly account for seasonal variations or phosphorus speciation. Such effects are inherent in the empirical model calibration, which may need to be revised if there are significant changes in the seasonality and/or speciation of phosphorus loads from various sources. Effler (2002) describe these and other factors that may influence differential responses to changes in point and nonpoint loads.

As the lake approaches a phosphorus-limited condition, inputs of soluble reactive phosphorus to the epilimnion during the summer would have the greatest potential impact on algal growth. The following table summarizes flow and phosphorus inputs from Metro (discharge + bypass) expressed as a percentage of the total lake inputs on a yearly and seasonal basis, as derived from Tables 3-8:

1997-2001	Year	May-Sept
Flow	22%	27%
Total P Load	56%	64%
SRP Load	65%	80%

The relative importance of the Metro discharges ranges from 56% (based upon annual total P loads) to 80% (based upon seasonal SRP loads). Because of the residence time of water in the epilimnion and phosphorus cycling processes within the Lake and its sediments, however, phosphorus entering in other forms and/or seasons is not necessarily unimportant. A dynamic nutrient cycling model would be needed to reflect these factors. Depending upon the degree to which these additional processes are actually understood and the feasibility of obtaining accurate estimates of the parameters describing them, such a model may provide more accurate forecasts of lake response to load reductions, as compared with a simplified loading model.

DEVELOPMENT OF DAILY LOAD ESTIMATES

Under the existing mass-balance framework (Figure 1), the AUTOFLUX program is used develop annual and seasonal (May-September) load estimates for each year, tributary, and water quality constituent. Load estimates on a shorter time scale would be needed to evaluate seasonal factors discussed above and to support development of a mechanistic water quality model of the Lake. This section evaluates the potential for upgrading the framework to provide daily load estimates for each source using the same flow and concentration data that are used in the current framework.

Simulation of lake dynamics would not necessary require accurate estimation of variations in loads on a day-to-day basis. Lake response to daily load variations are dampened by the relatively large volume of water stored in the Lake. Estimation of loads on a daily basis is convenient, however, given the availability of daily flow data. Load time series for other period (weekly, monthly, seasonal, annual) can be readily computed from the daily series.

The challenge in estimating daily loads is that tributary concentrations are sampled biweekly (with supplemental high-flow and storm-event sampling). Creek sampling frequency in recent years appears to capture the dominant features of the seasonal hydrograph, as well as many of the isolated storm events (Figure 7). To generate a daily load time series, a means for estimating concentrations between sampling events is needed.

Walker & Havens (2002) described and demonstrated a combined regression/interpolation algorithm for computing daily loads from sparse datasets. The resulting load time series was used to drive a dynamic chloride and phosphorus model of Florida lake. The algorithm is a modification of one of the methods offered in the FLUX program (Walker, 1999) for generating load time series. A multiple regression model representing concentration variations associated with flow, season, and year (trend) is fit to sample concentration and flow data in a given time period. This model is used to generate a daily series of predicted concentrations for each day. Another daily time series is generated by interpolating residuals (observed – predicted concentrations) between adjacent sampling dates. The predicted and residual time series are added together to generate daily concentration and load series for use in lake modeling. Concentrations are log-transformed when appropriate to reduce skewness and promote normality in model residuals. When the variance explained by the regression is small, the algorithm collapses to a direct interpolation of concentrations between sampling dates.

Results of applying the above algorithm to estimate total phosphorus loads for each creek and the lake outlet over the 1998-2001 period are shown in Figure 8 Daily loads are summed for each year and compared with estimates generated by the AUTOFLUX algorithm currently used in the mass balance framework. In most cases, the load estimates are not significantly different, relative to the standard error of the AUTOFLUX estimate. If each method generates unbiased load estimates, we would expect the results to be similar.

The interpolation algorithm yields significantly lower results in 2001 for Ninemile, Ley, and Onondaga Creeks. The differences primarily reflect the fact that high concentrations measured in th September 24-26, 2001 storm had disproportionately large influence on the AUTOFLUX load estimates for that year. Loadings during this storm were largely particulate and, in the case of Onondaga Creek, apparently originated in the relatively undeveloped portions of the watershed above Dorwin Avenue and Route 20.

The AUTOFLUX algorithm assumes that concentrations are related only to flow. Other factors, such as seasonal variations or hysteresis (tendency for concentrations at a given flow to be higher on the rising limb than on the tailing limb of a storm or seasonal flow pulse, particularly), would be captured by the regression/interpolation algorithm but not by the AUTOFLUX algorithm.

Figure 8 suggests that the correlation between TP concentration and flow varies with season in Onondaga Creek. At a given flow, concentrations tend to be much higher in the summer and early fall (June – October), as compared with the rest of the year. Similar patterns may be present in other creeks. The relatively high AUTOFLUX loading estimate for 2001 (Figure 7) may reflect the assumption that the concentration distributions under spring high flows and the September storm are similar. If the alternative algorithm is used to estimate creek loads in 2001, the total nonpoint load decreases from 38,000 ± 6,000 kg to 25,000 kg and the total lake load decreases from 62,000 ± 6,000 kg to 49,000 kg.

Refinement of the mass balance framework to generate daily load estimates would serve lake modeling needs and appears to be feasible using recent monitoring data than include periodic, high-flow, and storm-event sampling. Because the regression/interpolation algorithm accounts for factors that are not considered in the existing AUTOFLUX algorithm, it is possible that the refined framework would improve the accuracy and precision of annual load estimates, as well. Further refinement of the regression/interpolation algorithm, including application to data for other constituents and development of methods for estimating precision, is recommended.

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Mass Balance Appendix

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Table 1: 10-Year Trends in Load & Concentration

Load Trends (% / yr) **Period:** 1992 **to** 2001 **Season: Year**

Term	ALK	BOD5	CA	CL	NA	NH3N	NO2N	NO3N	SRP	TIC	TKN	TN	TOC	TP	TSS
Metro	-3%	-7%			4%	-11%		18%	-12%	-3%	-10%	-6%	-7%	-9%	
Bypass															
Allied						-28%					-23%				
Crucible	19%		20%	21%	19%	17%			36%	19%	16%			29%	23%
Harbor/Hiawatha															
Ley/Park															
Ninemile/Rt48			-6%	-7%	-8%										
Onond./Kirkpatrick															
Harbor/Velasko		18%		15%	17%			17%				16%	14%		
Onondaga/Dorwin															
Total Gauged	-4%	-9%	-4%			-11%		6%	-14%		-10%	-6%	-8%	-9%	
NonPoint Gauged			-4%												
Ungauged			-4%												
Total NonPoint			-4%												
Total Industrial						-21%									18%
Total Municipal	-5%	-12%			3%	-12%		17%	-17%	-4%	-11%	-7%	-11%	-13%	-8%
Total External	-4%	-9%	-4%			-11%		6%	-14%		-10%	-6%	-8%	-9%	
Total Inflow	-4%	-9%	-4%			-11%		6%	-14%		-10%	-6%	-8%	-9%	
Total Outflow		-5%	-3%			-11%			-10%		-10%	-6%	-5%	-11%	
Retention	-8%	-12%				-12%					-10%	-7%	-15%		
Outlet2		-6%	-4%			-12%			-9%		-10%	-6%	-5%	-10%	
Outlet12		-5%	-3%			-11%			-10%		-10%	-6%	-5%	-11%	
South Epil.		-5%	-3%			-12%	-6%		-13%		-11%	-7%	-5%	-11%	

Concentration Trends (% / yr) **Period:** 1992 **to** 2001 **Season: Year**

Term	ALK	BOD5	CA	CL	NA	NH3N	NO2N	NO3N	SRP	TIC	TKN	TN	TOC	TP	TSS
Metro	-3%	-7%			4%	-11%		18%	-12%	-3%	-10%	-6%	-7%	-9%	
Bypass	-3%	-7%				-5%		19%	-17%		-6%	-7%	-12%	-7%	
Allied	-3%		-4%			-13%	-9%			-4%	-9%	-5%	-5%		10%
Crucible	1%	-5%					-9%		22%	2%			-6%	12%	
Harbor/Hiawatha	-1%			6%	5%										
Ley/Park															8%
Ninemile/Rt48	-1%	5%		-4%	-4%										
Onond./Kirkpatrick	-1%	7%				5%				-1%	4%	1%			
Harbor/Velasko						-14%	-46%	5%	-21%			4%			
Onondaga/Dorwin	-2%	6%		4%	4%			2%		-1%		2%			
Total Gauged	-2%	-6%	-1%			-9%		9%	-12%	-1%	-8%	-4%	-5%	-6%	
NonPoint Gauged	-1%														
Ungauged	-1%														
Total NonPoint	-1%														
Total Industrial		-4%				-17%	-17%	-4%			-12%	-8%	-6%		
Total Municipal	-3%	-11%			4%	-11%		18%	-15%	-3%	-10%	-6%	-10%	-12%	-7%
Total External	-2%	-6%	-1%			-9%		8%	-11%	-1%	-8%	-4%	-5%	-6%	
Total Inflow	-2%	-6%	-2%			-9%		8%	-11%	-1%	-8%	-4%	-5%	-6%	
Total Outflow	-1%					-9%		5%		-1%	-8%	-3%	-2%	-8%	
Outlet2	-1%	-3%	-1%			-9%		3%		-1%	-8%	-4%	-2%	-7%	
Outlet12	-1%					-9%		5%		-1%	-8%	-3%	-2%	-8%	
South Epil.						-9%		5%	-11%		-8%	-4%	-3%	-8%	

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

Table 2: Chloride Balance for 1997-2001

Variable: Chloride **Average for Years:** 1997 thru 2001 **Season:** Year

Term	Flow 10^6 m3	Load mtons	Std Error mtons	Conc ppm	RSE %	Sampl per yr	Percent of Total Inflow Flow %	Load %	Error %	Drain. Area km2	Runoff cm	Export mtons/ km2
Metro Effluent	89.24	31098	2207	348	7%	27	21%	20%	35%			
Metro Bypass	1.60	777	191	485	25%	4	0%	0%	0%			
East Flume	0.32	150	7	468	4%	27	0%	0%	0%			
Crucible	1.51	612	18	406	3%	27	0%	0%	0%			
Harbor Brook	8.05	2128	132	264	6%	30	2%	1%	0%	29.3	27.5	72.6
Ley Creek	32.68	9540	729	292	8%	29	8%	6%	4%	77.5	42.2	123.1
Ninemile Creek	118.80	51721	1640	435	3%	28	29%	33%	19%	298.1	39.9	173.5
Onondaga Creek	136.48	54189	2244	397	4%	30	33%	35%	36%	285.1	47.9	190.0
Nonpoint Gauged	296.01	117577	2877	397	2%	117	71%	75%	59%	690.0	42.9	170.4
Nonpoint Ungauged	15.89	6310	865	397	14%	0	4%	4%	5%	37.0	42.9	170.4
NonPoint Total	311.90	123887	3004	397	2%	117	75%	79%	65%	727.0	42.9	170.4
Industrial	1.83	762	20	417	3%	55	0%	0%	0%			
Municipal	90.84	31875	2215	351	7%	31	22%	20%	35%			
Total External	404.57	156524	3732	387	2%	203	97%	100%	100%	727.0	55.6	215.3
Precipitation	10.77	11	1	1	9%	0	3%	0%	0%	11.7	92.0	0.9
Total Inflow	415.33	156535	3732	377	2%	203	100%	100%	100%	738.7	56.2	211.9
Evaporation	8.86						2%			11.7	75.7	
Outflow	406.48	180899	2399	445	1%		98%	116%	41%	738.7	55.0	244.9
Retention	0.00	-24364	4437		18%		0%	-16%				
Alternative Estimates of Lake Output												
Outlet 12 Feet	406.48	180899	2399	445	1%	25	98%	116%	41%	738.7	55.0	244.9
Outlet 2 Feet	406.48	148961	3661	366	2%	25	98%	95%	96%	738.7	55.0	201.6
Lake Epil	406.48	175773	1937	432	1%	21	98%	112%	27%	738.7	55.0	237.9
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	7.60	1730	65	228	4%	28	2%	1%	0%	25.9	29.3	66.8
Downstream - Hiawatha	8.05	2128	132	264	6%	30	2%	1%	0%	29.3	27.5	72.6
Local Inflow	0.46	397	148	869	37%		0%	0%	0%	3.4	13.6	117.9
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	105.23	13277	505	126	4%	30	25%	8%	2%	229.4	45.9	57.9
Downstream - Kirkpatrick	136.48	54189	2244	397	4%	30	33%	35%	36%	285.1	47.9	190.0
Local Inflow	31.25	40912	2300	1309	6%		8%	26%	38%	55.7	56.1	734.1

Lake Overflow Rate 34.74 m/yr Calib. Settling Rate -4.7 m/yr RSE % = Relative Std. Error of Load & Inflow Conc. Estimates
Lake Residence Time 0.31 years Calib. Retention Coef. -16% Error % = Percent of Variance in Total Inflow Load Estimate

Table 3: Total Phosphorus Balance for 1997-2001

Variable: **Total Phosphorus** **Average for Years:** **1997** **thru** **2001** **Season:** **Year**

						Percent of Total Inflow				Drain.		Export
	Flow	Load	Std Error	Conc	RSE	Sampl	Flow	Load	Error	Area	Runoff	kg /
Term	**10^6 m3**	**kg**	**kg**	**ppb**	**%**	**per yr**	**%**	**%**	**%**	**km2**	**cm**	**km2**
Metro Effluent	89.24	30698	276	344	1%	365	21%	53%	2%			
Metro Bypass	1.60	1974	69	1232	3%	36	0%	3%	0%			
East Flume	0.32	65	6	203	9%	27	0%	0%	0%			
Crucible	1.51	183	6	122	3%	27	0%	0%	0%			
Harbor Brook	8.05	525	41	65	8%	30	2%	1%	0%	29.3	27.5	17.9
Ley Creek	32.68	3703	316	113	9%	29	8%	6%	3%	77.5	42.2	47.8
Ninemile Creek	118.80	7708	927	65	12%	28	29%	13%	26%	298.1	39.9	25.9
Onondaga Creek	136.48	11951	1491	88	12%	30	33%	20%	67%	285.1	47.9	41.9
Nonpoint Gauged	296.01	23887	1784	81	7%	116	71%	41%	96%	690.0	42.9	34.6
Nonpoint Ungauged	15.89	1282	204	81	16%	0	4%	2%	1%	37.0	42.9	34.6
NonPoint Total	311.90	25169	1796	81	7%	116	75%	43%	98%	727.0	42.9	34.6
Industrial	1.83	248	8	136	3%	54	0%	0%	0%			
Municipal	90.84	32673	284	360	1%	401	22%	56%	2%			
Total External	404.57	58090	1818	144	3%	571	97%	99%	100%	727.0	55.6	79.9
Precipitation	10.77	323	29	30	9%	0	3%	1%	0%	11.7	92.0	27.6
Total Inflow	415.33	58413	1818	141	3%	571	100%	100%	100%	738.7	56.2	79.1
Evaporation	8.86						2%			11.7	75.7	
Outflow	406.48	34993	1439	86	4%		98%	60%	63%	738.7	55.0	47.4
Retention	0.00	23420	2319		10%		0%	40%				
Alternative Estimates of Lake Output												
Outlet 12 Feet	406.48	34993	1439	86	4%	25	98%	60%	63%	738.7	55.0	47.4
Outlet 2 Feet	406.48	32473	1327	80	4%	25	98%	56%	53%	738.7	55.0	44.0
Lake Epil	406.48	31970	1271	79	4%	21	98%	55%	49%	738.7	55.0	43.3
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	7.60	369	67	49	18%	28	2%	1%	0%	25.9	29.3	14.2
Downstream - Hiawatha	8.05	525	41	65	8%	30	2%	1%	0%	29.3	27.5	17.9
Local Inflow	0.46	156	79	342	50%		0%	0%	0%	3.4	13.6	46.4
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	105.23	6986	731	66	10%	30	25%	12%	16%	229.4	45.9	30.5
Downstream - Kirkpatrick	136.48	11951	1491	88	12%	30	33%	20%	67%	285.1	47.9	41.9
Local Inflow	31.25	4965	1660	159	33%		8%	8%	83%	55.7	56.1	89.1

Lake Overflow Rate	34.74 m/yr	Calib. Settling Rate	23.3 m/yr	RSE % = Relative Std. Error of Load & Inflow Conc. Estimates
Lake Residence Time	0.31 years	Calib. Retention Coef.	40%	Error % = Percent of Variance in Total Inflow Load Estimate

Table 4: Soluble Reactive P Balance for 1997-2001

Variable: **Soluble Reactive Phosphorus** **Average for Years:** 1997 thru 2001 **Season:** Year

Term	Flow 10^6 m3	Load kg	Std Error kg	Conc ppb	RSE %	Sampl per yr	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	89.24	6891	608	77	9%	28	21%	63%	83%			
Metro Bypass	1.60	187	70	117	37%	4	0%	2%	1%			
East Flume	0.32	32	5	100	16%	27	0%	0%	0%			
Crucible	1.51	68	2	45	4%	27	0%	1%	0%			
Harbor Brook	8.05	140	11	17	8%	29	2%	1%	0%	29.3	27.5	4.8
Ley Creek	32.68	554	34	17	6%	29	8%	5%	0%	77.5	42.2	7.1
Ninemile Creek	118.80	993	130	8	13%	28	29%	9%	4%	298.1	39.9	3.3
Onondaga Creek	136.48	1713	224	13	13%	30	33%	16%	11%	285.1	47.9	6.0
Nonpoint Gauged	296.01	3399	261	11	8%	115	71%	31%	15%	690.0	42.9	4.9
Nonpoint Ungauged	15.89	182	29	11	16%	0	4%	2%	0%	37.0	42.9	4.9
NonPoint Total	311.90	3581	263	11	7%	115	75%	33%	16%	727.0	42.9	4.9
Industrial	1.83	100	6	55	6%	54	0%	1%	0%			
Municipal	90.84	7079	612	78	9%	32	22%	65%	84%			
Total External	404.57	10760	666	27	6%	201	97%	99%	100%	727.0	55.6	14.8
Precipitation	10.77	162	15	15	9%	0	3%	1%	0%	11.7	92.0	13.8
Total Inflow	415.33	10922	667	26	6%	201	100%	100%	100%	738.7	56.2	14.8
Evaporation	8.86						2%			11.7	75.7	
Outflow	406.48	17091	1519	42	9%		98%	156%	519%	738.7	55.0	23.1
Retention	0.00	-6170	1658		27%		0%	-56%				
Alternative Estimates of Lake Output												
Outlet 12 Feet	406.48	17091	1519	42	9%	25	98%	156%	519%	738.7	55.0	23.1
Outlet 2 Feet	406.48	14084	1192	35	8%	25	98%	129%	320%	738.7	55.0	19.1
Lake Epil	406.48	11318	1256	28	11%	21	98%	104%	355%	738.7	55.0	15.3
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	7.60	65	5	9	8%	28	2%	1%	0%	25.9	29.3	2.5
Downstream - Hiawatha	8.05	140	11	17	8%	29	2%	1%	0%	29.3	27.5	4.8
Local Inflow	0.46	74	12	163	16%		0%	1%	0%	3.4	13.6	22.1
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	105.23	733	96	7	13%	29	25%	7%	2%	229.4	45.9	3.2
Downstream - Kirkpatrick	136.48	1713	224	13	13%	30	33%	16%	11%	285.1	47.9	6.0
Local Inflow	31.25	980	243	31	25%		8%	9%	13%	55.7	56.1	17.6

Lake Overflow Rate	34.74 m/yr	Calib. Settling Rate	-12.5 m/yr	RSE % = Relative Std. Error of Load & Inflow Conc. Estimates
Lake Residence Time	0.31 years	Calib. Retention Coef.	-56%	Error % = Percent of Variance in Total Inflow Load Estimate

Table 5: Total Nitrogen Balance for 1997-2001

Variable: **Total Nitrogen** **Average for Years: 1997 thru 2001** **Season: Year**

						Percent of Total Inflow				Drain.		Export
	Flow	Load	Std Error	Conc	RSE	Sampl	Flow	Load	Error	Area	Runoff	kg/
Term	**10^6 m3**	**kg**	**kg**	**ppb**	**%**	**per yr**	**%**	**%**	**%**	**km2**	**cm**	**km2**
Metro Effluent	89.24	1245515	23090	13957	2%	39	21%	68%	53%			
Metro Bypass	1.60	21370	17053	13330	80%	4	0%	1%	29%			
East Flume	0.32	2254	61	7049	3%	27	0%	0%	0%			
Crucible	1.51	3044	188	2019	6%	27	0%	0%	0%			
Harbor Brook	8.05	16674	389	2070	2%	27	2%	1%	0%	29.3	27.5	569.2
Ley Creek	32.68	51652	2682	1580	5%	26	8%	3%	1%	77.5	42.2	666.4
Ninemile Creek	118.80	214357	8753	1804	4%	27	29%	12%	8%	298.1	39.9	719.1
Onondaga Creek	136.48	220185	9260	1613	4%	27	33%	12%	8%	285.1	47.9	772.2
Nonpoint Gauged	296.01	502868	13027	1699	3%	108	71%	28%	17%	690.0	42.9	728.8
Nonpoint Ungauged	15.89	26988	3744	1699	14%	0	4%	1%	1%	37.0	42.9	728.8
NonPoint Total	311.90	529856	13554	1699	3%	108	75%	29%	18%	727.0	42.9	728.8
Industrial	1.83	5298	198	2899	4%	54	0%	0%	0%			
Municipal	90.84	1266885	28705	13946	2%	43	22%	70%	81%			
Total External	404.57	1802039	31745	4454	2%	205	97%	99%	100%	727.0	55.6	2478.6
Precipitation	10.77	20457	1840	1900	9%	0	3%	1%	0%	11.7	92.0	1748.5
Total Inflow	415.33	1822496	31798	4388	2%	205	100%	100%	100%	738.7	56.2	2467.0
Evaporation	8.86						2%			11.7	75.7	
Outflow	406.48	1305377	20931	3211	2%		98%	72%	43%	738.7	55.0	1767.0
Retention	0.00	517120	38068		7%		0%	28%				
Alternative Estimates of Lake Output												
Outlet 12 Feet	406.48	1305377	20931	3211	2%	25	98%	72%	43%	738.7	55.0	1767.0
Outlet 2 Feet	406.48	1141204	26187	2808	2%	25	98%	63%	68%	738.7	55.0	1544.8
Lake Epil	406.48	1331502	16095	3276	1%	22	98%	73%	26%	738.7	55.0	1802.4
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	7.60	15576	362	2050	2%	27	2%	1%	0%	25.9	29.3	600.9
Downstream - Hiawatha	8.05	16674	389	2070	2%	27	2%	1%	0%	29.3	27.5	569.2
Local Inflow	0.46	1098	531	2401	48%		0%	0%	0%	3.4	13.6	325.8
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	105.23	165576	8157	1574	5%	27	25%	9%	7%	229.4	45.9	721.8
Downstream - Kirkpatrick	136.48	220185	9260	1613	4%	27	33%	12%	8%	285.1	47.9	772.2
Local Inflow	31.25	54609	12341	1747	23%		8%	3%	15%	55.7	56.1	979.9

Lake Overflow Rate 34.74 m/yr Calib. Settling Rate 13.8 m/yr RSE % = Relative Std. Error of Load & Inflow Conc. Estimates

Lake Residence Time 0.31 years Calib. Retention Coef. 28% Error % = Percent of Variance in Total Inflow Load Estimate

Table 6: Ammonia Nitrogen Balance for 1997-2001

Variable: **Ammonia Nitrogen** **Average for Years:** 1997 thru 2001 **Season:** Year

Term	Flow 10^6 m3	Load kg	Std Error kg	Conc ppb	RSE %	Sampl per yr	Percent of Total Inflow Flow %	Load %	Error %	Drain. Area km2	Runoff cm	Export kg/ km2
Metro Effluent	89.24	637215	10248	7141	2%	364	21%	87%	69%			
Metro Bypass	1.60	12210	811	7616	7%	35	0%	2%	0%			
East Flume	0.32	356	17	1114	5%	27	0%	0%	0%			
Crucible	1.51	232	7	154	3%	27	0%	0%	0%			
Harbor Brook	8.05	1361	112	169	8%	27	2%	0%	0%	29.3	27.5	46.4
Ley Creek	32.68	13777	649	422	5%	26	8%	2%	0%	77.5	42.2	177.8
Ninemile Creek	118.80	45834	6678	386	15%	27	29%	6%	29%	298.1	39.9	153.8
Onondaga Creek	136.48	19200	1140	141	6%	27	33%	3%	1%	285.1	47.9	67.3
Nonpoint Gauged	296.01	80172	6806	271	8%	108	71%	11%	30%	690.0	42.9	116.2
Nonpoint Ungauged	15.89	4303	692	271	16%	0	4%	1%	0%	37.0	42.9	116.2
NonPoint Total	311.90	84474	6841	271	8%	108	75%	11%	31%	727.0	42.9	116.2
Industrial	1.83	589	18	322	3%	54	0%	0%	0%			
Municipal	90.84	649424	10280	7149	2%	400	22%	88%	69%			
Total External	404.57	734487	12348	1815	2%	562	97%	100%	100%	727.0	55.6	1010.2
Precipitation	10.77	1077	97	100	9%	0	3%	0%	0%	11.7	92.0	92.0
Total Inflow	415.33	735564	12349	1771	2%	562	100%	100%	100%	738.7	56.2	995.7
Evaporation	8.86						2%			11.7	75.7	
Outflow	406.48	481615	13803	1185	3%		98%	65%	125%	738.7	55.0	651.9
Retention	0.00	253949	18521		7%		0%	35%				
Alternative Estimates of Lake Output												
Outlet 12 Feet	406.48	481615	13803	1185	3%	25	98%	65%	125%	738.7	55.0	651.9
Outlet 2 Feet	406.48	399805	16834	984	4%	25	98%	54%	186%	738.7	55.0	541.2
Lake Epil	406.48	496227	17395	1221	4%	22	98%	67%	198%	738.7	55.0	671.7
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	7.60	712	44	94	6%	27	2%	0%	0%	25.9	29.3	27.5
Downstream - Hiawatha	8.05	1361	112	169	8%	27	2%	0%	0%	29.3	27.5	46.4
Local Inflow	0.46	648	120	1418	18%		0%	0%	0%	3.4	13.6	192.4
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	105.23	10420	532	99	5%	27	25%	1%	0%	229.4	45.9	45.4
Downstream - Kirkpatrick	136.48	19200	1140	141	6%	27	33%	3%	1%	285.1	47.9	67.3
Local Inflow	31.25	8780	1258	281	14%		8%	1%	1%	55.7	56.1	157.5

Lake Overflow Rate 34.74 m/yr Calib. Settling Rate 18.3 m/yr RSE % = Relative Std. Error of Load & Inflow Conc. Estimates

Lake Residence Time 0.31 years Calib. Retention Coef. 35% Error % = Percent of Variance in Total Inflow Load Estimate

Table 7: Total Phosphorus Balance for May-September, 1997-2001

Variable: **Total Phosphorus** **Average for Years:** 1997 thru 2001 **Season:** MaySept

Term	Flow 10^6 m3	Load kg	Std Error kg	Conc ppb	RSE %	Sampl per yr	Percent of Total Inflow: Flow %	Load %	Error %	Drain. Area km2	Runoff cm	Export kg / km2
Metro Effluent	34.33	11910	155	347	1%	153	27%	61%	5%			
Metro Bypass	0.42	597	243	1407	41%	13	0%	3%	13%			
East Flume	0.09	15	1	179	5%	11	0%	0%	0%			
Crucible	0.60	78	3	131	4%	11	0%	0%	0%			
Harbor Brook	2.58	189	30	73	16%	12	2%	1%	0%	29.3	8.8	6.4
Ley Creek	10.28	1368	92	133	7%	12	8%	7%	2%	77.5	13.3	17.7
Ninemile Creek	32.82	2043	194	62	10%	11	26%	10%	9%	298.1	11.0	6.9
Onondaga Creek	36.51	2919	555	80	19%	12	29%	15%	70%	285.1	12.8	10.2
Nonpoint Gauged	82.18	6519	596	79	9%	47	65%	33%	80%	690.0	11.9	9.4
Nonpoint Ungauged	4.41	350	60	79	17%	0	3%	2%	1%	37.0	11.9	9.4
NonPoint Total	86.59	6869	599	79	9%	47	68%	35%	81%	727.0	11.9	9.4
Industrial	0.68	94	3	137	3%	22	1%	0%	0%			
Municipal	34.76	12507	288	360	2%	166	27%	64%	19%			
Total External	122.03	19470	665	160	3%	235	96%	99%	100%	727.0	16.8	26.8
Precipitation	4.75	143	13	30	9%	0	4%	1%	0%	11.7	40.6	12.2
Total Inflow	126.78	19612	665	155	3%	235	100%	100%	100%	738.7	17.2	26.5
Evaporation	6.18						5%			11.7	52.8	
Outflow	120.60	6468	323	54	5%		95%	33%	24%	738.7	16.3	8.8
Retention	0.00	13144	739		6%		0%	67%				
Alternative Estimates of Lake Output												
Outlet 12 Feet	120.60	6468	323	54	5%	11	95%	33%	24%	738.7	16.3	8.8
Outlet 2 Feet	120.60	6923	374	57	5%	11	95%	35%	32%	738.7	16.3	9.4
Lake Epil	120.60	6526	214	54	3%	11	95%	33%	10%	738.7	16.3	8.8
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	2.33	89	22	38	25%	11	2%	0%	0%	25.9	9.0	3.4
Downstream - Hiawatha	2.58	189	30	73	16%	12	2%	1%	0%	29.3	8.8	6.4
Local Inflow	0.24	100	37	408	38%		0%	1%	0%	3.4	7.2	29.6
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	25.28	1689	214	67	13%	12	20%	9%	10%	229.4	11.0	7.4
Downstream - Kirkpatrick	36.51	2919	555	80	19%	12	29%	15%	70%	285.1	12.8	10.2
Local Inflow	11.23	1231	595	110	48%		9%	6%	80%	55.7	20.1	22.1

Lake Overflow Rate 24.61 m/yr   Calib. Settling Rate 50.0 m/yr   RSE % = Relative Std. Error of Load & Inflow Conc. Estimates

Lake Residence Time 0.44 years   Calib. Retention Coef. 67%   Error % = Percent of Variance in Total Inflow Load Estimate

Table 8: Soluble Reactive P Balance for May-September, 1997-2001

Variable: **Soluble Reactive Phosphorus** **Average for Years:** 1997 thru 2001 **Season:** MaySept

Term	Flow 10^6 m3	Load kg	Std Error kg	Conc ppb	RSE %	Sampl per yr	Percent of Total Inflow Flow %	Load %	Error %	Drain. Area km2	Runoff cm	Export kg / km2
Metro Effluent	34.33	4254	423	124	10%	11	27%	79%	96%			
Metro Bypass	0.42	60	28	140	47%	1	0%	1%	0%			
East Flume	0.09	6	1	65	11%	11	0%	0%	0%			
Crucible	0.60	25	1	41	5%	11	0%	0%	0%			
Harbor Brook	2.58	57	6	22	10%	12	2%	1%	0%	29.3	8.8	2.0
Ley Creek	10.28	193	13	19	7%	12	8%	4%	0%	77.5	13.3	2.5
Ninemile Creek	32.82	244	28	7	11%	11	26%	5%	0%	298.1	11.0	0.8
Onondaga Creek	36.51	429	77	12	18%	12	29%	8%	3%	285.1	12.8	1.5
Nonpoint Gauged	82.18	922	83	11	9%	47	65%	17%	4%	690.0	11.9	1.3
Nonpoint Ungauged	4.41	49	9	11	17%	0	3%	1%	0%	37.0	11.9	1.3
NonPoint Total	86.59	972	83	11	9%	47	68%	18%	4%	727.0	11.9	1.3
Industrial	0.68	30	1	44	5%	22	1%	1%	0%			
Municipal	34.76	4313	424	124	10%	12	27%	80%	96%			
Total External	122.03	5315	432	44	8%	81	96%	99%	100%	727.0	16.8	7.3
Precipitation	4.75	71	6	15	9%	0	4%	1%	0%	11.7	40.6	6.1
Total Inflow	126.78	5386	432	42	8%	81	100%	100%	100%	738.7	17.2	7.3
Evaporation	6.18						5%			11.7	52.8	
Outflow	120.60	1232	287	10	23%		95%	23%	44%	738.7	16.3	1.7
Retention	0.00	4155	519		12%		0%	77%				
Alternative Estimates of Lake Output												
Outlet 12 Feet	120.60	1232	287	10	23%	11	95%	23%	44%	738.7	16.3	1.7
Outlet 2 Feet	120.60	1561	163	13	10%	11	95%	29%	14%	738.7	16.3	2.1
Lake Epil	120.60	907	158	8	17%	11	95%	17%	13%	738.7	16.3	1.2
Upstream/Downstream Contrast- Harbor Brook												
Upstream - Velasko	2.33	19	4	8	19%	11	2%	0%	0%	25.9	9.0	0.7
Downstream - Hiawatha	2.58	57	6	22	10%	12	2%	1%	0%	29.3	8.8	2.0
Local Inflow	0.24	39	7	159	17%		0%	1%	0%	3.4	7.2	11.5
Upstream/Downstream Contrast - Onondaga Creek												
Upstream - Dorwin	25.28	145	17	6	12%	12	20%	3%	0%	229.4	11.0	0.6
Downstream - Kirkpatrick	36.51	429	77	12	18%	12	29%	8%	3%	285.1	12.8	1.5
Local Inflow	11.23	284	79	25	28%		9%	5%	3%	55.7	20.1	5.1

Lake Overflow Rate 24.61 m/yr Calib. Settling Rate 83.0 m/yr RSE % = Relative Std. Error of Load & Inflow Conc. Estimates

Lake Residence Time 0.44 years Calib. Retention Coef. 77% Error % = Percent of Variance in Total Inflow Load Estimate

Figure 1

Framework for Mass-Balance Calculations

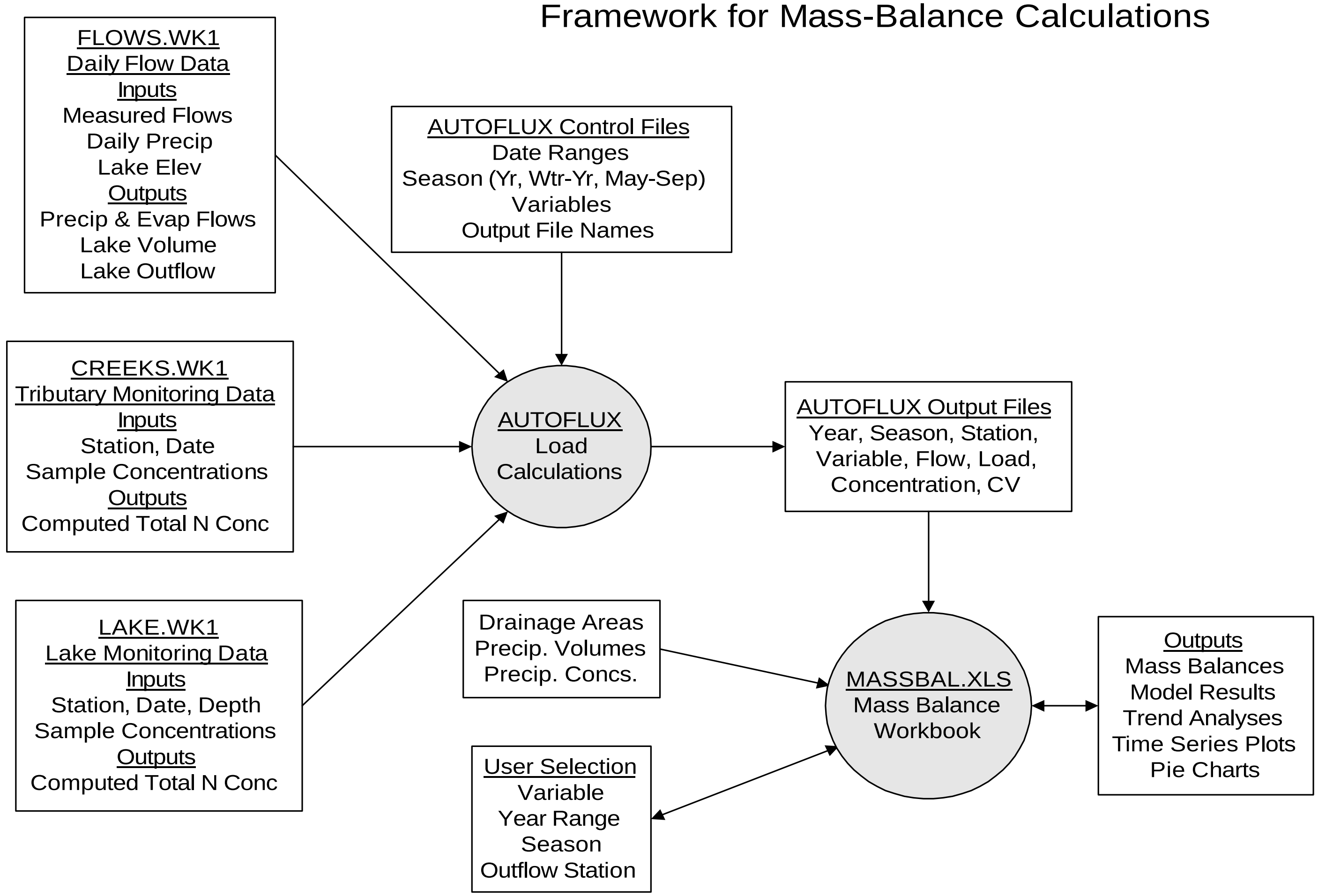
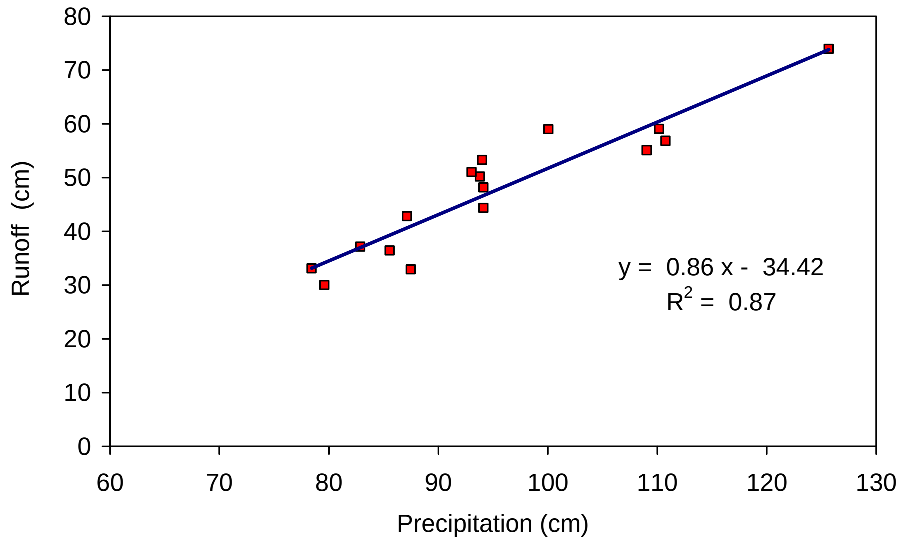
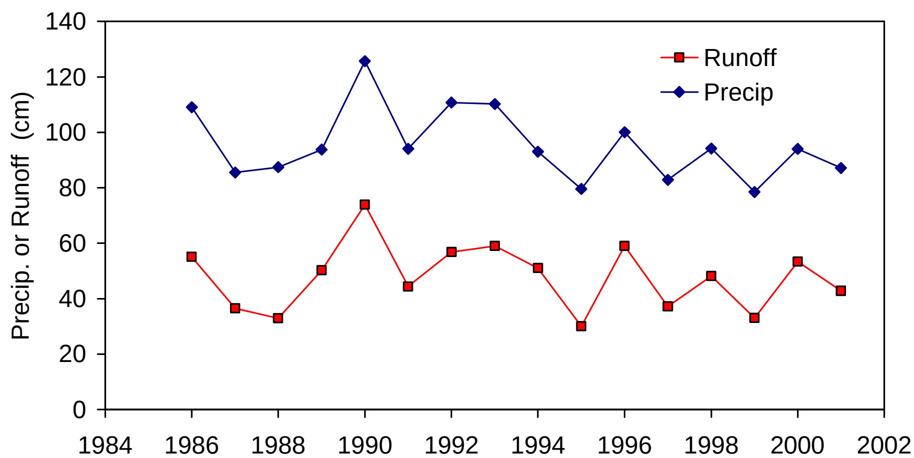


Figure 2
Precipitation, Runoff, & Lake Inflow Volumes





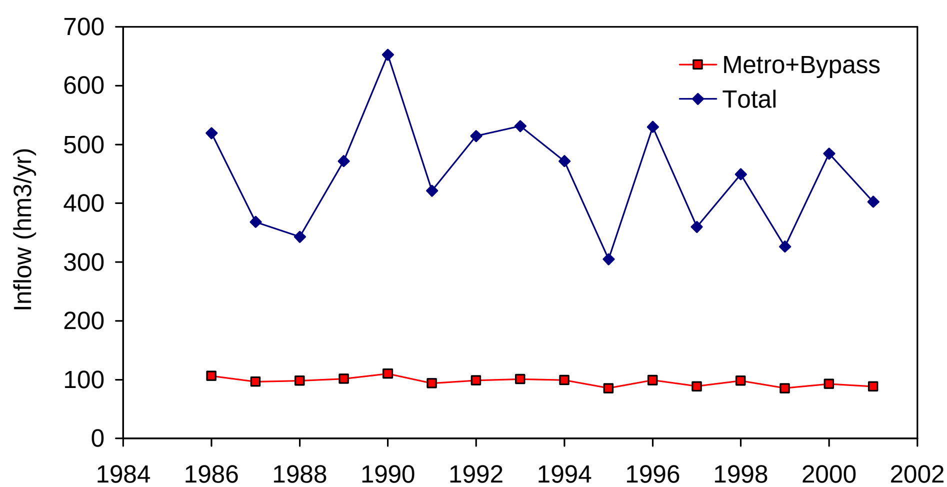
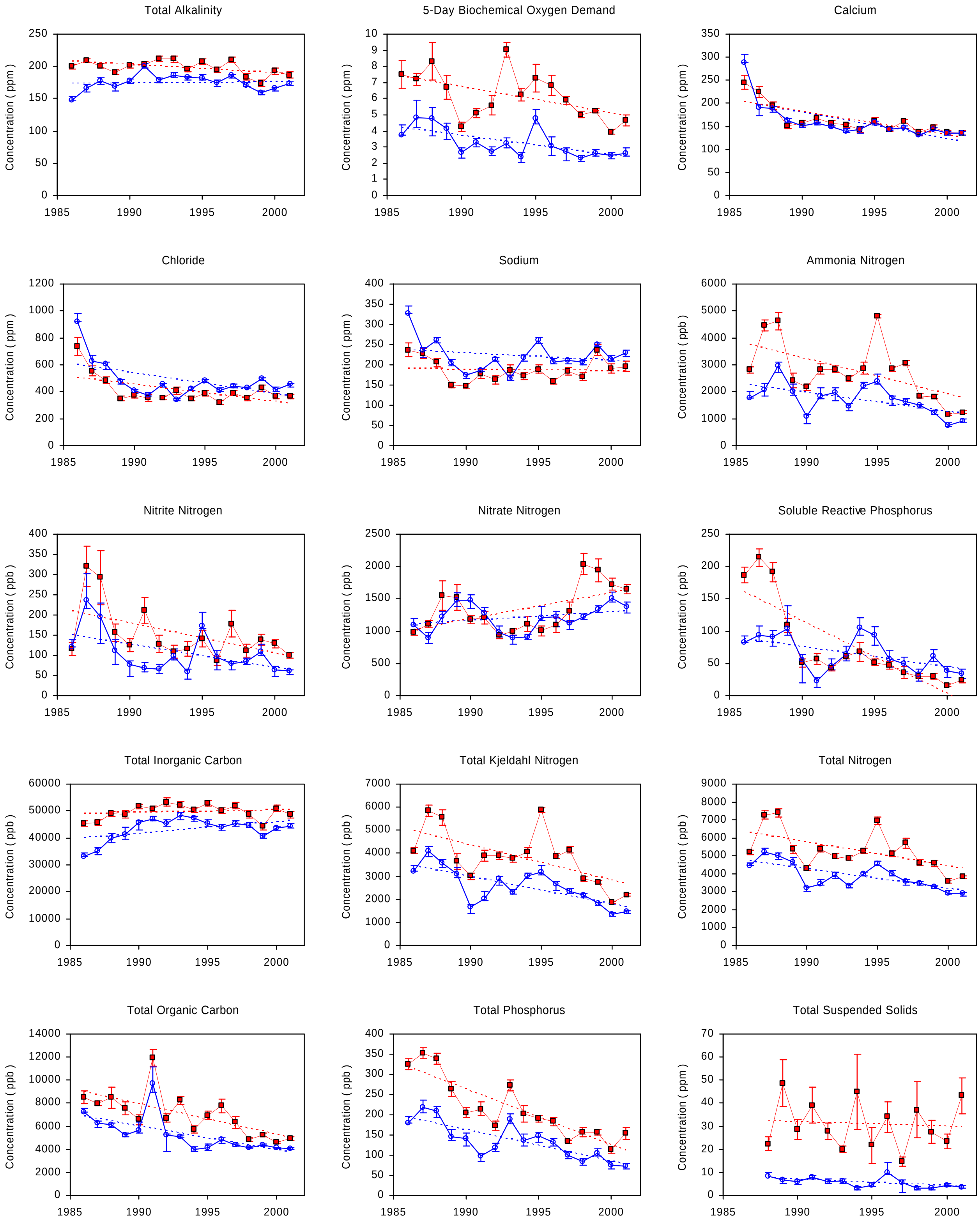
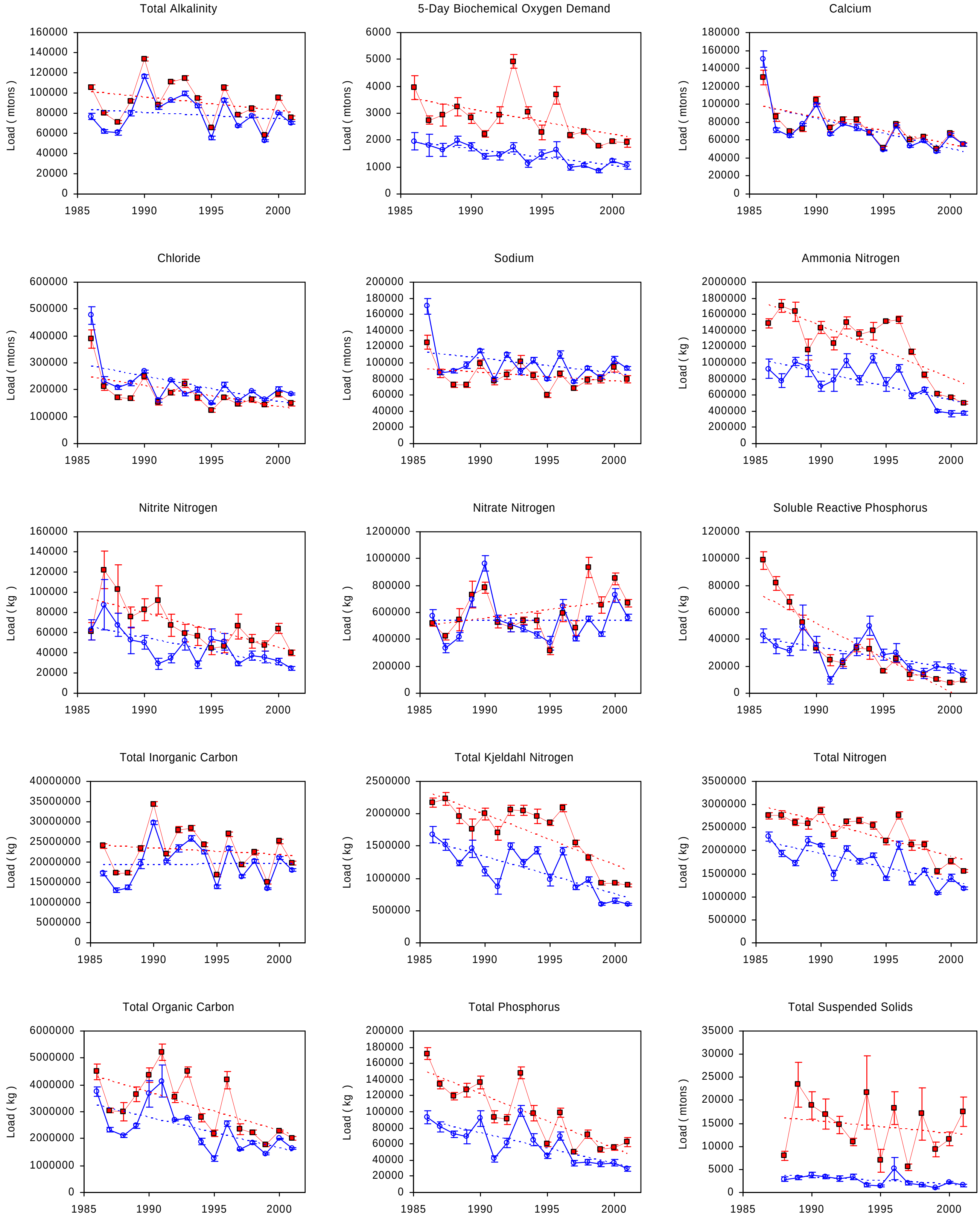


Figure 3
Long-Term Trends in Total Inflow & Outflow Concentrations



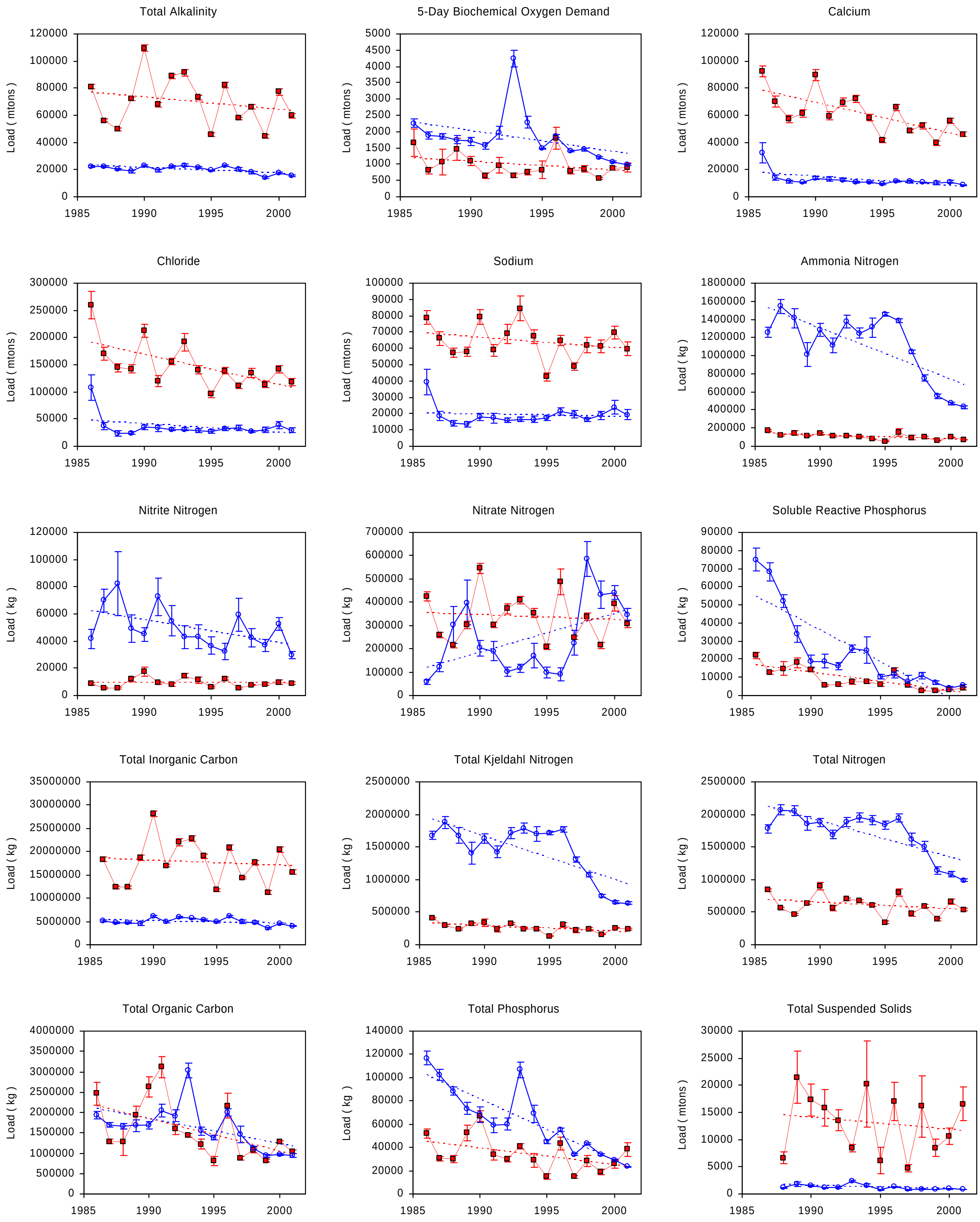
Squares = Inflow, Circles = Outflow   Error Bars = +/- 1 Standard Error   Dotted Lines = Linear Trends   X-Axis = Calendar Year

Figure 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 5
Long-Term Trends in NonPoint & Metro Loads

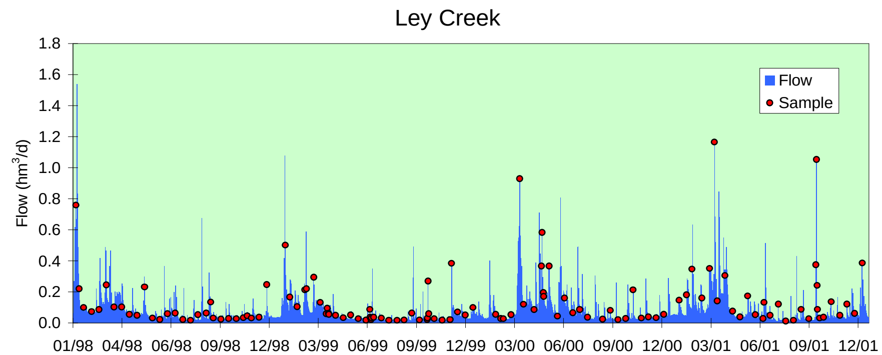


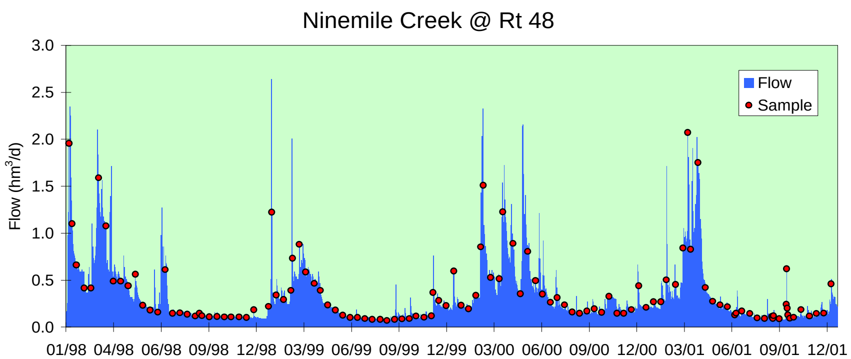
Squares = NonPoint, Circles = Metro+Bypass   Error Bars = +/- 1 Standard Error   Dotted Lines = Linear Trends   X-Axis = Calendar Year

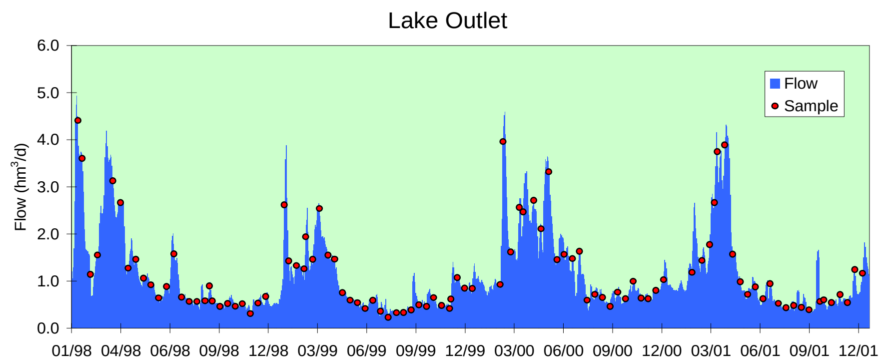
Figure 6 **Creek Daily Hydrographs & Sampling Dates**

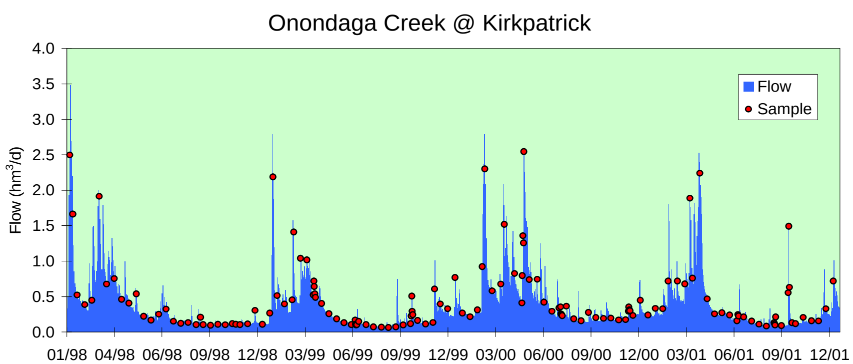
Filled Area Daily Flows

Symbols Flow on Date of Sample Collection









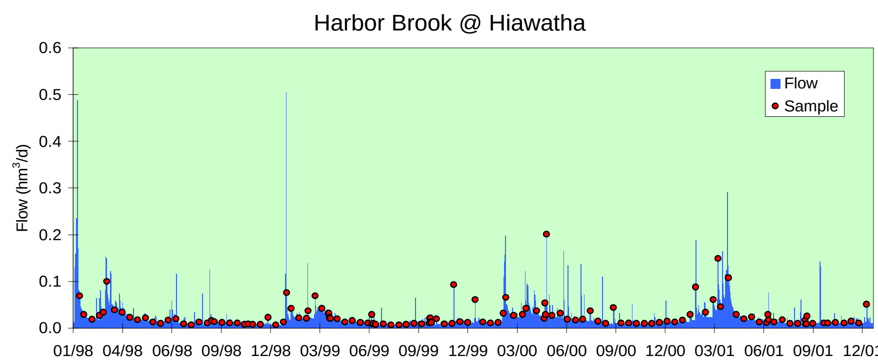
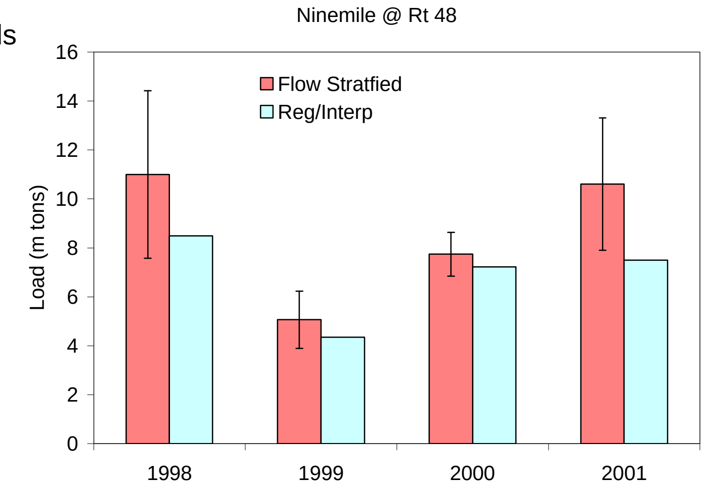
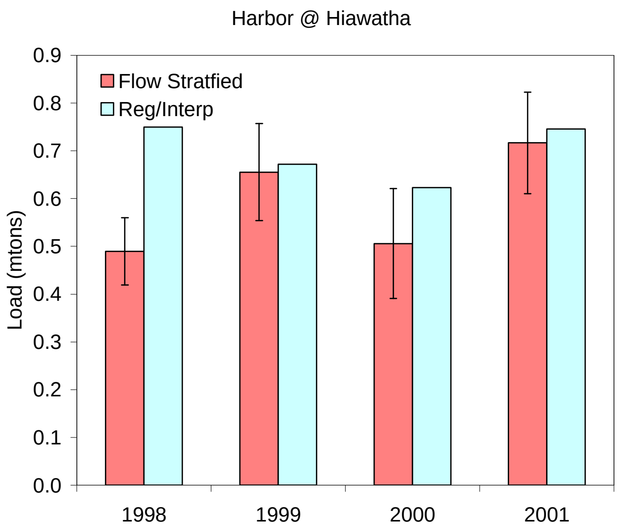
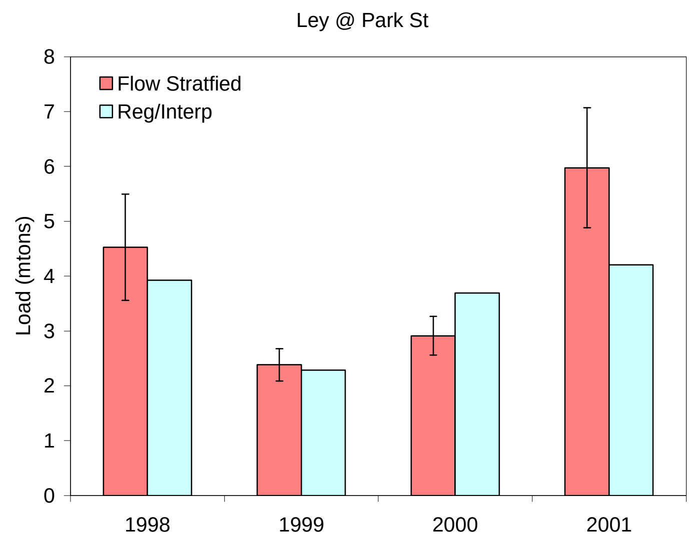


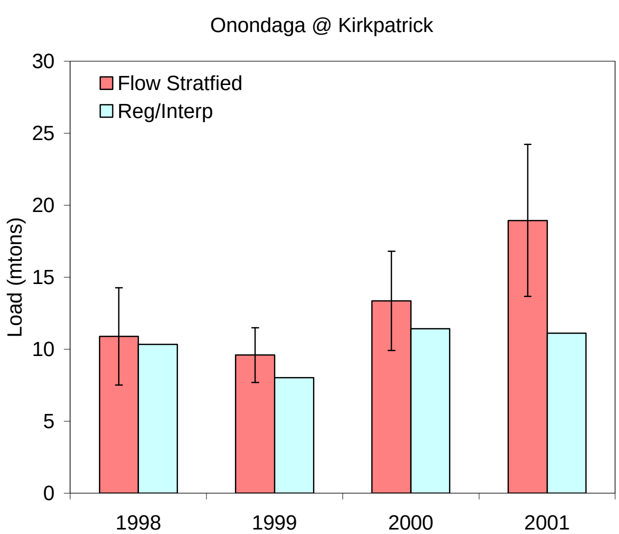
Figure 7
Yearly Total P Loads Estimated Using Two Methods

Units	Metric Tons per Year
Flow Stratified	AUTOFLUX with 2 Flow Strata Mean +/- 1 Standard Error
Reg/Interp	Regression & Interpolation Algorithm Sum of Daily Loads









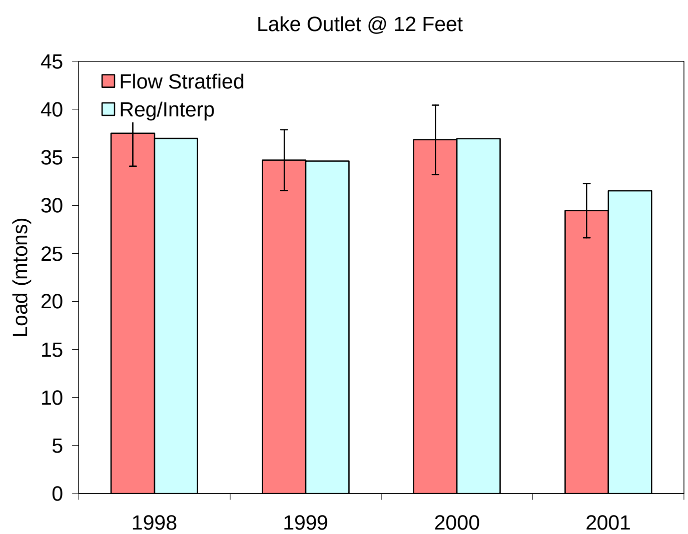


Figure 8
Seasonal Correlations between Total P Concentration & Daily Flow
Onondaga Creek @ Kirkpatrick, 1998-2001